Joint Review Panel Request for Additional Information
Response Package to JRP IR Package 6
Addendum 11

Benga Mining Limited
Grassy Mountain Coal Project

March 2020

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AIR QUALITY

Information Request 6.1

Tenth Addendum to the Environmental Impact Assessment. Response to Information Request 1.5. (CIAR #251).

Comments from Jillian Lynn Lawson. (CIAR #282).

Comments from the Livingstone Land Owners Group. (CIAR #288).

Comments from Allan Garbutt. (CIAR #290).

In response to Information Request (IR) 1.5 (CIAR #251), Benga provided a wind speed frequency distribution table (Table 1.5-2) for the four (4) meteorological stations considered in the project assessment. The two on-site stations were only operational for a short period of time, and the 2 metre measurement heights may limit the representativeness of the data collected. The Environment and Climate Change Canada (ECCC) Crowsnest station located in Coleman, AB is likely the nearest meteorological station to the proposed project location. Benga summarized 5-years of wind data (2010 to 2014) and indicated a maximum wind speed of 52 km/hr. The maximum wind speed presented appears to be an hourly average measured at the station and not instantaneous gust speeds. Although Benga has provided consideration of the maximum average wind speed, Benga has not addressed concerns relating to high (gust) wind speed events.

In addition, Benga responded to IR 1.5 (CIAR #251), with a discussion regarding high wind speeds, and its effect on wind blown dust and coal loading/unloading operations. With respect to wind blown dust, Benga utilized a U.S. EPA AP-42 emission factor to calculate the wind driven total suspended particulates from active areas of operation (aggregate pits, overburden stripping, unpaved haul roads, stockpiles). The emission factor does not directly correlate to wind speed, but rather the frequency of time where wind speeds are greater than 5.36 m/s. For the purposes of their calculations, Benga assumed wind speeds were greater than 5.36 m/s, 100% of the time. Benga also noted that this assumption does not consider mitigative circumstances such as precipitation, vegetation coverage, and crust formations. Benga indicated that wind blown emissions were conservatively accounted for, and the emission factor calculation results in the maximum emissions estimate. Further, Benga referenced the inverse relationship of C=Q/U (C is predicted concentration, Q is emission rate, U is wind speed), where the higher the wind speed, the higher the dilution factor. For loading/unloading operations, Benga also used a U.S. EPA AP-42 emission factor.

Benga, in its modeling assessment, assumed a mean wind speed of 3.9 m/s. Benga indicated that if the wind speed was doubled, dust emissions would increase by $2^{1.3}$ or approximately 250%. Benga again referenced the inverse relationship of C=Q/U, which suggests that the concentration of dust will decrease with increased wind speed. Benga stated that due to dilution, the reported 250% increase in dust emissions would result in a net increase in concentration of only about 50%. While the U.S. EPA AP-42 emission factors are the commonly accepted practice of estimating dust emissions from mining

operations, the inverse relationship of C=Q/U may be an oversimplification of particulate dispersion.

Members of the public (CIAR #282, #288, and #290), suggested that Benga did not sufficiently address concerns relating to evaluation of high wind speed events and the potential effect on dust transport in the region. Comments also indicated that Benga did not consider peak (gust) wind speed events, nor full magnitude of wind blown particulate emissions.

The information requested below is required in order to complete the following:

- Terms of Reference, Section 4.1.2 [B]: *"Identify stages or elements of the project that are sensitive to changes or variability in climate parameters, including frequency and severity of extreme weather events. Discuss what impacts changes to climate parameters may have on elements of the project that are sensitive to climate parameters."*

a) Provide a detailed summary of Crowsnest and Beaver Mine wind data for the most recent 10-years of available data, including maximum wind gust speeds. Include tabulated statistical summaries and graphical representations of average and gust wind speeds.

Response:

Summaries of wind data from the most recent 10 years at Crowsnest and Beaver Mine are provided below. For reference, the location of the two wind stations are shown in Figure 6.1-1. The anemometers are located 10 m above ground level.

Daily Maximum Wind Gust

According to the American Meteorological Society, in U.S. weather observing practice (http://glossary.ametsoc.org/wiki/Gust), gusts are reported when the peak wind speed reaches at least 16 knots (about 30 km/h) and the variation in wind speed between the peaks and lulls is at least 9 knots (about 17 km/h). The duration of a gust is usually less than 20 seconds.

Hourly maximum wind gust data are not available from Environment Climate Change Canada (ECCC); therefore, daily maximum gust wind speeds are summarized. Daily maximum wind gust data (*i.e.,* the highest 20-second wind speed in each day) at Crowsnest and Beaver Mines stations for the most recent 10 years were downloaded from the ECCC website (https://climate.weather.gc.ca/). ECCC indicates that wind character and wind gust speed are acquired at a height of 10 m (https://climate.weather.gc.ca/doc/Technical_Documentation.pdf). Daily maximum gust data at Beaver Mines station is available beginning in 2012.

Figure 6.1-2 shows the overall frequency distribution of daily maximum gust and Figure 6.1-3 shows seasonal variation of daily maximum gust at the two stations. Figures 6.1-4 and 6.1-5 show the wind rose for each site, showing the direction from which the maximum wind gust

speed blew. Tables 6.1-1 and 6.1-2 summarize the counts of daily maximum gust in each month of year at Crowsnest and Beaver Mines stations, respectively.

The figures and tables indicate the following:

- Daily maximum wind gusts above 30 km/h occurred frequently at the 10 m level.
- The occurrence of daily maximum gust above 80 km/h is less than 1.5% at Crowsnest and 3.7% at Beaver Mines stations.
- Median gusts are higher during the summer month and lower in winter months.
- Daily maximum gusts are strongest in January at both stations.
- Gusts are channelled along the valley as evidenced by WNW winds at the Crowsnest station and SW winds at Beaver Mines (which is in a different valley system).

Table 6.1-1 Summary of Max Gust at Crowsnest (2010 – 2019)

Max Gust (km/h)	Count of Max Gust in Month of Year												Year	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Count	% of total Gust Count
30-40	93	112	107	122	163	98	106	165	145	105	90	91	1397	40%
40-50	60	58	95	79	88	119	114	82	66	89	69	42	961	27%
50-60	51	56	55	55	36	57	54	43	50	41	60	61	619	18%
60-70	59	29	28	26	10	19	19	10	13	40	41	42	336	10%
70-80	31	12	10	11	3	1	6	4	11	13	21	30	153	4.3%
80-90	10	3	6	0	1	0	0	1	1	6	6	9	43	1.2%
90-100	4	2	1	0	1	0	0	0	0	0	1	0	9	0.3%
>100	1	0	0	0	0	0	0	0	0	0	0	0	1	0.0%

Table 6.1-2 Summary of Max Gust at Beaver Mines (2012 – 2019)

Max Gust (km/h)	Count of Max Gust in Month of Year												Year	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Count	% of total Gust Count
30-40	53	68	74	88	121	105	118	135	112	79	48	62	1063	40%
40-50	32	32	43	47	70	55	60	54	44	49	48	26	560	21%
50-60	29	28	34	49	26	44	34	25	38	35	46	35	423	16%
60-70	54	40	48	29	10	22	10	5	13	29	37	48	345	13%
70-80	18	13	19	14	4	5	3	2	5	23	36	23	165	6.2%
80-90	13	11	8	2	1	0	2	0	2	10	8	10	67	2.5%
90-100	9	2	2	1	0	0	0	0	0	3	6	5	28	1.1%
>100	1	0	0	0	0	0	0	0	0	1	0	0	2	0.1%

One-hour Average Wind Speed

Figure 6.1-6 shows the frequency distribution of hourly average wind speed and Figure 6.1-7 shows seasonal variation of the hourly average wind speed at the two stations. Figures 6.1-8 and 6.1-9 show the wind rose for each site.

The seasonal variation in wind speed is like that for wind gusts, indicating the highest hourly average wind speeds are associated with the highest gust wind speeds.

The hourly average wind rose for Crowsnest (Figure 6.1-8) has more winds from the SE than the gust wind rose (Figure 6.1-4).

Table 6.1-3 summarizes the maximum gust and hourly wind speeds at the two ECCC climate stations for the most recent 10 years of available data. It indicates that wind gusts are about twice the hourly average wind speeds at Crowsnest and about 1.5 times higher at Beaver Mines.

Table 6.1-3 Maximum Hourly Wind Speed and Wind Gust at Two ECCC Climate Stations

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Period
Crowsnest (2010 – 2019)													
Maximum Gust (km/h)	106	93	93	80	95	76	80	83	83	89	91	89	**106**
Maximum Hourly Wind (km/h)	50	52	55	43	46	35	35	43	44	48	52	50	**55**
Ratio Gust/Hourly	2.1	1.8	1.7	1.9	2.1	2.2	2.3	1.9	1.9	1.9	1.8	1.8	**1.9**
Beaver Mines (2012 – 2019)													
Maximum Gust (km/h)	107	95	100	91	85	80	89	78	89	103	98	99	**107**
Maximum Hourly Wind (km/h)	71	60	61	54	52	46	51	37	50	62	63	67	**71**
Ratio Gust/Hourly	1.5	1.6	1.6	1.7	1.6	1.7	1.7	2.1	1.8	1.7	1.6	1.5	**1.5**

b) Evaluate the potential effects of wind blown dust, with the consideration of the observed maximum wind gust speeds at the Crowsnest and Beaver Mine stations.

Response:

Wind-blown dust as discussed in response to part a) refers to dust blowing from surfaces. These surfaces could be the pit area, a haul road, or a storage pile.

U.S. EPA (2006) states "Dust emissions may be generated by wind erosion of open aggregate storage piles and exposed areas within an industrial facility. These sources typically are characterized by nonhomogeneous surfaces impregnated with non-erodible elements (particles larger than approximately 1 centimeter [cm] in diameter). Field testing of coal piles and other exposed materials using a portable wind tunnel has shown that (a) threshold wind speeds exceed 5 meters per second (m/s) (11 miles per hour [mph]) at 15 cm above the surface …, and (b) particulate emission rates tend to decay rapidly (half-life of a few minutes) during an erosion event. In other words, these aggregate material surfaces are characterized by finite availability of erodible material (mass/area) referred to as the erosion potential."

The calculation of wind-blown dust by Environment Canada (2011) references the threshold speed of 19.3 km/h (5.4 m/s) for particulate in the $PM_{2.5}$, PM_{10} and TSP size ranges. Below this speed, no emissions occur. Above it, emissions occur while erosion potential remains. At higher speeds, no further emissions in these size ranges occur although it would be expected that coarser

particles could become airborne at higher speeds. Emissions are not continuous – after the first gusts elevate the material, no further emission occurs until additional material settles to the surface.

For overburden and road-bed material, the threshold speed for creating additional wind-blown dust is about 21 m/s (76 km/h) and 27 m/s (97 km/h), respectively (U.S. EPA 2006). The threshold for an uncrusted coal pile is 23 m/s (83 km/h).

The effect of wind gusts in generating additional wind-blown dust from overburden and road-bed material was estimated by comparing the frequency of wind gusts above these thresholds. The frequency of wind gusts for the Project was estimated with two approaches:

- By examining the maximum observed wind gust in each day, from Figure 6.1-2.
- By assuming a gust to one-hour average wind speed ratio of 2, from Table 6.1-3.

Maximum Observed Daily Wind Gust

Table 6.1-4 shows, using observed wind gusts at Crowsnest and Beaver Mine in Figure 6.1-2, for a variety of surface types, the maximum frequency of wind-blown dust generation is less than 6% of days.

Table 6.1-4 Frequency of Potential Wind-Blown Dust Generation by Material Type – Daily Max Gust

	Crowsnest Winds	Beaver Mines Winds
Overburden (76 km/h)	2.7%	5.8%
Uncrusted Coal Pile (83 km/h)	0.7%	2.6%
Road-bed Material (97 km/h)	0.03%	0.4%

Gust to Mean Ratio

Using a gust to mean wind speed ratio of 2 at both sites, from Table 6.1-3, the frequency of hourly gusts based on hourly mean speeds in Figure 6.1-6 was estimated. To do this, the wind speed in each speed range was doubled. For example, at Beaver Mines, the mean wind category 40-60 km/h had a frequency of 2%. Therefore, for the assessment, it was estimated the gust category of 80-120 km/h also had a frequency of 2%. Table 6.1-5 summarizes these results.

Table 6.1-5 Frequency of Potential Wind-Blown Dust Generation by Material Type – Gust from Mean Speed		
	Crowsnest Winds	**Beaver Mines Winds**
Overburden (76 km/h)	0.6%	3.0%
Uncrusted Coal Pile (83 km/h)	0.2%	1.5%
Road-bed Material (97 km/h)	0.01%	0.4%

Implications for Dust Generation

The considerations in modelling wind-blown dust are:

- Wind speed increases with height above ground depending on atmospheric stability and roughness of the surface. Using the information in U.S. EPA (2006), a threshold wind speed of 5 to 5.4 m/s at a height of 15 cm corresponds to a speed of roughly 10-11 m/s (36-40 km/h) at 10 m above ground where standard winds are measured.
- EC stations document hourly mean wind speed and the daily maximum wind gust. The gust to mean wind speed ratio (called the gust factor) ranges from about 1.5 to 2.3 at the two EC sites. The assessment used a gust factor of 2.
- Model winds provided by AEP are 1-hour averages. Model winds do not include gusts.
- To account for gusts, the model approach was to apply the 5.4 m/s threshold speed for fine dust generation to winds at 10 m rather than at 15 cm above ground. Using a gust factor of 2, this corresponds to a gust of about 10.8 m/s at a height of 10 m above ground. In effect, whenever the model winds gust above 10.8 m/s (about 38 km/h), wind-blown dust can be generated.
- The U.S. EPA notes particulate emission rates tend to decay rapidly (half-life of a few minutes) during an erosion event. Higher winds above the threshold wind speed do not generate more dust in the $PM_{2.5}$ to TSP size range. The pool of dust available for transport is limited by the half-life, but the model assumes the dust pool is unlimited.

In the model, a threshold velocity of 5.4 m/s (about 20 km/h) was applied to 10-m CALMET winds and all surface types. Furthermore, the erosion potential was unlimited – the model assumed that the surfaces were disturbed every hour to create new fine material for erosion. According to Figure 6.1-10, wind-blown dust was generated 19-24% of the time in the mine operations area. In other words, the model generated wind-blown dust at the mine site substantially more often than either of the frequency estimates in Tables 6.1-4 and 6.1-5. The implication for the Project is that the model has not under-estimated the frequency of occurrence of wind-blown dust, *i.e.,* is conservative from this perspective.

Implications for Climate Change

As documented in Section 5.14.2 of CR#1 (EIA, CR#1, Section 5.14.2, CIAR#42), wind-blown dust emissions are expected at all stages of the project – construction, operations and reclamation. It is expected climate change would affect the latter stages of the Project.

Under global warming, the severity and frequency of future wind gust events could be expected to change later this century. Cheng *et al*. (2014) modelled the frequency of future wind gusts across Canada for two different emission scenarios and documented results (Figure 6.1-11) for Lethbridge, which has a higher frequency of wind gusts than other locations in the region. By 2065, the frequency of hourly winds above 28 km/h (roughly the threshold for fine wind-blown dust) could increase by 10-13% (considering the first and third bars in the bottom left Lethbridge chart corresponding to 2065).

In Cheng *et al*. (2014), the highest increase for 70 km/h winds (roughly the gust threshold for overburden) is about 60%, which would increase the highest frequency in Table 6.1-5 to 5%. The frequency of future daily max gusts over 70 km/h increases by up to 40%, increasing the highest value in Table 6.1-4 to about 8%. These increased frequencies (5%, 8%) are within the envelope of 19-24% dust generation frequency predicted by application of the model.

Adaptative Management for Dust Mitigation

The above discussion on wind-blown dust generation is based on air quality and climate model predictions, and on regional Environment Canada wind measurements.

Benga has also committed to monitoring airborne particulate associated with its operations and has developed a draft Air Quality Monitoring and Adaptive Management Plan (as provided in Addendum 10, JRP IR-1.3, CIAR#251). The specific mitigation measures in Section 5 of that plan that apply to wind-blown dust in all phases of operation are:

- Trees and bushes will be preserved around mines, plant and loadout, because they effectively trap dust emissions from construction and operations activities downwind of sources. Trees and bushes downwind of dust sources also reduce wind speed in their wake, which leads to increased dust deposition by removing it from the atmosphere.
- Trees and bushes upwind of emission sources also reduce wind speeds in their wake, which would reduce the generation of wind-blown dust at source.
- Envirobind DCT (as discussed in Addendum 10, JRP IR-1.1, CIAR#251) will be applied at the loadout to reduce wind-blown emissions of coal dust from rail cars during transport.

A range of other practices also reduce the potential for wind-blown dust generation, including the application of dust suppressant to haul road and plant area surfaces, enclosing the rail loadout and conveyors, and maintaining snow cover on surfaces in winter. Prompt reclamation and revegetation will reduce wind-blown emissions at end of life.

Section 7 of the Plan (Addendum 10, JRP IR-1.3, Appendix 1.3-1, CIAR#251) identifies the factors that will be considered as part of adaptive management, based on the success of the proposed mitigation measures. The factors that directly affect wind-blown dust include varying water rates, alternative dust suppressants, and planting additional vegetation.

c) Substantiate and rationalize the emission factor used for wind blown dust calculations; and whether or not the threshold of 5.36 m/s is representative of dust emissions even at extreme wind speeds.

Response:

In Benga's response to Information Request 1.5. (Addendum 10, JRP IR-1.5, CIAR#251), the U.S. EPA emission equation for wind-blown dust was provided.

The method used to estimate wind driven emissions is derived from the fugitive emissions discussion in the Air & Waste Management Association (AWMA) Air Pollution Engineering Manual (AWMA 1992). The same method is recommended by NPI (2012) for Australian mines.

The value of 5.36 m/s is suggested in both documents as the threshold velocity for wind-driven emissions from coal stockpiles, where the speed is measured at the surface and, as indicated in the response to b) above, is the same threshold used by Environment Canada. Appendix A to CR#1 (EIA, CR#1, CIAR#42) noted that the threshold speed typically corresponds to a 10-m wind speed of about 11 m/s.

d) Evaluate the applicability of the simple relationship of C=Q/U in the complex terrain which the proposed project is located in. Provide any other rationale and applicable references to justify the applicability of the C=Q/U relationship used.

Response:

Using a Gaussian plume approach (*e.g.*, from https://www.eng.uwo.ca/people/esavory/Gaussian%20plumes.pdf), the concentration at any point at ground level along the centerline of a plume is given by:

$$C(x,0,0) = \frac{Q}{U}\frac{1}{\pi\sigma_y\sigma_z}e^{\left(\frac{-H^2}{2\sigma_z^2}\right)}$$

To further simplify, when the source height (H) is surface based, the equation becomes:

$$C(x,0,0) = \frac{Q}{U}\frac{1}{\pi\sigma_y\sigma_z}$$

This relationship illustrates that, other things being equal, when emission rates (Q) double, the predicted concentration (C) doubles. Similarly, when wind speed (U) doubles, the predicted

concentration becomes one-half the original value. The plume dimensions (σ's) may be constrained in valley situations but the simple relationship remains valid where the plume width is less than the valley width. This would be the case for the Project analysis.

REFERENCES:

Air & Waste Management Association (AWMA). 1992. Air Pollution Engineering Manual. Anthony J. Buonicore and Wayne T Davies (eds). Van Nostran Reinhold.

Cheng, Chad Shouquan, Lopes, Edwina, Fu, Chao and Huang, Zhiyong. 2014. Possible Impacts of Climate Change on Wind Gusts under Downscaled Future Climate Conditions: Updated for Canada. https://journals.ametsoc.org/doi/full/10.1175/JCLI-D-13-00020.1

Environment Canada. 2011. Pits and Quarries Guidance. https://www.canada.ca/en/environment-climate-change/services/national-pollutant-release-inventory/report/pits-quarries-guide.html.

National Pollution Inventory (NPI). 2012. Emission Estimation Technique Manual for Mining Version 3.1; January 2012 (First Published in March 1999).

U.S. Environmental Protection Agency. 2006. AP 42 Section 13.2.5 Industrial Wind Erosion. https://www3.epa.gov/ttnchie1/ap42/ch13/final/c13s0205.pdf.

LAND USE AND LAND MANAGEMENT

Information Request 6.2

Tenth Addendum to the Environmental Impact Assessment. Response to Information Request 3.4. (CIAR #251)

Public Lands Act. *Public Lands Administration Regulation*. Alberta Regulation 187/2011, Section 9(1)(e), p. 19.

The *Public Lands Act* application process requires applicants to obtain a public land standing report (PLSR) in order to identify the existing land occupants and interests on the public land subject to the application. Section 9(1)(e) of the *Public Lands Administration Regulation* specifies that an application for a disposition "must, if the application relates to public land that is already the subject of a disposition under the Act or a timber disposition, be accompanied with a statement of consent, in a form acceptable to the director, that is signed by the disposition holder or timber disposition holder". The process also requires that consent is included in an application where the lands are subject to an existing reservation or notation that requires consent.

In response to IR 3.4 (CIAR #251), Benga provided some consents, however there are still required consents that remain outstanding. In addition, some of the information provided by Benga are not consents, but simply the notifications that were sent to the land occupants. In certain circumstances, notifications and responses did not include appropriate disposition numbers, therefore confirmation of notification adequacy cannot be confirmed.

In order to comply with Section 9(1)(e) of the *Public Lands Administration Regulation*, Benga is required to review the Public Land Standing Report and all comments associated with each entry and provide the following information:

a) Submit a complete package of all required consents and clearances from the existing occupants and reservations/notations identified in the report; and

Response:

On December 6, 2019, Osler, Hoskin & Harcourt LLP (Osler) on behalf of Benga submitted a letter to the Joint Review Panel (JRP) respectfully requesting that the JRP reconsider and rescind JRP IR-6.2 (CIAR#300), based on the rationale that the legislative regime in Alberta is clear in that Benga is not required to obtain all consents prior to a public interest determination being made.

On January 20, 2020, the JRP issued a response letter rescinding JRP IR-6.2 (CIAR#306); however, the JRP stated that if consents required by the relevant legislation are not provided by the close of the hearing, even if all other requirements are met, the JRP will not be able to issue dispositions in relation to applications where those consents are required. The necessary

consents from Alberta Environment and Parks relating to the following reservations/activities are outstanding:

- CNT 190002
- PNT 090084
- PNT 090087
- PNT 900426 and DHR 000001
- PNT 900430

Benga acknowledges this and will work towards obtaining the necessary consents.

b) Submit all consents and notifications and include the appropriate disposition identifications. The letters of notification and requests for consent must identify the disposition number(s).

Response:

Please refer to response to part (a) above.

SOCIO ECONOMICS

Information Request 6.3

Grassy Mountain Coal Project - Updated Environmental Impact Assessment. Consultant Report #11 –Socio-Economic Impact. (CIAR #42).

Grassy Mountain Coal Project - Updated Environmental Impact Assessment. Section E – Socio-Economic. (CEAR #42).

Fifth Addendum to the Environmental Impact Assessment. Response to Information Request 68. (CIAR #69)

Tenth Addendum to the Environmental Impact Assessment. Response to Information Request 3.6. (CIAR #251)

Comments from the Coalition of Alberta Wilderness Association and Grassy Mountain Group, and Shirley Kirby ("the Coalition"). (CIAR #278)

In the Environmental Impact Assessment, Section E, Benga stated that the "Project will also contribute an estimated $140 million (NPV 2015) and $210 million (NPV 2015) to provincial and federal corporate income taxes respectively as well as approximately $195 million (NPV 2015) in provincial royalties over the 23-year operating life of the project assuming a $140 /tonne average real price of coal". (CIAR #42). These estimates are based on Benga's price forecast of $140 USD /tonne average real price of metallurgical coal. In response to IR 3.6 (CIAR #251), Benga provided estimates for provincial and federal income taxes based on price scenarios of US$100/tonne and US$200/tonne.

In its response to IR 68 (CIAR #69), Benga stated that it "considers $140/tonne is a reasonable long-term price for planning purposes", but did not specify whether it also relied on independent external price forecasts. Elsewhere in that response, Benga proposed $100/tonne and $200/tonne forecasts in response to the request to produce royalty forecasts using both low and high price scenarios. Benga reported these economic benefits in 2015 dollars (Consultant Report 11, CIAR #42). Benga has not provided an update on whether the benefit estimates may have changed since they were originally calculated.

The Coalition (CIAR #278) raised questions about the potential economic benefits of the project and asked for independent validation of Benga's price forecast. The Panel would like to better understand the latest projected benefit estimates.

The information requested below is required in order to complete the following:

- Terms of Reference, Section 8.2 [A] a. ii): "*Describe the socio-economic impacts of project construction and operation, including … impacts on the Regional and provincial economies".*

a) Confirm whether the stated metallurgical coal price forecast of $140/tonne is supported by independent external price forecasts and, if so, submit this supporting

information. Provide information on any credible external price forecasts for metallurgical coal that differ significantly from Benga's price forecast.

Response:

Benga maintains that the current long-term metallurgical coal price forecasts more or less correspond with its stated value of $140 USD/tonne. Since the initial economic review, the long-term forecasts for metallurgical coal prices have held a tight range, very close to the projected $140 USD/tonne. This is supported by the following extract from independent experts Wood Mackenzie. This example is from the recent Wood Mackenzie report entitled, "Global Metallurgical Coal Long-Term Outlook H2 2019: Future Brings Indian Order After China Chaos" in which they state: "*We think long-term prices will need to sit above US$150/t in real terms in order to meet our demand forecasts. Prices are expected to trough one year earlier in our outlook, reaching US$133/t in 2024…Despite some variation in trends, average prices in the long term are very similar to our previous update, reaching US$154/t in 2040.*"

The Wood Mackenzie report summarizes the projected metallurgical coal price in Figure 6.3-1.

Benga has received permission from Wood Mackenzie to provide the above information from the report but is not able to provide a copy of the report due to confidentiality and copyright restrictions.

b) For each of the price forecast scenarios of $100/tonne, $140/tonne, and $200/tonne, provide an updated calculation of projected government revenues (federal, provincial, and municipal) from taxes and royalties over the lifetime of the project, both Net Present Value in 2019 dollars as well as average annual amounts (specify real or nominal dollars). Include key assumptions used to inform the calculations, and indicate whether any of these assumptions have changed since the original benefits estimates were produced in Consultant Report 11 (CIAR #42).

Response:

Key assumptions used to inform the calculation of fiscal effects include:

• Capital Expenditure	$730 million (2015 – no change)
• Annual Operating Expenditure	$225 million per year (2015 – no change)
• Existing Alberta Coal Royalty Structure	(no significant changes)
• Existing Federal and Alberta Income Tax Structure	(most significant change is reduction of Alberta income tax rate from 10% in the previous model to 8%)
• Exchange rate	1 CAD = 0.8 USD (reduced)

The results using the updated information are provided in the Table 6.3-1.

Table 6.3-1 Estimates of Provincial and Federal Income Tax for Metallurgical Coal Prices of $100, $140 and $200 USD/Tonne

Met Coal Price (USD/Tonne)	100	140	200
Provincial Tax Avg/yr (2019) ($ Million)	$6	$19	$38
Provincial Tax NPV8 (2019) ($ Million)	$33	$126	$274
Federal Tax Avg/yr (2019) ($ Million)	$10	$28	$57
Federal Tax NPV8 (2019) ($ Million)	$49	$190	$411
Royalties Tax Avg/yr (2019) ($ Million)	$3	$30	$65
Royalties NPV8 (2019) ($ Million)	$26	$187	$452

Municipal tax amounts are independent of economic factors and depend solely on local tax regulations, Benga continues to estimate annual municipal tax payments to Ranchland and Crowsnest Pass at $990,000 and $490,000, respectively, once the project is fully operational. Using an 8% discount rate, the present value of the municipal taxes over the life of the project is estimated at $11.2 million (2019).

c) Given that three years has passed since the socio-economic impact assessment was submitted, comment on how the projected macroeconomic impacts associated with the Project may have changed with more current data and economic multipliers (e.g., jobs, GDP, etc.).

Response:

The socio-economic conditions in the region have evolved from those characterized in the SEIA, which relied on data collected as part of the 2006 and 2011 federal census and 2011 national household survey. The following is an overview of the differences in selected indicators between the Consultant Report #11 (EIA, CR#11, CIAR#42) and those available at the time of this writing – primarily 2016 census data.

Population

The historic population growth rates shown in Table 6.3-2 (formerly Table 3.1 of CR#11, EIA, CIAR#42) covered the 2001 to 2011 period. Updating these data to include 2016 census data reveal that the population in all of the communities within the RSA are decreasing as demonstrated in CR#11, albeit at a slower rate when the latest data are included.

Table 6.3-2 Updated Historic Population Growth					
Geography	**2001**	**2011**	**2016**	**AAGR (2001-2011)**	**AAGR (2001-2016)**
Ranchland	95	80	90	-1.7%	-0.4%
Crowsnest Pass	6,260	5,565	5,590	-1.2%	-0.8%
Total AB RSA	**6,355**	**5,645**	**5,680**	**-1.2%**	**-0.7%**
Sparwood	3,810	3,665	3,785	-0.4%	-0.04%
Total BC RSA	**3,810**	**3,665**	**3,785**	**-0.4%**	**-0.04%**
Total RSA	**10,165**	**9,310**	**9,465**	**-0.9%**	**-0.5%**
Alberta	2,974,805	3,645,255	4,067,175	2.1%	2.1%
British Columbia	3,907,740	4,400,055	4,648,055	1.2%	1.2%

Source: Statistics Canada 2001, 2006, 2011, 2016. Figures rounded for presentation purposes.

Labour Force

The composition of the labour force as identified in Figures 3.2 and 3.3 of CR#11 (presented again here as Figure 6.3-2 and Figure 6.3-3) is generally in line with the updated figures shown below. The relative concentration of the labour force in selected industries has varied slightly. For example, in the B.C. portion of the RSA, the portion of the labour force engaged in retail and accommodation has increased to surpass health care. However, the notable concentration of the RSA labour force in the mining and oil and gas extraction industry has not changed and continues to be well above both provincial averages.

The labour market conditions characterized in Table 3.2 of CR#11 (EIA, CIAR#42) have changed. Per Table 6.3-3:

- The participation rate in the Alberta portion of the RSA has increased slightly from 60.8% up to 63.1% and remains below the provincial average.
- The participation rate in the B.C. portion of the RSA is virtually unchanged from 68.8% and remains above the provincial average.
- The unemployment rate in both the B.C. and Alberta portions of the RSA have increased considerably – by 2.3% and 3.1% respectively.

Table 6.3-3 Updated Labour Force Indicators

Labour Force Indicator	Alberta Portion of RSA	Alberta	B.C. Portion of RSA	British Columbia
Labour Force Size	2,865	2,302,945	2,115	2,471,665
Participation Rate (%)	63.1%	71.8%	68.9%	63.9%
Unemployment Rate (%)	8.9%	9%	7.8%	6.7%

Source: Statistics Canada 2016.

The 2016 census data described in the table above represents the latest available community-specific labour force data for the RSA. More recent data are available for the economic regions that encompass the RSA and other nearby communities. However, the RSA communities represent a small fraction (*i.e.,* less than of the 1.5% in Alberta and 3% in B.C.) of the broader regional labour force. Accordingly, these more recent statistics are not likely to be representative of the specific conditions in RSA communities.

Education

The 2016 census data are consistent with the findings noted in CR#11 (EIA, CIAR#42). Specifically, the prominent role of resource extraction in the regional economy is reflected in the type of educational attainment of RSA residents. In the Alberta portion of the RSA, the percentage of the population holding an apprenticeship or trade certificate (13.5%) is above the provincial average (9.7%). In the B.C. portion of the RSA, the percentage of the population holding an apprenticeship or trade certificate is also above the provincial average (15.8% as compared to 8.8%). In addition, high school completion in both the Alberta and B.C. RSAs are below their provincial averages.

Median Household Income

Table 6.3-4 provides an update to Table 3.3 in CR#11 (EIA, CIAR#42) and shows median household income from the 2016 census. The general findings contained in CR#11 hold. Specifically:

- household income in the Alberta portion of the RSA is below the provincial average; and
- household income in the B.C. portion of the RSA is above the provincial average.

Table 6.3-4 Updated Median Household Income	
Geography	**2016**
Ranchland	$56,320
Crowsnest Pass	$73,856
Sparwood	$103,538
Alberta	$93,835
British Columbia	$69,995

Source: Statistics Canada 2016.

Economic Effects

The economic impacts described in Section 4 of CR#11 (EIA, CIAR#42) were derived using:

- the Alberta Finance Input-Output Model Multipliers which were published in 2015 and based on data collected in 2011;
- the British Columbia Provincial Economic Multipliers which were published in 2008 and based on data collected in 2004; and
- the 2011 Statistics Canada Interprovincial and international trade flows.

The year in which the data were collected is relevant insofar as the multipliers reflect the structure of the economy at that time. At the time of this writing, the most recent representation of the provincial economies of B.C. and Alberta is the 2016 Interprovincial Input-Output Model built and maintained by Statistics Canada and based on data collected in 2016. The economic impacts estimated by Statistics Canada are outlined below.

During construction, Project expenditures are expected to support total (*i.e.,* direct, indirect, and induced) GDP and labour income of approximately:

- $265 million and $192 million respectively in Alberta; and
- $70 million and $49 million respectively in B.C.

Project construction will also support total (*i.e.,* direct, indirect, and induced) employment of:

- 1,660 PYs in Alberta; and
- 475 PYs in B.C.

During operations, Project expenditures are expected to support annual total (*i.e.,* direct, indirect, and induced) GDP and labour income of approximately:

- $95 million and $62 million respectively in Alberta; and
- $38 million and $27 million respectively in B.C.

Project operations will also support annual total (*i.e.*, direct, indirect, and induced) employment of:

- 610 PYs in Alberta; and
- 250 PYs in B.C.

INDIGENOUS RIGHTS, LAND USE AND CULTURE

Information Request 6.4

Grassy Mountain Coal Project - Updated Environmental Impact Assessment. Section E – Historical Resources. (CEAR #42).

Tenth Addendum to the Environmental Impact Assessment. Appendix 4-1.1. (CEAR #251).

In Benga's response to IR 4.1 (CIAR # 251), Benga provided Appendix 4.1-1: titled "An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups." In Appendix 4.1-1, Benga noted that potential impacts of the Project on archeological sites of cultural interest were identified as part of the Historical Resources Impact Assessment (HRIA) that has been filed with Alberta Culture. Benga also indicated that it had "considered recommendations for mitigation as outlined in the HRIA". Benga did not however provide information on the outcome of the HRIA, nor any details on the recommendations and how it might address any potential impacts to sites identified as important by Indigenous groups.

Benga also noted in Appendix 4.1-1 that additional field work was completed on sites identified by Káínai Nation as culturally important, specifically DjPo-214, DjPo-216 and DjPo-219, and DjPo-37. These sites were not included in Benga's original assessment of historic resources in the EIA, however information on these sites was provided by Benga to Alberta Culture in the HRIA. According to Benga, Alberta Culture indicated that additional studies at sites 214, 216, and 219, would be required if avoidance of the sites was not possible.

The information requested below is required in order to complete the following:

- Terms of Reference Section 5 [A] (c): "*provide a summary of the results of the HRIA conducted to assess the potential impact of the project on archaeological, paleontological, and historic resources*"
- Terms of Reference Section 6 [A] (b): "*provide a map of vision quest sites, cabin sites, spiritual sites, graves, and other traditional use sites considered historic resources under the Historical Resources Act (if the aboriginal community or group is willing to have these locations disclosed), as well as traditional trails and resource activity patterns"*

a) Provide the Historical Resources Impact Assessment, and any additional updates or reports that may have been filed as a result of ongoing field work.

Response:

The *Final Report - Historical Resource Impact Assessment Benga Mining Limited (Riversdale Resources) Grassy Mountain Coal Project Municipality of Crowsnest Pass (ASA Permit 2015-074): Volumes 1 to 3*, was submitted to Alberta Culture and Tourism on March 4, 2016. As part of this information request, Alberta Culture and Tourism were contacted to confirm whether a copy could be provided to the public. Alberta Culture and Tourism have indicated that a copy can not be provided to the public as per their policy for the protection of historical sites.

A summary of the publicly available Historical Resources Impact Assessment information was provided in the EIA (Section E – Historical Resources, CEAR #42). No additional reports have been filed to date.

b) Provide a summary of the recommendations Benga has outlined in the HRIA and any additional recommendations received from Alberta Culture.

Response:

A summary of the recommendations from the *Final Report - Historical Resource Impact Assessment Benga Mining Limited (Riversdale Resources) Grassy Mountain Coal Project Municipality of Crowsnest Pass (ASA Permit 2015-074): Volume 2 (of 3), Tables 73 and 74*, submitted to Alberta Culture and Tourism on March 4, 2016, are presented in Appendix 6.4-1. At that time in 2015, all recommendations were subjected to approval from Alberta Culture and Tourism.

On December 20, 2017, Alberta Culture and Tourism issued a directive *via* the *Historical Resources Act* Requirements (4560-14-0001-003), which was based on the recommendations made in the 2015 HRIA Final Report. A pdf of the December 20, 2017 *Historical Resources Act* Requirements (4560-14-0001-003) is included in Appendix 6.4-2.

c) Describe how Benga proposes to respond to, or implement, the recommendations.

Response:

From the summer to winter of 2019, Benga has moved forward with the recommended Historical Resource works as listed in the December 20, 2017 *Historical Resources Act* Requirements (4560-14-0001-003) under Permit 19-105, which is included in Appendix 6.4-2.

d) Provide details of any sites of cultural interest identified by Indigenous groups that were not included in Benga's original assessment of historic resources or in the Historical Resources Impact Assessment.

Response:

No additional sites of cultural interest have been identified to Benga by Indigenous groups that were not included in Benga's original assessment of historic resources or in the Historical Resources Impact Assessment.

e) Provide updates on any ongoing or recently completed field programs on HRIA sites with Indigenous groups.

Response:

In 2019 Benga in coordination with the respective Indigenous leadership, arranged to employ and train members (with support from Bison Historical Services Ltd.) from the Blackfoot Nations including the Piikani, Kainai, and Siksika Nations.

The Blackfoot crew members were trained in standard and common archaeological excavation techniques from maintaining a controlled excavation within a 1-x-1 metre square pit, shovel shaving of soil in order to identified artifacts in-site (in place), the identification of artifacts and stone tools, the importance of documenting the provenience of artifacts found *in-situ,* the sifting of soil to identified artifacts, and the documentation of arbitrary 10 cm layers within each 1-x-1 metre square pit. These are the methods that are usually taught in a university level 6-week long archaeological field school.

Prior to commencement of archeological field work, a briefing was held with the Blackfoot Nations to describe the intended program and to solicit any concerns or feedback. A ceremony on site was conducted by elders of the Blackfoot Nations prior to commencement of excavation activities. Field visits to the excavation sites were conducted for Blackfoot Nations, Stoney Nakoda Nation, and Tsuut'ina Nation, during the summer of 2019.

Information Request 6.5

Final Environmental Impact Statement Guidelines. (CEAR #11).

Information Request Package #4 from the Joint Review Panel to Benga, Information Requests 4.1 and 4.2. (CIAR #212).

Tenth Addendum to the Environmental Impact Assessment. Response to Information Requests 4.1 and 4.2. (CIAR #251).

The EIS Guidelines, Section 6.4 (CIAR #11) require that Benga describe mitigation measures specific to each environmental effect identified. Mitigation measures are to be written as specific commitments that clearly describe how Benga intends to implement each mitigation measure and the environmental outcome the mitigation is designed to address. Mitigation measures are to be specific, achievable, measurable, and verifiable, and described in a manner that avoids ambiguity in intent, interpretation, and implementation.

In IRs 4.1 and 4.2 (CIAR #212), Benga was asked to provide a completed assessment of the effects of the Project on the current use of lands and resources for traditional purposes of Indigenous peoples. The mitigation measures identified throughout Benga's responses to IRs 4.1 and 4.2, as presented in Appendix 4.1-1 and 4.2-1 (CIAR #251), are however incomplete or lack sufficient explanation and very few have measurable criteria associated with the proposed mitigation. As an example, in Appendix 4.1-2 (CIAR #251) Benga has a mitigation listed as, "minimize the overall disturbance footprint through the mine planning process" and another as, "enforce a speed limit along the main access road". These are not specific commitments that describe how Benga intends to implement and evaluate each mitigation measure, nor do they describe the environmental outcome the mitigation is designed to address.

In order to better understand the proposed mitigation measures with respect to the current use of lands and resources for traditional purposes and the cultural heritage of

Indigenous peoples, and whether the proposed mitigation measures are likely to be effective, the Panel requires the following information from Benga.

a) Provide a table of all commitments and mitigation measures for the current use of lands and resources for traditional purposes, and a similar, separate table for physical and cultural heritage, that Benga commits to implement, should the Project be approved. Include mitigation measures within the LSA and RSA including for specific uses, practices or activities that occur outside of the boundaries of the RSA where a potential effect of the Project may occur. The response must include the following:

   i. The pathway of effect that a given mitigation measure or commitment is addressing;
   ii. A description of the mitigation measure or commitment. Ensure that each mitigation measure is specific, achievable, measurable, and verifiable;
   iii. A description of how Benga will implement each mitigation measure;
   iv. An explanation of how the mitigation measure is meant to address the effect;
   v. A discussion of the anticipated effectiveness of the mitigation measures;
   vi. The conclusion regarding whether there are residual effects after the application of mitigation measures; and
   vii. Reference to the document where the commitment was made or mitigation measure was described (i.e. EIA, Addendum, Registry document number, etc.).

Response:

Benga has undertaken extensive engagement with Indigenous groups throughout the EIA process over the last 6 years to understand potential effects on Indigenous interests. This included:

- Agreements
  - Project Agreements have been signed with most Treaty 7 First Nations and a letter of commitment has been sent to Métis Nation of Alberta. Benga is committed to fulfilling the terms, commitments, and additional mitigations outlined in these agreements; the details of which are not provided here due to confidentiality. Benga acknowledges that, despite the agreements in place, the JRP is mandated to review information on potential adverse environmental effects of the Project.
- Provision of Record of Consultation Logs
  - Extensive bi-monthly consultation logs and concern and response tables have been provided to Treaty 7 First Nations for review and verification that includes engagement starting from December 15, 2014. The logs include all engagement related communication between Benga and Treaty 7 First Nations, including

phone calls, e-mails, and meetings. The up to date consultation logs were provided in Addendum 9 (CIAR#185).

Mitigation for Project effects on the Indigenous VCs of Current Use of Lands and Resources and Indigenous Physical and Cultural Heritage has previously been provided:

- EIA (CIAR#42) Appendix 2, Appendix 2D: Mitigations and Commitments, Table 2D-1: page 15 outlines the mitigation for Indigenous Physical and Cultural Heritage and Traditional Land and Resource Use;
- EIA (CIAR#42) Section H: mitigation for each Indigenous group: Sections H.3.4, H.4.4, H.5.4, H.6.4, H.7.4, H.8.4, H.9.4, H.10.4, H.11.4, H.12.4, and H.13.4;
- Addendum 6 (CIAR#70), Appendix A-3: Summary of Effects, pdf pgs 552-554 outline the mitigation for Indigenous Physical and Cultural Heritage and Traditional Land and Resource Use;
- Addendum 10 (CIAR#251), Appendix 4.1.1: An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups, by Indigenous group for Current Use of Land and Resources: Sections 4.3.2, 5.3.2, 6.3.2, 7.3.2, 8.3.2, 9.3.2, 10.3.2, 11.3.2, 12.3.2, 13.3.2, 14.2.2, 15.3.2, 16.3.2, and 17.2.2;
- Addendum 10 (CIAR#251), Appendix 4.1.1: An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups, by Indigenous group for Physical and Cultural Heritage: Sections 4.4.2, 5.4.2, 6.4.2, 7.4.2, 8.4.2, 9.4.2, 10.4.2, 11.4.2, 12.4.2, 13.4.2, 14.3.2, 15.4.2, 16.4.2, and 17.3.2; and
- Addendum 10 (CIAR#251), Appendix 4.1-2: Consolidated Indigenous Mitigation List.

As per the request of the JRP, new summary tables have been compiled to detail the mitigation measures related to Indigenous VCs. The tables consist of both mitigations and commitments related to the Indigenous VCs (as listed in Table 6.5-1) as well as mitigations and commitments related to associated VCs that are interconnected with the Indigenous VCs. There are six tables, five for Current Use of Lands and Resources for Traditional Purposes (Tables 6.5-2 through 6.5-6) and one table for Physical and Cultural Heritage (Table 6.5-7). The contents of these tables include:

- the pathway of effect that a given mitigation measure is addressing;
- a description of the mitigation measures or commitment;
- reference to the document where the commitment was made or where the mitigation measure was described;
- description of how the mitigation will be implemented and the anticipated effectiveness of the mitigation measures;
- an explanation of how the mitigation is meant to address the effect; and
- the conclusion regarding whether there are residual effects after the application of mitigation measures.

As indicated in the EIA (Section D.2.5.2, CIAR#42), mitigation is often achieved through iterative Project design (*e.g.,* through site selection to avoid sensitive areas and application of best practices during construction). Additional mitigation measures, over and above mitigation integrated into Project design, were identified for each effect, as required. Types of mitigation measures that were considered include:

- environmental protection measures and protocols;
- site-specific measures (*e.g.,* timing of activities to avoid biologically sensitive periods, site-specific mitigation design measures); and
- contingency measures to address the possibility of accidental events that could affect the environment.

Mitigation for Project effects on Indigenous VCs is a combination of mitigation for associated VCs, plus mitigation specific to the Indigenous VCs. Once Project development begins and the mitigation has been implemented, effectiveness monitoring will commence and observed trends will be compared to predicted trajectories. An evaluation of the monitoring results will determine if adaptations to mitigation need to be implemented. A sequence of actions is triggered if monitoring data indicate that environmental performance does not meet targets. To ensure implementation, the mitigation described throughout the EIA, other submissions, and agreements, has been, and will continue to be, incorporated into mitigation and monitoring plans for the Project, many of which are in draft and have been provided to the JRP. Monitoring protocols will be established soon after Project development begins so that trends and progress can be evaluated. Should indicators not meet targets or trends diverge from the desired trajectory, mitigation can be modified as necessary.

Tables 6.5-2 through 6.5-7 include the mitigation related to effects on Indigenous VCs for the Project. The first section of each table outlines the pathways of effect to which a given mitigation measure is linked. Linked biophysical VCs and pathways of effects on Indigenous VCs were described in Tables 3.1.2-1 and 3.2.1-1 of *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups* (Addendum 10, Appendix 4.1-1, Section 3.2.1, CIAR#251). Table 3.1.2-1 has been updated to better reflect linkages between associated biophysical VCs and the effects on Indigenous VCs, and is presented below as Table 6.5-1. The layout of Tables 6.5-2 through 6.5-7 follows the order of VCs and the potential effects listed in Table 6.5-1. By structuring the table in this manner, it is clear how the mitigation is related to the potential effects on Indigenous VCs.

Table 6.5-1 Indigenous Valued Components and Potential Effects (formerly Table 3.1.2-1 in Addendum 10, Appendix 4.1-1, CIAR#251)

Indigenous Valued Components	Potential Effects to Indigenous Interests	Associated Valued Component
Current Use of Lands and Resources for Traditional Purposes		
Hunting	▪ Change in identified hunted species and habitat ▪ Change in use or access to identified hunting locations ▪ Change in preferred harvesting method	▪ Wildlife, (including elk, moose, grizzly bear) ▪ Land and Resource Use ▪ Trails and Travelways ▪ Noise ▪ Air Quality ▪ Cultural and Spiritual Values
Trapping	▪ Change in identified trapped species and habitat ▪ Change in use or access to identified trapping locations ▪ Change in preferred harvesting method	▪ Wildlife (including Canadian lynx, American marten) ▪ Land and Resource Use ▪ Trails and Travelways ▪ Noise ▪ Air Quality ▪ Cultural and Spiritual Values
Fishing	▪ Change in identified fishing species and habitat ▪ Change in use or access to identified fishing locations ▪ Change in preferred harvesting method	▪ Fish and Aquatic Resources ▪ Surface Water Quality ▪ Hydrology ▪ Trails and Travelways ▪ Land and Resource Use ▪ Noise ▪ Air Quality ▪ Cultural and Spiritual Values
Plant Gathering	▪ Change in identified vegetation species/habitat ▪ Change in use or access to identified plant gathering locations ▪ Change in preferred plant harvesting method	▪ Vegetation ▪ Soil Quality ▪ Land and Resource Use ▪ Trails and Travelways ▪ Noise ▪ Air Quality ▪ Cultural and Spiritual Values

Table 6.5-1 Indigenous Valued Components and Potential Effects (formerly Table 3.1.2-1 in Addendum 10, Appendix 4.1-1, CIAR#251)

Indigenous Valued Components	Potential Effects to Indigenous Interests	Associated Valued Component
Trails and Travelways	▪ Change in use or access to identified trails and travelways ▪ Disturbance to features associated with trails and travelways	▪ Land and Resource Use ▪ Noise ▪ Air Quality ▪ Historical Resources
Cultural and Spiritual Values (*e.g.*, sacred and ceremonial areas and activities, teaching areas, place names)	▪ Disturbance to sacred and culturally or spiritually important sites and access to, or use of, those sites ▪ Changes to the experience of engaging with sites and landscape features that have cultural or spiritual value ▪ Changes to the cultural value and importance associated with the engagement with the sites/features of cultural or spiritual value (including inter-generational teaching of traditional practices)	▪ Historical Resources ▪ Trails and Travelways ▪ Hunting ▪ Trapping ▪ Fishing ▪ Plant Gathering ▪ Noise ▪ Air Quality ▪ Land and Resource Use
Indigenous Physical and Cultural Heritage (including any structure, site or thing that is of historical, archaeological, paleontological or architectural significance)		
Indigenous Physical and Cultural Heritage	▪ Disturbance to physical and cultural heritage ▪ Change in access to physical and cultural heritage ▪ Change to cultural value or importance associated with physical and cultural heritage ▪ Change in relationship with physical or cultural heritage	▪ Historical Resources ▪ Land and Resource Use ▪ Trails and Travelways ▪ Noise ▪ Air Quality ▪ Hunting ▪ Trapping ▪ Fishing ▪ Plant Gathering

The primary Project effects on Indigenous VCs, before mitigation, are loss of Crown land, which will result in loss of and access to preferred hunting, trapping, fishing, plant gathering, and trails and travelways locations and change in experience of these activities through noise and other project-related disturbances. The Project may intersect or be in proximity to sacred, gathering, and habitation sites identified by some Indigenous groups. The consequences are:

- loss of opportunities for hunting, trapping, fishing, and plant gathering and reduced engagement in these activities, which could affect the cultural and spiritual relationship between Indigenous groups and their territory.

- loss of intergenerational knowledge transfer opportunities due to reduced locations and activities where and during these exchanges occur, which could affect the relationship between Indigenous groups and their cultural and spiritual values.
- change in use of, access to, or disturbance to features associated with sacred, gathering, or habitation sites, which may change the cultural value or importance to the value.

Benga has committed to implementing mitigation measures (Tables 6.5-2 through 6.5-7) to reduce Project effects on these VCs. The implementation of the mitigation measures and commitments will be through:

- Project-specific policies, procedures and training;
- numerous management plans developed (or to be developed) for the Project;
- commitments contained within agreements with the Indigenous groups; and
- expected conditions of regulatory approvals.

Monitoring and adaptive management will be an important part of ensuring that mitigation measures are effective. Indigenous groups have provided Benga with recommendations on mitigation measures that could address potential effects on Indigenous Rights (*e.g.,* hunting or fishing); these were summarized in response to Addendum 10, JRP IR-4.6 (CIAR#251) and in Addendum 10, Appendix 4.1-1, Section 18.3 (CIAR#251).

After the implementation of mitigation measures, there will be a remaining residual effect on hunting, trapping, fishing, plant gathering, and trails and travelways for Indigenous groups who identified hunting, trapping, fishing, plant gathering, and trails and travelways interests in the Project area. There will be a residual effect on cultural and spiritual values and physical and cultural heritage. Description and characterization of residual effects are provided for each Indigenous group in the response to JRP IR-6.7.

The tables of mitigation are organized as follows:

- Mitigation for Project effects on Current Use of Lands and Resources for Traditional Purposes
  - Table 6.5-2: Mitigation for Project effects on hunting and trapping.
  - Table 6.5-3: Mitigation for Project effects on fishing.
  - Table 6.5-4: Mitigation for Project effects on plant gathering.
  - Table 6.5-5: Mitigation for Project effects on trails and travelways.
  - Table 6.5-6: Mitigation for Project effects on cultural and spiritual values.
  - Table 6.5-7: Mitigation for Project effects on Physical and Cultural Heritage.

Table 6.5-2 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Hunting and Trapping

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**
Hunting and Trapping					
Change in identified hunted or trapped species and habitat; Change in use or access to identified hunting or trapping locations; Change in preferred harvesting method	Hunting and Trapping	**Mitigation measures that will be implemented to reduce adverse effects on hunting and trapping include:** • Support an Indigenous Environmental Stewardship Committee, one of whose functions will be to provide advice on environmental stewardship, land use values and sites of cultural, spiritual and traditional importance that may arise. • Support an Indigenous monitoring program(s) that will include monitoring of a suite of culturally defined environmental attributes, and consideration of cultural heritage impacts and monitoring for cultural sites. • Continue to work with the Indigenous community to identify ways in which TK can be considered during Project activities and in the development of environmental management plans. • Engage with the Indigenous communities during construction, operations and reclamation, including review and input into management and monitoring plans, discussion of options to facilitate access for traditional activities, construction timing and reclamation.	Addendum 10, Appendix 4.1-2, CIAR#251	Implementation of mitigation measures for hunting will be through the commitments contained within agreements with the Indigenous group, as well as expected conditions of regulatory approvals. Mitigation effectiveness will be monitored through development and implementation of Indigenous-led monitoring program with advice from the Indigenous Environmental Stewardship Committee.	Mitigations listed here are in addition to biophysical VC mitigations and were proposed by Indigenous groups to address Project effects on cultural and spiritual values such as hunting and trapping.
		• Benga will consider allowing access to Benga-owned lands outside the Project footprint within the RSA for traditional use such as hunting and trapping. Benga will work with the Nations to identify key areas and develop an Access Management Plan for traditional use.	Addendum 10, Appendix 4.1-1, Section 18.4.1.1.5, CIAR#251		
		• Benga has committed to developing an Indigenous monitoring program in cooperation with nearby Indigenous communities to work in parallel with other western science-based monitoring plans. In addition, Benga will consult with Indigenous groups in developing the monitoring programs through a series of workshops. Benga has committed to providing Annual Reporting documents to Indigenous groups highlighting the results from the monitoring programs and seeking any input that would help Benga improve monitoring and the effectiveness of mitigation measures.	Wildlife Mitigation and Monitoring Plan (WMMP) (Addendum 10, Appendix 5.39-1, Section 4.3, CIAR#251)		
		• Benga has committed to consulting and involving nearby Indigenous groups in the ongoing development of C&R plans and C&R related monitoring as the Project advances through the construction, operations, and progressive reclamation phases.	Updated C&R Plan (Addendum 10, Appendix 2.6-1, Section F.2.7, CIAR#251)		
Change in identified hunted or trapped species and habitat	Wildlife: including moose, elk, grizzly bear, American marten and Canada lynx (Loss of habitat availability due to vegetation clearing and sensory disturbance due to increased noise, odour, visual disturbance)	**Mitigation measures that will be implemented to reduce adverse effects on wildlife habitat include:** To support the reclamation plan mitigation measures, the following will be implemented to mitigate potential direct and indirect Project effects on wildlife habitat availability: • Cleaning and equipment use/storage/cleaning in undisturbed areas within and adjacent to the project footprint will be avoided. • Vegetation adjacent to high-activity linear corridors (*e.g.,* access roads, coal conveyor) will be retained to reduce the extent of noise and visual sensory disturbances to the extent possible. • Incorporate the existing legacy mining disturbances into the development and reclamation plans for the project, and other proposed land use activities to the best extent possible so that habitat loss, habitat fragmentation, linear disturbance features, and cumulative habitat loss are minimized. • Preserve remnant forest patches within the development areas where feasible to provide habitat, habitat connectivity and hide cover for wildlife species. • Protect important wildlife habitat features in areas of suitable wildlife habitat. • Where appropriate, vegetated buffer zones (100 m or minimum of 30 m; pending topography constraints) will be maintained between Project infrastructure and wetlands, creeks, and streams to the best extent possible. • Retain slash and large woody debris in the salvaged soil to provide microsites for native plant and hide cover for wildlife.	Wildlife Mitigation and Monitoring Plan (WMMP) (Addendum 10, Appendix 5.39-1, Section 5, Section 5, CIAR#251) [also EIA, CR#9, Section 7.1.3. CIAR#42; Updated C&R Plan, (Addendum 10, Appendix 2.6-1, Section F.2.8, CIAR#251); and	Implementation of the mitigation measures for hunting and trapping, as it relates to wildlife, will occur through the development and implementation of Project-specific policies, procedures, training, management plans and through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals. The wildlife mitigation will be implemented, monitored, and verified through its inclusion in the the Draft Wildlife Mitigation and Monitoring Plan (WMMP) and the updated C&R Plan. The WMMP contains both mitigation and mitigation monitoring components. The mitigation is expected to reduce the adverse effects of the Project on hunted species and their habitat.	Mitigations to reduce effects on wildlife habitat will, by extension, reduce effects on identified hunted or trapped species and habitat.

Table 6.5-2 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Hunting and Trapping

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**
		• Work with Indigenous groups to identify species of importance prior to construction activities. Undertake pre-disturbance surveys prior to construction activities to determine the occurrence of any important wildlife habitat features. • Maximize the direct placement of salvaged soil to enhance native plant development. • Establish a variety of vegetation species and communities suitable for wildlife, and encourage structural complexity within the forests. • Encourage understory complexity in reclaimed forests by planting native shrubs such as alder and willow. • Ensure that core security areas are provided for wildlife. • Provide water management program that ensures the surface water quality is maintained. • Limit sight lines by maintaining mature forest stands as buffers between roads and reclamation areas.	Addendum 10, Appendix 4.1-2, CIAR#251]	The monitoring program was developed to verify the effectiveness of mitigation designed to minimize changes in wildlife habitat availability, habitat connectivity and movement and mortality risk. Monitoring will be conducted throughout the life of the Project to document wildlife responses to the Project and to Benga's mitigation program. Monitoring is required to assess and verify environmental performance (*i.e.,* that the mitigation program is being completed as planned and is achieving its objectives) and to ensure continual improvement in environmental performance. The focus of the monitoring program will be on obtaining key information that can inform and guide the mitigation process. Benga will focus mitigation monitoring efforts on parameters that are directly related to mitigation effects that provide opportunities to improve mitigation performance over time. This wildlife monitoring approach will enable Benga to evaluate the effectiveness of their wildlife protection, mitigation, and reclamation procedures and to ensure that the Project does not adversely affect wildlife in the region. As with the mitigation program, the mitigation monitoring program is viewed as adaptive and is expected to change as understanding of the responses of wildlife to Project development increases (Addendum 10, Appendix 5.39-1, WMMP, CIAR#251).	
	Wildlife: including moose, elk, grizzly bear, American marten and Canada lynx (Increased wildlife mortality risk due to construction activities, vehicle collisions, and human-wildlife conflicts)	**Mitigation measures that will be implemented to reduce wildlife mortality risk include:** • Conducting pre-disturbance surveys (wildlife sweeps) in the development area prior to any construction activities during the Project. • All access to the Mine Permit will be controlled, no uncontrolled access will be permitted. • Support active bear management plans. If a site specific plan is required, it will be developed in consultation with Indigenous groups as part of the WMMP. The plan is expected to be a comprehensive document that outlines operational strategies and best practices for addressing concerns related to not only bear-human conflicts but potential risks to ungulates and other wildlife resulting from attraction of bears to the area. • A detailed Waste Management Plan will be developed and implemented prior to construction and operational activities to minimize the attraction of wildlife. Benga will follow the Best Management Practices for camps, fences, and barriers as described in Bear Smart: Best Management Practices for Camps, and ensure all waste is stored in wildlife-proof containers and disposed of properly. All on-site staff will receive Bear Awareness Training. • Implementing an Emergency Spill Response Plan to limit the effect of accidental spills. Spills will be minimized by restricting fuel storage and filling to designated areas that are at least 100 m from wetlands and watercourses as well as Project drainage ditches, sediment control ponds, and pit lakes. • Storing all hazardous materials, including those used for blasting, in secure areas that are inaccessible to wildlife (e.g, buildings, storage areas surrounded by wildlife-proof fencing). In addition, proper handling and storage of industrial materials and debris within the Project footprint will be maintained to minimize potential risks to wildlife. • Developing procedures to clear blasting areas of large mammals or birds prior to blasting. • Designing water management ponds and drainage ditches, and pit lakes to minimize potential entrapment of wildlife. • Enforcing speed limits (≤50 km/hr) along the main access road and utility corridors, and placing signs at identified wildlife crossings to increase driver diligence. Vehicles will yield to all wildlife crossing the main access road.	WMMP (Addendum 10, Appendix 5.39-1, Section 5, CIAR#251) [also EIA, CR#9, Section 7.1.5, CIAR#42; Updated C&R Plan (Addendum 10, Appendix 2.6-1, Section F.2.8, CIAR#251); and Addendum 10, Appendix 4.1-2, CIAR#251]		Mitigations to reduce effects on wildlife mortality risk will, by extension, reduce effects on identified hunted or trapped species and habitat.

	Wildlife: including moose, elk, grizzly bear, American marten and Canada lynx
	(Reduced wildlife movement due to creation of barriers)
		Mitigation measures that will be implemented to reduce adverse effects on wildlife movement include:
		• A minimum of six wildlife crossings (underpasses and overpasses) will be incorporated into the design of the coal conveyor:
		  ◦ Strategically placed in locations that will maximize wildlife use;
		  ◦ Additional pre-disturbance surveys will be conducted to identify important wildlife habitats and trails along the access road and conveyor corridor;
		  ◦ Natural underpasses using topography are preferred; and
		  ◦ Above-ground crossings may be required when topography is not favourable, conveyor will likely be raised higher above the ground to allow wildlife movement under it.
		• Road plowing and grading will be conducted in a manner that does not restrict wildlife from crossing access roads or accessing wildlife crossings.
			WMMP (Addendum 10, Appendix 5.39-1, Section 5, CIAR#251)
			[also EIA, CR#9, Section 7.1.4, CIAR#42;
			Updated C&R Plan (Addendum 10, Appendix 2.6-1,
					Mitigations to reduce effects on wildlife movement will, by extension, reduce effects on identified hunted or trapped species and habitat.

Table 6.5-2 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Hunting and Trapping

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**
		• Surface water management ponds and ditches located in undisturbed areas of the project footprint will be designed to allow wildlife to move around or cross safely. • Commence reclamation early on in mine operations by seeding reclaimable areas with plant species favourable to grizzly bear forage, and by planting shrub and tree species that provide suitable cover (*e.g.,* willow, alder, coniferous trees).	Section F.2.8, CIAR#251); and Addendum 10, Appendix 4.1-2, CIAR#251]		
	Wildlife: including moose, elk, grizzly bear, American marten and Canada lynx (Reduced wildlife health due to potential exposure to contaminants)	**Mitigation measures that will be implemented to reduce adverse effects on wildlife health include:** • Measures to control dust and other air emissions: water will be systematically applied to haul roads and to the plant access road and to any haul roads under construction. • Trees and bushes will be preserved around mines and plant, because they effectively trap dust emissions from mining activities and reduce dust concentrations farther from mining activities.	Air Quality Monitoring Plan (Addendum 10, Appendix 1.3-1, Section 5, CIAR#251)		Mitigations to reduce effects on wildlife health will, by extension, reduce effects on identified hunted or trapped species and habitat.
		• Store all hazardous materials, including those used for blasting, in secure areas that are inaccessible to wildlife (*e.g.,* buildings, storage areas surrounded by wildlife-proof fencing). In addition, proper handling and storage of industrial materials and debris within the Project footprint will be maintained to minimize potential risks to wildlife.	EIA, CR#9, Section 7.1.5, CIAR#42		
		• Provide water management program that ensures the surface water quality is maintained.	EIA, Section A.11.9, CIAR#42		
		• Implementing a water management plan to address selenium management and augmentation of potentially impacted tributaries for the Project.	EIA, Section C.8, CIAR#42		
Change in use or access to identified hunting or trapping locations; Change in preferred harvesting method	Trails and Travelways, Land and Resource Use (Loss or disruption of trails for hunting or trapping due to the mine site and access road; Loss of access to hunting or trapping locations)	**Mitigation measures that will be implemented to reduce adverse effects on access include:** • Benga will continue to work with affected Indigenous groups to improve the Access Management Plan (AMP) to grant access to non-operational areas of Benga land and crown land being used for the project. The AMP will control access to authorized persons, will ban fishing by employees, and facilitate access to traditional use areas for Indigenous groups, where feasible. The AMP will include notification of access restrictions during construction required for safety purposes to allow for planning alternate plant gathering locations and access routes. • Benga will allow Indigenous groups to access Benga private land, outside of the Project following the AMP for the purposes of harvesting lodgepole pine and other culturally important plants. • Engage with the Indigenous groups during construction, operations and reclamation, including review and input into management and monitoring plans, discussion of options to facilitate access for traditional activities, construction timing, and reclamation. • Where identified by Indigenous groups, sites of cultural and sacred importance within 100 m of Project activity and outside the Project footprint will be marked or otherwise protected prior to land disturbance. If avoidance of any these sites is not possible, Benga will work with Alberta Culture and Tourism and/or Indigenous groups to develop and plan for mitigation of the site. • Continuing to consult with local stakeholders and Indigenous groups through the life of the Project to identify concerns and proactively address issues when they arise. • Develop and implement a Cultural Site Discovery Contingency Plan in consultation with Indigenous communities for culturally important sites identified during construction and operations.	Addendum 10, Appendix 4.1-2, CIAR#251	Implementation of mitigation measures for access will be through the development and implementation of policies, procedures, training, and management plans. The mitigation to reduce Project effects on access will be implemented through its inclusion in the Access Management Plan (Addendum 10, Appendix 4.5-1, CIAR#251), the goals of which are to: • Maintain an open and transparent dialogue for traditional and recreational use requests through the duration of the Project; • Minimize the impact of changes to access within, and adjacent to, the Project footprint; • Maintain an effective access management strategy that balances Indigenous Rights, workplace safety, and environmental protection; • Monitor the effectiveness of defined access protocol (including permitting); and • Utilize an adaptive management approach to maximizing access opportunities where feasible. Mitigation will also be implemented through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals.	Mitigations to address effects on access will, by extension, reduce effects on access to hunting and trapping locations.
		Mitigation measures that will be implemented in the Access Management Plan include: • Provide training to all staff and contractors regarding respectful land use and access management: promote cultural diversity awareness to Benga's employees and contractors. • Access points and roads to be clearly labelled and documented. • Recreational land use restrictions for employees and contractors will be emphasized to minimize intensive hunting, fishing, and other recreational pressures around the Project boundary.	Access Management Plan (Addendum 10, Appendix 4.5-1, CIAR#251)		

Table 6.5-2 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Hunting and Trapping

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**
		• Notification of access restrictions during construction as required for safety purposes to allow for planning alternate trails and travelways. • Identified sensitive features (*e.g.*, species of management concern, important habitat features) to be flagged or fenced ahead of clearing. • Signage to be used for identifying areas that are not open for public use. • Share information about construction timing. • Share the environmental performance of the Project with Indigenous groups on a regular basis through the life of the Project. • Access and use of OHVs on Benga-owned lands and the Project footprint will be controlled through the AMP. • The only linear footprint of the project is along the main access road which will also incorporate the covered conveyor and the power line for supplying electricity to the mine. • Return Crown leases to the Crown after reclamation is completed.	[also Addendum 10, Appendix 4.1-1, Section 4.3.2.5]	To determine if the AMP is effective in accommodating traditional and recreational access requests, Benga will seek feedback from internal stakeholders, access users, Indigenous groups, and the Safety, Health & Environment department and identity indicators that can be monitored over time. The findings of the AMP monitoring program will drive adaptive changes to the way Benga manages access requests, communicating access permitting requirements, and soliciting feedback from access users.	
	Noise (Increased noise during construction and operation could affect use of hunting or trapping locations by Indigenous groups and preferred harvesting method)	**Mitigation measures that will be implemented to reduce adverse effects of noise include:** • Routing the haul trucks (conveying waste rock and coal) along the western slope of the south disposal area such that the south disposal area itself provides noise shielding between the operating equipment and the residential receptors to the east. • Monitor concerns that are raised by local residents and implement, if necessary, specific measures (*e.g.,* flashing light instead of backup alarm at night, directional backup alarms). • Use of mufflers on all internal combustion engines. • Installing and maintaining a 15 m tall earthen berm along the eastern edge of the south disposal area. • Blasting to occur only on weekdays during typical day-time hours. • Minimizing blasting during cloud cover. • Limiting blasting to smaller more localized blasts, which reduces the amount of explosives used at any one time.	EIA, Section E.2.5.1, CIAR#42	Implementation of mitigation measures for hunting and trapping, as it relates to noise, will be through the development and implementation of policies, procedures, training, and management plans and through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals.	Mitigations to address effects of noise by extension, reduce effects on use and enjoyment of hunting or trapping locations.
		• Should a low frequency noise complaint be received, Benga will conduct a comprehensive sound level (CSL) survey in accordance with the requirements of the AER Directive 038.	EIA, Section A.11.2.2, CIAR#42		
	Air Quality (Increased dust or odour during construction and operation could affect use of hunting or trapping locations by Indigenous groups and preferred harvesting method)	**Mitigation measures that will be implemented to reduce adverse effects of dust include:** • Speeds on mine roads will be limited to 50 km/hr. Speed reduction does not eliminate total emissions but does reduce acute concentrations/exposure. • Systemic application of water to haul roads and to the plant access road to minimize dust. • Gravel or crushed rock will be used as the underlay on the haul roads. Gravel is observed to produce less dust than clay and sandy surfaces. • Use of a grader to maintain the active surface of the access road. This procedure is expected to reduce the effective slit content of the portion of the road where the wheels of the haul trucks travel. • Reclamation and revegetation progressively to reduce windblown fugitive dust emissions. • Trees and bushes will be preserved around mines and plant to trap dust emissions from mining activities. • The coal processing plant module will be contained within an enclosed area and all coal material handling will be *via* covered conveyors. • Dust generation from transferring the coal from conveyor to the stockpile will be minimized by the use of luffing stackers which will minimize the drop height of the coal. • Fugitive dust generation will be minimized at the rail load-out, with full cladding on the sides of the load-out structure to create a wind shelter, and with the movable discharge chute of the bin located as close as practical to the coal within the rail cars.	Air Quality Monitoring Plan, (Addendum 10, Appendix 1.3-1, Section 5, CIAR#251) [also EIA, CR#1, Section 6.6, CIAR#42]	Implementation of the mitigation measures for hunting and trapping, as it relates to air quality, will occur through the development and implementation of Project specific policies, procedures, training and management plans and through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals. Mitigation will be implemented, monitored and verified through their inclusion in the Draft Air Quality Monitoring and Adaptive Management Plan. The mitigation is expected to reduce or minimize the adverse effects of the Project on air quality and will be monitored through the implementation of the air monitoring plans to verify the effectiveness of mitigation measures over time to ensure that the Project related effects on air quality are avoided or minimized.	Mitigations to address effects of dust and odour will, by extension, reduce effects on use and enjoyment of hunting or trapping locations.

Table 6.5-2 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Hunting and Trapping

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**
		Mitigation measures for NOx emissions that will be implemented to reduce adverse effects of odour include: • Use of Tier 4 engines in heavy duty mine equipment. • Benga will investigate alternative ANFO formulations that reduce NOx emissions during blasting. • Emissions will be managed through operations means by developing a program to minimize idling, optimizing the mine place to minimize haul distances, and maintaining the fleet to manufacturer's specifications.	EIA, Section E.1.4.1, CIAR#42; GHG Management Plan (Addendum 10, Appendix 1.8-1, CIAR#251)	The purpose of the Air Quality Monitoring Plan is to outline a process to mitigate potential Project effects on air quality, assess mitigation effectiveness through monitoring and adapt mitigation as necessary and possible based on monitoring results. Benga has already committed to these mitigation measures and expects that they would become part of the anticipated EPEA approval for the Project. A monitoring program has been developed (Section 6) to measure the effectiveness of mitigation in monitoring air emissions and air quality related to the Project. Benga will engage with Indigenous groups in the future to confirm that the air quality mitigation and monitoring plan accommodates input provided by Indigenous groups.	
	Lighting (Increased visual disturbances during construction and operation could affect use of hunting or trapping locations by Indigenous groups and preferred harvesting method)	**Mitigation measures that will be implemented to reduce adverse effects of Project lighting include:** • Use of low visibility spectrum lights on CHPP and rail loadout structures. • Use of low visibility spectrum lights in light stands, designed with directional shades to minimize illumination above the lights horizontal line and to direct light to the illuminated feature. • Implementation of an on-demand and adaptive light management strategy (*i.e.,* activated when needed) at the rail loadout during times a train set is not onsite for loading during nighttime hours. • Where possible, minimize the amount of train loading during nighttime hours. • Light-duty vehicles along the access road will be kept to a minimum. • The overland conveyor system will not be equipped with any additional lighting structures, as lighting would be provided by the associated access road lights. • Existing vegetation (mature trees) will not be cleared along areas requiring night-time illumination to reduce total viewshed. • Mobile lighting on the waste rock disposal area(s) would only be used when needed and will be equipped with low visibility spectrum lights. • Mobile lighting would be positioned (where possible) at the base of existing high points (such as the noise mitigation berm) to reduce their associated viewshed.	EIA, CR#1, Section 5.16.2, CIAR#42		Mitigations to address effects of lighting will, by extension, reduce effects on use and enjoyment of hunting and trapping locations.
		• Implement visual impact mitigation that reduces stray and non-essential artificial lighting to minimize wildlife effects and that will comply with OH&S safety requirements.	EIA, Section A.11.9, CIAR#42		
	Cultural and Spiritual Values (Loss of hunting or trapping opportunities or change in hunting methods could affect the cultural and spiritual relationship between the Nation and their territory)	See mitigations and commitments outlined in Table 6.5-6 for Cultural and Spiritual Values.	Table 6.5-6 (JRP IR-6.5)	See Table 6.5-6 for implementation and effectiveness of mitigation for Cultural and Spiritual Values.	Mitigations to address effects on cultural and spiritual values will, by extension, reduce effects on hunting and trapping opportunities.

Table 6.5-3 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Fishing

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**
Fishing					
Change in identified fishing species and habitat Change in use or access to identified fishing locations Change in preferred fishing method	Fishing	**Mitigation measures that will be implemented to reduce adverse effects on fishing include:** • Support an Indigenous Environmental Stewardship Committee, one of whose functions will be to provide advice on environmental stewardship, land use values and sites of cultural, spiritual and traditional importance that may arise. • Support an Indigenous monitoring program(s) that will include monitoring of a suite of culturally defined environmental attributes, and consideration of cultural heritage impacts and monitoring for cultural sites. • Continue to work with the Indigenous community to identify ways in which TK can be considered during Project activities and in the development of environmental management plans. • Engage with the Indigenous communities during construction, operations and reclamation, including review and input into management and monitoring plans, discussion of options to facilitate access for traditional activities, construction timing and reclamation.	Addendum 10, Appendix 4.1-2, CIAR#251	Implementation of mitigation measures for fishing will be through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals. Mitigation effectiveness will be monitored through development and implementation of Indigenous-led monitoring program with advice from the Indigenous Environmental Stewardship Committee.	Mitigations listed here are in addition to biophysical VC mitigations and were proposed by Indigenous groups to address Project effects on cultural and spiritual values such as fishing.
		• Benga will consider allowing access to Benga-owned lands outside the Project footprint within the RSA for traditional use such as fishing.	Addendum 10, Appendix 4.1-1, Section 18.4.1.2.4, CIAR#251		
Change in identified fishing species and habitat	Fish and Aquatic Resources (Westslope Cutthroat Trout), Surface Water Quality, Hydrology (Loss of habitat availability and quality, and change in flow regime; Decrease in fish health due to potential exposure to contaminants from sediment discharge)	**Mitigation measures that will be implemented to reduce adverse effects on fish and aquatic habitat include:** • A Detailed Fisheries Offsetting and Draft Offsetting Effectiveness Monitoring Plan have been proposed (Addendum 8, Appendices B1 and B2, CIAR#89) that more than offset the habitat losses caused by the Project related to Gold Creek and Blairmore Creek, and involve the enhancement/creation of aquatic and riparian habitat. • Maintain a 100 m undisturbed forested buffer around Blairmore and Gold Creeks.	Addendum 10, Appendix 4.1-2, CIAR#251	Implementation of the mitigation measures for fishing, as it relates to fish and fish habitat, will occur through the development and implementation of Project-specific policies, procedures, training, management plans, through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals. The aquatics and fish habitat mitigation will be implemented, monitored and verified through their inclusion in the Aquatic Monitoring Plan (Addendum 11, Appendix 6.23-1); Detailed Fisheries Offsetting Plan, (Addendum 8, Appendix B-1, CIAR#89); and the Offsetting Effectiveness Monitoring Plan (Addendum 8, Appendix B-2, CIAR#89). The mitigation is expected to reduce or minimize the adverse effects of the Project on fish and fish habitat and will be monitored through the implementation of the various aquatic monitoring plans to verify the effectiveness of mitigation measures over time to ensure that the Project related effects on the aquatic environment are avoided or minimized. Implementation and effectiveness of offsetting are managed by several sections in the Detailed Fisheries Offsetting Plan: Section 7.1.4 of the Offsetting Plan outlines contingency measure if the offsetting measures are deemed ineffective, potential additional offsetting measures have been identified. Section 8.0 details the implementation of the offsetting measures. Uncertainty regarding the offsetting mitigation is discussed in Section 9.1: Acknowledging Uncertainty, Time Lag, Underlying Habitat, and Complementary Measures. Increasing	Mitigations to address effects on Fish and Aquatic Resources, Surface Water Quality, and Hydrology will, by extension, reduce effects on changes in identified fishing species and habitat.
		Changes in water temperature will be mitigated by: • Minimize the removal of riparian vegetation. • Maintain appropriate riparian reserves and management zones from watercourses, where feasible. • Construction of online settling ponds for clean (non-contact) water and mine-influenced (contact) water in lowest reach of affected tributary streams. • Although changes in stream temperatures are not predicted to occur, implement monitoring of discharges and ambient variables in receiving environments to ensure that water quality is within tolerances for WSCT. • *i.e.*, Develop a progressive reclamation plan to accelerate revegetation, reforestation and end land uses to provide overhanging cover and shade for watercourses. **Changes in WSCT food supply will be mitigated by:** • Minimize the removal of riparian vegetation. • Maintain appropriate riparian reserves and management zones from watercourses, where feasible. • Construction of online settling ponds for clean (non-contact) water and mine-influenced (contact) water in lowest reach of affected tributary streams. • Monitor discharges and ambient variables in receiving environments to ensure that water quality is within tolerances for WSCT. • Develop a progressive reclamation plan to accelerate revegetation, reforestation and end land uses to provide overhanging cover and shade for watercourses.	Draft Aquatic Monitoring Plan (Addendum 11, Appendix 6.23-1, Table 5.0-1) [also in Addendum 1, CR#6, Table 4.2, CIAR#44]		

Table 6.5-3 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Fishing

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**
		Changes to sediment supply, transport mechanisms and sediment yield will be mitigated by: • Develop erosion and sediment control based on industry standards. • Design access and mine haul roads to a stable angle to reduce erosion. • Store salvaged topsoil away from watercourses and surface waterbodies. • Apply erosion and sediment control practices to salvaged soil to reduce potential erosion and sediment transport off-site. • Direct surface water runoff and pit water to the appropriate water management infrastructure (e.g., sedimentation ponds). • Discharge water to watercourses in a manner that does not cause erosion or other damage to downstream areas. • Develop a progressive reclamation plan to accelerate revegetation, reforestation and end land uses to provide overhanging cover and shade for watercourses. **Changes to surface water quality will be mitigated by:** • Clean-water (*i.e.,* runoff collected from natural non-disturbed areas; non mine-influenced water) will be directed towards sedimentation ponds. • Water quality will be managed to comply with water quality criteria that are protective of aquatic health. • Techniques identified in the mine plan and water management plan to mitigate mine-influenced water aimed to avoid the potential for water quality effects that can affect fish and fish habitat. **Changes to calcite precipitation will be mitigated by:** • Minimize the waste rock spoil areas within local watersheds to limit the area of waste rock that may come into contact with surface water systems. • Develop a calcite monitoring and management to monitor the potential formation of calcite in Gold and Blairmore creeks and to control precipitation of calcite to within acceptable level. **Changes to aquatic and/or riparian habitat for WSCT will be mitigated by:** • Minimize the Project's physical footprint. • Existing infrastructure, rather than new infrastructure, will be used or upgraded where feasible and sustainable. • Develop offsetting measures to counterbalance any permanent loss of riparian or fish habitat that cannot be avoided.		confidence is discussed in Section 9.2: Building Confidence in the Selected Offsetting Measures. Benga will implement a management, monitoring and reporting program to: 1. Monitor environmental protection during construction of offsetting activities; and 2. Confirm that habitat offsetting measures meet their intended design objectives through an initial as-built design compliance monitoring, and follow-up habitat performance effectiveness monitoring. The Draft Offsetting Effectiveness Monitoring Plan (Addendum 8, Appendix B-2, CIAR#89) focuses on effectiveness monitoring, that is comprised of a rigorous, science-based design. The goal of the Monitoring Plans design is to evaluate and verify the performance of the selected offsetting. The plan is designed to evaluate the efficacy of offsetting measures through the achievement of defined success criteria, and to evaluate the establishment of structure and function of the various ecological features of the offset habitats. The approach uses scientifically defensible sampling methodologies that will allow for the verification of identified habitat gains, thus fish productivity to confirm appropriate compensation has been provided to offset Project-related losses. A Draft Aquatics Monitoring Plan has been filed (Addendum 11, Appendix 6.23-1), which contains the mitigation listed here and is expected to be a condition of the EPEA approval. The Plan involved the monitoring of various aquatic components: water quality, aquatic effects, calcite, groundwater-surface water interactions, hydrology, fluvial geomorphology, bioenergetics, , and WSCT population, all aimed at monitoring the effectiveness of the mitigation related to fish and fish habitat.	
		Effects on flows will be mitigated through: • Coal handling and processing plant facilities will be aligned in such a way to minimize drainage diversions and runoff interception (*e.g.,* maintain natural vegetated buffers between active mine areas and undisturbed streams). • Design settling ponds according to the latest sizing methodology (1:10 year storm event and safely convey up to the 1:100 year flood event). • Design and construct any potential watercourse crossings to meet or exceed the regulatory requirements for approval under the provincial *Water Act.* • Construct clear span crossings over all watercourses identified as potential fish bearing streams • use appropriately sized culverts, as required, to maintain drainage along non-fish bearing headwater tributaries and/or ephemeral drainage draws. • Incorporating flow and erosion control methods, such as ditch check structures, natural depressions or low areas to trap sediment, silt fences or exfiltration ditches in small, low gradient areas adjacent to soil and stockpiles areas.	EIA, Section E.4.5, CIAR#42		

Table 6.5-3 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Fishing

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**
		Sediment concentration in surface water will be mitigated by: • Installing haul road berms to contain road runoff and direct it to designated runoff control works. • Incorporating erosion control measures, such as natural depressions or low areas to trap sediment, silt fences or exfiltration ditches in small, low gradient areas adjacent to soil and stockpiles areas. • Directing runoff from active mining areas, the north and south waste rock disposal areas, and topsoil stockpiles to the water management sedimentation and surge ponds for sediment settling treatment and as it relates to surge ponds. • Training personnel to minimize disturbances and use and maintain drainage and sediment controls.	EIA, Section E.4.5, CIAR#42		
Change in use or access to identified fishing locations, Change in preferred fishing method	Trails and Travelways Land and Resource Use (Loss or disruption of trails for accessing fishing locations and loss of access to fishing locations due to the mine site and road closure during construction and operation)	**Mitigation measures that will be implemented to reduce adverse effects on access include:** • Benga will continue to work with affected Indigenous groups to improve the AMP to grant access to non-operational areas of Benga land and crown land being used for the project. The AMP will control access to authorized persons, will ban fishing by employees, and facilitate access to traditional use areas for Indigenous groups, where feasible. The AMP will include notification of access restrictions during construction required for safety purposes to allow for planning alternate plant gathering locations and access routes. • Benga will allow Indigenous groups to access Benga private land, outside of the Project following the AMP for the purposes of harvesting lodgepole pine and other culturally important plants. • Engage with the Indigenous groups during construction, operations and reclamation, including review and input into management and monitoring plans, discussion of options to facilitate access for traditional activities, construction timing, and reclamation. • Where identified by Indigenous groups, sites of cultural and sacred importance within 100 m of Project activity and outside the Project footprint will be marked or otherwise protected prior to land disturbance. If avoidance of any these sites is not possible, Benga will work with Alberta Culture and Tourism and/or Indigenous groups to develop and plan for mitigation of the site. • Continuing to consult with local stakeholders and Indigenous groups through the life of the Project to identify concerns and proactively address issues when they arise. • Develop and implement a Cultural Site Discovery Contingency Plan in consultation with Indigenous communities for culturally important sites identified during construction and operations.	Addendum 10, Appendix 4.1-2, CIAR#251	Implementation of mitigation measures for access will be through the development and implementation of policies, procedures, training, and management plans. The mitigation to reduce Project effects on access will be implemented through its inclusion in the Access Management Plan (Addendum 10, Appendix 4.5-1, CIAR#251), the goals of which are to: • Maintain an open and transparent dialogue for traditional and recreational use requests through the duration of the Project; • Minimize the impact of changes to access within, and adjacent to, the Project footprint; • Maintain an effective access management strategy that balances Indigenous Rights, workplace safety, and environmental protection; • Monitor the effectiveness of defined access protocol (including permitting); and • Utilize an adaptive management approach to maximizing access opportunities where feasible. Mitigation will also be implemented through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals. To determine if the AMP is effective in accommodating traditional and recreational access requests, Benga will seek feedback from internal stakeholders, access users, Indigenous groups, and the Safety, Health & Environment department and identity indicators that can be monitored over time. The findings of the AMP monitoring program will drive adaptive changes to the way Benga manages access requests, communicating access permitting requirements, and soliciting feedback from access users.	Mitigations to address effects on trails, travelways, land and resource use will, by extension, reduce effects on fishing access and methods.
		Mitigation measures that will be implemented in the Access Management Plan include: • Provide training to all staff and contractors regarding respectful land use and access management: promote cultural diversity awareness to Benga's employees and contractors. • Access points and roads to be clearly labelled and documented. • Recreational land use restrictions for employees and contractors will be emphasized to minimize intensive hunting, fishing, and other recreational pressures around the Project boundary. • Notification of access restrictions during construction as required for safety purposes to allow for planning alternate trails and travelways. • Identified sensitive features (*e.g.,* species of management concern, important habitat features) to be flagged or fenced ahead of clearing. • Signage to be used for identifying areas that are not open for public use. • Share information about construction timing. • Share the environmental performance of the Project with Indigenous groups on a regular basis through the life of the Project. • Access and use of OHVs on Benga-owned lands and the Project footprint will be controlled through the AMP. • The only linear footprint of the project is along the main access road which will also incorporate the covered conveyor and the power line for supplying electricity to the mine. • Return Crown leases to the Crown after reclamation is completed.	Access Management Plan (Addendum 10, Appendix 4.5-1, CIAR#251) [also Addendum 10, Appendix 4.1-1, Section 4.3.2.5]		

Table 6.5-3 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Fishing

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**
	Noise (Increased noise during construction and operation could affects use of fishing locations by Indigenous groups and preferred harvesting method)	**Mitigation measures that will be implemented to reduce adverse effects of noise include:** • Routing the haul trucks (conveying waste rock and coal) along the western slope of the south disposal area such that the south disposal area itself provides noise shielding between the operating equipment and the residential receptors to the east. • Monitor concerns that are raised by local residents and implement, if necessary, specific measures (*e.g.,* flashing light instead of backup alarm at night, directional backup alarms). • Use of mufflers on all internal combustion engines. • Installing and maintaining a 15 m tall earthen berm along the eastern edge of the south disposal area. • Blasting to occur only on weekdays during typical day-time hours. • Minimizing blasting during cloud cover. • Limiting blasting to smaller more localized blasts, which reduces the amount of explosives used at any one time.	EIA, Section E.2.5.1, CIAR#42	Implementation of mitigation measures for fishing, as it relates to noise, will be through the development and implementation of policies, procedures, training, and management plans and through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals.	Mitigations to address effects of noise, by extension, reduce effects on use of fishing locations and harvesting methods.
		• Should a low frequency noise complaint be received, Benga will conduct a comprehensive sound level (CSL) survey in accordance with the requirements of the *AER Directive 038.*	EIA, Section A.11.2.2 CIAR#42		
	Air Quality (Increased dust or odour during construction and operation could affects use of fishing locations by Indigenous groups and preferred harvesting method)	**Mitigation measures that will be implemented to reduce adverse effects of dust include:** • Speeds on mine roads will be limited to 50 km/hr. Speed reduction does not eliminate total emissions but does reduce acute concentrations/exposure. • Systemic application of water to haul roads and to the plant access road to minimize dust. • Gravel or crushed rock will be used as the underlay on the haul roads. Gravel is observed to produce less dust than clay and sandy surfaces. • Use of a grader to maintain the active surface of the access road. This procedure is expected to reduce the effective slit content of the portion of the road where the wheels of the haul trucks travel. • Reclamation and revegetation progressively to reduce windblown fugitive dust emissions. • Trees and bushes will be preserved around mines and plant to trap dust emissions from mining activities. • The coal processing plant module will be contained within an enclosed area and all coal material handling will be *via* covered conveyors. • Dust generation from transferring the coal from conveyor to the stockpile will be minimized by the use of luffing stackers which will minimize the drop height of the coal. • Fugitive dust generation will be minimized at the rail load-out, with full cladding on the sides of the load-out structure to create a wind shelter, and with the movable discharge chute of the bin located as close as practical to the coal within the rail cars.	Air Quality Monitoring Plan, (Addendum 10, Appendix 1.3-1, Section 5, CIAR#251 [also EIA, CR#1, Section 6.6, CIAR#42]	Implementation of the mitigation measures for fishing, as it relates to air quality, will occur through the development and implementation of Project-specific policies, procedures, training and management plans and through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals. Mitigation will be implemented, monitored and verified through their inclusion in the Draft Air Quality Monitoring and Adaptive Management Plan. The mitigation is expected to reduce or minimize the adverse effects of the Project on air quality and will be monitored through the implementation of the air monitoring plans to verify the effectiveness of mitigation measures over time to ensure that the Project related effects on air quality are avoided or minimized. The purpose of the Air Quality Monitoring Plan is to outline a process to mitigate potential Project effects on air quality, assess mitigation effectiveness through monitoring and adapt mitigation as necessary and possible based on monitoring results. Benga has already committed to these mitigation measures and expects that they would become part of the anticipated EPEA approval for the Project. A monitoring program has been developed to measure the effectiveness of mitigation in monitoring air emissions and air quality related to the Project.	Mitigations to address effects of dust and odour will, by extension, reduce effects on use and enjoyment of fishing locations.
		Mitigation measures for NOx emissions that will be implemented to reduce adverse effects of odour include: • Use of Tier 4 engines in heavy duty mine equipment. • Benga will investigate alternative ANFO formulations that reduce NOx emissions during blasting.	EIA, Section E.1.4.1, CIAR#42		
		• Emissions will be managed through operations means by developing a program to minimize idling, optimizing the mine place to minimize haul distances, and maintaining the fleet to manufacturer's specifications.	GHG Management Plan (Addendum 10, Appendix 1.8-1, CIAR#251)		

Table 6.5-3 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Fishing

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**
	Lighting (Increased visual disturbance during construction and operation could affect use of fishing locations by Indigenous groups and preferred harvesting method)	**Mitigation measures that will be implemented to reduce adverse effects of Project lighting include:** • Use of low visibility spectrum lights on CHPP and rail loadout structures. • Use of low visibility spectrum lights in light stands, designed with directional shades to minimize illumination above the lights horizontal line and to direct light to the illuminated feature. • Implementation of an on-demand and adaptive light management strategy (*i.e.,* activated when needed) at the rail loadout during times a train set is not onsite for loading during nighttime hours. • Where possible, minimize the amount of train loading during nighttime hours. • Light-duty vehicles along the access road will be kept to a minimum. • The overland conveyor system will not be equipped with any additional lighting structures, as lighting would be provided by the associated access road lights. • Existing vegetation (mature trees) will not be cleared along areas requiring night-time illumination to reduce total viewshed. • Mobile lighting on the waste rock disposal area(s) would only be used when needed and will be equipped with low visibility spectrum lights. • Mobile lighting would be positioned (where possible) at the base of existing high points (such as the noise mitigation berm) to reduce their associated viewshed.	EIA, CR#1, Section 5.16.2, CIAR#42	Benga will engage with Indigenous groups in the future to confirm that the air quality mitigation and monitoring plan accommodates input provided by Indigenous groups.	Mitigations to address effects of lighting will, by extension, reduce effects on use and enjoyment of fishing locations.
		• Implement visual impact mitigation that reduces stray and non-essential artificial lighting to minimize wildlife effects and that will comply with OH&S safety requirements.	EIA, Section A.11.9, CIAR#42		
	Cultural and Spiritual Values (Loss of fishing opportunities could affect the cultural and spiritual relationship between the Nation and their territory. This could result in loss of cultural identity and human health and well-being)	See mitigations and commitments outlined in Table 6.5-6 for Cultural and Spiritual Values.	Table 6.5-6 (JRP IR-6.5)	See Table 6.5-6 for implementation and effectiveness of mitigation for Cultural and Spiritual Values.	Mitigations to address effects on cultural and spiritual values will, by extension, reduce effects on fishing for traditional purposes.

Table 6.5-4 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Plant Gathering

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**
Plant Gathering					
Change in use or access to identified vegetation species/habitat Change in use or access to identified plant gathering locations Change in preferred plant gathering method	Plant Gathering	**Mitigation measures that will be implemented to reduce adverse effects on plant gathering include:** • Support an Indigenous Environmental Stewardship Committee, one of whose functions will be to provide advice on environmental stewardship, land use values and sites of cultural, spiritual and traditional importance that may arise. • Support an Indigenous monitoring program that will include monitoring of a suite of culturally defined environmental attributes. • Provide access to Benga private land outside if the Project for Indigenous harvesting of lodgepole pine and other culturally important species. • Continue to work with the Indigenous community to identify ways in which TK can be considered during Project activities and in the development of environmental management plans. • Engage with the Indigenous communities during construction, operations and reclamation, including review and input into management and monitoring plans, discussion of options to facilitate access for traditional activities, construction timing and reclamation. • Conduct on-going consultation with Indigenous communities in designing mitigation measures for plant gathering including sharing information about construction timing and management of valued vegetation. • Incorporate the existing legacy mining disturbances into the development and reclamation plans for the Project. • Consider mitigation suggestions proposed by Indigenous communities regarding traditional and medicinal plants.	Addendum 10, Appendix 4.1-2, CIAR#251	Implementation of mitigation measures for plant gathering will be through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals. Mitigation effectiveness will be monitored through development and implementation of Indigenous-led monitoring program with advice from the Indigenous Environmental Stewardship Committee.	Mitigations listed here are in addition to biophysical VC mitigations and were proposed by Indigenous groups to address Project effects on cultural and spiritual values such as plant gathering.
		• Benga has committed to developing an Indigenous monitoring program in cooperation with nearby Indigenous communities to work in parallel with other western science-based monitoring plans. In addition, Benga will consult with Indigenous groups in developing the monitoring programs through a series of workshops. Benga has committed to providing Annual Reporting documents to Indigenous groups highlighting the results from the monitoring programs and seeking any input that would help Benga improve monitoring and the effectiveness of mitigation measures.	WMMP (Addendum 10, Section 4.3, CIAR#251)		
		• Benga has committed to consulting and involving nearby Indigenous groups in the ongoing development of C&R plans and C&R related monitoring as the Project advances through the construction, operations, and progressive reclamation phases.	Updated C&R Plan (Addendum 10, Section F.2.7, CIAR#251)		

Change in use or access to identified vegetation species/habitat	Vegetation, Soil Quality
	(Loss of or disturbance to vegetation, wetlands, and ecosystems that support traditional use plants due to vegetation clearing and dust deposition;
	Change in land capability due to disturbance to soil during construction and loss of soil quality during operation due to dust deposition)
		Mitigation measures that will be implemented to reduce adverse effects on traditional use (TEK) vegetation include:
		• Implementing a re-vegetation program that will aim at re-establishing vegetation communities that are common to the pre-disturbed landscape and that will support TEK vegetation.
		• Providing opportunities to identify and collect suitable lodgepole pine for traditional use ceremonies.
		• TEK vegetation species to be established that correspond with targeted reclamation species include:
		  ◦ Species to be Established - Planting and Natural Recovery: Lodgepole pine; Prickly Rose; Ground Juniper; Willow; Aspen; and Balsam Poplar.
		  ◦ Naturally-occurring plant species to be encouraged: Saskatoon; Thimbleberry; Bearberry; and Dwarf Birch.
		  ◦ Native Woody Plant Species for Reclamation (tree plantings from locally collected seed or cuttings): Subalpine fir; and Dogwood.
		• Implementing a re-vegetation program that utilizes native vegetation species and does not include agronomic invasive species.
		• Revegetate with locally collected seed to preserve the legacy of species and of place, where practicable.
		• Consult with Indigenous groups on the C&R Plan. The C&R Plan will include the use of native species and wherever possible to support revegetation of traditional-use species and end land use decisions made in consultation with Indigenous groups. Traditional land use opportunities will be integrated.
		• Maintain a 100 m riparian buffer zone around Blairmore and Gold Creeks to minimize disturbance to riparian vegetation.
			Updated C&R Plan (Addendum 10, Appendix 2.6-1, Section F.2.8, CIAR#251)
			[also EIA, CR#8, Section 4.6.4.1, CIAR#42; and Addendum 10, Appendix 4.1-2, CIAR#251]
				Implementation of mitigation measures for plant gathering, as it relates to effects on vegetation and wetlands, will occur through the development and implementation of Project-specific policies, procedures, training, and management plans. The vegetation mitigation will be implemented, monitored, and verified through its inclusion in the Updated Conservation and Reclamation Plan (Addendum 10, Appendix 2.6-1, Table F.2.8-1, CIAR#251).
				The mitigation is expected to reduce or minimize the adverse effects of the Project on vegetation and will be monitored through the implementation of monitoring plans to verify the effectiveness of
					Mitigations to address effects on Vegetation and Soil Quality will, by extension, reduce effects on identified plant species and ecosystems.

Table 6.5-4 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Plant Gathering

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**

		Reclamation that will be implemented to reduce adverse effects on plant gathering include:
		• Implementation of a re-vegetation program which aims at the establishment of target vegetation with equivalent capability:
		  • Seed steeper slopes to stabilize soil;
		  • Use natural recovery on areas with low erosion potential;
		  • Collect seed for trees and shrubs locally and store to use later;
		  • Use wildling transplants from adjacent undisturbed areas; and
		  • Re-vegetate with locally collected seed to preserve the legacy of species and of place, where practicable.
		• Develop a reclamation plan that includes the establishment of communities that are locally and regionally limited in distribution where conditions allow.
		• Preservation of adjacent vegetation communities by limiting disturbance to areas required for development of the Project.
		• Use of an appropriate soil substrate where re-vegetated areas can establish.
		• Seed cover soil stockpiles with suitable vegetation species mix to ensure long term stability of the soil piles, which reduces erosion and the potential for weed establishment.
		• The use of coarse woody debris and direct soil placement techniques.
		• The use of direct placement of soil for provision of propagules to enhance opportunity for re- establishment of native species composition and enhanced species richness.
		• Implement a weed management and control program.
		• Incorporate traditional use plants into the reclamation program.
		• Establish multiple layers of native vegetation (*e.g.,* trees, shrubs and graminoids) to provide initial structure for wildlife habitat and to enhance biodiversity.
			Updated C&R Plan, Addendum 10, Appendix 2.6-1, Section F.2.8, CIAR#251
			[also EIA, CR#8, Section 4.1.5.1, CIAR#42]
				mitigation measures over time to ensure that the Project-related effects on vegetation are avoided or minimized. Mitigation will also be implemented through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals.
				Within the C&R plan, there are several other mitigation plans, each of which will have associated monitoring to evaluate the mitigation effectiveness: Rare plant propagule or relocation mitigation plan (Section F.3.2.1); Rare plant species general mitigation plan (F.3.2.2); Whitebark pine and limber pine mitigation plan (F.3.2.3); Foothills rough fescue mitigation plan (F.3.2.4).
				An important component of the reclamation program will be the monitoring of the biophysical aspects of the program. The identification of successes and limitations early in the reclamation process will allow modifications to be made through the adaptive management program to be used at the Project. In addition to providing important feedback on the effectiveness of reclamation techniques, it will also provide data to use in planning the certification of reclaimed lands and the release of lands back to the Crown. The details of this program are outlined in Section F.3.9.3 of the Updated C&R Plan. Benga has committed to developing an Indigenous monitoring program in cooperation with nearby Indigenous groups to work in parallel with other western science-based monitoring plans. In addition, Benga will consult with Indigenous groups in developing the monitoring programs through a series of workshops. Benga has committed to providing Annual Reporting documents to Indigenous groups highlighting the results from the monitoring programs and seeking any input that would help Benga improve monitoring and the effectiveness of mitigation measures.	

		Implementation of the Fescue Grassland Community Mitigation Plan to reduce adverse effects on plant gathering include: • Minimize overall project disturbance and avoid fescue where possible. • Identify potential areas on hill crests and southern aspects suitable for re-establishment of native fescue grasslands. • Direct reclamation material placement from grassland areas when opportunities exist. • Collect native foothills rough fescue seed from across the site. • Use wild harvested certified weed-free native seed as a monoculture and as part of a certified, weed-free native seed mix. • Seed and grow foothills rough fescue plugs in a greenhouse for transplanting onto reclaimed areas of the site. • Promote seeding of foothills rough fescue on the rough areas of the golf course to increase overall distribution of fescue grasslands.	Updated C&R Plan (Addendum 10, Appendix 2.6-1, Section F.2.8, CIAR#251) [also EIA, CR#8, Section 4.3.4.1, CIAR#42]		

		Implementation of the Whitebark Pine and Limber Pine Mitigation Plan to reduce adverse effects on plant gathering include:
		• Minimizing the Project footprint to avoid populations of whitebark pine where possible.
		• Adhering to the mitigation approaches outlined in the Alberta Whitebark Pine Recovery Plan.
		• Introducing white pine blister rust resistant strains during reclamation phases.
		• Conserving genetic diversity, by collecting cones from whitebark pine trees within the disturbance Footprint that are healthy and free of disease after harvesting is completed. The cones will be provided to a greenhouse and seed will be extracted and stored until needed for the reclamation program.
		• Planting according to the following strategies:
		  • Identification of high light, low competition sites;
		  • Planting in pure stands or patches to avoid competition from other trees;
		  • Avoidance of potential swales and frost pockets;
		  • Creation of microsites for seedling establishment (rocks, stumps or other coarse woody debris);
		  • Use of recommended spacing to avoid interspecies competition; and
		  • Preferentially planting seedlings in the fall to avoid hot dry summer conditions.
			Updated C&R Plan (Addendum 10, Appendix 2.6-1, Section F.2.8, CIAR#251)
			[also EIA, CR#8, Section 4.2.6.3, CIAR#42]		

Table 6.5-4 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Plant Gathering

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**
		Mitigation measures that will be implemented to reduce adverse effects on forest resources include: • Salvage of merchantable timber, both coniferous and deciduous. • Collection of locally available cones and seed for future reforestation programs. • Plant seedlings on areas where reclamation and revegetation have been completed. **Mitigation measures that will be implemented to reduce adverse effects on old growth forest resources include:** • Reclamation using tree species capable of achieving of old growth conditions with equivalent capabilities prior to development. • Preserving adjacent vegetation communities by minimizing the area required for construction and operation of the Project.	Updated C&R Plan (Addendum 10, Appendix 2.6-1, Section F.2.8, CIAR#251) [also EIA, CR#8, Sections 4.4.4.1 and 4.5.4, CIAR#42]		
		Mitigation measures that will be implemented to reduce adverse effects on wetlands include: • The use of wetland construction best practices to maintain the hydrologic regime of mineral soil wetlands. • The creation of transition areas between re-vegetated ecological units to the treed swamps. • Re-vegetation of appropriate depression wetland areas to mineral soil wetlands, where possible. • Re-vegetation of mineral soil wetlands with wetland riparian, emergent, and submergent vegetation species. • During construction, salvage and store wetland soil and propagule materials from existing (baseline) wetlands within the Footprint for replacement during wetland reclamation and reconstruction activities. • Opportunities to directly place wetland soil materials (soils and propagules) from adjacent wetlands, to provide a soil substrate with a propagule source for wetlands will occur. • Where applicable, culverts will be placed within wetlands that may be divided by roads to ensure that water flow between wetlands will not be affected.	Updated C&R Plan (Addendum 10, Appendix 2.6-1, Section F.2.8, CIAR#251) [also EIA, CR#8, Section 4.7.4.1, CIAR#42]		
Change in use or access to identified plant gathering locations; Change in preferred plant gathering method	Land and Resource Use Trails and Travelways (Loss or disruption of trails, loss of access to plant gathering locations, and loss of and preferred methods for plant gathering due to the mine site and access road)	**Mitigation measures that will be implemented to reduce adverse effects on access include:** • Benga will continue to work with affected Indigenous groups to improve the AMP to grant access to non-operational areas of Benga land and crown land being used for the project. The AMP will control access to authorized persons, will ban fishing by employees, and facilitate access to traditional use areas for Indigenous groups, where feasible. The AMP will include notification of access restrictions during construction required for safety purposes to allow for planning alternate plant gathering locations and access routes. • Benga will allow Indigenous groups to access Benga private land, outside of the Project following the AMP for the purposes of harvesting lodgepole pine and other culturally important plants. • Engage with the Indigenous groups during construction, operations and reclamation, including review and input into management and monitoring plans, discussion of options to facilitate access for traditional activities, construction timing, and reclamation. • Where identified by Indigenous groups, sites of cultural and sacred importance within 100 m of Project activity and outside the Project footprint will be marked or otherwise protected prior to land disturbance. If avoidance of any these sites is not possible, Benga will work with Alberta Culture and Tourism and/or Indigenous groups to develop and plan for mitigation of the site. • Continuing to consult with local stakeholders and Indigenous groups through the life of the Project to identify concerns and proactively address issues when they arise. • Develop and implement a Cultural Site Discovery Contingency Plan in consultation with Indigenous communities for culturally important sites identified during construction and operations.	Addendum 10, Appendix 4.1-2, CIAR#251	Implementation of mitigation measures for access will be through the development and implementation of policies, procedures, training, and management plans. The access mitigation will be implemented through its inclusion in the Access Management Plan (Addendum 10, Appendix 4.5-1, CIAR#251), the goals of which are to: • Maintain an open and transparent dialogue for traditional and recreational use requests through the duration of the Project; • Minimize the impact of changes to access within, and adjacent to, the Project footprint; • Maintain an effective access management strategy that balances Indigenous Rights, workplace safety, and environmental protection; • Monitor the effectiveness of defined access protocol (including permitting); and	Mitigations to address effects on lands, resources use, trails and travelways will, by extension, reduce effects in changes in use and access to identified plant gathering locations and preferred plant harvesting methods.
		Mitigation measures that will be implemented in the Access Management Plan include: • Provide training to all staff and contractors regarding respectful land use and access management: promote cultural diversity awareness to Benga's employees and contractors. • Access points and roads to be clearly labelled and documented.	Access Management Plan (Addendum 10, Appendix 4.5-1, CIAR#251) [also Addendum 10, Appendix 4.1-1, Section 4.3.2.5, CIAR#251]		

Table 6.5-4 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Plant Gathering

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**
		• Recreational land use restrictions for employees and contractors will be emphasized to minimize intensive hunting, fishing, and other recreational pressures around the Project boundary. • Notification of access restrictions during construction as required for safety purposes to allow for planning alternate trails and travelways. • Identified sensitive features (*e.g.,* species of management concern, important habitat features) to be flagged or fenced ahead of clearing. • Signage to be used for identifying areas that are not open for public use. • Share information about construction timing. • Share the environmental performance of the Project with Indigenous groups on a regular basis through the life of the Project. • Access and use of OHVs on Benga-owned lands and the Project footprint will be controlled through the AMP. • The only linear footprint of the project is along the main access road which will also incorporate the covered conveyor and the power line for supplying electricity to the mine. • Return Crown leases to the Crown after reclamation is completed.		• Utilize an adaptive management approach to maximizing access opportunities where feasible. Mitigation will also be implemented through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals. To determine if the AMP is effective in accommodating traditional and recreational access requests, Benga will seek feedback from internal stakeholders, access users, Indigenous groups, and the Safety, Health & Environment department and identity indicators that can be monitored over time. The findings of the AMP monitoring program will drive adaptive changes to the way Benga manages access requests, communicating access permitting requirements, and soliciting feedback from access users.	
	Noise (Increase in noise during construction and operation could affect use and enjoyment of plant gathering locations or methods of plant gathering)	**Mitigation measures that will be implemented to reduce adverse effects of noise include:** • Routing the haul trucks (conveying waste rock and coal) along the western slope of the south disposal area such that the south disposal area itself provides noise shielding between the operating equipment and the residential receptors to the east. • Monitor concerns that are raised by local residents and implement, if necessary, specific measures (*e.g.,* flashing light instead of backup alarm at night, directional backup alarms). • Use of mufflers on all internal combustion engines. • Installing and maintaining a 15 m tall earthen berm along the eastern edge of the south disposal area. • Blasting to occur only on weekdays during typical day-time hours. • Minimizing blasting during cloud cover. • Limiting blasting to smaller more localized blasts, which reduces the amount of explosives used at any one time.	EIA, Section E.2.5.1, CIAR#42	Implementation of mitigation measures for plant gathering, as it relates to noise, will be through the development and implementation of Project-specific policies, procedures, training, and management plans and through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals.	Mitigations to address noise will, by extension, reduce effects in changes in use and access to identified plant gathering locations and preferred plant harvesting methods.
		• Should a low frequency noise complaint be received, Benga will conduct a comprehensive sound level (CSL) survey in accordance with the requirements of the *AER Directive 038.*	EIA, Section A.11.2.2, CIAR#42		
	Air Quality (Increase in dust or odour during construction and operation could affect use and enjoyment of plant gathering locations or methods of plant gathering)	**Mitigation measures that will be implemented to reduce adverse effects of dust include:** • Speeds on mine roads will be limited to 50 km/hr. Speed reduction does not eliminate total emissions but does reduce acute concentrations/exposure. • systemic application of water to haul roads and to the plant access road to minimize dust. • Gravel or crushed rock will be used as the underlay on the haul roads. Gravel is observed to produce less dust than clay and sandy surfaces. • Use of a grader to maintain the active surface of the access road. This procedure is expected to reduce the effective slit content of the portion of the road where the wheels of the haul trucks travel. • Reclamation and revegetation progressively to reduce windblown fugitive dust emissions. • Trees and bushes will be preserved around mines and plant to trap dust emissions from mining activities.	Air Quality Monitoring Plan (Addendum 10, Appendix 1.3-1, Section 5, CIAR#251) [also EIA, CR#1, Section 6.6, CIAR#42]	Implementation of the mitigation measures for plant gathering, as it relates to air quality, will occur through the development and implementation of Project-specific policies, procedures, training and management plans and through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals. Mitigation will be implemented, monitored and verified through their inclusion in the Draft Air	Mitigations to address dust and odour will, by extension, reduce effects in changes in use and access to identified plant gathering locations and preferred plant harvesting methods.

Table 6.5-4 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Plant Gathering

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**
		• The coal processing plant module will be contained within an enclosed area and all coal material handling will be *via* covered conveyors. • Dust generation from transferring the coal from conveyor to the stockpile will be minimized by the use of luffing stackers which will minimize the drop height of the coal. • Fugitive dust generation will be minimized at the rail load-out, with full cladding on the sides of the load-out structure to create a wind shelter, and with the movable discharge chute of the bin located as close as practical to the coal within the rail cars.		Quality Monitoring and Adaptive Management Plan. The mitigation is expected to reduce or minimize the adverse effects of the Project on air quality and will be monitored through the implementation of the air monitoring plans to verify the effectiveness of mitigation measures over time to ensure that the Project-related effects on air quality are avoided or minimized. The purpose of the Air Quality Monitoring Plan is to outline a process to mitigate potential Project effects on air quality, assess mitigation effectiveness through monitoring and adapt mitigation as necessary and possible based on monitoring results. Benga has already committed to these mitigation measures and expects that they would become part of the anticipated EPEA approval for the Project. A monitoring program has been developed to measure the effectiveness of mitigation in monitoring air emissions and air quality related to the Project. Benga will engage with Indigenous groups in the future to confirm that the air quality mitigation and monitoring plan accommodates input provided by Indigenous groups.	
		Mitigation measures for NOx emissions that will be implemented to reduce adverse effects of odour include: • Use of Tier 4 engines in heavy duty mine equipment. • Benga will investigate alternative ANFO formulations that reduce NOx emissions during blasting. • Emissions will be managed through operations means by developing a program to minimize idling, optimizing the mine place to minimize haul distances, and maintaining the fleet to manufacturer's specifications.	EIA, Section E.1.4.1, CIAR#42 GHG Management Plan (Addendum 10, Appendix 1.8-1, CIAR#251)		
	Lighting (Increased visual disturbances during construction and operation could affect use and enjoyment of plant gathering locations or methods of plant gathering)	**Mitigation measures that will be implemented to reduce adverse effects of Project lighting include:** • Use of low visibility spectrum lights on CHPP and rail loadout structures. • Use of low visibility spectrum lights in light stands, designed with directional shades to minimize illumination above the lights horizontal line and to direct light to the illuminated feature. • Implementation of an on-demand and adaptive light management strategy (*i.e.,* activated when needed) at the rail loadout during times a train set is not onsite for loading during night time hours. • Where possible, minimize the amount of train loading during night time hours. • Light-duty vehicles along the access road will be kept to a minimum. • The overland conveyor system will not be equipped with any additional lighting structures, as lighting would be provided by the associated access road lights. • Existing vegetation (mature trees) will not be cleared along areas requiring night-time illumination to reduce total viewshed. • Mobile lighting on the waste rock disposal area(s) would only be used when needed and will be equipped with low visibility spectrum lights. • Mobile lighting would be positioned (where possible) at the base of existing high points (such as the noise mitigation berm) to reduce their associated viewshed.	EIA, CR#1, Section 5.16.2, CIAR#42		Mitigations to address lighting will, by extension, reduce effects in changes in use and access to identified plant gathering locations and preferred plant harvesting methods.
		• Implement visual impact mitigation that reduces stray and non-essential artificial lighting to minimize wildlife effects and that will comply with OH&S safety requirements.	EIA, Section A.11.9, CIAR#42		
	Cultural and Spiritual Values (Loss of use or access could affect the cultural and spiritual relationship between the Nation and their territory. This could result in loss of cultural identity and human health and well-being)	See mitigations and commitments outlined in Table 6.5-6 for Cultural and Spiritual Values.	Table 6.5-6 (JRP IR-6.5)	See Table 6.5-6 for implementation and effectiveness of mitigation for Cultural and Spiritual Values.	Mitigations to address effects on cultural and spiritual values will, by extension, reduce effects in changes in use and access to identified plant gathering locations and preferred plant harvesting methods.

Table 6.5-5 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Trails and Travelways

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**
Trails and Travelways					
Change in use or access to identified trails and travelways; Disturbance to features associated with trails and travelways	Trails and Travelways	**Mitigation measures that will be implemented to reduce adverse effects on trails and travelways include:** • Support an Indigenous Environmental Stewardship Committee, one of whose functions will be to provide advice on environmental stewardship, land use values and identify any additional sites of cultural, spiritual and traditional importance that may arise. • Support an Indigenous monitoring program(s) that will include monitoring of a suite of culturally defined environmental attributes and consideration of cultural heritage impacts and monitoring for cultural sites. • Continue to work with the Indigenous community to identify ways in which TK can be considered during Project activities and in the development of environmental management plans. • Engage with the Indigenous communities during construction, operations and reclamation, including review and input into management and monitoring plans, discussion of options to facilitate access for traditional activities, construction timing and reclamation. • Incorporate the existing legacy mining disturbances into the development and reclamation plans for the Project.	Addendum 10, Appendix 4.1-2, CIAR#251	Implementation of mitigation measures for trails and travelways will be through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals. Mitigation effectiveness will be monitored through development and implementation of Indigenous-led monitoring program with advice from the Indigenous Environmental Stewardship Committee.	Mitigations listed here are in addition to biophysical VC mitigations and were proposed by Indigenous groups to address Project effects on cultural and spiritual values such as trails and travelways.
Change in use or access to identified trails and travelways	Land and Resource Use (Loss or disruption of trails and travelways due to the mine site and access road)	**Mitigation measures that will be implemented to reduce adverse effects on access include:** • Benga will continue to work with affected Indigenous groups to improve the AMP to grant access to non-operational areas of Benga land and crown land being used for the project. The AMP will control access to authorized persons, will ban fishing by employees, and facilitate access to traditional use areas for Indigenous groups, where feasible. The AMP will include notification of access restrictions during construction required for safety purposes to allow for planning alternate plant gathering locations and access routes. • Benga will allow Indigenous groups to access Benga private land, outside of the Project following the AMP for the purposes of harvesting lodgepole pine and other culturally important plants. • Engage with the Indigenous groups during construction, operations and reclamation, including review and input into management and monitoring plans, discussion of options to facilitate access for traditional activities, construction timing, and reclamation. • Where identified by Indigenous groups, sites of cultural and sacred importance within 100 m of Project activity and outside the Project footprint will be marked or otherwise protected prior to land disturbance. If avoidance of any these sites is not possible, Benga will work with Alberta Culture and Tourism and/or Indigenous groups to develop and plan for mitigation of the site. • Continuing to consult with local stakeholders and Indigenous groups through the life of the Project to identify concerns and proactively address issues when they arise. • Develop and implement a Cultural Site Discovery Contingency Plan in consultation with Indigenous communities for culturally important sites identified during construction and operations.	Addendum 10, Appendix 4.1-2, CIAR#251	Implementation of mitigation measures for access will be through the development and implementation of Project-specific policies, procedures, training, and management plans. The access mitigation will be implemented through its inclusion in the Access Management Plan (Addendum 10, Appendix 4.5-1, CIAR#251), the goals of which are to: • Maintain an open and transparent dialogue for traditional and recreational use requests through the duration of the Project; • Minimize the impact of changes to access within, and adjacent to, the Project footprint; • Maintain an effective access management strategy that balances Indigenous Rights, workplace safety, and environmental protection; • Monitor the effectiveness of defined access protocol (including permitting); and • Utilize an adaptive management approach to maximizing access opportunities where feasible. Mitigation will also be implemented through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals. To determine if the AMP is effective in accommodating traditional and recreational access requests, Benga will seek feedback from internal stakeholders, access users, Indigenous groups, and the Safety, Health & Environment department and identity indicators that can be monitored over time. The findings of the AMP monitoring program will drive adaptive changes to the way Benga manages	Mitigations to address effects on lands and resources use will, by extension, reduce effects of changes in use or access to identified trails and travelways.
		Mitigation measures that will be implemented in the Access Management Plan include: • Provide training to all staff and contractors regarding respectful land use and access management: promote cultural diversity awareness to Benga's employees and contractors. • Access points and roads to be clearly labelled and documented. • Recreational land use restrictions for employees and contractors will be emphasized to minimize intensive hunting, fishing, and other recreational pressures around the Project boundary. • Notification of access restrictions during construction as required for safety purposes to allow for planning alternate trails and travelways. • Identified sensitive features (*e.g.*, species of management concern, important habitat features) to be flagged or fenced ahead of clearing. • Signage to be used for identifying areas that are not open for public use.	Access Management Plan (Addendum 10, Appendix 4.5-1, CIAR#251) [also Addendum 10, Appendix 4.1-1, Section 4.3.2.5, CIAR#251]		

Table 6.5-5 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Trails and Travelways

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**
		• Share information about construction timing. • Share the environmental performance of the Project with Indigenous groups on a regular basis through the life of the Project. • Access and use of OHVs on Benga-owned lands and the Project footprint will be controlled through the AMP. • The only linear footprint of the project is along the main access road which will also incorporate the covered conveyor and the power line for supplying electricity to the mine. • Return Crown leases to the Crown after reclamation is completed.		access requests, communicating access permitting requirements, and soliciting feedback from access users.	
	Noise (Disturbance in enjoyment of use of trails and travelways due to noise, during construction and operation)	**Mitigation measures that will be implemented to reduce adverse effects of noise include:** • Routing the haul trucks (conveying waste rock and coal) along the western slope of the south disposal area such that the south disposal area itself provides noise shielding between the operating equipment and the residential receptors to the east. • Monitor concerns that are raised by local residents and implement, if necessary, specific measures (*e.g.,* flashing light instead of backup alarm at night, directional backup alarms). • Use of mufflers on all internal combustion engines. • Installing and maintaining a 15 m tall earthen berm along the eastern edge of the south disposal area. • Blasting to occur only on weekdays during typical day-time hours. • Minimizing blasting during cloud cover. • Limiting blasting to smaller more localized blasts, which reduces the amount of explosives used at any one time.	EIA, Section E.2.5.1, CIAR#42	Implementation of mitigation measures for trails and travelways, as it relates to noise, will be through the development and implementation of policies, procedures, training, and management plans and through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals.	Mitigations to address effects of noise will, by extension, reduce effects of changes in use or access to identified trails and travelways.
		• Should a low frequency noise complaint be received, Benga will conduct a comprehensive sound level (CSL) survey in accordance with the requirements of the *AER Directive 038.*	EIA, Section A.11.2.2, CIAR#42		
	Air Quality (Disturbance in enjoyment of use of trails and travelways due to odour, and other air quality issues [dust] during construction and operation)	**Mitigation measures that will be implemented to reduce adverse effects of dust include:** • Speeds on mine roads will be limited to 50 km/hr. Speed reduction does not eliminate total emissions but does reduce acute concentrations/exposure. • systemic application of water to haul roads and to the plant access road to minimize dust. • Gravel or crushed rock will be used as the underlay on the haul roads. Gravel is observed to produce less dust than clay and sandy surfaces. • Use of a grader to maintain the active surface of the access road. This procedure is expected to reduce the effective slit content of the portion of the road where the wheels of the haul trucks travel. • Reclamation and revegetation progressively to reduce windblown fugitive dust emissions. • Trees and bushes will be preserved around mines and plant to trap dust emissions from mining activities. • The coal processing plant module will be contained within an enclosed area and all coal material handling will be *via* covered conveyors. • Dust generation from transferring the coal from conveyor to the stockpile will be minimized by the use of luffing stackers which will minimize the drop height of the coal. • Fugitive dust generation will be minimized at the rail load-out, with full cladding on the sides of the load-out structure to create a wind shelter, and with the movable discharge chute of the bin located as close as practical to the coal within the rail cars.	Air Quality Monitoring Plan (Addendum 10, Appendix 1.3-1, Section 5, CIAR#251) [also EIA, CR#1, Section 6.6 CIAR#42]	Implementation of the mitigation measures for trails and travelways, as it relates to air quality, will occur through the development and implementation of Project-specific policies, procedures, training and management plans and through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals. Mitigation will be implemented, monitored and verified through their inclusion in the Draft Air Quality Monitoring and Adaptive Management Plan. The mitigation is expected to reduce or minimize the adverse effects of the Project on air quality and will be monitored through the implementation of the air monitoring plans to verify the effectiveness of mitigation measures over time to ensure that the Project related effects on air quality are avoided or minimized. The purpose of the Air Quality Monitoring Plan is to outline a process to mitigate potential Project effects on air quality, assess mitigation effectiveness through monitoring and adapt mitigation as necessary and possible based on monitoring results. Benga has already committed to these mitigation measures and expects that they would become part of the anticipated EPEA approval for the Project. A monitoring program has been developed to measure the effectiveness of mitigation in monitoring air emissions and air quality related to the Project.	Mitigations to address effects on air quality will, by extension, reduce effects of changes in use or access to identified trails and travelways.
		Mitigation measures for NOx emissions that will be implemented to reduce adverse effects of odour include: • Use of Tier 4 engines in heavy duty mine equipment. • Benga will investigate alternative ANFO formulations that reduce NOx emissions during blasting. • Emissions will be managed through operations means by developing a program to minimize idling, optimizing the mine place to minimize haul distances, and maintaining the fleet to manufacturer's specifications.	EIA, Section E.1.4.1 CIAR#42 GHG Management Plan (Addendum 10, Appendix 1.8-1, CIAR#251)		

Table 6.5-5 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Trails and Travelways

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**
	Lighting (Disturbance in enjoyment of use of trails and travelways due to lighting during construction and operation)	**Mitigation measures that will be implemented to reduce adverse effects of Project lighting include:** • Use of low visibility spectrum lights on CHPP and rail loadout structures. • Use of low visibility spectrum lights in light stands, designed with directional shades to minimize illumination above the lights horizontal line and to direct light to the illuminated feature. • Implementation of an on-demand and adaptive light management strategy (*i.e.,* activated when needed) at the rail loadout during times a train set is not onsite for loading during night time hours. • Where possible, minimize the amount of train loading during night time hours. • Light-duty vehicles along the access road will be kept to a minimum. • The overland conveyor system will not be equipped with any additional lighting structures, as lighting would be provided by the associated access road lights. • Existing vegetation (mature trees) will not be cleared along areas requiring night-time illumination to reduce total viewshed. • Mobile lighting on the waste rock disposal area(s) would only be used when needed and will be equipped with low visibility spectrum lights. • Mobile lighting would be positioned (where possible) at the base of existing high points (such as the noise mitigation berm) to reduce their associated viewshed.	EIA, CR#1, Section 5.16.2, CIAR#42	Benga will engage with Indigenous groups in the future to confirm that the air quality mitigation and monitoring plan accommodates input provided by Indigenous groups.	Mitigations to address effects of lighting will, by extension, reduce effects of changes in use or access to identified trails and travelways.
		• Implement visual impact mitigation that reduces stray and non-essential artificial lighting to minimize wildlife effects and that will comply with OH&S safety requirements.	EIA, Section A.11.9, CIAR#42		
Disturbance to features associated with trails and travelways	Historical Resources (Loss or disturbance to features associated with trails and travelways due to the mine site and access road)	**Mitigation measures that will be implemented to reduce adverse effects on sites and special features include:** • Benga will continue work to fully document these resources as directed by Alberta Culture and Tourism and will obtain clearance under the *Historical Resources Act* prior to undertaking any development that may impact known historic resources.	EIA, Section A.10.10, CIAR#42	Implementation of mitigation measures for historical resources will be through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals, in particular those under the *Historical Resources Act*. Mitigation effectiveness will be monitored through development and implementation of Indigenous-led monitoring program with advice from the Indigenous Environmental Stewardship Committee.	Mitigations to address effects on historical resources will, by extension, reduce effects of disturbance to features associated with trails and travelways.
		• To mitigate potential rail yard impacts, pertinent best management practices, as outlined in the Guidelines for the New Development in Proximity to Railway Operations, will be adhered to. • Disturbance of any further remains located within the proposed rail load out footprint, will be mitigated with controlled excavations to remove the remains. • A mitigation excavation of approximately 80 m^2 will occur in the CHPP footprint in advance of Project development to remove all remaining historical resources or representative samples. • Historic mine remains will be completely documented and recorded. • Historic mining camp remains will be documented in a 20 m^2 excavation. • Additional field surveys and documentation, where required.	EIA, Section A.11.13.1, CIAR#42		

Table 6.5-6 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Spiritual and Cultural Values

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**
Spiritual and Cultural Values					
Disturbance to sacred and culturally or spiritually important sites and access to, or use, of those sites; Changes to the experience of engaging with sites and landscape features that have cultural or spiritual value; Changes to the cultural value and importance associated with the engagement with the sites/features of cultural or spiritual value (including inter-generational teaching of traditional practices)	Cultural and Spiritual Values	**Mitigation measures that will be implemented to reduce adverse effects on cultural and spiritual values include:** • Support in the development of an Indigenous Environmental Stewardship Committee, one of whose functions would be to provide advice on environmental stewardship, land use values and identify any additional sites of cultural, spiritual and traditional importance that may arise. • Support an Indigenous-led monitoring program that will include monitoring of a suite of culturally defined environmental attributes for reclamation success, and including archaeological sites of historical and cultural significance. • Incorporate the existing legacy mining disturbances into the development and reclamation plans for the Project. • Engage with the Indigenous groups during construction, operations and reclamation, including review and input into management and monitoring plans, discussion of options to facilitate access for traditional activities, construction timing and reclamation. • Support a cultural competency program for its employees and contractors. • Continue to support local and Indigenous cultural events and ceremonies through its Indigenous engagement and initiatives such as its community sponsorship program. • Develop and implement a Cultural Site Discovery Contingency Plan in consultation with Indigenous communities for culturally important sites discovered during construction and operations. • Benga will continue to work with Indigenous groups to discuss management of identified culturally important and sacred sites.	Addendum 10, Appendix 4.2-1, CIAR#251	Implementation of mitigation measures for cultural and spiritual values will be through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals. Mitigation effectiveness will be monitored through development and implementation of Indigenous-led monitoring program with advice from the Indigenous Environmental Stewardship Committee.	Mitigations listed here are in addition to biophysical VC mitigations and were proposed by Indigenous groups to address Project effects on cultural and spiritual values.
		• Allow access to Benga-owned lands outside the Project footprint within the RSA for traditional use.	Addendum 10, Appendix 4.1-1, Section 18.4.1.5.2, CIAR#251		
Disturbance to sacred and culturally or spiritually important sites and access to, or use, of those sites Changes to the experience of engaging with sites and landscape features that have cultural or spiritual value Changes to the cultural value and importance associated with the engagement with the sites/features of	Historical Resources, Trails and Travelways, Land and Resource Use, Hunting, Trapping, Fishing, Plant Gathering (Loss or disturbance or disruption of trails to important sites due to the mine site and access road Loss of hunting, trapping, fishing, and plant gathering opportunities Loss of experience in hunting, trapping, fishing, and plant gathering could affect the cultural and spiritual relationships, which could result in loss of cultural	**All the mitigation for Historical Resources, Trails and Travelways, Land and Resource Use, Hunting, Trapping, Fishing, Plant Gathering) are applicable mitigation for reducing effects on cultural and spiritual values.** Mitigation measures that will be implemented to reduce adverse effects on: • historical resources, trails and travelways, and land and resource use are listed in Table 6.5-5; • hunting and trapping are listed in Table 6.5-2; • fishing are listed in Table 6.5-3; and • plant gathering are listed in Table 6.5-4.	Table 6.5-2 Table 6.5-3 Table 6.5-4 Table 6.5-5 (JRP IR-6.5)	Implementation and effectiveness of mitigation for each of historical resources, trails and travelways, land and resource use, hunting, trapping, fishing and plant gathering, and mitigation for linked VCs is discussed in Tables 6.5-2 through 6.5-5. Implementation of mitigation and monitoring for mitigation effectiveness will be in large part through: • Approval conditions • Agreements with Indigenous groups • Indigenous Environmental Stewardship Committee • Wildlife Mitigation and Monitoring Plan • Detailed Fisheries Offsetting Plan • Offsetting Effectiveness Monitoring Plan • Aquatic Monitoring Plan • Updated C&R Plan • Air Quality Monitoring and Adaptive Management Plan • Access Management Plan • Cultural Site Discovery Contingency Plan	Mitigations to address effects on historical resources, trails, travelways, hunting, trapping, fishing and plant gathering, noise and air quality will, by extension, reduce effects of: - disturbance to sacred and culturally or spiritually important sites and access to, or use, of those sites; - changes to the experience of engaging with sites and landscape features that have cultural or spiritual value; and
		In addition, mitigation measures that will be implemented to reduce adverse effects on sacred and culturally or spiritually important sites include: • Where identified by Indigenous groups, sites of cultural and sacred importance within 100 m of Project activity and outside the Project footprint will be flagged or marked prior to land disturbance. • Continue to work with Alberta Culture and Tourism and the Indigenous community to develop a plan for mitigation of identified TK/TU features if avoidance is not possible. • Benga will work with affected Indigenous groups to develop an AMP to grant access to non-operational areas of Benga land and crown land being used for the project. The AMP will control access to authorized persons, will ban fishing by employees, and facilitate access to traditional use areas for Indigenous groups, where feasible. The AMP will include notification of access restrictions during construction required for safety purposes to allow for planning alternate plant gathering locations. • Benga will continue to work with the Indigenous groups to identify ways in which TK can be considered during Project activities and in the development of environmental management plans.	Addendum 10, Appendix 4.1-2, CIAR#251		

Table 6.5-6 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Spiritual and Cultural Values

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**
cultural or spiritual value (including inter-generational teaching of traditional practices)	identity and human health/well-being Loss of hunting, trapping, fishing, and plant gathering opportunities could affect intergenerational teaching of traditional practices, which could result in loss of cultural identity, sense of place, and human health/well-being Loss of access, or Loss of or damage to unique sites and special features due to construction and operation activities)	• To mitigate potential rail yard impacts, pertinent best management practices, as outlined in the Guidelines for the New Development in Proximity to Railway Operations, will be adhered to. • Disturbance of any further remains located within the proposed rail load out footprint, will be mitigated with controlled excavations to remove the remains. • A mitigation excavation of approximately 80 m^2 will occur in the CHPP footprint in advance of Project development to remove all remaining historical resources or representative samples. • Historic mine remains will be completely documented and recorded. • Historic mining camp remains will be documented in a 20 m^2 excavation. • Additional field surveys and documentation, where required.	EIA, Section A.11.13.1, CIAR#42		-changes to the cultural value and importance of sites/features of cultural or spiritual values.

		Mitigation measures that will be implemented to reduce adverse effects on trails and travelways include:
		• Continue to improve the AMP that will include the following:
		  • Access points and roads to be clearly labelled and documented.
		  • Notification of access restrictions during construction as required for safety purposes to allow for planning alternate trails and travelways.
		  • Identified sensitive features (*e.g.*, species of management concern, important habitat features) to be flagged or fenced ahead of clearing.
		  • Signage to be used for identifying areas that are not open for public use.
		  • Share information about construction timing.
			Addendum 10, Appendix 4.1-1, Section 4.3.2.5, CIAR#251		

		Mitigation measures that will be implemented to reduce adverse effects on access include: • Benga will allow Indigenous groups to access Benga private land, outside of the Project following the AMP for the purposes of harvesting lodgepole pine and other culturally important plants. • Engage with the Indigenous groups during construction, operations and reclamation, including review and input into management and monitoring plans, discussion of options to facilitate access for traditional activities, construction timing, and reclamation. • Continuing to consult with local stakeholders and Indigenous groups through the life of the Project to identify concerns and proactively address issues when they arise.	Addendum 10, Appendix 4.1-2, CIAR#251		
	Noise (Increase in noise during construction and operation could affect use, and enjoyment of, or experience of using culturally and spiritually important sites)	**Mitigation measures that will be implemented to reduce adverse effects of noise include:** • Routing the haul trucks (conveying waste rock and coal) along the western slope of the south disposal area such that the south disposal area itself provides noise shielding between the operating equipment and the residential receptors to the east. • Monitor concerns that are raised by local residents and implement, if necessary, specific measures (*e.g.*, flashing light instead of backup alarm at night, directional backup alarms). • Use of mufflers on all internal combustion engines. • Installing and maintaining a 15 m tall earthen berm along the eastern edge of the south disposal area. • Blasting to occur only on weekdays during typical day-time hours. • Minimizing blasting during cloud cover. • Limiting blasting to smaller more localized blasts, which reduces the amount of explosives used at any one time.	EIA, Section E.2.5.1, CIAR#42	Implementation of mitigation measures for noise, will be through the development and implementation of Project-specific policies, procedures, training, and management plans and through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals.	Mitigations to address effects of noise will, by extension, reduce effects of changes to the experience of engaging with sites and landscape features that have cultural or spiritual value
		• Should a low frequency noise complaint be received, Benga will conduct a comprehensive sound level (CSL) survey in accordance with the requirements of the *AER Directive 038.*	EIA, Section A.11.2.2, CIAR#42		

Table 6.5-6 Mitigation Measures and Commitments for Current Use of Lands and Resources for Traditional Purposes for Spiritual and Cultural Values

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How the Mitigation Addresses Effects on Indigenous VC**
	Air Quality (Increase in dust and odour during construction and operation could affect use, and enjoyment of, or experience of using culturally and spiritually important sites)	**Mitigation measures that will be implemented to reduce adverse effects of dust include:** • Speeds on mine roads will be limited to 50 km/hr. Speed reduction does not eliminate total emissions but does reduce acute concentrations/exposure. • systemic application of water to haul roads and to the plant access road to minimize dust. • Gravel or crushed rock will be used as the underlay on the haul roads. Gravel is observed to produce less dust than clay and sandy surfaces. • Use of a grader to maintain the active surface of the access road. This procedure is expected to reduce the effective slit content of the portion of the road where the wheels of the haul trucks travel. • Reclamation and revegetation progressively to reduce windblown fugitive dust emissions. • Trees and bushes will be preserved around mines and plant to trap dust emissions from mining activities. • The coal processing plant module will be contained within an enclosed area and all coal material handling will be via covered conveyors. • Dust generation from transferring the coal from conveyor to the stockpile will be minimized by the use of luffing stackers which will minimize the drop height of the coal. • Fugitive dust generation will be minimized at the rail load-out, with full cladding on the sides of the load-out structure to create a wind shelter, and with the movable discharge chute of the bin located as close as practical to the coal within the rail cars.	Air Quality Monitoring Plan, Addendum 10, Appendix 1.3-1, Section 5, CIAR#251 [also EIA, CR#1, Section 6.6, CIAR#42]	Implementation of the mitigation measures for spiritual and cultural values, as it relates to air quality, will occur through the development and implementation of Project-specific policies, procedures, training and management plans and through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals. Mitigation will be implemented, monitored and verified through their inclusion in the Draft Air Quality Monitoring and Adaptive Management Plan. The mitigation is expected to reduce or minimize the adverse effects of the Project on air quality and will be monitored through the implementation of the air monitoring plans to verify the effectiveness of mitigation measures over time to ensure that the Project related effects on air quality are avoided or minimized. The purpose of the Air Quality Monitoring Plan is to outline a process to mitigate potential Project effects on air quality, assess mitigation effectiveness through monitoring and adapt mitigation as necessary and possible based on monitoring results. Benga has already committed to these mitigation measures and expects that they would become part of the anticipated EPEA approval for the Project. A monitoring program has been developed to measure the effectiveness of mitigation in monitoring air emissions and air quality related to the Project. Benga will engage with Indigenous groups in the future to confirm that the air quality mitigation and monitoring plan accommodates input provided by Indigenous groups.	Mitigations to address effects on air quality will, by extension, reduce effects of changes to the experience of engaging with sites and landscape features that have cultural or spiritual value.
		Mitigation measures for NOx emissions that will be implemented to reduce adverse effects of odour include: • Use of Tier 4 engines in heavy duty mine equipment. • Benga will investigate alternative ANFO formulations that reduce NOx emissions during blasting. • Emissions will be managed through operations means by developing a program to minimize idling, optimizing the mine place to minimize haul distances, and maintaining the fleet to manufacturer's specifications.	EIA, Section E.1.4.1, CIAR#42 GHG Management Plan (Addendum 10, Appendix 1.8-1, CIAR#251)		
	Lighting (Increased visual disturbance during construction and operation could affect use, and enjoyment of, or experience of using culturally and spiritually important sites)	**Mitigation measures that will be implemented to reduce adverse effects of Project lighting include:** • Use of low visibility spectrum lights on CHPP and rail loadout structures. • Use of low visibility spectrum lights in light stands, designed with directional shades to minimize illumination above the lights horizontal line and to direct light to the illuminated feature. • Implementation of an on-demand and adaptive light management strategy (*i.e.*, activated when needed) at the rail loadout during times a train set is not onsite for loading during night time hours. • Where possible, minimize the amount of train loading during night time hours. • Light-duty vehicles along the access road will be kept to a minimum. • The overland conveyor system will not be equipped with any additional lighting structures, as lighting would be provided by the associated access road lights. • Existing vegetation (mature trees) will not be cleared along areas requiring night-time illumination to reduce total viewshed. • Mobile lighting on the waste rock disposal area(s) would only be used when needed and will be equipped with low visibility spectrum lights. • Mobile lighting would be positioned (where possible) at the base of existing high points (such as the noise mitigation berm) to reduce their associated viewshed.	EIA, CR#1, Section 5.16.2, CIAR#42		Mitigations to address effects of lighting will, by extension, reduce effects of changes to the experience of engaging with sites and landscape features that have cultural or spiritual value
		• Implement visual impact mitigation that reduces stray and non-essential artificial lighting to minimize wildlife effects and that will comply with OH&S safety requirements.	EIA, Section A.11.9, CIAR#42		

Table 6.5-7 Mitigation Measures and Commitments for Indigenous Physical and Cultural Heritage

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How this Mitigation Addresses Effects on Indigenous VC**
Physical and Cultural Heritage					
Disturbance to physical and cultural heritage; Change in access to physical and cultural heritage; Change to cultural value or importance associated with physical and cultural heritage; and Change in relationship with physical or cultural heritage.	Physical and Cultural Heritage	**Mitigation measures that will be implemented to reduce adverse effects on Indigenous physical and cultural heritage include:** • Support in the development of an Indigenous Environmental Stewardship Committee, one of whose functions would be to provide advice on environmental stewardship, land use values and identify and additional sites of cultural, spiritual and traditional importance that may arise. • Benga will support an Indigenous-led monitoring program that will include consideration of cultural heritage impacts and monitoring for cultural sites. • Incorporate the existing legacy mining disturbances into the development and reclamation plans for the Project. • Engage with the Indigenous groups during construction, operations and reclamation, including review and input into management and monitoring plans, discussion of options to facilitate access for traditional activities, construction timing and reclamation. • Support a cultural competency program for its employees and contractors. • Continue to support local and Indigenous cultural events and ceremonies through its Indigenous engagement and initiatives such as its community sponsorship program. • Benga will continue to work with Indigenous groups to discuss management of identified culturally important and sacred sites.	Addendum 10, Appendix 4.2-1, CIAR#251	Implementation of mitigations measures for Indigenous Physical and Cultural Heritage will be through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals. Mitigation effectiveness will be monitored through development and implementation of Indigenous-led monitoring program with advice from the Indigenous Environmental Stewardship Committee.	Mitigations listed here are in addition to biophysical or other linked associated VCs mitigations and were proposed by Indigenous groups to address Project effects on physical and cultural heritage.
		• Allow access to Benga-owned lands outside the Project footprint within the RSA for traditional use.	Addendum 10, Appendix 4.1-1, Section 18.4.1.5.2, CIAR#251		
Disturbance to physical and cultural heritage	Historical Resources (Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities)	**Mitigation measures that will be implemented to reduce adverse effects on unique sites and features include:** • A Cultural Site Discovery Contingency Plan will be developed and implemented in consultation with Indigenous communities for culturally important sites identified during construction or operations. • Where identified by Indigenous groups, sites of cultural and sacred importance within 100 m of Project activity and outside the Project footprint will be flagged prior to land disturbance. • Work with Alberta Culture and Tourism and the Indigenous community to develop and plan for mitigation of identified TK/TU features if avoidance is not possible. • Make minor modifications to the Project footprint to avoid and protect pre-contact sites DjPo-98 and DjPo-130.	Addendum 10, Appendix 4.2-1, CIAR#251	Implementation of mitigation measures for historical resources will be through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals, in particular those under the *Historical Resources Act*. Mitigation effectiveness will be monitored through development and implementation of Indigenous-led monitoring program with advice from the Indigenous Environmental Stewardship Committee.	Mitigations to address effects on historical resources will, by extension, reduce effects of disturbance to physical and cultural heritage.
		• To mitigate potential rail yard impacts, pertinent best management practices, as outlined in the Guidelines for the New Development in Proximity to Railway Operations, will be adhered to. • Disturbance of any further remains located within the proposed rail load out footprint, will be mitigated with controlled excavations to remove the remains. • A mitigation excavation of approximately 80 m^2 will occur in the CHPP footprint in advance of Project development to remove all remaining historical resources or representative samples. • Historic mine remains will be completely documented and recorded. • Historic mining camp remains will be documented in a 20 m^2 excavation. • Additional field surveys and documentation, where required.	EIA, Section A.11.13.1, CIAR#42		

Table 6.5-7 Mitigation Measures and Commitments for Indigenous Physical and Cultural Heritage

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How this Mitigation Addresses Effects on Indigenous VC**

Change in access to physical and cultural heritage	Land and Resource Use,
	Trails and Travelways
	(Loss or disruption of trails to unique sites and special features associated with physical or cultural heritage due to the mine site and access road)
		Mitigation measures that will be implemented to reduce adverse effects on trails and travelways include:
		• Continue to improve the AMP that will include the following:
		  • Access points and roads to be clearly labelled and documented.
		  • Notification of access restrictions during construction as required for safety purposes to allow for planning alternate trails and travelways.
		  • Identified sensitive features (*e.g.*, species of management concern, important habitat features) to be flagged or fenced ahead of clearing.
		  • Signage to be used for identifying areas that are not open for public use.
		• Share information about construction timing.
			Addendum 10, Appendix 4.1-1, Section 4.3.2.5, CIAR#251	Implementation of mitigation measures for access will be through the development and implementation of policies, procedures, training, and management plans. The access mitigation will be implemented through its inclusion in the Access Management Plan (Addendum 10, Appendix 4.5-1, CIAR#251), the goals of which are to:
				• Maintain an open and transparent dialogue for traditional and recreational use requests through the duration of the Project;
				• Minimize the impact of changes to access within, and adjacent to, the Project footprint;
				• Maintain an effective access management strategy that balances Indigenous Rights, workplace safety, and environmental protection;
				• Monitor the effectiveness of defined access protocol (including permitting); and
				• Utilize an adaptive management approach to maximizing access opportunities where feasible.
				Mitigation will also be implemented through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals.
				To determine if the AMP is effective in accommodating traditional and recreational access requests, Benga will seek feedback from internal stakeholders, access users, Indigenous groups, and the Safety, Health & Environment department and identity indicators that can be monitored over time. The findings of the AMP monitoring program will drive adaptive changes to the way Benga manages access requests, communicating access permitting requirements, and soliciting feedback from access users.
					Mitigations to address effects on land and resources use, trail and travelways will, by extension, reduce effects on changes in access to physical and cultural heritage.

		Mitigation measures that will be implemented to reduce adverse effects on access include: • Benga will allow Indigenous groups to access Benga private land, outside of the Project following the AMP for the purposes of harvesting lodgepole pine and other culturally important plants. • Engage with the Indigenous groups during construction, operations and reclamation, including review and input into management and monitoring plans, discussion of options to facilitate access for traditional activities, construction timing, and reclamation. • Continuing to consult with local stakeholders and Indigenous groups through the life of the Project to identify concerns and proactively address issues when they arise.	Addendum 10, Appendix 4.1-2, CIAR#251		
		Mitigation measures that will be implemented in the Access Management Plan include: • Provide training to all staff and contractors regarding respectful land use and access management: promote cultural diversity awareness to Benga's employees and contractors. • Access points and roads to be clearly labelled and documented. • Recreational land use restrictions for employees and contractors will be emphasized to minimize intensive hunting, fishing, and other recreational pressures around the Project boundary. • Notification of access restrictions during construction as required for safety purposes to allow for planning alternate trails and travelways. • Identified sensitive features (*e.g.*, species of management concern, important habitat features) to be flagged or fenced ahead of clearing. • Signage to be used for identifying areas that are not open for public use. • Share information about construction timing. • Share the environmental performance of the Project with Indigenous groups on a regular basis through the life of the Project. • Access and use of OHVs on Benga-owned lands and the Project footprint will be controlled through the AMP. • The only linear footprint of the project is along the main access road which will also incorporate the covered conveyor and the power line for supplying electricity to the mine. • Return Crown leases to the Crown after reclamation is completed.	Access Management Plan (Addendum 10, Appendix 4.5-1, CIAR#251) [also Addendum 10, Appendix 4.1-1, Section 4.3.2.5, CIAR#251]		

Table 6.5-7 Mitigation Measures and Commitments for Indigenous Physical and Cultural Heritage

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How this Mitigation Addresses Effects on Indigenous VC**
Change to cultural value or importance associated with physical and cultural heritage	Noise (Increase in noise during construction and operation could result in reduced engagement with the sites/features of cultural value)	**Mitigation measures that will be implemented to reduce adverse effects of noise include:** • Routing the haul trucks (conveying waste rock and coal) along the western slope of the south disposal area such that the south disposal area itself provides noise shielding between the operating equipment and the residential receptors to the east. • Monitor concerns that are raised by local residents and implement, if necessary, specific measures (*e.g.,* flashing light instead of backup alarm at night, directional backup alarms). • Use of mufflers on all internal combustion engines. • Installing and maintaining a 15 m tall earthen berm along the eastern edge of the south disposal area. • Blasting to occur only on weekdays during typical day-time hours. • Minimizing blasting during cloud cover. • Limiting blasting to smaller more localized blasts, which reduces the amount of explosives used at any one time.	EIA, Section E.2.5.1, CIAR#42	Implementation of mitigation measures for noise, will be through the development and implementation of policies, procedures, training, and management plans and through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals.	Mitigation to address effects of noise will, by extension, reduce effects on changes to cultural value or importance associated with physical and cultural heritage.
		• Should a low frequency noise complaint be received, Benga will conduct a comprehensive sound level (CSL) survey in accordance with the requirements of the *AER Directive 038.*	EIA, Section A.11.2.2, CIAR#42		
	Air Quality (Increase in odour and dust during construction and operation could result in reduced engagement with the sites/features of cultural value)	**Mitigation measures that will be implemented to reduce adverse effects of dust include:** • Speeds on mine roads will be limited to 50 km/hr. Speed reduction does not eliminate total emissions but does reduce acute concentrations/exposure. • Systemic application of water to haul roads and to the plant access road to minimize dust. • Gravel or crushed rock will be used as the underlay on the haul roads. Gravel is observed to produce less dust than clay and sandy surfaces. • Use of a grader to maintain the active surface of the access road. This procedure is expected to reduce the effective slit content of the portion of the road where the wheels of the haul trucks travel. • Reclamation and revegetation progressively to reduce windblown fugitive dust emissions. • Trees and bushes will be preserved around mines and plant to trap dust emissions from mining activities. • The coal processing plant module will be contained within an enclosed area and all coal material handling will be *via* covered conveyors. • Dust generation from transferring the coal from conveyor to the stockpile will be minimized by the use of luffing stackers which will minimize the drop height of the coal. • Fugitive dust generation will be minimized at the rail load-out, with full cladding on the sides of the load-out structure to create a wind shelter, and with the movable discharge chute of the bin located as close as practical to the coal within the rail cars.	Air Quality Monitoring Plan, Addendum 10, Appendix 1.3-1, Section 5, CIAR#251 [also EIA, CR#1, Section 6.6, CIAR#42]	Implementation of the mitigation measures for physical and cultural heritage, as it relates to air quality, will occur through the development and implementation of Project-specific policies, procedures, training and management plans and through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals. Mitigation will be implemented, monitored and verified through their inclusion in the Draft Air Quality Monitoring and Adaptive Management Plan. The mitigation is expected to reduce or minimize the adverse effects of the Project on air quality and will be monitored through the implementation of the air monitoring plans to verify the effectiveness of mitigation measures over time to ensure that the Project related effects on air quality are avoided or minimized. The purpose of the Air Quality Monitoring Plan is to outline a process to mitigate potential Project effects on air quality, assess mitigation effectiveness through monitoring and adapt mitigation as necessary and possible based on monitoring results. Benga has already committed to these mitigation measures and expects that they would become part of the anticipated EPEA approval for the Project. A monitoring program has been developed to measure the effectiveness of mitigation in monitoring air emissions and air quality related to the Project. Benga will engage with Indigenous groups in the future to confirm that the air quality mitigation and monitoring plan accommodates input provided by Indigenous groups.	Mitigation to address effects of odour and dust will, by extension, reduce effects on changes to cultural value or importance associated with physical and cultural heritage.
		Mitigation measures for NOx emissions that will be implemented to reduce adverse effects of odour include: • Use of Tier 4 engines in heavy duty mine equipment. • Benga will investigate alternative ANFO formulations that reduce NOx emissions during blasting. • Emissions will be managed through operations means by developing a program to minimize idling, optimizing the mine place to minimize haul distances, and maintaining the fleet to manufacturer's specifications.	EIA, Section E.1.4.1, CIAR#42 GHG Management Plan (Addendum 10, Appendix 1.8-1, CIAR#251)		
	Lighting (Increased visual disturbance during construction and operation could result in reduced engagement with the sites/features of cultural value)	**Mitigation measures that will be implemented to reduce adverse effects of Project lighting include:** • Use of low visibility spectrum lights on CHPP and rail loadout structures. • Use of low visibility spectrum lights in light stands, designed with directional shades to minimize illumination above the lights horizontal line and to direct light to the illuminated feature. • Implementation of an on-demand and adaptive light management strategy (*i.e.,* activated when needed) at the rail loadout during times a train set is not onsite for loading during nighttime hours. • Where possible, minimize the amount of train loading during nighttime hours.	EIA, CR#1, Section 5.16.2, CIAR#42		Mitigation to address effects of lighting will, by extension, reduce effects on changes to cultural value or importance associated with physical and cultural heritage.

Table 6.5-7 Mitigation Measures and Commitments for Indigenous Physical and Cultural Heritage

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How this Mitigation Addresses Effects on Indigenous VC**
		• Light-duty vehicles along the access road will be kept to a minimum. • The overland conveyor system will not be equipped with any additional lighting structures, as lighting would be provided by the associated access road lights. • Existing vegetation (mature trees) will not be cleared along areas requiring night-time illumination to reduce total viewshed. • Mobile lighting on the waste rock disposal area(s) would only be used when needed and will be equipped with low visibility spectrum lights. • Mobile lighting would be positioned (where possible) at the base of existing high points (such as the noise mitigation berm) to reduce their associated viewshed.			
		• Implement visual impact mitigation that reduces stray and non-essential artificial lighting to minimize wildlife effects and that will comply with OH&S safety requirements.	EIA, Section A.11.9, CIAR#42		
	Historical Resources (Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities)	**Mitigation measures that will be implemented to reduce adverse effects on unique sites and features include:** • A Cultural Site Discovery Contingency Plan will be developed and implemented in consultation with Indigenous communities for culturally important sites identified during construction or operations. • Where identified by Indigenous groups, sites of cultural and sacred importance within 100 m of Project activity and outside the Project footprint will be flagged prior to land disturbance. • Work with Alberta Culture and Tourism and the Indigenous community to develop and plan for mitigation of identified TK/TU features if avoidance is not possible. • Make minor modifications to the Project footprint to avoid and protect pre-contact sites DjPo-98 and DjPo-130.	Addendum 10, Appendix 4.2-1, CIAR#251	Implementation of mitigation measures for historical resources will be through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals, in particular those under the *Historical Resources Act*. Mitigation effectiveness will be monitored through development and implementation of Indigenous-led monitoring program with advice from the Indigenous Environmental Stewardship Committee.	Mitigation to address effects on historical resources will, by extension, reduce effects on changes to cultural value or importance associated with physical and cultural heritage.
		• To mitigate potential rail yard impacts, pertinent best management practices, as outlined in the Guidelines for the New Development in Proximity to Railway Operations, will be adhered to. • Disturbance of any further remains located within the proposed rail load out footprint, will be mitigated with controlled excavations to remove the remains. • A mitigation excavation of approximately 80 m^2 will occur in the CHPP footprint in advance of Project development to remove all remaining historical resources or representative samples. • Historic mine remains will be completely documented and recorded. • Historic mining camp remains will be documented in a 20 m^2 excavation. • Additional field surveys and documentation, where required.	EIA, Section A.11.13.1, CIAR#42		

Table 6.5-7 Mitigation Measures and Commitments for Indigenous Physical and Cultural Heritage

Effects Pathways		Mitigation Measures			
Potential Effect on Indigenous VC	**Related VCs and Effects Pathway on Related VCs that Affect the Indigenous VC**	**Mitigation / Commitments**	**Reference for Mitigation or Commitment**	**Implementation and Effectiveness of Mitigation**	**How this Mitigation Addresses Effects on Indigenous VC**
Change in relationship with physical or cultural heritage	Historical Resources, Noise, Air Quality, and Lighting (Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities could result in loss of relationship with heritage. Increase in noise, odour, and visual disturbance during construction and operation could result in reduced engagement with the sites/features associated with physical or cultural heritage)	The mitigation listed above for historical resources, noise, dust, odour, and lighting are applicable for reducing the effects of the Project on changing the relationship with aspects of physical or cultural heritage through reducing the loss or damage to unique sites or special features or by reducing the loss of engagement with these features.	--	Implementation of mitigation measures for historical resources will be through the commitments contained within agreements with the Indigenous groups, as well as expected conditions of regulatory approvals, in particular those under the *Historical Resources Act*. Mitigation effectiveness will be monitored through development and implementation of Indigenous-led monitoring program with advice from the Indigenous Environmental Stewardship Committee. See applicable sections above for more details on implementation and effectiveness for air quality.	Mitigation to address effects on historical resources, noise, air quality, and lighting will, by extension, reduce effects on changes in relationship with physical or cultural heritage.
	Hunting, Trapping, Fishing, Plant Gathering (Loss of hunting, trapping, fishing, and plant gathering opportunities due to construction and operation and access restrictions could result in loss of relationship with wildlife and cultural practices)	Mitigation measures that will be implemented to reduce adverse effects on hunting and trapping are listed in Table 6.5-2; fishing in Table 6.5-3,and plant gathering in Table 6.5-4. These mitigation measures are expected to reduce the effects of the Project on the change in relationship with wildlife or cultural practices.	Table 6.5-2 Table 6.5-3 Table 6.5-4 (JRP IR-6.5)	Implementation and effectiveness of mitigation for each of hunting, trapping, fishing, plant gathering, noise and air quality, and mitigation for linked VCs is discussed in Table 6.5-2 to 6.5-4. Implementation of mitigation and monitoring for mitigation effectiveness will be in large part through: • Approval conditions • Agreements with Indigenous groups • Indigenous Environmental Stewardship Committee • Wildlife Mitigation and Monitoring Plan • Detailed Fisheries Offsetting Plan • Offsetting Effectiveness Monitoring Plan • Aquatic Monitoring Plan • Updated C&R Plan • Air Quality Monitoring and Adaptive Management Plan • Access Management Plan	Mitigation to address effects on hunting, trapping, fishing and plant gathering will, by extension, reduce effects on changes in relationship with physical or cultural heritage.

Information Request 6.6

Information Request Package #4 from the Joint Review Panel to Benga, Information Requests 4.2 and 4.4. (CIAR #212).

Tenth Addendum to the Environmental Impact Assessment. Response to Information Request 4.2 and 4.4. (CIAR #251).

Canadian Environmental Assessment Agency "Technical Guidance for Assessing Physical and Cultural Heritage or any Structure, Site or Thing that is of Historical, Archeological, Paleontological or Architectural Significance under the *Canadian Environmental Assessment Act, 2012*". (March 2015).

As the Panel noted in IR 4.2 (CIAR #212), physical and cultural heritage is not only associated with an individual physical site, but also with the experience lived by Indigenous peoples in those areas, and the importance of the landscape as a whole. In Appendix 4.1-1 (CIAR #251), in response to IR 4.4, Benga provides information on the potential effects to cultural heritage sites for specific Indigenous groups. For example, with respect to Tsuut'ina Nation, Benga states that "the potential effects… could result in a change in use or access or disturbance to features associated with sacred, gathering, or habitation sites. Together, these changes will change the cultural value or importance to the value." In another instance, Benga states "The Project will intersect or be in proximity to sacred, gathering and habitation sites identified by the Ktunaxa Nation." Benga notes that "spiritual integrity of the landscape will be forever changed despite lasting reclamation efforts" however, no further description of the initial state of the spiritual integrity of the landscape, or the residual effects that will result in a permanent alteration of the spiritual landscape, is provided.

The "Technical Guidance for Assessing Physical and Cultural Heritage or any Structure, Site or Thing that is of Historical, Archeological, Paleontological or Architectural Significance under the *Canadian Environmental Assessment Act, 2012*"[1] states that the heritage value of a resource is embodied in tangible and/or intangible character-defining elements. These elements include the materials, forms, location, spatial configurations, uses and cultural associations or meanings that embody the heritage value of a cultural resource, which must be retained to preserve that value.

Tsuut'ina Nation stated (CIAR #286) that Benga has failed to properly scope and understand the impacts of the Project on transmission of knowledge, language and culture through lack of access to sites. Benga acknowledges in Appendix 4.1-1 that "Intergenerational knowledge provides instruction on cultural and spiritual practices such as gathering plants for food and subsistence, ceremonial procedures, legends, using plants as medicine and harvesting berries" and indicates that the effects pathways consider both tangible and intangible values. Appendix 4.1-1 indicates that Tsuut'ina members are

[1] Available online: Technical Guidance for Assessing Physical and Cultural Heritage or any Structure, Site or Thing that is of Historical, Archeological, Paleontological or Architectural Significance under the *Canadian Environmental Assessment Act, 2012*. https://www.canada.ca/en/impact-assessment-agency/services/policy-guidance/technical-guidance-assessing-physical-cultural-heritage-or-structure-site-or-thing.html

"granted the privilege of harvesting specific species, many of which are only found in specific environments (e.g., alpine areas such as at Grassy Mountain). Such rights are designated within the context of celebrations and customs, such as annual bundle openings and Sun Dance ceremonies" (CIAR #251). Transmission of knowledge is however not carried forward as an effects pathway for cultural heritage, as shown in Table 3.2.1-1.

Tsuut'ina Nation has stated that Benga's cumulative effects assessment in relation to their physical and cultural heritage is deficient as it does not consider the impacts of the Project on intangible culture, such as the ability to transmit knowledge to future generations because of access restrictions or avoidance of areas because of noise and dust (CIAR #286). Tsuut'ina Nation notes "Once knowledge of a place is lost by one generation, it is very difficult if not impossible to regain this knowledge in the future because this information is passed along inter-generationally" (CIAR #286).

The EIS Guidelines, Section 6.3.4 (CEAR #11) require Benga to consider how changes to the environment caused by the Project will affect the cultural value or importance associated with physical and cultural heritage and the current uses of land and resources for traditional purposes (e.g., inter-generational teaching of language or traditional practices, communal gatherings) and indirect effects such as avoidance of the area due to increased disturbance (e.g., noise, presence of workers).

a) Provide an assessment of the effects of the Project on the intangible aspects of cultural heritage, including but not limited to cultural and spiritual practices, ceremonies, and intergenerational transfer of language, knowledge, and culture.

b) For each biophysical VC that is identified as having a link to an Indigenous VC:

   i. describe the link from the biophysical VC or physical or cultural heritage site to any cultural and spiritual practices, ceremonies, and related intergenerational transfer of knowledge (i.e. if specific plants are used for ceremonial purposes, describe the ceremony, and its importance in Indigenous culture); and

   ii. describe how the effects to the specific biophysical VC or physical or cultural heritage site may affect cultural and spiritual practices, ceremonies, and intergenerational transfer of knowledge.

c) Where residual effects to cultural and spiritual practices, ceremonies, and/or intergenerational transfer of knowledge are identified, describe the residual effect.

d) Update the cumulative effects assessment in relation to the current use of lands and resources for traditional purposes and the physical and cultural heritage of Indigenous

peoples to consider the effects of the Project on cultural and spiritual practices, ceremonies, and intergenerational transfer of knowledge.

Response:

Throughout its analysis of effects on Indigenous communities, Benga has focused on the following Indigenous Valued Components (VCs):

- Hunting and Trapping;
- Fishing;
- Plant Gathering;
- Trails and Travelways;
- Physical and Cultural Heritage; and
- Cultural and Spiritual Values

Benga recognizes that predicted effects on wildlife, vegetation, water and air quality, aquatic ecosystems, noise, and other biophysical valued components impact on each of these Indigenous VCs in tangible and intangible ways. The combined effects of biophysical and secondary indirect project effects work to change the cultural value or importance of these values for each VC; these effects can act synergistically on cultural and spiritual values to create intangible project effects on cultural and spiritual identity and community and individual well-being. These effects are therefore likely to be cumulative or residual in nature.

In preparing responses to related IRs in this package, Benga has endeavoured to describe the Project and cumulative impact as well as proposed mitigative measures in its responses. As such, to the extent possible, Benga has included tangible and intangible effects on Indigenous VCs in the responses to the following IRs:

- the responses to JRP IR-6.5 and 6.7 link biophysical effects to intangible cultural and spiritual effects;
- the response to JRP IR-6.5 provides a list of mitigative measures to address Project effects;
- the response to JRP IR-6.7 provides an updated characterization of residual Project effects; and
- the response to JRP IR-6.8 provides an updated characterization of cumulative effects, including intangible effects, that are cumulative in nature.

In particular, Benga notes that the Project site has been previously impacted by mining activity from the 1960s and is not currently in its natural condition which will be corrected during the reclamation phase of the Project. Further, Benga has worked extensively with the most impacted Indigenous communities and has managed to reach agreement with many on mitigation

measures, related to both tangible and intangible effects, so that they have been willing to provide letters of non-objection to the Project.

In preparing these responses (JRP IR-6.5 through 6.8), Benga is aware that intangible effects are by definition those effects that cannot be objectively measured or evaluated. In fact, intangible in the Cambridge Dictionary is defined as, "impossible to touch, to describe exactly, or to give an exact value". Further, Benga understands that effects on culture or personal mental well-being can be subjective, different between groups or individuals, and difficult to comprehend or understand by an observing third party.

In order to incorporate intangible effects of the Project into its responses, therefore, Benga has relied heavily on the input received from the Indigenous communities during the course of consultation for the Project. Benga has further, provided a draft of this response to the most impacted Indigenous groups for comment and validation prior to submission to the JRP. Any comments received have been incorporated into this version.

In order to support the evaluations in responses to JRP IR-6.5, 6.7 and 6.8, which all deal with tangible and intangible effects, Benga has utilized the input summarized in the following sections.

Kainai Nation

The Kainai TKUA indicates that the Crowsnest Pass area is a "very sensitive area" and is central to Blackfoot culture, spirituality and culture (O'Connor, 2018, p. 63). The Káínai Nation maintain a strong and historically rooted cultural and spiritual connection to the land and animals surrounding the proposed mine site.

There are many well-known and documented sacred places and gathering areas throughout the Káínai Nation territory. These sacred sites are unifying symbols, provide evidence for cultural continuity and establish and reinforce national and personal connections to the landscape. The Káínai Nation noted Crowsnest Mountain (approximately 10 km west of the Grassy Mountain LSA) as an important landscape marker and associated with Blackfoot myths and traditional culture and is still referenced in ceremonial purposes (Káínai Nation, 2015, Appendix 7c, EIA, CIAR#42).

While country foods have always been important for food, subsistence and sustenance, the practice of hunting has important cultural and spiritual considerations. Intergenerational knowledge about ceremonies, traditions and customs as well as use of harvested animals as medicine, food, tools, clothing, shelter and more is shared while hunting. In additional to this educational context, hunting practices are typically linked to other intangible values with spiritual, artistic and aesthetic elements. Likewise, fishing has always been important for food, subsistence and sustenance and the activity of fishing has important cultural and spiritual considerations. Intergenerational knowledge about ceremonies, legends as well as fish use as

medicine, food and more is shared while fishing. In addition to this educational context, the activity of fishing is typically linked to other intangible values with spiritual, artistic and aesthetic elements. For example, fishing typically provides for quiet enjoyment of the landscape or access to water for other uses.

Intergenerational knowledge provides instruction on cultural and spiritual practices such as gathering plants for food and subsistence, ceremonial procedures, legends, using plants as medicine and harvesting berries. In addition to this educational context, plant gathering activities are typically linked to other intangible values with spiritual, artistic, aesthetic and artistic elements.

Table 6.6-1 Mitigation Measures, Residual Effects, and Cumulative Effects Related to Intangible Cultural and Spiritual Project Effects for Kainai Nation

Intangible Cultural and Spiritual Effect	Mitigation Measures	Residual Effects Assessment	Cumulative Effects Assessment
Loss of inter-generational teaching of language or traditional practices	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	See Table 6.7-2, JRP IR-6.7	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8
Change in sense, experience, or enjoyment of cultural practices and spiritual places (*i.e.,* Changes to the relationship between the Kainai Nation and the visual and sensory experience of their cultural and spiritual values (Addendum 10, Appendix 4.1-1, CIAR#251))	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	See Table 6.7-2, JRP IR-6.7	See Tables 6.8-1 and 6.8-2 in IR 6.8
Negative effects on the physiological wellness of the Kainai Nation members and their connection to their traditional territory within the LSA (O'Connor, 2018, p. 94)	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	See Table 6.7-2, JRP IR-6.7	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8

Piikani Nation

As with all Indigenous nations in the Project area, the Piikani Nation draw their culture from the area – the land, the landscape and the animals. There is a kinship with the animals which continues to provide lessons and teachings by which to live. For example, beavers provided lessons in etiquette, pain, industry and work, seasonal cycles and vegetation. Other animals were symbols of prestige or had strict restrictions when it comes to sharing (Piikani Nation, 2015a, Appendix 7c, EIA, CIAR#42).

The Piikani Nation say that stories are connected with Grassy Mountain, but also all the mountains. The Piikani Nation's creation story is linked to the mountains which is one reason why they had camps sites and sacred spaces in the flat places in the mountains. Warrior societies at one time protected these places (Piikani Nation, 2015a, Appendix 7c, EIA, CIAR#42). The land is understood as a storybook.

The Piikani Nation have not forgotten their connection to the land and their animals. They are deeply aware of the connection and the relationship. Elders have placed great pressure on themselves to make sure that cultural and spiritual values are not lost even when they can no long access these sites or harvest the animals (Piikani Nation, 2015a, Appendix 7c, EIA, CIAR#42). The Piikani Nation continue with their traditional practices today and share what they know with their youth. It was acknowledged in a series of workshops that sharing cultural and spiritual knowledge is not without its challenges. Frequently, they cannot access areas in their traditional territory and must exercise their traditional practices elsewhere (Piikani Nation, 2015a, Appendix 7c, EIA, CIAR#42).

Among the critical cultural and spiritual knowledge that is passed along is information on the seasonal round, animal behaviour in each season and what it says about seasonal conditions and ecological functioning, plants especially medicinal plants, harvesting skills, knowledge of symbology and the meaning behind symbology, travel and navigation and ceremonies (Piikani Nation, 2015a, Appendix 7c, EIA, CIAR#42). Cultural, spiritual, and ceremonial teachings are inextricably bound.

While country foods have always been important for subsistence and sustenance, the practice of hunting has important cultural and spiritual considerations. Intergenerational knowledge about ceremonies, traditions and customs as well as use of harvested animals as medicine, food, tools, clothing, shelter and more is shared while hunting. In addition to this educational context, hunting practices are typically linked to other intangible values with spiritual, artistic and aesthetic elements. Likewise, fishing has always been important for food, subsistence and sustenance and the activity of fishing has important cultural and spiritual considerations. Intergenerational knowledge about ceremonies, legends as well as fish use as medicine, food and more is shared while fishing. In addition to this educational context, the activity of fishing is typically linked to other intangible values with spiritual, artistic and aesthetic elements. For example, fishing typically provides for quiet enjoyment of the landscape or access to water for other uses.

The practice of gathering plants has important cultural and spiritual considerations as well as for food, subsistence and sustenance. Intergenerational knowledge about ceremonies, legends as well as plant use as medicine, food and more is shared while harvesting berries and plants. In addition to this educational context, plant gathering activities are typically linked to other intangible values with spiritual, artistic, aesthetic and artistic elements.

Table 6.6-2 Mitigation Measures, Residual Effects, and Cumulative Effects Related to Intangible Cultural and Spiritual Project Effects for Piikani Nation

Intangible Cultural and Spiritual Effect	Mitigation Measures	Residual Effects Assessment	Cumulative Effects Assessment
Loss of inter-generational teaching of culture, language or traditional practices (*i.e.,* Piikani Nation storytelling, protocols, vison quests (Appendix 4.1-1, Addendum 10, CIAR#251))	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	See Table 6.7-3, JRP IR-6.7	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8
Change in sense, experience, or enjoyment of cultural practices and spiritual places (*i.e.,* Increase in noise, dust and visual disturbance that could affect the relationship between the Piikani Nation and their cultural and spiritual values (Addendum 10, Appendix 4.1-1, CIAR#251))	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	See Table 6.7-3, JRP IR-6.7	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8

Stoney Nakoda Nation

Stoney Nakoda Nation's spirituality and peoples' connection to the land is profound; the land is where spirit is renewed. Honouring, respecting and trying to understand Stoney Nakoda Nation's spirituality is at the core of an appreciation for Stoney Nakoda Nation's traditional knowledge and land use. (Stoney Nakoda Nation, 2015, p. 6, Appendix 7c, EIA, CIAR#42). Physical and spiritual levels of existence are central to the Stoney Nakoda Nation's way of life. Plant species are important to the Stoney Nakoda Nation's ceremony, healing practices and spirituality. While the Stoney Nakoda Nation Site Summary does not provide exact locations of sacred places within the Project area, it mentions that there are areas on the mountain that are recognized by the Stoney Nakoda Nation Members as meditation sites.

While country foods have always been important for food, subsistence and sustenance, the practice of hunting has important cultural and spiritual considerations. Intergenerational knowledge about ceremonies, traditions and customs as well as use of harvested animals as medicine, food, tools, clothing, shelter and more is shared while hunting. In addition to this educational context, hunting practices are typically linked to other intangible values with spiritual, artistic and aesthetic elements. Likewise, fishing has always been important for food, subsistence and sustenance, the activity of fishing has important cultural and spiritual considerations. Intergenerational knowledge about ceremonies, legends as well as fish use as

medicine, food and more is shared while fishing. In addition to this educational context, the activity of fishing is typically linked to other intangible values with spiritual, artistic and aesthetic elements. For example, fishing typically provides for quiet enjoyment of the landscape or access to water for other uses.

The practice of gathering plants has important cultural and spiritual considerations as well as for food, subsistence and sustenance. Intergenerational knowledge about ceremonies, legends as well as plant use as medicine, food and more is shared while harvesting berries and plants. In addition to this educational context, plant gathering activities are typically linked to other intangible values with spiritual, artistic, aesthetic and artistic elements.

Table 6.6-3 Mitigation Measures, Residual Effects, and Cumulative Effects Related to Intangible Cultural and Spiritual Project Effects for Stoney Nakoda Nation

Intangible Cultural and Spiritual Effect	Mitigation Measures	Residual Effects Assessment	Cumulative Effects Assessment
Loss of inter-generational teaching of language or traditional practices	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	See Table 6.7-5, JRP IR-6.7	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8
Change in sense, experience, or enjoyment of cultural practices and spiritual places	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	See Table 6.7-5, JRP IR-6.7	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8

Tsuut’ina Nation

The Tsuut’ina Nation has a strong spiritual and cultural connection with the land in and around the proposed Project area. The geography and landscape of the Crowsnest Pass and the surrounding area play important roles in the spirituality of the Tsuut’ina Nation. There are sites sacred to the Tsuut’ina Nation in the area, including ceremonial sites and natural material to make ceremonial paint (*e.g.,* ochre) and items (Tsuut’ina Nation, 2015, Appendix 7c, EIA, CIAR#42).

There are many well-known and documented sacred places and gathering areas throughout the Tsuut'ina Nation territory. These sacred sites are unifying symbols, providing evidence for cultural continuity and establishing and reinforcing national and personal connections to the landscape. The Project area and its associated features are used for spiritual purposes, including ceremonies. For example, various alpine plants are crucial for the Tsuut’ina Nation ceremonial purposes on Grassy Mountain and for healing practices and cultural identity (Tsuut’ina Nation, 2015, Appendix 7c, EIA, CIAR#42).

While the Tsuut'ina Nation works to retain and pass on knowledge from generation to generation, the Tsuut'ina Nation's, "connection to their homeland through stories, myths and the continued use of and reverence for, sacred elements in the landscape such as Crowsnest Mountain is paramount to their cultural identity and survival" (Tsuut'ina Nation, 2015, p. 49, Appendix 7c, EIA, CIAR#42). The Tsuut'ina way of life operates at different levels of existence, through the physical and spiritual worlds (Tsuut'ina Nation, 2015, Appendix 7c, EIA, CIAR#42). The Tsuut'ina Nation members act as stewards to plants and wildlife, with specific responsibilities, rights and powers transferred through songs and oral history (Tsuut'ina Nation, 2015, Appendix 7c, EIA, CIAR#42). For example, such rights are designated within the context of celebrations and customs, such as annual bundle openings and Sun Dance ceremonies. Indeed, the Tsuut'ina 'feel closer to the Creator' at elevations and vision quest sites such as those on Grassy Mountain (Tsuut'ina Nation, 2015, p. 49, Appendix 7c, EIA, CIAR#42).

While country foods have always been important for subsistence and sustenance, the practice of hunting has important cultural and spiritual values. Intergenerational knowledge about ceremonies, traditions and customs as well as use of harvested animals as medicine, food, tools, clothing, shelter and more is shared while hunting. Many species of wildlife and birds are culturally and spiritually important to the Tsuut'ina Nation. In addition to this educational context, hunting practices are typically linked to other intangible values with spiritual, artistic and aesthetic elements (Tsuut'ina Nation, 2015, Appendix 7c, EIA, CIAR#42).

Intergenerational knowledge provides instruction on cultural and spiritual practices such as gathering plants for food and subsistence, ceremonial procedures, legends, using plants as medicine and harvesting berries. In addition to this educational context, plant gathering activities are typically linked to other intangible values with spiritual, artistic, aesthetic and artistic elements.

Table 6.6-4 Mitigation Measures, Residual Effects, and Cumulative Effects Related to Intangible Cultural and Spiritual Project Effects for Tsuut'ina Nation

Intangible Cultural and Spiritual Effect	Mitigation Measures	Residual Effects Assessment	Cumulative Effects Assessment
Loss of inter-generational teaching of cultural, ceremonial, language or traditional practices (*i.e.,* Loss of traditional Tsuut'ina Nation stewardship protocols on how to care for the land, loss of cultural protocols surrounding harvesting rights in the proposed project area, transferred through songs, stories, celebrations, and customs such as bundle openings and Sun Dance ceremonies (Tsuut'ina Nation, 2015, pg. 44, 46, 49, Appendix 7c, EIA, CIAR#42)	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	See Table 6.7-6, JRP IR-6.7	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8
Change in sense, experience, or enjoyment of cultural practices and spiritual places	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	See Table 6.7-6, JRP IR-6.7	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8

Siksika Nation

The Siksika Nation do not view their spirituality as centralized in one physical location. Rather, they view their spirituality as expressed in sites that are part of a complex that is roughly crescent shaped from Gold Creek and Blairmore Creek valleys and benches and the saddle of land connecting those between Grassy Mountain and Grassy Mountain South (Siksika Nation Consultation Office, 2018, Addendum 9, CIAR#185). It is at nearby Crowsnest Mountain that the Siksika Nation received the Thunder Pipe from Thunder before he was forced by Crow to live at Chief Mountain. For millennia, the Thunder Pipe ceremony was held at Grassy Mountain when the first thunder was heard each year. The Siksika Nation have used the area for over 9,000 years. With the coming of non-Blackfoot settlers, the Siksika Nation lost access to many of their sacred sites. They equate Grassy Mountain as being analogous to Lourdes (Siksika Nation, 2018, Addendum 9, CIAR#185). The Siksika Nation considers yellow ochre sites to be sacred and indicated that such sites are present in the LSA.

The Siksika Nation remains connected to the land. There are many well-known and documented sacred places and gathering areas throughout the Siksika Nation territory. These sacred sites are unifying symbols, provide evidence for cultural continuity and establish and reinforce national

and personal connections to the landscape. Elders have placed great pressure on themselves to make sure that cultural and spiritual values are not lost even when they can no longer access these sites or harvest the animals (Siksika Nation, 2015, Appendix 7c, EIA, CIAR#42). Among the critical cultural and spiritual knowledge that is passed along is information on the seasonal round, animal behaviour in each season and what it says about seasonal conditions and ecological functioning, plants, especially medicinal plants, harvesting skills, knowledge of symbology and the meaning behind symbology, travel and navigation and ceremonies (Siksika Nation, 2015, Appendix 7c, EIA, CIAR#42). Cultural, spiritual and ceremonial teachings are inextricably bound. While country foods have always been important for food, subsistence and sustenance, the practice of hunting has important cultural and spiritual considerations. Intergenerational knowledge about ceremonies, traditions and customs as well as use of harvested animals as medicine, food, tools, clothing, shelter and more is shared while hunting. In addition to this educational context, hunting practices are typically linked to other intangible values with spiritual, artistic and aesthetic elements.

Likewise, fishing has always been important for food, subsistence and sustenance, the activity of fishing has important cultural and spiritual considerations. Intergenerational knowledge about ceremonies, legends as well as fish use as medicine, food and more is shared while fishing. In addition to this educational context, the activity of fishing is typically linked to other intangible values with spiritual, artistic and aesthetic elements. For example, fishing typically provides for quiet enjoyment of the landscape or access to water for other uses.

The practice of gathering plants has important cultural and spiritual considerations as well as for food, subsistence and sustenance. Intergenerational knowledge about ceremonies, legends as well as plant use as medicine, food and more is shared while harvesting berries and plants. In addition to this educational context, plant gathering activities are typically linked to other intangible values with spiritual, artistic, aesthetic and artistic elements.

Table 6.6-5 Mitigation Measures, Residual Effects, and Cumulative Effects Related to Intangible Cultural and Spiritual Project Effects for Siksika Nation

Intangible Cultural and Spiritual Effect	Mitigation Measures	Residual Effects Assessment	Cumulative Effects Assessment
Loss of inter-generational teaching of culture, spirituality, language, and traditional practices (Addendum 10, Table 4.6-4, JRP IR-4.6, CIAR#251)	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	See Table 6.7-4, JRP IR-6.7	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8

Table 6.6-5 Mitigation Measures, Residual Effects, and Cumulative Effects Related to Intangible Cultural and Spiritual Project Effects for Siksika Nation

Intangible Cultural and Spiritual Effect	Mitigation Measures	Residual Effects Assessment	Cumulative Effects Assessment
Change in sense, experience, or enjoyment of cultural practices and spiritual places (*i.e.,* Loss of materials critical to ceremonial practices (*i.e.,* yellow ochre) (Addendum 10, Appendix 4.1-1, CIAR#251))	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	See Table 6.7-4, JRP IR-6.7	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8
Disruption of cultural fabric/continuity (Addendum 10, Table 4.6-4, JRP IR-4.6, CIAR#251)	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	Addressed in JRP IR-6.7	Addressed in JRP IR-6.8

Ktunaxa Nation

Based on submissions received from Ktunaxa Nation Council, the Ktunaxa Nation has identified places of cultural, ceremonial and spiritual importance throughout the Crowsnest Pass area are central to a larger Ktunaxa cultural landscape that supports Ktunaxa intangible cultural resources, including endangered place-based knowledge, language and knowledge transmission between generations. As indicated in submissions, and communicated during site visits to the Project area, qukin ʔakitɬaʔis (Raven's House or Crowsnest Mountain) is of particular importance as it forms the headwaters for the Crowsnest watershed, supporting Ktunaxa confidence in water and wild foods, and also embodies oral histories and cultural associations as the home of the creation being, Raven. The place name is also associated with oral histories of Ktunaxa chiefs from the area and specific ceremonial practices reliant on the cultural landscape and view scape surrounding Raven's House. Details regarding Ktunaxa ceremonial practice are considered private and confidential to the Ktunaxa Nation.

Another key site located west of the LSA is Kuɬwiaʔki (Crowsnest Lake), also in the headwaters of the Crowsnest Watershed, translated as "Heart of the Water" (Schaeffer fieldnotes, 1932, p. 33, 1966 *in* Firelight Group, 2019, p. 15, Addendum 9, CIAR#185). There is also Ktunaxa Nation oral history associated with Frank and nearby Turtle Mountain. Current use of lands and resources for the Ktunaxa Nation is grounded in the concept of ʔa·kxaṁis q̓api qapsin meaning "the root all things and the relationship between all things including land, water, animals, Indigenous peoples and the air that we breathe," (Firelight Group, 2019, p. 16, Addendum 9, CIAR#185). The Project will affect this living balance that is said to link to the Ktunaxa Nation language and culture, connecting all things with the creator and with one another (Firelight Group, 2019, Addendum 9, CIAR#185). One site-specific cultural site called maȼuk (Dirty

Water/ Bellevue) was reported in the category of cultural activity within the LSA although it is unclear whether this in a cultural heritage site or an area of use (Firelight Group, 2019, Addendum 9, CIAR#185).

The Project area and the Crowsnest Pass contain a multitude of ecological values tied to cultural and spiritual use and stewardship of the landscape, including the following animal species of critical importance: bighorn sheep, moose, elk, grizzly bear, mountain goat and bison. Bison is a particularly critical consideration for Ktunaxa use and oral history in the area (Firelight Group, 2019, Addendum 9, CIAR#185).

While wild foods have always been important for food, subsistence and sustenance, the practice of hunting also has important cultural and spiritual considerations. Intergenerational knowledge about ceremonies, traditions and customs as well as use of harvested animals as medicine, food, tools, clothing, shelter and more is shared while hunting. In addition to this educational context, hunting practices are typically linked to other intangible values with spiritual, artistic and aesthetic elements. Likewise, fishing has always been important for food, subsistence and sustenance, the activity of fishing has important cultural and spiritual considerations. Intergenerational knowledge about ceremonies, legends as well as fish use as medicine, food and more is shared while fishing. In addition to this educational context, the activity of fishing is typically linked to other intangible values with spiritual, artistic and aesthetic elements. For example, fishing typically provides for quiet enjoyment of the landscape or access to water for other uses.

The practice of gathering plants has important cultural and spiritual considerations as well as for food, subsistence and sustenance. Intergenerational knowledge about ceremonies, legends as well as plant use as medicine, food and more is shared while harvesting berries and plants. In addition to this educational context, plant gathering activities are typically linked to other intangible values with spiritual, artistic, aesthetic and artistic elements.

While travel throughout ʔamakʔis Ktunaxa on traditional Travelways was once necessary for subsistence and sustenance, today the practice of engaging with these Travelways is in addition a part of cultural identity and ceremonial and spiritual practice. Beyond using trails for traditional activities such as hunting, fishing, gathering plants, *etc.*, Travelways are paths to reconnect with ancestors, oral traditions and the quiet enjoyment of nature (Firelight Group, 2019, Addendum 9, CIAR#185).

Table 6.6-6 Mitigation Measures, Residual Effects, and Cumulative Effects Related to Intangible Cultural and Spiritual Project Effects for Ktunaxa Nation

Intangible Cultural and Spiritual Effect	Mitigation Measures	Residual Effects Assessment	Cumulative Effects Assessment
Loss of inter-generational teaching of language or traditional practices	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	See Table 6.7-7, JRP IR-6.7	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8
Change in sense, experience, or enjoyment of cultural practices and spiritual places (*i.e.*, place-specific knowledge is reliant on the integrity of the view scape and sensory environment surrounding qukin ʔakitɬaʔis (Crowsnest Mountain), Kuɬwiaʔki (the Crowsnest Pass, and specifically Crowsnest Lake), Turtle Mountain and Frank, and other important areas within and beyond the Ktunaxa LSA (Addendum 10, Appendix 4.1-1, CIAR#251))	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	See Table 6.7-7, JRP IR-6.7	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8
Impacts on environmental and cultural-spiritual values associated with the integrity of water resources at the headwaters of the Crowsnest River and downstream (Addendum 10, Appendix 4.1-1, CIAR#251)	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	See Table 6.7-7, JRP IR-6.7	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8
Potential impacts on Ktunaxa governance, stewardship, and relationships with neighbouring Indigenous communities in the Crowsnest Pass region. (Addendum 10, Appendix 4.1-1, CIAR#251)	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	See Table 6.7-7, JRP IR-6.7	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8

Samson Cree Nation

There are many well-known and documented sacred places and gathering areas throughout the Samson Cree Nation territory. These sacred sites are unifying symbols, provide evidence for cultural continuity and establish and reinforce national and personal connections to the

landscape. For the Samson Cree Nation, the bear holds high spiritual and ceremonial value, along with timber (Samson Cree Nation, 2014, Appendix 7c, EIA, CIAR#42).

The Samson Cree Nation expresses this connectivity in describing their connection with the lands within their territory, highlighting how they continue to further their culture and spiritual practices on the lands and water in and around the Rocky Mountain Foothills Region by:

- Carrying on Samson's traditional way of life by maintaining its preferred use sites in and around the Program area (Samson Cree Nation, 2014, Appendix 7c, EIA, CIAR#42);
- Carrying out a variety of practices, traditions and customs within Samson Territory in and around the Program Area (Samson Cree Nation, 2014, Appendix 7c, EIA, CIAR#42);
- Cultivating and harvesting traditional herbs and medicines (Samson Cree Nation, 2014, Appendix 7c, EIA, CIAR#42); and
- Timber is important to the Samson Cree Nation because it is critical to hold ceremony (Samson Cree Nation, 2014, p. 10, Appendix 7c, EIA, CIAR#42).

The Samson Cree Nation assert that their practices, traditions and customs are integral to their distinctive culture and traditional way of life (Samson Cree Nation, 2014, Appendix 7c, EIA, CIAR#42). For example, annual ceremonies and other traditional practices are utilized on a seasonal basis (Samson Cree Nation, 2014, Appendix 7c, EIA, CIAR#42). The Samson Cree Nation note the region of the Project holds spiritual importance for its members (Samson Cree Nation, 2014, Appendix 7c, CIAR#42); however, Samson Cree Nation has not identified current or historic use for sacred sites, gathering sites, or habitation sites in the Project area.

The Samson Cree Nation's cultural well-being is impacted by access to lands and their ability to harvest traditional foods, which are also essential for ceremonies and feasts (Samson Cree Nation, 2014, Appendix 7c, EIA, CIAR#42). Further, social and cultural opportunities for learning and knowledge transmission rely on these traditional practices. Samson Cree Nation holds ideals about respect for and reciprocity with wildlife and the land (Samson Cree Nation, 2014, Appendix 7c, EIA, CIAR#42). Traditional networks and plant harvesting, and cultivation sites hold cultural importance for the Nation (Samson Cree Nation, 2014, Appendix 7c, EIA, CIAR#42).

Table 6.6-7 Mitigation Measures, Residual Effects, and Cumulative Effects Related to Intangible Cultural and Spiritual Project Effects for Samson Cree Nation

Intangible Cultural and Spiritual Effect	Mitigation Measures	Residual Effects Assessment	Cumulative Effects Assessment
Loss of inter-generational teaching of language or traditional practices	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	See Table 6.7-8, JRP IR-6.7	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8
Change in sense, experience, or enjoyment of cultural practices and spiritual places	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	See Table 6.7-8, JRP IR-6.7	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8
Direct and adverse effects on culturally significant sites and access to sites of "high ceremony value", especially related to Samson Cree Nations' spiritual connection to the bear (Addendum 10, Appendix 4.1-1, CIAR#251)	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	See Table 6.7-8, JRP IR-6.7	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8

Metis Nation of Alberta Region 3

There are many well-known and documented sacred places and gathering areas throughout the Métis Nation of Alberta territory. These sacred sites are unifying symbols, provide evidence for cultural continuity and establish and reinforce national and personal connections to the landscape.

While country foods have always been important for food, subsistence and sustenance, the practice of hunting has important cultural and spiritual considerations. Intergenerational knowledge about ceremonies, traditions and customs as well as use of harvested animals as medicine, food, tools, clothing, shelter and more is shared while hunting. In addition to this educational context, hunting practices are typically linked to other intangible values with spiritual, artistic and aesthetic elements. Likewise, fishing has always been important for food, subsistence and sustenance and the activity of fishing has important cultural and spiritual considerations. Intergenerational knowledge about ceremonies, legends as well as fish use as medicine, food and more is shared while fishing. In addition to this educational context, the activity of fishing is typically linked to other intangible values with spiritual, artistic and aesthetic elements. For example, fishing typically provides for quiet enjoyment of the landscape or access to water for other uses.

Wildlife species that hold cultural value to Métis Nation of Alberta include deer, elk, grizzly bear, black bear, wild turkey and grouse (Solstice, 2016; MNA, 2016, Addendum 9, CIAR#185). Although current use for cultural and spiritual values was not identified in the TLUS, the Métis

Nation of Alberta participants noted that the RSA provides habitat for these species. In addition, information pertaining to medicinal plants is passed down through families and generations and is considered culturally important. While specific gathering locations are not identified, Métis Nation of Alberta identified that there are ecosystems that support medicinal plants existing within the Project area.

Table 6.6-8 Mitigation Measures, Residual Effects, and Cumulative Effects Related to Intangible Cultural and Spiritual Project Effects for Métis Nation of Alberta

Intangible Cultural and Spiritual Effect	Mitigation Measures	Residual Effects Assessment	Cumulative Effects Assessment
Loss of inter-generational teaching of language or traditional practices	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	See Table 6.7-9, JRP IR-6.7	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8
Change in sense, experience, or enjoyment of cultural practices and spiritual places (*i.e.*, effects on Métis Nation of Alberta enjoyment and experience of cultural traditions due to noise and visual disturbance (Addendum 10, Appendix 4.1-1, CIAR#251))	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	See Table 6.7-9, JRP IR-6.7	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8

Ermineskin Cree Nation

Information regarding cultural and spiritual values is not identified in public sources and has not been provided by the Ermineskin Cree Nation.

Table 6.6-9 Mitigation Measures, Residual Effects, and Cumulative Effects Related to Intangible Cultural and Spiritual Project Effects for Ermineskin Cree Nation

Intangible Cultural and Spiritual Effect	Mitigation Measures	Residual Effects Assessment	Cumulative Effects Assessment
Loss of inter-generational teaching of language or traditional practices.	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	No Information Available	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8

Table 6.6-9 Mitigation Measures, Residual Effects, and Cumulative Effects Related to Intangible Cultural and Spiritual Project Effects for Ermineskin Cree Nation

Intangible Cultural and Spiritual Effect	Mitigation Measures	Residual Effects Assessment	Cumulative Effects Assessment
Change in sense, experience, or enjoyment of cultural practices and spiritual places.	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	No Information Available	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8

Louis Bull Tribe

Limited information was found regarding the Louis Bull Tribe's cultural and spiritual values. The Louis Bull Tribe's cultural practices such as sun dance and sweat ceremonies are maintained by transferring the culture to the younger generations (Louis Bull Tribe, 2018b as cited in Appendix 4.1-1, Addendum 10, CIAR#251). Indeed, "familial connections engender and sustain continued traditions of resources exchanged between Louis Bull members and other nations including the trade of plants, herbs and preserved food that are used for ceremony and as medicine" (Louis Bull Tribe, 2018b, p.3 as cited in Appendix 4.1-1, Addendum 10, CIAR#251).

Table 6.6-10 Mitigation Measures, Residual Effects, and Cumulative Effects Related to Intangible Cultural and Spiritual Project Effects for Louis Bull Tribe

Intangible Cultural and Spiritual Effect	Mitigation Measures	Residual Effects Assessment	Cumulative Effects Assessment
Loss of inter-generational teaching of language or traditional practices (*i.e.,* Louis Bull Tribe sun dance and sweat ceremonies).	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	No Information Available	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8
Change in sense, experience, or enjoyment of cultural practices and spiritual places.	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	No Information Available	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8

Montana First Nation

Information regarding cultural and spiritual values is not identified in public sources and has not been provided by the Montana First Nation.

Table 6.6-11 Mitigation Measures, Residual Effects, and Cumulative Effects Related to Intangible Project Effects for Montana First Nation

Intangible Cultural and Spiritual Effect	Mitigation Measures	Residual Effects Assessment	Cumulative Effects Assessment
Loss of inter-generational teaching of language or traditional practices (*i.e.*, Cree language, cultural traditions and ceremonies (Addendum 10, Appendix 4.1-1, CIAR#251)).	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	No Information Available	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8
Change in sense, experience, or enjoyment of cultural practices and spiritual places.	See Table 6.5-6, Cultural and Spiritual Values, Mitigation Measures, in JRP IR-6.5	No Information Available	See Tables 6.8-1 and 6.8-2 in JRP IR-6.8

Shuswap Indian Band, Foothills Ojibway First Nation, Métis Nation of British Columbia Region 4

No information regarding the cultural and spiritual values of the Shuswap Indian Band, Foothills Ojibway First Nation or the Métis Nation of British Columbia Region 4 was available about use in the region through engagement on the project nor publicly available sources.

REFERENCES:

O'Connor, D. 2018. Blood Tribe/Kainai Traditional Knowledge & Use Assessment. Prepared by Dermot O'Connor, Oak Road Concepts Inc., Cochrane, AB. (submitted under confidentiality restrictions by Kainai to the JRP)

Information Request 6.7

Final Environmental Impact Statement Guidelines. (CIAR #11)

Eighth Addendum to the Environmental Impact Assessment, Section 15. (CEAR #89).

Tenth Addendum to the Environmental Impact Assessment, Appendix 4.1-1. (CIAR #251).

Canadian Environmental Assessment Agency "Technical Guidance for Assessing Current Use of Lands and Resources for Traditional Purposes under the *Canadian Environmental Assessment Act, 2012*". (December 2015).

Canadian Environmental Assessment Agency "Technical Guidance for Assessing Physical and Cultural Heritage or any Structure, Site or Thing that is of Historical, Archeological, Paleontological or Architectural Significance under the *Canadian Environmental Assessment Act, 2012*" (March 2015)

In Benga's response to IR 4.1, 4.2, and 4.4, Benga provided Appendix 4.1-1 titled "An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups" (CIAR #251). Sections 4 to 17 of Appendix 4.1-1 contain Benga's effects assessment with respect to the current use of lands and resources for traditional purposes and cultural and physical heritage of Indigenous peoples, individually for each group.

The EIS Guidelines (CIAR #11) require that residual effects, even if very small or deemed insignificant, be described in sufficient detail to enable the Panel to review Benga's analysis. The EIS Guidelines also require that Benga provide an analysis of the significance of the identified residual effects of the Project using predefined criteria (e.g. magnitude; geographic extent, etc.). Although Benga has provided some of this information in Appendix 4.1-1, Benga has not adequately described the residual effects. For example, in the assessment of potential effects to Siksika Nation's hunting activities, Benga stated that:

> "The Project will affect the wildlife VCs hunted by the Siksika Nation (e.g., moose, elk, bear, eagles) through changes in habitat availability, habitat fragmentation/connectivity and mortality risk. With successful application of mitigation measures, the residual effects of the Project on habitat availability, habitat fragmentation/connectivity, mortality risk and abundance within the Wildlife LSA (WLSA) were deemed not significant".

In this example, Benga has not described how the residual effects on the wildlife VCs hunted by Siksika are connected to the Indigenous VCs nor has Benga described the residual effect to hunting (e.g. to resources, access, use, experience, culture, etc.) that will remain after mitigation measures have been implemented. At a minimum, the description of residual effects should focus on the nature of the effect and describe changes to resources, access, use, and experience as well as taking into consideration cultural and spiritual practices, ceremonies, and intergenerational transfer of knowledge.

Benga characterized the residual effects to hunting as being of moderate magnitude; local geographic extent; long-term duration; continuous frequency; reversible; and sensitive in ecological and social context. It remains unclear however what specific residual effects to hunting Benga has characterized. Benga did not provide an explanation of how the significance criteria were applied to the residual effects nor did Benga provide a rationale for how the conclusion of "not significant" was made.

Provide the following:

a) A description of each residual effect of the Project on the current use of lands and resources for traditional purposes following the Agency's "Technical Guidance for

Assessing Current Use of Lands and Resources for Traditional Purposes under the *Canadian Environmental Assessment Act, 2012*"[2].

b) A description of each residual effect of the Project on the physical and cultural heritage following the Agency's "Technical Guidance for Assessing Physical and Cultural Heritage or any Structure, Site or Thing that is of Historical, Archeological, Paleontological or Architectural Significance under the *Canadian Environmental Assessment Act, 2012*"[3].

c) An updated characterization of the residual effects of the Project for the current use of lands and resources for traditional purpose and the physical and cultural heritage of Indigenous peoples using the descriptions of the residual effects above.

Response:

Benga described and characterized residual effects of the Project on Current Use of Lands and Resources for Traditional Purposes following the Agency's "Technical Guidance for Assessing Current Use of Lands and Resources for Traditional Purposes under the *Canadian Environmental Assessment Act, 2012*" and residual effects of the Project on the Physical and Cultural Heritage following the Agency's "Technical Guidance for Assessing Physical and Cultural Heritage or any Structure, Site or Thing that is of Historical, Archeological, Paleontological or Architectural Significance under the *Canadian Environmental Assessment Act, 2012"*. Benga considered potential changes in resources, access, use, and experience of engaging in traditional activities in the assessment of effects on Indigenous VCs.

To address parts a) and b) of the information request, a description of the residual effects on Indigenous VCs (those listed in Tables 6.5-2 through 6.5-7 after mitigation) are provided in Tables 6.7-2a through 6.7-9a. This description incorporates residual effects on associated VCs and how they are connected to the Indigenous VCs. The tables contain both the residual effects on Current Use of Lands and Resources for Traditional Purposes, and Physical and Cultural Heritage.

To address part c) of the information request, the characterization of residual effects, including an explanation of how the significance criteria were applied, is provided in Tables 6.7-2 through 6.7-9. The conclusions of the characterization do not differ from those provided in *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups* (Addendum 10, Appendix 4.1-1, CIAR#251). The definitions of the significance criteria used to

[2] Available online: Technical Guidance for Assessing the Current Use of Lands and Resources for Traditional Purposes under the *Canadian Environmental Assessment Act, 2012*. https://www.canada.ca/en/impact- assessment-agency/services/policy-guidance/technical-guidance-assessing-current-use-lands-resources- traditional-purposes-under-ceaa-2012.html

[3] Available online: Technical Guidance for Assessing Physical and Cultural Heritage or any Structure, Site or Thing that is of Historical, Archeological, Paleontological or Architectural Significance under the *Canadian Environmental Assessment Act, 2012*. https://www.canada.ca/en/impact-assessment-agency/services/policy-guidance/technical- guidance-assessing-physical-cultural-heritage-or-structure-site-or-thing.html

characterize significant effects were described in Table 3.3-1 in Appendix 4.1-1 (Addendum 10, CIAR#251) and are provided below for reference as Table 6.7-1.

Tables 6.7-2 through 6.7-9 provide a description and characterization of residual effects on Indigenous VCs for each Indigenous group for whom residual effects were determined:

- Kainai Nation: Table 6.7-2a
- Piikani Nation: Table 6.7-3a
- Siksika Nation: Table 6.7-4a
- Stoney Nakoda Nation: Table 6.7-5a
- Tsuut'ina Nation: Table 6.7-6a
- Ktunaxa Nation: Table 6.7-7a
- Samson Cree Nation: Table 6.7-8a
- Metis Nation of Alberta - Region 3: Table 6.7-9a

No residual effects were predicted for Metis Nation of British Columbia – Region 4 (Addendum 10, Appendix 4.1-1, Section 14, CIAR#251). Shuswap, Foothills Ojibway, Erminskin Cree, Louis Bull, and Montana groups did not provide sufficient information to determine if there were residual Project effects (Addendum 10, Appendix 4.1-1, Sections 11, 12, 15, 16, and 17 respectively, CIAR#251).

Table 6.7-1 Characterization of Residual Effects on Indigenous Valued Components [Source: Table 3.1.2-1, *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups,* Appendix 4.1-1, Addendum 10, CIAR#251]

Residual Effects Characterization Criteria	Description	Definition
Magnitude	Magnitude describes the amount of change associated with the residual adverse effect to Indigenous Interests within the spatial boundaries.	Negligible – no change in the ability to exercise an Indigenous interest Low – a change in the ability to exercise an Indigenous Interest but within normal annual variability. Will not affect the ability to exercise an Indigenous interest in the RSA. Moderate – a change in the ability to exercise an Indigenous Interest outside a normal annual variability. Will not affect the ability to exercise the Indigenous interest in the RSA. High – a change in the ability to exercise an Indigenous interest outside of normal annual variability. May affect the ability to exercise the Indigenous Interest within the RSA.

Table 6.7-1 Characterization of Residual Effects on Indigenous Valued Components [Source: Table 3.1.2-1, *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups,* Appendix 4.1-1, Addendum 10, CIAR#251]

Residual Effects Characterization Criteria	Description	Definition
Geographic extent	Geographic extent refers to the spatial scale within which a residual adverse effect is predicted.	Local = local study area Regional = regional study area
Duration	Duration is the length of time that the potential residual effect could last.	Short term – limited to the construction phase Medium term – construction to operation Long-term – beyond the Project lifespan
Frequency	Frequency is related to duration and it refers to how often the residual effect is expected to occur.	Once = occurs once Regular = occurs regularly Continuous = occurs continuously
Reversibility	Reversibility refers to whether the residual adverse effect can be reversed to baseline conditions.	Reversible Non reversible - permanent
Ecological and social context	Context refers to the sensitivity and resilience of the Indigenous Interest to change caused by the Project.	Sensitive – the Indigenous interest is sensitive or has low resiliency to disruption Resilient – the Indigenous interest is not sensitive or has high resiliency to disruption

Description and Characterization of Residual Effects on Kainai Nation

The description and characterization of residual effects on the Kainai Nation are found below in Table 6.7-2a. A summary table of this characterization was provided as Table 4.4.4-1 in Appendix 4.1-1 (Appendix 4.1-1: *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups*, Addendum 10, CIAR#251), and is copied below for the convenience of the reader, presented as Table 6.7-2b. The results of the characterization are not changed from the conclusions reached in Appendix 4.1-1.

Table 6.7-2a Description and characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Káinai Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Hunting	1. Hunted species and habitat:
	The Project will have temporary effects on land access for traditional resource use and on the distribution and abundance of species hunted for traditional purposes.
	Species preferring recently disturbed and young habitats are expected to return first, followed by species preferring increasingly older habitat types with reclamation.
	Moose and Elk:
	• Suitable moose and elk habitat will decline initially but is predicted to be more abundant than baseline levels by end of mine due, in part, to reclamation of legacy mine sites that overlap the Project footprint (EIA, CR#9, Section 5.6.2.1, CIAR#42).
	• The changes in abundance of moose and elk year-round in the WLSA are expected to follow a similar pattern as individuals of both species will be displaced into adjacent habitats.
	Grizzly Bear:
	• Highly suitable grizzly bear habitat in the WLSA will decrease initially during the construction and operation phases and then increase throughout the duration of progressive reclamation. Mortality risk also increases with Project development but then decreases with progressive reclamation. With reclamation, the Project footprint is expected to offer more suitable habitat (dietary resources) and lower mortality risk than under baseline conditions, which are anticipated to allow for an increase in the size of the grizzly bear population that the local area can support.
	Wildlife Residual Effects (EIA, CR#9, Table 5.3-26, CIAR#42):
	• Effects on habitat availability for hunted species (moose, elk, grizzly bear) due to vegetation clearing and sensory disturbance (due to increased noise, odour, visual disturbance) are low magnitude, positive Project contribution, and reversible in the long-term.
	• Effects on wildlife movement for hunted species (moose, elk, grizzly bear) due to construction and operation are low magnitude, and reversible in the long-term.
	• Effects on wildlife abundance for hunted species (moose, elk, grizzly bear) in hunting location is low magnitude, positive Project contribution for elk and grizzly bear, neutral Project contribution for moose, and reversible in the long-term.
	• Effects on wildlife mortality risk for hunted species due to construction activities, vehicle collisions, and human-wildlife conflicts are low magnitude, frequency is occasional, and reversible in the long-term. With the Access Control Policy and firearm prohibition by Project personnel, poaching and non-Indigenous hunting of moose, elk, and grizzly bear will decline in the WLSA during the life of mine and may result in increased abundance of moose, elk, and grizzly bear in the areas accessible by Indigenous groups (EIA, CR#9, Section 5.6.2.1, CIAR#42).
	• A screening level wildlife risk assessment was conducted, the results of which indicate that there is no potential risk of adverse effects associated with Project emissions on the health of wildlife in the study areas (Addendum 10, Appendix 4.9-1, Section 8.0, Updated Human Health and Wildlife Screening Risk Assessment, CIAR#251).
	• The wildlife risk assessment was amended to include an evaluation of water-based exposure pathways (both groundwater and surface water) and the results presented for Blairmore Creek, Gold Creek and the Oldman Reservoir were not considered to be indicative of adverse effects (Addendum 11, JRP IR-6.28). For the proposed end pit lake (EPL) (at closure), the results of the risk assessment are not considered indicative of a human health concern; however, management considerations of the EPL are warranted and actual measured concentrations at the time of EPL creation should be used to revisit predicted effects (Addendum 11, JRP IR-6.27). The assessment includes an Indigenous-specific conceptual model, which describes source-pathway linkages between the Project and Indigenous use of all aquatic pathways including the end pit lake, Blairmore and Gold Creeks, the Crowsnest River and the Oldman Reservoir in the post closure landscape.
	2. Use or access to hunting locations and harvesting methods:
	• Where Project construction and operations activities overlap with hunting locations, access to active mining areas may be limited until they are reclaimed and safe. Indigenous groups will continue to have access to hunting and trapping locations where safety is not compromised (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• The Project's access restrictions within the mine permit area may also affect Indigenous groups' ability to use their preferred harvesting methods and seasonal rounds by altering the times of year that Indigenous groups have access to areas of interest for hunting within the mine permit area (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• The residual effects on trails and travelways was assessed as moderate magnitude.
	• Increased noise, odour, and visual disturbance during construction and operation could affect use of locations and the experience of hunting within the vicinity of the Project (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89); residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42):
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	• Where Indigenous groups utilize firearms for hunting, the Project's firearms restriction policy would affect their ability to use that harvesting method within the mine footprint. Alternate hunting methods may be possible in parts of the mine footprint that have not yet been disturbed or which have been reclaimed under the AMP (Addendum 8, Appendix A-1, Section 15.2.1.1.3, CIAR#89).
	In summary, effects on linked VCs will act synergistically to change identified hunted species and habitat, change use or access to identified hunting locations, and change preferred harvesting methods. There will be residual effects on hunting for Káinai Nation due to reduction in hunting opportunities, engagement in hunting, and hunting success during construction and operation due to loss of access of hunting locations, sensory disturbance, and change in wildlife use within the mine permit area, which could affect the cultural and spiritual relationship between the Nation and their territory, which is addressed below.
		Residual effects on hunting are characterized as:
		• Magnitude is moderate because there is predicted to be a change in the ability to hunt for the Káinai Nation in the area but this does not change the ability to hunt in the RSA. Although Káinai Nation do not hunt as extensively in the area today as they did in the past, they have identified use of and access to hunting locations within the vicinity of the Project and the area continues to be the source of wildlife hunted for use in ceremonies, sacred bundles, and for subsidence purposes (Addendum 10, Appendix 4.1-1, Section 4.3.1.1, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but will be limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency because loss of hunting opportunities will be continuous throughout construction and operation.
		• Reversibility is characterized as reversible because reclamation is planned and expected to re-establish natural processes and ecosystems that support hunted species and access will be restored following the AMP.
		• Ecological and social context is sensitive because Káinai Nation noted that past present activities have placed hunting already at moderate to high risk, and hunted species that occur in the Project area remain important sources of food for members of Káinai Nation (Carlson *et al.* 2018; Addendum 10, JRP IR-4.6, CIAR#251).

Table 6.7-2a Description and characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Káinai Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Trapping	1. Trapped species and habitat:
	The Project will have temporary effects on land access for traditional resource use and on the distribution and abundance of species trapped for traditional purposes.
	Species preferring recently disturbed and young habitats are expected to return first, followed by species preferring increasingly older habitat types with reclamation.
	Canada Lynx:
	• There is a loss of lynx habitat in the WLSA. The loss of effective habitat, along with sensory disturbances associated with the Project, will likely displace lynx to other more suitable undisturbed habitats located west, north and east of the WLSA. Canada lynx rarely use the area around the access road, so it is not expected to have significant effects on lynx movement.
	American Marten:
	• There will be a temporary, long-term loss of habitat for American marten. Reclamation of disturbed areas will occur throughout and after the life of the Project; however, American martens prefer mature to old-growth coniferous forests, which will take many decades to become re-established. East-west movements of American marten will likely be affected by the Project footprint since they tend to avoid open landscapes. The access road and coal conveyor will also likely affect marten movements. North-south marten movements along Blairmore and Gold Creeks should be relatively unaffected by Project development. With mitigation, Project effects on American marten habitat availability and movement in the WLSA are expected to be local in extent, extended in duration, continuous in frequency, reversible in the long-term, moderate in magnitude for habitat availability and low for movement (EIA, CR#9, Section 5.3.6.1, CIAR#42).
	Wildlife Residual Effects (EIA, CR#9, Table 5.3-26, CIAR#42):
	• Effects on habitat availability for trapped species (lynx, American marten) due to vegetation clearing and sensory disturbance (due to increased noise, odour, visual disturbance) are moderate magnitude, negative Project contribution, and reversible in the long-term.
	• Effects on wildlife movement for trapped species (lynx, American marten) due to construction and operation are low magnitude, and reversible in the long-term.
	• Effects on wildlife abundance for trapped species (lynx, American marten) in hunting locations due to is low magnitude, negative Project contribution and, for American marten, reversible in the long-term and for the Canada lynx, reversible in the short term.
	• Effects on wildlife mortality risk for trapped species (lynx, American marten) due to construction activities, vehicle collisions, and human-wildlife conflicts are low magnitude, frequency is occasional, and reversible in the short term.
	2. Use or access to trapping locations and harvesting methods:
	• Where Project construction and operations activities overlap with hunting and trapping locations, access to active mining areas may be limited until they are reclaimed and safe. Indigenous groups will continue to have access to hunting and trapping locations where safety is not compromised (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• The Project's access restrictions within the mine permit area may also affect Indigenous groups' ability to use their preferred harvesting methods and seasonal rounds by altering the times of year that Indigenous groups have access to areas of interest for hunting/trapping within the mine permit area (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• Loss or disruption of traplines or trails used for trapping and loss of access to trapping locations may occur due to the mine site and road closure during construction and operation. The residual effects on trails and travelways was assessed as moderate magnitude.
	• Increased noise, odour, and visual disturbance during construction and operation could affect use of locations and the experience of hunting within the vicinity of the Project (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89); residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42):
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change identified trapped species and habitat, change use or access to identified trapping locations, and change preferred harvesting methods. There will be residual effects on trapping for Káinai Nation due reduction or loss of trapping opportunities and the change in trapping methods could affect the cultural and spiritual relationship between the Nation and their territory, which is addressed below.
		Residual effects on trapping are characterized as:
		• Magnitude is moderate because there is predicted to be a change in the ability to trap for the Káinai Nation in the area but this does not change the ability to trap in the RSA. The Káinai Nation have noted that trapping may occur today in and around the Project area for both subsistence and ceremonial purposes (Addendum 10, Appendix 4.1-1, Section 4.3.1.2, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency because loss of trapping opportunities will be continuous throughout construction and operation.
		• Reversibility is characterized as reversible because reclamation is planned and expected to re-establish natural processes and ecosystems that support trapped species and access will be restored following the AMP.
		• Ecological and social context is sensitive because Káinai Nation noted that past present activities, particularly mining, have placed trapping already at risk (Carlson *et al*. 2018; Addendum 10, JRP IR-4.6, CIAR#251).

Table 6.7-2a Description and characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Káinai Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Fishing	1. Fishing species and habitat:
	Westslope Cutthroat Trout (WSCT)
	• The physical footprint of surface water management infrastructure and open pits will cause permanent change to WSCT habitat. The loss of riparian and aquatic habitat will be reversed by gains achieved through implementing an Offsetting Plan approved by DFO. The magnitude of this effect will be moderate, the duration is long, the frequency will be continuous, however, reversibility is characterized as reversible in the long-term. (Addendum 1, CR#6, Section 4.5, CIAR#44).
	• Changes in hydrology will cause alteration in WSCT aquatic habitat of Gold and Blairmore creeks. The alteration of habitat will be offset by gains achieved through implementing an Offsetting Plan approved by DFO. The magnitude of residual adverse effects will be moderate, the duration is extended, the frequency will be continuous, however, reversibility is characterized as reversible in the long-term. (Addendum 1, CR#6, Section 4.5, CIAR#44).
	2. Use or access to fishing locations and harvesting methods:
	• Current access to the portions of the watercourses adjacent to Grassy Mountain is located on Benga private land. During construction and operation phases of the mine, this road will be closed to the general public, and alternate routes will need to be used to access and fish those portions of Blairmore and Gold Creeks (Addendum 8, Appendix A-1, Section 15.2.2.1.2, CIAR#89) which will be managed *via* the AMP.
	• Loss or disruption of trails for accessing fishing locations due to the mine site and road closure during construction and operation. The residual effects on trails and travelways was assessed as moderate magnitude.
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of fishing locations by Indigenous Nations and preferred harvesting method.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1 CIAR#42).
	  • Odour (mostly NO2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change use or access to identified fishing locations, and change in preferred harvesting methods. There will be residual effects on fishing for Káinai Nation due to reduction in fishing opportunities, engagement in fishing, and fishing success during construction and operation due to loss of access of fishing locations and sensory disturbance within the mine permit area.
		Residual effects on fishing are characterized as:
		• Magnitude is moderate. The Káinai Nation have advised they have fishing interests in the Project area and identified species, including Westslope Cutthroat trout (Addendum 10, Appendix 4.1-1, Section 4.3.2.3, CIAR#251). There is predicted to be a change in the ability to fish for Káinai Nation.
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because access restrictions will apply beyond the life of the mine in some areas that may affect access to fishing locations.
		• Continuous frequency because loss of fishing opportunities will be continuous throughout construction and operation.
		• Reversibility is characterized as reversible because reclamation and offsetting is planned and expected maintain the fish population and access will be restored following the AMP.
		• Ecological and social context is resilient because the Káinai Nation engage in fishing primarily outside the Project LSA in the Crowsnest River watershed and Old Man River watershed north of the LSA and not in close proximity to industrial sites and other features used for non-TLU purposes (Section 4.3.1.3, Addendum 10; Carlson *et al*. 2018). The Project area overlaps existing industry which has already resulted in change in fishing. Therefore, Kainai Nation engagement in fishing is not sensitive to disruption from the Project.

Plant Gathering	1. Plant species and habitat:
	• The Project will result in loss of traditional use of vegetation within the vegetation local study area. Residual effects to TEK vegetation are local, long-term in duration, continuous, reversible and high magnitude. The Project will have a neutral contribution with respect to valued species and communities. After reclamation, the reclaimed land will support a range of communities with equivalent capabilities to those of the surrounding lands and that existing prior to Project development.
	• Residual adverse effects on vegetation were assessed as high magnitude for rare plants, community diversity, and TEK species, low magnitude for forest, and moderate for wetlands (EIA, CR#8, Section 4.0, CIAR#42).
	• Duration of effects on vegetation will be extended. Reclaimed land will require time to return the ecosystem to a condition that supports traditional use plants (EIA, CR#8, Section 4.1, CIAR#42).
	• Frequency of effects on vegetation, including rare plants and rare plant communities and traditional ecological knowledge, will be continuous through the operational phase of the project and cease only after reclamation is completed (EIA, CR#8, Section 4.0, CIAR#42).
	• Effects on vegetation are reversible in the long-term with the implementation of progressive reclamation (EIA, CR#8, Section 4.0, CIAR#42).
	2. Use or access to plant gathering locations and harvesting methods:
	• Loss or disruption of trails, loss of access to plant gathering locations, and loss of preferred methods for plant gathering due to the mine site and access road. Residual effects on trails and travelways was assessed as moderate magnitude.
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of plant gathering locations by Indigenous Nations and preferred harvesting method.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO2 in the community (EIA, CR#1, Section 6.3 CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change identified plant gathering species and habitat, change use or access to identified harvesting locations, and change in preferred harvesting methods. There will be residual effects on plant gathering for Káinai Nation due to reduction in harvesting opportunities, engagement in plant gathering, and harvesting success during construction and operation due to loss of access of plant gathering locations and sensory disturbance within the mine permit area.
		Residual effects on plant gathering are characterized as:
		• Magnitude is moderate. The Káinai Nation have identified habitat and species for plant gathering in the proximity of the Project (Addendum 10, Appendix 4.1-1, Section 4.3.2.3, CIAR#251). There is predicted to be a change in the ability to gather plants for Káinai Nation.
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine.
		• Reversibility is characterized as reversible because reclamation (of terrain, soil, vegetation) is planned and expected to re-establish natural processes and ecosystems that support traditional use plants (high density planting of disease-resistant whitebark pine seedlings will contribute to the successful re-establishment of the native ecosystem); and, access to plant gathering locations will be re-established after mine closure.
		• Ecological and social context is sensitive because engagement in plant gathering is sensitive to disruption and past and present activities have resulted in traditional land use at high risk (Carlson *et al*. 2018; Addendum 10, JRP IR-4.6, CIAR#251).

Table 6.7-2a Description and characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Káinai Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Trails and Travelways	1. Use or access to trails and travelways:
	• Loss or disruption of trails and travelways due to the mine site and access road. The Project will have residual adverse effects on use of trails and travelways because the Project could result in loss of trails and travelways that are fully or partially within the mine permit boundary.
	• The Project footprint will be reclaimed to land use capability equivalent to pre-mining; however, it will not be accessible for use as trails and travelways during construction and operations. Access to areas around the Project will be possible using existing trails from Highway 40 to reach the area west of Blairmore Creek and Crown Land north of the Project and from either the north or the south along the Gold Creek. With the implementation of the AMP, potential residual effects will be further reduced as Benga will be providing access to adjacent privately owned Benga lands for traditional practices (Addendum 10, Appendix 4.1-1, Section 4.3.3.5, CIAR#251).
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of trails and travelways by Indigenous Nations.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	2. Features associated with trails and travelways:
	• Loss or disturbance to features associated with trails and travelways due to the mine site and access road.
	• Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42).
	• Residual adverse effects on access and utilities in the Lands and Resource Use VC was assessed as nil magnitude after reclamation (EIA, CR#10, CIAR#42).
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42).
	• Residual effects will extend beyond the mine footprint but will be limited to within the zone of influence (generally 1.5 km) for noise, visual disturbance, and effect on access (EIA, CR#2, CIAR#42).
	• The geographic extent of residual effects on historical resources and on land and resource use is characterized as local (EIA, CR#10, Section E, CIAR#42).
	• The frequency of impact on access and utilities in the lands and resource use is continuous (EIA, CR#2, CIAR#42).
	• The frequency of impact of noise and other disturbances to trail use will continue throughout the Project lifespan (EIA, CR#2, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change use or access and change preferred trails and travelways. There will be residual effects on trails and travelways for Káinai Nation due to restriction in use or access, and engagement with features associated with trails and travelways during construction and operation due to loss of access to trails and travelways locations, sensory disturbance, and change in use within the mine permit area.
		Residual effects on trails and travelways is characterized as:
		• Magnitude is moderate. The Project will intersect or be in proximity to territory that has been identified as trails or travelways by the Káinai Nation (Addendum 10, Appendix 4.1-1, Section 4.3.2.5, CIAR#251). There is predicted to be a change in the ability to use or access trails and travelways for Káinai Nation.
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency during construction and operation due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine.
		• Non-reversible where trails and travelways are lost because when a trail is inaccessible it will not be maintained or used, resulting in the potential loss of the knowledge of or loss of the physical trail or travelway.
		• Ecological and social context is resilient because the Káinai Nation can use alternative routes to travel between cultural and spiritual sites and resources within their traditional territory (Section 4.3.1.5, Appendix 4.1-1, Addendum 10). Therefore, Káinai Nation use and access to trails and travelways is not sensitive to disruption from the Project.

Cultural and Spiritual Values	1. Use of and access to sacred important sites with cultural or spiritual value: • Residual adverse effects on access and utilities in the Lands and Resource Use VC was assessed as nil magnitude (EIA, CR#10, CIAR#42). • Loss or disruption of trails to important sites due to the mine site and access road. • Loss of hunting, trapping, fishing, and plant gathering opportunities. The residual effects, as seen above, on hunting, trapping and plant gathering were assessed as moderate magnitude. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect use and enjoyment of culturally and spiritually important sites. Increased noise levels extend 1.5 km from the Project (EIA, CR#2, CIAR#42). Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). • Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42). 2. Experience of engaging with sites of cultural or spiritual value: • Loss or disturbance to important sites due to the mine site and access road. • Loss of experience in hunting, trapping, fishing, and plant gathering, which could affect the cultural and spiritual relationships with the resource. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect enjoyment or experience of using culturally and spiritually important sites. 3. Cultural values associated with sites/features: • Loss of hunting, trapping, fishing, and plant gathering opportunities, which could affect intergenerational teaching of traditional practices, and result in loss of cultural identity, sense of place, and human health/well-being. • Loss of access to sites/features due to construction and operation activities. • Loss of or damage to unique sites and special features as a result of clearing and construction activities. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect enjoyment or experience of engaging with the sites/features of cultural or spiritual value. In summary, effects on linked VCs will act synergistically to change use or access to sites with cultural or spiritual value, change the experience of using these sites, and change the cultural value associated with sites and features. There will be residual effects on cultural and spiritual values for Káinai Nation during construction and operation due to loss of or access to culturally or spiritually important sites and sensory disturbance within the mine permit area.	Residual effect on cultural and spiritual values is characterized as: • Magnitude is moderate. The Káinai Nation indicated that the Project area is highly significant and culturally important (Addendum 10, Appendix 4.1-1, Section 4.3.3.6, CIAR#251). The Káinai Nation has also stated the Project footprint would destroy documented and undocumented sites of cultural and spiritual significance (Addendum 10, Appendix 4.1-1, Section 4.3.2.6, CIAR#251). There is predicted to be a change in the values associated with cultural or spiritual sites for the Káinai Nation. • Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA. • Long-term duration because the loss of experience in hunting, trapping, fishing, and plant gathering could affect the long-term cultural and spiritual relationships between Indigenous groups and their resources and territory. Change in land use and access will extend beyond the Project lifespan. • Continuous frequency due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine. • Non-reversible because loss of cultural and spiritual sites and experience in engaging in land use could result in loss of the knowledge of cultural and spiritual values. • Ecological and social context is sensitive because loss of engagement in land use affects cultural identity, human well-being and relationships, and intergenerational transfer of knowledge.

Table 6.7-2a Description and characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Káinai Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC
Indigenous Physical and Cultural Heritage	1. Physical and cultural heritage: • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities. • The geographic extent of residual effects on historical resources is local (EIA, Section E, CIAR#42). 2. Access to physical and cultural heritage: • Loss or disruption of trails to unique sites and special features associated with physical or cultural heritage due to the mine site and access road. • The magnitude of effects on trails and travelways was characterized as moderate. 3. Cultural value and importance associated with physical and cultural heritage: • Increase in noise, odour, and visual disturbance during construction and operation could result in reduced engagement with the sites/features of cultural value. • Magnitude was assessed as high for TEK plant species (EIA, CR#8, CIAR#42), whereas magnitude is low to moderate for hunted and trapped wildlife (EIA, CR#9, CIAR#42). • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities. • The magnitude of effects on cultural and spiritual values was characterized as moderate. 4. Relationship with physical and cultural heritage: • Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42) and access and utilities in the Lands and Resource Use VC was assessed as nil magnitude (EIA, CR#10, CIAR#42), but for those VCs that affect the relationships with physical and cultural heritage (*e.g.,* air quality, noise, plant gathering, hunting and trapping), magnitude is assessed as high for odour and low to moderate for emissions including dust (EIA, CR#1 CIAR#42), and moderate for hunting, trapping and plant gathering. • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities could result in loss of relationship with heritage. • Loss of hunting, trapping, fishing, and plant gathering opportunities due to construction and operation and access restrictions could result in loss of relationship with wildlife and cultural practices. • Increase in noise, odour, and visual disturbance during construction and operation could result in reduced engagement with the sites/features associated with physical or cultural heritage. In summary, effects on linked VCs will act synergistically to change use or access to physical and cultural heritage, change the value and importance, and change the relationship the Káinai Nation have with these sites. There will be residual effects on Indigenous physical and cultural heritage for Káinai Nation during construction and operation due to loss of access and sensory disturbance within the mine permit area.	Residual effects on Indigenous Physical and cultural heritage are characterized as: • Magnitude is moderate. The TKUA provided by the Káinai Nation specifies sites within the Project TLU LSA and RSA as significant for traditional material culture. The Káinai Nation field team visited thirteen (13) sites that relate to Indigenous physical and cultural heritage during Project site visits (Addendum 10, Appendix 4.1-1, Section 4.4.1, CIAR#251). There is predicted to be a change in the access to and value of physical and cultural heritage for the Káinai Nation. • Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA. • Long-term duration because disturbance to or loss of unique sites and features will extend beyond the Project lifespan. • Regular frequency because disturbance to unique sites and features will occur during construction and operation activities whenever sites or features are discovered. • Non-reversible because loss of heritage sites and features and experience in engaging in land use could result in loss of the knowledge of cultural heritage. • Ecological and social context is sensitive because Káinai Nation identified the Project LSA as significant for traditional material culture, such as material for knives and arrowheads (O'Connor, 2018; Addendum 10, JRP IR-4.6, CIAR#251), and loss of heritage sites and features or loss of engagement with physical and cultural heritage could affect cultural identity, human well-being, and intergenerational transfer of knowledge.

In summary, the residual effects characterization has not changed from that already provided. As such, the summary Table 4.4.4-1 from *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups* (Appendix 4.1-1, Addendum 10, CIAR#251) is provided below as Table 6.7-2b.

Table 6.7-2b Summary of Residual Adverse Effects to the Káinai Nation [Source: Table 4.4.4-1, *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups,* Appendix 4.1-1, Addendum 10, CIAR#251]

Valued Component	Magnitude	Geographic Extent	Duration	Frequency	Reversibility	Ecological and Social Context	Significance
Hunting/ Trapping	Moderate	Local	Long-term	Continuous	Reversible	Sensitive	Not significant
Plant Gathering	Moderate	Local	Long-term	Continuous	Reversible	Sensitive	Not significant
Fishing	Moderate	Local	Long-term	Continuous	Reversible	Resilient	Not significant
Trails and travelways	Moderate	Local	Long-term	Continuous	Not reversible where trails and travelways are lost	Resilient	Not significant
Cultural and Spiritual Values	Moderate	Local	Long-term	Continuous	Not reversible	Sensitive	Not Significant
Indigenous Physical and Cultural Heritage	Moderate	Local	Long-term	Regular	Not reversible	Sensitive	Not significant

Description and Characterization of Residual Effects on Piikani Nation

The description and characterization of residual effects on the Piikani Nation are found below in Table 6.7-3a. A summary table of this characterization was provided as Table 5.4.4-1 (Appendix 4.1-1: *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups*, Addendum 10, CIAR#251), and is copied below for the convenience of the reader, as Table 6.7-3b. The results of the characterization are not changed from the conclusions reached in Appendix 4.1-1.

Table 6.7-3a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Piikani Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Hunting	1. Hunted species and habitat:
	The Project will have temporary effects on land access for traditional resource use and on the distribution and abundance of species hunted for traditional purposes.
	Species preferring recently disturbed and young habitats are expected to return first, followed by species preferring increasingly older habitat types with reclamation.
	Moose and Elk:
	• Suitable moose and elk habitat will decline initially but is predicted to be more abundant than baseline levels by end of mine due, in part, to reclamation of legacy mine sites that overlap the Project footprint (EIA, CR#9, Section 5.6.2.1, CIAR#42).
	• The changes in abundance of moose and elk year-round in the WLSA are expected to follow a similar pattern as individuals of both species will be displaced into adjacent habitats.
	Grizzly Bear:
	• Highly suitable grizzly bear habitat in the WLSA will decrease initially during the construction and operation phases and then increase throughout the duration of progressive reclamation. Mortality risk also increases with Project development but then decreases with progressive reclamation. With reclamation, the Project footprint is expected to offer more suitable habitat (dietary resources) and lower mortality risk than under baseline conditions, which are anticipated to allow for an increase in the size of the grizzly bear population that the local area can support.
	Wildlife Residual Effects (EIA, CR#9, Table 5.3-26, CIAR#42):
	• Effects on habitat availability for hunted species (moose, elk, grizzly bear) due to vegetation clearing and sensory disturbance (due to increased noise, odour, visual disturbance) are low magnitude, positive Project contribution, and reversible in the long-term.
	• Effects on wildlife movement for hunted species (moose, elk, grizzly bear) due to construction and operation are low magnitude, and reversible in the long-term.
	• Effects on wildlife abundance for hunted species (moose, elk, grizzly bear) in hunting location is low magnitude, positive Project contribution for elk and grizzly bear, neutral Project contribution for moose, and reversible in the long-term.
	• Effects on wildlife mortality risk for hunted species due to construction activities, vehicle collisions, and human-wildlife conflicts are low magnitude, frequency is occasional, and reversible in the long-term. With the Access Control Policy and firearm prohibition by Project personnel, poaching and non-Indigenous hunting of moose, elk, and grizzly bear will decline in the WLSA during the life of mine and may result in increased abundance of moose, elk, and grizzly bear in the areas accessible by Indigenous groups (EIA, CR#9, Section 5.6.2.1, CIAR#42).
	• A screening level wildlife risk assessment was conducted, the results of which indicate that there is no potential risk of adverse effects associated with Project emissions on the health of wildlife in the study areas (Addendum 10, Appendix 4.9-1, Section 8.0, Updated Human Health and Wildlife Screening Risk Assessment, CIAR#251).
	• The wildlife risk assessment was amended to include an evaluation of water-based exposure pathways (both groundwater and surface water) and the results presented for Blairmore Creek, Gold Creek and the Oldman Reservoir were not considered to be indicative of adverse effects (Addendum 11, JRP IR-6.28). For the proposed end pit lake (EPL) (at closure), the results of the risk assessment are not considered indicative of a human health concern; however, management considerations of the EPL are warranted and actual measured concentrations at the time of EPL creation should be used to revisit predicted effects (Addendum 11, JRP IR-6.27). The assessment includes an Indigenous-specific conceptual model, which describes source-pathway linkages between the Project and Indigenous use of all aquatic pathways including the end pit lake, Blairmore and Gold Creeks, the Crowsnest River and the Oldman Reservoir in the post closure landscape.
	2. Use or access to hunting locations and harvesting methods:
	• Where Project construction and operations activities overlap with hunting locations, access to active mining areas may be limited until they are reclaimed and safe. Indigenous groups will continue to have access to hunting and trapping locations where safety is not compromised (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• The Project's access restrictions within the mine permit area may also affect Indigenous groups' ability to use their preferred harvesting methods and seasonal rounds by altering the times of year that Indigenous groups have access to areas of interest for hunting within the mine permit area (Addendum 8, Appendix A-1, Section 15.2.1.1.2 CIAR#89).
	• The residual effects on trails and travelways was assessed as moderate magnitude (Addendum 10, Appendix 4.1-1, Section 4.3.3.5, CIAR#251).
	• Increased noise, odour, and visual disturbance during construction and operation could affect use of locations and the experience of hunting within the vicinity of the Project (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89); residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42):
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	• Where Indigenous groups utilize firearms for hunting, the Project's firearms restriction policy would affect their ability to use that harvesting method within the mine footprint. Alternate hunting methods may be possible in parts of the mine footprint that have not yet been disturbed or which have been reclaimed under the AMP (Addendum 8, Appendix a-1, Section 15.2.1.1.3, CIAR#89).
	In summary, effects on linked VCs will act synergistically to change identified hunted species and habitat, change use or access to identified hunting locations, and change preferred harvesting methods. There will be residual effects on hunting for Piikani Nation due to reduction in hunting opportunities, engagement in hunting, and hunting success during construction and operation due to loss of access of hunting locations, sensory disturbance, and change in wildlife use within the mine permit area.
		Residual effects on hunting are characterized as:
		• Magnitude is moderate because there is predicted to be a change in the ability to hunt but it will not affect the ability to hunt in the RSA. For the Piikani Nation, hunting occurs for subsistence as well as for medicinal and ceremonial purposes such as for use in bundle and Sundance ceremonies, and they have identified wildlife sites used for hunting that partially or fully overlap the LSA (Addendum 10, Appendix 4.1-1, Section 5.3.1.1, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency because loss of hunting opportunities will be continuous throughout construction and operation.
		• Reversible because reclamation is planned and expected to re-establish natural processes and ecosystems that support hunted species and access will be restored following the AMP.
		• Ecological and social context is sensitive because hunted species that occur in the Project area remain important sources of food for members of Piikani Nation and because loss of hunting as a traditional practice has low resiliency to disruption for future generations.

Table 6.7-3a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Piikani Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Trapping	1. Trapped species and habitat:
	The Project will have temporary effects on land access for traditional resource use and on the distribution and abundance of species trapped for traditional purposes.
	Species preferring recently disturbed and young habitats are expected to return first, followed by species preferring increasingly older habitat types with reclamation.
	Canada Lynx:
	• There is a loss of lynx habitat in the WLSA. The loss of effective habitat, along with sensory disturbances associated with the Project, will likely displace lynx to other more suitable undisturbed habitats located west, north and east of the WLSA. Canada lynx rarely use the area around the access road, so it is not expected to have significant effects on lynx movement.
	American Marten:
	• There will be a temporary, long-term loss of habitat for American marten. Reclamation of disturbed areas will occur throughout and after the life of the Project; however, American martens prefer mature to old-growth coniferous forests, which will take many decades to become re-established. East-west movements of American marten will likely be affects by the Project footprint since they tend to avoid open landscapes. The access road and coal conveyor will also likely affect marten movements. North-south marten movements along Blairmore and Gold Creeks should be relatively unaffected by Project development. With mitigation, Project effects on American marten habitat availability and movement in the WLSA are expected to be local in extent, extended in duration, continuous in frequency, reversible in the long-term, moderate in magnitude for habitat availability and low for movement (EIA, CR#9, Section 5.3.6.1, CIAR#42).
	Wildlife Residual Effects (EIA, CR#9, Table 5.3-26, CIAR#42):
	• Effects on habitat availability for trapped species (lynx, American marten) due to vegetation clearing and sensory disturbance (due to increased noise, odour, visual disturbance) are moderate magnitude, negative Project contribution, and reversible in the long-term.
	• Effects on wildlife movement for trapped species (lynx, American marten) due to construction and operation are low magnitude, and reversible in the long-term.
	• Effects on wildlife abundance for trapped species (lynx, American marten) in hunting locations due to is low magnitude, negative Project contribution and, for American marten, reversible in the long-term and for the Canada lynx, reversible in the short term.
	• Effects on wildlife mortality risk for trapped species (lynx, American marten) due to construction activities, vehicle collisions, and human-wildlife conflicts are low magnitude, frequency is occasional, and reversible in the short term.
	2. Use or access to trapping locations and harvesting methods:
	• Where Project construction and operations activities overlap with hunting and trapping locations, access to active mining areas may be limited until they are reclaimed and safe. Indigenous groups will continue to have access to hunting and trapping locations where safety is not compromised (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CEAR #89).
	• The Project's access restrictions within the mine permit area may also affect Indigenous groups' ability to use their preferred harvesting methods and seasonal rounds by altering the times of year that Indigenous groups have access to areas of interest for hunting/trapping within the mine permit area (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• Loss or disruption of traplines or trails used for trapping and loss of access to trapping locations due to the mine site and road closure during construction and operation. The residual effects on trails and travelways was assessed as moderate magnitude.
	• Increased noise, odour, and visual disturbance during construction and operation could affect use of locations and the experience of hunting within the vicinity of the Project (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89); residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42):
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change identified trapped species and habitat, change use or access to identified trapping locations, and change preferred harvesting methods. There will be residual effects on trapping for Piikani Nation due to reduction or loss of trapping opportunities and the change in trapping methods could affect the cultural and spiritual relationship between the Nation and their territory, as described below.
		Residual effects on trapping are characterized as:
		• Magnitude is low because there is predicted to be a change in the ability to trap in the Project area but it will not affect the ability to trap in the RSA. The Piikani Consultation Team has not identified an interest in trapping in the Project area (Addendum 10, Appendix 4.1-1, Section 5.3.1.2, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency because loss of trapping opportunities will be continuous throughout construction and operation.
		• Reversibility is characterized as reversible because reclamation is planned and expected to re-establish natural processes and ecosystems that support trapped species and access will be restored following the AMP.
		• Ecological and social context is unknown due to lack of information from Piikani Nation regarding sensitivity to changes to trapping. For the purposes of this evaluation it has been rated as sensitive in line with the conclusion for hunting.

Table 6.7-3a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Piikani Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Fishing	1. Fishing species and habitat:
	Westslope Cutthroat Trout (WSCT)
	• The physical footprint of surface water management infrastructure and open pits will cause permanent change to WSCT habitat. The loss of riparian and aquatic habitat will be reversed by gains achieved through implementing an Offsetting Plan approved by DFO. The magnitude of this effect will be moderate, the duration is long, the frequency will be continuous, however, reversibility is characterized as reversible in the long-term (Addendum 1, CR#6, Section 4.5, CIAR#44).
	• Changes in hydrology will cause alteration in WSCT aquatic habitat of Gold and Blairmore creeks. The alteration of habitat will be offset by gains achieved through implementing an Offsetting Plan approved by DFO. The magnitude of residual adverse effects will be moderate, the duration is extended, the frequency will be continuous, however, reversibility is characterized as reversible in the long-term (Addendum 1, CR#6, Section 4.5, CIAR#44).
	2. Use or access to fishing locations and harvesting methods:
	• Current access to the portions of the watercourses adjacent to Grassy Mountain is located on Benga private land. During construction and operation phases of the mine, this road will be closed to the general public, and alternate routes will need to be used to access and fish those portions of Blairmore and Gold Creeks (Addendum 8, Appendix A-1, Section 15.2.2.1.2, CIAR#89) which will be managed *via* the AMP.
	• Loss or disruption of trails for accessing fishing locations due to the mine site and road closure during construction and operation. The residual effects on trails and travelways was assessed as moderate magnitude.
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of fishing locations by Indigenous Nations and preferred harvesting method.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1 CIAR#42).
	  • Odour (mostly NO2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change use or access to identified fishing locations and change in preferred harvesting methods. There will be residual effects on fishing for Piikani Nation due to reduction in fishing opportunities, engagement in fishing, and fishing success during construction and operation due to loss of access of fishing locations and sensory disturbance within the mine permit area.
		Residual effects on fishing are characterized as:
		• Magnitude is moderate because there is predicted to be a change in the ability to fish for Piikani Nation in the Project area but it will not affect the ability to fish in the RSA. The Piikani Nation have advised that they have a fishing interest in the Project area and identified species, including Westslope Cutthroat trout, which Project effects were assessed as moderate magnitude. Members currently fish in streams and lakes near the reserve primarily for sport. These areas are outside of the Project LSA (Addendum 10, Appendix 4.1-1, Section 5.3.1.3 and Section 5.3.2.3 CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because access restrictions will apply beyond the life of the mine in some areas that may affect access to fishing locations.
		• Continuous frequency because loss of fishing opportunities will be continuous throughout construction and operation.
		• Reversibility is characterized as reversible because reclamation and offsetting is planned and expected to maintain fish populations and access will be restored following the AMP.
		• Ecological and social context is sensitive because the Piikani Nation have expressed a concern with changes to fish species and habitat, fishing locations and harvesting methods; therefore, change in fishing may be sensitive to disruption. The Piikani Nation noted that they began harvesting fish as a means of subsistence after the extirpation of bison (Addendum 10, Appendix 4.1-1, Section 4.3.2.3, CIAR#251).

Plant Gathering	1. Plant species and habitat:
	• The Project will result in loss of traditional use of vegetation within the vegetation local study area. Residual effects to TEK vegetation are local, long-term in duration, continuous, reversible and high magnitude. The Project will have a neutral contribution with respect to valued species and communities. After reclamation, the reclaimed land will support a range of communities with equivalent capabilities to those of the surrounding lands and that existing prior to Project development.
	• Residual adverse effects on vegetation were assessed as high magnitude for rare plants, community diversity, and TEK species, low magnitude for forest, and moderate for wetlands (EIA, CR#8, Section 4.0, CIAR#42).
	• Duration of effects on vegetation will be extended. Reclaimed land will require time to return the ecosystem to a condition that supports traditional use plants (EIA, CR#8, Section 4.1, CIAR#42).
	• Frequency of effects on vegetation, including rare plants and rare plant communities and traditional ecological knowledge, will be continuous through the operational phase of the project and cease only after reclamation is completed (EIA, CR#8, Section 4.0, CIAR#42).
	• Effects on vegetation are reversible in the long-term with the implementation of progressive reclamation (EIA, CR#8, Section 4.0, CIAR#42).
	2. Use or access to plant gathering locations and harvesting methods:
	• Loss or disruption of trails, loss of access to plant gathering locations, and loss of and preferred methods for plant gathering due to the mine site and access road. Residual effects on trails and travelways was assessed as moderate magnitude.
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of plant gathering locations by Indigenous Nations and preferred harvesting method.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42,).
	  • Odour (mostly NO2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO2 in the community (EIA, CR#1, Section 6.3 CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change identified plant gathering species and habitat, change use or access to identified harvesting locations, and change in preferred harvesting methods. There will be residual effects on plant gathering for Piikani Nation due to reduction in harvesting opportunities, engagement in plant gathering, and harvesting success during construction and operation due to loss of access of plant gathering locations and sensory disturbance within the mine permit area.
		Residual effects on plant gathering are characterized as:
		• Magnitude is moderate because there is predicted to be a change in the ability to gather plants for Piikani Nation in the Project area. The Piikani Nation have identified habitat and species for plant gathering in the Project LSA (Addendum 10, Appendix 4.1-1, Section 5.3.2.4, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine.
		• Reversibility is characterized as reversible because reclamation (of terrain, soil, vegetation) is planned and expected to re-establish natural processes and ecosystems that support traditional use plants (high density planting of disease-resistant whitebark pine seedlings will contribute to the successful re-establishment of the native ecosystem); and, access to plant gathering locations will be re-established after mine closure.
		• Ecological and social context is sensitive because engagement in plant gathering is sensitive to disruption and past and present activities have resulted in traditional land use assessed as high risk. The Piikani Nation have noted that in and around the Project area, there are plant species crucial to Piikani ceremony, healing practices, and spirituality that are not found at lower elevations where the majority of the community resides (Carlson *et al*. 2018; Addendum 10, JRP IR-4.6, CIAR#251).

Table 6.7-3a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Piikani Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Trails and Travelways	1. Use or access to trails and travelways:
	• Loss or disruption of trails and travelways due to the mine site and access road. The Project will have residual adverse effects on use of trails and travelways because the Project could result in loss of trails and travelways that are fully or partially within the mine permit boundary.
	• The Project footprint will be reclaimed to land use capability equivalent to pre-mining; however, it will not be accessible for use as trails and travelways during construction and operations. Access to areas around the Project will be possible using existing trails from Highway 40 to reach the area west of Blairmore Creek and Crown Land north of the Project and from either the north or the south along the Gold Creek. With the implementation of the AMP, potential residual effects will be further reduced as Benga will be providing access to adjacent privately owned Benga lands for traditional practices (Addendum 10, Appendix 4.1-1, Section 5.3.3.5, CIAR#251).
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of trails and travelways by Indigenous Nations.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	2. Features associated with trails and travelways:
	• Loss or disturbance to features associated with trails and travelways due to the mine site and access road.
	• Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42).
	• Residual adverse effects on access and utilities in the Lands and Resource Use VC was assessed as nil magnitude after reclamation (EIA, CR#10, CIAR#42).
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42).
	• Residual effects will extend beyond the mine footprint but limited to within the zone of influence (generally 1.5 km) for noise, visual disturbance, and effect on access (EIA, CR#2, CIAR#42).
	• The geographic extent of residual effects on historical resources and on land and resource use is characterized as local (EIA, CR#10, Section E, CIAR#42).
	• The frequency of impact on access and utilities in the lands and resource use is continuous (EIA, CR#2, CIAR#42).
	• The frequency of impact of noise and other disturbances to trail use will continue throughout the Project lifespan (EIA, CR#2, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change use or access and change preferred trails and travelways. There will be residual effects on trails and travelways for Piikani Nation due to restriction in use or access, and engagement with features associates with trails and travelways during construction and operation due to loss of access to trails and travelways locations, sensory disturbance, and change in use within the mine permit area.
		Residual effects on trails and travelways is characterized as:
		• Magnitude is moderate because there is predicted to be a change in the ability to use or access trails and travelways for Piikani Nation as the Project will intersect or be in proximity to territory that is identified for trails and travelways by the Piikani Nation and cultural heritage sites associated with these trails. However, it will not affect the ability to use trails and travelways in the RSA (Addendum 10, Appendix 4.1-1, Section 5.3.2.5, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine.
		• Non-reversible where trails and travelways are lost because when a trail is inaccessible it will not be maintained or used, resulting in the potential loss of the knowledge of or loss of the physical trail or travelway.
		• Ecological and social context is resilient because, although Piikani Nation identified trails and travelways within the LSA (Addendum 10, Appendix 4.1-1, Section 5.3.1.5 and Section 5.3.2.5, CIAR#251), they can use alternative routes to travel between cultural and spiritual sites and resources within their traditional territory. Therefore, Piikani Nation use and access to trails and travelways is not sensitive to disruption from the Project.

Cultural and Spiritual Values	1. Use of and access to sacred important sites with cultural or spiritual value: • Residual adverse effects on access and utilities in the Lands and Resource Use VC was assessed as nil magnitude (EIA, CR#10, CIAR#42). • Loss or disruption of trails to important sites due to the mine site and access road. • Loss of hunting, trapping, fishing, and plant gathering opportunities. The residual effects, as seen above, on hunting, trapping and plant gathering were assessed as moderate magnitude. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect use and enjoyment of culturally and spiritually important sites. Increased noise levels extend 1.5 km from the Project (EIA, CR#2, CIAR#42). Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). • Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42). 2. Experience of engaging with sites of cultural or spiritual value: • Loss or disturbance to important sites due to the mine site and access road. • Loss of experience in hunting, trapping, fishing, and plant gathering, which could affect the cultural and spiritual relationships with the resource. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect enjoyment or experience of using culturally and spiritually important sites. 3. Cultural values associated with sites/features: • Loss of hunting, trapping, fishing, and plant gathering opportunities, which could affect intergenerational teaching of traditional practices, and result in loss of cultural identity, sense of place, and human health/well-being. • Loss of access to sites/features due to construction and operation activities. • Loss of or damage to unique sites and special features as a result of clearing and construction activities. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect enjoyment or experience of engaging with the sites/features of cultural or spiritual value. In summary, effects on linked VCs will act synergistically to change use or access to sites with cultural or spiritual value, change the experience of using these sites, and change the cultural value associated with sites and features. There will be residual effects on cultural and spiritual values for Piikani Nation during construction and operation due to loss of or access to culturally or spiritually important sites and sensory disturbance within the mine permit area.	Residual effect on cultural and spiritual values is characterized as: • Magnitude is moderate because there is predicted to be a change in the values ad experience associated with cultural or spiritual sites for the Piikani Nation through direct disturbance and change in noise and air quality. However, this will not affect the ability to use or access sites associated with cultural and spiritual values in the RSA. The Piikani Nation have stories that are connected with Grassy Mountain such as cultural and spiritual knowledge, cultural practices, and TEK, which is passed down in areas throughout their territory (Addendum 10, Appendix 4.1-1, Section 5.3.1.6, CIAR#251). In addition to a direct change to cultural and spiritual values and associated features, it is expected that the visual and sensory experience of visiting these locations will also change. The Project will cause a certain change in noise, dust and a visual disturbance (Addendum 10, Appendix 4.1-1, Section 5.3.2.6, CIAR#251). The Piikani Nation has also stated the Project footprint would destroy documented and undocumented sites of cultural and spiritual significance; however, the Nation did not identify specific sites (Addendum 10, Appendix 4.1-1, Section 5.3.2.6, CIAR#251). • Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA. • Long-term duration because the loss of experience in hunting, trapping, fishing, and plant gathering could affect the long-term cultural and spiritual relationships between Indigenous groups and their resources and territory. Change in land use and access will extend beyond the Project lifespan. • Continuous frequency due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine. • Non-reversible because loss of cultural and spiritual sites and experience in engaging in land use could result in loss of the knowledge of cultural and spiritual values. • Ecological and social context is sensitive because loss of engagement in land use affects cultural identity, human well-being and relationships, and intergenerational transfer of knowledge.

Table 6.7-3a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Piikani Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC
Physical and Cultural Heritage	1. Physical and cultural heritage: • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities. • The geographic extent of residual effects on historical resources is local (EIA, Section E, CIAR#42). 2. Access to physical and cultural heritage: • Loss or disruption of trails to unique sites and special features associated with physical or cultural heritage due to the mine site and access road. • The magnitude of effects on trails and travelways was characterized as moderate. 3. Cultural value and importance associated with physical and cultural heritage: • Increase in noise, odour, and visual disturbance during construction and operation could result in reduced engagement with the sites/features of cultural value. • Magnitude was assessed as high for TEK plant species (EIA, CR#8, CIAR#42), whereas magnitude is low to moderate for hunted and trapped wildlife (EIA, CR#9, CIAR#42). • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities. • The magnitude of effects on cultural and spiritual values was characterized as moderate. 4. Relationship with physical and cultural heritage: • Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42) and access and utilities in the Lands and Resource Use VC was assessed as nil magnitude (EIA, CR#10, CIAR#42), but for those VCs that affect the relationships with physical and cultural heritage (*e.g.,* air quality, noise, plant gathering, hunting and trapping), magnitude is assessed as high for odour and low to moderate for emissions including dust (EIA, CR#1 CIAR#42), and moderate for hunting, trapping and plant gathering. • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities could result in loss of relationship with heritage. • Loss of hunting, trapping, fishing, and plant gathering opportunities due to construction and operation and access restrictions could result in loss of relationship with wildlife and cultural practices. • Increase in noise, odour, and visual disturbance during construction and operation could result in reduced engagement with the sites/features associated with physical or cultural heritage. In summary, effects on linked VCs will act synergistically to change use or access to physical and cultural heritage, change the value and importance, and change the relationship the Káinai Nation have with these sites. There will be residual effects on Indigenous physical and cultural heritage for Piikani Nation during construction and operation due to loss of access and sensory disturbance within the mine permit area.	Residual effects on Indigenous Physical and cultural heritage are characterized as: • Magnitude is moderate because there is predicted to be a change in the access to and value of physical and cultural heritage for the Piikani Nation. The Piikani Nation identified four cultural heritage sites; however, the specific locations of these sites were not provided to Benga. Therefore, it is anticipated that the Project may affect access and use of these sites (Addendum 10, Appendix 4.1-1, Section 5.3.2.5, CIAR#251). • Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA. • Long-term duration because disturbance to or loss of unique sites and features will extend beyond the Project lifespan. • Regular frequency because disturbance to unique sites and features will occur during construction and operation activities whenever sites or features are discovered. • Non-reversible because loss of heritage sites and features and experience in engaging in land use could result in loss of the knowledge of cultural heritage. • Ecological and social context is sensitive because loss of heritage sites and features or loss of engagement with physical and cultural heritage affects cultural identity, human well-being and relationships, and intergenerational transfer of knowledge. The Piikani Nation noted that historic mining within their territory had disturbed the “few remnants of Piikani presence” on the land (Addendum 10, JRP IR-4.6, CIAR#251).

In summary, the residual effects characterization has not changed from that already provided. As such, the summary Table 5.4.4-1 from *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups* (Appendix 4.1-1, Addendum 10, CIAR#251) is provided below, as Table 6.7-3b.

Table 6.7-3b Summary of Residual Effects to the Piikani Nation [Source: Table 5.4.4-1, *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups* Appendix 4.1-1, Addendum 10, CIAR#251]

Valued Component	Magnitude	Geographic Extent	Duration	Frequency	Reversibility	Ecological and Social Context	Significance
Hunting and Trapping	Moderate	Local	Long-term	Continuous	Reversible	Sensitive	Not significant
Fishing	Moderate	Local	Long-term	Continuous	Reversible	Sensitive	Not significant
Plant Gathering	Moderate	Local	Long-term	Continuous	Reversible	Sensitive	Not significant
Trails and Travelways	Moderate	Local	Long-term	Continuous	Not reversible	Resilient	Not significant
Cultural and Spiritual Values	Moderate	Local	Long-term	Continuous	Not Reversible	Sensitive	Not significant
Indigenous Physical and Cultural Heritage	Moderate	Local	Long-term	Regular	Not reversible	Sensitive	Not significant

Description and Characterization of Residual Effects on the Siksika Nation

The description and characterization of residual effects on the Siksika Nation are found below in Table 6.7-4a. A summary table of this characterization was provided as Table 6.4.4-1 (Appendix 4.1-1: *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups*, Addendum 10, CIAR#251), and is copied below for the convenience of the reader, as Table 6.7-4b.

Table 6.7-4a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Siksika Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Hunting	1. Hunted species and habitat:
	The Project will have temporary effects on land access for traditional resource use and on the distribution and abundance of species hunted for traditional purposes. Species preferring recently disturbed and young habitats are expected to return first, followed by species preferring increasingly older habitat types with reclamation.
	Moose and Elk:
	• Suitable moose and elk habitat will decline initially but is predicted to be more abundant than baseline levels by end of mine due, in part, to reclamation of legacy mine sites that overlap the Project footprint (EIA, CR#9, Section 5.6.2.1, CIAR#42).
	• The changes in abundance of moose and elk year-round in the WLSA are expected to follow a similar pattern as individuals of both species will be displaced into adjacent habitats.
	Grizzly Bear:
	• Highly suitable grizzly bear habitat in the WLSA will decrease initially during the construction and operation phases and then increase throughout the duration of progressive reclamation. Mortality risk also increases with Project development but then decreases with progressive reclamation. With reclamation, the Project footprint is expected to offer more suitable habitat (dietary resources) and lower mortality risk than under baseline conditions, which are anticipated to allow for an increase in the size of the grizzly bear population that the local area can support.
	Wildlife Residual Effects (EIA, CR#9, Table 5.3-26, CIAR#42):
	• Effects on habitat availability for hunted species (moose, elk, grizzly bear) due to vegetation clearing and sensory disturbance (due to increased noise, odour, visual disturbance) are low magnitude, positive Project contribution, and reversible in the long-term.
	• Effects on wildlife movement for hunted species (moose, elk, grizzly bear) due to construction and operation are low magnitude, and reversible in the long-term.
	• Effects on wildlife abundance for hunted species (moose, elk, grizzly bear) in hunting location is low magnitude, positive Project contribution for elk and grizzly bear, neutral Project contribution for moose, and reversible in the long-term.
	• Effects on wildlife mortality risk for hunted species due to construction activities, vehicle collisions, and human-wildlife conflicts are low magnitude, frequency is occasional, and reversible in the long-term. With the Access Control Policy and firearm prohibition by Project personnel, poaching and non-Indigenous hunting of moose, elk, and grizzly bear will decline in the WLSA during the life of mine and may result in increased abundance of moose, elk, and grizzly bear in the areas accessible by Indigenous groups (EIA, CR#9, Section 5.6.2.1, CIAR#42).
	• A screening level wildlife risk assessment was conducted, the results of which indicate that there is no potential risk of adverse effects associated with Project emissions on the health of wildlife in the study areas (Addendum 10, Appendix 4.9-1, Section 8.0, Updated Human Health and Wildlife Screening Risk Assessment, CIAR#251).
	• The wildlife risk assessment was amended to include an evaluation of water-based exposure pathways (both groundwater and surface water) and the results presented for Blairmore Creek, Gold Creek and the Oldman Reservoir were not considered to be indicative of adverse effects (Addendum 11, JRP IR-6.28). For the proposed end pit lake (EPL) (at closure), the results of the risk assessment are not considered indicative of a human health concern; however, management considerations of the EPL are warranted and actual measured concentrations at the time of EPL creation should be used to revisit predicted effects (Addendum 11, JRP IR-6.27). The assessment includes an Indigenous-specific conceptual model, which describes source-pathway linkages between the Project and Indigenous use of all aquatic pathways including the end pit lake, Blairmore and Gold Creeks, the Crowsnest River and the Oldman Reservoir in the post closure landscape.
	2. Use or access to hunting locations and harvesting methods:
	• Where Project construction and operations activities overlap with hunting locations, access to active mining areas may be limited until they are reclaimed and safe. Indigenous groups will continue to have access to hunting and trapping locations where safety is not compromised (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• The Project's access restrictions within the mine permit area may also affect Indigenous groups' ability to use their preferred harvesting methods and seasonal rounds by altering the times of year that Indigenous groups have access to areas of interest for hunting within the mine permit area (Addendum 8, Appendix A-1, Section 15.2.1.1.2 CIAR#89).
	• The residual effects on trails and travelways was assessed as moderate magnitude.
	• Increased noise, odour, and visual disturbance during construction and operation could affect use of locations and the experience of hunting within the vicinity of the Project (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89); residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42):
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	• Where Indigenous groups utilize firearms for hunting, the Project's firearms restriction policy would affect their ability to use that harvesting method within the mine footprint. Alternate hunting methods may be possible in parts of the mine footprint that have not yet been disturbed or which have been reclaimed under the AMP (Addendum 8, Appendix A-1, Section 15.2.1.1.3, CIAR#89).
	In summary, effects on linked VCs will act synergistically to change identified hunted species and habitat, change use or access to identified hunting locations, and change preferred harvesting methods. There will be residual effects on hunting for Siksika Nation due to reduction in hunting opportunities, engagement in hunting, and hunting success during construction and operation due to loss of access of hunting locations, sensory disturbance, and change in wildlife use within the mine permit area.
		Residual effects on hunting are characterized as:
		• Magnitude is moderate because there is predicted to be a change in the ability to hunt for the Siksika Nation in the area, but this does not change the ability to hunt in the RSA. There are no specific hunting sites identified by the Siksika Nation in the Project LSA; however, Project activities will intersect or be in proximity to habitat and species that are identified for hunting by the Siksika Nation. The Siksika Nation continues to hunt throughout their traditional territory (Addendum 10, Appendix 4.1-1, Section 6.3.2.1, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency because loss of hunting opportunities will be continuous throughout construction and operation.
		• Reversibility is characterized as reversible because reclamation is planned and expected to re-establish natural processes and ecosystems that support hunted species and access will be restored following the AMP.
		• Ecological and social context is sensitive because Siksika Nation have noted a decline in the number of species, including elk and deer, limited accessibility due to private land ownership, non-traditional land use activities, and community members avoidance due to concerns about contamination, safety and overall negative experiences on the land. These issues have placed hunting at moderate to high risk and hunted species that occur in the Project area remain important sources of food for members of Siksika Nation (Carlson *et al*. 2018; Addendum 10, JRP IR-4.6, CIAR#251).

Table 6.7-4a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Siksika Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Trapping	1. Trapped species and habitat:
	The Project will have temporary effects on land access for traditional resource use and on the distribution and abundance of species trapped for traditional purposes.
	Species preferring recently disturbed and young habitats are expected to return first, followed by species preferring increasingly older habitat types with reclamation.
	Canada Lynx:
	• There is a loss of lynx habitat in the WLSA. The loss of effective habitat, along with sensory disturbances associated with the Project, will likely displace lynx to other more suitable undisturbed habitats located west, north and east of the WLSA. Canada lynx rarely use the area around the access road, so it is not expected to have significant effects on lynx movement.
	American Marten:
	• There will be a temporary, long-term loss of habitat for American marten. Reclamation of disturbed areas will occur throughout and after the life of the Project; however, American martens prefer mature to old-growth coniferous forests, which will take many decades to become re-established. East-west movements of American marten will likely be affects by the Project footprint since they tend to avoid open landscapes. The access road and coal conveyor will also likely affect marten movements. North-south marten movements along Blairmore and Gold Creeks should be relatively unaffected by Project development. With mitigation, Project effects on American marten habitat availability and movement in the WLSA are expected to be local in extent, extended in duration, continuous in frequency, reversible in the long-term, moderate in magnitude for habitat availability and low for movement (EIA, CR#9, Section 5.3.6.1, CIAR#42).
	Wildlife Residual Effects (EIA, CR#9, Table 5.3-26, CIAR#42):
	• Effects on habitat availability for trapped species (lynx, American marten) due to vegetation clearing and sensory disturbance (due to increased noise, odour, visual disturbance) are moderate magnitude, negative Project contribution, and reversible in the long-term.
	• Effects on wildlife movement for trapped species (lynx, American marten) due to construction and operation are low magnitude, and reversible in the long-term.
	• Effects on wildlife abundance for trapped species (lynx, American marten) in hunting locations due to is low magnitude, negative Project contribution and, for American marten, reversible in the long-term and for the Canada lynx, reversible in the short term.
	• Effects on wildlife mortality risk for trapped species (lynx, American marten) due to construction activities, vehicle collisions, and human-wildlife conflicts are low magnitude, frequency is occasional, and reversible in the short term.
	2. Use or access to trapping locations and harvesting methods:
	• Where Project construction and operations activities overlap with hunting and trapping locations, access to active mining areas may be limited until they are reclaimed and safe. Indigenous groups will continue to have access to hunting and trapping locations where safety is not compromised (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CEAR #89).
	• The Project's access restrictions within the mine permit area may also affect Indigenous groups' ability to use their preferred harvesting methods and seasonal rounds by altering the times of year that Indigenous groups have access to areas of interest for hunting/trapping within the mine permit area (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• Loss or disruption of traplines or trails used for trapping and loss of access to trapping locations due to the mine site and road closure during construction and operation. The residual effects on trails and travelways was assessed as moderate magnitude.
	• Increased noise, odour, and visual disturbance during construction and operation could affect use of locations and the experience of hunting within the vicinity of the Project (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89); residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42):
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change identified trapped species and habitat, change use or access to identified trapping locations, and change preferred harvesting methods. There will be residual effects on trapping for Siksika Nation due reduction or loss of trapping opportunities and the change in trapping methods could affect the cultural and spiritual relationship between the Nation and their territory, which is addressed below.
		Residual effects on trapping are characterized as:
		• Magnitude is low because there is predicted to be a change in the ability to trap in the Project area, it will not affect the ability to trap in the RSA. The Siksika did not identify active trapping within the LSA (Addendum 10, Appendix 4.1-1, Section 6.3.2.2, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency because loss of trapping opportunities will be continuous throughout construction and operation.
		• Reversibility is characterized as reversible because reclamation is planned and expected to re-establish natural processes and ecosystems that support trapped species and access will be restored following the AMP.
		• Ecological and social context is sensitive because Siksika Nation have noted a decline in the number of species limited accessibility due to private land ownership, non-traditional land use activities, and community members avoidance due to concerns about contamination, safety and overall negative experiences on the land. These issues have placed trapping at moderate to high risk (Carlson *et al*. 2018; Addendum 10, JRP IR-4.6, CIAR#251).

Table 6.7-4a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Siksika Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Fishing	1. Fishing species and habitat:
	Westslope Cutthroat Trout (WSCT)
	• The physical footprint of surface water management infrastructure and open pits will cause permanent change to WSCT habitat. The loss of riparian and aquatic habitat will be reversed by gains achieved through implementing an Offsetting Plan approved by DFO. The magnitude of this effect will be moderate, the duration is long, the frequency will be continuous, however, reversibility is characterized as reversible in the long-term (Addendum 1, CR#6, Section 4.5, CIAR#44).
	• Changes in hydrology will cause alteration in WSCT aquatic habitat of Gold and Blairmore creeks. The alteration of habitat will be offset by gains achieved through implementing an Offsetting Plan approved by DFO. The magnitude of residual adverse effects will be moderate, the duration is extended, the frequency will be continuous, however, reversibility is characterized as reversible in the long-term (Addendum 1, CR#6, Section 4.5, CIAR#44).
	2. Use or access to fishing locations and harvesting methods:
	• Current access to the portions of the watercourses adjacent to Grassy Mountain is located on Benga private land. During construction and operation phases of the mine, this road will be closed to the general public, and alternate routes will need to be used to access and fish those portions of Blairmore and Gold Creeks (Addendum 8, Appendix A-1, Section 15.2.2.1.2, CIAR#89) which will be managed *via* the AMP.
	• Loss or disruption of trails for accessing fishing locations due to the mine site and road closure during construction and operation. The residual effects on trails and travelways was assessed as moderate magnitude.
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of fishing locations by Indigenous Nations and preferred harvesting method.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1 CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to use or access to identified fishing locations, and change in preferred harvesting methods. There will be residual effects on fishing for Siksika Nation due to reduction in fishing opportunities, engagement in fishing, and fishing success during construction and operation due to loss of access to fishing locations and sensory disturbance within the mine permit area.
		Residual effects on fishing are characterized as:
		• Magnitude is moderate because there is predicted to be a change in the ability to fish for Siksika Nation as they have advised that they have fishing interests and identified species in the Project area (Addendum 10, Appendix 4.1-1, Section 6.3.2.3, CIAR#251). However, this will not affect the ability to fish in the RSA.
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because access restrictions will apply beyond the life of the mine in some areas that may affect access to fishing locations.
		• Continuous frequency because loss of fishing opportunities will be continuous throughout construction and operation.
		• Reversibility is characterized as reversible because reclamation and offsetting is planned and expected to maintain fish populations and access will be restored following the AMP.
		• Ecological and social context is sensitive because Siksika Nation noted that past present activities have substantially reduced fishing opportunities in the area (Carlson *et al*. 2018; Addendum 10, JRP IR-4.6, CIAR#251).

Plant Gathering	1. Plant species and habitat:
	• The Project will result in loss of traditional use of vegetation within the vegetation local study area. Residual effects to TEK vegetation are local, long-term in duration, continuous, reversible and high magnitude. The Project will have a neutral contribution with respect to valued species and communities. After reclamation, the reclaimed land will support a range of communities with equivalent capabilities to those of the surrounding lands and that existing prior to Project development.
	• Residual adverse effects on vegetation were assessed as high magnitude for rare plants, community diversity, and TEK species, low magnitude for forest, and moderate for wetlands (EIA, CR#8, Section 4.0, CIAR#42).
	• Duration of effects on vegetation will be extended. Reclaimed land will require time to return the ecosystem to a condition that supports traditional use plants (EIA, CR#8, Section 4.1, CIAR#42).
	• Frequency of effects on vegetation, including rare plants and rare plant communities and traditional ecological knowledge, will be continuous through the operational phase of the project and cease only after reclamation is completed (EIA, CR#8, Section 4.0, CIAR#42).
	• Effects on vegetation are reversible in the long-term with the implementation of progressive reclamation (EIA, CR#8, Section 4.0, CIAR#42).
	2. Use or access to plant gathering locations and harvesting methods:
	• Loss or disruption of trails, loss of access to plant gathering locations, and loss of and preferred methods for plant gathering due to the mine site and access road. Residual effects on trails and travelways was assessed as moderate magnitude.
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of plant gathering locations by Indigenous Nations and preferred harvesting method.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO2 in the community (EIA, CR#1, Section 6.3 CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change identified plant gathering species and habitat, change use or access to identified harvesting locations, and change in preferred harvesting methods. There will be residual effects on plant gathering for Siksika Nation due to reduction in harvesting opportunities, engagement in plant gathering, and harvesting success during construction and operation due to loss of access to plant gathering locations and sensory disturbance within the mine permit area.
		Residual effects on plant gathering are characterized as:
		• Magnitude is moderate because there is predicted to be a change in the ability to gather plants for the Siksika Nation in the Project Area. The Siksika Nation have identified habitat and species for plant gathering in the Project LSA, including areas specific for harvesting culturally important plants species. The Nation is concerned that they may lose a source of yellow ochre which is critical to ceremonial practices (Addendum 10, Appendix 4.1-1, Section 6.3.2.4, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine.
		• Reversibility is characterized as reversible because reclamation (of terrain, soil, vegetation) is planned and expected to re-establish natural processes and ecosystems that support traditional use plants (high density planting of disease-resistant whitebark pine seedlings will contribute to the successful re-establishment of the native ecosystem); and, access to plant gathering locations will be re-established after mine closure.
		• Ecological and social context is sensitive because engagement in plant gathering is sensitive to disruption and past and present activities have resulted in traditional land use at high risk (Carlson *et al*. 2018; Addendum 10, JRP IR-4.6, CIAR#251).

Table 6.7-4a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Siksika Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Trails and Travelways	1. Use of or access to trails and travelways:
	• Loss or disruption of trails and travelways due to the mine site and access road. The Project will have residual adverse effects on use of trails and travelways because the Project could result in loss of trails and travelways that are fully or partially within the mine permit boundary.
	• The Project footprint will be reclaimed to land use capability equivalent to pre-mining; however, it will not be accessible for use as trails and travelways during construction and operations. Access to areas around the Project will be possible using existing trails from Highway 40 to reach the area west of Blairmore Creek and Crown Land north of the Project and from either the north or the south along the Gold Creek. With the implementation of the AMP, potential residual effects will be further reduced as Benga will be providing access to adjacent privately owned Benga lands for traditional practices (Addendum 10, Appendix 4.1-1, Section 6.3.3.5, CIAR#251).
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of trails and travelways by Indigenous Nations.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	2. Features associated with trails and travelways:
	• Loss or disturbance to features associated with trails and travelways due to the mine site and access road.
	• Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42).
	• Residual adverse effects on access and utilities in the Lands and Resource Use VC was assessed as nil magnitude after reclamation (EIA, CR#10, CIAR#42).
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42).
	• Residual effects will extend beyond the mine footprint but limited to within the zone of influence (generally 1.5 km) for noise, visual disturbance, and effect on access (EIA, CR#2, CIAR#42).
	• The geographic extent of residual effects on historical resources and on land and resource use is characterized as local (EIA, CR#10, Section E, CIAR#42).
	• The frequency of impact on access and utilities in the lands and resource use is continuous (EIA, CR#2, CIAR#42).
	• The frequency of impact of noise and other disturbances to trail use will continue throughout the Project lifespan (EIA, CR#2, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change use or access and change preferred trails and travelways. There will be residual effects on trails and travelways for Siksika Nation due to restriction in use or access, and engagement with features associated with trails and travelways during construction and operation due to loss of or access to trails and travelways locations, sensory disturbance, and change in use within the mine permit area.
		Residual effects on trails and travelways is characterized as:
		• Magnitude is moderate because there is predicted to be a change in the ability to use or access trails and travelways for Siksika Nation as they are fully or partially within the mine permit boundary. However, it will not affect the ability to use trails and travelways in the RSA (Addendum 10, Appendix 4.1-1, Section 6.3.2.5, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency during due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine.
		• Non-reversible where trails and travelways are lost because when a trail is inaccessible it will not be maintained or used, resulting in the potential loss of the knowledge of or loss of the physical trail or travelway.
		• Ecological and social context is resilient because the Siksika Nation can use alternative routes to travel between cultural and spiritual sites and resources within their traditional territory (Addendum 10, Appendix 4.1-1, Section 6.3.1.5, CIAR#251). Therefore, Siksika Nation use and access to trails and travelways is not sensitive to disruption from the Project.

Cultural and Spiritual Values	1. Use and access to sacred important sites with cultural or spiritual value: • Residual adverse effects on access and utilities in the Lands and Resource Use VC was assessed as nil magnitude (EIA, CR#10, CIAR#42). • Loss or disruption of trails to important sites due to the mine site and access road. • Loss of hunting, trapping, fishing, and plant gathering opportunities. The residual effects, as seen above, on hunting, trapping and plant gathering were assessed as moderate magnitude. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect use and enjoyment of culturally and spiritually important sites. Increased noise levels extend 1.5 km from the Project (EIA, CR#2, CIAR#42). Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). • Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42). 2. Experience of engaging with sites of cultural or spiritual value: • Loss or disturbance to important sites due to the mine site and access road. • Loss of experience in hunting, trapping, fishing, and plant gathering, which could affect the cultural and spiritual relationships with the resource. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect enjoyment or experience of using culturally and spiritually important sites. 3. Cultural values associated with sites/features • Loss of hunting, trapping, fishing, and plant gathering opportunities, which could affect intergenerational teaching of traditional practices, and result in loss of cultural identity, sense of place, and human health/well-being. • Loss of access to sites/features due to construction and operation activities. • Loss of or damage to unique sites and special features as a result of clearing and construction activities. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect enjoyment or experience of engaging with the sites/features of cultural or spiritual value. In summary, effects on linked VCs will act synergistically to change use or access to sites with cultural or spiritual value, change the experience of using these sites, and change the cultural value associated with sites and features. There will be residual effects on cultural and spiritual values for Siksika Nation during construction and operation due to loss of access to culturally or spiritually important sites and sensory disturbance within the mine permit area.	Residual effect on cultural and spiritual values is characterized as: • Magnitude is moderate because there is predicted to be a change in the values ad experience associated with cultural or spiritual sites for the Siksika Nation through direct disturbance and change in noise and air quality (Addendum 10, Appendix 4.1-1, Section 5.3.2.6, CIAR#251). However, this will not affect the ability to use or access sites associated with cultural and spiritual values in the RSA. The Siksika Nation has expressed concern for continuing loss of cultural and spiritual values not only through hunting, trapping, fishing and plant gathering, but also through changes to the landscape and sacred and ceremonial sites. It is expected that the visual and sensory experience of visiting these locations will also change (Addendum 10, Appendix 4.1-1, Section 6.3.2.6, CIAR#251). • Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA. • Long-term duration because the loss of experience in hunting, trapping, fishing, and plant gathering could affect the long-term cultural and spiritual relationships between Indigenous groups and their resources and territory. Change in land use and access will extend beyond the Project lifespan. • Continuous frequency during due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine. • Non-reversible because loss of cultural and spiritual sites and experience in engaging in land use could result in loss of the knowledge of cultural and spiritual values. • Ecological and social context is sensitive because loss of engagement in land use affects cultural identity, human well-being and relationships, and intergenerational transfer of knowledge.

Table 6.7-4a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Siksika Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC
Physical and Cultural Heritage	1. Physical and cultural heritage: • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities. • The geographic extent of residual effects on historical resources is local (EIA, Section E, CIAR#42). 2. Access to physical and cultural heritage: • Loss or disruption of trails to unique sites and special features associated with physical or cultural heritage due to the mine site and access road. • The magnitude of effects on trails and travelways was characterized as moderate. 3. Cultural value and importance associated with physical and cultural heritage: • Increase in noise, odour, and visual disturbance during construction and operation could result in reduced engagement with the sites/features of cultural value. • Magnitude was assessed as high for TEK plant species (EIA, CR#8, CIAR#42) whereas magnitude is low to moderate for hunted and trapped wildlife (EIA, CR#9, CEAR #42). • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities. • The magnitude of effects on cultural and spiritual values was characterized as moderate. 4. Relationship with physical and cultural heritage: • Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42) and access and utilities in the Lands and Resource Use VC was assessed as nil magnitude (EIA, CR#10, CIAR#42), but for those VCs that affect the relationships with physical and cultural heritage (*e.g.,* air quality, noise, plant gathering, hunting and trapping), magnitude is assessed as high for odour and low to moderate for emissions including dust (EIA, CR#1 CIAR#42), and moderate for hunting, trapping and plant gathering. • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities could result in loss of relationship with heritage. • Loss of hunting, trapping, fishing, and plant gathering opportunities due to construction and operation and access restrictions could result in loss of relationship with wildlife and cultural practices. • Increase in noise, odour, and visual disturbance during construction and operation could result in reduced engagement with the sites/features associated with physical or cultural heritage. In summary, effects on linked VCs will act synergistically to change use or access to physical and cultural heritage, change the value and importance and the relationship the Siksika Nation have with these sites. There will be residual effects on Indigenous physical and cultural heritage for Siksika Nation during construction and operation due to loss of access and sensory disturbance within the mine permit area.	Residual effects on Indigenous physical and cultural heritage are characterized as: • Magnitude is moderate because there is predicted to be a change in the access to and value of physical and cultural heritage for the Siksika Nation in the Project area. The Siksika Nation have identified cultural and spiritual sites on Grassy Mountain (Addendum 10, Appendix 4.1-1, Section 6.3.2.6, CIAR#251). • Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA. • Long-term duration because disturbance to or loss of unique sites and features will extend beyond the Project lifespan. • Regular frequency because disturbance to unique sites and features will occur during construction and operation activities whenever sites or features are discovered. • Non-reversible because loss of heritage sites and features and experience in engaging in heritage sites could result in loss of the knowledge of cultural heritage. • Ecological and social context is sensitive because loss of heritage sites and features or loss of engagement with physical and cultural heritage could affect cultural identity, human well-being, and intergenerational transfer of knowledge.

In summary, the residual effects characterization has not changed greatly from that already provided. The only change from the previous effects characterization is that the magnitude for trapping has been corrected from moderate to low for the reasons explained above. As such, the summary Table 6.4.4-1 from *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups* (Appendix 4.1-1, Addendum 10, CIAR#251) is provided below as Table 6.7-4b, with this one correction.

Table 6.7-4b Summary of Residual Effects to the Siksika Nation [Source: Table 6.4.4-1, *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups* Appendix 4.1-1, Addendum 10, CIAR#251]

Valued Components	Magnitude	Geographic Extent	Duration	Frequency	Reversibility	Ecological and Social Context	Significance
Hunting and Trapping	Moderate Low (Trapping)	Local	Long-term	Continuous	Reversible	Sensitive	Not significant
Fishing	Moderate	Local	Long-term	Continuous	Reversible	Sensitive	Not significant
Plant Gathering	Moderate	Local	Long-term	Continuous	Reversible	Sensitive	Not significant
Trails and Travelways	Moderate	Local	Long-term	Continuous	Not Reversible where trails and travelways are lost	Resilient	Not significant
Cultural and Spiritual Values	Moderate	Local	Long-term	Continuous	Not Reversible	Sensitive	Not significant
Physical and Cultural Heritage	Moderate	Local	Long-term	Regular	Not Reversible	Sensitive	Not significant

Description and Characterization of Residual Effects on the Stoney Nakoda Nation

The description and characterization of residual effects on the Stoney Nakoda Nation are found below in Table 6.7-5a. A summary table of this characterization was provided as Table 7.4.4-1 (Appendix 4.1-1: *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups*, Addendum 10, CIAR#251), and is copied below for the convenience of the reader as Table 6.7-5b.

Table 6.7-5a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Stoney Nakoda Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Hunting	1. Hunted species and habitat:
	The Project will have temporary effects on land access for traditional resource use and on the distribution and abundance of species hunted for traditional purposes.
	Species preferring recently disturbed and young habitats are expected to return first, followed by species preferring increasingly older habitat types with reclamation.
	Moose and Elk:
	• Suitable moose and elk habitat will decline initially but is predicted to be more abundant than baseline levels by end of mine due, in part, to reclamation of legacy mine sites that overlap the Project footprint (EIA, CR#9, Section 5.6.2.1, CIAR#42).
	• The changes in abundance of moose and elk year-round in the WLSA are expected to follow a similar pattern as individuals of both species will be displaced into adjacent habitats.
	Grizzly Bear:
	• Highly suitable grizzly bear habitat in the WLSA will decrease initially during the construction and operation phases and then increase throughout the duration of progressive reclamation. Mortality risk also increases with Project development but then decreases with progressive reclamation. With reclamation, the Project footprint is expected to offer more suitable habitat (dietary resources) and lower mortality risk than under baseline conditions, which are anticipated to allow for an increase in the size of the grizzly bear population that the local area can support.
	Wildlife Residual Effects (EIA, CR#9, Table 5.3-26, CIAR#42):
	• Effects on habitat availability for hunted species (moose, elk, grizzly bear) due to vegetation clearing and sensory disturbance (due to increased noise, odour, visual disturbance) are low magnitude, positive Project contribution, and reversible in the long-term.
	• Effects on wildlife movement for hunted species (moose, elk, grizzly bear) due to construction and operation are low magnitude, and reversible in the long-term.
	• Effects on wildlife abundance for hunted species (moose, elk, grizzly bear) in hunting location is low magnitude, positive Project contribution for elk and grizzly bear, neutral Project contribution for moose, and reversible in the long-term.
	• Effects on wildlife mortality risk for hunted species due to construction activities, vehicle collisions, and human-wildlife conflicts are low magnitude, frequency is occasional, and reversible in the long-term. With the Access Control Policy and firearm prohibition by Project personnel, poaching and non-Indigenous hunting of moose, elk, and grizzly bear will decline in the WLSA during the life of mine and may result in increased abundance of moose, elk, and grizzly bear in the areas accessible by Indigenous groups (EIA, CR#9, Section 5.6.2.1, CIAR#42).
	• A screening level wildlife risk assessment was conducted, the results of which indicate that there is no potential risk of adverse effects associated with Project emissions on the health of wildlife in the study areas (Addendum 10, Appendix 4.9-1, Section 8.0, Updated Human Health and Wildlife Screening Risk Assessment, CIAR#251).
	• The wildlife risk assessment was amended to include an evaluation of water-based exposure pathways (both groundwater and surface water) and the results presented for Blairmore Creek, Gold Creek and the Oldman Reservoir were not considered to be indicative of adverse effects (Addendum 11, JRP IR-6.28). For the proposed end pit lake (EPL) (at closure), the results of the risk assessment are not considered indicative of a human health concern; however, management considerations of the EPL are warranted and actual measured concentrations at the time of EPL creation should be used to revisit predicted effects (Addendum 11, JRP IR-6.27). The assessment includes an Indigenous-specific conceptual model, which describes source-pathway linkages between the Project and Indigenous use of all aquatic pathways including the end pit lake, Blairmore and Gold Creeks, the Crowsnest River and the Oldman Reservoir in the post closure landscape.
	2. Use or access to hunting locations and harvesting methods:
	• Where Project construction and operations activities overlap with hunting locations, access to active mining areas may be limited until they are reclaimed and safe. Indigenous groups will continue to have access to hunting and trapping locations where safety is not compromised (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• The Project's access restrictions within the mine permit area may also affect Indigenous groups' ability to use their preferred harvesting methods and seasonal rounds by altering the times of year that Indigenous groups have access to areas of interest for hunting within the mine permit area (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• The residual effects on trails and travelways was assessed as moderate magnitude.
	• Increased noise, odour, and visual disturbance during construction and operation could affect use of locations and the experience of hunting within the vicinity of the Project (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89); residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42):
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	• Where Indigenous groups utilize firearms for hunting, the Project's firearms restriction policy would affect their ability to use that harvesting method within the mine footprint. Alternate hunting methods may be possible in parts of the mine footprint that have not yet been disturbed or which have been reclaimed under the AMP (Addendum 8, Appendix A-1, Section 15.2.1.1.3, CIAR#89).
	In summary, effects on linked VCs will act synergistically to change identified hunted species and habitat, change use or access to identified hunting locations, and change in preferred harvesting methods. There will be residual effects on hunting for Stoney Nakoda Nation due to reduction in hunting opportunities, engagement in hunting, and hunting success during construction and operation due to loss of access of hunting locations, sensory disturbance, and change in wildlife use within the mine permit area.
		Residual effects on hunting are characterized as:
		• Magnitude is moderate because there is predicted to be a change in the ability to hunt for the Stoney Nakoda Nation in the area but this does not change the ability to hunt in the RSA. Although no specific hunting sites were identified, the Stoney Nakoda Nation continues to hunt throughout their traditional territory for species found in the Project area. The Project activities will intersect or be in proximity to habitat and species that are identified for hunting by the Stoney Nakoda Nation (Addendum 10, Appendix 4.1-1, Section 7.3.2.1, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency because loss of hunting opportunities will be continuous throughout construction and operation.
		• Reversible because reclamation is planned and expected to re-establish natural processes and ecosystems that support hunted species and access will be restored following the AMP.
		• Ecological and social context is sensitive because engagement in hunting is sensitive to disruption and hunting is important to the Stoney Nakoda Nation for cultural and spiritual relationship between members and wildlife (Addendum 10, Appendix 4.1-1, Section 7.3.2.1, CIAR#251). Stoney Nakoda Nation continue to hunt throughout their traditional territory for subsistence, medicinal, and ceremonial purposes for species for which habitats will be affected by the Project through loss of habitat and avoidance of area (*e.g.,* elk, moose, bear) (Addendum 10, Appendix 4.1-1, Section 7.3.2.1, CIAR#251).

Table 6.7-5a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Stoney Nakoda Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC
Trapping	The Stoney Nakoda Nation Consultation Team has not identified an interest in trapping in the Project area. It is not anticipated that the Project will have adverse effects to trapping activities for the Stoney Nakoda Nation, however, if they do trap, the mitigations above in the hunting section will apply (Addendum 10, Appendix 4.1-1, Section 7.3.2.2, CIAR#251).	There is no residual effect to trapping.

Fishing	1. Fishing species and habitat:
	Westslope Cutthroat Trout (WSCT)
	• The physical footprint of surface water management infrastructure and open pits will cause permanent change to WSCT habitat. The loss of riparian and aquatic habitat will be reversed by gains achieved through implementing an Offsetting Plan approved by DFO. The magnitude of this effect will be moderate, the duration is long, the frequency will be continuous, however, reversibility is characterized as reversible in the long-term. (Addendum 1, CR#6, Section 4.5, CIAR#44).
	• Changes in hydrology will cause alteration in WSCT aquatic habitat of Gold and Blairmore creeks. The alteration of habitat will be offset by gains achieved through implementing an Offsetting Plan approved by DFO. The magnitude of residual adverse effects will be moderate, the duration is extended, the frequency will be continuous, however, reversibility is characterized as reversible in the long-term. (Addendum 1, CR#6, Section 4.5, CIAR#44).
	2. Use or access to fishing locations and harvesting methods:
	• Current access to the portions of the watercourses adjacent to Grassy Mountain is located on Benga private land. During construction and operation phases of the mine, this road will be closed to the general public, and alternate routes will need to be used to access and fish those portions of Blairmore and Gold Creeks (Addendum 8, Appendix A-1, Section 15.2.2.1.2, CIAR#89) which will be managed *via* the AMP.
	• Loss or disruption of trails for accessing fishing locations due to the mine site and road closure during construction and operation. The residual effects on trails and travelways was assessed as moderate magnitude (Addendum 10, Appendix 4.1-1, Table 7.4.4-1, CIAR#251).
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of fishing locations by Indigenous Nations and preferred harvesting method.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change use or access to identified fishing locations, and change preferred harvesting methods. There will be residual effects on fishing for Stoney Nakoda Nation due to reduction in fishing opportunities, engagement in fishing, and fishing success during construction and operation due to loss of access of fishing locations and sensory disturbance within the mine permit area.
		Residual effects on fishing are characterized as:
		• Magnitude is moderate because there is predicted to be a change in the ability to fish for Stoney Nakoda Nation as they have fishing interests and identified species in the Project area (Addendum 10, Appendix 4.1-1, Section 7.3.2.3, CIAR#251) and Project effects on Westslope cutthroat trout was assessed as moderate magnitude. This will not affect the ability to fish in the RSA.
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because access restrictions will apply beyond the life of the mine in some areas that may affect access to fishing locations.
		• Continuous frequency because loss of fishing opportunities will be continuous throughout construction and operation.
		• Reversibility is characterized as reversible because reclamation and offsetting is planned and expected to maintain the fish population and access will be restored following the AMP.
		• Ecological and social context is resilient because the Stoney Nakoda Nation engage in fishing primarily outside the Project LSA in the Crowsnest River watershed and Old Man River watershed north of the LSA.

Plant Gathering	1. Plant species and habitat:
	• The Project will result in loss of traditional use of vegetation within the vegetation local study area. Residual effects to TEK vegetation are local, long-term in duration, continuous, reversible and high magnitude. The Project will have a neutral contribution with respect to valued species and communities. After reclamation, the reclaimed land will support a range of communities with equivalent capabilities to those of the surrounding lands and that existing prior to Project development.
	• Residual adverse effects on vegetation were assessed as high magnitude for rare plants, community diversity, and TEK species, low magnitude for forest, and moderate for wetlands (EIA, CR#8, Section 4.0, CIAR#42).
	• Duration of effects on vegetation will be extended. Reclaimed land will require time to return the ecosystem to a condition that supports traditional use plants (EIA, CR#8, Section 4.1, CIAR#42).
	• Frequency of effects on vegetation, including rare plants and rare plant communities and traditional ecological knowledge, will be continuous through the operational phase of the project and cease only after reclamation is completed (EIA, CR#8, Section 4.0, CIAR#42).
	• Effects on vegetation are reversible in the long-term with the implementation of progressive reclamation (EIA, CR#8, Section 4.0, CIAR#42).
	2. Use or access to plant gathering locations and harvesting methods:
	• Loss or disruption of trails, loss of access to plant gathering locations, and loss of and preferred methods for plant gathering due to the mine site and access road. Residual effects on trails and travelways was assessed as moderate magnitude.
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of plant gathering locations by Indigenous Nations and preferred harvesting method.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3 CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change identified plant gathering species and habitat, change use or access to identified harvesting locations, and change preferred harvesting methods. There will be residual effects on plant gathering for Stoney Nakoda Nation due to reduction in harvesting opportunities, engagement in plant gathering, and harvesting success during construction and operation due to loss of access to plant gathering locations and sensory disturbance within the mine permit area.
		Residual effects on plant gathering are characterized as:
		• Magnitude is moderate because there is predicted to be a change in the ability to gather plants for the Stoney Nakoda Nation in the Project area. The Stoney Nakoda Nation have identified habitat and species for plant gathering in the proximity of the Project (Addendum 10, Appendix 4.1-1, Section 7.3.2.4, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine.
		• Reversibility is characterized as reversible because reclamation (of terrain, soil, vegetation) is planned and expected to re-establish natural processes and ecosystems that support traditional use plants (high density planting of disease-resistant whitebark pine seedlings will contribute to the successful re-establishment of the native ecosystem); and, access to plant gathering locations will be re-established after mine closure.
		• Ecological and social context is sensitive because engagement in plant gathering is sensitive to disruption and past and present activities have resulted in traditional land use at high risk. The Stoney Nakoda Nation have noted that in and around the Project area, there are plant species central to ceremony, healing practices, and spirituality (Addendum 10, JRP IR-4.6, CIAR#251).

Table 6.7-5a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Stoney Nakoda Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Trails and Travelways	1. Use or access to trails and travelways:
	• Loss or disruption of trails and travelways due to the mine site and access road. The Project will have residual adverse effects on use of trails and travelways because the Project could result in loss of trails and travelways that are fully or partially within the mine permit boundary.
	• The Project footprint will be reclaimed to land use capability equivalent to pre-mining; however, it will not be accessible for use as trails and travelways during construction and operations. Access to areas around the Project will be possible using existing trails from Highway 40 to reach the area west of Blairmore Creek and Crown Land north of the Project and from either the north or the south along the Gold Creek. With the implementation of the AMP, potential residual effects will be further reduced as Benga will be providing access to adjacent privately owned Benga lands for traditional practices (Addendum 10, Appendix 4.1-1, Section 7.3.3.5, CIAR#251).
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of trails and travelways by Indigenous Nations.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	2. Features associated with trails and travelways:
	• Loss or disturbance to features associated with trails and travelways due to the mine site and access road.
	• Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42).
	• Residual adverse effects on access and utilities in the Lands and Resource Use VC was assessed as nil magnitude after reclamation (EIA, CR#10, CIAR#42).
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42).
	• Residual effects will extend beyond the mine footprint but limited to within the zone of influence (generally 1.5 km) for noise, visual disturbance, and effect on access (EIA, CR#2, CIAR#42).
	• The geographic extent of residual effects on historical resources and on land and resource use is characterized as local (EIA, CR#10, Section E, CIAR#42).
	• The frequency of impact on access and utilities in the lands and resource use is continuous (EIA, CR#2, CIAR#42).
	• The frequency of impact of noise and other disturbances to trail use will continue throughout the Project lifespan (EIA, CR#2, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change use or access and change preferred trails and travelways. There will be residual effects on trails and travelways for Stoney Nakoda Nation due to restriction in use or access, and engagement with features associates with trails and travelways during construction and operation due to loss of access to trails and travelways locations, sensory disturbance, and change in use within the mine permit area.
		Residual effects on trails and travelways is characterized as:
		• Magnitude is moderate because there is predicted to be a change in the ability to use or access trails and travelways for The Stoney Nakoda Nation. The Nation did not disclose in exact detail of how the Project area was used, however, following aerial surveillance of the area, the Nation pointed out the possibility of "trails according to geomorphology, elevation, and landscape features" (Stoney Nakoda Nation, 2015, p.19). Although it is possible that the Project may intersect or be in proximity to areas that are identified for trails and travelways by Stoney Nakoda, none were identified (Addendum 10, Appendix 4.1-1, Section 7.3.2.5, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but are limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency during operations and construction due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine.
		• Non-reversible where trails and travelways are lost because when a trail is inaccessible it will not be maintained or used, resulting in the potential loss of the knowledge of or loss of the physical trail or travelway.
		• Ecological and social context is resilient because Stoney Nakoda Nation did not identify trails and travelways in the Project area but outside. Although it is possible that the Project may intersect or be in proximity to areas that are identified for trails and travelways by Stoney Nakoda Nation, none were identified (Addendum 10, Appendix 4.1-1, Section 7.3.2.5, CIAR#251) and they can use alternative routes to travel between cultural and spiritual sites and resources within their traditional territory. Therefore, Stoney Nakoda Nation use and access to trails and travelways is not sensitive to disruption from the Project.

Cultural and Spiritual Values	1. Use and access to sacred important sites with cultural or spiritual value: • Residual adverse effects on access and utilities in the Lands and Resource Use VC was assessed as nil magnitude (EIA, CR#10, CIAR#42). • Loss or disruption of trails to important sites due to the mine site and access road. • Loss of hunting, fishing, and plant gathering opportunities. The residual effects, as seen above, on hunting and plant gathering were assessed as moderate magnitude, and there is no residual effect on trapping. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect use and enjoyment of culturally and spiritually important sites. Increased noise levels extend 1.5 km from the Project (EIA, CR#2, CIAR#42). Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). • Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42). 2. Experience of engaging with sites of cultural or spiritual value: • Loss or disturbance to important sites due to the mine site and access road. • Loss of experience in hunting, fishing, and plant gathering, which could affect the cultural and spiritual relationships with the resource. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect enjoyment or experience of using culturally and spiritually important sites. 3. Cultural values associated with sites/features: • Loss of hunting, fishing, and plant gathering opportunities, which could affect intergenerational teaching of traditional practices, and result in loss of cultural identity, sense of place, and human health/well-being. • Loss of access to sites/features due to construction and operation activities. • Loss of or damage to unique sites and special features as a result of clearing and construction activities. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect enjoyment or experience of engaging with the sites/features of cultural or spiritual value. In summary, effects on linked VCs will act synergistically to change use or access to sites with cultural or spiritual value, change the experience of using these sites, and change the cultural value associated with sites and features. There will be residual effects on cultural and spiritual values for Stoney Nakoda Nation during construction and operation due to loss of access to culturally or spiritually important sites and sensory disturbance within the mine permit area.	Residual effect on cultural and spiritual values is characterized as: • Magnitude is moderate because there is predicted to be a change in the values ad experience associated with cultural or spiritual sites for the Stoney Nakoda Nation through direct disturbance and change in noise and air quality. It was noted that the Project may intersect or be in proximity to areas that are identified for cultural and spiritual values for the Stoney Nakoda Nation (Addendum 10, Appendix 4.1-1, Section 7.3.2.6, CIAR#251). In addition to a direct change to cultural and spiritual values and associated features, it is expected that the visual and sensory experience of visiting these locations will also change. The Project will cause a certain change in noise, dust and a visual disturbance (Addendum 10, Appendix 4.1-1, Section 7.3.2.6, CIAR#251). • Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA. • Long-term duration because the loss of experience in hunting, fishing, and plant gathering could affect the long-term cultural and spiritual relationships between Indigenous groups and their resources and territory. Change in land use and access will extend beyond the Project lifespan. • Continuous frequency during due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine. • Non-reversible because loss of cultural and spiritual sites and experience in engaging in land use could result in loss of the knowledge of cultural and spiritual values. • Ecological and social context is sensitive because loss of heritage sites and features or loss of engagement with physical and cultural heritage affects cultural identity, human well-being and relationships, and intergenerational transfer of knowledge. The Stoney Nakoda have stated that the Project will "continue the diminution of our traditional culture by irreversibly destroying our spiritual and ceremonial use sites on the Mountain from which we worship at Crowsnest Mountain. Traditional Blackfoot spirituality is the fabric that binds our culture and people together." (Addendum 10, Appendix 4.1-1, Section 7.3.2.4, CIAR#251)

Table 6.7-5a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Stoney Nakoda Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC
Physical and Cultural Heritage	1. Physical and cultural heritage: • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities. • The geographic extent of residual effects on historical resources is local (EIA, Section E, CIAR#42). 2. Access to physical and cultural heritage: • Loss or disruption of trails to unique sites and special features associated with physical or cultural heritage due to the mine site and access road. • The magnitude of effects on trails and travelways was characterized as moderate. 3. Cultural value and importance associated with physical and cultural heritage: • Increase in noise, odour, and visual disturbance during construction and operation could result in reduced engagement with the sites/features of cultural value. • Magnitude was assessed as high for TEK plant species (EIA, CR#8, CIAR#42), whereas magnitude is low to moderate for hunted and trapped wildlife (EIA, CR#9, CIAR#42). • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities. • The magnitude of effects on cultural and spiritual values was characterized as moderate. 4. Relationship with physical and cultural heritage: • Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42) and access and utilities in the Lands and Resource Use VC was assessed as nil magnitude (EIA, CR#10, CIAR#42), but for those VCs that affect the relationships with physical and cultural heritage (*e.g.,* air quality, noise, plant gathering, hunting and), magnitude is assessed as high for odour and low to moderate for emissions including dust (EIA, CR#1 CIAR#42), and moderate for hunting and plant gathering. • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities could result in loss of relationship with heritage. • Loss of hunting, fishing, and plant gathering opportunities due to construction and operation and access restrictions could result in loss of relationship with wildlife and cultural practices. • Increase in noise, odour, and visual disturbance during construction and operation could result in reduced engagement with the sites/features associated with physical or cultural heritage. In summary, effects on linked VCs will act synergistically to change use or access to physical and cultural heritage, change the value and importance, and change the relationship the Stoney Nakoda Nation have with these sites. There will be residual effects on Indigenous physical and cultural heritage for Stoney Nakoda Nation during construction and operation due to loss of access and sensory disturbance within the mine permit area.	Residual effects on Indigenous Physical and cultural heritage are characterized as: • Magnitude is moderate because there is predicted to be a change in the access to and value of physical and cultural heritage for the Stoney Nakoda Nation. While the Stoney Nakoda Nation Site Summary does not provide exact locations of sacred places within the Project area, it mentions that there are areas on the mountain that are recognized by the Stoney Nakoda Members as meditation sites (Addendum 10, Appendix 4.1-1, Section 7.3.1.6, CIAR#251). • Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA. • Long-term duration because disturbance to or loss of unique sites and features will extend beyond the Project lifespan. • Regular frequency because disturbance to unique sites and features will occur during construction and operation activities whenever sites or features are discovered. • Non-reversible because loss of heritage sites and features and experience in engaging in land use could result in loss of the knowledge of cultural heritage. • Ecological and social context is sensitive because loss of heritage sites and features or loss of engagement with physical and cultural heritage could affect cultural identity, human well-being, and intergenerational transfer of knowledge.

In summary, the residual effects characterization has not changed greatly from that already provided. The only change from the previous effects characterization is that the ecological and social context for fishing has been corrected from sensitive to resilient for the reasons explained above. As such, the summary Table 7.4.4-1 from *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups* (Appendix 4.1-1, Addendum 10, CIAR#251) is provided below as Table 6.7-5b, with this one correction.

Table 6.7-5b Summary of Residual Effects to the Stoney Nakoda Nation [Source: Table 7.4.4-1, *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups* Appendix 4.1-1, Addendum 10, CIAR#251]

Valued Components	Magnitude	Geographic Extent	Duration	Frequency	Reversibility	Ecological and Social Context	Significance
Hunting	Moderate	Local	long-term	Continuous	Reversible	Sensitive	Not significant
Fishing	Moderate	Local	Long-term	Continuous	Reversible	Resilient	Not significant
Plant Gathering	Moderate	Local	Long-term	Continuous	Reversible	Sensitive	Not significant
Trails and Travelways	Moderate	Local	Long-term	Continuous	Not Reversible where trails and travelways are lost	Resilient	Not significant
Cultural and Spiritual Values	Moderate	Local	Long-term	Continuous	Not Reversible	Sensitive	Not significant
Indigenous Physical and Cultural Heritage	Moderate	Local	Long-term	Regular	Not Reversible	Sensitive	Not significant

Description and Characterization of Residual Effects on the Tsuut'ina Nation

The description and characterization of residual effects on the Tsuut'ina Nation are found below in Table 6.7-6a. A summary table of this characterization was provided as Table 8.4.4-1 (Appendix 4.1-1: *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups*, Addendum 10, CIAR#251), and is copied below for the convenience of the reader as Table 6.7-6b.

Table 6.7-6a Description and characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Tsuut'ina Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Hunting	1. Hunted species and habitat:
	The Project will have temporary effects on land access for traditional resource use and on the distribution and abundance of species hunted for traditional purposes.
	Species preferring recently disturbed and young habitats are expected to return first, followed by species preferring increasingly older habitat types with reclamation.
	Moose and Elk:
	• Suitable moose and elk habitat will decline initially but is predicted to be more abundant than baseline levels by end of mine due, in part, to reclamation of legacy mine sites that overlap the Project footprint (EIA, CR#9, Section 5.6.2.1, CIAR#42).
	• The changes in abundance of moose and elk year-round in the WLSA are expected to follow a similar pattern as individuals of both species will be displaced into adjacent habitats.
	Grizzly Bear:
	• Highly suitable grizzly bear habitat in the WLSA will decrease initially during the construction and operation phases and then increase throughout the duration of progressive reclamation. Mortality risk also increases with Project development but then decreases with progressive reclamation. With reclamation, the Project footprint is expected to offer more suitable habitat (dietary resources) and lower mortality risk than under baseline conditions, which are anticipated to allow for an increase in the size of the grizzly bear population that the local area can support.
	Wildlife Residual Effects (EIA, CR#9, Table 5.3-26, CIAR#42):
	• Effects on habitat availability for hunted species (moose, elk, grizzly bear) due to vegetation clearing and sensory disturbance (due to increased noise, odour, visual disturbance) are low magnitude, positive Project contribution, and reversible in the long-term.
	• Effects on wildlife movement for hunted species (moose, elk, grizzly bear) due to construction and operation are low magnitude, and reversible in the long-term.
	• Effects on wildlife abundance for hunted species (moose, elk, grizzly bear) in hunting location is low magnitude, positive Project contribution for elk and grizzly bear, neutral Project contribution for moose, and reversible in the long-term.
	• Effects on wildlife mortality risk for hunted species due to construction activities, vehicle collisions, and human-wildlife conflicts are low magnitude, frequency is occasional, and reversible in the long-term. With the Access Control Policy and firearm prohibition by Project personnel, poaching and non-Indigenous hunting of moose, elk, and grizzly bear will decline in the WLSA during the life of mine and may result in increased abundance of moose, elk, and grizzly bear in the areas accessible by Indigenous groups (EIA, CR#9, Section 5.6.2.1, CIAR#42).
	• A screening level wildlife risk assessment was conducted, the results of which indicate that there is no potential risk of adverse effects associated with Project emissions on the health of wildlife in the study areas (Addendum 10, Appendix 4.9-1, Section 8.0, Updated Human Health and Wildlife Screening Risk Assessment, CIAR#251).
	• The wildlife risk assessment was amended to include an evaluation of water-based exposure pathways (both groundwater and surface water) and the results presented for Blairmore Creek, Gold Creek and the Oldman Reservoir were not considered to be indicative of adverse effects (Addendum 11, JRP IR-6.28). For the proposed end pit lake (EPL) (at closure), the results of the risk assessment are not considered indicative of a human health concern; however, management considerations of the EPL are warranted and actual measured concentrations at the time of EPL creation should be used to revisit predicted effects (Addendum 11, JRP IR-6.27). The assessment includes an Indigenous-specific conceptual model, which describes source-pathway linkages between the Project and Indigenous use of all aquatic pathways including the end pit lake, Blairmore and Gold Creeks, the Crowsnest River and the Oldman Reservoir in the post closure landscape.
	2. Use or access to hunting locations and harvesting methods:
	• Where Project construction and operations activities overlap with hunting locations, access to active mining areas may be limited until they are reclaimed and safe. Indigenous groups will continue to have access to hunting and trapping locations where safety is not compromised (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• The Project's access restrictions within the mine permit area may also affect Indigenous groups' ability to use their preferred harvesting methods and seasonal rounds by altering the times of year that Indigenous groups have access to areas of interest for hunting within the mine permit area (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• The residual effects on trails and travelways was assessed as moderate magnitude
	• Increased noise, odour, and visual disturbance during construction and operation could affect use of locations and the experience of hunting within the vicinity of the Project (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89); residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42):
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	• Where Indigenous groups utilize firearms for hunting, the Project's firearms restriction policy would affect their ability to use that harvesting method within the mine footprint. Alternate hunting methods may be possible in parts of the mine footprint that have not yet been disturbed or which have been reclaimed under the AMP (Addendum 8, Appendix A-1, Section 15.2.1.1.3, CIAR#89).
	In summary, effects on linked VCs will act synergistically to change identified hunted species and habitat, change use or access to identified hunting locations, and change preferred harvesting methods. There will be residual effects on hunting for Tsuut'ina Nation due to reduction in hunting opportunities, engagement in hunting, and hunting success during construction and operation due to loss of access to hunting locations, sensory disturbance, and change in wildlife use within the mine permit area.
		Residual effects on hunting are characterized as:
		• Magnitude is moderate because there is predicted to be a change in the ability to hunt for the Tsuut'ina Nation in the area but this does not change the ability to hunt in the RSA. Although the Tsuut'ina Nation do not hunt as extensively as compared to past levels of hunting, they still use the Crowsnest Pass area for hunting (Addendum 10, Appendix 4.1-1, Section 8.3.1.1, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency because loss of hunting opportunities will be continuous throughout construction and operation.
		• Reversibility is characterized as reversible because reclamation is planned and expected to re-establish natural processes and ecosystems that support hunted species and access will be restored following the AMP.
		• Ecological and social context is resilient because the Tsuut'ina Nation do not hunt as extensively as compared to past levels of hunting, they still use the Crowsnest Pass area for hunting (Addendum 10, Appendix 4.1-1, Section 8.3.1.1, CIAR#251). This is outside the Project LSA. Tsuut'ina Nation did not identify hunting areas in the Project area. Tsuut'ina Nation engagement in hunting is considered not sensitive to disruption from the Project.

Trapping	The Tsuut'ina Nation Consultation Team did not provide information about current trapping practices. Based on information provided by the Tsuut'ina Nation, there are no traplines currently in use within the LSA (Addendum 10, Appendix 4.1-1, Section 8.3.1.2, CIAR#251). There is no predicted residual effect on trapping.	There is no residual effect on trapping.

Table 6.7-6a Description and characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Tsuut'ina Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Fishing	1. Fishing species and habitat:
	Westslope Cutthroat Trout (WSCT)
	• The physical footprint of surface water management infrastructure and open pits will cause permanent change to WSCT habitat. The loss of riparian and aquatic habitat will be reversed by gains achieved through implementing an Offsetting Plan approved by DFO. The magnitude of this effect will be moderate, the duration is long, the frequency will be continuous, however, reversibility is characterized as reversible in the long-term. (Addendum 1, CR#6, Section 4.5, CIAR#44).
	• Changes in hydrology will cause alteration in WSCT aquatic habitat of Gold and Blairmore creeks. The alteration of habitat will be offset by gains achieved through implementing an Offsetting Plan approved by DFO. The magnitude of residual adverse effects will be moderate, the duration is extended, the frequency will be continuous, however, reversibility is characterized as reversible in the long-term. (Addendum 1, CR#6, Section 4.5, CIAR#44).
	2. Use or access to fishing locations and harvesting methods:
	• Current access to the portions of the watercourses adjacent to Grassy Mountain is located on Benga private land. During construction and operation phases of the mine, this road will be closed to the general public, and alternate routes will need to be used to access and fish those portions of Blairmore and Gold Creeks (Addendum 8, Appendix A-1, Section 15.2.2.1.2, CIAR#89) which will be managed *via* the AMP.
	• Loss or disruption of trails for accessing fishing locations due to the mine site and road closure during construction and operation. The residual effects on trails and travelways was assessed as moderate magnitude.
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of fishing locations by Indigenous Nations and preferred harvesting method.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1 CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change use or access to identified fishing locations, and change preferred harvesting methods. There will be residual effects on fishing for Tsuut'ina Nation due to reduction in fishing opportunities, engagement in fishing, and fishing success during construction and operation due to loss of access to fishing locations and sensory disturbance within the mine permit area.
		Residual effects on fishing are characterized as:
		• Magnitude is low because the Tsuut'ina Nation has not identified an interest in fishing in the Project area. Thus, it is anticipated that the Project would not affect fishing activities, resources or access for the Tsuut'ina Nation (Addendum 10, Appendix 4.1-1, Section 8.3.2.3, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because access restrictions will apply beyond the life of the mine in some areas that may affect access to fishing locations.
		• Continuous frequency because loss of fishing opportunities will be continuous throughout construction and operation.
		• Reversibility is characterized as reversible because reclamation and offsetting is planned and expected to maintain fish populations and access will be restored following the AMP.
		• Ecological and social context is resilient because Tsuut'ina Nation did not identify an interest in fishing in the Project area. Thus, it is anticipated that the Project would not affect fishing activities, resources or access for the Tsuut'ina Nation (Addendum 10, Appendix 4.1-1, Section 8.3.2.3, CIAR#251). Tsuu'tina Nation identified fishing outside the Project area, *e.g.,* Bow River, Bragg Creek and Fish Creek during the summer. Tsuut'ina Nation engagement in fishing is considered not sensitive to disruption from the Project.

Plant Gathering	1. Plant species and habitat:
	• The Project will result in loss of traditional use of vegetation within the vegetation local study area. Residual effects to TEK vegetation are local, long-term in duration, continuous, reversible and high magnitude. The Project will have a neutral contribution with respect to valued species and communities. After reclamation, the reclaimed land will support a range of communities with equivalent capabilities to those of the surrounding lands and that existing prior to Project development.
	• Residual adverse effects on vegetation were assessed as high magnitude for rare plants, community diversity, and TEK species, low magnitude for forest, and moderate for wetlands (EIA, CR#8, Section 4.0, CIAR#42).
	• Duration of effects on vegetation will be extended. Reclaimed land will require time to return the ecosystem to a condition that supports traditional use plants (EIA, CR#8, Section 4.1, CIAR#42).
	• Frequency of effects on vegetation, including rare plants and rare plant communities and traditional ecological knowledge, will be continuous through the operational phase of the project and cease only after reclamation is completed (EIA, CR#8, Section 4.0, CIAR#42).
	• Effects on vegetation are reversible in the long-term with the implementation of progressive reclamation (EIA, CR#8, Section 4.0, CIAR#42).
	2. Use or access to plant gathering locations and harvesting methods:
	• Loss or disruption of trails, loss of access to plant gathering locations, and loss of and preferred methods for plant gathering due to the mine site and access road. Residual effects on trails and travelways was assessed as moderate magnitude.
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of plant gathering locations by Indigenous Nations and preferred harvesting method.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO2 in the community (EIA, CR#1, Section 6.3 CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change identified plant gathering species and habitat, change use or access to identified harvesting locations, and change preferred harvesting methods. There will be residual effects on plant gathering for Tsuut'ina Nation due to reduction in harvesting opportunities, engagement in plant gathering, and harvesting success during construction and operation due to loss of access to plant gathering locations and sensory disturbance within the mine permit area.
		Residual effects on plant gathering are characterized as:
		• Magnitude is moderate because there is predicted to be a change in the ability to gather plants for Tsuut'ina Nation in the Project area. The Tsuut'ina Nation have identified habitat and species for plant gathering that are in the proximity of the Project (Addendum 10, Appendix 4.1-1, Section 8.3.2.4, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine.
		• Reversibility is characterized as reversible because reclamation (of terrain, soil, vegetation) is planned and expected to re-establish natural processes and ecosystems that support traditional use plants (high density planting of disease-resistant whitebark pine seedlings will contribute to the successful re-establishment of the native ecosystem); and, access to plant gathering locations will be re-established after mine closure.
		• Ecological and social context is sensitive because Indigenous engagement in plant gathering is sensitive to disruption. Loss of use or access or change in gathering methods could affect the cultural and spiritual relationship between the Nation and their territory. This could result in loss of cultural identity and human health and well-being. Further, multiple alpine plants found at Grassy Mountain that are crucial to Tsuut'ina Nation ceremony, healing practices, cultural identity, and spirituality are not found at lower elevations near Tsuut'ina Nation communities (Addendum 10, JRP IR-4.6, Table 4.6-5, CIAR#251).

Table 6.7-6a Description and characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Tsuut'ina Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Trails and Travelways	1. Use or access to trails and travelways:
	• Loss or disruption of trails and travelways due to the mine site and access road. The Project will have residual adverse effects on use of trails and travelways because the Project could result in loss of trails and travelways that are fully or partially within the mine permit boundary.
	• The Project footprint will be reclaimed to land use capability equivalent to pre-mining; however, it will not be accessible for use as trails and travelways during construction and operations. Access to areas around the Project will be possible using existing trails from Highway 40 to reach the area west of Blairmore Creek and Crown Land north of the Project and from either the north or the south along the Gold Creek. With the implementation of the AMP, potential residual effects will be further reduced as Benga will be providing access to adjacent privately owned Benga lands for traditional practices (Addendum 10, Appendix 4.1-1, Section 8.3.3.5, CIAR#251).
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of trails and travelways by Indigenous Nations.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	3. Features associated with trails and travelways:
	• Loss or disturbance to features associated with trails and travelways due to the mine site and access road.
	• Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42).
	• Residual adverse effects on access and utilities in the Lands and Resource Use VC was assessed as nil magnitude after reclamation (EIA, CR#10, CIAR#42).
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42).
	• Residual effects will extend beyond the mine footprint but limited to within the zone of influence (generally 1.5 km) for noise, visual disturbance, and effect on access (EIA, CR#2, CIAR#42).
	• The geographic extent of residual effects on historical resources and on land and resource use is characterized as local (EIA, CR#10, Section E, CIAR#42).
	• The frequency of impact on access and utilities in the lands and resource use is continuous (EIA, CR#2, CIAR#42).
	• The frequency of impact of noise and other disturbances to trail use will continue throughout the Project lifespan (EIA, CR#2, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change use or access and change preferred trails and travelways. There will be residual effects on trails and travelways for Tsuut'ina Nation due to restriction in use or access, and engagement with features associated with trails and travelways during construction and operation due to loss of access to trails and travelways locations, sensory disturbance, and change in use within the mine permit area.
		Residual effects on trails and travelways are characterized as:
		• Magnitude is moderate because there is predicted to be a change in the ability to use or access trails and travelways in and around the Project area. Tsuut'ina oral history describes where they travelled, including in proximity of the Project. Travel and access to the Crowsnest Pass by the Tsuut'ina Nation members has diminished since contact with Euro-Canadian settlers. While the Nation continues to use hunting trails throughout the Grassy Mountain area, this is done less than in the past. No site-specific details were provided to Benga. (Addendum 10, Appendix 4.1-1, Section 8.3.1.5, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency during construction and operation due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine.
		• Non-reversible where trails and travelways are lost because when a trail is inaccessible it will not be maintained or used, resulting in the potential loss of the knowledge of or loss of the physical trail or travelway.
		• Ecological and social context is resilient because Tsuut'ina Nation did not identify trails and travelways in the Project area but outside the LSA. Tsuut'ina Nation can use alternative routes to travel between cultural and spiritual sites and resources within their traditional territory. Therefore, Tsuut'ina Nation use and access to trails and travelways is not sensitive to disruption from the Project.

Cultural and Spiritual Values	1. Use and access to sacred important sites with cultural or spiritual value: • Residual adverse effects on access and utilities in the Lands and Resource Use VC was assessed as nil magnitude (EIA, CR#10, CIAR#42). • Loss or disruption of trails to important sites due to the mine site and access road. • Loss of hunting, fishing, and plant gathering opportunities. The residual effects, as seen above, on hunting, and plant gathering were assessed as moderate magnitude, and fishing was low. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect use and enjoyment of culturally and spiritually important sites. Increased noise levels extend 1.5 km from the Project (EIA, CR#2, CIAR#42). Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). • Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42). 2. Experience of engaging with sites of cultural or spiritual value: • Loss or disturbance to important sites due to the mine site and access road. • Loss of experience in hunting, fishing, and plant gathering, which could affect the cultural and spiritual relationships with the resource. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect enjoyment or experience of using culturally and spiritually important sites. 3. Cultural values associated with sites/features: • Loss of hunting, fishing, and plant gathering opportunities, which could affect intergenerational teaching of traditional practices, and result in loss of cultural identity, sense of place, and human health/well-being. • Loss of access to sites/features due to construction and operation activities. • Loss of or damage to unique sites and special features as a result of clearing and construction activities. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect enjoyment or experience of engaging with the sites/features of cultural or spiritual value. In summary, effects on linked VCs will act synergistically to change use or access to sites with cultural or spiritual value, change the experience of using these sites, and change the cultural value associated with sites and features. There will be residual effects on cultural and spiritual values for Tsuut'ina Nation during construction and operation due to loss of access to culturally or spiritually important sites and sensory disturbance within the mine permit area.	Residual effects on cultural and spiritual values is characterized as: • Magnitude is moderate because there is predicted to be a change in the values ad experience associated with cultural or spiritual sites for the Tsuut'ina Nation through direct disturbance and change in noise and air quality. However, this will not affect the ability to use or access sites associated with cultural and spiritual values in the RSA. The Tsuut'ina Nation consider many traditional practices conducted in and around the project site as holding cultural and spiritual value. Hunting has important cultural and spiritual values; intergenerational knowledge is shared while hunting. Plant gathering activities are likewise linked to intangible values with spiritual, artistic, and aesthetic elements (Addendum 10, Appendix 4.1-1, Section 8.3.1.6, CIAR#251). In addition to a direct change to cultural and spiritual values and associated features, it is expected that the visual and sensory experience of visiting these locations will also change. The Project will cause a certain change in noise, dust and a visual disturbance (Addendum 10, Appendix 4.1-1, Section 8.3.2.6, CIAR#251). • Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA. • Long-term duration because the loss of experience in hunting, fishing, and plant gathering could affect the long-term cultural and spiritual relationships between Indigenous groups and their resources and territory. Change in land use and access will extend beyond the Project lifespan. • Continuous frequency during due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine. • Non-reversible because loss of cultural and spiritual sites and experience in engaging in land use could result in loss of the knowledge of cultural and spiritual values. • Ecological and social context is sensitive because loss of engagement in land use affects cultural identity, human well-being and relationships, and intergenerational transfer of knowledge. The Tsuut'ina Nation has indicated that the Project area has been one of the most preferred sites for Tsuut'ina Elders to conduct spiritual ceremonies (Addendum 10, JRP IR-4.6, Table 4.6-5, CIAR#251).

Table 6.7-6a Description and characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Tsuut'ina Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC
Physical and Cultural Heritage	1. Physical and cultural heritage: • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities. • The geographic extent of residual effects on historical resources is local (EIA, Section E, CIAR#42). 2. Access to physical and cultural heritage: • Loss or disruption of trails to unique sites and special features associated with physical or cultural heritage due to the mine site and access road. • The magnitude of effects on trails and travelways was characterized as moderate. 3. Cultural value and importance associated with physical and cultural heritage: • Increase in noise, odour, and visual disturbance during construction and operation could result in reduced engagement with the sites/features of cultural value. • Magnitude was assessed as high for TEK plant species (EIA, CR#8, CIAR#42), whereas magnitude is low to moderate for hunted and trapped wildlife (EIA, CR#9, CIAR#42). • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities. • The magnitude of effects on cultural and spiritual values was characterized as moderate. 4. Relationship with physical and cultural heritage: • Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42) and access and utilities in the Lands and Resource Use VC was assessed as nil magnitude (EIA, CR#10, CIAR#42), but for those VCs that affect the relationships with physical and cultural heritage (*e.g.,* air quality, noise, plant gathering, hunting and trapping), magnitude is assessed as high for odour and low to moderate for emissions including dust (EIA, CR#1, CIAR#42), and moderate for hunting and plant gathering. • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities could result in loss of relationship with heritage. • Loss of hunting, fishing, and plant gathering opportunities due to construction and operation and access restrictions could result in loss of relationship with wildlife and cultural practices. • Increase in noise, odour, and visual disturbance during construction and operation could result in reduced engagement with the sites/features associated with physical or cultural heritage. In summary, effects on linked VCs will act synergistically to change use or access to physical and cultural heritage, change the value and importance, and change the relationship the Tsuut'ina Nation have with these sites. There will be residual effects on Indigenous physical and cultural heritage for Tsuut'ina Nation during construction and operation due to loss of access and sensory disturbance within the mine permit area.	Residual effects on physical and cultural heritage are characterized as: • Magnitude is moderate because there is predicted to be a change in the access to and value of physical and cultural heritage for the Tsuut'ina Nation. The Tsuut'ina Nation has a strong spiritual and cultural connection with the land in and around the proposed Project area. There are sites sacred to the Nation in the Crowsnest Pass and surrounding area, including ceremonial sites and natural material to make ceremonial paint and items. The Project area and its associated features are used for spiritual purposes, including ceremonies (Addendum 10, Appendix 4.1-1, Section 8.3.1.6, CIAR#251). • Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA. • Long-term duration because disturbance to or loss of unique sites and features will extend beyond the Project lifespan. • Regular frequency because disturbance to unique sites and features will occur during construction and operation activities whenever sites or features are discovered. • Non-reversible because loss of heritage sites and features and experience in engaging in land use could result in loss of the knowledge of cultural heritage. • Ecological and social context is sensitive because loss of heritage sites and features or loss of engagement with physical and cultural heritage affects cultural identity, human well-being and relationships, and intergenerational transfer of knowledge. The Tsuut'ina Nation has indicated that the ability to pass on stories is tied to taking the next generation out on the land, which could be impeded by the Project (Addendum 10, JRP IR-4.6, Table 4.6-5, CIAR#251).

In summary, the residual effects characterization has not changed from that already provided. As such, the summary Table 8.4.4-1 from *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups* (Appendix 4.1-1, Addendum 10, CIAR#251) is provided below. A correction to the table has been made. The text in Section 8, Appendix 4.1-1 correctly identifies the duration for hunting as long-term, however it was incorrectly copied into the table. Therefore, the table has been updated to correct that error and is presented below as Table 6.7-6b.

Table 6.7-6b Summary of Residual Effects to the Tsuut'ina Nation [Source: Table 8.4.4-1, *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups* Appendix 4.1-1, Addendum 10, CIAR#251]

Valued Components	Magnitude	Geographic Extent	Duration	Frequency	Reversibility	Ecological and Social Context	Significance
Hunting	Moderate	Local	Long-term	Continuous	Reversible	Resilient	Not significant
Fishing	Low	Local	Long-term	Continuous	Reversible	Resilient	Not significant
Plant Gathering	Moderate	Local	Long-term	Continuous	Reversible	Sensitive	Not significant
Trails and Travelways	Moderate	Local	Long-term	Continuous	Non-reversible where trails and travelways are lost	Resilient	Not significant
Cultural and Spiritual Values	Moderate	Local	Long-term	Continuous	Non-reversible	Sensitive	Not significant
Indigenous Physical and Cultural Heritage	Moderate	Local	Long-term	Regular	Non-Reversible	Sensitive	Not significant

Description and Characterization of Residual Effects on the Ktunaxa Nation

The description and characterization of residual effects on the Ktunaxa Nation are found below in Table 6.7-7a. A summary table of this characterization was provided as Table 9.4.4-1 (Appendix 4.1-1: *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups*, Addendum 10, CIAR#251), and is copied below for the convenience of the reader, as Table 6.7-7b.

Table 6.7-7a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Ktunaxa Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Hunting	1. Hunted species and habitat:
	The Project will have temporary effects on land access for traditional resource use and on the distribution and abundance of species hunted for traditional purposes.
	Species preferring recently disturbed and young habitats are expected to return first, followed by species preferring increasingly older habitat types with reclamation.
	Moose and Elk:
	• Suitable moose and elk habitat will decline initially but is predicted to be more abundant than baseline levels by end of mine due, in part, to reclamation of legacy mine sites that overlap the Project footprint (EIA, CR#9, Section 5.6.2.1, CIAR#42).
	• The changes in abundance of moose and elk year-round in the WLSA are expected to follow a similar pattern as individuals of both species will be displaced into adjacent habitats.
	Grizzly Bear:
	• Highly suitable grizzly bear habitat in the WLSA will decrease initially during the construction and operation phases and then increase throughout the duration of progressive reclamation. Mortality risk also increases with Project development but then decreases with progressive reclamation. With reclamation, the Project footprint is expected to offer more suitable habitat (dietary resources) and lower mortality risk than under baseline conditions, which are anticipated to allow for an increase in the size of the grizzly bear population that the local area can support.
	Wildlife Residual Effects (EIA, CR#9, Table 5.3-26, CIAR#42):
	• Effects on habitat availability for hunted species (moose, elk, grizzly bear) due to vegetation clearing and sensory disturbance (due to increased noise, odour, visual disturbance) are low magnitude, positive Project contribution, and reversible in the long-term.
	• Effects on wildlife movement for hunted species (moose, elk, grizzly bear) due to construction and operation are low magnitude, and reversible in the long-term.
	• Effects on wildlife abundance for hunted species (moose, elk, grizzly bear) in hunting location is low magnitude, positive Project contribution for elk and grizzly bear, neutral Project contribution for moose, and reversible in the long-term.
	• Effects on wildlife mortality risk for hunted species due to construction activities, vehicle collisions, and human-wildlife conflicts are low magnitude, frequency is occasional, and reversible in the long-term. With the Access Control Policy and firearm prohibition by Project personnel, poaching and non-Indigenous hunting of moose, elk, and grizzly bear will decline in the WLSA during the life of mine and may result in increased abundance of moose, elk, and grizzly bear in the areas accessible by Indigenous groups (EIA, CR#9, Section 5.6.2.1, CIAR#42).
	• A screening level wildlife risk assessment was conducted, the results of which indicate that there is no potential risk of adverse effects associated with Project emissions on the health of wildlife in the study areas (Addendum 10, Appendix 4.9-1, Section 8.0, Updated Human Health and Wildlife Screening Risk Assessment, CIAR#251).
	• The wildlife risk assessment was amended to include an evaluation of water-based exposure pathways (both groundwater and surface water) and the results presented for Blairmore Creek, Gold Creek and the Oldman Reservoir were not considered to be indicative of adverse effects (Addendum 11, JRP IR-6.28). For the proposed end pit lake (EPL) (at closure), the results of the risk assessment are not considered indicative of a human health concern; however, management considerations of the EPL are warranted and actual measured concentrations at the time of EPL creation should be used to revisit predicted effects (Addendum 11, JRP IR-6.27). The assessment includes an Indigenous-specific conceptual model, which describes source-pathway linkages between the Project and Indigenous use of all aquatic pathways including the end pit lake, Blairmore and Gold Creeks, the Crowsnest River and the Oldman Reservoir in the post closure landscape.
	2. Use or access to hunting locations and harvesting methods:
	• Where Project construction and operations activities overlap with hunting locations, access to active mining areas may be limited until they are reclaimed and safe. Indigenous groups will continue to have access to hunting and trapping locations where safety is not compromised (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• The Project's access restrictions within the mine permit area may also affect Indigenous groups' ability to use their preferred harvesting methods and seasonal rounds by altering the times of year that Indigenous groups have access to areas of interest for hunting within the mine permit area (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• The residual effects on trails and travelways was assessed as moderate magnitude
	• Increased noise, odour, and visual disturbance during construction and operation could affect use of locations and the experience of hunting within the vicinity of the Project (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89); residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42):
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	• Where Indigenous groups utilize firearms for hunting, the Project's firearms restriction policy would affect their ability to use that harvesting method within the mine footprint. Alternate hunting methods may be possible in parts of the mine footprint that have not yet been disturbed or which have been reclaimed under the AMP (Addendum 8, Appendix A-1, Section 15.2.1.1.3, CIAR#89).
	In summary, effects on linked VCs will act synergistically to change identified hunted species and habitat, change use or access to identified hunting locations, and change preferred harvesting methods. There will be residual effects on hunting for Ktunaxa Nation due to reduction in hunting opportunities, engagement in hunting, and hunting success during construction and operation due to loss of access to hunting locations, sensory disturbance, and change in wildlife use within the mine permit area.
		Residual effects on hunting are characterized as:
		• Magnitude is moderate because there is predicted to be a change in the ability to hunt in the area but this does not change the ability to hunt in the RSA. Although the Ktunaxa Nation has not identified site-specific hunting areas within the Project assessment area, hunting remains important to the Ktunaxa Nation for subsistence as well as guide-outfitting activities (Addendum 10, Appendix 4.1-1, Section 9.3.1.1, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency because loss of hunting opportunities will be continuous throughout construction and operation.
		• Reversibility is characterized as reversible because reclamation is planned and expected to re-establish natural processes and ecosystems that support hunted species and access will be restored following the AMP.
		• Ecological and social context is sensitive because the Project is in an area valued by Ktunaxa citizens for wildlife habitat for culturally-important species that are critical to Ktunaxa harvesting and stewardship and hunting remains important to the Ktunaxa Nation for subsistence as well as guide-outfitting activities (Addendum 10, JRP IR-4.6, Table 4.6-6, CIAR#251).

Table 6.7-7a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Ktunaxa Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Trapping	1. Trapped species and habitat:
	The Project will have temporary effects on land access for traditional resource use and on the distribution and abundance of species trapped for traditional purposes. Species preferring recently disturbed and young habitats are expected to return first, followed by species preferring increasingly older habitat types with reclamation.
	Canada Lynx:
	• There is a loss of lynx habitat in the WLSA. The loss of effective habitat, along with sensory disturbances associated with the Project, will likely displace lynx to other more suitable undisturbed habitats located west, north and east of the WLSA. Canada lynx rarely use the area around the access road, so it is not expected to have significant effects on lynx movement.
	American Marten:
	• There will be a temporary, long-term loss of habitat for American marten. Reclamation of disturbed areas will occur throughout and after the life of the Project; however, American martens prefer mature to old-growth coniferous forests, which will take many decades to become re-established. East-west movements of American marten will likely be affects by the Project footprint since they tend to avoid open landscapes. The access road and coal conveyor will also likely affect marten movements. North-south marten movements along Blairmore and Gold Creeks should be relatively unaffected by Project development. With mitigation, Project effects on American marten habitat availability and movement in the WLSA are expected to be local in extent, extended in duration, continuous in frequency, reversible in the long-term, moderate in magnitude for habitat availability and low for movement (EIA, CR#9, Section 5.3.6.1, CIAR#42).
	Wildlife Residual Effects (EIA, CR#9, Table 5.3-26, CIAR#42):
	• Effects on habitat availability for trapped species (lynx, American marten) due to vegetation clearing and sensory disturbance (due to increased noise, odour, visual disturbance) are moderate magnitude, negative Project contribution, and reversible in the long-term.
	• Effects on wildlife movement for trapped species (lynx, American marten) due to construction and operation are low magnitude, and reversible in the long-term.
	• Effects on wildlife abundance for trapped species (lynx, American marten) in hunting locations due to is low magnitude, negative Project contribution and, for American marten, reversible in the long-term and for the Canada lynx, reversible in the short term.
	• Effects on wildlife mortality risk for trapped species (lynx, American marten) due to construction activities, vehicle collisions, and human-wildlife conflicts are low magnitude, frequency is occasional, and reversible in the short term.
	2. Use or access to trapping locations and harvesting methods:
	• Where Project construction and operations activities overlap with hunting and trapping locations, access to active mining areas may be limited until they are reclaimed and safe. Indigenous groups will continue to have access to hunting and trapping locations where safety is not compromised (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• The Project's access restrictions within the mine permit area may also affect Indigenous groups' ability to use their preferred harvesting methods and seasonal rounds by altering the times of year that Indigenous groups have access to areas of interest for hunting/trapping within the mine permit area (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• Loss or disruption of traplines or trails used for trapping and loss of access to trapping locations due to the mine site and road closure during construction and operation. The residual effects on trails and travelways was assessed as low magnitude.
	• Increased noise, odour, and visual disturbance during construction and operation could affect use of locations and the experience of hunting within the vicinity of the Project (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89); residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42):
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change identified trapped species and habitat, change use or access to identified trapping locations, and change preferred harvesting methods. There will be residual effects on trapping for Ktunaxa Nation due to reduction or loss of trapping opportunities and the change in trapping methods could affect the cultural and spiritual relationship between the Nation and their territory, which is addressed below.
		Residual effects on trapping are characterized as:
		• Magnitude is low because there is predicted to be a change in the ability to trap in the area but this does not change the ability of Ktunaxa Nation to trap in the RSA. The Ktunaxa Nation do not currently actively trap within the Project assessment area: the Nation has not identified site-specific trapping in the Project assessment area (Addendum 10, Appendix 4.1-1, Section 9.3.1.2, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency because loss of trapping opportunities will be continuous throughout construction and operation.
		• Reversibility is characterized as reversible because reclamation is planned and expected to re-establish natural processes and ecosystems that support trapped species and access will be restored following the AMP.
		• Ecological and social context is sensitive because the Project area and Crowsnest Pass contain ecological values tied to harvesting practices, including trapping and current use of the Project assessment area for trapping has been impeded since coal mining began in the 1900s (Addendum 10, JRP IR-4.6, Table 4.6-6 CIAR#251).

Table 6.7-7a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Ktunaxa Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Fishing	1. Fishing species and habitat:
	Westslope Cutthroat Trout (WSCT)
	• The physical footprint of surface water management infrastructure and open pits will cause permanent change to WSCT habitat. The loss of riparian and aquatic habitat will be reversed by gains achieved through implementing an Offsetting Plan approved by DFO. The magnitude of this effect will be moderate, the duration is long, the frequency will be continuous, however, reversibility is characterized as reversible in the long-term. (Addendum 1, CR#6, Section 4.5, CIAR#44).
	• Changes in hydrology will cause alteration in WSCT aquatic habitat of Gold and Blairmore creeks. The alteration of habitat will be offset by gains achieved through implementing an Offsetting Plan approved by DFO. The magnitude of residual adverse effects will be moderate, the duration is extended, the frequency will be continuous, however, reversibility is characterized as reversible in the long-term. (Addendum 1, CR#6, Section 4.5, CIAR#44).
	2. Use or access to fishing locations and harvesting methods:
	• Current access to the portions of the watercourses adjacent to Grassy Mountain is located on Benga private land. During construction and operation phases of the mine, this road will be closed to the general public, and alternate routes will need to be used to access and fish those portions of Blairmore and Gold Creeks (Addendum 8, Appendix A-1, Section 15.2.2.1.2, CIAR#89) which will be managed *via* the AMP.
	• Loss or disruption of trails for accessing fishing locations due to the mine site and road closure during construction and operation. The residual effects on trails and travelways was assessed as low magnitude (Addendum 10, Appendix 4.1-1, Section 9.3.3.5, CIAR#251).
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of fishing locations by Indigenous Nations and preferred harvesting method.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1 CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change use or access to identified fishing locations, and change preferred harvesting methods. There will be residual effects on fishing for Ktunaxa Nation due to reduction in fishing opportunities, engagement in fishing, and fishing success during construction and operation due to loss of access to fishing locations and sensory disturbance within the mine permit area.
		Residual effects on fishing are characterized as:
		• Magnitude is low because there is predicted to be a change in the ability to fish in the area but this does not change the ability of Ktunaxa Nation to fish in the RSA. The Ktunaxa Nation does not currently actively fish within the Project assessment area and has not identified site-specific current use in the Project area for fishing. Historical fishing locations identified in literature are located outside of the Project assessment area (Addendum 10, Appendix 4.1-1, Section 9.3.1.3, CIAR#251). There is predicted to be a change in the ability to fish for Ktunaxa Nation.
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because access restrictions will apply beyond the life of the mine in some areas that may affect access to fishing locations.
		• Continuous frequency because loss of fishing opportunities will be continuous throughout construction and operation.
		• Reversibility is characterized as reversible because offsetting is planned and expected to maintain fish populations and access will be restored following the AMP.
		• Ecological and social context is resilient because the Ktunaxa Nation does not currently actively fish in the Project area and has not identified site-specific current use in the Project area for fishing. Fishing locations are located outside of the LSA (Addendum 10, Appendix 4.1-1, Section 9.3.1.3, CIAR#251). Therefore, Ktunaxa Nation engagement in fishing is not sensitive to disruption from the Project.

Plant Gathering	1. Plant species and habitat:
	• The Project will result in loss of traditional use of vegetation within the vegetation local study area. Residual effects to TEK vegetation are local, long-term in duration, continuous, reversible and high magnitude. The Project will have a neutral contribution with respect to valued species and communities. After reclamation, the reclaimed land will support a range of communities with equivalent capabilities to those of the surrounding lands and that existing prior to Project development.
	• Residual adverse effects on vegetation were assessed as high magnitude for rare plants, community diversity, and TEK species, low magnitude for forest, and moderate for wetlands (EIA, CR#8, Section 4.0, CIAR#42).
	• Duration of effects on vegetation will be extended. Reclaimed land will require time to return the ecosystem to a condition that supports traditional use plants (EIA, CR#8, Section 4.1, CIAR#42).
	• Frequency of effects on vegetation, including rare plants and rare plant communities and traditional ecological knowledge, will be continuous through the operational phase of the project and cease only after reclamation is completed (EIA, CR#8, Section 4.0, CIAR#42).
	• Effects on vegetation are reversible in the long-term with the implementation of progressive reclamation (EIA, CR#8, Section 4.0, CIAR#42).
	2. Use or access to plant gathering locations and harvesting methods:
	• Loss or disruption of trails, loss of access to plant gathering locations, and loss of and preferred methods for plant gathering due to the mine site and access road. Residual effects on trails and travelways was assessed as low magnitude.
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of plant gathering locations by Indigenous Nations and preferred harvesting method.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42,).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3 CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change identified plant gathering species and habitat, change use or access to identified harvesting locations, and change preferred harvesting methods. There will be residual effects on plant gathering for Ktunaxa Nation due to reduction in harvesting opportunities, engagement in plant gathering, and harvesting success during construction and operation due to loss of access to plant gathering locations and sensory disturbance within the mine permit area.
		Residual effects on plant gathering are characterized as:
		• Magnitude is low. The Ktunaxa Nation did not identify site-specific current use of plant gathering in and around the Project area, therefore the magnitude of effect has been characterized as low (Section 9.3.1.4, Appendix 4.1-1, Addendum 10).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine.
		• Reversibility is characterized as reversible because reclamation (of terrain, soil, vegetation) is planned and expected to re-establish natural processes and ecosystems that support traditional use plants (high density planting of disease-resistant whitebark pine seedlings will contribute to the successful re-establishment of the native ecosystem); and, access to plant gathering locations will be re-established after mine closure.
		• Ecological and social context is resilient because Ktunaxa Nation current plant gathering sites are outside the Project area (*e.g.,* Crowsnest Pass) and Ktunaxa Nation did not identify site-specific current use in the Project area for plant gathering. Therefore, Ktunaxa Nation engagement in plant gathering is not sensitive to disruption from the Project.

Table 6.7-7a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Ktunaxa Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Trails and Travelways	1. Use or access to trails and travelways:
	• Loss or disruption of trails and travelways due to the mine site and access road. The Project will have residual adverse effects on use of trails and travelways because the Project could result in loss of trails and travelways that are fully or partially within the mine permit boundary.
	• The Project footprint will be reclaimed to land use capability equivalent to pre-mining; however, it will not be accessible for use as trails and travelways during construction and operations. Access to areas around the Project will be possible using existing trails from Highway 40 to reach the area west of Blairmore Creek and Crown Land north of the Project and from either the north or the south along the Gold Creek. With the implementation of the AMP, potential residual effects will be further reduced as Benga will be providing access to adjacent privately owned Benga lands for traditional practices (Addendum 10, Appendix 4.1-1, Section 9.3.3.5, CIAR#251).
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of trails and travelways by Indigenous Nations.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	2. Features associated with trails and travelways:
	• Loss or disturbance to features associated with trails and travelways due to the mine site and access road.
	• Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42).
	• Residual adverse effects on access and utilities in the Lands and Resource Use VC was assessed as nil magnitude after reclamation (EIA, CR#10, CIAR#42).
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42).
	• Residual effects will extend beyond the mine footprint but limited to within the zone of influence (generally 1.5 km) for noise, visual disturbance, and effect on access (EIA, CR#2, CIAR#42).
	• The geographic extent of residual effects on historical resources and on land and resource use is characterized as local (EIA, CR#10, Section E, CIAR#42).
	• The frequency of impact on access and utilities in the lands and resource use is continuous (EIA, CR#2, CIAR#42).
	• The frequency of impact of noise and other disturbances to trail use will continue throughout the Project lifespan (EIA, CR#2, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change use or access and change preferred trails and travelways. There will be residual effects on trails and travelways for Ktunaxa Nation due to restriction in use or access, and engagement with features associated with trails and travelways during construction and operation due to loss of access to trails and travelways locations, sensory disturbance, and change in use within the mine permit area.
		Residual effects on trails and travelways are characterized as:
		• Magnitude is low because although there is predicted to be a change in the ability access routes by Ktunaxa Nation in the Project area and there are several trails and travelways used by the Ktunaxa Nation for movement through the Rocky Mountains that directly intersect the Project area, the Ktunaxa Nation does not currently actively use the trails and travelways that are within the Project assessment area (Addendum 10, Appendix 4.1-1, Section 9.3.1.5, CIAR#251). This will not change the ability of Ktunaxa Nation to access trails and travelways in the RSA.
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency during construction and operation due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine.
		• Non-reversible where trails and travelways are lost because when a trail is inaccessible it will not be maintained or used, resulting in the potential loss of the knowledge of or loss of the physical trail or travelway.
		• Ecological and social context is resilient because Ktunaxa Nation does not currently actively use the trails and travelways within the Project area (Addendum 10, Appendix 4.1-1, Section 9.3.1.5, CIAR#251). Trails and travelways used by the Ktunaxa Nation for movement through the Rocky Mountains to and from the plains intersect areas to the north and south of the Project. Therefore, Ktunaxa Nation trails and travelways is not sensitive to disruption from the Project.

Cultural and Spiritual Values	1. Use and access to sacred important sites with cultural or spiritual value: • Residual adverse effects on access and utilities in the Lands and Resource Use VC was assessed as nil magnitude (EIA, CR#10, CIAR#42). • Loss or disruption of trails to important sites due to the mine site and access road. • Loss of hunting, trapping, fishing, and plant gathering opportunities. The residual effects, as seen above, on hunting was assessed as moderate magnitude, and trapping, plant gathering and fishing were assessed as low magnitude. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect use and enjoyment of culturally and spiritually important sites. Increased noise levels extend 1.5 km from the Project (EIA, CR#2, CIAR#42). Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). • Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42). 2. Experience of engaging with sites of cultural or spiritual value: • Loss or disturbance to important sites due to the mine site and access road. • Loss of experience in hunting, trapping, fishing, and plant gathering, which could affect the cultural and spiritual relationships with the resource. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect enjoyment or experience of using culturally and spiritually important sites. 3. Cultural values associated with sites/features • Loss of hunting, trapping, fishing, and plant gathering opportunities, which could affect intergenerational teaching of traditional practices, and result in loss of cultural identity, sense of place, and human health/well-being. • Loss of access to sites/features due to construction and operation activities. • Loss of or damage to unique sites and special features as a result of clearing and construction activities. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect enjoyment or experience of engaging with the sites/features of cultural or spiritual value. In summary, effects on linked VCs will act synergistically to change use or access to sites with cultural or spiritual value, change the experience of using these sites, and change the cultural value associated with sites and features. There will be residual effects on cultural and spiritual values for Ktunaxa Nation during construction and operation due to loss of access to culturally or spiritually important sites and sensory disturbance within the mine permit area.	Residual effects on cultural and spiritual values is characterized as: • Magnitude is moderate because there is predicted to be a change in cultural and spiritual values for the Ktunaxa Nation in the Project area. The Ktunaxa Nation has expressed that the Project area and the Crowsnest Pass contain a multitude of ecological values tied to cultural and spiritual use and stewardship of the landscape. Hunting, fish, and plant gathering have important cultural and spiritual considerations, including sharing intergenerational knowledge during these activities (Addendum 10, Appendix 4.1-1, Section 9.3.1.6, CIAR#251). • Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA. • Long-term duration because the loss of experience in hunting, trapping, fishing, and plant gathering could affect the long-term cultural and spiritual relationships between Indigenous groups and their resources and territory. Change in land use and access will extend beyond the Project lifespan. • Continuous frequency during due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine. • Non-reversible because loss of cultural and spiritual sites and experience in engaging in land use could result in loss of the knowledge of cultural and spiritual values. • Ecological and social context is sensitive because loss of engagement in land use affects cultural identity, human well-being and relationships, and intergenerational transfer of knowledge. Archival and oral histories indicate that the Ktunaxa rely on the Project area for preferred cultural-spiritual practices including teaching of oral histories and transmission of knowledge (Addendum 10, JRP IR-4.6, Table 4.6-6, CIAR#251).

Table 6.7-7a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Ktunaxa Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC
Physical and Cultural Heritage	1. Physical and cultural heritage: • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities. • The geographic extent of residual effects on historical resources is local (EIA, Section E, CIAR#42). 2. Access to physical and cultural heritage: • Loss or disruption of trails to unique sites and special features associated with physical or cultural heritage due to the mine site and access road. • The magnitude of effects on trails and travelways was characterized as low. 3. Cultural value and importance associated with physical and cultural heritage: • Increase in noise, odour, and visual disturbance during construction and operation could result in reduced engagement with the sites/features of cultural value. • Magnitude was assessed as high for TEK plant species (CEAR #42, EIA, CR#8) whereas magnitude is low to moderate for hunted and trapped wildlife (CEAR #42, EIA, CR#9). • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities. • The magnitude of effects on cultural and spiritual values was characterized as moderate. 4. Relationship with physical and cultural heritage: • Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42) and access and utilities in the Lands and Resource Use VC was assessed as nil magnitude (EIA, CR#10, CIAR#42), but for those VCs that affect the relationships with physical and cultural heritage (*e.g.*, air quality, noise, plant gathering, hunting and trapping), magnitude is assessed as high for odour and low to moderate for emissions including dust (EIA, CR#1 CIAR#42), moderate for hunting, and low for plant gathering, trapping and fishing. • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities could result in loss of relationship with heritage. • Loss of hunting, trapping, fishing, and plant gathering opportunities due to construction and operation and access restrictions could result in loss of relationship with wildlife and cultural practices. • Increase in noise, odour, and visual disturbance during construction and operation could result in reduced engagement with the sites/features associated with physical or cultural heritage. In summary, effects on linked VCs will act synergistically to change use or access to physical and cultural heritage, change the value and importance, and change the relationship the Ktunaxa Nation have with these sites. There will be residual effects on Indigenous physical and cultural heritage for Ktunaxa Nation during construction and operation due to loss of access and sensory disturbance within the mine permit area.	Residual effects on Indigenous physical and cultural heritage are characterized as: • Magnitude is moderate because there is predicted to be a change in access to or engagement with physical and cultural heritage for the Ktunaxa Nation in the area, but this does not change access to or engagement with physical and cultural heritage in the RSA. The Ktunaxa Nation identified several cultural, ceremonial and spiritual sites throughout the Crowsnest Pass including during visits to the Project area. One site-specific cultural site was reported in the category of cultural activity within the LSA (unclear whether this is in a cultural heritage site or an area of use) (Addendum 10, Appendix 4.1-1, Section 9.3.1.6, CIAR#251). • Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA. • Long-term duration because disturbance to or loss of unique sites and features will extend beyond the Project lifespan. • Regular frequency because disturbance to unique sites and features will occur during construction and operation activities whenever sites or features are discovered. • Non-reversible because loss of heritage sites and features and experience in engaging in land use could result in loss of the knowledge of cultural heritage. • Ecological and social context is sensitive because loss of heritage sites and features or loss of engagement with physical and cultural heritage affects cultural identity, human well-being, and intergenerational transfer of knowledge. Certain sites and areas are considered especially sensitive, sacred, and tied to Ktunaxa Nation oral history (Addendum 10, JRP IR-4.6, Table 4.6-6, CIAR#251).

In summary, the residual effects characterization has not changed greatly from that already provided. The changes from the previous effects characterization is that the magnitude for trapping and trails and travelways have been corrected from moderate to low, and the physical and cultural heritage reversibility has been corrected from reversible to not-reversible for the reasons explained above. As such, the summary Table 9.4.4-1 from *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups* (Appendix 4.1-1, Addendum 10, CIAR#251) is provided below with these corrections, and is presented as Table 6.7-7b.

Table 6.7-7b Summary of Residual Effects to the Ktunaxa Nation [Source: Table 9.4.4-1, *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups* Appendix 4.1-1, Addendum 10, CIAR#251]

Valued Components	Magnitude	Geographic Extent	Duration	Frequency	Reversibility	Ecological and Social Context	Significance
Hunting	Moderate	Local	Long-term	Continuous	Reversible	Sensitive	Not significant
Trapping	Low	Local	Long-term	Continuous	Reversible	Sensitive	Not significant
Fishing	Low	Local	Long-term	Continuous	Reversible	Resilient	Not significant
Plant Gathering	Low	Local	Long-term	Continuous	Reversible	Resilient	Not significant
Trails and Travelways	Low	Local	Long-term	Continuous	Not Reversible where trails and travelways are lost	Resilient	Not significant
Cultural and Spiritual Values	Moderate	Local	Long-term	Continuous	Not Reversible	Sensitive	Not significant
Indigenous Physical and Cultural Heritage	Moderate	Local	Long-term	Regular	Not Reversible	Sensitive	Not significant

Description and Characterization of Residual Effects on the Samson Cree Nation

The description and characterization of residual effects on the Samson Cree Nation are found below in Table 6.7-8a. A summary table of this characterization was provided as Table 10.4.2-1 (Appendix 4.1-1: *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups*, Addendum 10, CIAR#251), and is copied below for the convenience of the reader, and presented as Table 6.7-8b.

Table 6.7-8a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Samson Cree Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Hunting	1. Hunted species and habitat:
	The Project will have temporary effects on land access for traditional resource use and on the distribution and abundance of species hunted for traditional purposes.
	Species preferring recently disturbed and young habitats are expected to return first, followed by species preferring increasingly older habitat types with reclamation.
	Moose and Elk:
	• Suitable moose and elk habitat will decline initially but is predicted to be more abundant than baseline levels by end of mine due, in part, to reclamation of legacy mine sites that overlap the Project footprint (EIA, CR#9, Section 5.6.2.1, CIAR#42).
	• The changes in abundance of moose and elk year-round in the WLSA are expected to follow a similar pattern as individuals of both species will be displaced into adjacent habitats.
	Grizzly Bear:
	• Highly suitable grizzly bear habitat in the WLSA will decrease initially during the construction and operation phases and then increase throughout the duration of progressive reclamation. Mortality risk also increases with Project development but then decreases with progressive reclamation. With reclamation, the Project footprint is expected to offer more suitable habitat (dietary resources) and lower mortality risk than under baseline conditions, which are anticipated to allow for an increase in the size of the grizzly bear population that the local area can support.
	Wildlife Residual Effects (EIA, CR#9, Table 5.3-26, CIAR#42):
	• Effects on habitat availability for hunted species (moose, elk, grizzly bear) due to vegetation clearing and sensory disturbance (due to increased noise, odour, visual disturbance) are low magnitude, positive Project contribution, and reversible in the long-term.
	• Effects on wildlife movement for hunted species (moose, elk, grizzly bear) due to construction and operation are low magnitude, and reversible in the long-term.
	• Effects on wildlife abundance for hunted species (moose, elk, grizzly bear) in hunting location is low magnitude, positive Project contribution for elk and grizzly bear, neutral Project contribution for moose, and reversible in the long-term.
	• Effects on wildlife mortality risk for hunted species due to construction activities, vehicle collisions, and human-wildlife conflicts are low magnitude, frequency is occasional, and reversible in the long-term. With the Access Control Policy and firearm prohibition by Project personnel, poaching and non-Indigenous hunting of moose, elk, and grizzly bear will decline in the WLSA during the life of mine and may result in increased abundance of moose, elk, and grizzly bear in the areas accessible by Indigenous groups (EIA, CR#9, Section 5.6.2.1, CIAR#42).
	• A screening level wildlife risk assessment was conducted, the results of which indicate that there is no potential risk of adverse effects associated with Project emissions on the health of wildlife in the study areas (Addendum 10, Appendix 4.9-1, Section 8.0, Updated Human Health and Wildlife Screening Risk Assessment, CIAR#251).
	• The wildlife risk assessment was amended to include an evaluation of water-based exposure pathways (both groundwater and surface water) and the results presented for Blairmore Creek, Gold Creek and the Oldman Reservoir were not considered to be indicative of adverse effects (Addendum 11, JRP IR-6.28). For the proposed end pit lake (EPL) (at closure), the results of the risk assessment are not considered indicative of a human health concern; however, management considerations of the EPL are warranted and actual measured concentrations at the time of EPL creation should be used to revisit predicted effects (Addendum 11, JRP IR-6.27). The assessment includes an Indigenous-specific conceptual model, which describes source-pathway linkages between the Project and Indigenous use of all aquatic pathways including the end pit lake, Blairmore and Gold Creeks, the Crowsnest River and the Oldman Reservoir in the post closure landscape.
	2. Use or access to hunting locations and harvesting methods:
	• Where Project construction and operations activities overlap with hunting locations, access to active mining areas may be limited until they are reclaimed and safe. Indigenous groups will continue to have access to hunting and trapping locations where safety is not compromised (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• The Project's access restrictions within the mine permit area may also affect Indigenous groups' ability to use their preferred harvesting methods and seasonal rounds by altering the times of year that Indigenous groups have access to areas of interest for hunting within the mine permit area (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• The residual effects on trails and travelways was assessed as low magnitude
	• Increased noise, odour, and visual disturbance during construction and operation could affect use of locations and the experience of hunting within the vicinity of the Project (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89); residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42):
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	• Where Indigenous groups utilize firearms for hunting, the Project's firearms restriction policy would affect their ability to use that harvesting method within the mine footprint. Alternate hunting methods may be possible in parts of the mine footprint that have not yet been disturbed or which have been reclaimed under the AMP (Addendum 8, Appendix A-1, Section 15.2.1.1.3, CIAR#89).
	In summary, effects on linked VCs will act synergistically to change identified hunted species and habitat, change use or access to identified hunting locations, and change preferred harvesting methods. There will be residual effects on hunting for Samson Cree Nation due to reduction in hunting opportunities, engagement in hunting, and hunting success during construction and operation due to loss of access of hunting locations, sensory disturbance, and change in wildlife use within the mine permit area.
		Residual effects on hunting are characterized as:
		• Magnitude is low because, although the Samson Cree Nation continue to hunt throughout their traditional territory, no site-specific locations, seasonal use, or methods have been identified for hunting in the Project area (Addendum 10, Appendix 4.1-1, Sections 10.3.1.1 and 10.3.2.1, CIAR#251). Therefore, there is predicted to be little change in the ability to hunt for the Samson Cree Nation.
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency because loss of hunting opportunities will be continuous throughout construction and operation.
		• Reversible because reclamation is planned and expected to re-establish natural processes and ecosystems that support hunted species and access will be restored following the AMP.
		• Ecological and social context is resilient because, as Samson Cree Nation did not identify hunting areas in the Project area and important cultural areas for Samson Cree Nation are outside the LSA, Samson Cree Nation engagement in hunting is considered not sensitive to disruption from the Project.

Table 6.7-8a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Samson Cree Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Trapping	1. Trapped species and habitat:
	The Project will have temporary effects on land access for traditional resource use and on the distribution and abundance of species trapped for traditional purposes. Species preferring recently disturbed and young habitats are expected to return first, followed by species preferring increasingly older habitat types with reclamation.
	Canada Lynx:
	• There is a loss of lynx habitat in the WLSA. The loss of effective habitat, along with sensory disturbances associated with the Project, will likely displace lynx to other more suitable undisturbed habitats located west, north and east of the WLSA. Canada lynx rarely use the area around the access road, so it is not expected to have significant effects on lynx movement.
	American Marten:
	• There will be a temporary, long-term loss of habitat for American marten. Reclamation of disturbed areas will occur throughout and after the life of the Project; however, American martens prefer mature to old-growth coniferous forests, which will take many decades to become re-established. East-west movements of American marten will likely be affects by the Project footprint since they tend to avoid open landscapes. The access road and coal conveyor will also likely affect marten movements. North-south marten movements along Blairmore and Gold Creeks should be relatively unaffected by Project development. With mitigation, Project effects on American marten habitat availability and movement in the WLSA are expected to be local in extent, extended in duration, continuous in frequency, reversible in the long-term, moderate in magnitude for habitat availability and low for movement (EIA, CR#9, Section 5.3.6.1, CIAR#42).
	Wildlife Residual Effects (EIA, CR#9, Table 5.3-26, CIAR#42):
	• Effects on habitat availability for trapped species (lynx, American marten) due to vegetation clearing and sensory disturbance (due to increased noise, odour, visual disturbance) are moderate magnitude, negative Project contribution, and reversible in the long-term.
	• Effects on wildlife movement for trapped species (lynx, American marten) due to construction and operation are low magnitude, and reversible in the long-term.
	• Effects on wildlife abundance for trapped species (lynx, American marten) in hunting locations due to is low magnitude, negative Project contribution and, for American marten, reversible in the long-term and for the Canada lynx, reversible in the short term.
	• Effects on wildlife mortality risk for trapped species (lynx, American marten) due to construction activities, vehicle collisions, and human-wildlife conflicts are low magnitude, frequency is occasional, and reversible in the short term.
	2. Use or access to trapping locations and harvesting methods:
	• Where Project construction and operations activities overlap with hunting and trapping locations, access to active mining areas may be limited until they are reclaimed and safe. Indigenous groups will continue to have access to hunting and trapping locations where safety is not compromised (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• The Project's access restrictions within the mine permit area may also affect Indigenous groups' ability to use their preferred harvesting methods and seasonal rounds by altering the times of year that Indigenous groups have access to areas of interest for hunting/trapping within the mine permit area (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• Loss or disruption of traplines or trails used for trapping and loss of access to trapping locations due to the mine site and road closure during construction and operation. The residual effects on trails and travelways was assessed as low magnitude.
	• Increased noise, odour, and visual disturbance during construction and operation could affect use of locations and the experience of hunting within the vicinity of the Project (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89); residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42):
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change identified trapped species and habitat, change use or access to identified trapping locations, and change preferred harvesting methods. There will be residual effects on trapping for Samson Cree Nation due reduction or loss of trapping opportunities and the change in trapping methods could affect the cultural and spiritual relationship between the Nation and their territory, which is addressed below.
		Residual effects on trapping are characterized as:
		• Magnitude is low because, although the Samson Cree Nation have advised that they have an interest in trapping in the Project area, no specific locations, seasonal use, or methods have been identified for trapping in the Project area (Addendum 10, Appendix 4.1-1, Section 10.3.1.2, CIAR#251). Therefore, there is predicted to be little change in the ability to trap for the Samson Cree Nation.
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency because loss of hunting opportunities will be continuous throughout construction and operation.
		• Reversible because reclamation is planned and expected to re-establish natural processes and ecosystems that support hunted species and access will be restored following the AMP.
		• Ecological and social context resilient because, as Samson Cree Nation did not identify trapping areas in the Project area and important cultural areas for Samson Cree Nation are outside the LSA, Samson Cree Nation engagement in trapping is considered not sensitive to disruption from the Project.

Table 6.7-8a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Samson Cree Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Fishing	1. Fishing species and habitat:
	Westslope Cutthroat Trout (WSCT)
	• The physical footprint of surface water management infrastructure and open pits will cause permanent change to WSCT habitat. The loss of riparian and aquatic habitat will be reversed by gains achieved through implementing an Offsetting Plan approved by DFO. The magnitude of this effect will be moderate, the duration is long, the frequency will be continuous, however, reversibility is characterized as reversible in the long-term. (Addendum 1, CR#6, Section 4.5, CIAR#44).
	• Changes in hydrology will cause alteration in WSCT aquatic habitat of Gold and Blairmore creeks. The alteration of habitat will be offset by gains achieved through implementing an Offsetting Plan approved by DFO. The magnitude of residual adverse effects will be moderate, the duration is extended, the frequency will be continuous, however, reversibility is characterized as reversible in the long-term. (Addendum 1, CR#6, Section 4.5, CIAR#44).
	2. Use or access to fishing locations and harvesting methods:
	• Current access to the portions of the watercourses adjacent to Grassy Mountain is located on Benga private land. During construction and operation phases of the mine, this road will be closed to the general public, and alternate routes will need to be used to access and fish those portions of Blairmore and Gold Creeks (Addendum 8, Appendix A-1, Section 15.2.2.1.2, CIAR#89) which will be managed *via* the AMP.
	• Loss or disruption of trails for accessing fishing locations due to the mine site and road closure during construction and operation. The residual effects on trails and travelways was assessed as low magnitude.
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of fishing locations by Indigenous Nations and preferred harvesting method.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1 CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to use or access to identified fishing locations, and change in preferred harvesting methods. There will be residual effects on fishing for Samson Cree Nation due to reduction in fishing opportunities, engagement in fishing, and fishing success during construction and operation due to loss of access to fishing locations and sensory disturbance within the mine permit area.
		Residual effects on fishing are characterized as:
		• Magnitude is low because there is predicted to be little change in the ability to fish for the Samson Cree Nation. The Samson Cree Nation have advised that they have a fishing interest in the Project area. However, no site-specific information on fish or fishing areas, fishing seasons, or the importance of fishing in the Project area has been provided (Addendum 10, Appendix 4.1-1, Section 10.3.1.3, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because access restrictions will apply beyond the life of the mine in some areas that may affect access to fishing locations.
		• Continuous frequency because loss of fishing opportunities will be continuous throughout construction and operation.
		• Reversible because reclamation and offsetting is planned and expected maintain fish populations and access will be restored following the AMP.
		• Ecological and social context is resilient because, as Samson Cree Nation did not identify fishing in the Project area and important cultural areas for Samson Cree Nation are outside the LSA, Samson Cree Nation engagement in fishing is considered not sensitive to disruption from the Project.

Plant Gathering	1. Plant species and habitat:
	• The Project will result in loss of traditional use of vegetation within the vegetation local study area. Residual effects to TEK vegetation are local, long-term in duration, continuous, reversible and high magnitude. The Project will have a neutral contribution with respect to valued species and communities. After reclamation, the reclaimed land will support a range of communities with equivalent capabilities to those of the surrounding lands and that existing prior to Project development.
	• Residual adverse effects on vegetation were assessed as high magnitude for rare plants, community diversity, and TEK species, low magnitude for forest, and moderate for wetlands (EIA, CR#8, Section 4.0, CIAR#42).
	• Duration of effects on vegetation will be extended. Reclaimed land will require time to return the ecosystem to a condition that supports traditional use plants (EIA, CR#8, Section 4.1, CIAR#42).
	• Frequency of effects on vegetation, including rare plants and rare plant communities and traditional ecological knowledge, will be continuous through the operational phase of the project and cease only after reclamation is completed (EIA, CR#8, Section 4.0, CIAR#42).
	• Effects on vegetation are reversible in the long-term with the implementation of progressive reclamation (EIA, CR#8, Section 4.0, CIAR#42).
	2. Use or access to plant gathering locations and harvesting methods:
	• Loss or disruption of trails, loss of access to plant gathering locations, and loss of and preferred methods for plant gathering due to the mine site and access road. Residual effects on trails and travelways was assessed as low.
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of plant gathering locations by Indigenous Nations and preferred harvesting method.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42,).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3 CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change identified plant gathering species and habitat, change use or access to identified harvesting locations, and change in preferred harvesting methods. There will be residual effects on plant gathering for Samson Cree Nation due to reduction in harvesting opportunities, engagement in plant gathering, and harvesting success during construction and operation due to loss of access of plant gathering locations and sensory disturbance within the mine permit area.
		Residual effects on plant gathering are characterized as:
		• Magnitude is low because there is predicted to be little change in the ability to gather plants for the Samson Cree Nation. Although Samson Cree Nation stated that there are important gathering and cultivation sites in proximity to the Project for plants that are used for medicinal, ceremonial and dietary purposes as well as for traditional teachings, no site-specific information was provided (Addendum 10, Appendix 4.1-1, Section 10.3.1.4, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine.
		• Reversibility is characterized as reversible because reclamation (of terrain, soil, vegetation) is planned and expected to re-establish natural processes and ecosystems that support traditional use plants (high density planting of disease-resistant whitebark pine seedlings will contribute to the successful re-establishment of the native ecosystem); and, access to plant gathering locations will be re-established after mine closure.
		• Ecological and social context is resilient because important cultural areas for Samson Cree Nation are outside the LSA and the Project area is marginally used by Samson Cree Nation for plant gathering. Therefore, Samson Cree Nation engagement in plant gathering is considered not sensitive to disruption from the Project.

Table 6.7-8a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Samson Cree Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Trails and Travelways	1. Use or access to trails and travelways:
	• Loss or disruption of trails and travelways due to the mine site and access road. The Project will have residual adverse effects on use of trails and travelways because the Project could result in loss of trails and travelways that are fully or partially within the mine permit boundary.
	• The Project footprint will be reclaimed to land use capability equivalent to pre-mining; however, it will not be accessible for use as trails and travelways during construction and operations. Access to areas around the Project will be possible using existing trails from Highway 40 to reach the area west of Blairmore Creek and Crown Land north of the Project and from either the north or the south along the Gold Creek. With the implementation of the AMP, potential residual effects will be further reduced as Benga will be providing access to adjacent privately owned Benga lands for traditional practices (Addendum 10, Appendix 4.1-1, Section 10.3.3.5, CIAR#251).
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of trails and travelways by Indigenous Nations.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	2. Features associated with trails and travelways:
	• Loss or disturbance to features associated with trails and travelways due to the mine site and access road.
	• Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42).
	• Residual adverse effects on access and utilities in the Lands and Resource Use VC was assessed as nil magnitude after reclamation (EIA, CR#10, CIAR#42).
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42).
	• Residual effects will extend beyond the mine footprint but limited to within the zone of influence (generally 1.5 km) for noise, visual disturbance, and effect on access (EIA, CR#2, CIAR#42).
	• The geographic extent of residual effects on historical resources and on land and resource use is characterized as local (EIA, CR#10, Section E, CIAR#42).
	• The frequency of impact on access and utilities in the lands and resource use is continuous (EIA, CR#2, CIAR#42).
	• The frequency of impact of noise and other disturbances to trail use will continue throughout the Project lifespan (EIA, CR#2, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change use or access and change preferred trails and travelways. There will be residual effects on trails and travelways for Samson Cree Nation due to restriction in use or access, and engagement with features associated with trails and travelways during construction and operation due to loss of access to trails and travelways locations, sensory disturbance, and change in use within the mine permit area.
		Residual effects on trails and travelways is characterized as:
		• Magnitude is low. Samson Cree Nation advised that trail networks are located throughout their traditional territory; however, they did not advise of any trails or travelways of importance or use in the Project area (Addendum 10, Appendix 4.1-1, Section 10.3.1.5, CIAR#251). There is predicted to be little change in the use or access to trails and travelways for the Samson Cree Nation.
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency during construction and operation due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine.
		• Reversible as Samson Cree Nation did not identify any trails or travelways in and around the Project area.
		• Ecological and social context is resilient because, as Samson Cree Nation did not identify trails and travelways in the Project area and important cultural areas for Samson Cree Nation are outside the LSA and accessible outside the Project area, Samson Cree Nation trails and travelways is considered not sensitive to disruption from the Project.

Cultural and Spiritual Values	1. Use and access to sacred important sites with cultural or spiritual value: • Residual adverse effects on access and utilities in the Lands and Resource Use VC was assessed as nil magnitude (EIA, CR#10, CIAR#42). • Loss or disruption of trails to important sites due to the mine site and access road. • Loss of hunting, trapping, fishing, and plant gathering opportunities. The residual effects, as seen above, on hunting, trapping and plant gathering were assessed as low magnitude. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect use and enjoyment of culturally and spiritually important sites. Increased noise levels extend 1.5 km from the Project (EIA, CR#2, CIAR#42). Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). • Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42). 2. Experience of engaging with sites of cultural or spiritual value: • Loss or disturbance to important sites due to the mine site and access road. • Loss of experience in hunting, trapping, fishing, and plant gathering, which could affect the cultural and spiritual relationships with the resource. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect enjoyment or experience of using culturally and spiritually important sites. 3. Cultural values associated with sites/features: • Loss of hunting, trapping, fishing, and plant gathering opportunities, which could affect intergenerational teaching of traditional practices, and result in loss of cultural identity, sense of place, and human health/well-being. • Loss of access to sites/features due to construction and operation activities. • Loss of or damage to unique sites and special features as a result of clearing and construction activities. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect enjoyment or experience of engaging with the sites/features of cultural or spiritual value. In summary, effects on linked VCs will act synergistically to change use or access to sites with cultural or spiritual value, change the experience of using these sites, and change the cultural value associated with sites and features. There will be residual effects on cultural and spiritual values for Samson Cree Nation during construction and operation due to loss of access to culturally or spiritually important sites and sensory disturbance within the mine permit area.	Residual effects on cultural and spiritual values are characterized as: • Magnitude is low. Samson Cree Nation notes the region of the Project holds spiritual importance for its members; however, they have not identified current or historic use for sacred sites, gathering sites, or habitation sites in the Project area (Addendum 10, Appendix 4.1-1, Section 10.3.1.6, CIAR#251). There is predicted to be little change in cultural and spiritual values for the Samson Cree Nation. • Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA. • Long-term duration because the loss of experience in hunting, trapping, fishing, and plant gathering could affect the long-term cultural and spiritual relationships between Indigenous groups and their resources and territory. Change in land use and access will extend beyond the Project lifespan. • Continuous frequency during due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine. • Non-reversible because loss of cultural and spiritual sites and experience in engaging in land use could result in loss of the knowledge of cultural and spiritual values. • Ecological and social context is resilient because, as Samson Cree Nation did not identify cultural and spiritual values in the Project area and important cultural areas for Samson Cree Nation are outside the LSA, Samson Cree Nation cultural and spiritual values is considered not sensitive to disruption from the Project.

Table 6.7-8a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Samson Cree Nation

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC
Physical and Cultural Heritage	1. Physical and cultural heritage: • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities. • The geographic extent of residual effects on historical resources is local (CEAR #42, EIA, Section E). 2. Access to physical and cultural heritage: • Loss or disruption of trails to unique sites and special features associated with physical or cultural heritage due to the mine site and access road. • The magnitude of effects on trails and travelways was characterized as low. 3. Cultural value and importance associated with physical and cultural heritage: • Increase in noise, odour, and visual disturbance during construction and operation could result in reduced engagement with the sites/features of cultural value. • Magnitude was assessed as high for TEK plant species (CEAR #42, EIA, CR#8), whereas magnitude is low to moderate for hunted and trapped wildlife (CEAR #42, EIA, CR#9). • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities. • The magnitude of effects on cultural and spiritual values was characterized as low. 4. Relationship with physical and cultural heritage: • Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42) and access and utilities in the Lands and Resource Use VC was assessed as nil magnitude (EIA, CR#10, CIAR#42), but for those VCs that affect the relationships with physical and cultural heritage (*e.g.,* air quality, noise, plant gathering, hunting and trapping), magnitude is assessed as high for odour and low to moderate for emissions including dust (EIA, CR#1 CIAR#42), and low for hunting, trapping and plant gathering. • Loss of or damage to unique sites and special features associated with physical or cultural heritage as a result of clearing and construction activities could result in loss of relationship with heritage. • Loss of hunting, trapping, fishing, and plant gathering opportunities due to construction and operation and access restrictions could result in loss of relationship with wildlife and cultural practices. • Increase in noise, odour, and visual disturbance during construction and operation could result in reduced engagement with the sites/features associated with physical or cultural heritage. In summary, effects on linked VCs will act synergistically to change use or access to physical and cultural heritage, change the value and importance, and change the relationship the Samson Cree Nation have with these sites. There will be residual effects on Indigenous physical and cultural heritage for Samson Cree Nation during construction and operation due to loss of access and sensory disturbance within the mine permit area.	Residual effects on Indigenous physical and cultural heritage are characterized as: • Magnitude is low. Although the Samson Cree Nation have advised that they have an interest in hunting, trapping, fishing, and plant gathering in the Project area, no specific locations, seasonal use, or methods have been identified in the Project area (Addendum 10, Appendix 4.1-1, Section 10.3, CIAR#251). Samson Cree Nation did not identify current or historic use for sacred sites, gathering sites, or habitation sites in the Project area (Addendum 10, Appendix 4.1-1, Section 10.3.1.6, CIAR#251). • Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA. • Long-term duration because disturbance to or loss of unique sites and features will extend beyond the Project lifespan. • Regular frequency because disturbance to unique sites and features will occur during construction and operation activities whenever sites or features are discovered. • Non-reversible because loss of heritage sites and features and experience in engaging in land use could result in loss of the knowledge of cultural heritage. • Ecological and social context is resilient because, as Samson Cree Nation did not identify physical or cultural heritage sites in the Project area and important cultural areas for Samson Cree Nation are outside the LSA, Samson Cree Nation physical and cultural heritage is considered not sensitive to disruption from the Project.

In summary, the residual effects characterization has not greatly changed from that already provided. The only change from the previous effects characterization is that the frequency for physical and cultural heritage has been corrected from continuous to regular for the reasons explained above. As such, the summary Table 10.4.2-1 from *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups* (Appendix 4.1-1, Addendum 10, CIAR#251) is provided below, as Table 6.7-8b.

Table 6.7-8b Summary of Residual Effects on the Samson Cree Nation [Source: Table 10.4.2-1, An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups Appendix 4.1-1, Addendum 10, CIAR#251]

Valued Components	Magnitude	Geographic Extent	Duration	Frequency	Reversibility	Ecological and Social Context	Significance
Hunting and Trapping	Low	Local	Long-term	Continuous	Reversible	Resilient	Not significant
Fishing	Low	Local	Long-term	Continuous	Reversible	Resilient	Not significant
Plant Gathering	Low	Local	Long-term	Continuous	Reversible	Resilient	Not significant
Trails and Travelways	Low	Local	Long-term	Continuous	Reversible	Resilient	Not significant
Cultural and Spiritual Values	Low	Local	Long-term	Continuous	Not Reversible	Resilient	Not significant
Indigenous Physical and Cultural Heritage	Low	Local	Long-term	Regular	Not reversible	Resilient	Not significant

Description and Characterization of Residual Effects on the Metis Nation of Alberta

The description and characterization of residual effects on the Metis Nation of Alberta are found below in Table 6.7-9a. A summary table of this characterization was provided as Table 13.4.2-1 (Appendix 4.1-1: *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups*, Addendum 10, CIAR#251), and is copied below for the convenience of the reader, as Table 6.7-9b. The results of the characterization are not changed from the conclusions reached in Appendix 4.1-1.

Table 6.7-9a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Métis Nation of Alberta

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Hunting	1. Hunted species and habitat:
	The Project will have temporary effects on land access for traditional resource use and on the distribution and abundance of species hunted for traditional purposes.
	Species preferring recently disturbed and young habitats are expected to return first, followed by species preferring increasingly older habitat types with reclamation.
	Moose and Elk:
	• Suitable moose and elk habitat will decline initially but is predicted to be more abundant than baseline levels by end of mine due, in part, to reclamation of legacy mine sites that overlap the Project footprint (EIA, CR#9, Section 5.6.2.1, CIAR#42).
	• The changes in abundance of moose and elk year-round in the WLSA are expected to follow a similar pattern as individuals of both species will be displaced into adjacent habitats.
	Grizzly Bear:
	• Highly suitable grizzly bear habitat in the WLSA will decrease initially during the construction and operation phases and then increase throughout the duration of progressive reclamation. Mortality risk also increases with Project development but then decreases with progressive reclamation. With reclamation, the Project footprint is expected to offer more suitable habitat (dietary resources) and lower mortality risk than under baseline conditions, which are anticipated to allow for an increase in the size of the grizzly bear population that the local area can support.
	Wildlife Residual Effects (EIA, CR#9, Table 5.3-26, CIAR#42):
	• Effects on habitat availability for hunted species (moose, elk, grizzly bear) due to vegetation clearing and sensory disturbance (due to increased noise, odour, visual disturbance) are low magnitude, positive Project contribution, and reversible in the long-term.
	• Effects on wildlife movement for hunted species (moose, elk, grizzly bear) due to construction and operation are low magnitude, and reversible in the long-term.
	• Effects on wildlife abundance for hunted species (moose, elk, grizzly bear) in hunting location is low magnitude, positive Project contribution for elk and grizzly bear, neutral Project contribution for moose, and reversible in the long-term.
	• Effects on wildlife mortality risk for hunted species due to construction activities, vehicle collisions, and human-wildlife conflicts are low magnitude, frequency is occasional, and reversible in the long-term. With the Access Control Policy and firearm prohibition by Project personnel, poaching and non-Indigenous hunting of moose, elk, and grizzly bear will decline in the WLSA during the life of mine and may result in increased abundance of moose, elk, and grizzly bear in the areas accessible by Indigenous groups (EIA, CR#9, Section 5.6.2.1, CIAR#42).
	• A screening level wildlife risk assessment was conducted, the results of which indicate that there is no potential risk of adverse effects associated with Project emissions on the health of wildlife in the study areas (Addendum 10, Appendix 4.9-1, Section 8.0, Updated Human Health and Wildlife Screening Risk Assessment, CIAR#251).
	• The wildlife risk assessment was amended to include an evaluation of water-based exposure pathways (both groundwater and surface water) and the results presented for Blairmore Creek, Gold Creek and the Oldman Reservoir were not considered to be indicative of adverse effects (Addendum 11, JRP IR-6.28). For the proposed end pit lake (EPL) (at closure), the results of the risk assessment are not considered indicative of a human health concern; however, management considerations of the EPL are warranted and actual measured concentrations at the time of EPL creation should be used to revisit predicted effects (Addendum 11, JRP IR-6.27). The assessment includes an Indigenous-specific conceptual model, which describes source-pathway linkages between the Project and Indigenous use of all aquatic pathways including the end pit lake, Blairmore and Gold Creeks, the Crowsnest River and the Oldman Reservoir in the post closure landscape.
	2. Use or access to hunting locations and harvesting methods:
	• Where Project construction and operations activities overlap with hunting locations, access to active mining areas may be limited until they are reclaimed and safe. Indigenous groups will continue to have access to hunting and trapping locations where safety is not compromised (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• The Project's access restrictions within the mine permit area may also affect Indigenous groups' ability to use their preferred harvesting methods and seasonal rounds by altering the times of year that Indigenous groups have access to areas of interest for hunting within the mine permit area (Addendum 8, Appendix A-1, Section 15.2.1.1.2 CIAR#89).
	• The residual effects on trails and travelways was assessed as low magnitude.
	• Increased noise, odour, and visual disturbance during construction and operation could affect use of locations and the experience of hunting within the vicinity of the Project (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89); residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42):
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	• Where Indigenous groups utilize firearms for hunting, the Project's firearms restriction policy would affect their ability to use that harvesting method within the mine footprint. Alternate hunting methods may be possible in parts of the mine footprint that have not yet been disturbed or which have been reclaimed under the AMP (Addendum 8, Appendix A-1, Section 15.2.1.1.3, CIAR#89).
	In summary, effects on linked VCs will act synergistically to change identified hunted species and habitat, change use or access to identified hunting locations, and change preferred harvesting methods. There will be residual effects on hunting for Métis Nation of Alberta due to reduction in hunting opportunities, engagement in hunting, and hunting success during construction and operation due to loss of access to hunting locations, sensory disturbance, and change in wildlife use within the mine permit area.
		Residual effects on hunting are characterized as:
		• Magnitude is low because the Project effects on hunted species (e.g, elk) habitat can be mitigated through the Project wildlife mitigation and monitoring plan. The Métis Nation of Alberta raised concern about the restricted access of the area around the Project site, which limits their ability to practice traditional land use. However, they believe this may be alleviated by entering into a Métis Access Agreement with Riversdale (Addendum 10, JRP IR-4.6, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency because loss of hunting opportunities will be continuous throughout construction and operation.
		• Reversibility is characterized as reversible because reclamation is planned and expected to re-establish natural processes and ecosystems that support hunted species and access will be restored following the AMP.
		• Ecological and social context is resilient because, as Métis Nation of Alberta did not identify hunting areas in the Project area but outside the LSA, Métis Nation of Alberta engagement in hunting is considered not sensitive to disruption from the Project.

Table 6.7-9a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Métis Nation of Alberta

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Trapping	1. Trapped species and habitat:
	The Project will have temporary effects on land access for traditional resource use and on the distribution and abundance of species trapped for traditional purposes. Species preferring recently disturbed and young habitats are expected to return first, followed by species preferring increasingly older habitat types with reclamation.
	Canada Lynx:
	• There is a loss of lynx habitat in the WLSA. The loss of effective habitat, along with sensory disturbances associated with the Project, will likely displace lynx to other more suitable undisturbed habitats located west, north and east of the WLSA. Canada lynx rarely use the area around the access road, so it is not expected to have significant effects on lynx movement.
	American Marten:
	• There will be a temporary, long-term loss of habitat for American marten. Reclamation of disturbed areas will occur throughout and after the life of the Project; however, American martens prefer mature to old-growth coniferous forests, which will take many decades to become re-established. East-west movements of American marten will likely be affects by the Project footprint since they tend to avoid open landscapes. The access road and coal conveyor will also likely affect marten movements. North-south marten movements along Blairmore and Gold Creeks should be relatively unaffected by Project development. With mitigation, Project effects on American marten habitat availability and movement in the WLSA are expected to be local in extent, extended in duration, continuous in frequency, reversible in the long-term, moderate in magnitude for habitat availability and low for movement (EIA, CR#9, Section 5.3.6.1, CIAR#42).
	Wildlife Residual Effects (EIA, CR#9, Table 5.3-26, CIAR#42):
	• Effects on habitat availability for trapped species (lynx, American marten) due to vegetation clearing and sensory disturbance (due to increased noise, odour, visual disturbance) are moderate magnitude, negative Project contribution, and reversible in the long-term.
	• Effects on wildlife movement for trapped species (lynx, American marten) due to construction and operation are low magnitude, and reversible in the long-term.
	• Effects on wildlife abundance for trapped species (lynx, American marten) in hunting locations due to is low magnitude, negative Project contribution and, for American marten, reversible in the long-term and for the Canada lynx, reversible in the short term.
	• Effects on wildlife mortality risk for trapped species (lynx, American marten) due to construction activities, vehicle collisions, and human-wildlife conflicts are low magnitude, frequency is occasional, and reversible in the short term.
	2. Use or access to trapping locations and harvesting methods:
	• Where Project construction and operations activities overlap with hunting and trapping locations, access to active mining areas may be limited until they are reclaimed and safe. Indigenous groups will continue to have access to hunting and trapping locations where safety is not compromised (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• The Project's access restrictions within the mine permit area may also affect Indigenous groups' ability to use their preferred harvesting methods and seasonal rounds by altering the times of year that Indigenous groups have access to areas of interest for hunting/trapping within the mine permit area (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89).
	• Loss or disruption of traplines or trails used for trapping and loss of access to trapping locations due to the mine site and road closure during construction and operation. The residual effects on trails and travelways was assessed as low magnitude
	• Increased noise, odour, and visual disturbance during construction and operation could affect use of locations and the experience of hunting within the vicinity of the Project (Addendum 8, Appendix A-1, Section 15.2.1.1.2, CIAR#89); residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42):
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change identified trapped species and habitat, change use or access to identified trapping locations, and change preferred harvesting methods. There will be residual effects on trapping for Métis Nation of Alberta due to reduction or loss of trapping opportunities and the change in trapping methods could affect the cultural and spiritual relationship between the Nation and their territory, which is addressed below.
		Residual effects on trapping are characterized as:
		• Magnitude is low because there is predicted to be a change in the ability to trap in the Project area but it will not affect the ability to trap in the RSA. The Métis Nation of Alberta did not identify active trapping within the LSA (Addendum 10, Appendix 4.1-1, Section 13.2.1.2, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency because loss of trapping opportunities will be continuous throughout construction and operation.
		• Reversibility is characterized as reversible because reclamation is planned and expected to re-establish natural processes and ecosystems that support trapped species and access will be restored following the AMP.
		• Ecological and social context is resilient because, as Métis Nation of Alberta did not identify trapping areas in the Project area but outside the LSA, Métis Nation of Alberta engagement in trapping is considered not sensitive to disruption from the Project.

Table 6.7-9a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Métis Nation of Alberta

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Fishing	1. Fishing species and habitat:
	Westslope Cutthroat Trout (WSCT)
	• The physical footprint of surface water management infrastructure and open pits will cause permanent change to WSCT habitat. The loss of riparian and aquatic habitat will be reversed by gains achieved through implementing an Offsetting Plan approved by DFO. The magnitude of this effect will be moderate, the duration is long, the frequency will be continuous, however, reversibility is characterized as reversible in the long-term. (Addendum 1, CR#6, Section 4.5, CIAR#44).
	• Changes in hydrology will cause alteration in WSCT aquatic habitat of Gold and Blairmore creeks. The alteration of habitat will be offset by gains achieved through implementing an Offsetting Plan approved by DFO. The magnitude of residual adverse effects will be moderate, the duration is extended, the frequency will be continuous, however, reversibility is characterized as reversible in the long-term. (Addendum 1, CR#6, Section 4.5, CIAR#44).
	2. Use or access to fishing locations and harvesting methods:
	• Current access to the portions of the watercourses adjacent to Grassy Mountain is located on Benga private land. During construction and operation phases of the mine, this road will be closed to the general public, and alternate routes will need to be used to access and fish those portions of Blairmore and Gold Creeks (Addendum 8, Appendix A-1, Section 15.2.2.1.2, CIAR#89) which will be managed *via* the AMP.
	• Loss or disruption of trails for accessing fishing locations due to the mine site and road closure during construction and operation. The residual effects on trails and travelways was assessed as low magnitude
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of fishing locations by Indigenous Nations and preferred harvesting method.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1 CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change use or access to identified fishing locations, and change preferred harvesting methods. There will be residual effects on fishing for Métis Nation of Alberta due to reduction in fishing opportunities, engagement in fishing, and fishing success during construction and operation due to loss of access to fishing locations and sensory disturbance within the mine permit area.
		Residual effects on fishing are characterized as:
		• Magnitude is low because there is predicted to be a change in the ability to fish in the Project area but it will not affect the ability to fish in the RSA. The Métis Nation of Alberta have advised that they have a fishing interest in the Project area and identified species, including Westslope Cutthroat trout (Addendum 10, Appendix 4.1-1, Section 13.3.1.3, CIAR#251). The Métis Nation of Alberta raised concern about the restricted access of the area around the Project site, which limits their ability to practice traditional land use such as fishing. However, they believe this may be alleviated by entering into a Métis Access Agreement with Riversdale (Addendum 10, JRP IR-4.6, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration access restrictions will apply beyond the life of the mine in some areas that may affect access to fishing locations.
		• Continuous frequency because loss of fishing opportunities will be continuous throughout construction and operation.
		• Reversibility is characterized as reversible because reclamation and offsetting is planned and expected maintain fish populations and access will be restored following the AMP.
		• Ecological and social context is resilient because, as Métis Nation of Alberta did not identify fishing areas in the Project area for which access would be affected by the Project, Métis Nation of Alberta engagement in fishing is considered not sensitive to disruption from the Project.

Plant Gathering	1. Plant species and habitat:
	• The Project will result in loss of traditional use of vegetation within the vegetation local study area. Residual effects to TEK vegetation are local, long-term in duration, continuous, reversible and high magnitude. The Project will have a neutral contribution with respect to valued species and communities. After reclamation, the reclaimed land will support a range of communities with equivalent capabilities to those of the surrounding lands and that existing prior to Project development.
	• Residual adverse effects on vegetation were assessed as high magnitude for rare plants, community diversity, and TEK species, low magnitude for forest, and moderate for wetlands (EIA, CR#8, Section 4.0, CIAR#42).
	• Duration of effects on vegetation will be extended. Reclaimed land will require time to return the ecosystem to a condition that supports traditional use plants (EIA, CR#8, Section 4.1, CIAR#42).
	• Frequency of effects on vegetation, including rare plants and rare plant communities and traditional ecological knowledge, will be continuous through the operational phase of the project and cease only after reclamation is completed (EIA, CR#8, Section 4.0, CIAR#42).
	• Effects on vegetation are reversible in the long-term with the implementation of progressive reclamation (EIA, CR#8, Section 4.0, CIAR#42).
	2. Use or access to plant gathering locations and harvesting methods:
	• Loss or disruption of trails, loss of access to plant gathering locations, and loss of and preferred methods for plant gathering due to the mine site and access road. Residual effects on trails and travelways was assessed as low magnitude.
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of plant gathering locations by Indigenous Nations and preferred harvesting method.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3 CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change identified plant gathering species and habitat, change use or access to identified harvesting locations, and change preferred harvesting methods. There will be residual effects on plant gathering for Métis Nation of Alberta due to reduction in harvesting opportunities, engagement in plant gathering, and harvesting success during construction and operation due to loss of access to plant gathering locations and sensory disturbance within the mine permit area.
		Residual effects on plant gathering are characterized as:
		• Magnitude is low because there is predicted to be a change in the ability to gather plants in the Project area but it will not affect the ability in the RSA. Although the Métis Nation of Alberta identified an interest in gathering plants and berries for medicinal and consumption purposes in the Project footprint and identified that there are ecosystems that support medicinal plants existing within the Project area (Addendum 10, Appendix 4.1-1, Section 13.3.1.6, CIAR#251), they did not identify active plant gathering locations (EIA, CR#8, CIAR#42). The Métis Nation of Alberta provided recommendations during construction that would protect plant populations; these measures could minimize effects on plant gathering (, Addendum 10, JRP IR-4.6 CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine.
		• Reversibility is characterized as reversible because reclamation (of terrain, soil, vegetation) is planned and expected to re-establish natural processes and ecosystems that support traditional use plants (high density planting of disease-resistant whitebark pine seedlings will contribute to the successful re-establishment of the native ecosystem); and, access to plant gathering locations will be re-established after mine closure.
		• Ecological and social context is resilient because, as Métis Nation of Alberta did not identify sites used for plant gathering in the Project area but outside the LSA, Métis Nation of Alberta engagement in plant gathering is considered not sensitive to disruption from the Project.

Table 6.7-9a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Métis Nation of Alberta

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC

Trails and Travelways	1. Use or access to trails and travelways:
	• Loss or disruption of trails and travelways due to the mine site and access road. The Project will have residual adverse effects on use of trails and travelways because the Project could result in loss of trails and travelways that are fully or partially within the mine permit boundary.
	• The Project footprint will be reclaimed to land use capability equivalent to pre-mining; however, it will not be accessible for use as trails and travelways during construction and operations. Access to areas around the Project will be possible using existing trails from Highway 40 to reach the area west of Blairmore Creek and Crown Land north of the Project and from either the north or the south along the Gold Creek. With the implementation of the AMP, potential residual effects will be further reduced as Benga will be providing access to adjacent privately owned Benga lands for traditional practices (Addendum 10, Appendix 4.1-1, Section 13.3.3.5, CIAR#251).
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). Increased noise, odour, and visual disturbance during construction and operation could affect use of trails and travelways by Indigenous Nations.
	  • The noise modelling results indicate that the Project noise levels during the day-time, with the addition of the Ambient Sound Levels (ASLs), will be greater than 35 dBA within 1,500 m of the Project footprint including areas that could be used by Indigenous groups during construction and operation (EIA, CR#2, Figures 3, 5, and 7, CIAR#42); however, noise levels will be below the PSLs for all residential and theoretical 1,500 m receptors (EIA, CR#2, Section 5.1, CIAR#42).
	  • Odour (mostly NO_2) is predicted to be detectable, localized in exceedances, and was assessed as high magnitude; however, the Project does not change the frequency of detectable odours from NO_2 in the community (EIA, CR#1, Section 6.3, CIAR#42).
	  • Particulate deposition was assessed as moderate magnitude and continuous but localized and reversible in the short-term (EIA, CR#1, Table 6.5-1, CIAR#42).
	2. Features associated with trails and travelways:
	• Loss or disturbance to features associated with trails and travelways due to the mine site and access road.
	• Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42).
	• Residual adverse effects on access and utilities in the Lands and Resource Use VC was assessed as nil magnitude after reclamation (EIA, CR#10, CIAR#42).
	• Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42).
	• Residual effects will extend beyond the mine footprint but limited to within the zone of influence (generally 1.5 km) for noise, visual disturbance, and effect on access (EIA, CR#2, CIAR#42).
	• The geographic extent of residual effects on historical resources and on land and resource use is characterized as local (EIA, CR#10, Section E, CIAR#42).
	• The frequency of impact on access and utilities in the lands and resource use is continuous (EIA, CR#2, CIAR#42).
	• The frequency of impact of noise and other disturbances to trail use will continue throughout the Project lifespan (EIA, CR#2, CIAR#42).
	In summary, effects on linked VCs will act synergistically to change use or access and change preferred trails and travelways. There will be residual effects on trails and travelways for Métis Nation of Alberta due to restriction in use or access, and engagement with features associated with trails and travelways during construction and operation due to loss of access of trails and travelways locations, sensory disturbance, and change in use within the mine permit area.
		Residual effects on trails and travelways is characterized as:
		• Magnitude is low because, although there is predicted to be a change in trails and travelways in the Project area, the Métis Nation of Alberta did not identify any trails or travelways or features associated with navigation within the Project LSA and (Addendum 10, Appendix 4.1-1, Section 13.3.1.5, CIAR#251). The Métis Nation of Alberta raised concern about the restricted access of the area around the Project site, which limits their ability to practice traditional land use. However, they believe this may be alleviated by entering into a Métis Access Agreement with Riversdale (Addendum 10, JRP IR-4.6, CIAR#251).
		• Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA.
		• Long-term duration because reclamation will require time to return the ecosystem to a condition that supports wildlife habitat and access restrictions will apply beyond life of mine in some areas.
		• Continuous frequency during due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine.
		• Reversible effects in trails and travelways as the Métis Nation of Alberta did not identify any trails or travelways in and around the Project site.
		• Ecological and social context is resilient because, as Métis Nation of Alberta did not identify trails and travelways in the Project area and important cultural areas for Métis Nation of Alberta are outside the LSA and accessible outside the Project area, Métis Nation of Alberta trails and travelways is considered not sensitive to disruption from the Project. However, the Métis Nation of Alberta noted that access to Crown Lands beyond the project area as a major concern, historically, and members have been permitted to use trails and undeveloped roadways to access areas north of the proposed mine. The Métis Nation of Alberta further noted that Benga has restricted access to the roads leading to areas such as Daisy Creek which has resulted in a greatly extended travel time to reach areas for traditional use as land users must go around the project area (Addendum 10, JRP IR-4.6, Table 4.6-13, CIAR#251).

Cultural and Spiritual Values	1. Use and access to sacred important sites with cultural or spiritual value: • Residual adverse effects on access and utilities in the Lands and Resource Use VC was assessed as nil magnitude (EIA, CR#10, CIAR#42). • Loss or disruption of trails to important sites due to the mine site and access road. • Loss of hunting, trapping, fishing, and plant gathering opportunities. The residual effects, as seen above, on hunting, trapping, fishing, and plant gathering were assessed as low magnitude. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect use and enjoyment of culturally and spiritually important sites. Increased noise levels extend 1.5 km from the Project (EIA, CR#2, CIAR#42). Residual adverse effects on air quality was assessed as high magnitude for odour, low magnitude for lighting, and low to moderate magnitude for emissions including dust (EIA, CR#1, CIAR#42). • Residual adverse effects on historical resources was assessed as low (EIA, Section E, CIAR#42). 2. Experience of engaging with sites of cultural or spiritual value: • Loss or disturbance to important sites due to the mine site and access road. • Loss of experience in hunting, trapping, fishing, and plant gathering, which could affect the cultural and spiritual relationships with the resource. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect enjoyment or experience of using culturally and spiritually important sites. 3. Cultural values associated with sites/features: • Loss of hunting, trapping, fishing, and plant gathering opportunities, which could affect intergenerational teaching of traditional practices, and result in loss of cultural identity, sense of place, and human health/well-being. • Loss of access to sites/features due to construction and operation activities. • Loss of or damage to unique sites and special features as a result of clearing and construction activities. • Increase in noise, odour, and visual disturbance during construction and operation, which could affect enjoyment or experience of engaging with the sites/features of cultural or spiritual value. In summary, effects on linked VCs will act synergistically to change use or access to sites with cultural or spiritual value, change the experience of using these sites, and change the cultural value associated with sites and features. There will be residual effects on cultural and spiritual values for Métis Nation of Alberta during construction and operation due to loss of access to culturally or spiritually important sites and sensory disturbance within the mine permit area.	Residual effect on cultural and spiritual values is characterized as: • Magnitude is low because although there is predicted to be a change in use, access, and experience of engaging with sites of cultural and spiritual values in the Project area, this does not affect use, access, and experience of engaging with sites of cultural and spiritual values in the RSA. The Métis Nation of Alberta raised concern about the restricted access of the area around the Project site, which limits their ability to practice traditional land use. However, they believe this may be alleviated by entering into a Métis Access Agreement with Riversdale (Addendum 10, JRP IR-4.6, CIAR#251). • Local geographic extent because residual effects will extend beyond the mine footprint but limited to the LSA. • Long-term duration because the loss of experience in hunting, trapping, fishing, and plant gathering could affect the long-term cultural and spiritual relationships between Indigenous groups and their resources and territory. Change in land use and access will extend beyond the Project lifespan. • Continuous frequency during due to continuous mine disturbance (loss of vegetation, access restrictions, noise, visual) throughout life of mine. • Non-reversible because loss of cultural and spiritual sites and experience in engaging in land use could result in loss of the knowledge of cultural and spiritual values. • Ecological and social context is resilient because, as Métis Nation of Alberta did not identify cultural and spiritual values in the Project area and important cultural areas for Métis Nation of Alberta are outside the LSA, Métis Nation of Alberta cultural and spiritual values is considered not sensitive to disruption from the Project.

Table 6.7-9a Description and Characterization of Residual Project Effects on Current Use of Lands and Resources for Traditional Purposes and Indigenous Physical and Cultural Heritage for the Métis Nation of Alberta

Indigenous VC	Description of Residual Project Effects	Characterization of Residual Project Effects on the Indigenous VC
Indigenous Physical and Cultural Heritage	Physical and cultural heritage sites are located throughout Region 3 (AMHS, 2015) which are located outside of the Project RSA (Addendum 10, Appendix 4.1-1, Section 13.4.1, CIAR#251). The Project will not intersect or be in proximity to any sacred, gathering and habitation sites identified by the Métis Nation of Alberta. Physical and cultural heritage sites are not in proximity to the Project and are located outside of the Project RSA As a result, the Project is not expected to have a residual effect on physical or cultural heritage of the Métis Nation of Alberta Region 3 (Addendum 10, Appendix 4.1-1, Section 13.4.2, CIAR#251).	The Project will not intersect or be in proximity to any sacred, gathering and habitation sites identified by the Métis Nation of Alberta. Physical and cultural heritage sites are not in proximity to the Project and are located outside of the Project RSA. As a result, the Project is not expected to have a residual effect on physical or cultural heritage of the Métis Nation of Alberta Region 3. Physical and cultural heritage is not assessed further (Addendum 10, Appendix 4.1-1, Section 13.4.2, CIAR#251).

In summary, the residual effects characterization has not changed from that already provided. As such, the summary Table 13.4.2-1 from *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups* (Appendix 4.1-1, Addendum 10, CIAR#251) is provided below, as Table 6.7-9b.

Table 6.7-9b Summary of Residual Effects on Métis Nation of Alberta [Source: Table 13.4.2-1, *An Updated Assessment of the Potential Effects of the Grassy Mountain Project on Indigenous Groups* Appendix 4.1-1, Addendum 10, CIAR#251]

Valued Components	Magnitude	Geographic Extent	Duration	Frequency	Reversibility	Ecological and Social Context	Significance
Hunting and Trapping	Low	Local	Long-term	Continuous	Reversible	Resilient	Not significant
Fishing	Low	Local	Long-term	Continuous	Reversible	Resilient	Not significant
Plant Gathering	Low	Local	Long-term	Continuous	Reversible	Resilient	Not significant
Trails and Travelways	Low	Local	Long-term	Continuous	Reversible	Resilient	Not significant
Cultural and Spiritual Values	Low	Local	Long-term	Continuous	Not Reversible	Resilient	Not significant

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O'Connor, D. 2018. Blood Tribe/Kainai Traditional Knowledge & Use Assessment. Prepared by Dermot O'Connor, Oak Road Concepts Inc., Cochrane, AB. (submitted under confidentiality restrictions by Kainai to the JRP)

Stoney Nakoda Nation. 2015. Grassy Mountain Coal Project – "We Could Write a Book about this Place" Non-Confidential Summary of Traditional Use: Site Tour in the Grassy Mountain Area in June 2014.

Information Request 6.8

Final Environmental Impact Statement Guidelines. (CIAR #11)

Eighth Addendum to the Environmental Impact Assessment, Section 15. (CEAR #89).

Tenth Addendum to the Environmental Impact Assessment, Appendix 4.1-1. (CIAR #251).

Canadian Environmental Assessment Agency interim Technical Guidance "Assessing Cumulative Environmental Effects under the *Canadian Environmental Assessment Act, 2012*". (March 2018).

Addendum 8, Section 15 (CEAR #89) and Appendix 4.1-1 (CIAR #251) contain Benga's cumulative effects assessment with respect to the current use of lands and resources for traditional purposes and the cultural and physical heritage of Indigenous peoples.

Benga noted in Appendix 4-1.1 that cumulative effects from development, change in land use, settlement, access and climate change have already resulted in significant adverse effects on hunting and trapping since European settlement. However, Benga did not elaborate on the Project's specific incremental contributions to the above named

pathways (*e.g.* land use, access, climate change) of cumulative effects and determined that cumulative effects on hunting and trapping were not significant.

In addition, the cumulative effects assessment relied on the consideration of residual effects to biophysical (associated) VCs but did not directly assess effects to Indigenous VCs, including intangible components such as consideration of experience, culture, governance, knowledge and other factors. For example, Benga states:

> "The cumulative effects on associated VCs (wildlife and wildlife habitat, land and resource use) are not significant. Based on this and the characterization of residual cumulative effects on hunting and trapping, the cumulative effects on hunting and trapping are not significant."

The Canadian Environmental Assessment Agency's interim Technical Guidance for "Assessing Cumulative Environmental Effects under the *Canadian Environmental Assessment Act, 2012*"[4] states that the first step to carrying out a cumulative effects assessment is to identify the VCs for which residual environmental effects are predicted after the consideration of mitigation measures. The EIS Guidelines (CIAR #11) require Benga to identify and provide a rationale for the selection of VCs that will constitute the focus of the cumulative effects assessment. The Guidelines also require that residual effects, even if very small or deemed insignificant, must be described. This should be done in sufficient detail to enable the Panel to review Benga's analysis of the cumulative effects, based on these residual effects.

Further information on the cumulative effects resulting from the incremental contribution of the Project's residual effects on the environment and Indigenous peoples, is required to support the Panel's mandate under CEAA 2012.

a) Describe how the Project's residual effects contribute, in a cumulative manner, to existing effects from other activities and in combination with other physical activities will be carried out.

b) Update the cumulative effects assessment with respect to the current use of lands and resources for traditional purposes and the cultural and physical heritage of Indigenous peoples using the descriptions of the residual effects above. Use the Canadian Environmental Assessment Agency's interim Technical Guidance for "Assessing Cumulative Environmental Effects under the *Canadian Environmental Assessment Act, 2012*" to guide the cumulative effects assessment.

Response:

The cumulative effects assessment (CEA) results presented here are consistent with those presented previously in Section 18: Cumulative Effects in *An Updated Assessment of the Potential Effect of the Grassy Mountain Project on Indigenous Groups* (Addendum 10, Appendix 4.1-1, CIAR#251) and the updated CEA (Addendum 8, Appendix A-1, Section 15,

[4] Available online: Interim Technical Guidance "Assessing Cumulative Environmental Effects under the *Canadian Environmental Assessment Act, 2012*". https://www.canada.ca/en/impact-assessment-agency/services/policy-guidance/assessing-cumulative-environmental-effects-ceaa2012.html.

CIAR#89). The cumulative effects results are also consistent with the process outlined in *Assessing Cumulative Environmental Effects under CEAA 2012*, Interim Technical Guidance (March 2018).

The first step for this current analysis is to identify the Valued Components (VCs) for which residual environmental effects are predicted after consideration of mitigation measures. The residual effects on Indigenous VCs are described in the response to JRP IR-6.7 and do not differ from those predicted in Appendix 4.1-1 (Addendum 10, CIAR#251). Residual effects were predicted for:

- Current Use of Lands and Resources for Traditional Purposes:
  - hunting and trapping;
  - fishing;
  - plant gathering;
  - trails and travelways; and
  - cultural and spiritual values.
- Indigenous Physical and Cultural Heritage.

These residual effects were carried forward into the CEA. Residual effects on related biophysical VCs were also considered in the CEA; however, they were not the only factors considered. Other factors considered included extensive consultation with Indigenous groups, intangible (spiritual and cultural) considerations, and findings from Traditional Land Use (TLU) studies, all of which helped support the CEA as presented below in Table 6.8-1.

As requested, a summary of the Project's contribution to cumulative effects on Indigenous groups VC's and its interaction with past, present, and future projects are presented in Table 6.8-1 for Current Use of Lands and Resources for Traditional Purposes and in Table 6.8-2 for Indigenous Physical and Cultural Heritage. The tables also include the mitigation measures proposed to address cumulative effects and the characterization of the residual cumulative effects. The extensive background information that supports these tables was provided in Addendum 10, Appendix 4.1-1, Section 18, CIAR#251.

Table 6.8-1 Summary of Residual Cumulative Effects on Current Use of Lands and Resources for Traditional Purposes

Residual Effects on Indigenous VCs Carried Forward to the Project's Cumulative Effects Assessment	Summary of Past and Present Development Activities that have Affected Indigenous VCs (from Addendum 10, Appendix 4.1-1 and JRP IR-4.6)	Project's Contribution to Cumulative Effects	Interaction with Past, Present, and Future Development Activities	Mitigation Measures to Address Cumulative Effects	Residual Cumulative Effects
Hunting and Trapping (residual effects on hunting are described in Tables 6.7-2 through 6.7-9): 1) Change in identified hunted / trapped species and habitats. 2) Change in use or access to identified hunting locations, traplines and trapping locations. 3) Change in preferred harvesting method.	Past and present development since European settlement within the RSA has resulted in loss of natural land cover and altered land use, which have reduced wildlife abundance and habitat effectiveness, increased hunting pressure, and restricted access to land for traditional purposes. According to the Siksika Nation and Káinai Nation cumulative effects study (Carlson *et al*. 2018a,b), this has placed hunting and trapping already at moderate to high risk and according to the Ktunaxa Nation, current use of the RSA for trapping has been impeded since coal mining began in the 1900s (Appendix 10, JRP IR-4.6, CIAR#251). Some Indigenous groups do not hunt in close proximity (*e.g.,* 500 m) to industrial sites, settlements, rural residence and other features used for non-traditional use purposes due to concerns regarding contamination, safety, and the overall negative experience on the land (Addendum 10, Appendix 4.1-1, Section 4.3.1.1, CIAR#251). Some Indigenous groups have indicated that they do not hunt in parks or ecological reserves, so these areas in the RSA are considered inaccessible for traditional land use (Addendum 10, Appendix 4.1-1, Section 4.3.1.3, CIAR#251). The Ktunaxa Nation identified that the viability of the Project area is especially important as it is located in the only area in ʔamakʔis Ktunaxa where Ktunaxa citizens can practice hunting rights on both sides of the Rockies without interruption and interference from National Park restrictions (Appendix 10, JRP IR-4.6, CIAR#251).	After the implementation of project-specific mitigation measures, there will be a residual project effect on hunting and trapping of low to moderate magnitude because the Project will result in loss of access to hunting/trapping areas and reduced quality of experience. This could affect Indigenous cultural and spiritual values such as Indigenous relationship with wildlife and engaging in traditional practices. The overall Project contribution to cumulative effects on hunting and trapping is deemed low because: • the Project footprint overlaps historic disturbances (unreclaimed, legacy mine site that overlaps one third of the Project area); • existing (non-Benga related) disturbances already limit access to hunting and trapping; • the Project's Conservation and Reclamation Plan will integrate traditional land use opportunities; • the Project footprint will be progressively reclaimed to improve land use capability for traditional purposes by reclaiming previously disturbed legacy mine areas; • Benga has committed to return Crown leases to the Crown after reclamation is completed; • the Project's Access Management Plan (AMP) will improve hunting and trapping opportunities after mine closure (following 23 years of mine operations), by allowing affected Indigenous groups access to non-operational areas of Benga owned and crown land being used for the project; • in the continuous development and improvement of the AMP, Benga will continue to consult with Indigenous groups to identify alternative areas for hunting and trapping. The AMP is intended to limit access to authorized persons, and facilitate access to traditional use areas for Indigenous groups; and • Benga will continue to work with Indigenous groups to identify species of importance prior to construction activities.	The Project will interact with past, present, and reasonably foreseeable future development in the Crowsnest Pass. The Project footprint overlaps historic disturbances such as mining, rail, roads, and altered land use that have already resulted in adverse effects on hunting and trapping. Future development includes mining, logging, highway re-alignment, transmission, agriculture, urban development (Addendum 10, Appendix 4.1-1, Section 18.2, CIAR#251). Other foreseeable future projects such as forestry and other mining projects have the potential to act cumulatively with the Project by incrementally reducing the number of wildlife harvesting sites (Addendum 10, Appendix 4.1 1, Section 18.4.1.1.3, CIAR#251 Based on Káinai Nation and Siksika Nation cumulative effects assessment (Carlson *et al*. 2018a,b), hunting opportunities will decline by 10% for elk and by 2% for land access in the next 50 years.	Potential impacts to hunting and trapping have been mitigated at the Project level and are described in Table 6.5-2 (JRP IR-6.5). Benga is committed to implementing measures to reduce cumulative effects on hunting and trapping on a regional scale through the following: • minimize the overall disturbance footprint through the mine planning process (Addendum 10, Appendix 4.1-2, CIAR#251); • incorporate the existing legacy mining disturbances into the development and reclamation plans for the Project (Addendum 10, Appendix 4.1-2, CIAR#251); • engage with the Indigenous communities during construction, operations and reclamation, including review and input into management and monitoring plans, discussion of options to facilitate access for traditional activities, construction timing and reclamation (Addendum 10, Appendix 4.1-2, CIAR#251); • Benga will support an Indigenous Environmental Stewardship Committee, one of whose functions will be to provide advice on environmental stewardship and land use values as they arise (Addendum 10, Appendix 4.1-2, CIAR#251); • implement an Indigenous-led monitoring program, over the life of the Project, which will include, but not be limited to, monitoring for culturally valued resources and monitoring of reclamation success (Addendum 10, JRP IR-4.3, CIAR#251); • Benga will consider allowing access to Benga-owned lands outside the Project footprint within the RSA for traditional use such as hunting and trapping. Benga will work with the Nations to identify key areas and develop an Access Management Plan for traditional use (Addendum 10, Appendix 4.1-1, Section 18.4.1.1.5, CIAR#251); and • continue to improve the Access Management Plan for construction and operation phases of the Project that includes notification of access restrictions during construction as required for safety purposes to allow for planning alternate hunting locations and to reduce effects to wildlife (Addendum 10, Appendix 4.1-2, CIAR#251).	With the implementation of Project-specific mitigation measures and measures to address cumulative effects, residual cumulative effects on hunting and trapping are characterized as (Addendum 10, Appendix 4.1-1, Section 18.4.1.1.6, CIAR#251): Low magnitude because the Project footprint overlaps existing disturbance and contributions of the Project and future development to cumulative effects are predicted to be less than 10% further reduction in the next 50 years (Carlson *et al*. 2018). Regional geographic extent because cumulative effects are occurring over the traditional territories used by Indigenous groups. Medium-term because with reclamation the Project footprint is expected to improve hunting and trapping opportunities following mine closure. Continuous frequency because cumulative loss of hunting and trapping opportunities will be continuous until reclamation improves conditions. Reversible because implementation of the AMP, Conservation and Reclamation Plan (C&R Plan), Wildlife Mitigation and Monitoring Plan (WMMP), and regional efforts will improve conditions for traditional land use such as hunting and trapping.

Table 6.8-1 Summary of Residual Cumulative Effects on Current Use of Lands and Resources for Traditional Purposes

Residual Effects on Indigenous VCs Carried Forward to the Project's Cumulative Effects Assessment	Summary of Past and Present Development Activities that have Affected Indigenous VCs (from Addendum 10, Appendix 4.1-1 and JRP IR-4.6)	Project's Contribution to Cumulative Effects	Interaction with Past, Present, and Future Development Activities	Mitigation Measures to Address Cumulative Effects	Residual Cumulative Effects
Fishing (residual effects on fishing are described in Tables 6.7-2 to 6.7-9): 1) Change in identified species and habitat. 2) Change in use or access to identified fishing locations. 3) Change in preferred harvesting method.	Use and access to fishing locations and preferred harvesting methods have already been altered due to the creation of parks and protected areas, private land, land use regulations and restrictions, rail and road corridors, agriculture, and settlements. Some Indigenous groups indicated they do not fish in close proximity to well sites (approximately 500 m), or near industrial sites, settlements, rural residence and other features used for non-traditional use purposes due to concerns regarding contamination, safety and the overall negative experience on the land (Addendum 10, Appendix 4.1-1, Section 18.3.1, CIAR#251). The Káinai Nation also indicated that they do not fish in parks or ecological reserves, so these areas have already been deemed inaccessible for traditional land use (Addendum 10, Appendix 4.1-1, Section 4.3.1.3, CIAR#251).	Residual Project effects on fishing are considered low to moderate magnitude, depending on the Indigenous group, but reversible post-mine closure. The Project will contribute to cumulative effects on fishing, specifically use of and access to fishing locations because access to portions of watercourses are on Benga private land and Benga will implement road closures to general public for safety reasons (Addendum 10, Appendix 4.1-1, Section 18.4.1.2.3, CIAR#251). The Project's contribution to cumulative effects on fishing is low because: • existing disturbances already restrict access to fishing; • the Access Management Plan includes notifying about access restrictions to allow for planning alternate fishing locations and access routes; • reclamation and access management plans will improve fishing opportunities after mine closure because affected Indigenous groups will be granted access to non-operational areas of Benga land and crown land being used for the Project. The AMP will control access to authorized persons, will ban fishing by employees, and facilitate access to traditional use areas for Indigenous groups, where feasible; • Benga will continue to consult with Indigenous groups on the further development of the Conservation and Reclamation plans to ensure that fishing is considered as the site is reclaimed; • design and implementation of a Fisheries Offsetting Plan early in the Project development will offset permanent loss of fish habitat; • Benga has committed to return Crown leases to the Crown after reclamation is completed; • the fisheries offset plan will be discussed with Indigenous groups as it is being developed and before it is finalized; • Benga will put in place a program to monitor fish health and to check for selenium in the fish populations and water; and • groundwater monitoring wells will be used to ensure that the ground water quantity and quality meet expectations.	The Project will interact with other projects in the Crowsnest Pass (*e.g.,* nearby farming and sewage, forest cover loss, mining and roads, and future development such as mining and highway realignment) that affect fishing (Addendum 10, Appendix 4.1-1, Section 18.4.1.2.2, CIAR#251). Specifically, loss of and reduced suitability of fish habitat (aquatic and/or riparian, water quality), loss of access to fishing locations due to cumulative access restrictions, and reduced engagement in fishing due to cumulative noise, visual disturbances, and concerns regarding perceived contamination of fish.	Potential impacts to fishing have been mitigated at the Project level and are described in Table 6.5-3 (JRP IR-6.5). Benga is committed to implementing measures to reduce cumulative effects on fishing on a regional scale through the following: • maintain a 100 m undisturbed forested buffer around Blairmore and Gold Creeks (Addendum 10, Appendix 4.1-2, CIAR#251); • Benga will support an Indigenous Environmental Stewardship Committee, one of whose functions will be to provide advice on environmental stewardship and land use values as they arise (Addendum 10, Appendix 4.1-2, CIAR#251); • implement an Indigenous-led monitoring program, over the life of the Project, which will include, but not be limited to, monitoring for culturally valued resources and monitoring of reclamation success (Addendum 10, JRP IR-4.3, CIAR#251); • implement a Fisheries Offsetting Plan and Offsetting Effectiveness Monitoring Plan that more than offset the habitat losses caused by the Project related to Gold Creek and Blairmore Creek (Addendum 10, Appendix 4.1-2: Fishing, CIAR#251); • Benga has committed to developing an Indigenous monitoring program in cooperation with nearby First Nations to work in parallel with other western science-based monitoring programs. In addition, Benga will consult with Indigenous groups in developing all of the monitoring programs through a series of workshops. Benga has committed to providing Annual Reporting documents to Indigenous groups highlighting the results from the monitoring programs and seeking any input that would help Benga improve monitoring and the effectiveness of mitigation measures (Addendum 10, Appendix 5.4-1, Section 4.0, CIAR#251); • continue to improve the Access Management Plan for construction and operation phases of the Project that includes notification of access restrictions during construction as required for safety purposes to allow for planning alternate fishing locations and access routes (Addendum 10, Appendix 4.1-2, CIAR#251); • Benga will consider allowing access to Benga-owned lands outside the Project footprint within the RSA for traditional use such as fishing (Addendum 10, Appendix 4.1-1, Section 18.4.1.2.4, CIAR#251); • conduct ongoing consultation with Indigenous communities during construction, operations and reclamation, including review and input into management plans, discussion of options to facilitate access for traditional activities, construction timing, and reclamation (Addendum 10, Appendix 4.1-2, CIAR#251); and • engage with Indigenous groups prior to and during mine construction to allow for opportunities for species of interest to be harvested, re-located or otherwise utilized (Addendum 8, Appendix A-1, Section 15.2.2.2, CIAR#89).	After implementation of project-specific mitigation measures and mitigations to address cumulative effects, and assuming future projects occur as planned, the residual cumulative effects on fishing are primarily due to future development interaction with past and present development. The residual cumulative effects on fishing are characterized as (Addendum 10, Appendix 4.1-1, Section 18.4.1.2.5, CIAR#251): Low magnitude because Benga will offset Project effects on fish and fish habitat in an Offsetting Plan and will provide access to fishing locations for affected Indigenous groups. Regional geographic extent because cumulative effects are occurring within watersheds in Indigenous groups' traditional territories. Medium-term because, with reclamation, AMP, and Offsetting Plan, residual cumulative effects are expected to last for the duration of the Project. Continuous frequency because cumulative loss of fishing opportunities will be continuous during construction and operation. Reversible because implementation of the AMP, C&R Plan, Fisheries Offsetting Plan, and regional efforts will improve conditions for traditional land use such as fishing.

Table 6.8-1 Summary of Residual Cumulative Effects on Current Use of Lands and Resources for Traditional Purposes

Residual Effects on Indigenous VCs Carried Forward to the Project's Cumulative Effects Assessment	Summary of Past and Present Development Activities that have Affected Indigenous VCs (from Addendum 10, Appendix 4.1-1 and JRP IR-4.6)	Project's Contribution to Cumulative Effects	Interaction with Past, Present, and Future Development Activities	Mitigation Measures to Address Cumulative Effects	Residual Cumulative Effects
Plant Gathering (residual effects on plant gathering are described in Tables 6.7-2 to 6.7-9): 1) Change in identified plant species and ecosystems. 2) Change in use or access to identified plant gathering locations. 3) Change in preferred plant gathering method.	Limited information was provided on past and present plant gathering locations and practices in the RSA through consultation with the various Indigenous groups. Although Indigenous groups have not identified site-specific current use in the Project area for plant gathering, Benga acknowledges that this knowledge is typically sacred and not widely shared (Addendum 10, Appendix 4.1-1, Section 9.3.1.4, CIAR#251). Based on this, Benga has assumed that the Project will intersect or be in proximity to habitat and species that are identified for plant gathering by Indigenous groups (Addendum 10, Appendix 4.1-1, Section 4.3.2.4, CIAR#251), which is supported by the fact Piikani Nation field crew members recorded four harvest sites for plant gathering and hunting that partially or fully overlap the LSA as part of a TLU study (Addendum 10, Appendix 4.1-1, Section 5.3.1.4, CIAR#251). Past development has likely resulted in cumulative adverse effects on plant gathering due to past and present change in land use and air quality since European settlement (Addendum 10, Appendix 4.1-1, Section 18.4.1.3.1, CIAR#251).	Residual Project effects on plant gathering are considered low to moderate magnitude, depending on the Indigenous group, but reversible post-mine closure. The Project will contribute to cumulative effects on plant gathering, specifically loss of available traditional use plants, use of and access to gathering locations, and decline in engagement in plant gathering. The Project's contribution to cumulative effects on plant gathering is low because: • existing disturbances already restrict access; • reclamation will improve plant gathering opportunities after mine closure; • the AMP will include notification to allow for planning alternate plant gathering locations; • Benga will allow Indigenous groups to access Benga private land for the purposes of limited timber harvesting and gathering of plants; • Benga will work with Indigenous groups to identify other mitigations regarding traditional and medicinal plants; • Benga will work with the Indigenous groups to identify key areas and develop an AMP for traditional use such as plant gathering (Addendum 10, Appendix 4.1-1, Section 18.4.1.3.2, CIAR#251); and • Benga will consult with Indigenous groups on the C&R Plan and vegetation management program. The C&R Plan will include the planting of native species and support revegetation of traditional use species and end land use decisions made in consultation with Indigenous groups. Traditional land use opportunities will be integrated.	The Project will interact with other past, present, and future physical activities that affect plant gathering in the region. This includes development (*e.g.*, mining) that directly disturbs ecosystems that support traditional use plants and projects that result in loss of access to and use of plant gathering locations.	Potential impacts to plant gathering have been mitigated at the Project level and are described in Table 6.5-4 (JRP IR-6.5). Benga is committed to implementing measures to reduce cumulative effects on plant gathering on a regional scale through the following: • implement a re-vegetation program which will target the re-establishment of vegetation communities, such as closed conifer forests, mature mixed forests, native upland herbaceous grasslands and treed swamps, common to the pre-disturbed landscape that will support valued vegetation (Addendum 10, Appendix 4.1-2, CIAR#251); • support an Indigenous Environmental Stewardship Committee, one of whose functions will be to provide advice on environmental stewardship and land use as they arise (Addendum 10, Appendix 4.1-2, CIAR#251); • implement an Indigenous-led monitoring program, over the life of the Project, which will include, but not be limited to, monitoring for culturally valued resources and monitoring of reclamation success (Addendum 10, JRP IR-4.3, CIAR#251); • support an Indigenous monitoring program which will include monitoring of a suite of culturally defined environmental attributes (Addendum 10, Appendix 4.1-2: Plant Gathering, CIAR#251); • continue to improve the Access Management Plan for construction and operation phases of the Project that includes notification of access restrictions during construction as required for safety purposes to allow for planning alternate plant gathering locations (Addendum 10, Appendix 4.1-2, CIAR#251); • provide access to Benga private land outside of the Project for Indigenous harvesting of lodgepole pine and other culturally important plants (Addendum 10, Appendix 4.1-2, CIAR#251).	After implementation of the project-specific mitigations and mitigation measures to address cumulative effects, and assuming future projects occur as planned, the residual cumulative effects on plant gathering are primarily due to future development interaction with past and present development. Residual cumulative effects are characterized as (Addendum 10, Appendix 4.1-1, Section 18.4.1.3.3, CIAR#251): Low magnitude because the Project footprint overlaps existing disturbance and contributions of the Project and future development to cumulative effects are predicted to be less than 10% further reduction in the next 50 years (Carlson *et al*. 2018). Regional geographic extent because cumulative effects are occurring over the traditional territories used by Indigenous groups. Medium-term because with reclamation the Project footprint is expected to improve plant gathering opportunities following mine closure. Continuous frequency because cumulative loss of plant gathering opportunities will be continuous until reclamation improves conditions. Reversible because implementation of the AMP, C&R Plan, and regional efforts will improve conditions for traditional land use such as plant gathering.

Table 6.8-1 Summary of Residual Cumulative Effects on Current Use of Lands and Resources for Traditional Purposes

Residual Effects on Indigenous VCs Carried Forward to the Project's Cumulative Effects Assessment	Summary of Past and Present Development Activities that have Affected Indigenous VCs (from Addendum 10, Appendix 4.1-1 and JRP IR-4.6)	Project's Contribution to Cumulative Effects	Interaction with Past, Present, and Future Development Activities	Mitigation Measures to Address Cumulative Effects	Residual Cumulative Effects
Trails and travelways (*e.g.,* sacred and ceremonial areas and activities, teaching areas, place name) (residual effects on trails and travelways are described in Tables 6.7-2 to 6.7-9)	Limited information was provided by Indigenous groups on trails and travelways in the RSA, although Tsuut'ina Nation reported that hunting trails, tied strongly to wildlife trails and other key habitat types, continue to exist today and are used throughout the Grassy Mountain area, and Métis Nation of Alberta had concerns that Benga has restricted access to the roads leading to areas such as Daisy Creek (Addendum 10, JRP IR-4.6, CIAR#251). Traditional trails and travelways and their use have likely been affected by past and present land use (Addendum 10, Appendix 4.1-1, Section 18.4.1.4.1, CIAR#251) due to private land, land use regulations and restrictions, rail and road corridors, agriculture, and settlements. Travel and access to the Crowsnest Pass by the Tsuut'ina Nation members has diminished since contact with Euro-Canadian settlers. While the Nation continues to use hunting trails throughout the Grassy Mountain area, this is done less than in the past (Addendum 10, Appendix 4.1-1, Section 8.3.1.5, CIAR#251).	Residual Project effects on trails and travelways are considered moderate magnitude and irreversible for Indigenous groups who maintain traditional trails and travelways in the area (see response to JRP IR-6.7). The Project's contribution to cumulative effects on trails and travelways is low because: • existing disturbances already restrict access; • Benga will work with affected Indigenous groups to develop the AMP to plan alternative travel routes or allow Indigenous groups to access Benga private land for traditional purposes such as traveling to sacred and ceremonial sites; and • Benga has committed to return Crown leases to the Crown after reclamation is completed.	The Project will interact with other past, present, and future physical activities that affect trails and travelways in the region, such as cumulative increase in private land (agriculture, residential, mining operations) that restricts access and landscape connectivity for traditional purposes.	Potential impacts to trails and travelways have been mitigated at the Project level and are described in Table 6.5-5 (JRP IR-6.5). Benga is committed to implementing measures to reduce cumulative effects on trails and travelways on a regional scale through the following: • Benga is working with Indigenous communities to develop an Indigenous Environmental Stewardship Committee, one of whose functions will be to provide advice on environmental stewardship and land use values as they arise (Addendum 10, JRP IR-4.3, CIAR#251); • implement an Indigenous-led monitoring program, over the life of the Project, which will include, but not be limited to, monitoring for culturally valued resources and monitoring of reclamation success (Addendum 10, JRP IR-4.3, CIAR#251); • will consider allowing access to Benga-owned lands outside the Project footprint within the RSA for traditional use. Benga will work with the Nations to identify key areas and develop an Access Management Plan for traditional use (Addendum 10, Appendix 4.1-1, Section 18.4.1.4.2, CIAR#251); • continue to improve the Access Management Plan that will include notification of access restrictions during construction as required for safety purposes to allow for planning alternate trails and travelways (Addendum 10, Appendix 4.1-2, CIAR#251); • share information about construction timing (Addendum 10, Appendix 4.1-2, CIAR#251); • develop and implement a Cultural Site Discovery Contingency Plan for culturally important sites identified during construction or operations (Addendum 10, Appendix 4.1-2, CIAR#251).	After implementation of the Project-specific mitigations and mitigation measures to address cumulative effects, and assuming future projects occur as planned, the residual cumulative effects on trails and travelways are primarily due to future access restrictions and land use interacting with past and present development. Residual cumulative effects are characterized as (Addendum 10, Appendix 4.1-1, Section 18.4.1.4.3, CIAR#251): Low magnitude because traditional trails and travelways have already been affected by past and existing land use and Benga will allow access on Benga-owned lands within the RSA. Regional geographic extent because cumulative effects are occurring over the traditional territories and between watersheds used by Indigenous groups. Long-term because cumulative loss of access to or use of traditional trails and travelways will occur beyond the life of mine. Continuous frequency because cumulative effects will be continuous until traditional access is restored. Reversible because implementation of the AMP, C&R Plan, and regional access management strategies will improve land use for traditional purposes such as use and maintenance of traditional trails and travelways.

Table 6.8-1 Summary of Residual Cumulative Effects on Current Use of Lands and Resources for Traditional Purposes

Residual Effects on Indigenous VCs Carried Forward to the Project's Cumulative Effects Assessment	Summary of Past and Present Development Activities that have Affected Indigenous VCs (from Addendum 10, Appendix 4.1-1 and JRP IR-4.6)	Project's Contribution to Cumulative Effects	Interaction with Past, Present, and Future Development Activities	Mitigation Measures to Address Cumulative Effects	Residual Cumulative Effects
Cultural and Spiritual Values (residual effects on cultural and spiritual values are described in Tables 6.7-2 to 6.7-9): 1) Disturbance to sacred and culturally or spiritually important sites and access to, or use, of those sites. 2) Changes to the experience of engaging with sites and landscape features that have cultural or spiritual value. 3) Changes to the cultural value and importance associated with the engagement with the sites/features of cultural or spiritual value (including inter-generational teaching of traditional practices).	Limited information was received from Indigenous groups regarding the locations of culturally and spiritually significant sites that overlap with the Project footprint; however, Káinai Nation identified the area in and around the Project has important Blackfoot place names and Ktunaxa Nation identified the Project LSA and footprint in the Blairmore and Frank areas as places and teaching areas to pass on Ktunaxa knowledge and history (Addendum 10, Appendix 4.1-1, Section 18.4.1.5.5, CIAR#251; Addendum 10, JRP IR-4.6, CIAR#251). Nonetheless, the Project is in an area with cultural and spiritual significance, where several Indigenous peoples continue to practice their Indigenous and Treaty Rights. Past and existing physical activities have already interfered with Indigenous traditional practices (Addendum 10, Appendix 4.1-1, Section 18.4.1.5, CIAR#251). Use, access, and changes in experience of sacred, culturally, and/or spiritually important sites and landscape features may have already been altered due to the creation of rail and road corridors in the area, parks and protected areas, private land, land use regulations and restrictions, agriculture, and settlements (Addendum 10, Appendix 4.1-1, Section 18.2.1, CIAR#251).	Residual Project effects on cultural and spiritual values are considered moderate magnitude and irreversible for Indigenous groups who continue to practice their Indigenous and Treaty rights in the area (see response to JRP IR-6.7). The Project's contribution to cumulative effects on cultural and spiritual values may occur through reduced or loss of access to important sites and indirect effects due to avoidance of areas (*i.e.,* perceived diminished value of wildlife/plants/harvested materials), and conflict with other land users (Addendum 10, Appendix 4.1-1, Section 18.3.1, CIAR#251). This loss of access means loss of areas that are important for community members to engage in culturally/spiritually important practices and to pass on knowledge and skills to future generations (Addendum 10, Appendix 4.1-1, Section 18.4.1.5.1, CIAR#251). Indigenous groups have identified that these losses can cause adverse effects on Indigenous individual's psychological health (Addendum 10, Appendix 4.1-1, Section 18.4.1.5.1, CIAR#251).	The Project will interact with other past, present, and future physical activities in the region to further interfere with the ability to pass on culture to the next generation, which could lead to loss of cultural identity (Addendum 10, Appendix 4.1-1, Section 18.4.1.5.1, CIAR#251). This includes disruption of knowledge transmission to future generations and associated adverse effects on Indigenous health and well-being (Addendum 10, Appendix 4.1-1, Section 18.4.1.5.1, CIAR#251).	Potential impacts to VCs linked to cultural and spiritual values have been mitigated at the Project level and are described in Table 6.5-6 (JRP IR-6.5). Benga is committed to implementing measures to reduce cumulative effects on VCs linked to cultural and spiritual values on a regional scale through the following: • mark or otherwise protected identified sites of cultural and sacred importance within 100 m of Project activity and outside the Project footprint prior to land disturbance (Addendum 10, Appendix 4.1-2: Cultural and Spiritual Values, CIAR#251); • work with Alberta Culture and Tourism and the Indigenous community to develop and plan for mitigation of identified TK/TU features if avoidance is not possible (Addendum 10, Appendix 4.1-2: Cultural and Spiritual Values, CIAR#251); • Benga has and will continue to support local and Indigenous cultural events and ceremonies through its Indigenous engagement and initiatives such as its community sponsorship program (Addendum 10, Appendix 4.1-2: Cultural and Spiritual Values, CIAR#251); • support a cultural competency program for its employees and contractors (Addendum 10, Appendix 4.1-2: Cultural and Spiritual Values, CIAR#251); • Benga has committed to providing Annual Reporting documents to Indigenous groups highlighting the results from the monitoring programs and seeking any input that would help Benga improve monitoring and the effectiveness of mitigation measures. (Addendum 10, WMMP, Section 4.3, CIAR#251); • support an Indigenous Environmental Stewardship Committee to provide advice on land use values and sites of cultural, spiritual and traditional importance as they arise (Addendum 10, Appendix 4.1-2, CIAR#251); • support an Indigenous monitoring program which will include monitoring of a suite of culturally defined environmental attributes, including archaeological sites of historical and cultural significance (Addendum 10, Appendix 4.1-2, CIAR#251); • develop and implement a Cultural Site Discovery Contingency Plan in consultation with Indigenous communities for culturally important sites discovered during construction or operations (Addendum 10, Appendix 4.1-2, CIAR#251); • continue to work with Indigenous communities to improve the Access Management Plan to grant access to non-operational areas of Benga land and crown land being used for the Project. The AMP will control access to authorized persons, will ban fishing by employees and facilitate access to traditional use areas for the Indigenous community where feasible. The AMP will include notification of access restrictions during construction required for safety purposes to allow for planning alternate plant gathering locations (Addendum 10, Appendix 4.1-2, CIAR#251); • Benga will continue to consult with Indigenous groups on the further development of the Conservation and Reclamation plans to ensure that cultural and spiritual values and other traditional and cultural values are considered as the site is reclaimed. This includes working with Indigenous communities to identify landscape attributes that support traditional practices, uses, and cultural learning (Addendum 10, JRP IR-4.3, CIAR#251); and • Benga will allow access to Benga-owned lands outside the Project footprint within the RSA for traditional use (Addendum 10, Appendix 4.1-1, Section 18.4.1.5.2, CIAR#251).	After implementation of the mitigations and assuming future projects occur as planned, residual cumulative effects on cultural and spiritual values are expected. Residual cumulative effects are characterized as (Addendum 10, Appendix 4.1-1, Section 18.4.1.5.3, CIAR#251): Low magnitude because past and present activities have already interfered with Indigenous traditional practices and experiences, and the Project's contribution will be mitigated through Benga's commitments to supporting regional programs to address cumulative effects on cultural and spiritual values. Regional geographic extent because cumulative effects are occurring within the territories of Indigenous groups and could affect cultural identity and community well-being. Long-term because cumulative loss of cultural and spiritual values could affect generations and the long-term community well-being. Continuous frequency because cumulative effects on cultural and spiritual values will be continuous in time and between generations. Non-reversible because cumulative loss of cultural and spiritual sites and experience in engaging in land use could result in permanent loss of the knowledge of cultural and spiritual values.

Table 6.8-2 Summary of Residual Cumulative Effects on Indigenous Physical and Cultural Heritage

Indigenous VCs	Summary of Past and Present Development Activities	Project's Contribution to Cumulative Effects	Interaction with Past, Present, and Future Development Activities	Mitigation Measures to Address Cumulative Effects	Residual Cumulative Effects
Indigenous Physical and Cultural Heritage (residual effects are described in Tables 6.7-2 to 6.7-9): 1) Disturbance to physical and cultural heritage. 2) Change in access to physical and cultural heritage. 3) Change to cultural value or importance associated with physical and cultural heritage.	Limited information was received from Indigenous groups regarding the locations of physical and cultural heritage (Addendum 10, Appendix 4.1-1, Section 18.4.2.1.2, CIAR#251). Káinai Nation identified sites within the Project LSA that are significant for traditional material culture, such as material for knives and arrowheads (Addendum 10, JRP IR-4.6, CIAR#251). Stoney Nakoda Nation reported areas in the Project area that are recognized by the members as meditation sites (Addendum 10, Appendix 4.1-1, Section 7.4.1, CIAR#251). Tsuut'ina Nation field crew recorded several rock cairns used as a navigational tool situated along historic trails (Addendum 10, Appendix 4.1-1, Section 8.4.1, CIAR#251). Physical and cultural heritage sites, and use and access to these sites, have likely already been altered by past and present land use in the area such as development, private land, land use regulations and restrictions, rail and road corridors, agriculture, and settlements.	Residual Project effects on Indigenous physical and cultural heritage are considered moderate magnitude and irreversible for Indigenous groups who identified the area contains physical and cultural heritage (see response to JRP IR-6.7). Project effects will include disturbance to features associated with sacred, gathering, or habitation sites and change in access to physical and cultural heritage. The Project's contribution to cumulative effects on physical and cultural heritage is low because Benga has the following commitments: • Where identified by Indigenous groups, sites of cultural and sacred importance within 100 m of Project activity and outside the Project footprint will be marked or otherwise protected prior to land disturbance. • If avoidance of any TK/TU features is not possible, Benga will work with Alberta Culture and Tourism and/or Indigenous groups to develop and plan for mitigation of the site. • Benga has committed to return Crown leases to the Crown after reclamation is completed. • Benga will continue to work with Indigenous groups to mitigate potential Project effects on sacred lands. • Benga will develop work camp policies related to protecting historical resources and will provide this information to Indigenous groups. • A Cultural Site Discovery Contingency Plan will be developed and implemented for culturally important sites identified during pre-construction or construction. • Benga will consult with Indigenous groups prior to conducting mitigation excavations to ensure opportunities are provided for the development of culturally appropriate practices. • Benga will continue to consult with Indigenous groups on the further development of the Conservation and Reclamation plans to ensure that Indigenous physical and cultural heritage are considered as the site is reclaimed. This includes working with Indigenous communities to identify landscape attributes that support traditional practices, uses, and cultural learning (Addendum 10, JRP IR-4.3, CIAR#251).	The Project will interact with other past, present, and future physical activities that disturb features associated with sacred, gathering, or habitation sites and change access to physical and cultural heritage.	Potential impacts to Indigenous physical and cultural heritage have been mitigated at the Project level and are described in Table 6.5-7 (JRP IR-6.5). Benga is committed to implementing measures to reduce cumulative effects on Indigenous physical and cultural heritage on a regional scale through the following: • an Indigenous Environmental Stewardship Committee will be established, to provide advice on land use values and sites of cultural, spiritual and traditional importance as they arise (Addendum 10, Appendix 4.1-1, Section 19.0, CIAR#251); • support an Indigenous Monitoring Program that will include consideration of cultural heritage impacts and monitoring for cultural sites (Addendum 10, Appendix 4.1-2, CIAR#251); • work with Alberta Culture and Tourism and the Indigenous community to develop and plan for mitigation of identified TK/TU features if avoidance is not possible (Addendum 10, Appendix 4.1-2, CIAR#251); • make minor modifications to the Project footprint to avoid and protect pre-contact sites DjPo-98 and DjPo-130 (Addendum 10, Appendix 4.1-2, , CIAR#251); • continue to meet with Indigenous communities to discuss management of identified culturally important and sacred sites (Addendum 10, Appendix 4.1-2, CIAR#251); • develop and implement a Cultural Site Discovery Contingency Plan in consultation with Indigenous communities for culturally important sites discovered during construction or operations (Addendum 10, Appendix 4.1-2, CIAR#251); and • continue to improve the AMP for construction and operation phases of the Project that includes notification of access restrictions during construction as required for safety purposes to allow for planning alternate land use locations (Addendum 10, Appendix 4.1-2, CIAR#251).	After implementation of the mitigations and assuming future projects occur as planned, there will be residual cumulative effects on physical and cultural heritage due to disturbance to features associated with sacred, gathering, or habitation sites, disturbance to use or access to physical and cultural heritage, and change in the cultural value or importance associated with physical and cultural heritage. Residual cumulative effects are characterized as (Addendum 10, Appendix 4.1-1, Section 18.4.2.2, CIAR#251): Low magnitude because the Project footprint overlaps existing disturbance and contributions of the Project and future development to cumulative effects are predicted to be small. The Project's contribution will be reduced by implementing pre-construction measures and a cultural site discovery contingency plan. Regional geographic extent because cumulative effects are occurring over the traditional territories used by Indigenous groups. Medium-term because disturbance to sites and features and loss of access will occur during construction and operation, and reclamation the Project footprint is expected to improve land use for traditional purposes following mine closure. Continuous frequency because cumulative loss of physical and cultural heritage will be continuous throughout construction and operation until closure. Non-reversible because, although implementation of the AMP, C&R Plan, and regional efforts will improve conditions for traditional land use such as access to physical and cultural heritage sites and features, any loss of heritage sites and features or loss of engagement with physical and cultural heritage could have a permanent affect on cultural identity and human well-being from loss of intergenerational transfer of knowledge.

REFERENCES:

Carlson M, Berg K, Dyck T, Stelfox B, Straker J. 2018a. Cumulative effects assessment for Kainai First Nation. Prepared for Kainai First Nation, Standoff, AB, and JFK Law, Vancouver, BC. Prepared by Integral Ecology Group, Ltd., Duncan, BC, and the ALCES Group, Calgary, AB.

Carlson M, Berg K, Dyck T, Stelfox B, Straker J. 2018b. Cumulative effects assessment for Siksika Nation. Prepared for Siksika Nation, Siksika, AB, and MLT Aikins, Calgary, AB. Prepared by Integral Ecology Group, Ltd., Duncan, BC, and the ALCES Group, Calgary, AB.

WILDLIFE

Information Request 6.9

Grassy Mountain Coal Project - Updated Environmental Impact Assessment. Consultant Report #9 – Wildlife. (CIAR #42).

Information Request Package #5 from the Joint Review Panel to Benga, Information Request 5.34. (CIAR #215).

Tenth Addendum to the Environmental Impact Assessment. Response to Information Request 5.34. (CIAR #251).

Information Request 5.34 (CIAR #215) requested Benga provide an assessment of the American Badger, which was recently listed on the *Species at Risk Act*, Schedule 1. The assessment was to include habitat requirements, identified critical habitat and/or recovery habitat of the species at risk. This assessment also requested Benga provide the potential Project effects on the species and their critical habitat.

Benga's response to IR 5.34 (CIAR #251), regarding the American Badger, provided a description of its habitat requirements and respective changes in habitat availability within an Application Case assessment. Benga stated, "Traditional American badger habitat is characterized by grassland, steppe and open forest but recent studies have shown that they will also utilize open or roaded areas within forest environments (COSEWIC 2012)". Benga also noted that "Other suitable habitat includes linear corridors, particularly in forested areas, non-forested or open-forested patches in alpine regions, wetlands and grasslands."

Within the Application Case assessment, Benga stated that the primary effect of the Project development is related to direct habitat loss. The assessment focuses on habitat availability and includes grasslands (290.3 ha or 5.1%), perennial forage crops (37.3 ha or 3.8%), clearings (212.4 ha or 3.8%), road-sides (124.8 ha or 2.2 %), and seeded wellsites and pipeline right-of-ways (65.2 ha or1.1%). These habitats account for 12.9% (730 ha) of the Wildlife Local Study Area (WLSA) however Benga's assessment does not include a discussion of open forest habitat types.

Consultant Report #9, Table 2.4-1 Wildlife Habitat Types and Ecosite Phases Present in the Wildlife Local Study Area (WLSA) indicates open forest habitat exists within the WLSA (CIAR #42). Further, Table 2.4-31 titled "Detection Frequency (No./100 Camera Days) of Carnivores by Camera and Habitat Type in the WLSA 2015-2016" indicates detection of American badger within a habitat type categorized as "Moderate Mixed Coniferous."

In Consultant Report #9, Table 2.4-1 Wildlife Habitat Types and Ecosite Phases Present in the Wildlife Local Study Area (CIAR #42), Benga provided an area of 37.3ha or 0.7% for perennial forage crops (agriculture) which differs from the above stated percentage of 3.8% for perennial forage crops. The same 3.8% for perennial forage crops was also used for the Baird's Sparrow's Application Case assessment.

The information requested below is required in order to complete the following:

- Terms of Reference, Section 4.7.1 [A]: *"Describe, quantify, and map all existing habitat disturbance (including exploration activities) and identify those habitat disturbances that are related to existing approved project operations."*
- EIS Guidelines, Section 6.3.3: *"direct and indirect effects of the Project on federally listed species at risk and those species listed by COSEWIC classified as extirpated, endangered, threatened, or of special concern (flora and fauna)…".*

a) Explain why Benga excluded open forested areas from the American Badger's habitat availability assessment under the Application Case.

Response:

Open forested areas within the WLSA should have been included in the Application Assessment. Therefore, Benga has updated the Response to JRP IR-5.34 (Addendum 10, CIAR#251) for American badger as indicated below in the response to part 6.9b (Note – new information or changes have been underlined).

b) Provide an updated assessment with the inclusion of the open forested areas for the American Badger.

Response:

AMERICAN BADGER

The American badger was listed as a Schedule 1 species under the SARA on February 2, 2018 following the submission of the updated EIA for the Grassy Mountain Project in 2016 (CIAR#42). A detailed description of the vegetation and biophysical features of the local and regional study areas is presented, Consultant Report (CR) #8 – Vegetation and Wetlands (EIA, CIAR#42) and wildlife study areas, baseline inventory methods and information on baseline wildlife habitats are provided in, CR#9 – Wildlife (EIA, CIAR#42).

Status

Distribution

Three subspecies of American Badger (*Taxidea taxus)* occur in Canada (*T. t. jacksoni, T. t. taxus and T. t. jeffersonii*). Populations, which occur in four designatable units (DU), are distributed throughout southern regions of western and central Canada, inhabiting areas from the eastern slopes of the coastal mountains in British Columbia to the boreal forest of south-eastern Manitoba (COSEWIC 2012). The *taxus* subspecies occurs in the Alberta, Saskatchewan, Manitoba and northwestern Ontario DU. In Alberta, its range extends approximately from the North Saskatchewan border south to the Montana border, and from the Saskatchewan border west to the foothills (Scobie 2002).

Prior to the definition of subspecies boundaries, the American badger was considered to represent a single population in Canada and was classified as "No Designation Required" in 1979 by COSEWIC. The designation was changed to "Not at Risk" when COSEWIC terminology changed in 1995. The populations were then defined by the geographical boundaries in 2000 and reassessed. The status of American badger occurring in Alberta, Saskatchewan and Manitoba was reassessed again in 2012 and designated as Special Concern under COSEWIC (COSEWIC 2012). The *taxus* subspecies was added to Schedule 1 of the SARA and classified as "Special Concern" in February 2018.

There is no evident decline in populations occurring in Alberta and while the estimated number of mature individuals is unknown, badgers continue to be harvested for fur and mortality by landowners in the province is not regulated. The main threats to badger habitat and populations are land use changes (*e.g.,* intensive agricultural practices), vehicle collisions, use of rodenticides (*e.g.,* in relation to pasture lands, loss of important prey species such as northern pocket gophers and Richardson's ground squirrels), and fire suppression (increasing shrubs and woody vegetation) (Scobie 2002, COSEWIC 2012).

Population Trend

Based on an Alberta wildlife survey in conducted in 1999, COSEWIC estimated that the badger population ranged from 1,000 to 10,000 individuals. There are no reliable population trends over the past 10 years, although fur records suggest a significant historical decline in population levels. For example, 18,000 pelts were recorded in 1928 while recent fur data shows a decrease in pelts sold between 1999 and 2010 with an average of 734 badgers trapped annually (COSEWIC 2012). The west and east DUs have a population of less than 250 and 160 mature individuals, respectively while the south-western Ontario population is estimated at less than 200 adults (COSEWIC 2012). In Alberta, annual fur production of badger based on export permits decreased from 391 in 2013/2014 to 155 in 2017/2018 for a five year average of 244 pelts (GoA 2019).

Life History and Habitat Requirements

Habitat Preferences

Traditional American badger habitat is characterized by grassland, steppe and open forest but recent studies have shown that they will also utilize open or roaded areas within forest environments (COSEWIC 2012). Specifically, badgers require suitable soil conditions for digging and abundant prey within the habitat. The soil must be able to maintain its structure when tunnelled such as course silts, fine sands and low colluvial material. Other suitable habitat includes linear corridors, particularly in forested areas, non-forested or open-forested patches in alpine regions, wetlands and grasslands. Critical habitat for American badger has only been identified for Ontario (Environment Canada 2013) but has not yet been established for the Alberta population. The American badger is carnivorous, feeding on other animals such as

voles, deer mice, wood rats, prairie dogs, gophers, squirrels, moles, marmots, birds and even insects.

Life History

Badgers begin mating in July and August. Males do not mature until after their first year and less than half of females will breed during their first summer (COSEWIC 2012). Females give birth to a litter ranging from 1 to 5 kits in March or April. Badgers are adaptable to fluctuating weather conditions and resource availability. They may enter into a shallow torpor during winter and are generally tolerant of humans and certain development. Their diet primarily consists of small rodents such as ground squirrels, marmot and woodchucks. Pocket gophers, voles, mice, insects, birds, reptiles and amphibians also supplement the badger's diet.

Movements and Home Range

Although the home range of the American badger in Alberta is unknown (Scobie 2002), home ranges in British Columbia varies from 33 to 64 km^2 for males and 16 to 18 km^2 for females and varies widely in the United States, depending on the season (COSEWIC 2012). Based on a review of nine studies conducted in North America, the average home range size was 97 km^2 for males and 12 km^2 for females. In Canada, Badgers (*taxus* subspecies) occur in the Prairie Provinces from east of Winnipeg, south of Lake Winnipeg and west to the Alberta Rocky Mountains. Their northern extent is defined into the Boreal Transition ecoregion. For these prairie ranges, the extent of occurrence is estimated at 721,096 km^2 while the index of area of occupancy is approximately 173,000 km^2 (COSEWIC 2012).

Juvenile badgers leave within their first summer and may travel as far as 52 km for females and 110 km for males although the average dispersal rate is 11 km by 106 days of age (COSEWIC 2012). They have the ability to cross major physiogeographic barriers and their home range size is likely dependent on female availability.

Regional Importance

American Badgers are top predators in their specific ecosystems. With their diet mainly consisting of small mammals such as ground squirrels, voles and mice, they have a role in maintaining these populations. Badgers also create patch disturbances in grassland habitats which can influence plant communities by loosening and aerating the soil, promoting humus formation and increasing permeability. Other burrowing species will use badger dens for shelter and nesting such as snakes, pocket gophers, swift fox and burrowing owls. Badgers are also valued for their fur in Alberta and their skins are of importance to the Piikani Nation in the Crowsnest Pass region which are used as traditional garments.

Application Case Assessment

Change in Habitat Availability

The primary effect of Project development on available American badger in the WLSA is related to direct habitat loss. Potential badger habitats include open natural grassy areas in the montane and alpine zones of the WLSA associated with forests such as open pine (516.7 ha or 9.2% of the WLSA), open deciduous (51.6 ha or 0.9%), open mixedwood (291.2 ha or 5.2%) and open mixed coniferous (440.5 ha or 7.8%) habitats along with grasslands (290.3 ha or 5.1%) (EIA, CR#9, Table 5.5-1, CIAR#42). In addition, badgers may also use various anthropogenic disturbance types in the WLSA that are grass-dominated such as perennial forage crops (37.3 ha or 0.7%), early seral clearcuts (239.7 ha or 4.2%), clearings (212.4 ha or 3.8%), and road-sides (124.8 ha or 2.2 %) and seeded well sites and pipeline rights-of-way (65.2 ha or 1.1%) (EIA, CR#9, Table 2.4-1, CIAR#42). Overall, potential badger habitats account for 40.2% (2,269.7 ha) of the WLSA.

During maximum project disturbance in Year 14, a loss of potential suitable badger habitat is predicted. This includes losses of 150.7 ha (-51.9%) of grassland and 161.2 (-44.3%) of open forest habitats, along with 1,520.7 ha (-80.1%) associated with the Project footprint (EIA, CR#9, Table 5.1-1, CIAR#42). These habitat losses are expected to be temporary since the availability of potentially suitable badger habitat in the WLSA is expected to increase as the Project-related disturbances are progressively reclaimed.

In year 27, changes in habitat availability resulting from Project development are expected to result in an increase in grassland habitat of 58.8 ha (20.2%) and a decrease in open forest habitats of 37% (-129.0 ha) (Table 5.1-1). This represents a slight net loss of 70.2 ha (-3.1%, 2,199.5 ha of habitat available at Year 27) from baseline (2,269.7 ha) of potential badger habitat in the WLSA. Potentially suitable anthropogenic disturbance habitats located outside the Project footprint, but within the WLSA (such as perennial forage crops, early seral clearcuts, clearings, road-sides, and seeded well sites and pipeline rights-of-way) are expected to be roughly similar to baseline conditions.

However, existing anthropogenic disturbances (*e.g.,* trails, roads) within the Project footprint will be reclaimed at closure. In addition, as Project reclamation progresses across the landscape, grass-dominated reclaimed sites may provide suitable habitat for badgers for many years. For example, grassland and open shrubby habitats were rated as high and moderately high for elk, respectively (EIA, CR#9, Appendix C, Section 2.8, CIAR#42). These habitat types, which provide important foraging habitats for elk throughout the year, are expected to decrease by 46% (-197.0 ha) at Year 14 but increase by 129% (550.1 ha) from baseline as reclamation progresses across the Project footprint (EIA, CR#9, Table 5.3-20, Figure 5.3-46, CIAR#42).

Overall, potential American badger habitat in the WLSA is predicted to decrease slightly from baseline conditions following mitigation and reclamation. Project development is not expected

to negatively affect badger habitat in the WRSA since most of the suitable habitat is located east and southeast of the Project footprint.

Table 5.1-1 Change in Wildlife Habitat Between the Baseline and Application Cases in the Wildlife Local Study Area (Source: EIA, CR#9, CIAR#42)

Habitat Type	Baseline (ha)	Year 14			Year 27		
		Application (ha)	Change		Application (ha)	Change	
			ha	%		ha	%
Open Pine	516.7	455.1	-61.6	-11.9	455.1	-61.6	-11.9
Open Deciduous	51.6	48.4	-3.2	-6.3	48.4	-3.2	-6.3
Open Mixedwood	291.2	254.4	-36.8	-12.6	254.4	-36.8	-12.6
Open Mixed Coniferous	440.5	380.9	-59.6	-13.5	413.10	-27.4	-6.2
Moderate Mixed Coniferous	1,375.8	988.8	-387.0	-28.1	934.0	-441.8	-32.1
Closed Deciduous	27.6	27.6	0.0	0.1	27.6	0.0	0.1
Closed Mixedwood	991.2	682.3	-308.9	-31.2	682.3	-308.9	-31.2
Closed Spruce	79.4	74.7	-4.7	-6.0	74.7	-4.7	-6.0
Closed Mixed Coniferous	419.5	271.8	-147.7	-35.2	266.3	-153.2	-36.5
Grassland	290.3	139.6	-150.7	-51.9	349.1	58.8	20.2
Upland Shrub	0.2	0.2	0.0	-24.2	0.2	0.0	-24.2
Shrubby Wetland	17.9	1.6	-16.3	-91.1	1.6	-16.3	-91.1
Treed Wetland	4.8	4.8	0.0	0.0	4.8	0.0	0.0
Rock Barren	48.6	16.8	-31.8	-65.5	57.5	8.9	18.3
Waterbody	63.9	63.8	-0.1	-0.1	82.2	18.3	28.6
Total Anthropogenic Disturbance	1,027.3	2,235.7	1,208.4	117.6	1,995.2	967.9	94.2
Totals	**5,646.4**	**5,646.4**	-	-	**5,646.4**	-	-

Change in Movement

Movements of American badgers in the WLSA will be affected since most of the habitat available for badgers will be affected by development of the Project footprint at Year 14 (EIA, CR#9, Figure 5.1-1, CIAR#42). However, following mitigation and reclamation, badger movements are not expected to be affected in Year 27. The single badger that was photographed was travelling on a trail at the edge of a moderate mixed coniferous stand and the existing coal mine disturbance in an alpine area of the WLSA. Badgers will be displaced to other more suitable habitats adjacent to the Project footprint. While badgers are relatively tolerant of

anthropogenic disturbances, movements along the access corridor and the 5.4 km long coal conveyor may be affected.

Change in Mortality Risk

The American badger is still managed in Alberta as a furbearing species and one of the main anthropogenic risks of mortality in the WLSA and WRSA is trapping. Both the WLSA and WRSA fall within Fur Management Zones (FMZ) 6 where badger trapping can occur from December 1 to April 15. In addition, the badger may be hunted, without a license and during all seasons, by a resident on privately owned land to which the resident has the right of access AEP (2019). With Project development, hunting and trapping will not be allowed with the Mine Permit Area which should function in minimizing this risk for the American badger.

The badger is also highly susceptible to road-kill. Badger prey are generally attracted to roadside conditions of quality grass and friable soils (Weir *et al.* 2004b, cited in COSEWIC 2012) causing badger to become prone to mortality from vehicles. There is no data collected on road- kill in the Alberta populations but badgers have suffered high rates of road-kill in similar ecosystems such as southern Idaho (Messick and Hornocker 1981). Vehicle collisions can be reduced by establishing and enforcing a low speed limit on the access road. Density of roads are not likely to increase but traffic volume will rise along the access road to the mine.

Change Relative Abundance

Although the American badger was identified as wildlife species that could potentially occur in the WLSA, its presence within the WLSA was confirmed through wildlife camera trapping in August 2015 (EIA, CR#9, Section 2.4.3.3.2.1, CIAR#42). This was the only badger sighting recorded either incidentally or through baseline wildlife inventories conducted in the WLSA between 2013 and 2016. It appears that the American badger is one of the least abundant mustelid species at baseline in the WLSA, although should the Project be approved, pre-disturbance surveys will be conducted to further confirm species presence and relative abundance.

Mitigation Measures

Benga will implement the appropriate best management practices, Project features and mitigation measures to minimize risk on federally-listed (*SARA*) species at risk. Although critical habitat has not been identified for American badger in Alberta, any future federal action plans including any species-specific mitigation and monitoring plans developed by ECCC and applicable to the *taxus* DU will be implemented. In the interim, if any badgers are detected during pre-disturbance surveys that will be conducted in the WLSA should the Project be approved, specific mitigation measures will be developed in consultation with AEP and ECCC.

Many of the Project effects associated with wildlife habitat loss (including badger habitat) will be minimized by implementing the Project's reclamation plan which includes the following:

- minimize the overall disturbance footprint through the mine planning process to avoid critical breeding habitats, nesting and denning sites, and movement corridors to the extent possible;
- preserve remnant forest patches within the development areas where feasible to provide habitat, habitat connectivity and hide cover for wildlife species;
- remnant patches should protect known essential raptor habitat features by incorporating these habitat features (*i.e.,* mature balsam poplar and aspen) where possible;
- maximize the direct placement of salvaged soil to enhance native plant development;
- retain slash and large woody debris in the salvaged soil to provide microsites for native plant and hide cover for wildlife;
- establish a variety of vegetation species and communities suitable for wildlife, and encourage structural complexity within the forests;
- encourage understory complexity in reclaimed forests by planting native shrubs such as alder and willow;
- ensure that core security areas are provided for wildlife;
- provide water management program that ensures the surface water quality is maintained; and
- limit sight lines by maintaining mature forest stands as buffers between roads and reclamation areas.

To support the reclamation plan mitigation measures, the following will be implemented to mitigate potential direct and indirect Project effects on wildlife habitat availability:

- Incorporate existing legacy mining disturbances into the development and reclamation plans for the Project, and other proposed land use activities to the best extent possible so that habitat loss, habitat fragmentation, linear disturbance features, and cumulative habitat loss are minimized.
- Pre-disturbance surveys (wildlife sweeps) will be conducted in the development area prior to any construction activities during Project development to determine the occurrence of any important wildlife habitat features such as migratory bird nests, mineral licks, active dens, bat habitat and hibernacula, active raptor nest sites, and essential raptor habitat features (*i.e.,* mature balsam poplar, platform/stick nests) that could indicate the presence of species at risk.
- Protect all important wildlife habitat features in areas of suitable wildlife habitat (on the edge of the Project footprint boundary) appropriate setback distances (or buffer zones) will be considered.
- Clearing and equipment use/storage/cleaning in undisturbed areas within and adjacent to the Project footprint will be avoided.

- Vegetation adjacent to high-activity linear corridors (*e.g.,* access roads, coal conveyor) will be retained to reduce the extent of noise and visual sensory disturbances to the extent possible.
- The overland coal conveyor system was designed in such a manner to prevent any deposition of coal product along the route from the CHPP to the rail load-out area. This includes a cover for the length of the conveyor to reduce dust, and motor specifications to reduce industrial noise levels.
- Where appropriate, vegetated buffer zones (100 m or minimum of 30 m; pending topography constraints) will be maintained between Project infrastructure and wetlands, creeks, and streams to the best extent possible.
- As required by the *Weed Control Act* and Regulations, all identified noxious and invasive weed species populations will be controlled prior to any site disturbance and mine operation to prevent the further spread of weeds. Noxious weed management will occur in compliance with R&R/03-4 *Weeds on Industrial Development Sites*.
- As the presence of artificial lighting can potentially affect bird and bat use of nearby habitats, Benga has developed a visual impact mitigation plan that reduces stray and non-essential artificial lighting to minimize wildlife effects and that will comply with OH&S safety requirements (EIA, CR#1 – Air Quality, CIAR#42).
- To mitigate the potential effects of sensory disturbance (acoustic and visual) on effective habitat availability in the southeast portion of the Gold Creek valley, Benga will install and maintain a 15-m tall earth berm along the eastern edge of the south disposal area (EIA, CR#2 – Noise Impact Assessment, CIAR#42). The earth berm will be constructed/maintained during the day-time when required and will grow in elevation as the height of the disposal area increases.
- Sensory disturbance from the active mine site will be further mitigated through the use of mufflers on all internal combustion engines, utilizing mine pit topography to shield noise generated from haul trucks, and conducting blasting during daylight hours (EIA, CR#2 – Noise Impact Assessment, CIAR#42).

The following general wildlife mitigation measures will be implemented to minimize potential disruption to daily and seasonal wildlife movements:

- A minimum of six wildlife crossings (underpasses and overpasses) will be incorporated into the design of the coal conveyor (the conveyor route is approximately 5.4 km in length):
  - will be strategically placed in locations that will maximize wildlife use (*e.g.,* presence of well used trails, suitable habitats, and terrain features such as valleys and depressions that act as natural crossings);
  - additional pre-disturbance surveys will be conducted to identify important wildlife habitats and trails along the access road and conveyor corridor;
  - natural underpasses using topography are preferred; and

    - above-ground crossings may be required when topography isn't favourable, conveyor will likely be raised higher above the ground to allow wildlife movement under it.
- Surface water management ponds and ditches located in undisturbed areas of the Project footprint will be designed to allow wildlife to move around or cross safely.
- Road plowing and grading will be conducted in a manner that does not restrict wildlife from crossing access roads or accessing wildlife crossings.
- Measures to control dust and other air emissions (*e.g.,* watering of roads and use of dust suppressants, minimizing engine idling, *etc.*) within the Project footprint will be implemented to minimize effects on adjacent wildlife habitats (EIA, CR#1 – Air Quality, CIAR#42).

Project-specific mitigations targeted to carnivore species have been incorporated into the reclamation planning. Many of these will also support habitat connectivity for migratory birds, raptors, and species at risk, and include:

- minimize the overall disturbance footprint through the mine planning process;
- preserve remnant forest patches in the development areas to provide essential habitat, habitat connectivity, and hide cover for wildlife species;
- retain slash and large woody debris in the replaced soil landscape;
- plant native shrubs early in the reclamation process to initiate hiding cover;
- establish mixed wood forest stands and high density coniferous tree stands;
- provide understory complexity in the reclaimed forests by planting native shrubs such as alder and willow to provide security cover for the carnivores and their prey;
- maximize the amount of ungulate habitat;
- prior to final reclamation, disrupt linear disturbances and sight lines by mounding surface soils, piling brush; and
- limit sight lines by maintaining mature forest stands or by planting high density coniferous stands to act as buffers between roads, project disturbance boundaries and the reclaimed mine areas.

Wildlife mortality risk may increase as a result of increased traffic, wildlife encountering equipment, or elements of the Project footprint, and wildlife being attracted to Project facilities or humans. The Grassy Mountain area currently has a considerable network of trails and roads that are heavily used. Plans are already being implemented to reduce this level of access and with the approval of this Project, the levels will be reduced considerably more. Mitigation measures that will be implemented to reduce wildlife mortality risk include:

- All access to the Mine Permit will be controlled, no uncontrolled access will be permitted. Common operational practices will include:
    - prohibiting use of snowmobiles and ATVs;

  - prohibiting hunting, harassment, or feeding of wildlife; and
  - implementing a strictly enforced zero tolerance policy on the use of firearms.
- Timing vegetation site clearing activities to occur outside the April 15 to August 31 period to avoid disrupting nesting migratory and resident songbirds and raptors:
  - In the event that vegetation clearing must occur within the restricted activity period, pre-disturbance nesting surveys will be conducted by experienced avian biologists according to established sensitive species inventory guidelines (GoA, 2013b). Establish species-appropriate setback distances around confirmed active nest sites until fledging in consultation with Environment Canada and AEP. If the status of a nest cannot be confirmed, or if a nest is found outside of the breeding season, a setback distance will be implemented until such time as the nest status can be confirmed (GoA, 2013b).
- Confirm the presence/absence of bats in high quality habitats located within the Project footprint prior to the initiation of any clearing activities and develop a mitigation plan if bats are found.
- Conducting pre-disturbance denning (bears, marten, *etc.*) and roosting (bats) surveys prior to vegetation clearing and other high-disturbance activities. Consult with AEP as needed to develop appropriate mitigation and management strategies.
- Conducting pre-disturbance surveys (acoustic surveys and visual searches) to identify wetlands and watercourses used by breeding Columbia spotted frogs and western toads that feed into the protection plans.
- Benga commits to supporting active bear management plans associated with the Project. If a site-specific plan is required, it will be developed in consultation with AEP personnel as part of the Wildlife Mitigation and Monitoring Plan. The plan is expected to be a comprehensive document that outlines operational strategies and best practices for addressing concerns related to not only bear-human conflicts but potential risks to ungulates and other wildlife resulting from attraction of bears to the area.
- Developing a Beneficial Management Plan guide to minimize potential Project-specific impacts on migratory birds and their habitat by identifying more site-specific mitigation and monitoring measures following Project approval and in consultation with federal and provincial regulators.
- A detailed Waste Management Plan will be developed and implemented prior to construction and operational activities to minimize the attraction of wildlife. Benga will follow the Best Management Practices for camps, fences, and barriers as described in Bear Smart: Best Management Practices for Camps, and ensure all waste is stored in wildlife-proof containers and disposed of properly. Some of the waste management and bear awareness/Bear Smart guidelines that will be implemented include:
  - ensuring food waste, refuse, and other attractants are securely contained in enclosed and approved bear-proof containers and/or facilities (*e.g.,* hard-sided buildings, fenced compounds, and bear-proof transfer station) prior to transportation to a disposal facility to prevent access by scavenging bears;

  - providing adequate signage to inform employees of the location and proper use of bear-proof storage containers/facilities;
  - ensuring waste storage containers/facilities are not filled beyond capacity;
  - ensuring regular inspection and maintenance of waste storage containers/facilities is carried out;
  - ensuring measures contained in the bear management plan are diligently followed by all employees and contractors;
  - all on-site staff will receive Bear Awareness Training; and
  - bear warning signs will be installed to advise staff of locations where problem bears have been reported.
- Implementing an Emergency Spill Response Plan to limit the effect of accidental spills. Spills will be minimized by restricting fuel storage and filling to designated areas that are at least 100 m from wetlands and watercourses as well as Project drainage ditches, sediment control ponds, and pit lakes.
- Storing all hazardous materials, including those used for blasting, in secure areas that are inaccessible to wildlife (*e.g.,* buildings, storage areas surrounded by wildlife-proof fencing). In addition, proper handling and storage of industrial materials and debris within the Project footprint will be maintained to minimize potential risks to wildlife.
- Developing procedures to clear blasting areas of large mammals or birds prior to blasting.
- Designing water management ponds and drainage ditches, and pit lakes to minimize potential entrapment of wildlife.
- Developing a strategy to minimize changes in water quality upstream of the mine in conjunction with a water-quality monitoring program.
- Enforcing speed limits (≤50 km/hr) along the main access road and utility corridors, and placing signs at identified wildlife crossings to increase driver diligence to minimize wildlife-vehicle collisions. Vehicles will yield to all wildlife crossing the main access road.
- Bird collisions with buildings will be mitigated by placing visual markers on windows, and collisions with the proposed power line will be mitigated by installing large 'floats' or other markers.

Wildlife monitoring will be used to monitor the effects of the Project on wildlife species at risk or species of management concern during construction and operation of the Project and post-closure. In particular, the effects of the Project on wildlife VCs, including disturbance, mortality, and movement will be monitored. Monitoring will consist of a systematic monitoring program along with incidental observations. The wildlife monitoring program will serve a number of important functions including:

- verifying impact predictions and monitoring the effectiveness of mitigation measures;

- improving Benga's understanding of the effects of Project construction and operation;
- on wildlife within the WLSA and surrounding area to enable the implementation of adaptive;
- management practices when required; and
- ensuring compliance with the terms and conditions of the Operating Approval and Project environmental standards once the Project has been approved by AER and CEAA.

Details of the monitoring plan have been developed and are presented in the Wildlife Mitigation and Monitoring Plan (Addendum 10, Appendix 5.39-1 in response to JRP IR-5.39, CIAR#251).

Effects Assessment

The primary effect that Project development will have on American badger is likely associated with direct habitat loss. Potential habitat types in the WLSA that provide either suitable foraging or burrowing habitats for badgers includes native grasslands, open forest and grass-dominated anthropogenic habitat types (*e.g.,* perennial forage crops, seeded well sites and pipeline rights-of-way, *etc.*). In addition, further indirect habitat loss will occur from increased noise levels associated with construction and operations activities even though the badger can be relatively tolerant of certain anthropogenic activities. Any American badgers present within the immediate vicinity of the Project footprint will be displaced to other more suitable habitats present to the east and south until at least progressive reclamation is initiated.

With Project development, mortality risk associated with hunting and trapping will not be allowed within the Mine Permit Area which should function in minimizing these risks for the American badger. However, the badger is susceptible to collisions with vehicles because of the presence of suitable foraging and burrowing habitats associated with roadsides. The potential for badger-vehicle collisions can be reduced by establishing and enforcing a low speed limit on the access road. Badger movements are not expected to be affected by the Project.

Potential direct or indirect effects resulting from increased exposure to chemicals of concern as a result of the Project were assessed in the updated screening-level wildlife risk assessment (Addendum 10, JRP IR-4.9, Appendix H, CIAR#251; Addendum 11, JRP IR-6.28, Appendix 6.28-1) evaluated potential adverse population-level effects to terrestrial wildlife associated with chemical emissions from the Project.

As previously mentioned in the Baird 's sparrow effects assessment summary, the methods and guidelines as provided in the screening level-WRA were established to be protective of population-level adverse effect(s) and exposures to chemical(s) at concentrations lower than those presented in the updated screening level-WRA would not be expected to cause ill-effect. As such, the TRVs used within the updated screening-level WRA are considered protective of the American badger and the conclusions of the screening-level WRA remain unchanged.

Specifically, that chemical concentrations associated with Project emissions would not be expected to cause population level adverse effects on wildlife.

Of note, the updated screening-level WRA was amended as part of this IR response package (Addendum 11, JRP IR-6.28) to include an evaluation of water-based exposure pathways (both groundwater and surface water) and the results presented for Blairmore Creek and Gold Creek were not considered to be indicative of adverse effects to wildlife (Addendum 11, JRP IR-6.28). For the proposed end pit lake (EPL) (at closure, when the pit is proposed to be created), the results of the risk assessment are not considered indicative of a human health concern; however, the conservative modeling associated with the development of the HQ for mallard duck (only) indicated a potential risk for that particular group, as such management considerations of the EPL were noted, and actual measured concentrations at the time of EPL creation (at closure) would be used to revisit predicted effects.

The overall effects of Project development on the American badger in the WLSA are predicted to be local in extent, extended in duration, continuous in frequency, low in magnitude, and high in probability. The Project contribution to changes in abundance and habitat availability will be negative during the lifespan of the Project, but will be reversible in the long-term. The confidence rating associated with this assessment is moderate, since although a single badger was recorded, the American badger is likely an uncommon species in the WLSA. In terms of the potential effects of the Project on the persistence of this species in southwestern Alberta, the effects are considered to be Not Significant. This rating is partly based on the small proportion of potential grassland and open forest habitats that will be lost to the Project, the likelihood that most of the habitats potentially used by American badger will be replaced or increased over the long term through the proposed reclamation program, and with implementation of the general wildlife and species-specific mitigation and monitoring plans.

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c) Confirm the percentage of perennial forage crop available.

Response:

There is a typographical error in reporting the percentage of perennial forage crops available for Baird's sparrow and American badger in the text of the assessments. It appears that the value of 3.8%, which is the value of cleared habitats (ecosite phases CL and CO) located immediately above the perennial forage crop line in Table 2.4-1 (EIA, CR#9, CIAR#251), was inadvertently used instead of 0.7%. However, the correct value of 0.7% was used in all habitat calculations.

d) Confirm the total potential habitat for Baird's Sparrow and America Badger.

Response:

The total potential habitat for American Badger is confirmed in the response to part b).

As noted in the response to part c), despite the typographical error, the percentage for perennial forage crop was used correctly in all habitat calculations, and as such, the total potential habitat for Baird's Sparrow of 730 ha (as reported in the response to JRP IR-5.34, Addendum 10, CIAR#251) remains unchanged.

Information Request 6.10

Grassy Mountain Coal Project - Updated Environmental Impact Assessment. Consultant Report #9 – Wildlife. (CIAR #42).

Information Request Package #5 from the Joint Review Panel to Benga, Information Request 5.35. (CIAR #215).

Information Request 5.35 (CIAR #125) requested Benga provide clarification regarding the use of Elk as a surrogate species for Common Nighthawk and Bobolink, with supporting research or literature to justify the approach. Benga's response in the Tenth Addendum (CIAR #251) stated that, "Elk (as a VC) and common nighthawk (as a special status species) do have similar habitat requirements during the snow- free period…". Benga also stated, "If the Bobolink does occur in the WLSA, it would most likely be associated with grassland and grass-dominated anthropogenic habitats (Table 2.4-1, CR#9, EIA) similar to habitats used by both Elk and Common nighthawk."

Benga provided various habitat assessments within Consultant Report #9 (CIAR #42) for Elk, Common Nighthawk, and Bobolink. Based on these assessments, Benga suggested that the habitat requirements for Elk provide a sufficient representation for migratory birds associated with grassland and open country habitat preference, including Common Nighthawk and Bobolink.

Table 4.6-1 in Consultant Report #9 titled "Migratory Bird Species with the Potential to Occur in the WLSA and Their Habitat Preferences" indicated that Elk, a VC with similar habitat requirements to Grassland or Open Country Birds, provides a suitable surrogate to Project effects on habitat availability (CIAR #42). Benga also indicated, as a result, Project effects on Elk and their respective habitat are expected to be similar for the Bobolink and Common Nighthawk.

The information requested below is required in order to complete the following:

- Terms of Reference, Section 4.7.1 [A]: *"Describe, quantify, and map all existing habitat disturbance (including exploration activities) and identify those habitat disturbances that are related to existing approved project operations."*
- EIS Guidelines, Section 6.3.3: *"direct and indirect effects of the Project on federally listed species at risk and those species listed by COSEWIC classified as extirpated, endangered, threatened, or of special concern (flora and fauna)…".*

a) Describe how the use of Elk as a surrogate species for Common Nighthawk and Bobolink provides adequate habitat overlap to assess Project effects. Include potential gaps or uncertainties.

Response:

Benga would like to clarify, for the purposes of this information request, that elk was not used as a direct surrogate species for bobolink and common nighthawk as part of the wildlife impact assessment. Although an assessment of Project effects on common nighthawk was completed in the EIA (CR#9, Section 5.4.2, CIAR#42), Benga considered the information pertinent to Project

effects on elk habitat availability were appropriate and relevant to the understanding of effects on other species with similar habitat requirements. Based on that, Benga applied some of the results of the elk assessment (specifically pre and post reclamation habitat suitability losses and gains) in conjunction with the qualitative assessment on common nighthawk, as well as the assessment of the grassland migratory bird species guild (CR#9, Section 5.5, CIAR#42) to provide a fulsome understanding of the potential effects on common nighthawk. The approach of using a single wide-ranging species as an indicator or "umbrella" to predict effects on other similar species within a particular guild or functional community is an accepted practice in biological conservation and assessment (Simberloff 1998, Favreau *et al*. 2006).

Commentary on elk having similar habitat requirements to grassland migratory birds originates from Table 4.6-1 in CR#9 (EIA, CIAR#42). That particular table is reproduced here (Table 6.10-1) with updates (noted in bold) to support with this clarification.

Table 6.10-1 Migratory Bird Species[1] with the Potential[2] to Occur in the WLSA and Their Habitat Preferences – Updated [Source: EIA, CR#9, Table 4.6-1, CIAR#42]

Migratory Bird Group	Species Included	SARA-Listed Species	Habitat Preferences	VCs With Similar Requirements
Shorebirds and Other Birds Reliant on Marshes or Rivers	American Dipper, Bank Swallow, Common Yellowthroat, Killdeer, Lincoln's Sparrow, Marsh Wren, Northern Waterthrush, Sora, Spotted Sandpiper, Wilson's Snipe, Wilson's Phalarope, Wilson's Warbler	None	Wetlands, ponds, lakeshores, streams. Wet, shrubby area in case of Wilson's Warbler and Common Yellowthroat.	Columbia Spotted Frog, Western Toad
Waterfowl	American Coot, American Wigeon, Barrow's Goldeneye, Blue-winged Teal, Bufflehead, Canada Goose, Common Goldeneye, Common Merganser, Green-winged Teal, Harlequin Duck, Hooded Merganser, Lesser Scaup, Mallard, Northern Shoveler, Northern Pintail, Ring-necked Duck, Redhead, Wood Duck	None	Wetlands, lakes, rivers, streams	Columbia Spotted Frog, Western Toad
Grassland or Open Country Birds	American Goldfinch, American Pipit, Baird's Sparrow, ~~**Bobolink**~~, Brewer's Sparrow, Clay-colored Sparrow, Common Nighthawk, Eastern Kingbird, Fox Sparrow, Grasshopper Sparrow, Golden-crowned Sparrow, Mountain Bluebird, Mourning Dove, Savannah Sparrow, Tree Swallow, Vesper Sparrow, Western Bluebird, Western Kingbird, Western Meadowlark, White-crowned Sparrow	~~**Bobolink,**~~ Common Nighthawk, **Baird's Sparrow**	Grasslands. Shrubby habitats at forest edges (Fox, Golden-crowned and White-crowned Sparrow)	**Common nighthawk was assessed as a special status species** **Baird's sparrow was assessed in JRP IR-5.34** Elk
Old-Growth Forest Birds	American Three-toed Woodpecker, Black-backed Woodpecker, Brown Creeper, Evening Grosbeak, Pileated Woodpecker	None	Mature to Old Growth Forests	Great Gray Owl, American Marten

Table 6.10-1 Migratory Bird Species[1] with the Potential[2] to Occur in the WLSA and Their Habitat Preferences – Updated [Source: EIA, CR#9, Table 4.6-1, CIAR#42]

Migratory Bird Group	Species Included	SARA-Listed Species	Habitat Preferences	VCs With Similar Requirements
Coniferous-dominant Forest Birds	Boreal Chickadee, Cassin's Finch, Cordilleran Flycatcher, Golden-crowned Kinglet, Hammond's Flycatcher, Mountain Chickadee, Olive-sided Flycatcher, Pine Grosbeak, Purple Finch, Red-breasted Nuthatch, Red Crossbill, Ruby-crowned Kinglet, Townsend's Solitaire, Townsend's Warbler, Varied Thrush, Western Tanager, White-winged Crossbill, Winter Wren, Yellow-rumped Warbler	Olive-sided Flycatcher	Coniferous or Coniferous-dominant Mixedwood Forests	Olive-sided Flycatcher, American Marten, Canada Lynx Common nighthawk was assessed as a special status species
Deciduous-dominant Forest Birds	Alder Flycatcher, American Redstart, Baltimore Oriole, Black-capped Chickadee, Black-headed Grosbeak, Downy Woodpecker, Gray Catbird, Lazuli Bunting, Least Flycatcher, Nashville Warbler, Ovenbird, Red-eyed Vireo, Red-naped Sapsucker, Veery, Warbling Vireo, White-breasted Nuthatch, Willow Flycatcher, Yellow Warbler	None	Deciduous or Deciduous-dominant Mixedwood Forests.	Little Brown Myotis, Moose
Anthropogenic Habitat Birds	Barn Swallow, Eastern Phoebe	Barn Swallow		None Barn Swallow was assessed as a special status wildlife species in Section 5.4.1.

[1] Refers to species that are protected under the *Migratory Birds Convention Act*

[2] Refers to migratory bird species with a high, moderate or confirmed Probability of Occurrence rating in Table 2.4-2, CR# 9.

Additional rationale associated with these updates (in bold) include:

- Removal of bobolink from the table as an errata. The criteria for "potential to occur" as described in footnote 2 of the table, are those "migratory bird species with a high, moderate, or confirmed Probability of Occurrence rating in Table 2.4-2, CR# 9" (EIA, CIAR#42). In Table 2.4-2, bobolink is listed as "low." As such, bobolink should not have been included in Table 4.6-1. Bobolink range in Alberta includes "central and southern Alberta (from Beaverhill Lake to the border regions)…, where it appears to be sporadic (absent from the foothills of the Rockies)" (COSEWIC 2010, pg. 8). This was shown in Figure 5.35-1 (Addendum 10, JRP IR-5.35, CIAR#251), presented here again for this information request as Figure 6.10-1. This is also supported by results of field work, where Bobolink were not detected during breeding bird surveys nor incidentally observed during other wildlife surveys conducted within the WLSA. Bobolink is not assessed or discussed further, as an assessment of Project effects for species not present in the WLSA is not required.
- This is further supported by other additional sources of existing information on bobolink distribution in Alberta: the North American Breeding Bird Survey (BBS) and the Alberta Biodiversity Monitoring Institute (ABMI) monitoring program. BBS Route 04-205 (Coleman) extends in a northeast direction from the Town of Coleman along Range Roads 43A, 40A, 35A and 34A (EIA, CR#9, Figure 2.2-1, CIAR#42) providing a longer term source of information on birds in the region (Pardieck *et al*. 2019). The Coleman BBS route was surveyed on 10 occasions over an 18 year period extending from 2000 to 2017b. During these 10 surveys, no bobolinks were recorded. No other BBS survey routes occur in the WRSA although there are two routes nearby which may be more reflective of bobolink habitat. The Summerview route (BBS-04-304) is located 13.5 km east of the WLSA and the Trout Creek route (BBS 04-404) is located approximately 7.2 km to the northeast (Figure 6.10-2). Based on this regional BBS data, which are available for a 13 year period (2006 to 2018), seven bobolinks were recorded only in 2017 along the Trout Creek route (Pardieck *et al.* 2019). The BBS results indicate that the WLSA does not provide suitable habitat for bobolink and that this species is more likely to occur in higher quality habitats located beyond the WRSA. The Alberta Biodiversity Monitoring Institute (ABMI) breeding bird database does not have reports of bobolink at their monitoring sites located near the Project (and outside the GBRSA) (ABMI 2020). Clarification for the grassland or open country bird group that common nighthawk was assessed as a special status species.
- Addition of Baird's sparrow to the grassland or open country bird group. Baird's sparrow was added to SARA Schedule 1 on February 3, 2017, after submission of the EIA. Benga subsequently provided an assessment for this species (Addendum 10, JRP IR-5.34, CIAR#251). Since it was not a SARA-listed bird at the time of completion of the EIS, it was not originally included in the SARA-listed species column of the table.

Common nighthawk and elk have similarities in their primary habitat requirements. Potential habitat types in the WLSA that provide either good foraging or nesting habitats for common

nighthawks may include open forested stands (*e.g.,* open pine, open deciduous, open mixedwood, and open mixed coniferous types), wetlands (*e.g.,* shrubby and treed wetlands), open natural areas (*e.g.,* grassland, rock/barren types), and various anthropogenic disturbances (*e.g.,* cutblocks, pipelines, well sites, perennial crops, and other clearings) (CR#9, Section 5.4.2.1, CIAR#42).

Elk prefer grasslands and open areas for foraging in both winter and summer and this habitat received the highest ratings in the habitat suitability model. The assessment of potential Project effects on effective habitat for elk included open forested stands (open pine, open deciduous, open mixedwood, open mixed coniferous types), grassland, and various anthropogenic disturbances (cutblocks, perennial crops and clearings).

In summary, differences in habitat preferences between elk and common nighthawk (*e.g.,* wetlands and rock/barren types) are very limited within the WLSA (CR#9, Table 5.1-1, CIAR#42). As such, information on Projects effects on elk habitat are relevant for supporting the understanding of habitat disturbances on common nighthawk, when viewed in conjunction with the nighthawk-specific assessment.

b) Describe how Project effects on Common Nighthawk and Bobolink can be understood through Project effects on Elk.

Response:

As per the clarification provided in JRP IR-6.10 a) of this information request, an assessment on common nighthawk was completed as part of the original EIA (CR#9, Section 5.4.2, CIAR#42). This section is copied below.

Benga considers the assessment is adequate on its own; however, felt it was strengthened when viewed in conjunction with the assessment of the grassland or open country migratory bird group (CR#9, Section 5.5, CIAR#42), and the current elk habitat effectiveness assessment (CR#9, Section 5.3.10, CIAR#42). The information combined provides a fulsome understanding of potential effects on common nighthawk.

"5.0 Application Case Assessment

5.4 Special Status Wildlife Species

5.4.2 Common Nighthawk

5.4.2.1 Species Account and Potential Project Effects

The primary effect that Project development will have on common nighthawks is likely associated with direct habitat loss. Potential habitat types in the WLSA that provide either good foraging or nesting habitats for common nighthawks may include open

forested stands (*e.g.*, open pine, open deciduous, open mixedwood, and open mixed coniferous types), wetlands (*e.g.*, shrubby and treed wetlands), open natural areas (*e.g.*, grassland, rock/barren types), and various anthropogenic disturbances (*e.g.*, cutblocks, pipelines, well sites, perennial crops, and other clearings).

Project development may result in further indirect habitat loss for common nighthawks from increased noise levels associated with construction and operations activities. It is unclear how common nighthawks are affected by anthropogenic noise, although they often live and breed in cities and therefore likely habituate easily to many sources of noise (Brigham *et al*., 2011). Common nighthawks are therefore unlikely to be completely displaced from the WLSA, although they may avoid areas around the active mine site while high-impact activities (such as blasting) take place. Common nighthawk abundance may decrease during the life of the Project but will likely recover following reclamation of the area.

Common nighthawk mortality associated with Project development is likely to be limited to nest destruction associated with vegetation clearing. However, by conducting vegetation clearing outside of the recommended restricted activity period (May to August), common nighthawk mortality (eggs and/or chicks) can be avoided (Environment Canada, 2015a). Other sources of mortality associated with Project development include collisions with vehicles and Project infrastructure, such as buildings and transmission lines. Vehicle collisions can be reduced by establishing and enforcing a low speed limit on the access road. Bird collisions with buildings can be reduced by placing visual markers on windows, and collisions with the proposed power line can be reduced by placing large 'floats' or other markers on it (APLIC, 2012).

Project development is unlikely to alter common nighthawk movement in the area. The effects of Project development on common nighthawks in the WLSA are predicted to be local in extent, long in duration, continuous in frequency, low in magnitude, high in probability, and not significant (Table 5.4-1). The Project contribution to changes in common nighthawk abundance and habitat availability will be negative during the lifespan of the Project, but will be reversible in the short-term. The confidence rating associated with this assessment is moderate, as common nighthawks are known to occur and likely breed in the WLSA.

5.4.2.2 Impacts to Recovery Strategy

The recovery strategy for common nighthawk (*Contopus cooperi*) in Canada (Environment Canada, 2016b) indicated that there is currently little understanding of what comprises critical habitat for the species in Canada and what are the primary threats to this species' survival. However, reduced availability of insect prey is thought to be a key factor in the decline of this species. There is little known about this species' habitat

preferences, and its distribution and abundance across Canada. No action plan has yet been developed for this species but planning to eliminate or reduce knowledge gaps about the species is a priority of the recovery strategy. The recovery strategy indicates several knowledge gaps requiring research, including, but not limited to, identification of critical habitat, determining relative important of breeding and non-breeding habitats, determining threats to the species and its prey, determining availability of nesting sites, determining impacts of climate change, and understanding what site characteristics lead to high collision rates.

The objectives of the recovery strategy include reducing the decline of the species across its Canadian range (abundance and distribution), halting the national decline of the species by 2025, and subsequently ensuring a 10 year increase in abundance across the country. A loss of suitable breeding habitat and reduced population density arising from Project effects in the WLSA would be counter to the initial 10 year plan for common nighthawk.

Working in consultation with the common nighthawk recovery team to monitor presence, abundance, habitat use, fidelity to breeding sites, and factors affecting survival and reproductive output within the WLSA would provide valuable information required for the conservation of this species in both the short-term and long-term."

The assessment for migratory birds from the EIA (CR#9, Section 5.5, CIAR#42) is provided below.

"5.0 Application Case Assessment

5.5 Migratory Birds

The effects of Project development on 10 selected wildlife VCs were assessed quantitatively using habitat suitability index or resource selection function modelling approaches. One of these species, the olive-sided flycatcher, is protected under the MBCA and SARA. In addition, high-level assessments (which did not include habitat suitability index modelling) were conducted for eight species, two of which are protected by the MBCA and SARA (common nighthawk and barn swallow).

As indicated in Section 3.2.3, wildlife VCs were selected based on various criteria including ecological, economic, and traditional use importance. The selected VCs serve as indicator species, which collectively represent most wildlife species in the WLSA, to focus the wildlife assessment in accordance with current practice in Alberta and Canada.

To further assess the effects of the Project on migratory birds, species that may occur in the WLSA were divided into groups based on their preferred habitat type (Table 5.5-1). Most of the migratory bird groups have habitat requirements that are similar to wildlife

species selected as VCs (Table 4.6-1), although some do not. A high level assessment of potential Project effects on habitat availability, fragmentation and connectivity, mortality risk and health, and abundance for each group of migratory birds was conducted based on the criteria described in Table 3.2-3.

5.5.1 Change in Habitat Availability

The greatest effect of Project development on migratory birds will be direct habitat loss, most of which is expected to be temporary as disturbed habitats will be reclaimed progressively during Project operations. Wildlife habitat availability under the Baseline and Application (Years 14 and 27) Cases is summarized in Table 5.1-1.The largest extent of habitat loss will occur by Year 14 of Project development, and the largest losses will be of moderate mixed coniferous forest and closed mixedwood forest.

Due to the relative scarcity of wet, shrubby habitats in the WLSA, shorebirds, waterfowl, and other wetland-dependent birds (Table 4.6-1) are expected to be minimally affected by habitat loss. The abundance of species that prefer wet, shrubby habitats, such as common yellowthroat and Wilson's warbler, may decrease in the WLSA as they will be displaced to similar, nearby habitats.

Grassland species (Table 4.6-1) occur in the WLSA but are uncommon because of the relative scarcity of grassland habitat. By Year 14, it is expected that grassland habitat will be reduced by 52% (151 ha) while upland shrub habitat will remain unchanged. However, by Year 27, grassland habitat is predicted to increase by 20% (from 290 has to 349 ha) through progressive reclamation. Therefore, while there will be a temporary decrease in habitat availability for grassland-dwelling migratory birds up to Year 14, grassland habitat availability is expected to increase in the WLSA following progressive reclamation.

Forest-dwelling migratory bird species, particularly those that nest in coniferous and mixedwood forests (Table 4.6-1), will likely be the most affected by Project development. By Year 27 of the Application Case, there will be a reduction in the area of coniferous forest (open pine, open mixed coniferous, moderate mixed coniferous, closed spruce, and closed mixed coniferous habitat types) from 2,832 ha to 2,171 ha (661 ha; 23%) and a reduction in the area of mixedwood forest (open mixedwood and closed mixedwood habitat types) from 1,282 ha to 937 ha (345 ha; 27%). The area of deciduous forest in the WLSA (79 ha) will be minimally affected by Project development. By Year 27 of the Application Case, it is expected that deciduous forest will be reduced by 3.2 ha.

Species preferring old-growth forests are generally vulnerable to habitat loss as it can take 100 years or more for a young forest to display old-growth forest characteristics. The WLSA contains 169 ha of old growth forest, of which 8.3 ha will be affected by Project development (CR#8 – Vegetation and Wetlands, Section 4.5.1). Thus, effects of

habitat loss on these species are anticipated to be minimal. The loss of habitat may potentially be offset if mature forests within the undisturbed parts of the WLSA reach the old-growth stage by Year 27 of the Application Case.

A small number of migratory bird species breed in open, rocky habitats, including alpine habitats (Table 4.6-1). By Year 14, it is expected that there will be a loss of 32 ha (66%) of rocky and barren habitat. However, by Year 27, the area of rocky barren habitat is predicted to be 18% greater than Baseline.

Some species with the potential to occur in the WLSA frequently build their nests on anthropogenic structures such as buildings or bridges (Table 4.6-1). One of these is the barn swallow, and the effects of the proposed Project on this species are discussed in Section 5.4.1. The effects of the proposed Project on other species that tend to build their nests on anthropogenic structures are expected to be similar.

In addition to direct habitat losses, Project development may result in indirect habitat losses from sensory disturbances since some migratory birds may avoid otherwise suitable habitats located close to the Project footprint. Sensory disturbances (*e.g.*, noise, artificial lighting) arising from Project development may result in an indirect loss of habitat for migratory bird, as some birds may avoid otherwise suitable habitat because of this disturbance. For example, research conducted by Habib *et al*. (2007), Bayne *et al*. (2008), and Bayne and Dale (2011) in the boreal forest indicates that some migratory songbirds may be negatively affected by chronic anthropogenic noise through indirect loss of habitat (or reduced habitat effectiveness). Sound is important for avian communication and chronic noise from well pads, compressors, and road traffic has been reported to affect songbird density and pairing success (Habib *et al*., 2007; Bayne *et al*., 2008). Habib *et al*. (2007) reported that between 31% and 83% of the bird species analyzed were less abundant near a noise source (compressor station) than near a control site (a well pad without compressor station). These effects were noted up to 250 m from compressor stations. Bayne *et al*. (2008) found that up to one-third of bird species within 300 m of a compressor station were affected by noise levels averaging 48 dBA. The density of birds was 1.5 times higher in boreal aspen forests with no anthropogenic noise than in the same habitat beside a noise-generating compressor station (Bayne *et al*., 2008).

Overall, the geographic extent of all changes in habitat availability to migratory birds are predicted to be local, as no migratory bird species that occur in the area have breeding territories that exceed the size of the WLSA. The duration of Project effects will vary among species, but are predicted to be extended for forest-dwelling birds, residual for species that rely on old-growth forests, and long for all other species. The frequency of all Project-related effects on habitat availability for forest-dwelling migratory birds will be continuous, moderate in magnitude and reversible in the long-term. The frequency of

all Project-related effects on habitat availability for all non-forest-dwelling migratory bird species will be continuous, nil to low in magnitude, and reversible in the short-term. The proposed Project contribution to changes in habitat availability for migratory birds is predicted to be positive for waterfowl, grassland species, and rock/cliff dwelling species and negative for all other species. The confidence rating for these predicted effects is high, the probability of occurrence is high and the predicted significance is not significant.

5.5.2 Habitat Fragmentation and Connectivity

Depending on territory sizes and nest locations, some species may be reluctant to cross the active mine area while breeding. Due to their mobility, migratory birds in general are not expected to incur large changes to their movements in the WLSA.

With mitigation (Section 7.1.4), the effects of Project development on migratory bird movements are predicted to be local in extent, long in duration, continuous in frequency, reversible in the short-term, low in magnitude, and not significant. The Project contribution to migratory bird movements are predicted to be negative, the confidence rating for this prediction is high, and the probability of effect occurrence is high.

5.5.3 Change in Mortality Risk and Health

The destruction of nests during vegetation clearing could represent a source of migratory bird mortality associated with Project development. This source of mortality will be minimized by clearing vegetation outside of the period when most migratory birds breed in the WLSA (April 15 to August 31). Wherever possible, vegetation will be cleared outside of this time period. If clearing is required when migratory birds may be breeding, nest surveys will be completed prior to the clearing operations to determine if active nests are present in the vegetation to be cleared. If a nest is found, a temporary buffer zone will be established around the nest, where no clearing may take place until the nest is no longer active. The radius of the buffer will be based on both professional judgement and recommendations published by Environment Canada (2016d) and the Government of Alberta (2013c).

Other sources of migratory bird mortality associated with Project development may include bird collisions with windows, vehicles, or the proposed transmission line, or birds being poisoned through ingesting or swimming in contaminated water. After mitigation, increases in mortality from these causes are likely to be very low. Animal collisions on the access road will be reduced through establishing and enforcing a low speed limit, and bird collisions with buildings will be mitigated by placing visual markers on windows. Collisions with the proposed power line will be mitigated by installing large ‘floats’ or other markers on the lines. A strategy to minimize changes in water quality downstream of the proposed Project is being developed in conjunction with a water-quality

monitoring program. Post-mitigation, sedimentation ponds will be reclaimed to wetland areas and may be used as breeding and foraging habitat by shorebirds and waterfowl.

In addition, changes to the health of waterfowl, shorebirds, and other species that nest along the shorelines and feed on aquatic life could occur if such species nest along the edges of the surge ponds. However, it is anticipated that the level of ongoing disturbance and noise at the surge ponds will deter birds from nesting along the pond edges.

Many of the potential Project-related effects on migratory bird mortality risk will be mitigated (Section 7.1.5). The largest mortality risk for migratory birds associated with Project development is the destruction of nests during vegetation clearing. However, this source of mortality will be mitigated by clearing vegetation outside of the breeding season for migratory birds (April 15 to August 25) to the extent possible.

With mitigation (Section 7.1.5), the effects of Project development on migratory bird mortality risk and health are predicted to be local in extent, long in duration, isolated in frequency, reversible in the short term, low in magnitude, and not significant. The Project contribution to migratory bird mortality is predicted to be neutral, the confidence rating for this prediction is high, and the probability of effect occurrence is high.

5.5.4 Abundance

Changes in abundance of migratory birds may result from loss of habitats or direct mortality, as described in Sections 5.5.1 and 5.5.2.

Because of Project effects associated with direct and indirect habitat losses, the abundance of migratory birds within the Project footprint and adjacent habitats will be reduced over the short-term. Migratory birds will largely be displaced to other suitable habitats in the WLSA and surrounding region. With mitigation (Section 7.0), the effects of Project development on migratory bird abundance are predicted to be local in extent, long in duration, continuous in frequency, reversible in the long term, low in magnitude, and not significant. The Project contribution to migratory bird abundance is predicted to be negative, the confidence rating for this prediction is high, and the probability of effect occurrence is high."

A summary of the predicted Project effects on wildlife VCs is found in Table 5.4-1, CR#9 (EIA, CIAR#42). The information pertaining to common nighthawk has been reproduced here as Table 6.10-2.

Table 6.10-2 Summary of Predicted Project Effects on Common Nighthawk

Wildlife VC	Geographic Extent[1]	Duration[2]	Frequency[3]	Reversibility[4]	Magnitude[5]	Project Contribution[6]	Confidence Rating[7]	Probability of Occurrence[8]	Significance[9]
Common Nighthawk	Local	Long-term	Continuous	Short-term	Low	Negative	Moderate	High	Not Significant

[1] Local, Regional, Provincial, National, Global
[2] Short, Long, Extended, Residual
[3] Continuous, Isolated, Periodic, Occasional
[4] Reversible in short term, Reversible in long term, Irreversible – rare
[5].Nil, Low, Moderate, High
[6] Neutral, Positive, Negative
[7] Low, Moderate, High
[8].Low, Moderate, High
[9] Not Significant, Significant.

c) If main life stages of Common Nighthawk and Bobolink are not represented by Project effects on Elk as a surrogate species, describe the potential Project effects to these two species during these periods separately.

Response:

Please see the responses to parts a) and b) of JRP IR-6.10 above.

REFERENCES

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GEOTECHNICAL AND DAM SAFETY

Information Request 6.11

Tenth Addendum to the Environmental Impact Assessment. Response to Information Request 3.2. (CIAR #251).

It is unclear how the climate change based estimates presented in response to IR 3.2 c) (CIAR #251) will be incorporated into the final dam designs. Benga provided climate change projections for context, however Benga's proposed designs are based on historic precipitation statistics. Given the prediction that with consideration of climate change, the required pond volumes could be expected to be approximately 20% greater than under historic conditions (Tables 3.2-4 and 3.2-5, Addendum 10), Benga should consider the construction of larger structures, or operational consequences if the structures end up under-designed.

The information requested below is required in order to complete the following:

- Terms of Reference Section 3.2.6.2 [A], (d): *"factors used in the design of water management facilities that are in accordance with Water (Ministerial) Regulation, Part 6 (Dam and Canal Safety), as well as the Canadian Dam Safety Association Dam Safety Guidelines, including expected flood events and flood protection."*
- Terms of Reference Section 4.1.2 [B]: *"Identify stages or elements of the project that are sensitive to changes or variability in climate parameters, including frequency and severity of extreme weather events. Discuss what impacts changes to climate parameters may have on elements of the project that are sensitive to climate parameters."*

a) Describe if Benga will adjust its dam design, construction and operations to meet *Canadian Dam Association Guidelines* under the projected future changes in extreme precipitation (as summarized in response to IR 3.2c)).

Response:

As stated in the response to JRP IR-3.2 (c) (Addendum 10, CIAR#251), the design of the ponds was based on conservative data producing worst-case scenarios that allow for ample storage capacity. Inflow design flood criteria was based on either the 2/3 1,000 – year and PMF or the 200-year flood event with the minimum storage design criteria set at either the 100-year or 10-year flood event. The pond designs and overall water management plan allows for active management of any future short duration extreme precipitation events.

For clarification purposes, during detailed engineering, Benga will design each dam and the associated construction and operation plans, to meet Canadian Dam Association Guidelines, and will take into consideration the projected future changes in precipitation, evaporation, extreme precipitation, and will adjust each design accordingly. Possible changes to precipitation and evaporation patterns and extreme precipitation will be considered over the life of each facility.

As part of the detailed engineering design, each dam will be considered separately reflecting the function of the dam (*e.g.,* sediment dam or surge dam), and the design criteria regarding environmental protection and structural integrity. Each dam will be designed to meet two design criteria – (1) to retain a design flood based on local guidelines and (2) to protect the dam structure by either retaining the CDA inflow design flood or designing a spillway to safely pass that event. Final design criteria and calculations for each dam will be provided to the AER as part of the Canadian Dam Safety application(s).

b) If the answer to a) above is no, and the dams are therefore designed to meet *Canadian Dam Association Guidelines* under historic extreme precipitation but are operated under the projected future extreme rainfall, describe how Benga will operationally address this design issue.

Response:

See response to part a).

HYDROGEOLOGY

Information Request 6.12

Comments from Tsuut'ina Nation. (CIAR #220).

Tenth Addendum to the Environmental Impact Assessment. Response to Information Requests 5.18 and 5.19. (CIAR #251).

Given the depth of the saturated backfill zones, the size of the waste rock disposal areas, and the complex geology and large uncertainties associated with shallow and deep groundwater flow paths, the Panel requires additional information to assess the economic and technical feasibility of Benga's proposed mitigation measures and adaptive management approach; this includes how Benga intends to monitor both shallow and deeper groundwater for effects, and mitigation measures that can be implemented if effects are detected. Benga's response to IR 5.19 (CIAR #251) indicated that the installation of liners is unfeasible, and not technically achievable due to ground slopes. However, Benga did not substantiate this conclusion with the requested case studies of other mines with similar characteristics, where liners either failed, or were also deemed technically and economically unfeasible. Benga has suggested four other technically and economically feasible seepage capture options, however limited evidence has been provided to support these options as technically effective at monitoring and capturing contaminated groundwater. Tsuut'ina Nation notes that Benga has not provided adequate information to support the assertion that collection wells will collect all seepage water (CIAR #220).

The Panel requires Benga to provide additional details on proposed seepage capture options, including how monitoring downgradient from potential contamination sources will be an effective and technically achievable adaptive management measure, given the lack of a thorough hydrogeological understanding of the site.

Additionally, in response to IR 5.18 (vii) (CIAR #251), Benga states that 'Consideration will be given to include wells closer to receptors (listed in Part vi., above), as applicable and if feasible depending on access and ground conditions, to ensure no impact fails to be detected.' As large uncertainty remains regarding seepage water transport via porous media and/or fractures, potential faults, and old mine adits, monitoring wells should be placed slightly upgradient of receptors. If this monitoring is not done, contamination may be missed by near-source monitoring and capture and could reach receptors without warning.

The information requested below is required in order to complete the following:

- Terms of Reference Section 4.2.2 [C]: *"Describe programs to manage and protect groundwater resources, including*

  (a)) the early detection of potential contamination;
  (b) groundwater remediation options in the event that adverse effects are detected; and
  (c) the monitoring of groundwater production or dewatering impacts."

a) Provide additional evidence including estimated costs, to support Benga's conclusion that the installation of liners is not a technically or economically feasible seepage capture option.

Response:

Aside from storage of hazardous liquids and for limited applications in storing slurry tailings, there is no comparable precedent for the use of liners in the coal mining industry. Liners are typically used for storage of hazardous liquids and for limited applications as pond liners. We note that Teck in its report entitled "2019 Implementation Plan Adjustment – Annex J – Alternative Treatment Mitigation Plan" arrives at the same conclusion. In Section 3.2.2.2 (Appendix 6.19-1) Teck states that it has not considered geotextile liners for management of percolation at its rock dump sites due to the "*level of uncertainty in the science of covers…, combined with the high cost to deploy geosynthetic covers, and practical issues associated with that deployment…*".

Benga does not consider that liners can be successfully deployed in the application of the SBZ for technical reasons. When liners are installed, it is understood that their ability to withstand a puncture is minimal. For this reason, when designing ponds or other liner applications, great care is taken to ensure that there is a well-supported base of clay, sand or finely crushed rock so that larger rocks from below will not penetrate the liner. Similarly, as in the case of the SBZ, if rock or other material is to be layered on top of the liner, a sand (or finely crushed rock) bed of sufficient thickness is required on top of the liner to resist the weight of the meters of rock on top of the liner and prevent a puncture.

Although this type of installation may be technically feasible along the floor of the SBZ pit, it will not be possible to place the necessary padding material along the side walls of the pit due to their steep grade. As a result, lateral pressure from the rock fill will undoubtedly puncture a liner in multiple locations due to the sheer mass of rock. Any significant puncture in the liner at any location below the water level of the SBZ will result in flooding of the entire space below the liner and allow leakage as if the liner were not present. Any significant leakage due to a puncture will not be evident during the installation and will be impossible to find and repair after the fact.

Nonetheless, Benga recognizes the need to reasonably minimize seepage losses from the Saturated Backfill Zone (SBZ), and will use a combination of the following engineering options to achieve this objective:

- The pit will be extended to below the known level of existing underground openings. Where it is safe and practical, rock exposed in the pit floor will be mapped for open fractures associated with faults and joints. Depending on the state of the post

mining state of the pit floors, some of the following geophysical methods will be applied to identify and map the structure at depth beneath the pit floor:

- seismic refraction profiles can be acquired across the pit floor to measure changes in rock velocity with depth; and
- lines of ground-penetrating radar data can be acquired on a coarse grid across the pit floor to identify major fractures and any voids.

- Using drone technology and air photos, the observable joint sets in the pit walls will be mapped and plotted on a rose diagram to show the orientation of faults and joint sets. In addition, where it is safe and practical, groundwork could be done as warranted to confirm orientations (dip and strike) of these structures.
- Significant identified fractures will be assessed to determine if they can be sealed with cement or chemical grout, by adopting contact grouting procedures commonly utilized for water retaining dams. This assessment will consider factors including safety of the proposed operation, total number of features detected in the SBZ, and the technical feasibility of the sealing procedure.

b) Provide additional details on the following proposed seepage capture options, including an analysis with supporting evidence of their effectiveness by referencing case studies from other mines with similar characteristics to the Grassy Mountain Coal Project:

Response:

The proposed design for the waste dumps will include the following measures to minimize seepage losses to the ground:

- Most importantly, Benga has located the waste rock dumps in areas outside of Gold Creek and Blairmore Creek valley bottoms. To the best extent possible Benga located the waste rock dumps at higher locations where subsequent capture of any percolating water is possible. This mine design feature is not a common mining standard as it requires expensive hauling of waste rock up hill, which comes at an economic cost to the Project;
- Before depositing material, as much as possible organic, weak, or fine-grained materials within the foundation of the waste dumps will be removed prior to dumping waste rock. The waste dump foundation will consist of granular, till-like soils, or bedrock (EIA, Subsection B.8.6.3.2.1, page B-76, CIAR#42);
- Where bedrock is exposed, Benga will assess whether open fractures can be sealed with cement or chemical grout, by adopting contact grouting procedures commonly utilized for water retaining dams as described in item a) above; and,
- All spoils are designed to be constructed in 15m lifts or higher, which form a zone of segregated coarse rock at the base of each lift, particularly the base layer which will form the foundation of each spoil and provide adequate drainage through the bottom.

i. Grading the foundation to facilitate effective drainage;

Response:

In the proposed locations of the North Rock Disposal Area (NRDA) and South Rock Disposal Area (SRDA), the existing topography is sufficiently steep to provide natural drainage for water collected in the waste dumps (see topography details in Figure 6.12-1). The natural slopes are generally 3:1 for the SRDA and about 2.2:1 to 3:1 for the NRDA. Where necessary, potentially along the natural drainage course (indicated in blue in the Figure 6.12-1), the foundation may be graded to increase the natural slope and thus increase the proportion of water to be recovered from within the dumps.

ii. Use end-dumping techniques to establish a coarse permeable layer at the base of the dump;

Response:

The waste dumps will be constructed using a combination of end dumping (dumping from a certain height based on topography and filling in an area that is well confined to shorten haul distances) and bottom up construction. The lift heights on the SRDA and NRDA are planned to be more than 15m high. At this height, a zone of coarse rock sizes is expected to form at the bottom of the lifts which will function to aid in collecting drainage that percolates through the waste dumps (British Columbia Mine and Waste Rock Pile Research Committee, 1991; CANMET Rock Drain Research Program, 1997).

iii. Use of collection ditches to capture shallow seepage; and

Response:

Collection ditches and trenches will be used to convey captured discharge from the waste dumps to the surface water ponds. The NRDA is confined to one drainage area and all water will naturally collect at a low point at the SW corner of the NRDA, where a pond, Northwest Surge Pond, is designed at the decant point (Figure 6.12-1), from which the water will be conveyed back towards the pit through ditches or trenches.

The SRDA is located on a western-facing slope and the water will naturally drain to a pond on the NW corner of the SRDA. Where appropriate, the foundation will be sloped to direct the water in the waste dumps toward the collection ditches. Collection ditches will also be installed along the toe of the waste dump, where seepage emerges.

Where deep ditches/trenches may be required, these deep ditches/trenches would be backfilled with waste rock wrapped in geotextile fabric (EIA, Appendix 9b, Section 4.5, CIAR#42).

In addition, the waste dumps will be constructed in lifts of 15 m or more, with a minimum 8 m wide benches. Individual benches will be shaped to capture drainage runoff and direct it to

collection ditches on each side of the dump (British Columbia Mine and Waste Rock Pile Research Committee, 1991. CANMET Rock Drain Research Program, 1997).

iv. Installation and pumping of seepage capture wells.

Response:

Seepage capture wells will be used only as a last resort to capture seepage. The implementation of the proposed key measures for the construction of the waste dumps, as described previously, will minimize infiltration of water from the waste dumps into the foundation, facilitate drainage from the waste dumps that is designed to occur by gravity, and direct the drainage water also by gravity through ditches and trenches to the surface water ponds.

c) Explain how Benga's proposed seepage capture options will collect infiltration under low volume conditions where water will infiltrate through the shallow unsaturated (vadose) zone below the sources of contamination. Estimate the percentage of time (per year) when low volume seepage will bypass the seepage capture options via vertical infiltration under unsaturated soil conditions.

Response:

Benga does not consider that seepage from the SBZ can enter the unsaturated zone as the depth of the SBZ will be below the normal ground water level.

Several cross-sections were modelled across the site. The locations of the cross sections are shown in Figure 6.12-2 and the cross-sections are presented as Figures 6.12-3, 6.12-4, 6.12-5, 6.12-6, 6.12-7, and 6.12-8.

The Rock Disposal Areas (RDAs) are located on topographic highs and as such will always be above the water table, as illustrated on cross-section AA' in Figures 6.12-3, 6.12-4, and 6.12-5, and therefore will not typically be saturated. The water table will be located a few meters below the base of the RDAs and is expected to fluctuate seasonally. Seepage would essentially be immobile within the unsaturated zone.

Early reclamation and capping of the RDA will help reduce percolation to lower levels with the objective of consistently minimizing seepage migration towards the groundwater table. Seepage capture wells would operate below the groundwater table if monitoring demonstrates migration of seepage to this zone.

d) Provide details on how monitoring downgradient from potential contamination sources will be an effective and technically achievable adaptive management measure , by providing the following with sufficient technical details including

assumptions, justifications of assumptions, and all required details for decision making:

i. Describe the approach and criteria Benga will use to decide where the downgradient wells would be placed. Explain how Benga will account for shallow and deep groundwater pathways; as well as potential faults, fractures, and old mine adits, all of which could act as conduits for groundwater transport; and

ii. Discuss the approach and criteria Benga will use to determine the sampling depth(s) of each monitoring well, and how will Benga confirm the selected sampling depth is capturing potential seepage plumes.

Response:

Monitoring wells will be located downgradient of each RDA and downgradient of each surge pond. The exact placement and targeted depth of the monitoring wells will be dependent on the local site setting and determined during detailed design but monitoring wells will be located as close as practical to the potential source.

The main focus of the groundwater monitoring program will be on the shallow to intermediate groundwater systems that have the potential to discharge near or into the surface water receptors including Blairmore Creek and Gold Creek. As substantial measures will be implemented to capture potential contaminant at the source, *via* the measures described in a) and b), the groundwater monitoring program will have the primary objective to confirm the efficiency of the capture program and the secondary objective to ensure that the receptors are not negatively impacted by the project activities.

The legacy mining activities were assessed as part of the modelling exercise and were not found to be a pathway for groundwater transport. As a result, groundwater monitoring at these features will be limited. Groundwater monitoring will be at existing portals or seeps associated with historical mines, to confirm the lack of impact associated with the new mining activities.

A summary of the proposed groundwater monitoring locations is provided in Table 6.12-1 and Figure 6.12-9. Some of the proposed locations are similar to those proposed for the Aquatic Monitoring Plan. At these locations, only one set of monitoring wells will be installed, that will be used by multiple monitoring programs as part of an integrated groundwater and surface water monitoring program. Existing monitoring wells installed to collect baseline data for the EIA application will also be integrated to the program, as appropriate, to collect baseline data; however, the majority of these wells will be destroyed during construction or the development of the mine. In addition to the monitoring wells proposed, water samples will be collected from toe springs associated with the drainage of the RDAs, from the various surge ponds and sedimentation ponds and from end pit lake (either directly or *via* the discharge line).

Main fractures in bedrock will be the primary target of the monitoring wells completed within bedrock units. Data and mapping associated with the core hole exploration program conducted by Benga, including information about the presence of rock discontinuity and joints/fractures

will be reviewed to estimate the targeted depth for the upper and lower bedrock wells. The final depth will depend on the lithological and fracture information collected during the drilling at each individual location. Similarly, the location of joints, fractures or more permeable zones identified during the grading of the rock disposal areas or identified at the bottom of the pit will be reviewed and accounted for when selecting the final location of the monitoring wells.

The final locations of the monitoring wells will target preferential flow pathways, including more permeable fractures and bedrock zones, to maximize the effectiveness of the monitoring program in the early detection of adverse effect. Multiple nested well pairs using traditional nested wells or the use of single borehole multi-level technologies (*i.e.,* Solinst, FLUTe, *etc.*) will be considered to increase the ability to monitor multiple depth intervals, target the possible pathways from shallow to deep water bearing zones, and ensure a comprehensive detection of groundwater quantity (water levels and gradient) and quality (chemistry).

Table 6.12-1 Proposed Monitoring Locations and Rationale

Source	Main receptor	Monitoring well ID and Unit Targeted			Location	Rationale
		MW	Surficial	Bedrock		
Surge Ponds						
NWSP - northwest surge pond	Blairmore Creek	•MW1-1 (N#1S)	x		Downgradient of NWSP dam	Limited space between NWSP and receptor. MW targeting the surficial depsoits (alluvium) associated with Blairmore Creek. GW discharge likely part of a shallow system.
SWSP - southwest surge pond	Blairmore Creek	•MW2-1 (N#2) •MW2-2 (N#1S)	x	x	Downgradient of SWSP Upgradient of Blairmore Creek	Monitoring of GW quality directly downgradient of source and upgradient of receptor. GW discharge likely part of a shallow system.
SESP - southeast surge pond	Gold Creek	•MW3-1 (N#1S)	x		Downgradient of SESP dam Upgradient of Gold Creek	Location MW3a previously drilled and confirmed to include 7m of gravel deposits. Shallow GW system with strong horizontal gradient towards the creek. Unlikely to migrate to underlying bedrock confirmed to be cemented sandstone.
Sedimentation Ponds						
NESP - northeast sedimentation pond	Gold Creek	•MW4-1 (N#2) •MW4-2 (N#1S)	x	x	Downgradient of NESP dam, away from release point. Upgradient of Gold Creek (as available)	Limited space between NESP and receptor, may only be able to install one monitoring well. MW will target surficial materials.
ESP - east sedimentation pond	Gold Creek	•MW5-1 (N#1S) •MW5-2 (N#1S)	x		Downgradient of ESP dam Upgradient of Gold Creek	Monitoring of GW quality directly downgradient of source and upgradient of receptor. GW discharge likely part of a shallow system.
WSP - west sedimentation pond	Blairmore Creek	•MW6-1 (N#2) •MW6-2 (N#1S)	x	x	Downgradient of WSP Upgradient of Blairmore Creek	Monitoring of GW quality directly downgradient of source and upgradient of receptor. GW discharge likely part of a shallow system.
PSSP - plant site sedimentation pond	Blairmore Creek, surficial deposits	•MW7-1 (N#2) •MW7-2 (N#1S)	x	x	Downgradient of PSSP Upgradient of Blairmore Creek	Monitoring of GW quality directly downgradient of source and upgradient of receptor. GW discharge likely part of a shallow system.
Rail loadout sedimentation pond	Surficial deposits	•MW8-1 (N#1S)	x		Downgradient of sedimentation pond, upgradient of receptors	Monitoring of GW quality directly downgradient of source and upgradient of receptor. GW discharge likely part of a shallow system.
Saturated Fill Zones						
SZ1	Bedrock aquifers, Gold Creek	•MW9-1 (N#1S)	x		Upgradient of Gold Creek	No practical location to install downgradient of saturated zone. MW will target the surficial deposits, upper bedrock and lower bedrock (as needed). Bottom elevation of SZ1 (1720 masl) higher then Gold Creek elevation (~1600 masl).
SZ2	Bedrock aquifers, Blairmore Creek	•MW6-1 (N#2) •MW6-2 (N#1S) •MW6-3 (N#2)	x	x	Downgradient of SZ2 and WSP Upgradient of Blairmore Creek	Monitoring of GW quality downgradient of source and upgradient of receptor. Monitoring of shallow (surficial) and intermediate (bedrock) flow system.
SZ3	Bedrock aquifers, Blairmore Creek	•MW2-1 (N#2) •MW2-2 (N#1S) •MW7-1 (N#2) •MW7-2 (N#1S)	x	x	Downgradient of SWSP Upgradient of Blairmore Creek	Monitoring of GW quality downgradient of source and upgradient of receptor. Monitoring of shallow (surficial) and intermediate (bedrock) flow system.
End Pit Lake	N/A, bedrock aquifer*	-	-	-	-	Surface water quality monitoring within the pit
Rock pile areas						
NRDA - North rock disposal area,	Blairmore Creek	•MW10-1 (N#1B) •MW10-2 (N#1B) •MW10-3 (N#1B) •Toe Springs		x	Downgradient of NRDA Along boundary of NRDA	Monitoring of upper and lower bedrock targeting intermediate and deeper GW flow system.
CRDA - Central rock disposal area	Blairmore Creek & Gold Creek	•MW11-1 (N#2) •Toe Springs	x	x	Along east boundary of CRDA Upgradient of Gold Creek	Monitoring of surficial depsoits (if present) and upper bedrock targeting sjallow and intermediate GW flow system.
SRDA - South rock disposal area	Blairmore Creek & Gold Creek	•MW12-1 (N#2) •Toe Springs	x	x	Upgradient of Blairmore Creek and Gold Creek Along boundary of SRDA	Monitoring of surficial depsoits (if present) and upper bedrock targeting sjallow and intermediate GW flow system.

Table 6.12-1 Proposed Monitoring Locations and Rationale

Source	Main receptor	Monitoring well ID and Unit Targeted			Location	Rationale
		MW	Surficial	Bedrock		
Other						
Raw water pond	Bedrock aquifers, Blairmore Creek	•MW19-15-9 & MW19-15-16 (existing)	x	x	Downgradient of RWP	Location MW13-1 with nested well previously drilled and completed in surficial deposits and upper bedrock (intersecting a fracture). Monitoring of shallow and intermediate flow system.
Diversion ditches and drainage controls	N/A**, Surficial deposits	-	-	-	-	-
CHPP	Surficial deposits, Blairmore Creek	•MW13 - #TBD (N#2) •MW15-12-07 & MW15-12-14 (existing)	x	x	Downgradient of CHPP facilities Upgradient of Blairmore Creek	MW will be installed downgradient of facilities handling or storing waste oil, lubricants and gas & diesel. MW will primarily target the surficial deposits (water table) but a couple nested pair targeting the upper bedrock may also be installed to assess vertical gradients.
Mine Pit	Bedrock aquifers	•selection of existing wells installed in 2014		x	Within pit	Monitoring of the effect of the mining operations and especially of the pit dewatering on water levels within bedrock units. Monitroing wells installed in 2014 will be used until decommisioning prior to mining.
Overall Project	Surficial depsoits, Blairmore creek and Gold Creek	•MW14-1 (N#3) •MW14-2 (N#3) •Portals & historical mine seeps	x	x	Most downgradient of the Project along Blairmore Creek and Gold Creek	Monitoring of overall groundwater quality downgradient of the project and targeting multiple interval (surficial and bedrock)

* End pit lake will be in its own catchment basin with groundwater being captured towards the lake

** Minimal contribution due to limited footprint and construction used to contain water

N#1S: one shallow well in surficial deposits

N#1B: one shallow well in upper bedrock

N#2: nested type 2: One shallow (surficial) well and one upper bedrock well

N#3: nested type 3: One shallow (surficial) well, one upper bedrock well, and one deeper bedrock well (separation of at least 10 between the two bedrock wells)

e) Provide additional information on how Benga will use seepage capture wells to pump contaminated groundwater for treatment by providing the following:

i. Explain how the plume(s) will be delineated once they have been detected;

ii. Identify where Benga will place the capture wells relative to the plume's center of mass;

iii. Describe the strategy Benga will use to capture the plume and identify the percentage of capture Benga will aim to reach (ex. 100%, 70% etc.); and

iv. The capture wells will likely capture non-contaminated groundwater downgradient as well as contaminated groundwater, possibly resulting in a sizeable volume of water. Explain how Benga will be able to economically and technologically manage and treat this water.

Response:

Delineation will be conducted depending on the location of the plume and characteristics of the ground. If a groundwater plume is detected within surficial deposits, typical delineation methods would include drilling additional downgradient/ cross-gradient and deeper wells to understand the lateral and vertical concentrations of the chemical of concern, and ultimately of the plume distribution. Information from the delineation program would also refine the local understanding of the active flow pathways for the migration of the plume towards the receptors.

If the plume is detected within a bedrock well, the first step will consist of reviewing all of the information available for the local area, including maps showing the locations of faults and fractures, to identify potential flow pathways for the plume. If additional characterization is required, different techniques will be considered, specific to contaminant characterization in fractured bedrock. Methods appropriate for the characterization of contaminant in fractured rock (CLU-IN 2020; ITRC 2017) include, but are not limited to, the following:

- Geophysical characterization methods;
- Downhole methods & tools (including flowmeters); and
- Multilevel wells and monitoring systems.

The objective will be to collect specific information to characterize the fractures (aperture, orientation), identify the permeable zones and, if possible, quantify the groundwater flow in each fractured zone. This process will be conducted in phases, such that the results of the previous drilling phase will inform the next drilling phase with respect to presence/absence of faults/fractures and the presence/absence of the plume, until the plume is adequately delineated.

Once the plume has been sufficiently delineated, appropriate methods will be evaluated for the recovery and/or containment of the plume. As the plume center may coincide with the source (*i.e.,* rock disposal areas, saturated zones), recovery directly in the center of the plume may not be practical. Recovery downgradient of the source/ plume, but up-gradient of the receptors will

be considered instead. Options may include seepage capture wells, passive recovery trenches or treatment barriers. The objective will be to contain and mitigate the plume while protecting the downgradient receptors. Consideration will also be given to source control options, such as grouting preferential pathway(s) below the source or installing/ retrofitting liners at the bottom of the ponds.

The amount of capture targeted will depend on the setting of the plume (surficial deposits *versus* bedrock), the size of the plume and the type of contaminant but will be designed with the objective of protection of receptors. Benga acknowledges that within fractured rock settings, adequate capture will require a high level of effort to achieve. In such a case, Benga will implement capture measures that ensure as much protection and recovery to provide protection of the receptors, and implement a specific monitoring program for the plume, to evaluate the efficiency of the recovery program and monitor nearby receptors. Risk assessment and risk management may also be implemented to assess the effect of the portion of the plume that is not recovered by the capture system, as applicable.

An active treatment plant is part of the Project's contingency plan, if required. Depending on the volume and nature of the contaminants of potential concern (COPCs), consideration will be given to using the on-site treatment plant to treat recovered groundwater as part of a pump-and-treat system. If the use of the on-site treatment plant is not an option, alternative methods will be considered, including the use of portable treatment units. As different treatment options exist for inorganics and metals, the actual method selected will depend on the COPC present within the plume to be treated, volumes, and concentrations. Existing methods for the treatment of inorganic parameters and metals include granular activated carbon (GAC) adsorption, chemical precipitation-flocculation and sedimentation, ion exchange, and reverse osmosis (EPA 1997; ITRC 2017).

f) Describe the approach and criteria Benga will use to decide whether and where upgradient receptor based monitoring is required.

Response:

The proposed program, as presented in d) will include locations both downgradient of the potential sources and upgradient of the potential receptors, so the program will include upgradient receptor-based monitoring.

The monitoring wells located directly downgradient of the sources are intended to provide early detection of changes to the groundwater quality before any impact to a receptor. The monitoring wells located upgradient of the source will collect baseline water quality data and confirm that the receptors are not affected by the site activity. They will also act as a sentinel should a plume be detected by the downgradient monitoring wells.

A number of monitoring wells were installed at the Project to collect baseline data for the EIA Application. These monitoring wells will continue to exist until they get decommissioned ahead of the construction of the various mine components or get destroyed during mining. These existing monitoring wells will be considered for monitoring to establish background groundwater conditions, some of them being upgradient of the receptors.

All of the additional wells proposed for the groundwater monitoring program and other programs (*i.e.,* Aquatic Monitoring Program) will be installed ahead of the commencement of mining operations and will be sampled to collect baseline water level and chemistry data. A few locations proposed as part of the Aquatic Monitoring Program are already planned to be located upgradient of the receptors and will provide background information upgradient of the Project, as well. Information collected at these wells will be reviewed and incorporated to the groundwater monitoring program.

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HYDROLOGY

Information Request 6.13

First Addendum to the Environmental Impact Assessment. Consultant Report #6, Appendix A3 – Instream Flow Assessment. (CIAR #44).

Fifth Addendum to the Environmental Impact Assessment. Response to Information Request 207. (CEAR #69).

Eighth Addendum to the Environmental Impact Assessment. AER-R2-6 and AER-R2-7. (CIAR #89).

Tenth Addendum to the Environmental Impact Assessment. Response to Information Requests 5.16 and 5.29. (CIAR #251).

In the response to IR 5.16 (CIAR #251), Benga calculated weekly Q80 flows for Blairmore and Gold creeks using the Alberta Desktop Method. These flows were provided in Table 5.16-1. Without the details of Benga's computation and the data used by Benga, it is difficult to fully assess Benga's response.

Furthermore, in the response to IR 5.16, Benga suggested that there are "high uncertainties associated with applying a provincial-scale desktop-based instream flow needs assessment method" such as the Alberta Desktop Method. Benga proposes to use the field-based method associated with their instream flow assessment (IFA) executed as part of Appendix A3 of Consultant Report #6 (CIAR #44). However, Benga's IFA Assessment in Consultant Report #6 did not provide instream flow needs (IFN) numbers, and in the response to IR 207 (CIAR #69), when AER requested IFNs, Benga stated that, "the intent of the IFA was to assess this potential impact of changes in flow, and not to provide an IFN number". The Panel wants to review weekly IFN flows for Blairmore and Gold Creek based on Benga's IFA.

In response to IR 5.16 b (ii), Benga described 'Delta Water' and expects that Alberta Environment and Park's (AEP) Delta Stormwater Availability Tool (DWAT) would be available for application to the Project. However, the Panel understands that the DWAT is a decision support tool and not an operational hydrologic model. DWAT is also still under development to support an AEP policy that is in the draft stage and has not been finalised.

In Addendum 10, Benga proposed a flow augmentation calculation and suggested that the formula be accepted in principle, and the specific calculations for this project be developed before project start-up as per the AEP Delta Water policy.

However, in order for the Panel to properly assess potential risks to the streams due to the Project, the flow augmentation calculations need to be presented in detail. As highlighted in IR 6.17, there is a potential conflict between Benga's ability to release treated water while also retaining water that does not meet discharge limits on site for further treatment. As such, the details of return flow criteria need to be determined at this stage rather than during the operation phase, since the feasibility of water returns is an important part of the Panel's review with respect to the *Water Act*.

The information requested below is required in order to complete the following:

- Terms of Reference, Section 3.2.6.1 [A]: *"Describe the water supply requirements for the project, including (f) the expected cumulative effects on water losses/gains resulting from the project operations.*
- Terms of Reference, Section 3.2.6.2 [C]: *"Describe discharges to the watershed from existing and reclaimed sites, including potential end-pit lakes, and the management strategy for handling such releases".*

The Panel requests Benga provide weekly IFN flows for Blairmore and Gold Creeks, and develop a detailed flow augmentation calculation. An example of a flow augmentation methodology that would satisfy this request is included below.

a) Present IFN flows for Blairmore and Gold Creeks in weekly timesteps for a full calendar year. In addition, provide the exact latitude and longitude, or LSD location, for each computed IFN value. Benga may base these IFN flows on the Instream Flow Assessment completed as part of Consultant Report #6 (CIAR #44). Explain each step of the derivation of weekly IFN flows in detail using the results of the Instream Flow Assessment.

Response:

Instream Flow Needs (IFN) flows are provided in weekly timesteps for a full calendar year, in Figure 6.13-1 and Figure 6.13-2 for Gold Creek and Blairmore Creek respectively, for each macrohabitat study reach defined in the Instream Flow Assessment (IFA) (Addendum 1, CR#6, Appendix A3, CIAR#44) and near the mouth of each creek (at downstream hydrometric stations outside of the study reaches). Table 6.13-1 defines the latitude and longitude locations of these reach breaks and station locations.

As requested by the JRP, these data were calculated using the Alberta Desktop Method (ADM) (Locke and Paul 2011) as follows, which assumes IFN represent the greater of:

- a 15% instantaneous reduction from natural flow; or
- the lesser of either the natural flow or the 80% exceedance natural flow based on a weekly or monthly time step.

Daily long-term synthetic streamflow time-series, spanning the period from 1975-2016, were developed for these sites and further upstream based on methods outlined in the IFA report (Addendum 1, CR#6, Appendix A3, sub-appendix A1, CIAR#44). These data were used to characterize the baseline period and were averaged weekly for purposes of calculating the 'natural' flows using the ADM (*i.e.,* prior to any mine-capture or release of water). Note that natural flows, and the resulting IFN values generally increase further downstream except for Reach 6 on Gold Creek (near Lille; Addendum 1, CR#6, Appendix A3, Section 3.3.1, sub-appendix A1, CIAR#44).

These values were then reduced by 15% (Section 4.4.1, Locke and Paul 2011), and for each week an 80% exceedance value was calculated (*i.e.,* the flow equaled or exceeded 80% of the time, or every four years in five) for each weekly timestep. This 80% exceedance value represents the 'Ecosystem Base Flow' or EBF, Section 4.4.2 of the ADM. The final step combined the greater of either: (a) a 15% instantaneous reduction from natural flow, and (b) the lesser of either the natural flow or the EBF on a weekly timestep (Section 4.4.3, Locke and Paul 2011). Figures 6.13-3 and 6.13-4 provide an illustrative comparison of each calculation step, for each week, on Gold and Blairmore Creek, respectively (equivalent to Figure 8 and Figure 9 within the ADM) Appendix 6.13-1 provides calculations and Q80 values. The IFN curve included on each graph indicates the change in IFN flow across flow exceedance values (*i.e.,* at natural flow below the EBF, at EBF values thereafter until following 15% natural flow reductions once above the EBF). Values in Figure 6.13-1 and 6.13-2 represent the average of IFN values calculated for the range of flow values (exceedances) for a given weekly timestep (*e.g.,* as shown for the hydrometric station locations in Figure 6.13-3 and 6.13-4).

Table 6.13-1 Locations Related to IFN Calculations on Gold and Blairmore Creek

Creek	Location	Latitude (decimal degrees)	Longitude (decimal degrees)
Blairmore Creek	Reach 5	49.716	-114.462
	Reach 4	49.697	-114.444
	Reach 3	49.668 (end 49.660)	-114.436 (end -114.440)
	BL-H01 gauge	49.630	-114.457
Gold Creek	Reach 9	49.712	-114.399
	Reach 8	49.696	-114.396
	Reach 7	49.682	-114.395
	Reach 6	49.659	-114.401
	Reach 5	49.645 (end 49.645)	-114.392 (-114.392)
	GC-WSC gauge	49.602	-114.401

Note: Locations shown are at the upper reach breaks in each instance, except for hydrometric station gauges near the mouth downstream of the LSA macroreaches applied in the AEA/IFA.

As the JRP has noted, a detailed, (field-based) IFA was completed to improve confidence of predicting potential adverse alterations to westslope cutthroat (WSCT) habitat, specifically in the upper and mid-catchments of Blairmore and Gold creeks. The methodology associated with the IFA is a more precise hydraulic-habitat approach that more reliably predicts actual changes in stream hydraulics and associated changes habitat suitability/quantity for the target species (such as WSCT). Similar to a flow-based threshold, this IFA and other Alberta field-based studies (*e.g.,* Clipperton *et al*. 2003) assumed the threshold for "no significant" effects to fish due to

predicted flow changes was a <10% reduction in total habitat area for relevant biological stanzas. In average or wet hydrological conditions, all habitat losses predicted as part of the Grassy Mountain Project (stanza-averaged values for various Project phases) are predicted to be small and within the <10% flow reduction range. Only during extreme dry conditions, when habitat is naturally most stressed, did these reductions reach the 10% threshold (to a maximum of 11% under drought conditions). Using either a (10%) flow-based or habitat-based threshold, the risk to WSCT are low under nearly all flow scenarios throughout the proposed mine life.

b) Provide a flow augmentation methodology, including, for each part, detailed and complete description and formulation of:

i. how Benga would operationally determine how much water would be prevented from flowing to each of Gold Creek and Blairmore Creek due to the capturing of water within the Project footprint;

ii. how Benga would operationally determine the natural flow in each of Gold Creek and Blairmore Creek; and

iii. how the results of (i) and (ii) above would be used to operationally calculate the minimum daily release volume to meet the requirements of the Alberta Desktop Method, or another similar Instream Flow Needs methodology.

Response:

In consideration of IFN, and any water management actions (such as flow augmentation) required to meet these IFN, it is important to summarize the direction and magnitude of runoff changes as predicted by the Project's Water and Load Balance model.

The capture and collection of surface water runoff and groundwater as part of the Project's proposed water management plan is predicted to result in a slight reduction in flow in Gold Creek, while increasing flow in Blairmore Creek, relative to baseline flows in each system. The relative changes to Gold and Blairmore creeks are illustrated in Figures 43-45 and Figures 46-48 of the Hydrology Assessment (EIA, CR#4, CIAR#42), respectively, applying three hydrological scenarios (wet/average/dry). These changes incorporate all of the various water management decisions including those discussed in part (b) of the IR relating to Q_{site} and Q_{return}. Predicted changes in flow (reductions) for Gold Creek are included in Figure 6.13-5, (representative of Figure 43 in EIA, CR#4, CIAR#42), which demonstrates that all predicted reductions (at select nodes) will be less than 10% (with the exception of node GC-02 during mine decommissioning (2040's, when flow reductions reach 11%).

Based on the above, flow augmentation for Gold Creek is not required to meet the ADM IFN threshold (85%) given that all predicted withdrawals are well below 15%. Clearly, no flow augmentation would be required to meet the IFN values on Blairmore Creek given that flows are predicted to increase relative to baseline. Furthermore, the federal '*Framework for assessing the ecological flow requirements to support fisheries in Canada*' (DFO 2013) outlines the expert

consensus that cumulative flow alterations of less than +/- 10% of the magnitude of actual (instantaneous) flow in the river relative to a "natural flow regime" have a low probability of detectable negative impacts to ecosystems in Canada. The proposed flow changes on Gold Creek are almost entirely (Figure 6.13-5) within this 0-10% range, implying low risk to aquatic resources on Gold Creek.

Benga further notes that under the circumstances where mine affected water does not meet discharge limits and must be retained on site for further treatment, any resulting temporary reduction in daily water releases will only affect Blairmore Creek since the Project is designed to discharge all such treated water into Blairmore Creek. As noted above, the normal flows in Blairmore Creek will normally be increased by the Project and any such disruption will only serve to bring flows back down to baseline levels. As such, even under upset conditions, there will be no need to augment flows to Blairmore Creek (or to Gold Creek) to meet IFN requirements.

While the IFN values requested in this IR have been provided, please note that short-term mitigation measures may be considered if follow-up flow and habitat monitoring results do not align with the IFN and IFA predictions, respectively. Similarly, the predicted Project-related alterations to fish habitat under average conditions will be counterbalanced through the implementation of a Fisheries Offsetting Plan that aims to create a net gain of WSCT habitat in Gold Creek. After implementing these measures, the residual effects predicted from changes in hydrology from the Project on the WCST populations are expected to be mitigated. During the Project operation, monitoring activities will be completed across all disciplines related to the health of WSCT populations and habitat quality, to ultimately confirm there are no serious, irreversible changes occurring at the population level nor any decreases in the resilience of WSCT population along the length of Gold and Blairmore creeks.

REFERENCES

[DFO] Fisheries and Oceans Canada. 2013. Framework for Assessing the Ecological Flow Requirements to Support Fisheries in Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/017.

Locke, A. and A. Paul. 2011. A desk-top method for establishing environmental flows in Alberta rivers and streams. Alberta Environment and Alberta Sustainable Resource Development. Available at: http://www.environment.gov.ab.ca/info/library/8371.pdf

Clipperton, G.K., C.W. Koning, A.G.H. Locke, J.M. Mahoney and B. Quazi. 2003. Instream flow needs determinations for the South Saskatchewan River Basin, Alberta, Canada. Alberta Environment, Edmonton.

FISH AND FISH HABITAT

Information Request 6.14

Grassy Mountain Coal Project - Updated Environmental Impact Assessment. Section C. Figure C.5.3-1 to C.5.3-5. (CIAR #42).

First Addendum to the Environmental Impact Assessment. Consultant Report #6; Appendix A1, Figure 4.11. (CIAR #44).

Recovery Strategy for the Westslope Cutthroat Trout (*Oncorhynchus clarkii lewisi*), Alberta Populations in Canada. (CIAR #101).

Tenth Addendum to the Environmental Impact Assessment. Response to Information Request 5.20. (CIAR #251).

In reviewing the locations of the discharge points from the proposed mine (Figure C.5.3-1 to Figure C.5.3-5, CIAR #42), and the response to IR 5.20 (CIAR #251), it appears that the Northeast sedimentation pond on Gold Creek, and the West sedimentation ponds on Blairmore Creek will be discharging directly into high quality Westslope Cutthroat Trout spawning habitat (Figure 4.11, CIAR #44). The Northeast sedimentation pond is shown to discharge immediately upstream of the confluence of GCT10 with Gold Creek, in an area shown to be high quality spawning habitat with a moderate distribution of spawning adults. The West sedimentation pond on Blairmore Creek is shown to discharge into BCT06, in an area with the highest quality spawning habitat in the LSA, as shown by the highest distribution of spawning adults.

Given the known sensitivity of Westslope Cutthroat Trout spawning habitat to sedimentation and changes in stream temperature, the critical nature of quality spawning habitats, and importance of protecting these habitats to meet the objectives of the "Recovery Strategy and Action Plan for the Alberta Populations of Westslope Cutthroat Trout in Canada"(CIAR #101), it is unclear why the discharge points from the sedimentation ponds are located in these areas.

The information requested below is required in order to complete the following:

- Terms of Reference, Section 4.5.2 [A]: "*Describe the potential impacts to fish and fish habitat, such as stream alterations and changes to substrate conditions or water quality and quantity, while considering*
  - *(a) fish tainting, survival of eggs and fry, chronic or acute health effects, and increased stress on fish populations from release of contaminants, sedimentation, flow alterations, and temperature and habitat changes; and*
  - *(d) changes to benthic invertebrate communities that may affect food quality and availability for fish;"*
- Terms of Reference, Section 4.5.2. [C]: "*Discuss the design, construction, and operational factors to be incorporated into the project to minimize impacts on fish and fish habitat and protect aquatic resources. Describe how any water intakes have been designed to avoid entrapment and entrainment of fish and provide information on the species of fish considered.*"

- Terms of Reference, Section 4.5.2 [E]: "*Discuss the significance of any impacts on water quality and implications to aquatic resources (e.g., biota, biodiversity, and habitat) and related implications for First Nations' traditional and current use of these resources.*"
- Terms of Reference, Section 4.5.2 [F]: "*Describe the effects of any surface water withdrawals considered, including cumulative effects on fish and fish habitat.*"
- Terms of Reference, Section 9 [C]: "*Discuss the potential effectiveness of the proposed mitigation.*"
- Terms of Reference, Section 10 [A]: "*Describe the residual impacts of the project following implementation of the proponent's mitigation measures and outline plans to manage those residual impacts.*"
- Terms of Reference, Section 11 [A]: "*Describe the proponent's current and proposed monitoring programs…*"
- EIS Guidelines, Section 6.2.2: "*include changes to the physical environment including changes to […] water temperature*".
- EIS Guidelines, Section 6.3.3: "*include potential environmental effects to species at risk, including the direct and indirect effects on the survival or recovery of federally listed species (e.g. Westslope Cutthroat Trout).*"

a) Provide a rationale for locating the discharge points for the Northeast Sedimentation pond and West Sedimentation pond in documented high quality Westslope Cutthroat Trout spawning habitat.

Response:

The locations of the water management infrastructure features were based on existing natural drainage patterns associated with the current topography of Grassy Mountain during the conceptual engineering design.

b) Discuss the feasibility of relocating the discharge points of the sedimentation ponds downstream of documented Westslope Cutthroat Trout spawning habitat to avoid potential effects to Westslope Cutthroat Trout.

Response:

Benga does not consider it to be beneficial or necessary to relocate the discharge points of the sedimentation ponds for the following reasons:

- **Moving these discharges downstream will unnecessarily alter the natural flow regime.**
- **The area of the current discharges has not been identified as "high quality Westslope Cutthroat Trout spawning habitat" as suggested in the Rationale for this IR.** The WSCT Spawning Survey (Section 4.1.4, Appendix A1, CR#6, CIAR#44), which includes the referenced Figure 4.11, clearly states that "Spawning was not geographically concentrated, but rather spread throughout reaches and based on habitat availability." The information provided in Figure 4.11 (CIAR #44) represented the observations of mature WSCT within those portions of the watercourses during the spawning bio-period assessment.

- **The spawning grounds of WSCT in both Blairmore Creek and Gold Creek likely vary between years as habitat features in these small, high gradient streams is dynamic in nature** (Section 4.1.4, Appendix A1, CR#6, **CIAR #44**). As the spawning habitat may occur in different locations within both watercourses each year, any shift of a sedimentation discharge point will not necessarily avoid spawning habitat.
- **Temperature effects from the proposed sedimentation pond discharges have been assessed to be not significant.** In the response to JRP IR6.15, Benga clearly documents that the relative contributions of the sedimentation ponds to the receiving watercourses is low (3% for NESP and 5% for WSP). Stream temperatures in key WSCT bioperiods are predicted to change marginally at the immediate (local) mixing zones but will remain at or near the optimal temperature range for the species.
- **There will be no appreciable sedimentation in the creeks caused by the sedimentation pond discharges.** The sedimentation ponds are designed to collect non-disturbed catchment surface water run-off and, as part of the water management plan, pit water (not exposed to waste rock piles). The sedimentation ponds will be designed to settle total suspended solids (TSS) prior to release to either Blairmore Creek or Gold Creek.

Finally, as part of the Aquatic Monitoring Plan (AMP), the overall goal of this water quality monitoring component is to evaluate effluent released from the mine on the aquatic receiving environment of Blairmore Creek and verify that contact water from the mine does not adversely influence Gold Creek. The AMP (updated for JRP IR-6.23) water released from the sedimentation ponds will be monitored to assess the effectiveness of the associated sedimentation pond mitigations.

c) On a map displaying water management infrastructure and discharge locations (similar to Figure C.5.3-5), display where the current discharge locations are and where alternative discharge locations could be located. On the same map, include a layer that displays spawning habitat suitability.

Response:

Figure 6.14-1 displays the water management infrastructure discharge locations and observed spawning habitat only.

Based on the rationale presented in part B of this response, Benga is not considering alternative discharge locations for the identified sedimentation ponds.

d) Provide a supporting rationale for the proposed alternative discharge locations. In determining appropriate discharge locations for water management infrastructure, Benga should calculate the zone of influence for sedimentation and temperature associated with the discharge to protect sensitive habitats downstream of the points of discharge.

Response:

As discussed in part b) of this response, Benga is not considering alternative discharge locations for the sedimentation ponds. At the proposed discharge locations, potential effects due to changes in total suspended sediment and water temperature have been assessed to be not significant for spawning.

Information Request 6.15

Environmental Impact Assessment. Appendix 10b – Water and Load Balance Model. (CIAR #42).

First Addendum to the Environmental Impact Assessment. Consultant Report #6; Appendix A4. (CIAR #44).

Comments from Jim Rennie. (CIAR #133).

Comments from the Ktunaxa Nation Council. (CIAR #178).

Comments from Tsuut'ina Nation. (CIAR #192).

Information Request Package #5 from the Joint Review Panel to Benga, Information Request 5.20. (CIAR #215).

Tenth Addendum to the Environmental Impact Assessment. Response to Information Request 5.20. (CIAR #251).

In IR 5.20 (CIAR #215), Benga was directed to provide an assessment of the proportion of flow that each water management structure contributed to the baseflow at the point of discharge in order to assess the potential impacts these water management structures may have on the receiving aquatic ecosystem.

In the response to IR 5.20 (CIAR #251), Benga stated that the proportion of creek baseflows sourced from the Project's water management infrastructure developments were negligible at the mouth of Gold Creek at WSC Station 05AA0030 (i.e., 2.4%). The proportion of creek baseflow sourced from the Project's water management infrastructure near the mouth of Blairmore Creek at hydrometric station BC-H01 were estimated at 23.2% (annual average).

In the response to IR 5.20, Benga considered that the Water and Load Balance Model and the System for Environmental Flow Assessment (SEFA) model accounted for the discharge contributions from the Project's water management infrastructure developments and provided a reasonable prediction of temperature fluctuations. Those predictions were also presented in Addendum 1, Consultant Report #6, Appendix A4 (CIAR #44) and were considered by Benga to be not significant.

Benga's assessment considered the contributions from the water management structures at the watershed scale, concluding that discharge from sedimentation ponds represented 0.1% of baseflow in Blairmore Creek, and 0.2% of baseflow in Gold Creek. This watershed scale assessment was used to support the conclusion that contributing flows from the sediment ponds and the End Pit Lake would not result in significant changes to water temperatures in Blairmore Creek or Gold Creek, based on the outputs from the Water and Load Balance Model, and the SEFA Model. However, by assessing the potential impacts on stream temperatures as a result of discharging flows from sediment pond structures and the End Pit Lake at a watershed scale, Benga did not provide the requested assessment as described in 5.20 a) through f), which requested an assessment of the impacts to stream temperatures and potential changes to habitat suitability at a mesohabitat scale. Several submissions highlighted that, given the sensitivities of

Westslope Cutthroat Trout to potential changes in water temperature, localized potential changes in stream temperature at the mesohabitat scale should be quantified (CIAR #133, #178 and #192). Furthermore, given the location and the identified high productivity spawning habitat that is present in the immediate area and downstream of the discharge location (as discussed in IR 6.14), elevated temperatures during summer months could represent a potential risk to habitat suitability and reduced temperatures during the spring spawning season could represent a potential risk to spawning success in both Gold and Blairmore creeks.

The information requested in IR 5.20 is required to consider potential effects to stream temperatures and habitat suitability for the various Westslope Cutthroat Trout bioperiods at the mesohabitat scale. This response should also consider any alternative proposed discharge locations, as discussed in IR 6.14.

The information requested below is required in order to complete the sections of the Terms of Reference and EIS Guidelines referenced in IR 6.14 (above).

Provide the information initially requested in IR 5.20 a) through f) in consideration of the potential effects at the mesohabitat scale, and not at a watershed scale.

a) Provide an updated assessment discussing the proportion of base flow that each sediment pond, surge pond, and discharge point from the saturated backfill zone represents at the confluence of the water management structure's discharge outlet in both Gold Creek or Blairmore Creek (depending on which stream is receiving the discharge) in order to accurately assess the zone of influence of these water management structures on changes in stream temperatures.

Response:

Figure 6.15-1 provides updated values of water releases occurring from the Project as predicted by the Project's Water and Load Balance (EIA 2016, Appendix 10b, CIAR#42). This includes the three treated water discharge locations on Blairmore Creek (at nodes BC-07, BL-02 and BC-03), and the four sedimentation ponds with two on Blairmore Creek (Plant Site Sedimentation Pond [PSSP] and West Sedimentation Pond [WSP]) and two on Gold Creek (East Sedimentation Pond [ESP] and North East Sedimentation Pond [NESP]). Releases are far higher through the three discharge locations on Blairmore Creek, than through the sedimentation ponds on either creek, as indicated in the Water and Load Balance Model (EIA 2016, Appendix 10b, CIAR#42). Corresponding creek flow predictions, to calculate the percentage contributions from ESP, NESP, PSSP and WSP, were at nodes GC-04, GC-10, BC-03 and BC-07, respectively. The natural creek flows were calculated using the range of flow variability gauged within a long-term historical baseline period (1975-2016) and synthesized to the various Project reaches and model nodes. Both creek flows and discharges from all features are calculated on a total flow basis (*i.e.,* may include any losses through the gravels, *etc.*) used in the Water and Load Balance model.

The Project discharges were available at an annual time-step. For the purposes of this IR, the discharges from each pond were calculated assuming that all runoff from the pond sub-catchments was collected by the pond itself. This assumption is conservatively high as some water will be captured as contact water and sent to the saturated backfill zone (SBZ) depending on the state of mine development. The model also conservatively assumes the ponds exist into mine closure (after Year 27), when actually the ponds will be remediated during this period. On an annual basis, maximum pond contributions to the creek at the confluence were 2%, 2%, 1% and 8% at ESP, NESP, PSSP and WSP, respectively. If the pond releases were assumed to occur constantly year-round, maximum proportions on a monthly basis would be 4%, 5%, 2% and 13%, respectively. Of the three discharges from the SBZ, the maximum absolute and relative contributions to Blairmore Creek were highest further upstream at BC-07 where natural creek flows are lower; however, these are conservatively high and assume that all water requires treatment in the SBZ before any final treatment and release to Blairmore Creek. Additionally, high values occur when the annual release volumes are coincident with a low-runoff year. On an annual basis, in the worst-case year, the SBZ releases contributed approximately half the flow at BC-07, one-third the flow at BC-03, and even less at BL-02 (Figure 6.15-2).

b) Discuss the zone of influence that these water management structures have on stream temperatures using the maximum predicted monthly water temperatures in each water management structure, extending downstream from the confluence of the water management structures' discharge outlets, to the point where stream temperatures return to background levels after mixing with water discharged from these water management structures.

Response:

An integrated response to part b) and d) is provided below since the same information is requested across all Project structures in part b) and more specifically the Northeast Sediment Pond in part d).

Part a) introduced potential contributions of flows from each main water management feature to the corresponding flow at each corresponding confluence location on each creek. It is important to reiterate that only the sedimentation ponds will ultimately discharge directly to Blairmore and Gold creeks. The surge ponds and the raw water ponds will be re-diverted to the SBZ and will not directly influence stream temperatures as further discussed below.

Water detained within the SBZs is essentially analogous to groundwater with the same dampened temperature profile relative to any rapid surface runoff more likely to be at or near ambient air temperature. A small increase in temperature, during the transit from the SBZ through downstream treatment before arriving at Blairmore Creek is possible. Water temperatures within each sedimentation pond will likely increase with residence time and exposure to warming conditions during summer, and vice versa during winter. Since the heat

capacity of water is much higher than air, the temperature of the air will rise and fall much faster than pond temperature.

Water temperature simulations can be modelled analogous to contaminant mixing (*i.e.*, as a passive tracer), using the equation by Smith *et al*., (2001):

$$T_{downstream} = \frac{m_{Pflow} C_p T_{Pflow} + m_{upstream} C_p T_{upstream}}{m_{Pflow} C_p + m_{upstream} C_p}$$

Where m is the mass of the surface water flow (kg) per unit time, C_p is the heat capacity of water in J/(kg°C), and T is the temperature of each watercourse (P_{flow} for the Project-related flow such as treated effluent or pond discharge, upstream for the reference creek flow above the confluence with P_{flow}, and *downstream* for the total mixed flow including P_{flow} and *upstream* components). The heat capacity of water changes minimally (*i.e.*, <1%) across a wide temperature range (*i.e.*, 2ºC = 4.21 J/kgºC; 19ºC = 4.18 J/kgºC), and, assuming ice does not form in the watercourse, the above equation can then be simplified to:

$$\Delta T_{downstream} = T_{downstream} - T_{upstream} = \left(Q_{Pflow} T_{Pflow} + Q_{upstream} T_{upstream}\right) - T_{upstream}$$

Where Q_{Pflow} and $Q_{upstream}$ are the proportions of downstream (mixed) surface flow due to the Project-related flow, and upstream reference Blairmore Creek flow, respectively. $\Delta T_{downstream}$ may be considered as the temperature change immediately downstream of the confluence between these flows and assumes that further downstream, these temperature changes will decrease with additional inflow from natural groundwater sources along the length of the creek.

Continuous water temperature data collected from the Gold Creek watershed in 2016 is shown in Figure 6.15-3. Mid-watershed, Gold Creek streamflows increase by a factor of at least five, due to the large contribution of flow from Caudron Creek sourced primarily from large groundwater reserves captured within the Livingstone Range (Addendum 1, CR#6, Appendix A3, Section 3.3.1.1, CIAR#44). During 2016, the range of water temperatures monitored at Caudron Creek (station CC-T01, Figure 6.15-3) remained between 3-5ºC until late November. This is a much smaller range than on Gold Creek above the Caudron Creek inflows (station GC-T04) where temperatures varied from near-freezing to 9.5ºC. Gold Creek water temperatures downstream of Caudron Creek (station GC-H02) remained very close to the water temperatures of Caudron Creek, with a slight increase of up to 1ºC during summer months due to the small influence of warmer water temperatures from upstream Gold Creek flows. For reference, daily mean air temperatures varied by over 40ºC, from -25ºC to +18ºC during the 2016 monitoring period.

On Blairmore Creek, surface flows increase more gradually downstream (Addendum 1, CR#6, Appendix A3, Section 3.3.2.1, CIAR#44), and during a period of concurrent stream temperature monitoring from 2013-2014 (Figure 6.15-4), slight temperature increases occurred further

downstream (towards BL-H01) consistent with the transition to lower watershed and slightly warmer conditions.

The scenarios presented below, simulate potential changes in stream temperatures on Gold and Blairmore creeks, due to the influx of potential effluent or sedimentation pond discharge flows related to the Project. Since water temperatures within these discharges are not modelled explicitly by the Project's Water and Load Balance model, conservative assumptions related to surface flow changes and maximum water temperatures are introduced to estimate worst-case mixing and dilution zone delineation of water temperature at a mesohabitat-level at the select discharge points.

Scenario 1: Blairmore Creek- addition of WTP discharges

The above equations predict that, for any given water temperature differential between T_{Pflow} and $T_{upstream}$, $\Delta T_{downstream}$ will be highest when Q_{Pflow} is highest.

Table 6.15-1 tabulates the highest predicted Q_{Pflow} rates for each month of the year, taken across all future mining periods, hydrologic conditions, at BC-07 where the Project flow contributions are highest (part a of the IR).

$T_{upstream}$ values are assumed equivalent to current baseline-period values (*i.e.,* the monthly average values of daily water temperatures data shown in Figure 6.15-4). In the absence of T_{Pflow} estimates, May to October values were conservatively assumed to be equal to the monthly mean ambient air temperature, while November to April values were assumed to be 2°C warmer than current stream temperature, given that monthly air temperatures extend far below 0°C during these months and are not suitable as surrogate water temperature data.

The use of monthly mean air temperatures to approximate monthly T_{Pflow} values is very conservative given the relatively short exposure of water extracted from SBZs to ambient conditions; however, this approach is considered more realistic than other methods. In winter, when water potentially freezes above the surface, a 2°C incremental warming covers small increases that may be due to the pumping process and/or artificial warming to prevent water freezing. Ultimately, the generated year-round time-series of T_{Pflow} are considered acceptable maximum water temperatures of the treated water sought within parts (b) and (d) of the IR.

Table 6.15-1 indicates that worst-case stream temperature increase relative to baseline values will be up to 3.3°C warmer at BC-07 where treated effluent enters Blairmore Creek. BC-07 is equidistant between hydrometric stations BL-H03 (upstream) and BL-H02 (downstream); predicted increases are slightly higher (0.9°C higher) when applying data from BL-H03 given that water temperatures here are fractionally cooler.

Table 6.15-1 Input data and temperature predictions- Blairmore Creek at node BC-07 (nr. stations BL-H03 and BL-H02)

Bioperiod[1]							Month	*Flow*		*Air Temp. (°C)*	*Water temperatures (°C) BL-H03 location*				*Water temperatures (°C) BL-H02 location*			
1	2	3	4	5	6	7		Q_{Pflow}	$Q_{upstrean}$	T_{air}	$T_{BL-H03} = T_{upstream}$	T_{Pflow}	$T_{downstrea}$	$\Delta T_{downstrea}$	$T_{BL-H02} = T_{upstream}$	T_{Pflow}	$T_{downstrea}$	$\Delta T_{downstrea}$
	✓	✓	✓				Sep	66%	34%	9.8	4.8	9.8	8.1	3.3	6.1	9.8	8.5	2.5
			✓	✓			Oct	70%	30%	1.8	1.3	1.8	1.7	0.3	2.6	1.8	2.0	-0.6
				✓			Nov	68%	32%	-4.0	0.2	2.2	1.6	1.4	0.5	2.5	1.7	1.2
				✓			Dec	73%	27%	-9.2	0.2	2.2	1.7	1.5	0.2	2.2	1.7	1.5
				✓			Jan	79%	21%	-5.3	0.2	2.2	1.8	1.6	0.1	2.1	1.8	1.6
				✓			Feb	79%	21%	-12.4	0.2	2.2	1.8	1.6	0.1	2.1	1.7	1.7
			✓	✓	✓		Mar	80%	20%	-5.7	0.2	2.2	1.8	1.6	0.1	2.1	1.8	1.7
			✓	✓	✓		Apr	47%	53%	1.1	0.3	2.3	1.2	0.9	0.4	2.4	1.3	0.9
			✓			✓	May	22%	78%	5.5	2.1	5.5	2.9	0.8	2.6	2.6	3.2	0.7
✓			✓			✓	Jun	17%	83%	9.1	6.1	9.1	6.6	0.5	6.7	9.1	7.1	0.4
✓	✓		✓			✓	Jul	35%	65%	16.0	10.7	16.0	12.5	1.9	11.8	16.0	13.2	1.5
✓	✓	✓	✓				Aug	57%	43%	13.6	12.1	13.6	12.9	0.9	13.2	13.6	13.4	0.2

Notes:

Q_{Pflow} Estimated additional project flow released to Blairmore Creek, relative to baseline values; values shown are worst-case (highest) across all years and hydrologic conditions at BC-07.

$Q_{upstream}$ Estimated remaining creek-flow contribution to the discharge location, relative to baseline values.

T_{air} Monthly mean air temperature using data shown in Figure 6.15-2

$T_{upstream}$ Monthly mean measured water temperatures using data shown in Figure 6.15-2, assumed equivalent to the project-phase water temperatures in $Q_{upstream}$

T_{Pflow} Hypothetical water temperatures in project flow contributions; assumed equivalent to T_{air} from May-Sep and $T_{upstream}$ + 2ºC from Nov to May.

$T_{downstream}$ Calculated downstream (project-impacted) water temperature based on the various flow proportions and their respective temperatures (see equations)

$\Delta T_{downstream}$ Calculated water temperature difference due to project effluent discharges.

[1]Bioperiods and corresponding months were introduced in Table 3-9 of Addendum 1, CR#6, Appendix A3, including:
1: Egg Incubation, 2: Hatching, 3: Fry Emergence, 4: Rearing (feeding), 5: Overwintering, 6: Spawning Migration, 7, Spawning.

Table 6.15-2 Input data and temperature predictions: Gold Creek at node GC-10 (near proposed NESP)

Bioperiod[1]							Month	*Flow*		*Air Temp. (°C)*	*Water temperatures (°C) GC-T04 location*			
1	2	3	4	5	6	7		Q_{Pflow}	$Q_{upstream}$	T_{air}	$T_{BL-H03} = T_{upstream}$	T_{Pflow}	$T_{downstream}$	$\Delta T_{downstream}$
			✓	✓	✓		Mar	3%	97%	1.4	1.1	3.1	1.1	0.1
			✓	✓	✓		Apr	2%	98%	6.0	1.8	3.8	1.9	0.0
			✓			✓	May	3%	97%	7.3	3.8	7.3	3.9	0.1
✓			✓			✓	Jun	2%	98%	11.3	6.4	11.3	6.5	0.1
✓	✓		✓			✓	Jul	3%	97%	12.7	8.1	12.7	8.3	0.2
✓	✓	✓	✓				Aug	5%	95%	11.7	8.1	11.7	8.3	0.2
	✓	✓	✓				Sep	3%	97%	7.2	6.1	7.2	6.1	0.0
			✓	✓			Oct	3%	97%	2.8	3.7	2.8	3.6	0.0
				✓			Nov	4%	96%	1.7	2.4	4.4	2.5	0.1
				✓			Dec	2%	98%	-12.5	0.2	2.2	0.2	0.0
				✓			Jan	3%	97%	-11.7	0.2	2.2	0.3	0.1
				✓			Feb	3%	97%	-8.1	0.3	2.3	0.3	0.1

Notes:

Q_{Pflow} Estimated additional project flow released to Gold Creek due to sedimentation pond discharges; worst-case monthly flow value.

$Q_{upstream}$ Estimated remaining creek-flow contribution to the discharge location, relative to baseline values.

T_{air} Monthly mean air temperature using data shown in Figure 1-1. Values for Jan and Feb from 2017 not included in original EA or in Figure 1-1, but shown here to complete 12 monthly scenarios and predictions

$T_{upstream}$ Monthly mean measured water temperatures using data shown in Figure 1-1, assumed equivalent to the project-phase water temperatures in $Q_{upstream}$. Values for Jan and Feb from 2017 not included in original EA or in Figure 1-1, but shown here to complete 12 monthly scenarios and predictions.

T_{Pflow} Hypothetical water temperatures in project flow contributions; assumed equivalent to T_{air} from May-Sep and $T_{upstream}$ + 2ºC from Nov to May.

$T_{downstream}$ Calculated downstream (project-impacted) water temperature based on the various flow proportions and their respective temperatures (see equations).

$\Delta T_{downstream}$ Calculated water temperature difference due to project effluent discharge.

[1] Bioperiods and corresponding months were introduced in Table 3-9 of Addendum 1, CR#6, Appendix A3, including:
1: Egg Incubation, 2: Hatching, 3: Fry Emergence, 4: Rearing (feeding), 5: Overwintering, 6: Spawning Migration, 7, Spawning.

Scenario 2: Gold Creek- addition of NESP discharge

Part d) of the IR requests an analysis of potential temperature changes due to structures including the NESP further upstream on Gold Creek, next to model node GC-10.

Scenario 2 calculates a temperature change on Gold Creek, at GC-10 (upstream of Caudron Creek), using monthly water and air temperature values (Figure 6.15-3) monitored close to node GC-10 during baseline (Table 6.15-2). Worst-case mine contributions on a monthly basis range from 2% to 5% (or 2% on an annual basis, from IR part (a)).

Table 6.15-2 indicates that assumed mine water contributions of up to 5% only raised creek water temperatures by up to 0.2°C.

Discussion

The worst-case temperature increases highlighted above occur on Blairmore Creek, where the effluent discharges relative to current creek discharges are far higher than any sediment pond releases anywhere on Gold and/or Blairmore Creek. The modelled effluent discharges will raise water temperatures by up to 3.3°C, which is well within the natural variation of temperatures already experienced from season to season and year to year. Therefore, the temperature change caused by Project discharges is not expected to adversely influence key westslope cutthroat trout (WSCT) bioperiods in either Blairmore or Gold creeks and therefore do not pose a significant risk.

Benga notes that the worst-case temperature scenario described by this analysis is conservative and not likely to occur for the following reasons:

- the assumptions used to estimate the water temperature of Project discharges are very conservative; and
- spatially, the temperature increases experienced will decrease almost immediately upon mixing, which is ultimately influenced by site-specific factors and as the proportion of streamflow sourced by Project treated discharges becomes increasingly less.

Notwithstanding the very conservative approach used herein to model potential stream temperature changes due to the Project, as further discussed below in part e), water temperature changes in mesohabitats is predicted to experience minimal change immediately downstream of discharge points.

c) Clarify how, or if, pit lake water temperatures were calculated and incorporated into the water temperature model during closure/reclamation. Provide an assessment of the proportion of base flow that the pit lake represents to Gold Creek base flows once the flood elevation is exceeded, measured at the confluence of the discharge outlet from the pit lake through the Northeast sediment pond, in order to accurately

assess the zone of influence this discharge will have on stream temperatures within Gold Creek.

Response:

Water from the end pit lake as a potential source of water to Gold Creek, was presented as an option, if required in the EIA in August 2016. Subsequently, the Instream Flow Assessment (IFA) and Aquatic Ecology Effects Assessment were completed and filed in January 2017 (Addendum 1, CR#6, Appendix A3, CIAR#44). The results of the IFA indicated that there would be no need to provide water to Gold Creek from the end pit lake. Consequently, there will be no water from the end pit lake flowing into Gold Creek and no resultant temperature effect.

d) Discuss the zone of influence that the discharge from the pit lake via the Northeast sediment pond will have on stream temperatures in Gold Creek using the maximum predicted monthly water temperatures discharging from the Northeast sediment pond, extending downstream from the confluence of the Northeast sediment pond discharge outlet into Gold Creek to the point where stream temperatures return to background levels after mixing with the discharged water.

Response:

Please refer to Part b) of this response.

e) Discuss the effects on habitat suitability for Westslope Cutthroat Trout within the zones of influence described in b) and d), and how changes in stream temperatures will impact each biological stanza of Westslope Cutthroat Trout described in the EIA.

Response:

With respect to potential residual effects on habitat suitability for WSCT, calculations of Area Weighted Suitability do not depend explicitly on water temperature (unlike water depth, velocity and substrate, for which individual Habitat Suitability Curves exist; Hatfield 2017). However, the preferred temperature range of WSCT is 9 to 12°C (Alberta Westslope Cutthroat Trout Recovery Team 2013) and they are rarely found in waters exceeding 22°C (Behnke and Zarn 1976). More recent work by Bear and McMahon (2007) found the upper incipient lethal temperature of WSCT is 19.6°C. During winter, when water may be at risk of freezing, warmer water is preferred by WSCT as it reduces the severity of winter conditions for WSCT (*e.g.,* French *et al*. 2014). Therefore, although predicted Project-related increases in stream temperature at the mesohabitat level across key bioperiods are unlikely, a slight increase in temperature during the winter months could potentially have a beneficial influence on WSCT, similar to the benefits of groundwater input. At a daily timescale, stream temperatures in both Gold and Blairmore creeks during key WSCT bioperiods are predicted to change slightly at the immediate (local) mixing zones but will not adversely influence mesohabitat conditions in the vicinity or downstream of the discharge points. Furthermore, the changes are not predicted to

exceed incipient lethal temperatures throughout the lifetime of the mine when accounting for the predicted temperature changes (Table 6.15-1 and Table 6.15-2). At the monthly timescale, stream temperatures in mesohabitats immediately downstream of discharge points remained at or near the optimal temperature range, and several degrees lower than the incipient lethal temperatures.

The modelled results provided herein align with the macro-level stream temperature modeling results that were presented in Consultant Report #6, (Addendum 1, CR#6, CIAR#44).

f) Discuss technically and economically feasible mitigation and adaptive management measures that can be implemented to prevent and/or minimize changes in stream temperatures in Gold Creek and Blairmore Creek as a result of discharges from the water management structures discussed above.

Response:

Based on the analysis presented above, Benga does not consider that the Project will have a significant adverse effect on water temperatures in either Blairmore or Gold creeks. Temperature will be monitored in both creeks as part of the Project Fisheries and Aquatic Monitoring Plan (follow-up monitoring) and any changes outside of the modelled predictions will be noted for further action.

REFERENCES

Alberta Westslope Trout Recovery Team. 2013. Alberta Westslope Cutthroat Trout Recovery Plan. Edmonton (AB): Alberta Environment and Sustainable Resource Development, Alberta Species at Risk Recovery Plan No. 28.

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Behnke RJ, and Zarn, M. 1976. Biology and management of threatened and endangered western trout. US Department of Agriculture, Forest Services General Technical Report RM-28. 45 pp.

French W., Vondracek B., Ferrington L., Finlay J., Dieterman D. 2014. Winter feeding, growth and condition of brown trout *Salmo trutta* in a groundwater-dominated stream. Journal of Freshwater Ecology. 29(2):187-200

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SURFACE WATER QUALITY

Information Request 6.16

Grassy Mountain Coal Project - Updated Environmental Impact Assessment. Consultant Report #5 –Surface Water Quality. (CEAR #42).

Information Request Package #5 from the Joint Review Panel to Benga, Information Request 5.1. (CIAR #215).

Tenth Addendum to the Environmental Impact Statement. Response to Information Request 5.1. (CIAR #251).

Comments from Timberwolf Wilderness Society. (CIAR #281).

Benga did not provide the information requested in IR 5.1 a) (CIAR #215), which asked Benga to conduct an alternative risk assessment for selenium in the absence of sulphate as a toxicity modifying factor. In the IR response (CIAR #251), Benga indicated that sulphate mitigation of selenate uptake by algae has been known for decades, and suggests exclusion of sulphate mitigation in selenium guidelines is a result of inadequate paired data or lag time for regulations to catch up with the science.

The Timberwolf Wilderness Society (CIAR #281) comments noted that median sulphate concentrations were utilized by Benga when determining ameliorating effects of sulphate on selenium toxicity. The comments also noted that the sulphate concentrations presented in Consultant Report #5, Figure 6 (CIAR #42), are highly variable, and leave large room for error if only one point (e.g. median) is taken to characterize that parameter for any one time period. Using the median concentration, predicted sulphate concentrations are likely overestimated 50% of the time, and the ameliorating effects of sulphate may be overestimated during those times.

It is important for the Panel to understand what effect an overestimation of predicted sulphate concentrations would have on a site-specific selenium guideline which is, in part, based on sulphate concentrations.

a) Provide additional details on how seasonal variations in sulphate concentrations were accounted for in development of the proposed site-specific selenium guideline.

Response:

The site-specific selenium guideline developed for the Project (Water Quality Consultant Report CR#5, Appendix A1, CIAR#42) is sulphate-dependent:

$$SSWQG = 0.594 \times SO_4\ (mg/L)^{0.460}$$

This site-specific guideline was developed through tests with site-collected waters and using a range of sulphate concentrations predicted to encompass future site conditions. However, both sulphate and selenium concentrations in the receiving environment will vary seasonally, which will introduce seasonal variation to the proposed site-specific guideline and to ambient selenium concentrations that are compared with it. The following provides additional information on the

protectiveness of the site-specific guideline relative to predicted seasonal variability in sulphate (and selenium) concentrations.

The protectiveness of this site-specific guideline equation relative to selenium bioaccumulation and toxicity to westslope cutthroat trout (WSCT) was previously evaluated based on mean sulphate and selenium concentrations of 529 mg/L and 6.8 µg/L from post-mine closure modelling. To support with this IR, monthly predictions of selenium and sulphate concentrations from January 2017 through December 2099 at BC-07 were evaluated in order to further understand the influence of varying sulphate and selenium concentrations (a total of 996 paired sulphate and selenium predictions). The same selenium bioaccumulation model previously described was used for this evaluation.

The predicted sulphate and selenium concentrations from 2017 through 2099 covary, as expected (Graph A, Figure 6.16-1). Consequently, the sulphate-dependent selenium guideline also varies with predicted selenium concentrations (Graph B, Figure 6.16-1). During times when the sulphate-dependent selenium guideline is lower due to low sulphate concentrations, the predicted selenium concentration is also lower. The result is that predicted selenium concentrations are always less than the site-specific guideline (over all of the time periods modelled, the maximum selenium-to-guideline ratio is 0.83 and the average ratio is 0.50).

In addition to predicted water selenium concentrations always being less than the sulphate-dependent guideline, predicted selenium concentrations in WSCT from the bioaccumulation model continue to be less than the WSCT trout EC10 of 24.8 mg/kg dw based on the most conservative bioaccumulation model (Figure 6.16-2). In Figure 6.16-2, there are some conspicuous spikes and dips where the predicted WSCT egg selenium concentrations increase while the predicted surface water selenium concentrations decrease, and vice versa. This occurs because sulphate is correlated with selenium. When the predicted selenium concentration decreases the sulphate concentration likewise decreases, which results in higher selenium bioavailability predictions by the model. This explains why predicted WSCT egg selenium concentrations are not highly variable among all years of the model.

In summary, consideration of seasonal (monthly) variability in sulphate concentrations continues to predict that the sulphate-dependent selenium guideline will not be exceeded by predicted surface water selenium concentrations and that modelled selenium concentrations in WSCT will not exceed the WSCT-specific egg selenium EC10.

Information Request 6.17

Fifth Addendum to the Environmental Impact Assessment. Response to Information Request 86. (CIAR #69)

Comments from Tsuut'ina Nation. (CIAR #220).

Tenth Addendum to the Environmental Impact Assessment. Response to Information Request 5.1, 5.3, 5.5, and 5.16. (CIAR #251).

Comments from Victor and Barbara Koch. (CIAR #275).

A general theme put forth by Benga throughout multiple information request responses was that if water does not meet regulatory limits for release to the receiving environment, it will be pumped back instead of being released. In the response to IR 5.3 (CIAR #251), Benga stated "water not meeting the proposed effluent limit would be pumped to the raw water pond (RWP) for reuse in the CHPP (coal handling and processing plant) or to an SBZ (saturated backfill zone) and re-treated. Pump-back to the RWP or an SBZ is the general contingency plan for effluent that exceeds any effluent quality limit." This contingency measure (holding and recycling for re-treatment) is further confirmed in responses to IRs 5.1, 5.3, 5.5, as well as in response to previous rounds of information requests, and is Benga's proposed approach for off-spec water from saturated backfill zones and sedimentation ponds.

Benga noted in response to IR 5.5, that the time from planning to implementation of a fully functional selenium treatment plant would take three years. As highlighted by Benga in the response to IR 86 (CIAR #69), saturated backfill zones are expected to treat an estimated 4.5 M m^3/year, or approximately 12,300 m^3/day (in line with estimated daily volumes to be treated via a treatment plant, if needed, between 11,000 and 20,000 m^3/day). While it is likely that other contingency measures to treat elevated selenium concentrations could be implemented prior to the 3-year time period, all proposed alternative treatment methods (e.g. gravel bed bioreactors) would take several weeks or months to become operational, during which time off-spec water would need to be held on site and further treated. Tsuut'ina Nation (CIAR #220) expressed concerns regarding the length of time it would take for the alternative treatment methods to become operational. Victor and Barbara Koch (CIAR #275) expressed concerns regarding whether the raw water pond would be big enough to hold the off-spec water until adjustments are made.

In the response to IR 5.16 b)(ii), Benga proposed a flow augmentation methodology to determine the minimum water release rates to Blairmore and Gold Creeks to meet Instream Objectives required under their potential *Water Act* licence. If water quality does not meet regulatory limits under the *Environmental Protection and Enhancement Act* (EPEA) approval and is held back for further treatment, it may not be possible for Benga to achieve the required Instream Objectives. Conversely, if Benga proposes to meet Instream Objectives as required under a *Water Act* licence, it may not be feasible for Benga to hold back water that does not meet EPEA regulatory limits for further treatment.

a) Describe how Benga would meet the minimum release rates required under the *Water Act* licence conditions to meet the Instream Objectives for Blairmore Creek and Gold Creek when water does not meet EPEA regulatory limits and is proposed to be held on site for further treatment, and during any other time such as during maintenance of the saturated backfill zone when water is required to be held on site. Include

discussion of other potential sources of water (i.e. surface water sedimentation ponds) that could be used to ensure that Instream Objectives are met.

Response:

As outlined in the Instream Flow Assessment (IFA) (Addendum 1, CR#6, Appendix A3, Section 2.2, CIAR#44), Section 2.2 integrates the results of the Water and Load Balance Model for the Project. The results indicate that flows in Blairmore Creek are expected to increase relative to baseline conditions as a result of the additional contribution of flow from some Gold Creek sub-catchments (*e.g.,* as a result of the overall all water and selenium management plan, which has the treatment of effluent discharging at three nodes on Blairmore Creek [BC-07, BL-02, and BC-03] and not to Gold Creek), and due to the estimated increase in runoff caused by changes to the hydrological characteristics of developed mine areas (*i.e.,* increase in runoff coefficients for pit walls and waste rock areas) (EIA, Appendix 10B, 10C, and 10D within Appendix 10B: Water and Load Balance, CIAR#42).

If through operational monitoring the saturated backfill zones (SBZ) are deemed to be operating ineffectively for a period of time and there is a requirement to retain water on-site rather than release to the environment, this would serve to reduce the Blairmore Creek flows simulated downstream of each discharge node, during the period of SBZ shutdown; however, the flows would still be higher than current baseline flows as a result of the Project's Water Management Plan and Water Balance.

On Blairmore Creek, with the SBZ operating under normal design standards, very small increases in suitable habitat area ('Area Weighted Suitability' [AWS]) were predicted and displayed in Table 4-4 to Table 4-6 of the IFA (Addendum 1, CR#6, Appendix A3, CIAR#44). These three tables, (one each for various hydrologic conditions; downstream of the northwest surge pond to about 1 km below the BLT-04 tributary), indicate averaged improvements along the length of Blairmore Creek were up to 4% depending on the fish bio-period and hydrologic condition. With a portion of the incremental flows removed (*i.e.,* due to SBZ shutdown), these improvements (increases) in habitat area would only reduce slightly, and the AWS would still be higher than current baseline AWS values.

With respect to the instream objectives for Gold Creek; the IFA outlined that due to catchment modifications there would not be a significant reduction on overall flows within the adjacent reaches of Gold Creek. Since the retention of water on-site is only as a result of SBZ shutdown or ineffectiveness in meeting environmental guidelines, and there is no anticipated releases from that system to Gold Creek, there would not be any change to the Gold Creek flows related to this retention of water.

b) Provide details on the anticipated capacity that Benga has included in the water handling system associated with the raw water pond and saturated backfill zone, specifically:

i. Anticipated capacity of the raw water pond for pump back water and discussion of how many days of typical water release this would represent;

Response:

The Raw Water Pond (RWP) has been designed with a capacity of 1,200,000 m^3. During the first 10 years of operation, water extraction from the SBZ is anticipated to be 12,000 m^3/d on average with 18,000 m^3/d peak flow rates. It is likely that the RWP will be operated at a level which allows for the anticipated inflow design flood (IDF) for the RWP under CDA regulations which is approximately 664,000 m^3. Under this operating condition, the surge capacity within the RWP would allow recycle at the peak extraction rate for approximately 37 days and at the average extraction rate for 55 days.

After year 10 of operation, an additional 900,000 m^3 of SBZ volume will be made available (Addendum 2, Appendix 1D, Table 3.2.1, CIAR#53). If significant recycle to the RWP is still being experienced at this time, additional pumps can be installed to recycle directly back to the SBZ where the additional volume will be sufficient to ensure adequate retention time.

ii. Anticipated pumping capacity to be installed and redundancy (i.e. contingency plans in the event of pump failure);

Response:

The Project's water management infrastructure will be designed with pumping capacity to meet the conditions of both average flow and peak flow demand. For the first 10 years of operation , pumping systems for transfer of water from the Southeast surge ponds to the RWP and from the RWP to the saturated backfill zones (SBZ) will accommodate the anticipated peak flow rates through the use of three pumps, each designed to discharge at 250 m^3/hr for a total capacity of 18,000 m^3/d. This will allow flexibility to address varying flow conditions as well as redundancy of 1 pump (under average conditions) should a pump require servicing and maintenance. In addition, the extraction wells within the SBZ will be designed with the same design criteria of three pumps at 50% as well as the pumps that will convey water from the 24-hour buffer pond to the final clean water pond.

As more experienced is gained with the operation of the SBZs in conjunction with the RWP, and especially after year 10 when additional SBZ capacity becomes available, additional pumps can be added to the operation as required to ensure sufficient pumping capacity.

iii. Any other ponds or water structures that could be used to store water that does not meet EPEA specifications while more permanent treatment measures are developed; and

As indicated in the EIA (Addendum 2, Appendix 1D, Table 3.2.1, CIAR#53), the volume of the SBZ will grow dramatically after year 10 of operations when 900,000 m^3 of additional SBZ volume will become available and again at EOM, a total of nearly 7 million m^3 of SBZ volume will be available. After year 10, with the additional SBZ volume available, it is anticipated that the SBZ volume will itself serve as backup storage capacity.

As an interim measure, if additional water storage is required, a temporary holding pond can be constructed in the mined pit.

iv. How off-spec water would be stored, treated, and discharged during the 3-year period that would be needed to construct a selenium treatment plant, in the event that it would be required.

Response:

As discussed at length in JRP IR-6.25, even under scenarios where the SBZ does not perform as predicted in the EIA, selenium levels are not forecast to exceed the proposed selenium guideline in Blairmore Creek, until at least 10 years after the start of operations. This is based on the fact that, the rate of selenium leaching will be proportional to the amount of rock stored in the rock dump, which will increase through the years with mine activity. In addition, there is a delay between placement of rock in the waste rock disposal and presence of selenium in the affected water due to the time required for the rock to be wetted.

During these 10 years after mine start-up, Benga will be monitoring the selenium removal rates in the SBZ as well as selenium concentrations in the surge ponds, raw water pond, and in Blairmore Creek. If there is an indication that removal rates will not achieve the targeted levels of selenium removal or that selenium concentrations in untreated water are higher than expected, Benga will have several years to resolve the situation through operational adjustments to the SBZ or to implement another contingency plan to prevent unacceptably high selenium levels in Blairmore Creek. Given this long timeframe between the indication of a potential problem and reaching unacceptable selenium concentrations, Benga will be able to implement its contingency plans without having to store years of contaminated water.

If for some reason an urgent and unforeseen situation were to arise, Benga would take short term measures that may include:

- maximize storage in the RWP and other surge ponds;
- construction of a GBR (approximately one year to implement assuming design is done in advance);
- construction of temporary holding pond within the mined pit; and
- early implementation of additional SBZ phases.

Information Request 6.18

Tenth Addendum to the Environmental Impact Assessment. Response to Information Request 5.6. (CIAR #251).

In response to IR 5.6 d) (CIAR #251), Benga introduced the concept of using gravel bed bioreactors for the removal of selenium from surface water as a contingency measure. Benga supported this proposal by providing case studies, but provided no information on design and treatment effectiveness for selenium removal that would be relevant to the proposed mine site. Table 5.5-1 provided a high-level overview of gravel bed construction indicating this would occur over construction years five and six. Additional details on the treatment process, sizing, design parameters, location, equipment configuration, reagent (or additive) requirements, pre- and post-treatment requirements, and contingency plans in the event of delays in emergency commissioning and operationalization have not been provided.

Provide the following additional details as relates to gravel bed reactors:

a) Description of treatment process;

Response:

A Gravel Bed Reactor (GBR) consists of an engineered bed of gravel/media through which water containing constituents of concern (*e.g.,* nitrate and selenium) is passed for treatment. Electron donors are added to the water at the inlet of the GBR to promote the growth and activity of natural microbes that are capable of reducing the nitrate to nitrogen gas, and the selenium species (typically selenate and selenite) to elemental selenium, which becomes immobile in the gravel bed. The addition of electron donors to the influent water promotes the development of appropriate geochemical conditions that result in the biological reduction of selenate (SeVI) and selenite (SeIV), the predominant oxidized forms present in surface waters, to elemental selenium (Se0). Elemental selenium precipitates within the GBR media and is retained both within the biomass and as solid surface precipitates. The biological treatment mechanisms for nitrate and selenium reduction are well documented in literature (Sobolewski 2005; Zhang and Frankenberger 2005; Knotek *et al.*, 2006; Lenz *et al.,* 2008; Martin *et al*., 2009; Rutkowski *et al.,* 2010; USDIBR, 2011; and Herbert *et al.,* 2014). The nitrate- and selenium-reducing bacteria that mediate the biological reactions are naturally found in geographically diverse, pristine and contaminated waters (Nancharaiah and Lens, 2015).

Figure 6.18-1 shows a schematic design of a typical GBR system and the treatment process. GBRs are generally constructed within a natural depression or constructed cell near the water requiring treatment. The top and bottom of the treatment zone are lined using synthetic membranes to prevent water escape/influx and ensure hydraulic isolation from the surrounding environment. The bed is filled with gravel (or crushed waste rock) of a consistent size (typically 0.75 to 2 inch), with fines removed to promote predictable flow within the GBR. A top liner and insulating layer (*e.g.,* additional rock or soil) can then be installed as needed to maintain the temperature and prevent leakage, diffusion of air and infiltration of water into the GBR. A

buffer pond is in some cases used to aerate and retain effluent water before it is returned to the receiving environment.

Operation of a GBR requires pumping of the source water through the gravel bed, or in some cases, gravity can be used to move source water that may be located at a higher elevation, through a GBR. Liquid carbon amendment (*i.e.,* electron donor such as methanol, citric acid, *etc.*) is added as the electron donor to the water in the GBR influent. The initial target concentration of the electron donor is selected based on the concentration of electron acceptors in the source water, most notably oxygen and nitrate. The electron donor dosing is optimized based on monitoring of water chemistry in the GBR to achieve reduction of nitrate and selenium, while minimizing the potential for sulfate reduction and methanogenesis. During start-up, source water and electron donor are recirculated within the GBR to establish an active biofilm on the surface of the gravel media. Carbon utilization and establishment of anaerobic conditions are monitored, and electron donor dose is adjusted as needed. Once robust treatment of the nitrate and selenium is observed in the GBR, the unit is run in continuous forward flow, with the treated water aerated and discharged to the appropriate receiving water body.

Examples of applications of the GBR technology for the treatment of selenium include:

- A full scale GBR implemented to effectively reduce selenium concentrations in surface water from approximately 40 µg/L to less than 5 µg/L over an operating period of nearly eight years, to meet the requirements of Irvine Ranch Water District's (IRWD's) Nitrogen and Selenium Management Program (Mancini *et al.,* 2019; Geosyntec 2010) (Appendix 6.18-1). Sodium benzoate was used as the electron donor. Treatment flows in the GBR varied between 890 to 1500 m^3/day, with temperatures as low as 12 ºC, and achieved selenium removal rates ranging from 44 to 152 µg/L/d. Prior to full scale implementation, treatability and column studies were conducted by Geosyntec to confirm biological reduction of selenium and provide design parameters for the GBR. During start-up operations, Geosyntec evaluated the selenium and nitrogen treatment performance of the system, involving the approximation of plug-flow characteristics, sequestration of selenium, treatment of fecal indicator bacteria, and re-oxygenation of water prior to discharge. Testing occurred over extended durations, allowed for the characterization of short and mid-term operational conditions, and used extensive and varied testing protocols that informed the optimal operational conditions.
- A GBR implemented to treat selenium in seeps and surface water at a coal mine in West Virginia (Mancini *et al.*, 2019; Geosyntec 2010) (Appendix 6.18-1). The GBR was installed beneath a parking lot at the facility to accommodate limited available space. The GBR successfully reduced selenium concentrations from approximately 25 µg/L to less than 5 µg/L over an operating period of about one year, with temperatures as low as 13 ºC, using citric acid as the electron donor. Treatment flows in the GBR ranged from 270 to 550 m^3/d, and selenium removal rates ranged from 25 to 42 µg/L/day.

A bench scale column test of the GBR technology for the treatment of selenium and nitrate under varying operational conditions is currently being conducted by Geosyntec, and includes the following experimental set-up, testing and preliminary findings:

- Waste rock from the Benga site was used to pack the column using rock fragments ranging from 2 to 4 cm in size, as commonly used in GBRs.
- Synthetic water containing approximately 150 µg/L and 40 mg/L NO_3-N, which represents the anticipated mine water chemistry, and amended to represent the background geochemistry of the site's surface water in terms of anions, cations, *etc.*, was used in the column test (given that Se-impacted water is not yet being generated at the site).
- The column has been operated for over 12 months, testing varying conditions such as temperature to as low as 4 ºC, influent nitrate concentrations from 40 to 200 mg/L, influent selenium concentrations from 150 to 1000 µg/L, and varying hydraulic residence time.
- Preliminary results from the column study indicate that the GBR column can maintain a zero order nitrate removal rate of 20 to 188 mg/L/day and selenium removal rate of 6 to 278 µg/L/day at temperatures ranging from 4 to 8˚C and at influent concentrations of up to 200 mg/L and 1,000 µg/L for nitrate and selenium, respectively. These rates are consistent with and within the range of rates we have seen in other *in-situ* bioreactors.

Other field applications or field observations of successful microbially-mediated selenium reduction, including similar biogeochemical processes include but are not limited to:

- Saturated backfilled pits (Heffernan 2019; Deen 2018; Kirk, 2014; Bianchin *et al.,* 2013);
- Biochemical reactors (Conuma 2018; Baldwin *et al*., 2015; Luek *et al*., 2014; Rutkowski *et al.,* 2010); and,
- Hybrid gravel- and organic- media bed reactors (Sobolewski 2010; previously noted in response to JRP IR-5.6, Addendum 10, #251).

References are provided in Appendix 6.18-1.

b) Planned equipment location (including location on a map) in relation to site topography, depth to groundwater;

Response:

The major infrastructure and equipment planned for the GBR include a GBR reactor, GBR operations building area and a buffer pond. The GBR operations building area contains an influent heater and ehouse (power house, trailer to house control panels, and ancillary equipment for system control); a building to contain chemical dosing systems, chemical storage, sampling area, transfer tank, and reject transfer tank; and a buffer pond. The Phase 1 region of the mined

pit has been selected for the GBR location (indicated as "Phase 1 of Pit and Saturated Rock Fill" on Figure 6.18-2).

The Phase 1 area is a graded area of the spoil pile, located at 1565 m elevation with little change in topography. The anticipated groundwater depth of the Phase 1 graded spoil pile will be between 1450 m and 1500 m. Considering the elevation of the graded spoil pile, the groundwater depth is anticipated to be well below the 7 m depth required to account for the freeboard/barrier (*e.g.*, to account for the frost line) and GBR reactor depth (5 m).

Influent water to the GBR will be taken from the Raw Water Pond (RWP) which is located in the southern portion of the mine site. This pond receives impacted water from the Central Rock Disposal Area and South Rock Disposal Area (EIA, Appendix 10B, CIAR#42). There is an approximate elevation difference of 67 m from the top of the RWP to the top of the Phase 1 graded spoil pile. An influent conveyance pipeline will run from the RWP to the GBR. The estimated influent pipeline length would be approximately 605 m, including the distance from the RWP to a booster pump prior to inlet heater.

Although located within the same footprint of the SBZ, the GBR would be isolated from the SBZ through liner. For further details on the isolation of the GBR from the SBZ please refer to response JRP IR-6.18 m.

The GBR reactor, operations building, and buffer pond would be located within close proximity to each other as proposed on Figure 6.18-2.

c) Sizing criteria, design basis, and area (footprint) for a conceptual design, including pre-treatment and/or post-treatment units, if any, to meet target effluent concentrations for selenium;

Response:

The key design parameters for GBRs are flow rate, influent concentration, target effluent concentration, removal rate, and temperature (which affects removal rate). Sizing and footprint of the GBR can be estimated based on these parameters. For the GBR conceptual design, the design basis parameters are shown in Table 6.18-1.

Table 6.18-1 Summary of Design Parameters for Gravel Bed Reactor (GBR) for Removal of Selenium and Nitrate

Parameter	Units	Design Value
Selenium as Selenate	mg/L	0.6
Nitrate as Nitrogen	mg/L	40
Minimum Selenium Degradation Efficiency	%	97

Table 6.18-1 Summary of Design Parameters for Gravel Bed Reactor (GBR) for Removal of Selenium and Nitrate

Parameter	Units	Design Value
GBR Reactor Depth	m	5
Porosity	--	0.35 to 0.5
GBR Slope Ratio (depth:width)	--	0.5
Flow Rate	m^3/d	3,000

Assumptions for flow rate and influent chemistry are based on results of water quality modeling. Assumptions for nitrate and selenium removal rates were based on the ongoing column test currently being conducted to evaluate treatment of selenium and nitrate in simulated mine water, under varying operational conditions (response to JRP IR-6.18 a). A range in zero order nitrate removal rate of 20 to 188 mg/L/day and selenium removal rate of 6 to 278 µg/L/day, at temperatures ranging from 4 to 8 ºC and at influent concentrations of up to 200 mg/L and 1,000 µg/L for nitrate and selenium, respectively, were considered in GBR sizing based on previous bioreactor experience (as described in Addendum 10, JRP IR-5.5, CIAR#251; and response to JRP IR-6.18 a) and current column testing. influent concentrations of up to 200 mg/L and 1,000 µg/L for nitrate and selenium, respectively.

Conceptual design for pre-treatment units include influent heaters and amendment dosing systems to ensure that inlet temperature and adequate carbon and nutrients are provided for biomass maintenance and growth. An inlet heater is assumed as needed to maintain an inlet temperature at approximately 6 ºC in the winter months only. Conceptual design for post-treatment units include a buffer pond, aerators, and transfer pump with weir structure to control buffer pond water elevation.

Based on the assumed Project design parameters, the area (footprint) for the conceptual design of the Project GBR, GBR operations building (containing pre-treatment components), and buffer pond (containing post-treatment components) would be 89.25 m x 333 m, 40 m x 40 m, and 28.5 m x 66 m, respectively (Figure 6.18-3).

d) Description of design elements that maintain flows during winter months;

Response:

The following design elements are used to maintain flows during winter months:

- Influent water to the GBR will be sourced from the RWP at a flow rate of 3000 m^3/d. The size of the pond is anticipated to mitigate freezing below a certain depth. Conceptual design currently assumes a pontoon pump with de-icers on the RWP

surface, but a submersible pump station pulling water from a depth that is anticipated to maintain a more consistent water temperature will be considered in engineering design.

- An inlet water heater will ensure a minimum of 6°C is maintained in the influent of the GBR.
- GBR operations building will be heated so that chemicals in the building will not freeze and temperature meets all equipment suggested temperature operational ranges.
- If required, an electron donor dosing shed will have an HVAC/heater included to maintain suitable operational temperature within a with a suitable classification for the hazardous area rating.
- All pipelines for the GBR will be buried under mounded soil and installed so that pipelines will be under constant draining conditions.
- Lines that cannot be buried under mounded soil will be protected with heat tracing and insulation.
- The GBR will be constructed under the frost line (assumed 2 m) with a buffer layer of media.
- Membranes are used to ensure that infiltration does not occur within the GBR so that GBR capacity and temperature can be maintained.
- The buffer pond is designed to be under constant flow and aeration is anticipated to mitigate the formation of ice.
- Redundancy of any of the aspects / components to ensure consistent operations, should components fail, will be assessed in a hazard and operability study (HAZOP) meeting during engineering design.

e) Time required to design, procure, construct and commission the gravel bed reactors, startup time for normal and for emergency operation;

Response:

Final design of the GBR will take 8 to 10 months once final location and design parameters are selected. A field scale GBR pilot test is planned to be conducted prior to full scale application which will assist with reducing design time for the full scale GBR. Procurement and construction of a GBR system can be completed in one year. Initial start-up will take approximately 3 months and subsequent re-starts will take 1.5 to 2 months.

f) Volumes of water to be treated (design treatment capacity);

Response:

The GBR conceptual design has an active reactor volume of 111,333 m^3, a pore volume of 50,100 m^3, and is designed for 3,000 m^3/day to treat design basis concentrations of 40 mg/L of nitrate and 600 µg/L of selenium. The pumping system and systems supporting GBR turn-up and turn-down capabilities regarding flowrate will be evaluated further in the engineering design.

g) Utility requirements;

Response:

The utility requirements are currently assumed to be based on electrical heating although propane heating is an alternative that may be explored during detailed design.

Initial estimates of electrical demand assuming constant design flow are outlined below:

Winter Demand	1750 kW
Summer Demand	221 kW

h) Details on reagents (additives) to be used including:

i. proposed handling measures;

ii. storage requirements (including secondary containment, if applicable); and

iii. storage volumes.

Response:

The GBR may use the following chemicals (other options for each will be considered during detailed design):

- Methanol - Electron donor
  - Approximately 5,500 US Gallon Double Wall 304SS Tank (build according to API 12F modified code of construction due to small size).
  - Secondary containment area outdoors with 110% capacity of tank.
- Phosphoric Acid - Nutrient addition to GBR biomass
  - Approximately 1 Tote (275 US Gallons) storage.
  - Secondary Containment (385 Gallons).
- Yeast Extract [Lallemand FNI 150])
- sodium bromide or chloride – Tracer
  - Make-down Tank with Mixer (475 US Gallons)
  - Standard Pallet (to keep bags of tracer)
- Hydrochloric Acid (35%) for calcite mitigation.
  - 5,850 US Gallon corrosion resistant double wall fiberglass storage tank (assumed capacity of 5,500 US Gallon used)
  - Placed in secondary containment area in pre-treatment building with 110% capacity of tank (approximately 6,500 US Gallons).

- glycolic acid or oxidant - Biofouling mitigation
    - Storage space and spare chemical dosing pumps will be provided for miscellaneous chemicals to be used for biofouling mitigation as required. Estimates of consumption not developed.

During prior GBR applications (Mancini *et al.*, 2019; Geosyntec, 2010; response to JRP IR-6.18 a) reagent chemical concentrations within the GBR effluent met discharge requirements defined by regulations. This would be monitored as part of Project's Aquatic Monitoring Plan.

i) Proposed monitoring of efficacy, functionality and efficiency of selenium treatment;

Response:

A detailed monitoring program including routine sampling and analysis of GBR influent and effluent flow and chemistry, and sampling of the GBR monitoring wells will be implemented to assess the GBR selenium treatment performance. Selected parameters (flow rate, dissolved oxygen, oxygen reduction potential, pH) will be analyzed either continuously using in-line meters or using portable field meters. Other parameters, including total and dissolved selenium, nitrate, nitrite, alkalinity, dissolved and total organic carbon, microbial biological tools/biomass, anions and cations including metals will also be analyzed with varying degrees of frequency, as required to ascertain treatment performance. Like many other metals and metalloids, selenium can exist in various oxidation states, including selenate (SeVI), selenite (SeIV), elemental selenium (Se0), and selenide (Se-II). Selenium species, including organo-selenium complexes, will also be analyzed. A comprehensive sampling and analysis program will inform the potential need to adjust system parameters (*e.g.,* amendment dosing, flow rate) to optimize treatment performance.

At this stage of conceptual design, the GBR is designed to monitor for the efficacy, functionality, and efficiency of nitrate and selenium treatment through monitoring wells locations within the reactor (including monitoring wells locations, sampling ports, and removable media blocks to test for biomass parameters [referred to as media coupons]).

Monitoring well locations will be placed along the length and width of the GBR. Additional sampling lines from the source water, the GBR inlet (after chemical dosing), the GBR effluent, and the buffer pond effluent will also be incorporated in the sampling and analysis plan.

The sampling plan will include a combination of both field and external analytical tests on defined schedules to assess performance. Data collected from field monitoring will include oxygen reduction potential (ORP), temperature, flowrate, pressure, water level, pH, and

dissolved oxygen (DO) concentration. External analytical tests may include but are not limited to the following:

- ORP, nitrate, nitrite, dissolved and total selenium, selenium species, metals, chemical oxygen demand, dissolved organic carbon, volatile organic carbon, semi-volatile organic carbon, methanol, total suspended solids, volatile fatty acids, and biological analyses (*e.g.,* molecular biological tools, next generation sequencing, and quantitative polymerase chain reaction).

Selenium removal will be analyzed and interpreted through the following means:

- Rate of concentration decrease in monitoring locations, determined through comparison of samples taken at different locations of GBR with increasing residence times. These trends will be compared for nitrate, selenium, and available nutrients/amendments to direct operation.
- Tracer tests to evaluate GBR hydraulic properties and aid in adjustment of system to maintain residence times at monitoring points along the flow path. With an aid of a flow model, tracer studies will allow operators to determine if GBR is hydraulically distributing influent, nutrient, and electron donor effectively through the reactor. The hydraulic results of the tracer studies along with sample results will allow for the development of a 1D model of concentration *vs*. location of GBR (corresponding to an anticipated hydraulic retention time).
- Electron donor consumption will be strictly controlled and monitored at the monitoring locations. Through stoichiometric models, anticipated electron donor required dosages will be anticipated. Through the monitored locations operators can ensure that sufficient electron donor is being distributed within the reactor to consume nitrates and precipitate selenium. The electron donor consumption will be related to the observed changes in biogeochemistry of GBR water (see below) to gauge the microbial community composition and health.
- Changes in bio-geochemical composition of water along the flow path in the GBR will also be evaluated. This will include generation of reducing conditions, consumptions of electron acceptors, which are more readily consumed than selenate (*i.e.,* dissolved oxygen, ferric iron and nitrate), and those with a lower reduction potential than selenate (*i.e.,* sulphate and carbon dioxide).
- Periodic evaluation of microbial communities at different locations in the GBR. These evaluations will enable operators to determine potential adverse changes to the population, occurrence of possible inhibitory effects and/or the need to manage biofouling.

j) Expected variations in selenium removal efficacy including:

i. changes due to seasonal changes in temperature, ideally supported by field-validated seasonal removal rates;

ii. impacts of variable water flow rates;

iii. impacts of variable influent selenium concentrations; and

iv. discussion of any operational restriction points for the gravel bed reactors, i.e. does the process have significantly reduced efficacy or is the process ineffective below (or above) a certain operating temperature or selenium concentration.

Response:

The GBR is designed to treat 3,000 m^3/day at the design basis concentrations of 40 mg/L of nitrate and 600 µg/L of selenium. The current Benga column testing (see response to JRP IR-6.18 a), which is being performed at a water temperature of 8ºC, also included a phase with water temperatures decreased to 4ºC to evaluate low temperature effect on microbial activity. The observed removal rates for both nitrate and selenium did not change after the temperature decrease from 8ºC to 4ºC. Based on this, the target removal rates can be achieved as long as a minimum temperature of 4°C is maintained and enough amendments are provided.

It is expected that storage of water within the RWP will alleviate variable flow and act as an equalization pond during high precipitation events or freshet. As such, the removal efficacy of the GBR is not expected to vary due to changing influent flow rate and has been designed to treat 3,000 m^3/day. The pumping system and systems supporting GBR turn-up and turn-down capabilities regarding flowrate will be evaluated further in the engineering design.

The potential for the GBR to treat variable selenium concentrations is currently being investigated in an on-going column test. The tested influent concentrations have ranged from 40 to 200 mg/L for nitrate and from 150 to 1,000 µg/L for selenium. The test results have shown that removal of both constituents occurred concurrently, with kinetics of nitrate removal substantially faster than that for selenium. In general, the bulk removal rates observed in the tested ranges, were proportional with the influent concentrations, consistent with zero-order kinetics assumed for the modeling of GBR field design.

The operational restriction points of the GBR would be similar to any biological reactor and include primarily a minimum operating temperature of 4°C, below which enzymatic microbial functions of biomass are inhibited. A long-term column test is currently on-going to evaluate treatment of Se and NO_3 in mine water for the project under varying operational conditions, described in detail in response to JRP IR-6.18 a. The column testing included a phase with water temperatures of 4ºC to evaluate low temperature effect on microbial activity. The observed

removal rates for both nitrate and selenium did not change after the temperature decrease from 8ºC to 4ºC.

Interim results from the current column testing for the Project (see response to JRP IR-6.18 a), have shown selenium treatment up to the tested maximum concentration of 1,000 µg/L. Treatment of higher concentrations of Se in GBRs has not been tested previously to our knowledge. A maximum treatable selenium concentration may exist, but additional field performance tests or column testing would need to occur to confirm that value. Previous GBR trials have shown treatment of 20 to 40 µg/L of selenium, suggesting that this is the minimum treatable concentrations without additional testing for confirmation.

k) Expected seasonal variability in post-treatment effectiveness, such as water re-oxygenation before discharge;

Response:

Seasonal variability is not anticipated to have a major effect on post-treatment effectiveness. The GBR buffer pond incorporates aeration systems and will take into account potential lower oxygen uptake capability during warmer temperatures, if any. The buffer pond will be designed to minimize inflow/infiltration, there should not be a major difference in post-treatment effectiveness or performance that would be season dependent.

l) Details on short-term and long-term maintenance requirements of the system including discussion of any actions required to maintain the gravel bed (i.e. management of the biofilm and management of any precipitates); and

Response:

As provided in response to JRP IR- 5.5 (Addendum 10, CIAR#251), if biofouling or inorganic fouling occurs, it is expected to be predominantly near the influent end of the bioreactor. Engineering design and operational controls will be put into place to monitor and implement biofilm and precipitate accumulation, such that mitigation strategies can be implemented if and when needed. While engineering design can minimize these impacts, most long-term biotreatment projects will require some type of biofouling management program. These programs generally employ a combination of operational, physical and chemical measures for preventing or minimizing biofouling impacts, coupled with periodic rehabilitation of biofouled components and injection zones.

In development of biofouling controls for the GBR, Benga will consult previous experience such as that gathered during the development of the report “A Review of Biofouling Controls for Enhanced In Situ Bioremediation of Groundwater,” developed for the ESTCP (Environmental Security Technology Certification Program from the US Department of Defense) in October 2005 and the previous experience in biofouling mitigation approaches on previous GBR and *in-situ* biotreatment projects (Geosyntec, 2005b).

Short-term potential biofouling and inorganic fouling mitigation measures that may be considered in the GBR include the following:

- Dosing of antiscalant to reduce the potential for calcite precipitation and to interfere with the continued propagation of calcite precipitate when it does occur.
- Including the ability to perform chemical cleans (acid, caustic, oxidants, *etc.*) on individual nodes of the influent manifold, allowing for periodic localized *in-situ* cleans near the influent infrastructure. Cleaning chemical and sequence will be selected based on the nature of the fouling, whether biological or inorganic.

Long-term potential mitigation measures will include, at minimum, frequent monitoring of influent concentrations of nitrate and selenium such that carbon and nutrient dosing can be adjusted to maintain optimal levels of biomass.

m) Details on post-mining operational requirements and time required to decommission and reclaim the gravel bed reactor and related gravel bed reactor infrastructure.

Response:

The GBR is anticipated to operate post-mining with similar requirements to the mining operational requirements, however the chemical dosing demand is anticipated to decrease as the reduced nitrate load, which requires the bulk of electron donor, is offset by increasing selenium load (as outlined in Appendix 10B, Water and Load Balance Model Report (EIA, Appendix 10B, CIAR#42).

A GBR decommissioning plan and reclamation plan will be outlined in the engineering design phase. In concept, a benefit of the GBR is that upon completion of duty, the influent and effluent piping can be capped, and given the presence of its liner and cover, the GBR can be decommissioned/abandoned in place.

Calculations have shown that leakage rates through a liner are likely to be extremely small, and GBRs are therefore effectively hydraulically isolated from their surrounding environment. Considering a range of defects (1 to 4 defects per acre) and a liner surface area of 8.9 acres, the range in leakage considered would be between $1.6*10^{-3}$ m^3/year to $6.5*10^{-3}$ m^3/year (values of assumed leakage based on composite liner construction). As such, the GBR could be left in place saturated, which would maintain the anoxic conditions that maintain the selenium in immobile form, or they could be drained if there are concerns about water inadvertently leaking out of the GBR. All above ground infrastructure and equipment will be removed from the site at the end of the GBR lifetime, and infrastructure pads will be punctured at regular intervals to prevent ponding of water at the surface. GBR venting infrastructure will be removed last to ensure that all biological activity within the GBR has been exhausted prior to sealing or excavating the system.

Progressive reclamation can be considered for GBR, similar to the approach taken for the SBZ, where the area after decommissioning will be covered with clean soil and reclaim vegetation. Considerations need to be taken into the engineering stage for decommissioning of GBR ventilation lines, top liner, and cover media for the GBR. The GBR reactor volume will still be capped and buried to reduce risk of infiltration if GBR media is kept in place.

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Information Request 6.19

Grassy Mountain Coal Project - Updated Environmental Impact Assessment. Section C.8.3.1. (CIAR #42).

Grassy Mountain Coal Project - Updated Environmental Impact Assessment. Consultant Report #5 – Surface Water Quality. (CEAR #42).

Eighth Addendum to the Environmental Impact Statement. Appendix C-2; Figure 6. (CIAR #89).

Comments from the Government of Canada - Environment and Climate Change Canada submission. (CIAR #167).

Comments from Tsuut'ina Nation. (CIAR #192).Comments from Timberwolf Wilderness Society. (CIAR #281).

Tenth Addendum to the Environmental Impact Assessment. Response to Information Request 5.5. (CIAR #251).

As noted in Section C.8.3.1 (CEAR #42), Benga indicated that the Project will use comparable mining and processing methods as those employed by Teck Resources in the Elk Valley, British Columbia. In the response to IR 5.5, Benga provided supplemental information to demonstrate the effectiveness of the saturated backfill zone. Benga stated that the saturated backfill zone approach has been implemented and is providing excellent results at the Teck Elk Valley facility where a saturated backfill zone has been in operation since 2017. Timberwolf Wilderness Society (CIAR #281) indicated that no supporting evidence for this statement was cited and requested that technical reports, publications and data be provided to support the claim that the Teck Elk Valley facility "*is providing excellent results… since 2017*" in removing selenium from contaminated runoff and seepage water at the scale required by this project.

In Consultant Report #5 (CIAR #42), Benga stated that the saturated backfill zones are assumed to attenuate 99% of selenium loading. Environment and Climate Change Canada stated (CIAR #167) that according to Figure #6 of Appendix C-2 (CIAR #89), the rate of attenuation of selenium in optimal conditions tested under the barrel trial was

around 90%, and resulting concentration of selenium in the effluent would be 150 µg/L. Tsuut'ina Nation also highlighted (CIAR #192) that the consequences of the saturated backfill zone being slightly less effective than assumed would be enormous. In the response to IR 5.5, Benga summarized several case studies that noted different attenuation rates: 90-95% (Kirk et al. 2017), 97% (Jones et al. 2009; Ness et al. 2014), 98% (Pahler et al. 2007), and 99% (Bianchin et al. 2013). The response to IR 5.5 noted that for one saturated backfill zone example "the total selenium concentration in the in-pit saturated water is less than 1% that observed upgradient, suggesting that up to 99% of the selenium is being attenuated." However, there was no information presented with respect to whether the 99% attenuation rate was also the case at the Teck Elk Valley facility.

Although Benga provided the Elk Valley Water Quality Plan, none of the above-mentioned reports, publications, or data regarding the Teck Elk Valley facility were provided to support Benga's statements regarding the effectiveness of saturated backfill zone technology. If this information is to be considered by the Panel, it must be placed on the public record. Further details on the performance of the Teck Elk Valley facility are required to demonstrate and support Benga's assumptions of 99% removal efficiency of selenium.

a) Indicate whether the technical reports, publications (peer-reviewed or non-peer reviewed) and data regarding the Teck Elk Valley saturated backfill zone facility are publicly available, and if so, provide the information as supporting evidence to the Panel.

Response:

The references cited in the preamble above were provided in Addendum 10, JRP IR-5.5, Appendix 5.5-1 (CIAR#251). The locations of these publications within Addendum 10 is discussed below.

Table 6.19-1 provides the pdf pg numbers within Addendum 10, Appendix 5.5-1 (CIAR#251), that correspond with each publication listed in the preamble to this information request.

Table 6.19-1 Location of Requested Publications within Addendum 10, Appendix 5.5-1 (CIAR#251)

Reference Requested	Location in Addendum 10, CIAR#251
Kirk, L. B., C. Hwang, C. Ertuna, C. Kennedy, and B. Peyton. 2017. Column Tests of Selenium Biomineralization in Support of Saturated Rockfill Design.	Appendix 5.5-1 Pdf pg 437-441
Jones, R.G., S.H. Brienne, S.E. Jensen, and A.N. Tompkins. 2009. Selenium release from coal mines in the Elk Valley, and treatment R&D plans.	Appendix 5.5-1 Pdf pg 427-436

Table 6.19-1 Location of Requested Publications within Addendum 10, Appendix 5.5-1 (CIAR#251)

Reference Requested	Location in Addendum 10, CIAR#251
Ness, I., A. Janin, and K. Stewart. 2014. Passive Treatment of Mine Impacted Water in Cold Climates: A Review. Yukon Research Centre, Yukon College.	Appendix 5.5-1 Pdf pg 506-561
Pahler, J., R. Walker, T. Rutkowski, and J. Gusek. 2007. Passive removal of selenium from gravel pit seepage using selenium reducing bioreactors.	Appendix 5.5-1 Pdf pg 562-574
Bianchin, M., A. Martin, and J. Adams. 2013. *In-situ* Immobilization of Selenium within the Saturated Zones of Backfilled Pits and Coal-Mine Operations.	Appendix 5.5-1 Pdf pg 350-365

In regard to publicly available data regarding the Teck Elk Valley saturated backfill zone facility, Benga provided what was available at the time of submission of Addendum 10 (CIAR#251). At the request of the JRP, Benga included the Teck Elk Valley Water Quality Plan in Appendix 5.5-2 (Addendum 10, CIAR#251).

Since then, Teck has produced a report titled, Elk Valley Water Quality Plan: 2019 Implementation Plan Adjustment, July 31, 2019 (Revision 1.0), Annex J: Alternative Treatment Mitigation Plan, which describes the Saturated Rock Fill (SRF) technology and other alternative selenium treatment options (e.g., gravel bed reactors, similar to those presented by Benga [JRP IR-6.18]). This document has also been provided in Appendix 6.19-1.

There has also been an updated Elk Valley Water Quality Plan: Five Year Update (September 2019) which states:

"One of the most exciting advancements has come from our Research and Development program, which has developed a new form of water treatment using Saturated Rock Fills (SRF). Our first SRF has been commissioned at Elkview Operations and is achieving near complete removal of selenium and nitrate. SRF water treatment technology can help to achieve water quality objectives more quickly and efficiently than other forms of treatment. The SRF at Elkview is treating up to 10 million litres of water each day and we have plans to expand the Elkview SRF to treat 20 million litres per day."

The Elk Valley Water Quality Plan: Five Year Update (September 2019) has been provided in Appendix 6.19-2. Also provided in Appendix 6.19-3 is the Teck Permit 107517 Environmental Monitoring Committee 2019 Public Report, which summarizes their learnings around selenium management in 2018.

b) For the Teck Elk Valley information, discuss the selenium removal efficiency for the saturated backfill zones and provide evidence from the Teck Elk Valley facility to support the use of an attenuation rate of 99% for selenium in the saturated backfill zone proposed for this project.

Response:

Unfortunately, publicly available data on the performance of Teck Elk Valley's saturated backfill zones (SBZ) (or saturated rock fills) is not available at the time of submission of this Addendum 11 information request package. The schedule to release this type of data from Teck is currently unknown.

Teck (2019 Implementation Plan) indicate that they are continuing to conduct research and development to confirm that their SRFs are performing to set targets and will ultimately be proposed to provincial and federal governments in 2020 as an alternative means of selenium management, as opposed to mechanical treatment facilities.

Short of having Teck-specific data, to further reduce uncertainty in this technology, Benga has been working with several of the same technical experts who have also contributed to the Teck Elk Valley selenium treatment options for the Grassy Mountain Coal Project's selenium management plan design and engineering, (*e.g.*, saturated rock fill, and gravel bed reactor technology).

In regard to attenuation rate of 99%, for the response to JRP IR-6.25, Benga has presented a sensitivity analysis which shows model results for total selenium concentrations in Blairmore Creek assuming 95% and 90% removal of selenium in the saturated zones.

Although selenium levels are high in these scenarios, it is important to note that selenium levels are not forecasted to exceed the proposed selenium guideline, until 10 years after the start of operations. This is a result of the rate of selenium leaching being proportional to the amount of rock stored in the rock dump, which increases through the years with mine activity. As illustrated in Table 5.5-1 (Addendum 10, JRP IR-5.5, CIAR#251), Benga has committed to implementing research and development regarding saturated backfill technology, and during the first 10 years after mine start-up, Benga will also be monitoring the selenium removal rates in the SBZ as well as selenium concentrations in the surge ponds and raw water pond.

The lead up time to operations and early years of mine development equates to approximately 14 to 15 years, during which continuing research and continuous improvement in selenium management technologies will be advanced by Benga. It is assumed during this time that additional information from Teck Elk Valley will also become publicly available.

REFERENCES

Teck, 2019. Elk Valley Water Quality Plan: Five Year Update (September 2019)

Teck, 2019. Elk Valley Water Quality Plan: 2019 Implementation Plan Adjustment, July 31, 2019 (Revision 1.0), Annex J: Alternative Treatment Mitigation Plan.

Teck, 2019. Permit 107517 Environmental Monitoring Committee 2019 Public Report

Information Request 6.20

Tenth Addendum to the Environmental Impact Assessment. Response to Information Request 5.1, 5.5, Appendix 5.5-2. (CIAR #251).

Comments from the Government of Canada - Environment and Climate Change Canada submission. (CIAR #283).

Benga's response to comments on sufficiency. (CIAR #291).

In the response to IR 5.1 (CIAR #251), Benga indicated it is proposing to construct a cascade from the discharge point of the saturated backfill zone to allow re-oxygenation of the saturated backfill zone discharge and for the oxidation of selenite to selenate, subsequently reducing the uptake of selenium into aquatic algae.

Environment and Climate Change Canada (CIAR #283) indicated that a trial test of this proposed solution should be performed to demonstrate the efficiency of this additional treatment to change the speciation of selenium, or that appropriate literature, based on case studies elsewhere, should be provided.

In response to this comment, Benga stated (CIAR #291) that it was confident in the selenium removal mitigation using a saturated backfill zone, and committed to ensuring this mitigation is implemented to achieve the intended results. To assure the Panel of this commitment, Benga provided a draft plan outlining how Benga has and will continue to implement testing and other research and development initiatives to progressively develop the detailed engineering parameters for the saturated backfill zone.

Chapter 6 of the Elk Valley Water Quality Plan (Appendix 5.5-2) indicates that cascades could be used to relieve calcite supersaturation, but does not discuss the use of cascades to influence speciation of selenium.

In the response to IR 5.1 (CIAR #251), Benga re-iterated that following the oxidation step of the cascade, effluent would be monitored to assess speciation. Benga stated that if the effluent exhibited a high proportion of selenite, appropriate actions would be taken, such as re-cycling off-spec effluent to the raw water pond or back through the saturated backfill zone, or adjusting the treatment process. Benga did not provide supporting details regarding the efficiency of the cascade system to convert selenium from selenite to selenate.

a) Provide further details to support the efficacy of the cascade to convert selenite to selenate using appropriate literature and case studies;

Response:

For clarification purposes, the cascade or mechanical aeration was not intended to convert selenite to selenate, but to increase ORP and dissolved oxygen in the effluent before discharge to Blairmore Creek.

Aeration testing would also be performed to check the conversion of selenite to selenate; however, Benga recognizes that aeration through cascade or mechanical means alone will not be effective in this conversion process. Benga will implement advanced oxidation processes with powerful oxidant like hydrogen peroxide injection or ozone addition, if necessary, to further the conversion of carry-over selenite to selenate. The current proposal is that mechanical aeration will be used within the 24-hour buffer pond to address increase in dissolved oxygen.

b) Indicate if reagents such as hydrogen peroxide will be required to oxidize selenite to selenate within the short retention time provided by the cascades, and if so, explain any potential consequences on water quality parameters from the addition of these reagents;

Response:

Advanced oxidation processes, such as hydrogen peroxide and/or ozone may be needed to oxidize selenite to selenate (currently other mining companies are implementing this at site for Selenite and Nitrite oxidation) if carry over from the SBZ is found to be occurring. As noted above, the intended approach for re-aeration will be through cascade or mechanical aeration that will occur in the 24-hour buffer pond.

Hydrogen peroxide (H_2O_2) will be typically be supplied as 50% concentrated active solution and stored at site. Injection will be done inline followed by static mixer to ensure proper agitation and reaction. If Ozone gas (O_3) is used, Ozone will be generated *in-situ* at site by a prepackaged containerized Ozone generation unit consisting of air compressor, oxygen concentrators, ozone generator and cooling system. Such units are typically compacted in size and include all generation equipment pre-installed and wired inside a single or stacked 40’ or 53’ seacan. Ozone gas is injected inline through eductors or pressurized diffused vessel.

If additional reagents, such as hydrogen peroxide or ozone, are required to convert selenite to selenate, their residuals remaining after treatment may need to be quenched with reducing reagents such as sodium bisulfite before effluent discharge. Quenching requirements will be confirmed during the testing / monitoring program by Benga. Aeration process retention time will not be limited to mechanical aeration but will also extend to the 24-hour buffer pond, before treated water is discharged to Blairmore Creek.

c) If hydrogen peroxide or any other reagents will be required, present reaction stoichiometry and demonstrated removal mechanisms.

Response:

For Ozone:

$SeO_3^{-2} + O_3$------> $SeO_4^{-2} + O_2$, accordingly 1 mole of O_3 to 1 mole of SeO_3^{-2} (0.4 mg of O_3 required to oxidize 1 mg of SeO_3^{-2}).

Reference: Chemistry of Ozone in Water and Wastewater Treatment By Clemens von Sonntag, Urs von Gunten.

For Hydrogen Peroxide:

$SeO_3^{-2} + H_2O_2$ ------> $SeO_4^{-2} + H_2O$, accordingly 1 mole of H_2O_2 to 1 mole of SeO_3^{-2} (0.3 mg of H_2O_2 required to oxidize 1 mg of SeO_3^{-2}).

Reference: Kinetics of H_2O_2 Oxidation of Selenious acid By Francis J. Hughes and Don S. Martin.

Benga may utilize advanced oxidation process (*i.e.,* hydrogen peroxide and ozone together) to further promote the oxidation of selenite to selenate if carryover from the SBZ is noted as a concern during the monitoring of water quality at the site.

Information Request 6.21

Canadian Environmental Assessment Agency Operational Policy Statement: "Addressing "Purpose of" and "Alternative Means" under the *Canadian Environmental Assessment Act, 2012*". (March 2015).

Grassy Mountain Coal Project - Updated Environmental Impact Assessment. Section A.7. (CIAR #42).

Eighth Addendum to the Environmental Impact Assessment. Appendix C-2. (CIAR #89).

Comments from the Government of Canada - Environment and Climate Change Canada submission. (CIAR #167).

Comments from Tsuut'ina Nation. (CIAR #192).

Environment and Climate Change Canada (CIAR #167) and Tsuut'ina Nation (CIAR #192) have questioned the treatment performance of the saturated backfill zone proposed by Benga, and have noted that a decrease in the selenium attenuation rate from 99% to 95% would drastically increase selenium concentrations in Blairmore Creek. Although Benga presented the results of a barrel trial in Appendix C-2 of Addendum 8 (CIAR #89), Benga has not presented field data showing that a removal rate of 99% will be attainable with the saturated backfill zone at Grassy Mountain, nor that it can produce a final

effluent selenium concentration of 1 to 5 µg/L. Several other treatment technologies, such as an active treatment plant, can attain such removal rates or low selenium effluent concentrations, but have varying economic costs. In Section A.7 (CIAR #42), Benga identified that the saturated backfill zone option has been selected as the total capital costs are considerably less than the water treatment plant, and the ongoing operating costs are also considerably less as well.

In Section A.7 (CIAR #42), Benga presented an alternative means analysis that compared the technical and economic feasibility of the saturated backfill zone with an active treatment plant. However, this evaluation was insufficiently detailed: the technology for the active treatment plant was not specified (chemical precipitation, membrane filtration, or biological reduction), nor was its suitability to treat up to 30,000 m^3/day or to produce an effluent with 1 to 2 µg/L selenium evaluated.

Given the critical importance of the proposed saturated backfill zone in mitigating potential effects of selenium, and the limited examples of the use of these systems at a large scale, the Panel requests an updated and more detailed alternative means analysis that compares the technical and economic feasibility of alternative treatment options for selenium. Benga should follow the methodology presented in the Canadian Environmental Assessment Agency (CEAA) guidance entitled "Addressing "Purpose of" and "Alternative Means" under the *Canadian Environmental Assessment Act, 2012*"[5] to carry out its analysis.

a) Provide an alternative means analysis that investigates the technical and economic feasibility of the saturated backfill zone vs. an activate treatment plant for selenium removal. In addition to the completion of the steps as outlined in the CEAA guidance, this analysis should specifically:

   i. Present and rationalize evaluation criteria and their overall weighting. Identify a criterion that reflects the requirement for very long-term treatment;

   ii. Provide a design basis for the evaluation of treatment options (such as feed flow rates and chemistry, target effluent concentrations);

   iii. Include the ability of the system to have a maximum treatment capacity of 30,000 m^3/day as one of the criteria; and

   iv. Compare capital and operating costs on an equivalent basis (i.e., \$/1,000 m^3).

[5] Available online: Operational Policy Statement "Address the "Purpose of" and "Alternative Means" under the *Canadian Environmental Assessment Act, 2012*". https://www.ceaa.gc.ca/default.asp?lang=En&n=1B095C22-1&pedisable=true

b) Rate each option and present the rationale for allocating scores. Where a quantitative comparison is not possible, provide a qualitative justification for each of the scores.

Response:

Technically and Economically Feasible Alternatives for Selenium Treatment

In the EIA submitted in August 2016, Section A.7.6 (CIAR#42) Benga identified two technically and economically feasible alternatives for selenium treatment, being a Saturated Backfill Zone (SBZ) and an Active Treatment Plant. Since that time, Benga has also evaluated Gravel Bed Reactors (GBR) as a possible technology for selenium treatment. It is important to note that these technological solutions are not mutually exclusive but rather can all exist to some degree within the Project. Benga's preferred alternative, for reasons to be described below, is the SBZ. However, Benga has clearly stated in response to previous Information Requests that a small scale GBR may be constructed early in the Project as a field scale pilot to gain insight into the design considerations for full scale biological treatment of selenium. In addition, Benga has committed that either a GBR or an Active Treatment Plant may be built as a back up contingency if the SBZ performance is not adequate.

SBZ Description

The SBZ process and concept are described in the EIA (Appendix 10B, CIAR#42). The attenuation principle that anoxic conditions promote the conversion of soluble selenate ions (SeO_4^{2-}) to selenite (SeO_3^{2-}) or elemental selenium metal (Se^0). Selenite is less soluble and tends to adsorb to mineral surfaces. Elemental selenium is insoluble. Therefore, the conversion of selenate causes the reduced selenium species to become attenuated within the saturated backfill.

The key to the attenuation process is the formation of sub-oxic conditions. Sub-oxic conditions are generated by microorganisms as they metabolize carbon and nutrients. Therefore, the presence of carbon and nutrients in the mine water is required for the process to work. The waste rock in the saturated backfill serve as a substrate for the microorganisms. Figure 6.21-1 below shows the conceptual layout of an SBZ.

A managed SBZ simply consists of a system for adding an organic carbon source and nutrients to the mine water as it flows to the SBZ and a series of monitoring wells. This is identical to the process used in active water treatment plants for selenium removal such as the ABMet process developed by GE Water (Appendix 6.21-1) only on a much larger scale.

Sources of organic carbon that have been used in similar applications include molasses and methanol. The dose of organic carbon required depends primarily in the concentration of dissolved oxygen and nitrate in the mine water.

GBR Description

The concept of the GBR, complete with drawings, is fully described in response to JRP IR-6.18. A GBR uses the same removal concept as a SBZ but GBRs are generally constructed within a natural depression or constructed cell and the top and bottom of the treatment zone are lined using synthetic membranes to prevent water escape/influx and ensure hydraulic isolation from the surrounding environment. The bed is filled with gravel (or crushed waste rock) of a consistent size (typically 0.75 to 2 inch), with fines removed to promote predictable flow within the GBR. A top liner and insulating layer (*e.g.,* additional rock or soil) can then be installed as needed to maintain the temperature and prevent leakage, diffusion of air and infiltration of water into the GBR. A buffer pond is in some cases used to aerate and retain effluent water before it is returned to the receiving environment. Operation of a GBR requires pumping of the source water, mixed with an electron donor such as methanol, through the GBR. As with the SBZ, continuous monitoring and adjustment of operational parameters is required to maintain an effective treatment process.

Fluidized Bed Reactor Description

As indicated in response to JRP IR-5.6 (Addendum 10, CIAR#251), Benga would choose a **Fluidized Bed Reactor (FBR)** technology if it is required to install an active treatment plant for removal of selenium. This is the same technology that was chosen and installed by Teck at its Line Creek Operations and which has been shown to efficiently reduce selenium concentrations to below 20 ug/L based on a capacity of 7,500 m^3/day.

In an FBR system, wastewater is passed through a granular solid media (sand or granular activated carbon) at sufficient velocity to suspend the media and cause it to behave as though it were a fluid. Under anoxic/anaerobic conditions, heterotrophic facultative bacteria use nitrates, selenate, and selenite as electron acceptors as means of respiration. These bacteria grow on and are attached to the FBR's media. Fluidization of media with pumps keeps the media with attached biomass in suspension and expanded to a depth that promotes contact of the water with the biomass for effective treatment. Generally, the bacteria's preference of electron acceptor is for DO first, followed by the following oxyanions: nitrate, nitrite, selenate, selenite, chlorate, perchlorate, and sulfates. The bacteria need an organic carbon (electron donor) source to meet their food/energy requirements – typically methanol.

Because the FBR is fluidized, the FBR effluent will contain reduced elemental selenium in colloidal form (typically around 0.1 micron in size) attached to the sloughed off excess biomass from the media. Hence, it is critical that these solids be removed to prevent reoxidation of some elemental selenium back to soluble selenite and selenate forms in the aerobic biological polishing reactor and subsequently in the oxygen rich creek water. In order to remove the solids including particulate Se from the FBR effluent, ballasted sand clarifiers are used for liquid – solids separation. A ballasted sand clarifier could be selected for this application to maintain anoxic condition during liquid-solids separation.

Depending upon the biochemical oxygen demand (BOD) discharge requirements, the FBR will likely require aerobic polishing of the dissolved BOD from the ballasted sand clarifier effluent. The unused electron donor (organic carbon such as methanol) added to the FBRs as food for bacteria will be present as residual dissolved BOD. Given the low BOD concentrations of the clarifier effluent, this polishing can be done a variety of ways but most efficiently in an aerobic environment with another attached growth system such as a moving bed biofilm reactor (MBBR).

Effluent from the MBBR will contain suspended solids, primarily biological solids. Tertiary sand filtration system was selected to remove the suspended solids from the MBBR effluent before the final treated effluent discharge. Continuous upflow granular media filters with continuous backwash were selected for this process to enable continuous back wash flow without the addition of backwash pumps and tanks, which will increase the overall system footprint and complexity. The filter employs an airlift system for media scouring and solids removal. The slurry is removed from the system and sent to the solids thickener.

Finally, a solid handling system will be required to deal with the sludge removed from the water in the various filters and separators. Solids will be disposed with the mine waste rock during operations and subsequently in an approved manner at a land-fill site.

Comparative Potential Effects on Valued Components

Water Quality and Aquatic Habitat – All three potential technologies (SBZ, GBR and FBR) are technically capable of reducing selenium concentration in effluent to a level in the order of 0.015 mg/L. Performance below this threshold is not certain for any of the three. Given that the expected performance is the basis for assessing the alternatives to be "feasible", all three would be equivalent with regard to these VCs.

Air Quality (GHGs) – Benga considers that the SBZ will require the least energy to operate of the three alternative technologies. The SBZ and the GBR will be sufficiently large and deep below the surface to moderate the temperature of the water without energy input. The FBR will require heaters to manage water temperatures within a suitable range in winter and will therefore require more energy to operate.

Long Term Disturbance to Wildlife and Traditional Practices – As the treatment of selenium is projected to continue for decades after the completion of mining and reclamation of the surrounding area, the continuing presence of selenium treatment facilities will be the last disturbance affecting the return of wildlife to the area and the enjoyment of the reclaimed landscape for traditional purposes. In these terms, Benga considers the SBZ to be the least intrusive in the long term with perhaps the potential to transition from an actively managed treatment process to a passive process with few pumps or visible operating equipment. The GBR requires active management and continuous operational input simply because the flow rates are higher and the retention time lower than the SBZ; consequently, operational adjustments will be

required on a daily basis to maintain effective treatment. The FBR will be the most intrusive of the three alternatives in the long term requiring full time staff to operate the facility and a significant building to house the equipment.

Waste Management – Of the three technologies considered, the SBZ and the GBR are the only alternatives that will not normally produce sludge that will need to be disposed in a waste management facility. The biological materials within the SBZ and GBR will be permanently contained in the very large pore space of the reactors.

Economic Comparison

Benga has developed economic parameters for the 3 alternatives based on design criteria that are suitable for each of the technologies using an initial design capacity of 15,000 m^3/d. All of the technologies are scalable up to the required 30,000 m^3/day.

SBZ Economics – The creation of the SBZ itself does not present significant additional cost to the Project as the pit excavation and subsequent filling of the pit with waste rock will be done normally as part of the mine plan. There are additional dikes required to establish the water retention capabilities for the SBZ and prevent the remainder of the pit from flooding and additional care needs to be taken to arrange the in-fill rock to maximize treatment efficiency. Additional facilities required include injection wells, extraction wells, test wells and instrumentation, pumps and pipelines to transfer water and storage tanks for handling methanol required for the process. Benga has done a high-level estimate to construct the SBZ1 phase 1 - 3 which will have a volume of approximately 650,000 m^3 and be able to handle 15,000 m^3/d with peak throughputs of 18,000 m^3/day. The cost estimate for this SBZ is $60 million as per Table 6.21-1.

Table 6.21-1 Table of CAPEX for SBZ 1 (Phase 1 – 3) Alternative

Category	CAPEX
Engineering and Design	4.5 Million
Equipment (pumps, tanks, *etc.*)	4.5 Million
Earthworks (dikes, liners, grading, *etc.*)	19.0 Million
Civil (buildings, foundations, intake structures, *etc.*)	3.0 Million
Piping (water transfer pipelines)	5.5 Million
Electrical (power lines, transformers, switchgear)	10.0 Million
Instrumentation (sensors, and control systems)	1.5 Million
Contingency (25%)	12.0 Million
Total	60.0 Million

In terms of long-term operating costs, Benga considers that one or two full time employee or contractor could manage the day to day operation of a 15,000 m^3/d SBZ operation with periodic contracting to maintain pipes and pumps. Long term annual costs will be would be about $1.5 million per year. There will be very little cost to remediate the treatment system at end of life with only pumps, tanks and other above ground equipment to be taken away.

GBR Economics – Benga has prepared a preliminary design for a GBR that could manage a 3,000 m^3/day flow rate of water to be treated which would have a footprint of approximately 90 m by 335 m. This is about one fifth of the required 15,000 m^3/d required capacity and therefore the GBR would need to be expanded in size or additional GBR units would need to be built to accommodate the required water treatment capacity. To estimate costs for the GBR construction and operation on an equivalent basis to the SBZ, the following assumptions have been made: costs include construction and operation associated with the GBR reactor unit only. In other words, the cost estimate excludes all costs associated with excavation and preparation of land; rock to be used in construction of GBR reactor bed and cover; and heating of water within the reactor.

Based on the conceptual design, which is described in the response to JRP IR-6.18, Benga estimates the capital cost for a single module at a treatment flow rate of 3000 m^3/d to be $20 million; an expanded GBR to accommodate the full water treatment capacity of 15,000 m^3/d would be estimated to cost about $80 million. Regardless of the number of GBR reactors utilized at the facility all reactors will be within close proximity to each other given the site footprint. All controls can be accessed from a central location. Long term annual costs are anticipated to be in the order of $2.5 million. Decommissioning of the GBR(s) would be similar to the SBZ, with removal of equipment.

FBR Economics – Benga has corresponded with suppliers regarding the relative cost of an FBR system. Initial discussions indicate that an FBR designed to handle 15,000 m^3/day would be possible and would cost in the order of $250 - $300 million to construct. In addition, information from vendors indicates that annual operating costs including labor, chemicals, power, solids disposal and other operational costs will be about $25 million per year. Finally, to decommission the buildings and equipment associated with the FBR would be more costly than either of the other alternatives.

Overall Evaluation of Alternatives

Based on the discussion above, the three alternatives are ranked as follows in Table 6.21-2 (1 is best performance):

Table 6.21-2 Comparison of Alternative Selenium Treatment Options						
Alternative	**Water Quality**	**Air Quality**	**Long Term Disturbance**	**Solid Waste**	**Capex**	**Opex**
SBZ	1	1	1	1	1	1
GBR	1	1	1	1	2	2
FBR	1	2	3	2	3	3

Since the SBZ alternative is equal to, or superior to, the other two options in all categories considered for this evaluation, it is clearly the preferred alternative.

As stated at the outset, Benga is aware that both the GBR and the FBR have a longer track record in terms of proven application at this scale. For that reason, Benga continues to consider them as contingency plans or perhaps supplemental treatment options should the SBZ not function as anticipated. There is room to implement all three alternatives within the mine footprint if required.

Information Request 6.22

Eighth Addendum to the Environmental Impact Assessment. Response to Information Request AER-R2- 14. (CIAR #89).

Tenth Addendum to the Environmental Impact Assessment. Response to Information Request 5.6. (CIAR #251).

In the response to IR AER-R2-14 (CIAR #89) Benga noted that active management of the surge ponds is required beyond year 2100, and that it was not possible to reliably estimate the time horizon for when the rate of weathering and selenium release will diminish to a point where active management no longer is required. It is unclear how Benga can assure the Panel that treatment performance will be maintained over such a lengthy and indeterminate period of time.

In the response to IR 5.6 (CIAR #251), Benga stated that selenium removed by the saturated backfill zone becomes permanently lodged within the rockfill. Benga noted that conditions within the saturated backfill zone would remain anoxic, and the selenium would remain in stable form. Benga stated that the saturated backfill zone can be kept anoxic in perpetuity by ensuring that the water cover is maintained. Given that the saturated backfill zone is a new technology that it is expected to be operated for an indeterminate length of time, and that conditions for its operation are likely to vary over time, it is unclear how Benga will ensure that the saturated backfill zone will remove and retain selenium "in perpetuity".

Further information is required to reduce the uncertainty associated with the effectiveness of the saturated backfill zone over time.

a) Provide additional information demonstrating that treatment capacity of the saturated backfill zone will not be exceeded throughout its design life;

Response:

Benga proposes to use multiple saturated backfill zones (SBZ) for selenium treatment at the site. The SBZs will be constructed with multiple cells (phases) and expanded over time. As part of the advancing mine plan, once the initial cells' reach their design capacity, new cells will be prepared and utilized for treatment.

Benga has committed to developing and implementing a testing / development program to monitor the SBZ treatment capacity and predict future trends and treatment performance (Addendum 10, JRP IR-5.5, CIAR#251). If future monitoring and analysis indicate that an operating SBZ cell treatment efficiency is diminishing, the next SBZ phase will be advanced.

If monitoring indicates that all the planned SBZ zones will not be effective in treating the anticipated life of mine water balance, Benga has committed to implementing contingency measures including initiating an interim gravel bed reactor (JRP IR-6.18), looking for alternative sites to construct additional SBZ's, and constructing an active treatment facility. This will be part of the adaptive management process (Addendum 10, JRP IR-5.5, CIAR#251) initiated at the site to continuously monitor and assess the effectiveness of treatment zones and when adjustments may need to be made in the overall mine plan or schedule.

b) Provide additional information demonstrating that the saturated backfill zone, as designed, has sufficient adsorption capacity over its design life if selenium is removed via adsorption into iron oxides or other mineral species;

Response:

Adsorption is not the primary intended removal mechanism for selenium treatment within this Project's SBZ design. Adsorption capacity is related only to iron coprecipitation of selenite. Unless the raw water has a significant amount of iron, selenite adsorption is unlikely in the SBZ. To be clear, Benga has not indicated that adsorption would be important in the functioning of the SBZ in the EIA or previous information rounds to date.

In biological selenium removal systems, such as the SBZ proposed for the Project, reduced elemental selenium particles stay in the SBZ, attached to the rock surface, within void spaces and on the bacteria. Given the immense surface area represented by the rock within the various SBZs proposed for the Project, and the relatively smaller mass of elemental selenium to be removed during the life of the Project, Benga does not anticipate a capacity constraint. As noted in part a), the efficacy of treatment within the SBZ environment will be monitored continuously during operations and trend analyses will be conducted on the performance to help inform operational management decisions and timing of subsequent phases SBZ cell construction.

c) Describe whether the saturated backfill zone has the potential to become saturated with selenium in its elemental form and become less effective over time;

Response:

See the response to part b).

d) Describe the circumstances under which selenium could become remobilized, the potential effects associated of this remobilization, and present measures that would mitigate these potential effects (e.g., whether the ability to treat water can be restored after an event that remobilized selenium);

Response:

Benga does not foresee circumstances under which selenium could become remobilized in large quantities once it is deposited as elemental selenium and adhered to the rock surface in the SBZ. Such an occurrence would require a sudden "oxygenation" of the SBZ, which is not likely given that the entire SBZ is below the natural ground water level after mining.

During the mining operation, some degree of selenium remobilization may occur under certain operating conditions:

- a small portion of the selenate may not be completely reduced to elemental selenium and may exist in selenite form, which is soluble;
- too low of an oxygen reduction potential (ORP) in zones of the SBZ may reduce a small portion of selenium to soluble organic reduced selenium species such as selenocyante, methylated selenium, and other organic selenides, which are soluble; or
- a small amount of non-soluble elemental selenium may be carried out of the SBZ in the flowing water.

In all cases, it is likely that as the water moves through the SBZ it will encounter a zone with the appropriate anoxic conditions to re-establish the reduction of selenium from these forms back to elemental form, or that the floating elemental selenium will re-adhere to a rock surface.

If soluble species or floating elemental selenium are discharged as SBZ effluent to the Buffer Pond, Benga's testing and monitoring program would detect that non-optimal conditions are occurring within the SBZ, which would allow Benga time to react. This reaction may be in the form of placing effluent into recycle mode so that effluent will be re-injected to the SBZ to undertake another treatment pass. In addition, measures may be taken to adjust the SBZ operation, which may include adjustments to carbon injection fluxes, altering injection or withdrawal sites, and changing flow rates. Finally, if operational adjustments do not control the issue, contingency plans as discussed in part a) will be implemented.

e) Explain whether the effectiveness of the saturated backfill zone may be subject to 'drift' (a gradual change in performance) because of long-term changes in feed flows

or chemistry. Describe what design elements are proposed to detect such long-term trends, and to adjust system operation to maintain treatment performance. Discuss whether it is anticipated that the saturated backfill zone will need to be refurbished to restore optimal performance;

Response:

Benga expects and have anticipated that the effectiveness of the SBZ will change over time. Rigorous monitoring and trend analysis will be utilized to assess and predict drift within the system. This assessment will be used in conjunction with mine planning to schedule the construction of the next SBZ or to implement operational adjustments. Operational adjustments may include modifications to injection of carbon donor rates, adding additional injection or extraction points within the SBZ geometry or changing flow rates through the SBZ.

If SBZ effluent does not meet water quality limits, it would require reprocessing either in a new SBZ cell or in a gravel bed reactor or an active treatment system as per Benga's stated contingency plans. There is no intent to re-furbish the SBZ once it is constructed as this would be uneconomical and would not meet the overall mine waste rock material balances.

f) Discuss whether Benga anticipates the need to manage a residue, such as sludge or accumulating biomass. Describe how Benga will manage such residues, if necessary; and

Response:

Most solids are expected to stay in the SBZ, however some minor solids (*e.g.,* biomass) may slough off from the rocks and void spaces and carry over in the effluent and settle in the 24-hour buffer pond. In case of excessive solids accumulation in the 24-hour Buffer Pond, dredging and disposal of the solids would be required. Benga anticipates that disposal of such solids would be in pit with waste rock.

g) Provide additional information to support Benga's capacity and commitment to manage selenium levels at the Project site until active management is no longer required.

Response:

As with all aspects related to final reclamation of the Project site, Benga understands that natural processes will take some time after mine closure to re-establish stable and healthy ecosystems. In the case of selenium treatment, the very conservative assumptions taken in the modelling to date, combined with the novel approach represented by the SBZ technology itself, present some uncertainty relative to the duration and effort required to reach this desired outcome. However, during the course of the Project, these uncertainties will be reduced through experience and data and more precise estimates of time and effort will be available. For example, Benga anticipates that progressive reclamation of the South Rock Disposal area will begin before year 10 of mining

operations. Monitoring of the quantity and selenium concentration of water collected in the Southeast Surge Pond (SESP) following reclamation will provide important information for better estimating the effort and time required to manage selenium treatment after mine closure. Benga expects that these more precise estimates will be used to inform the Mine Financial Security Program (MFSP) administered by the Government of Alberta. Benga has provided estimates of reclamation costs, including long-term management of selenium treatment structures in its response to JRP IR-5.33 (Addendum 10, JRP IR-5.33, CIAR#251).

Information Request 6.23

Information Request Package #5 from the Joint Review Panel to Benga, Information Request 5. 4. (CIAR #215).

Tenth Addendum to the Environmental Impact Assessment. Response to Information Request 5.4 and 5.23 (d), Appendix 5.4-1. (CIAR #251).

Comments from the Government of Canada - Environment and Climate Change Canada and Fisheries and Oceans Canada submissions. (CIAR #283).

Comments from Canadian Parks and Wilderness Society Southern Alberta. (CIAR #284).

Benga's response to comments on sufficiency. (CIAR #291).

Information Request 5.4 (CIAR #215) outlined the requirements for a draft aquatic monitoring plan relating to monitoring, mitigation, adaptive management, and overall study design and analysis. Benga's response to IR 5.4 (CIAR #251) did not provide all of the information requested. Fisheries and Oceans Canada and Environment and Climate Change Canada (CIAR #283) also noted that the response was in. Specifically, the following deficiencies were noted:

- IR 5.4 a): a lack of details on adaptive management, instead outlining general concepts in an adaptive management plan (CIAR #283);
- IR 5.4 a): no description of past successful application of adaptive management and no response to parts a) i, ii, iii, iv and vi (CIAR #284);
- IR 5.4 c): no information on baseline monitoring provided. The Fisheries and Aquatic Monitoring Plan (Section 6.5, Appendix 5.4-1) did not contain details on the establishment of an accurate baseline assessment for water quality (CIAR #283); and
- IR 5.4 d): while mention is made of monitoring the population trends in Westslope Cutthroat Trout (Section 6.6 of Appendix 5.4-1) there is no discussion provided on how long-term trends will be evaluated and adverse effects mitigated for other aquatic components (water quality, algae, benthic invertebrates and fish health; (CIAR #283).

Given these gaps in information, there is uncertainty that potential effects to the aquatic environment can be adequately identified via monitoring, or mitigated via adaptive management. Further, given the lack of definitive reference areas and lack of details on

how baseline data will be incorporated into the Aquatic Monitoring Plan, it is unclear how effective the monitoring program will be at detecting potential changes in the receiving environment.

The Panel requires that Benga provide a draft Aquatic Monitoring Plan that addresses the information previously requested. This will allow the Panel to evaluate Benga's ability to detect potential changes in water quality, validate assessment predictions, and evaluate management measures to mitigate potential adverse effects. The Panel understands that the final plan would be finalized with appropriate regulatory agencies, such as Fisheries and Oceans Canada, but requires a complete draft version of the plan at this time, as was initially requested.

Response:

An updated Draft Aquatic Monitoring Plan (AMP) is attached to this response as Appendix 6.23-1, which incorporates the information requested as more particularly discussed below.

a) Provide project-specific details on adaptive management and mitigation specifically addressing the following points (as requested in IR 5.4 a):

i. potential effects of the project that require mitigation;

Response:

The potential Project effects on westslope cutthroat trout and the downstream aquatic environments of Blairmore Creek, Gold Creek, and the Crowsnest River that require mitigation are summarized in Section 4.0, Figure 4.0-1, and in Section 5.0, Table 5.0-1 of the updated AMP (Appendix 6.23-1).

ii. uncertainties that necessitate the use of adaptive management including, supporting evidence on the efficacy of proposed adaptive management measures;

Response:

Uncertainties that necessitate the use of adaptive management are described in Section 7.1 of the AMP (Appendix 6.23-1) and are related to the following elements of the EIA analysis that have led to the current assessment that the effects of the Project on the aquatic environment are not significant:

- **Representativeness of input data** – the EIA analysis is based on information about the Project from sampling that may not be representative of Project conditions. For example, the amount of selenium present in the waste rock is from a limited number of rock samples. If these samples turn out to be not representative, the total amount of selenium loading could be greater or smaller.
- **Other assumptions used for modelling the Project** – Some parts of the EIA analysis are based on assumptions using professional judgement and where possible,

conservative bias. There is a possibility that these assumptions may be incorrect and lead to unexpected impacts.

- **Errors and omissions** – Although the EIA analysis has been conducted with care and using quality control procedures to minimize errors, there is always a possibility that errors and omissions could lead to outcomes that are not currently foreseen.
- **Unforeseen external factors** – During the Project life, it is possible that currently unforeseen external or environmental changes could work to create a cumulative effect with the Project that is not included in the EIA analysis.

With respect to the efficacy of proposed adaptive management measures, all of the uncertainties listed above will lead to a deviation from baseline data or a deviation from the results predicted in the EIA. The AMP's mitigation effectiveness evaluation and adaptive management approach will focus on establishing indicators and thresholds according to baseline characterization, improved practices based on research and monitoring results, and input from the public engagement and Indigenous consultation programs. As the Project proceeds, monitoring throughout all Project phases will allow water quality targets to be reviewed and, if necessary, modifications can be made to site expectations.

Mitigation effectiveness evaluation and adaptive management is a planned and systematic process for continuously improving environmental management practices by learning about their outcomes. Mitigation effectiveness evaluation and adaptive management provides flexibility to identify and implement new mitigation measures or to modify existing ones during the life of a project. Benga's program is organized into four main components, which are reevaluated and reassessed in a feedback loop:

- Assess the Problem
- Adaptive Management Process Design
- Implement, Monitor, and Evaluate
- Adjust the Mitigation as Required

iii. proposed mitigation measures, mitigation objectives and associated pre-discharge mitigation performance indicators to be used in order to confirm the effectiveness of mitigation;

Response:

Proposed mitigation measures associated with effluent characterization and water quality monitoring are provided in the updated AMP in Section 5.0, Table 5.0-1 and in Section 6.1 (Appendix 6.23-1).

iv. details on receiving environment monitoring stressor indicators and effects indicators, including sampling location, frequency, and supporting information;

Additional information on the receiving environment monitoring stressor indicators and effects indicators are provided in the following sections of the updated AMP (Appendix 6.23-1):

- Section 6.1 – Water Quality Monitoring
- Section 6.2 – Aquatic Effects Monitoring
- Section 6.3 – Calcite Monitoring
- Section 6.4 – Groundwater/Surface Water Monitoring
- Section 6.5 – Hydrology Monitoring
- Section 6.6 – Westslope Cutthroat Trout Population Monitoring
- Section 6.7 – Bioenergetics Monitoring

v. supporting evidence, including reference to relevant examples, on the efficacy of the proposed mitigation measures described in (iii), along with contingency measures that are technically and economically feasible should the mitigations implemented in (iii) prove to be ineffective; and

Response:

Additional information on efficacy of the proposed mitigation measures are provided in Table 5.0-1 of the updated AMP (Appendix 6.23-1). Contingency measures or adaptive management options for each of the proposed mitigation measures, should the planned mitigations prove to be ineffective, are provided in Table 7.5-1 of the updated AMP (Appendix 6.23-1).

Supporting evidence on the efficacy of the saturated backfill zone-specific and gravel bed reactor-specific mitigation measures are provided in Addendum 10, JRP IR-5.5, CIAR#251 and in the response to JRP IR-6.18, respectively.

vi. methods to be used to develop thresholds that would trigger implementation of mitigation measures or adaptive management measures (e.g., a series of risk-based thresholds ranging from triggering confirmation of exceedance of guidelines, to confirming cause/effect, to triggering deployment of alternate or additional mitigation).

Response:

Methods to be used to develop thresholds that would trigger implementation of mitigation measures or adaptive management measures are provided in the updated AMP (Appendix 6.23-1) in Section 6.1.2.6 (for water quality) and in Section 7.0, which presents the Project's draft Mitigation Effectiveness Evaluation and Adaptive Management approach.

b) Discuss Benga's application of adaptive management to mitigate unanticipated environmental effects during project construction, operation, decommissioning

and/or reclamation, using examples from past mining, or other mining projects, to demonstrate Benga's understanding and ability to effectively implement adaptive management.

Response:

As indicated in the updated AMP in Section 7.0 (Appendix 6.23-1), Benga will incorporate adaptive management techniques as routine components in all of its environmental management activities. These techniques provide the opportunity to develop and fine-tune the monitoring program using data collected on-site and from other regional operators.

Benga will use the experience gained during the development of the Project, and other successes by the regional coal operators over the next 24 years, to manage and implement an effective monitoring program. Benga will work with other operators of coal mines, AEP, AER, DFO, ECCC, and local stakeholders, to further develop criteria and monitoring programs that clearly demonstrate the protection of aquatic ecosystems.

With respect to Project mitigation effectiveness evaluation and adaptive management, Benga is committed to achieving continual improvement in environmental performance. The development and implementation of all monitoring and mitigation identified for the Project and housed in the monitoring and follow-up programs will be tracked in relevant management plans. As site conditions and monitoring dictate, or as new technology emerges, Benga will adaptively manage its site practices and monitoring program to meet the defined objectives. For some programs this would involve regular evaluation of predictive models; which would be clearly defined in each applicable management plan.

In summary, if a monitoring and mitigation effectiveness evaluation identify that adverse environmental effects are greater than predicted, Benga will then evaluate whether they result in changes to the conclusions presented in the effects assessment. If changes are confirmed, Benga will then evaluate the need for revised mitigation actions and management practices to manage effects. Where the need for revised mitigations is identified, they will be further developed and implemented.

As Benga was formed specifically for the purposes of developing and executing the proposed Grassy Mountain Project, the Company does not have corporate history or examples from past mining projects to use as examples to demonstrate these points.

c) Provide details on sampling design, including how the baseline dataset will be established and used during monitoring.

Response:

Benga has incorporated details around Baseline Characterization for the various components to be monitored in the updated AMP (Appendix 6.23-1).

d) Provide a description of how long-term aquatic trends associated with construction, operation, decommissioning and reclamation of the mine will be identified and mitigated; with consideration of year to year variability within the aquatic ecosystems in Gold and Blairmore Creek.

Response:

Benga has taken into consideration the proposed Environmental Effects Monitoring (EEM) framework that ECCC are proposing as part of the Coal Mining Effluent Regulations, when developing the AMP.

The proposed EEM is proposing annual reports on effluent characterization, water quality, and sublethal toxicity, with biological related reports (*e.g.,* fish population studies, aquatic effects, *etc.*) every three years. Their rationale for these timelines is based on the ability to provide annual trends for parameters that require actions on a shorter time frame, *versus* other parameters that will take multiple seasons to determine a defensible trend. Benga proposes to adopt this reporting schedule, which will also provide consistency with the EEM and the proposed Coal Mining Effluent Regulations when they come into force; the anticipated date is 2022.

Information Request 6.24

Information Request Package #5 from the Joint Review Panel to Benga, Information Request 5.7. (CIAR #215).

Tenth Addendum to the Environmental Impact Assessment. Response to Information Request 5.7. (CIAR #251).

Tenth Addendum to the Environmental Impact Assessment. Appendix 5.4-1. (CIAR #251).

In IR 5.7 (CIAR #215), the Panel requested that Benga provide calculated probabilities for Westslope Cutthroat Trout egg selenium concentrations within the predicted range of concentrations, and provide a justification for why an uncertainty factor was not applied to Benga's proposed site-specific water selenium guideline. Benga responded by outlining the conservative assumptions included within its bioaccumulation model, and stated that application of an uncertainty factor would be an arbitrary policy decision not based in science (CIAR #251).

The Panel understands that water concentrations of selenium do not directly reflect risks of selenium ecotoxicity to fish and that tissue concentrations (egg/ovary concentrations) are more directly correlated with risk. The Panel also understands that selenium bioaccumulation and subsequent concentrations in egg/ovary tissue is highly site-specific and species-specific, and depends on such factors as the presence of lotic/lentic water bodies. Baseline information regarding selenium concentrations in water, sediment, and aquatic biota, particularly Westslope Cutthroat Trout, in Blairmore and Gold creeks are very limited. As previously noted in the rationale for IR 5.7 (CIAR #215), uncertainty factors (UF) are applied when site-specific data are limited and when uncertainties in modeled data exist, which is the case for this assessment. Examples of

the application of an uncertainty factor are the Alberta selenium egg/ovary tissue guidelines (11 µg/g dw with an UF of 2 applied) and Canadian Council for Ministers of the Environment recommendations of applying safety factors when deriving guideline values. Furthermore, the presence of Westslope Cutthroat Trout, a species at risk, also supports the application of an uncertainty factor.

Collection of site-specific data to support and refine conceptual and lab-based models for selenium bioaccumulation may serve to partially reduce existing uncertainty. The draft Fisheries and Aquatic Monitoring Plan (Appendix 5.4-1) outlines how some of this information would be collected, although Benga acknowledged that challenges exist in collecting substantial data in support of modeled predictions, such as fish tissue selenium concentrations. Confirmation of effects and mitigation through the plan would require substantial time to implement, and in the interim the project could pose the risk of permanent, irreversible harm to biota in receiving streams.

Given the above uncertainties, the Panel requires a more fulsome understanding of the potential risks associated with a site-specific objective for selenium. Specifically, the Panel would like to understand the spatial and temporal extent within the LSA where the established 2 µg/L water quality guideline for selenium would be exceeded, should the Project proceed as designed.

a) Provide detailed information on the locations within the aquatics Local Study Area predicted to exceed a water selenium concentration of 2 µg/L under all phases of the Project as currently proposed. Use the results of the modeling of mean monthly selenium concentrations provided in IR 6.26, as appropriate.

Response:

Surface water quality models were updated (from EIA submission, CIAR #42) to include hydrological and climate change inputs for the local study area (LSA) including Blairmore Creek and Gold Creek in order to address the JRP IR-6.25. In order to mitigate impacts on the flow rates in Blairmore Creek, the effluent from the water treatment ponds is directed to three model nodes in Blairmore Creek (BC-07, BL-02, and BC-03, see below). The attempt to return the contact water to the nodes generally from where it was collected is intended to minimize changes in flow conditions. However, no effluent is being directed to Gold Creek.

Water quality prediction nodes in the LSA were strategically selected to best support project effects on the receiving environment (*e.g.,* downstream of treatment zone/sedimentation ponds) throughout the project's life cycle. Water quality predictions were made in the following nodes:

On Blairmore Creek:

- lower Blairmore Creek at its mouth (BC-01);
- downstream of Saturated Treatment Zone (BC-03);
- downstream of Raw Water Pond (BL-02);
- downstream of West Sedimentation Pond (BC-07); and

- upstream control node (BL-03).

On Gold Creek:

- lower Gold Creek at its mouth (GC-01);
- downstream of Southeast Surge Pond (GC-02);
- downstream of East Sedimentation Pond (GC-04);
- downstream of Northeast Sedimentation Pond (GC-10); and
- upstream control node (GC-13).

Predicted selenium concentrations are presented in the response to JRP IR-6.25, Figure 6.25-4 and Figure 6.25-5 for Blairmore Creek and Gold Creek nodes, respectively. Concentrations are presented for all phases of mine cycle and compared against the generic AB/BC selenium guideline of 2 µg/L for the protection of aquatic life, as well as the proposed sulphate-based site-specific selenium objective, given Benga has proposed various mitigation measures to comply with this objective.

Screening Against the AB/BC Guideline:

- all nodes in Blairmore Creek except upstream control node (BL-03) are predicted to exceed the Alberta selenium guideline during the second half of operation and entire closure and post-closure phases (Figure 6.25-4; Table 6.24-1); and
- predicted selenium concentrations at all nodes in Gold Creek are below the Alberta selenium guideline of 2 µg/L during all mine phases during closure and post-closure phases of the mine (Figure 6.25-5; Table 6.24-1).

Screening Against the Site-specific Objective:

- Predicted selenium concentrations at all nodes in Blairmore Creek are below the proposed site-specific selenium objective, and below the BC and AB guideline of 2 µg/L during all mine phases (Figures 6.25-4 and 6.25-5, respectively; Table 6.24-1).

Table 6.24-1 Monthly exceedances of Alberta water quality guideline and the proposed site-specific objective in Blairmore Creek and Gold Creek over mine phases

Nodes	Pre-mining		Operation		Closure		Post-closure	
	Guideline	Site-Specific	Guideline	Site-Specific	Guideline	Site-Specific	Guideline	Site-Specific
Blairmore Creek								
BC-01	-	-	√	-	√	-	√	-
BC-03	-	-	√	-	√	-	√	-
BL-02	-	-	√	-	√	-	√	-

Table 6.24-1 Monthly exceedances of Alberta water quality guideline and the proposed site-specific objective in Blairmore Creek and Gold Creek over mine phases

Nodes	Pre-mining		Operation		Closure		Post-closure	
BC-07	-	-	√	-	√	-	√	-
BL-03	-	-	-	-	-	-	-	-
Gold Creek								
GC-01	-	-	-	-	-	-	-	-
GC-02	-	-	-	-	√	-	√	-
GC-04	-	-	-	-	-	-	-	-
GC-10	-	-	-	-	-	-	-	-
GC-13	-	-	-	-	-	-	-	-

Notes: √ = exceedance; - = no exceedance

b) Provide details on when locations identified in part a) would be expected to decrease to below a selenium concentration of 2 µg/L assuming mining construction, operation and closure and associated selenium management and treatment proceeds as currently proposed.

Response:

All nodes in Gold Creek remain below a selenium concentration of 2 µg/L in all mine phases due to proposed mitigation measures.

Predicted selenium concentrations at all nodes in Blairmore Creek (except the upstream node) exceed this threshold but remain below the proposed site-specific selenium objective.

In order to provide conservative estimates of selenium concentrations in the mine-affected water, the water balance model has not taken into account the beneficial effects of reclamation of the ex-pit waste rock areas. In addition, the design decision to locate waste rock disposal areas at higher elevations to avoid excessive percolation of water through the dumps is novel and the performance of these waste rock disposal sites, post reclamation had not been fully proven. Without additional information based on actual performance of the waste rock disposal areas post reclamation, the water balance model cannot accurately predict when the locations identified in part a) would be expected to decrease below 2 µg/L.

Benga has proposed to begin reclamation of the South Rock Dump as early as year 7 of operations. Therefore, it is likely that the data required to predict the effects of reclamation on future selenium concentrations will be available by year 10 or 12 of operations.

Information Request 6.25

Grassy Mountain Coal Project - Updated Environmental Impact Assessment. Appendix 10b – Water and Load Balance Model. (CIAR #42).

Comments from Tsuut'ina Nation. (CIAR #220).

Tenth Addendum to the Environmental Impact Statement. Response to Information Request 5.8. (CIAR #251).

Seasonal variation of contaminant concentrations was documented in the surface water quality baseline study; however, predicted contaminant concentrations in the receiving environment do not include seasonal variation (Appendix 10b, CIAR#42). A comprehensive effects assessment requires an understanding of seasonal variation of contaminant concentrations because some life stages (e.g. fish embryos) are more sensitive to contaminants (e.g. selenium) than others. If the presence of sensitive life stages corresponds with seasonally-high concentrations, the potential for adverse effects increases. Benga stated in its response to IR 5.8 (CIAR #251) that selenium concentrations in the receiving environment will vary with specific periods of its operation, peaking at closure. Model results presented in (Appendix 10b, CIAR #42) show that sulphate, selenium, cobalt and zinc, then remain elevated in Blairmore Creek and Gold Creek for the remaining modeled time period (to the year 2100).

Given that Benga has stated that post-mitigation mean annual concentrations of some contaminants in the receiving environment will exceed existing water quality guidelines and that in some cases exceedances will increase and then persist with time, mean annual estimates are an insufficient basis upon which to determine the potential adverse effects on aquatic life. It is particularly important that the potential for adverse effects to Westslope Cutthroat Trout, which is listed as 'Threatened' in Alberta under the *Species at Risk Act*, is estimated with confidence, using a good understanding of seasonal variability. In addition, the combined effects of the elevated contaminant concentrations (including any ameliorating effects of parameters such as sulphate on toxicity of selenium) may vary with time, resulting in variable likelihood of adverse effects.

a) Provide modeled estimates of mean monthly concentrations of contaminants of concern in Blairmore Creek and Gold Creek using available hydrographs and reasonable assumptions given the hydrologic period-of-record and the proximity of gauging stations. The use of synthetic hydrographs may be required. Conduct the modeling for the mine operation, at closure and post-closure. The post-closure period should include effects of climate change on variability of seasonal water flows.

Response:

Figure 6.25-1 and Figure 6.25-2 show updated hydrology for Gold Creek and Blairmore Creek on a mean monthly basis with climate change incorporated in the updated hydrological inputs.

Modelled estimates of mean monthly concentrations of contaminants of concern in Blairmore Creek and Gold Creek for this flow scenario are graphed in Appendix 6.25-1.

Figure 6.25-3 shows model results for total selenium concentration in Blairmore Creek under mean monthly flow scenarios over the 20-year time span during operations to illustrate the seasonal variation while Figure 6.25-4 and Figure 6.25-5 show the same results data for Blairmore and Gold creeks respectively but for an 80-year time span.

As indicated by the graphs, selenium concentrations in the creeks, modelled on a mean monthly basis, are significantly more variable than those that had been previously calculated based on annual average flows. Peak selenium levels in Blairmore Creek under this flow scenario are approximately 9 µg/L, which is slightly higher than the annual average calculation of 7 µg/L but still lower than the proposed Project-specific guideline for selenium.

b) Provide a sensitivity analysis of the effects of varying model inputs of the following five parameters:

i. Percentage removal in the saturated backfill zone (using a reasonable range of percent removal rates based upon available information);

Response:

Figure 6.25-6 shows model results for total selenium concentrations in Blairmore Creek assuming 95% removal of selenium in the saturated backfill zones. Water quality in Gold Creek is not affected by the assumed attenuation in the saturated backfill zones because treated effluent is only directed to Blairmore Creek. Figure 6.25-7 shows model results for a scenario that assumes 90% attenuation.

Obviously, under both scenarios, 90% and 95% removal of selenium, the resulting concentrations of selenium in Blairmore Creek are unacceptable at 70 µg/L and 35 µg/L, respectively. However, it is important to note that selenium levels are not forecast to exceed 10 µg/L, even in the 90% case, until 10 years after the start of operations. This is because, the rate of selenium leaching will be proportional to the amount of rock stored in the rock dump, which will increase through the years with mine activity. In addition, there is a delay between placement of rock in the waste rock disposal and presence of selenium in the affected water due to the time required for the rock to be wetted.

During these 10 years after mine start-up, Benga will be monitoring the selenium removal rates in the SBZ as well as selenium concentrations in the surge ponds and raw water pond. If there is an indication that removal rates will not achieve the targeted 99% or that selenium concentrations in untreated water are higher than expected, Benga will have several years to resolve the situation through operational adjustments to the SBZ or to implement another contingency plan to prevent unacceptably high selenium levels in Blairmore Creek.

Note that the removal rate of selenium in the SBZ does not affect any of the other COPCs studied for the Project.

ii. Extreme climate events (select specific events which would result in substantially elevated concentrations of contaminants of concern in surface water (e.g. severe drought over at least one season);

The 40-year synthetic flow record used for the hydrological input to the model (as shown in Figures 6.25-1 and 6.25-2) represents a wide range of climatic conditions and as such provides a good indication of how climatic conditions could affect water quality in Blairmore Creek and Gold Creek. As such, the peak selenium levels in the range of 9 µg/L shown in Figure 6.25-4 for Blairmore Creek occur during a multi-year dry period. Conversely, selenium ranges both prior to and after this dry period exhibit selenium concentrations closer to 6 µg/L.

iii. Contact water capture and attenuation of the contaminants of potential concern (COPCs) which are predicted to exceed water quality guidelines; i.e., selenium, nitrate, sulphate, cobalt, zinc, and any other COPCs with mean monthly concentrations predicted to exceed guidelines (using a reasonable range of variability of capture and attenuation as influenced by factors such as seasonal flows);

Figure 6.25-8 and Figure 6.25-9 show model results of total selenium concentrations in Blairmore Creek for scenarios that assume 90% and 80% capture of all contact water. The base case scenario for the EA model assumed 95% capture. A reduction in capture efficiency does not significantly affect concentrations in Gold Creek. Only nitrate, nitrite and selenium are assumed to be removed in the saturated zones. Loadings of remaining parameters are assumed to pass though the saturated zones unaffected. This means that the same total load of those parameters ends up reporting to the creeks whether it flows directly (*i.e.,* uncaptured) or it is routed *via* the saturated zones.

As indicated in part bi) of this response, it is important to note that even with the lower capture rates, water quality in Blairmore Creek does not exceed 10 µg/L (lower than the proposed site-specific water quality guideline for selenium) for the first decade of operation. Benga will be monitoring water quality in Blairmore Creek and will be able to detect any un-foreseen changes in water quality early and have several years to react with additional mitigative measures.

iv. Acid generating pit walls (using the range of acid generating potential as determined during Benga's baseline geological and geochemical studies); and

Response:

Results for a model scenario that assumes 100% acidic pit walls are included in Appendix 6.25-2. No additional mitigation such as post-treatment of SBZ discharge was implemented. Modelled concentrations of dissolved metals generally increased but the increases were typically marginal as illustrated in Figure 6.25-10 and Figure 6.25-11, which show total

zinc concentration in Blairmore Creek for the 100% acidic pit walls scenario and the non-acidic pit wall scenario.

v. Varying the volumes of water which may have to be recycled back to the saturated backfill zone if it does not meet discharge criteria.

Response:

This IR was addressed as follows: for each year in the model simulation, one month was selected randomly as the month in which all effluent from the saturated zones would be recycled back for additional treatment. The volume of water that would otherwise have been discharged in that month was discharged over the following 3 months (along with the regular discharges for those following 3 months).

Figure 6.25-12 shows results for total selenium concentrations in Blairmore Creek as a result of the irregular discharge pattern. Results for other parameters (Co, SO_4 and Zn) are included in Appendix 6.25-3. The peak selenium concentration under this scenario was slightly higher than the base case. However, it should be noted that the peak selenium concentration in Blairmore Creek occurs during a multi-year dry period during which it is likely that additional water management steps could be taken to discharge the extra water over a longer timeframe than 4 months to further mitigate the upset scenario. In any case, the peak selenium level under this scenario remains below the proposed site-specific water quality guideline for selenium.

c) Re-assess residual adverse effects on surface water quality using the mean monthly model predictions, including results of sensitivity analysis, and re-assess the likelihood of significant residual adverse effects on surface water quality by comparing results to Environmental Quality Guidelines for Alberta Surface Waters (2018)[6]. If Alberta guidelines do not exist for a particular COPC, compare results to the Canadian Council of Ministers of the Environment (CCME) guidelines for the protection of aquatic life[7]. Monthly predictions must also be used in the re-assessment of risk to aquatic life, as requested in IR 6.24.

Response:

The residual adverse effects on surface water quality using the mean monthly model predictions are not materially different from those discussed in the EIA's water quality assessment (EIA 2016, Consultant Report #4, CIAR#42). Water quality issues due to Project activities will be addressed by applying appropriate mitigation measures including treatment of nitrate and selenium in an SBZ plus treatment of other metals in a Water Treatment Plant (WTP) if

[6] Available online: Environmental Quality Guidelines for Alberta Surface Waters. https://open.alberta.ca/dataset/5298aadb-f5cc-4160-8620-ad139bb985d8/resource/38ed9bb1-233f-4e28-b344-808670b20dae/download/environmentalqualitysurfacewaters-mar28-2018.pdf.
[7] Available online: Canadian Council of Ministers of the Environment (CCME) Guidelines for the Protection of Aquatic Life. http://st-ts.ccme.ca/en/index.html.

necessary. After mitigation, effects of these water quality issues on receiving environment are assessed as not significant in both Gold Creek and Blairmore Creek.

Sulphate concentrations in Blairmore Creek are predicted to exceed the hardness-dependent sulphate guideline value of 429 mg/L for a maximum hardness level of 250 mg/L, as well as a published no-effect-threshold of 725 mg/L during late mine life and persisting long term. Therefore, use of a site-specific sulphate objective based on site water hardness is recommended.

Selenium concentrations in Blairmore Creek are predicted to exceed the Alberta Guideline of 2 µg/l about 12 years after start of construction (year 10 of operations). However, the selenium concentrations are below the proposed site-specific water quality objective for selenium in Appendix A1, CR#5 of the EA (CIAR#42) for all years.

Both selenium and sulphate are below the Alberta guidelines in Gold Creek since contact water, processed through the SBZ and, if necessary, a WTP, is not discharged to Gold Creek. Selenium levels are slightly lower in this analysis than were reported in the EA because the EPL is no longer assumed to discharge to Gold Creek.

All COPCs with the exception of selenium are unaffected by the sensitivity analyses related to capture percentage or selenium attenuation in the SBZ. Furthermore, Gold Creek is not affected by these sensitivities since contact water not captured would primarily continue to report to Blairmore Creek.

In Blairmore Creek, the concentration of selenium would rise above the proposed site-specific water quality objective for selenium around end of mining for capture rate sensitivities and for selenium attenuation of 95%. If selenium attenuation is only 90%, the site-specific objective would be surpassed in year 10. As indicated above, Benga will monitor selenium concentrations in the creeks as well as the SBZ discharge and in upstream ponds to have an early indication if there is an issue with capture percentage or attenuation rate in the SBZ. If early indications point to a long-term selenium concentration of concern, Benga will implement its adaptive management plan which may include additional treatment for selenium in a plant or through a GBR in order to achieve the objective.

Sensitivities related to acidic pit walls resulted in modelled concentrations of dissolved metals generally increased but the increases were typically marginal and not significant. Similarly, the sensitivity analysis related to irregular operation of the SBZ did not reveal significantly different results from the base case.

SURFACE WATER QUALITY

Information Request 6.26

Environmental Impact Statement Guidelines. (CIAR #11).

Grassy Mountain Coal Project - Updated Environmental Impact Assessment. Appendix 10b – Water and Load Balance Model. (CIAR #42).

Comments from Ron Fraser. (CIAR #249).

Tenth Addendum to the Environmental Impact Assessment. Response to Information Request 5.29. (CIAR #251).

Comments from Timberwolf Wilderness Society. (CIAR #281).

Comments from the Government of Canada - Environment and Climate Change Canada submission. (CIAR #283).

When asked to characterize the effects on all potentially affected aquatic and wildlife receptors in the Oldman Reservoir, Benga estimated, in the response to IR 5.29 (CIAR #251), that the selenium concentration in the Oldman Reservoir would be 0.6 µg/L based on contributing watershed areas and current selenium concentrations. Benga stated that the predicted selenium concentration in the Oldman Reservoir is well below the selenium guideline even when using conservative assumptions, and that there were negligible risks in the reservoir due to the predictions for Blairmore Creek.

However, in the Environment and Climate Change Canada (ECCC) evaluation of IR 5.9 d) (CIAR #283), ECCC indicated that the calculation of selenium accumulation provided by Benga is erroneous, and that it is inadequate to simply multiply the concentration of selenium in the river by loading volume to estimate selenium loading in the reservoir.

Timberwolf Wilderness Society (CIAR #281) noted that the selenium model for the proposed Project could be validated against the observed selenium data for the Fording, Elk, and Kootenay rivers in British Columbia, and Lake Koocanusa.

a) Using publicly available information, provide as much of the following baseline information for the Oldman Reservoir as possible in order to provide context for the assessment of the risk of selenium loadings:

Response:

The following information has been compiled from publicly available information to provide context for the assessment of the risk of selenium loading in the Oldman Reservoir. Note that subcomponents ii and iv have been combined as one response.

i. a characterization of surface water quality, including water temperature profiles (in order to establish the degree and extent of any thermal stratification), turbidity, hardness, nutrient concentrations, major ion concentrations, and

concentrations of contaminants of potential concern (COPCs) including selenium;

Response:

An extensive online literature search was conducted to summarize water quality data and information for the Oldman Reservoir. Information sources were mainly explored to characterize baseline surface water quality for the Reservoir (sources are noted in the Reference section).

Alberta Government's water quality data included open-water season (May to October) consecutive yearly data from 1991 to 1996 and then 2005 and 2015. Water quality variables included conventional physicochemical variables, major nutrients, and major ions. Temperature and dissolved oxygen profiles, as well metals data, were obtained from Mitchell (2001) that included data from 1991 to 1996. It should be noted that sampling locations were not consistent over the years and therefore results presented based on these data are regarded as general/overall trends of the Oldman Reservoir.

Although there is limited recent water quality data for the Oldman Reservoir, available data indicate that the Oldman Reservoir is currently oligotrophic (low nutrients, chl-a), clear (low TSS, DOC), well-oxygenated, weakly stratified, with an alkaline pH range and high hardness and alkalinity. Moderate concentrations of major ions are dominated by calcium, bicarbonate, and sulphate. Concentrations of most metals (including selenium and mercury) measured in years following reservoir establishment were generally low and below water quality guidelines for the protection of aquatic life with few exceptions (*e.g.,* total aluminum).

Trends for the major water quality variables in the Oldman Reservoir are summarized below:

Temperature and Dissolved Oxygen Profiles

Temperature and dissolved oxygen profiles for the Oldman Reservoir during open-water season in 1992 to 1996 are shown in Figures 6.26-1A and 6.26-1B (copied from Mitchell 2001). The Oldman Reservoir demonstrated weak or temporary thermal stratification over the summer due to disruption of the thermocline by high volume of inflow water and removal of cool water from the hypolimnion *via* the outflow. Wind events also likely contribute to water mixing observed to considerable depths. Outflow temperatures of the reservoir ranged from 5°C (spring) to 15°C (fall) during open-water seasons from 1994 to 1996. The lowest temperature in the bottom and the outflow would likely be a few degrees above freezing even during the coldest part of winter. There was no statistical relationship between water level and outflow temperature.

Dissolved oxygen (DO) concentrations remained fairly uniform from the surface to the bottom of the reservoir, and were generally above 70% saturation, even at the bottom. Lowest recorded DO concentrations were 0.10 to 0.17 mg/L, within the 4 m of the bottom on June 8, 1995, just after river inflow to the reservoir peaked during the flood event. However, at 6 m above the

bottom at that time, the DO concentration was high (9.2 mg/L). Although there was no temperature gradient at these depths, it is likely that cool, silty river water moved along the bottom, and organic matter in the water created an oxygen demand. Dissolved oxygen was also low (3.34 mg/L) on September 13, 1994 at 62 m depth. For all years except 1995, the lowest concentrations at the bottom occurred in late August or early September when water temperatures were highest. DO concentrations at reservoir outflow were always above 8.9 mg/L.

Conventional Physicochemical Variables

Temporal trends of major physicochemical variables are presented in Figures 6.26-2A and 6.26-2B. Levels of lab-measured specific conductivity were stable and moderate in range throughout the monitoring years with an average value of 310 µS/cm in the most recent recorded year (2015). Lab-measured pH was always in alkaline range with a value of 8.0 in 2015. Total hardness and alkalinity levels (on average, 160 and 140 mg/L in 2015, respectively) indicate Oldman Reservoir has relatively hard water with high buffering capacity and low acid sensitivity. Levels of non-filterable residue (TSS) were higher and unstable during initial years but became stable and low in 2015 (on average 2 mg/L). Secchi depth, indicating the water transparency, reflected a similar trend to TSS, with an average value of 2 m. Concentrations of dissolved organic carbon (DOC), indicative of water colour, decreased over the years and remained very low in 2015 (2 mg/L).

Major Ions

Temporal trends of major ions are presented in Figures 6.26-3A, 6.26-3B, and 6.26-3C. Concentrations of filterable residue (TDS) were stable and moderate in range across monitoring years, with an average value of 170 mg/L in 2015. Calcium was the dominant cation followed by magnesium, sodium, and potassium. Bicarbonate and sulphate were the dominant anions. Consistent with TDS, concentrations of all major anions and cations were stable throughout the monitoring years.

Major Nutrients, Chlorophyll *a*, and Trophic State

Temporal trends of major nutrients in the Oldman Reservoir are presented in Figure 6.26-3D. Total phosphorus (TP) concentrations were highly variable in Oldman Reservoir during 1991 to 1996, covering the range of aquatic productivity classifications from oligotrophic (<0.01 mg/L TP) to mesotrophic (<0.035 mg/L TP) to eutrophic (>0.035 mg/L TP). However, most recent available data (2005 and 2015) show that TP concentrations declined and stabilized over time to oligotrophic levels (average TP concentration 0.007 mg/L). Total dissolved phosphorus (representing largely bioavailable phosphorus) comprised 43% of TP on average. Total nitrogen (TN) concentrations also were highly variable in initial years but had stabilized at low levels by 2005 (average TN 0.24 mg/L) and 2015 (average TN 0.31 mg/L). Concentrations of individual inorganic nitrogen species (*i.e.,* total ammonia, nitrate, and nitrite) often were below analytical detection limits. Chlorophyll *a* concentrations (indicative of algal biomass)

demonstrated similar trends to nutrients, also reflecting oligotrophic status in recent data (*i.e.,* <2.5 µg/L chlorophyll *a*).

Metals

Average concentrations of total metals in the water column of the Oldman Reservoir from 1991 to 1996 are presented in Table 6.26-1, along with exceedances of relevant water quality guidelines for the protection of aquatic life at that time. More recent metals data could not be found. Concentrations of most metals including arsenic, copper, iron, mercury, molybdenum, selenium, and nickel were below the guidelines. Only total aluminum concentrations exceeded their guideline in about half of samples analyzed, only in 1994 (Alberta no longer has a total aluminum guideline, having replaced it with a guideline for dissolved aluminum). Other metals also sporadically exceeded guidelines (*e.g.,* iron, lead, copper), at concentrations near guideline values. Concentrations of most metals without guidelines were low or near detection limits. Selenium concentrations were at or below the analytical detection limit in all samples.

Table 6.26-1 Mean Concentrations of Metals (µg/L) in the Water Column of Oldman Reservoir, 1991 to 1996 (from Mitchell 2001)

Variable	Mean Value	Range	Guideline Value	% Compliance	Years Sampled	Number of Samples
Aluminum, T	123	5 – 400	100[a]	50%	1994	12
Arsenic, T	0.4	0.1 – 1.1	5[a]	100%	1994	12
Barium, T	107	90 – 130	None	N/A	1991 – 1994	46
Beryllium, T	<1	<1 – 2	None	N/A	1994	12
Cadmium, T	<1	<0.2 – <1	0.047[a]	96%	1991 – 1994	46
Chromium, T	6	1 – 16	N/A	N/A	1994	12
Cobalt, T	<1	<1 – 1.2	None	N/A	1994	12
Copper, T/E	1	0.5 – 6	7[b]	100%	1991 – 1994	44
Iron, T/E	80	20 – 300	300[a]	100%	1991 – 1994	46
Iron, D	8	5 – 20	None	N/A	1992 – 1994	13
Lead, T/E	1	0.5 – 5	4[a]	95%	1991 – 1994	44
Manganese, T/E	6	0.5 – 26	None	N/A	1991 – 1994	46
Manganese, D	2	0.5 – 6	None	N/A	1992 – 1994	16
Mercury, T	<0.05	<0.04 – <0.05	0.1[a]	100%	1991 – 1995	56
Mercury, low-level, T	0.0016	<0.00016 – <0.0034	0.005[b]	100%	1996	7
Molybdenum, T	<3	1.5 – 5	73[a]	100%	1994	12
Nickel, T	1	0.5 – 3	110[a]	100%	1994	10
Selenium, T	<0.2	<0.2 – 0.2	1[a]	100%	1994	12
Vanadium, T	<2	<2 – 3	None	N/A	1994	12
Zinc, T/E	6	0.5 – 51	30[a]	95%	1991 – 1994	40

a CEQG guideline for the protection of aquatic life

b Alberta guideline

ii. the presence and relative abundance of Westslope Cutthroat Trout as well as all available information on other fish species in the reservoir;

iii. a characterization of other aquatic species that could potentially be affected by bioaccumulation of selenium, including algae, zooplankton and benthic invertebrates that may use the Oldman Reservoir; and

iv. a list of any species listed as "at risk", "may be at risk", or "sensitive" in the General Status of Alberta Wild Species, and/or listed in Schedule 1 of the federal *Species at Risk Act*, and/or listed as "at risk" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) that are known to be present in the Oldman Reservoir.

Response:

Based on thorough search and review of publicly available sources, fisheries-specific studies/information for the Reservoir following establishment of the Oldman Reservoir is sparse. Of the limited reports available, fish species documented in the reservoir include: Bull Trout, Westslope Cutthroat Trout (WSCT), Rainbow Trout, Mountain Whitefish, Lake Whitefish, Burbot, Brown Trout, Northern Pike, Longnose Dace, White Sucker, Longnose Sucker and Brook Stickleback (ASRD 2012, Campen 2016, Lima *et al*. 2016, Moore *et al.* 1993, Warnock – as cited in Hurkett 2009).

Bull trout (Saskatchewan – Nelson Rivers populations) are present in the Oldman Reservoir and classified as "Threatened" under Alberta's *Wildlife Act* and Schedule 1 of the federal *Species at Risk Act*. The stock(s) inhabiting the Oldman River system have declined since the completion of the Oldman River Dam in 1991. Bull trout were abundant in the reservoir in 1991 (Moore *et al.* 1993), but severely declined five years post-completion (Lima *et al*. 2016). Even with the noticeable Bull Trout decline in the reservoir, a small population of adfluvial and resident Bull Trout (population estimate of 250 to 1,000 individuals) appear to persist in the Reservoir (ASRD 2012, Warnock in Hurkett 2009).

Westslope Cutthroat Trout are listed as "Threatened" under the *Species at Risk Act* and were abundant in the area prior to Oldman River Dam construction. Within five years of the Oldman River Dam Project, WSCT nearly disappeared from the reservoir area (Lima *et al*. 1993). Although the governments of Alberta (Alberta Westslope Cutthroat Trout Recovery Team 2013) and Canada (DFO 2014, DFO 2019) have developed a recovery plan and strategy for WSCT, Oldman Reservoir was not identified as critical habitat. With the abundance of rainbow trout in the Oldman Reservoir (Moore *et al*. 1993), it is likely that there are very few purestrain WSCT in this area, given the high occurrence of hybridization between rainbow trout and WSCT.

Several other fish species are documented within the reservoir; however, there are no records or studies that specifically discuss their abundance and/or status. Given the Oldman Reservoir is a lentic system, species with generalist traits for reproductive requirements (*i.e.,* tolerant to a wide

range of flows, open substratum, non-migratory) increased in relative abundance following completion of the Oldman Dam (Lima *at al.* 2016), including White Sucker, Longnose Sucker, Longnose Dace, Brook Stickleback and Northern Pike. Although Brown Trout, Mountain Whitefish and Lake Whitefish are present within the area (Moore *et al*. 1993, Campen 2016), no records of species/population abundance could be found in the public record.

The presence/characterization of lower trophic communities inhabiting the Oldman Reservoir appears to be limited to a graduate (MSc) thesis recently completed (Campen 2016) and a more dated limnological study (Mitchell 2001). Oldman Reservoir is an oligotrophic lake with a relatively high flushing rate and short residency time of water (0.17 years) due to the abundance of low nutrient rivers feeding into the reservoir (Campen 2016, Mitchell 2001). Short water residence time can have a washout effect on nutrients released into the water column and limit deposition of fine sediments, potentially affecting zooplankton communities and nutrient loading within the reservoir (Campen 2016). Macrophytes were not documented in Oldman Reservoir (Campen 2016). Additional information discussing the presence/absence of periphytic algae within the reservoir was not found within the public record. Given the oligotrophic status of the waterbody, it is expected that abundance of any periphytic algae is low.

Nine zooplankton taxa were collected in Oldman Reservoir by Campen including: Chydoridae, Cyclopidae, Daphnidae, Diaptomidae, Nauplii, and Rotifers, Sididae, Bosminidae, Centropagidae (2016). Of all the reservoirs sampled by Campen (2016), Oldman Reservoir consistently had the lowest zooplankton biomass 0.03 g/m^3.

No studies or reports found in the public domain presented information characterizing benthic invertebrate communities within the Oldman Reservoir.

b) Calculate monthly and annual selenium loadings to Blairmore Creek and Gold Creek, and subsequently to the Crowsnest River and the Oldman Reservoir, over the life of the mine and into the post closure period up to the year 2100. Benga may choose to use the Water and Load Balance Model (referenced in Appendix 10b of CIAR #42) with appropriate modifications which allow credible and reliable estimates of loading to the Oldman Reservoir. Hydrographs of seasonal surface water flow over the entire available period of record should be the basis for the loading calculations. Mean annual as well as mean monthly loading estimates should be produced and subsequently used to calculate mean annual as well as mean monthly selenium concentrations in the Oldman Reservoir. The predicted range of post-mitigation selenium concentrations at the most downstream locations in Blairmore Creek and Gold Creek over the life of mine as well as at closure and in the post-closure period should be used as input to the modeled loadings to the Reservoir. It is insufficient to produce one mean annual estimate of selenium loadings and concentrations in the Oldman Reservoir. Include details regarding how the model was validated including the use of site- specific relationships between selenium concentrations and loadings

for other nearby aquatic ecosystems (e.g. Fording, Elk and Kootenay rivers and Lake Koocanusa).

Response:

Water Quantity

The following section outlines the approach used to generate a high-quality, daily time-series of estimated inflows to the Oldman Reservoir, based on gauged and continuous streamflow records covering a 50-year period from 1966-2015 taken to represent the project baseline period for this particular analysis. The resulting monthly and annual flows to the reservoir are used as input to the Grassy Mountain Water and Load Balance Model, together with available selenium concentrations to estimate loading of selenium in the inflows to and Oldman Reservoir itself. A final section outlines the potential changes in selenium loadings which may occur through the life of Grassy Mountain Mine until 2100.

The Oldman Reservoir is an on-stream water body in the Oldman River Basin, with completion of the dam and filling of the reservoir occurring in 1991 to 1992. Reservoir inflows are heavily dominated by three separate river systems, including Oldman River from the north-west (the largest sub-drainage), Crowsnest River from the west (the smallest sub-drainage), and Castle River from the south-west.

All three river systems were gauged by Water Survey of Canada, for a two-decade period from ~1909 onwards, at gauge locations very close to (or inside) the current reservoir area, including 05AA001, 05AA002 and 05AA003 on the Oldman, Crowsnest and Castle Rivers respectively: total drainage area 3726 km^2. Gauging ceased during the 1930s and 1940s, but restarted in the 1950s at gauges located further upstream, including 05AA022, 05AA008 and 05AA023 on the Oldman, Crowsnest and Castle Rivers respectively. The first two of these continue to gauge uninterrupted through to present day, but in 2009 the Oldman River gauge was moved further downstream again (gauge 05AA035). Prior to 1965, gauging was only seasonal on the Crowsnest River at 05AA008, and during 2016-2017 gauging temporarily ceased at 05AA035, but during the 50-year period from 1966 to 2015 there were no missing data from any of the three gauges, and this length of dataset is ideal for characterizing flows under a huge range of conditions.

In support of a Limnological Assessment of the Oldman Reservoir (Mitchell 2001), inflows to the reservoir were estimated for the period from 1983 to 1998, and an annual water balance for the reservoir was calculated from 1991 to 1998 once damming had occurred. In this analysis, the three river inflows were characterized using the upstream gauges 05AA022, 05AA008 and 05AA023 (total area 2670 km^2), which only represent ~70% of the downstream gauge area considered to be more representative of actual river inflows to the reservoir (for instance, the 05AA008 gauge, Crowsnest River at Frank, is ~30 km^2 upstream of the earlier gauge, 05AA002, and does not include the contributions from tributaries including Gold Creek). For annual water

balance calculations, the remaining flow contributions downstream of these gauges, plus much smaller basins which contribute directly to the reservoir (*e.g.,* Todd Creek, Tennesse Creek), were solved as a residual term in the water balance calculations.

For the current analysis, flow data were obtained from the same gauges used as by Mitchell (2001); however, all flows across the 1966-2015 period were pro-rated higher, specifically to the former downstream gauge locations which more accurately represent actual reservoir inflows. For instance, a gauged daily flow of 1 m^3/s (Crowsnest River at Frank) becomes 1.68 m^3/s at the former 05AA002 gauge close to the reservoir, when scaling by 1.68 (the ratio of drainage areas; 676 km^2 and 403 km^2). This assumes the flow contribution per unit area remain constant between the upper (gauged) and lower (prediction node) locations on each river.

Figure 6.26-4 presents the flow records for each river and gauge introduced above. Corresponding daily statistics indicating the unit area flow contributions to each gauge are also presented. Figure 6.26-5 presents the mean monthly and annual flows from each river into the reservoir, averaged over the 1965 to 2015 (Water Year) period hypothetically assuming the Reservoir existed across this entire period. Figure 6.26-6 presents the total annual flow contributions from each river to the reservoir. From this, the mean annual inflow sum to the reservoir (1,397 million m^3) may slightly underestimate all true reservoir inputs (*e.g.,* including reservoir-area precipitation inputs, and remaining tributary inflows such as Todd and Tennesse creeks), but the flow estimates are considered sufficient for the purposes of this particular analysis. This mean value is also identical to the to the corresponding estimate (1,397 million m^3) calculated by Mitchell (2001) for the much shorter 1991-1996 study period, despite minor differences in the approach and calculated inflow terms (*i.e.,* higher and more realistic estimates for the Crowsnest, Castle and Oldman Rivers in the current study, at the expense of an additional 'residual' term used by Mitchell 2001). On a mean annual basis, the relative flow contributions to the reservoir were calculated in the current study to be 17%, 45% and 37% for the Crowsnest, Castle and Oldman Rivers respectively.

The total reservoir volume will fluctuate annually depending on natural water inputs and the managed series of water releases at the dam; for the purposes of this analysis, the average volume of 380 million m^3 calculated by Mitchell (2001) is considered sufficient for the current analysis. This value incorporated annual water-balance estimates from 1993 to 1996 (once the reservoir had been filled), ranging from 363-396 million m^3 covering both wet and dry hydrologic years.

Water Quality

While AEP maintains a provincial network of water quality sampling in major rivers and lakes/reservoirs, monitoring locations do not extend upstream of the Oldman Reservoir on any of the major tributaries, and selenium is not one of the publicly available parameter datasets

(https://www.alberta.ca/surface-water-quality-data.aspx). Selenium concentrations were not presented in the Oldman River State of the Watershed Reports Summary (2010).

The limnological assessment of the Oldman River Reservoir tabulated a summary of the initial selenium data collected at the reservoir and from the inflows; this data is summarized in Table 6.26-2. All samples fell below water quality guidelines for the protection of freshwater aquatic life (Alberta Environment 1999).

Table 6.26-2 1994 Total Selenium Data (in µg/L, presented in Mitchell 2001)

Location	Mean Value	Range	Guideline Value	% Compliance	Years Sampled	Number of Samples
Oldman Reservoir	<0.2	<0.2-0.2	1[1]	100%	1994	12
Oldman, Castle and Crowsnest Rivers	<0.2	<0.2-0.4	1[1]	100%	1994	18

Note: 1- CEQG guideline for the protection of aquatic life

Other, historic data were collected along the length of Crowsnest River from 1974 to 2008, from the headwaters area (above Coleman) to just upstream of the reservoir near Lundbreck. Table 6.26-3 summarizes this data by season. During 2013 to 2014, in support of the baseline monitoring as part of the Grassy Mountain Project, additional samples were collected on the Crownsest River just upstream and downstream of Blairmore Creek (CRR-W01 and CRR-W02, respectively), and these data are also summarized in Table 6.26-3. In both historic periods, the highest total selenium values marginally exceeded the CEQG water quality guideline of 1 mg/L in samples obtained from April to August, and also during fall (September to October) in the 2013 to 2014 sampling program. Dissolved selenium also exceeded the guideline during 2013 to 2014, but data from 1974 to 2008 were very sparse. Note that in BC and as adopted in Alberta, a higher freshwater guideline of 0.002 mg/L is used, and only one dissolved selenium sample exceeded this value. In watercourses downstream of the Teck mines in BC, measured selenium concentrations at the Upper Fording River reached 113µg/L (0.113 mg/L) (Antweiler 2019).

Table 6.26-3 Historic Selenium Data on Crowsnest River (in mg/L)

Variables		Total Selenium		Dissolved Selenium	
Units		mg/L			
DL		0.0001			
CEQG Guideline		0.001			
BC and AB Guideline		0.002			
Period		1974-2008	2013-2014	1974-2008	2013-2014
Spring (April – May)	n	2	4	1	3
	med	0.00025	**0.00139**	0.0002	**0.00136**
	min	<0.0002	**0.0012**	0.0002	**0.00128**
	max	0.0003	**0.00156**	0.0002	**0.00163**
Summer (June- Aug)	n	8	6	1	7
	med	0.00055	**0.00163**	0.0003	**0.0017**
	min	0.0003	**0.00142**	0.0003	**0.00149**
	max	**0.0016**	**0.00194**	0.0003	**0.00209**
Fall (Sep-Oct)	n	8	2	3	3
	med	0.00035	**0.001515**	<0.0002	**0.00151**
	min	<0.0002	**0.00143**	<0.0002	**0.0012**
	max	**0.0018**	**0.0016**	0.0004	**0.00169**
Winter (Nov-Mar)	n	1	0	0	0
	med	<0.0002	-		-
	min	<0.0002	-		-
	max	<0.0002	-		-

Note: Bold values indicate water quality guideline exceedance of 0.001 mg/L. 2013-2014 samples obtained at locations. Different number of total and dissolved selenium results were obtained, resulting in the potential for higher dissolved values than total dissolved values depending on when samples of each were obtained.

The Project's Water and Load Balance model was used to estimate future monthly loadings to Blairmore Creek and Gold Creek. The load estimates were derived from the model scenario that was presented in the Environmental Impact Assessment (Appendix 10B, CIAR#42). Estimates of concentrations in the Crowsnest River were calculated by adding the flow and load from Blairmore Creek and Gold Creek to the 50-year synthetic flow series developed for the Crowsnest River. Seasonal background total selenium concentrations (spring, summer, fall and winter) in the Crowsnest River were assumed to be the median of measured concentrations

between May 2013 and January 2015. The concentration estimates assume that flow from Blairmore Creek, Gold Creek and the Crowsnest River are fully mixed.

The combined loadings from the Project site and background loadings were assumed to flow to the Oldman Reservoir and mix completely with the full volume in the reservoir. Inflows and outflows from the reservoir where estimated based on the synthetic hydrograph developed for a 50-year period the Oldman Reservoir catchment. The assumed volume of the reservoir (380 Mm^3) and background total selenium concentration were adopted from Mitchell (2001). Again, monthly concentrations were calculated using a simple mass balance approach where influent selenium loads were fully mixed with the reservoir volume. Loadings in the discharge from the reservoir was calculated as the concentration calculated in the previous monthly timestep multiplied by the flow out of the reservoir (which was assumed to be equal to the flow into the reservoir) (Figure 6.26-7).

c) Using the loading information and predicted selenium concentrations in water in the Oldman Reservoir over the life of mine and into the post closure period calculated in b), provide an assessment of bioaccumulation in algae, zooplankton, benthic invertebrates and fish, (including Westslope Cutthroat Trout). Provide evidence of the validity of the predicted bioaccumulation of selenium by comparing results with information from other relevant aquatic ecosystems, including the Fording and Elk Rivers as well as Lake Koocanusa.

Response:

The response to JRP IR-6.28 provides an update to the wildlife risk assessment, which included direct and indirect exposure from air and surface water (as pathways) from chemicals of potential concern (COPCs) to the downstream receiving aquatic environments associated with Blairmore Creek, Gold Creek, and the Oldman Reservoir. The assessment included the contribution from air deposition being added to provided surface water concentrations, and these concentrations which were then applied to multi-media exposure modelling.

Indirect exposure was predicted through the multimedia exposure model for non-volatile, persistent and bioaccumulative COPCs. Modelling formulas for COPC transport and bioaccumulation were based on US EPA (2005) guidance on human health risk assessment. Selenium is unlike other COPC that bioconcentrate, as enrichment and the most consequential step in trophic transfer happens at the base of the food web. A worked example for selenium is presented in JRP IR-6.28.

Selenium enrichment and transfer through the trophic food web considers available guidance from the province of British Columbia (2014) and published trophic transfer factors from the US EPA (2016) that evaluates lotic or lentic habitats separately. These guidance documents recognise selenium enrichment and subsequent incorporation into the aquatic food web, as well as the variability between and within species as important considerations and a suite of different

guidelines for different media have been developed. However, water-only exposure studies were considered in the derivation of the whole-body guideline for BC and the US EPA recommends a water column concentration in their translation to fish tissue estimation. Based on this, modelled surface water concentrations were used to estimate fish tissue concentrations for the various habitats.

Results of the wildlife risk assessment presented in JRP IR-6.28 indicate that the conservative application of the 95th percentile selenium concentration (as indicated in JRP IR-6.26b) to the Oldman Reservoir is predicted to be 0.41 µg/L, does not pose a bioaccumulation risk to algae, zooplankton, benthic invertebrates or fish. The results of the updated human health assessment (JRP IR-6.27) also indicate that Project contributions to Blairmore Creek, Gold Creek and the Oldman Reservoir were not considered to be indicative of adverse human health effects.

The predicted 95th percentile concentration of 0.4 µg/L is less than all water quality guidelines and criteria for selenium in Canada and the United States. The Alberta water quality guideline for selenium is 2 µg/L with an alert concentration of 1 µg/L (Alberta Government 2018). As noted in the guidelines, "Exceedance of the alert concentration in sensitive environments indicates the need for increased monitoring of water and other ecosystem compartments to support early detection of potential Se bioaccumulation issues and provide earlier opportunities to commence proactive management actions." The U.S. Environmental Protection Agency's ambient water quality criterion for lentic waters, such as a reservoir, is 1.3 µg/L (USEPA 2016). Both the Alberta guideline and USEPA criterion are based on protection of fish based on bioaccumulation of selenium in the food web.

The predicted 95th percentile selenium concentration for Oldman Reservoir is below protective guidelines and criteria, including Alberta's alert concentration of 1 µg/L, which indicates that selenium is not of concern for bioaccumulation and toxicity in fish in the Oldman Reservoir.

d) Characterize any residual effects of the bioaccumulation of selenium in the Oldman Reservoir on Westslope Cutthroat Trout and other large and small-bodied fish species which are known to be present in the reservoir and present a conclusion regarding the significance of any residual effect, with emphasis on predicted selenium concentrations in egg/ovary tissue. Discuss how the residual effects may vary over the course of the life of the mine and the post closure period.

Response:

As noted in the response to JRP IR-6.26 (c), the predicted 95th percentile selenium concentration of 0.4 µg/L in Oldman Reservoir is below existing selenium guidelines and criteria, including an alert concentration of 1 µg/L. To provide further context around the predicted water selenium concentration in Oldman Reservoir, surface water selenium concentrations at the mouth of the Elk River in British Columbia and in its receiving water—Koocanusa Reservoir—are

summarized and discussed below. Selenium concentrations in fish species within Koocanusa Reservoir, including westslope cutthroat trout, are also discussed.

The Elk River drains the Elk Valley watershed, which includes several active coal mines. Selenium concentrations at the primary monitoring station (LK2) in Koocanusa Reservoir, downstream of the Elk River, averaged 1.1 µg/L from 2014 to 2018 with a range of 0.12 to 3.4 µg/L (Figure 6.26-8). The 95th percentile was 2.1 µg/L, which is about five-fold greater than the predicted 95th percentile of 0.4 µg/L for Oldman Reservoir. Selenium concentrations in Koocanusa Reservoir have been monitored in 12 fish species over the last several years, including westslope cutthroat trout. These data are discussed below.

Fish tissue selenium data for Koocanusa Reservoir were compiled from Lotic Environmental (2019). For purposes of the present evaluation, data were compiled from three routinely monitored locations: (1) near the mouth of the Elk River; (2) near Sand Creek upstream of the Elk River; and (3) near Gold Creek (a tributary to Lake Koocanusa; herein referred to as Gold Creek-B.C.) downstream of the Elk River. Means and standard deviations of the selenium concentrations were calculated by species and location. The data were plotted relative to Alberta's fish tissue-based selenium guidelines, which are 4 mg/kg dw for muscle and 11 mg/kg dw for eggs/ovaries (Alberta Government 2018).

For fish samples collected near the Elk River mouth, mean muscle selenium concentrations exceed the guideline of 4 mg/kg dw for largescale sucker, westslope cutthroat trout, yellow perch, and mountain whitefish (Figure 6.26-9). However, mean ovary selenium concentrations for largescale sucker and yellow perch are well below the egg/ovary selenium guideline of 11 mg/kg dw (Figure 6.26-9). In general, precedence is given to egg/ovary selenium concentrations as it is these concentrations that are most relevant to the endpoint of interest—effects on developing larvae from maternal transfer of selenium. There are three cyprinid species that have mean muscle selenium concentrations <4 mg/kg dw that have egg/ovary selenium concentrations that exceed the guideline of 11 mg/kg dw (peamouth chub, northern pikeminnow, and redside shiner) (Figure 6.26-9). The high bioaccumulation of selenium in ovaries of these cyprinids relative to muscle is interesting and unusual compared to other fish in the reservoir, but there is field and lab evidence that cyprinids are less sensitive to selenium than other fish such as trout and centrarchids (USEPA 2016). As such, the cyprinids should not be considered as general representatives of fish in other families.

Concentration patterns similar to the fish collected near the Elk River mouth are observed in fish collected from Koocanusa Reservoir upstream of the Elk River (Figure 6.26-10) and from Koocanusa Reservoir at Gold Creek-B.C. downstream of the Elk River (Figure 6.26-11); however, at these two locations, the only species with a mean muscle selenium concentration exceeding the Alberta muscle guideline of 4 mg/kg dw was mountain whitefish at Sand Creek. In addition, the only species with a mean ovary selenium concentration at these two locations that exceed the Alberta egg/ovary guideline of 11 mg/kg dw is redside shiner, while mean ovary

selenium concentrations for peamouth chub and northern pikeminnow approach the guideline at Sand Creek and peamouth chub and rainbow trout at Gold Creek-B.C. (Figure 6.26-8 and Figure 6.26-9, respectively). The uniqueness of these cyprinids was previously discussed.

Focusing on westslope cutthroat trout, ovary selenium concentrations are not available for this species in Koocanusa Reservoir, but mean (±SD) selenium concentrations in muscle are 4.4 (±3.2) mg/kg dw for samples collected near the Elk River, 3.1 (±1.5) mg/kg dw for samples collected near Sand Creek, and 3.0 (±2.1) mg/kg dw for samples collected near Gold Creek-B.C. (Figures 6.26-7 to 6.29-9). Although the mean muscle selenium concentration exceeds the guideline of 4 mg/kg dw near the Elk River, the means from the other two locations, including Gold Creek-B.C. downstream of the Elk River, are less than the guideline. The guideline of 4 mg/kg dw is conservative for westslope cutthroat trout. Based on the westslope cutthroat trout EC10 of 21.97 mg/kg dw, as derived in BCMOE (2014), and the mean egg-to-muscle selenium ratio of 1.8 for westslope cutthroat trout based on Rudolph *et al.* (2008), a muscle selenium EC10 of 12.2 mg/kg dw can be calculated.

In summary, the predicted 95th percentile selenium concentration of 0.4 µg/L for Oldman Reservoir is less than selenium water quality guidelines, including an alert concentration of 1 µg/L. Additionally, considering the selenium data for Koocanusa Reservoir, which has mean and 95th percentile concentrations of 1.1 and 2.1 µg/L, respectively, the resulting selenium concentrations in fish tissue, including westslope cutthroat trout, are not at concentrations of concern. These data for Koocanusa Reservoir provide further supporting evidence that fish in Oldman Reservoir are not at risk from the predicted 95th percentile surface water selenium concentration.

The Project is not predicted to have a significant residual effect on selenium loadings into the Oldman Reservoir. The characterization of this residual effect is as follows (following the Evaluation criteria for Water Quality as presented in Table A22-5 in Addendum 4, Attachment 2, CIAR#55):

- Low magnitude –The selenium loading is predicted to be somewhat above typical baseline conditions, but well within the Environmental Quality Guidelines for Alberta Surface Waters.
- Geographic extent is regional because the selenium is predicted to reach the Oldman Reservoir.
- Duration is residual because the effect may last longer than 50 years.
- Frequency is continuous based on the model predictions. However, since this is a 95th percentile value, then the selenium loading should be lower 95% of the time. As such, it is possible that the frequency is periodic.
- Reversibility is reversible in the long term. Effects will remain after cessation of activities and extend for some time into post-closure but will diminish with time. The

water sampling at the historic mining does not show much, indicating that if there was ever anything, then it was reversible.

- Based on this characterization, the residual effect is not significant.

e) Provide a characterization of potential cumulative effects from cumulative selenium loadings to the Oldman Reservoir on Westslope Cutthroat Trout and other fish species at risk that are present in the reservoir, in consideration of the variability in potential cumulative effects over the course of the life of the mine and the post closure period. Cumulative selenium loadings are to include past, present, and reasonably foreseeable projects, with particular attention on historic coal mining in the watershed and irrigation runoff to the reservoir.

Response:

The following provides a characterization of potential cumulative effects from cumulative selenium loadings to the Oldman Reservoir on Westslope Cutthroat Trout and other fish species at risk that are present in the reservoir. This cumulative effects assessment (CEA) was conducted following the process outlined in the Operational Policy Statement Assessing Cumulative Environmental Effects under the *Canadian Environmental Assessment Act, 2012*.

Step 1 - Scoping

i) Identification of Valued Components and Summary of Project-Specific Residual Effects

For the purposes of this characterization of cumulative effects, Westslope Cutthroat Trout (WSCT) has been selected as the valued component. As discussed in the response to part d), bull trout is the only other fish species at risk present in the Oldman Reservoir, and it is expected that the analysis and conclusions for WSCT will be representative for salmonid species within the context of this assessment.

The Project specific residual effects evaluated in this CEA are those from the release of effluent including selenium, as discussed in parts b) and d). The results of part d) show that the Project does not have a significant residual effect on selenium loadings into the Oldman Reservoir; however, because there is a residual effect, Benga has brought this residual effect forward into a cumulative effects analysis, with particular attention to residual effects from historic mining and irrigation runoff.

ii) Determination of Spatial and Temporal Boundaries

Spatial Boundaries

To address the request of the Panel, for this cumulative effects assessment on Se loading to the Oldman Reservoir, the study area is that described in the Oldman River State of the Watershed Report (2010), Chapter 2: the Mountain Sub-basins. This includes the Crowsnest River

watershed, the Castle River watershed, and a portion of the Oldman River mainstem as it leads to the Oldman Reservoir. These spatial boundaries are different than those defined as the RSA in the Cumulative Effects Assessment completed for water quality for the Project (Addendum 8, Appendix A-1, CIAR#89) where the Crowsnest River watershed provided the limits of the regional study area.

Temporal Boundaries

The timeline evaluated for this cumulative effects assessment looks into the past, to include historical activities that may have contributed selenium loadings to the Oldman River and Reservoir to identify noticeable trends, and into the future (post-closure) when mitigative reclamation is expected to be complete and residual effects will have ceased.

iii) Examining Past, Existing, and Future Physical Activities

Past and Existing Activities

Prior to the late 1800s, there was very little development in the area. In 1898, the construction of the Canadian Pacific Railway was completed with the town of Blairmore being established as the main siding in the region. Between 1920 and 1928, a road paralleling the railway was upgraded and graveled to facilitate automobile travel. The route which is now Highway 3 was eventually paved and rerouted to its current alignment. The Crowsnest River was modified with these developments to prevent damage to the structures due to flooding and river bed migration.

In the early 1900s, coal was discovered in the region and additional towns were established along the railway to support coal mines at Coleman, Bellevue and Frank. The communities in the RSA continued to develop primarily along the route of the highway and the railroad with the primary industry in the area being coal mining. The communities had an effect on water quality in the RSA as water users and generation of waste.

Historical coal mining in the region began with the establishment of the first mines in the early 1900s. Specifically, the legacy Greenhill Mine was located near Blairmore Creek, while the legacy Bear Valley Mine and Bellevue Mines were located in the vicinity of Gold Creek. All of these mines have since closed however a number of the historical mining areas remain in a disturbed condition including the Grassy Mountain Mine, which is situated within the project footprint and was in operation off and on from 1952 through to 1976. There is not enough evidence to demonstrate that these historical operations have a material effect on selenium levels in the creeks, as supported by the data below.

Substantial baseline monitoring was conducted for the Project to help determine if there were existing elevated selenium concentrations in surface water related to historic mining:

- A review of the surface water and groundwater samples collected from springs, toe springs, historic mine ponds and streams located in the vicinity of the historical mine,

conducted for the hydrogeological assessment (EIA, CR#3, Section 5.4.2, CIAR#42), indicates that overall very few exceedances of Freshwater Aquatic Life (FWAL) guidelines occurred. Selenium is the only element which was frequently detected above FWAL in surface water and groundwater samples. Selenium concentrations above guidelines were observed at surface water locations, including the Crowsnest River, streams, the Greenhill Portal (Main) and historic mine ponds. Selenium was monitored at the toe springs of the historical mine spoil (waste rock), but generally at concentrations below guidelines, which may be interpreted as indicative of no notable residual effect related to historical mining activities.

- Other, historic data were collected along the length of Crowsnest River from 1974 to 2008, from the headwaters area (above Coleman) to just upstream of the reservoir near Lundbreck. Table 6.26-3 summarizes this data by season. During 2013 to 2014, in support of the baseline monitoring as part of the Grassy Mountain Project, additional samples were collected on the Crownsest River just upstream and downstream of Blairmore Creek (CRR-W01 and CRR-W02, respectively), and these data are also summarized in Table 6.26-3. In both historic periods, the highest Total Selenium values marginally exceeded the water quality guideline exceedance of 1 mg/L in samples obtained from April to August, and also during fall (September to October) in the 2013 to 2014 sampling program. Dissolved selenium also exceeded the guideline during 2013 to 2014, but data from 1974 to 2008 were very sparse. Water quality surveys were conducted at five stations within the Blairmore Creek drainage and eight stations within the Gold Creek drainage, and three stations in the Crowsnest River from May 2013 to March 2016. A new station at Caudron Creek (CC-W01) was introduced in 2016 as a reference site for Gold Creek and sampled during winter and spring 2016. Blairmore Creek upstream station, BC-W03 also was proposed to be a reference station for Blairmore Creek during operations. These results were summarized in Table 10 (EIA, CR#5, CIAR#42) which indicate some exceedences of water quality guidelines for selenium in Gold Creek.
- There is not enough evidence to demonstrate that these historical operations have a material effect on selenium levels in the creeks, as they do not appear to follow patterns or trends related to historic mining specifically.

Water quality within the Oldman Reservoir is described in response to part a) i) and part b). With respect to historical water quality, average concentrations of total metals in the water column of the Oldman Reservoir from 1991 to 1996 are presented in Table 6.26-1 and Table 6.26-2, along with exceedances of relevant water quality guidelines for the protection of aquatic life at that time. Selenium concentrations were at or below the analytical detection limit in all samples.

The general use of lands in the area is described in the report: Oldman River State of the Watershed Report (2010). According to this report (pg. 41) forest and grassland cover the majority of this area. Forest is the dominant land cover in this area, at 64% and is largely managed by Forest Management Unit C5. Grassland is the next largest land cover type at 23%

of the area, consisting of Foothills Fescue and Montane natural sub-regions. These grasslands are largely used for grazing. "Since 87% of the Mountain Sub-basins is covered by forest and grassland, erosion is not an important concern" (pg. 45).

"Approximately 25% of the Mountain Sub-basins is altered by human development. Agricultural activities comprise the largest component (22%)" (pg. 49), consisting of grazing and cultivation. Cultivated land covers 8%, of which 60% is cereal crops and 38% is forage crops. "All irrigation projects within the Mountain Sub-basins are individual licensed private developments. There are no irrigation districts licensed to draw water from streams in the Mountain Sub-basins" (pg. 58). Table 2.7 indicates that the amount of irrigated land (which includes grazing and cropped land) is only 1% in the area. Selenium can be of concern in irrigation run-off, as seen historically in some areas in the Western USA. These areas "have in common an arid climate, closed drainage basins, seleniferous Cretaceous geology, and they receive irrigation drainage water from nearby agricultural areas. Similar conditions occur in SW Saskatchewan and SE Alberta." (Outridge *et al*., 1999, pg.81). Subsequently, Alberta Agriculture and Rural Development (Little *et al*., 2010) conducted a study of water quality in Alberta's Irrigation Districts to investigate these types of concerns. However, there are no irrigation districts within this cumulative effect assessment's spatial boundaries, which are located to the east. Both studies suggest that the potential for selenium loading related to irrigation is related to more eastern portions of the province where there is more extensive irrigation and higher likelihood of seleniferous geology. Within the irrigation districts water sampling, Little *et al*. (2010) found that "water quality guidelines for nutrients and metals were met that majority of the time" and found 87% compliance for selenium with protection of aquatic life guidelines (pg.vi).

Urban centres include Bellevue, Hillcrest, Frank, Blairmore, Coleman, Lundbreck and Cowley, which combined cover less than 1% of the Mountain Sub-basins. Approximately 2% of the area "supports infrastructure, primarily linear developments" (cutlines, wellsite access roads and pipelines) (pg. 47, Oldman Watershed Council 2010). There are major transportation corridors of Highways 3 and 22 that cross the area east/west and north/south respectively.

There are recreation uses within the area, such as campgrounds and trails, but less than 1% of the area is designated for that use (pg. 49, Oldman Watershed Council 2010).

As noted above, there is insufficient evidence to indicate that selenium levels in local creeks and downstream waterbodies (*e.g.,* Oldman Reservoir) have resulted in issues related to loading and/or bioaccumulation. Since the construction of the Oldman Reservoir/Dam in 1991, populations of key fish species have declined dramatically and habitat has been altered to a more lentic-type (*i.e.,* oligotrophic environment) with a relative high flushing rate and short residence time. Bull trout were abundant in the reservoir in 1991 (Moore *et al*. 1993), but severely declined five years post-completion (Lima *et al.* 2016). Even with the noticeable Bull Trout decline in the reservoir, a small population of adfluvial and resident Bull Trout (population

estimate of 250 to 1,000 individuals) appear to persist in the Reservoir (ASRD 2012, Warnock in Hurkett 2009). Within five years of the Oldman River Dam Project, WSCT nearly disappeared from the reservoir area (Lima *et al*. 1993). Although the governments of Alberta (Alberta Westslope Cutthroat Trout Recovery Team 2013) and Canada (DFO 2014, DFO 2019) have developed a recovery plan and strategy for WSCT, Oldman Reservoir was not identified as critical habitat. With the abundance of rainbow trout in the Oldman Reservoir (Moore *et al.* 1993), it is likely that the very few pure strain WSCT remain, given the high occurrence of hybridization between rainbow trout and WSCT.

Several other fish species are documented within the reservoir; however, there are no records or studies that specifically discuss their abundance and/or status. Given the Oldman Reservoir is a lentic system, species with generalist traits for reproductive requirements (*i.e.,* tolerant to a wide range of flows, open substratum, non-migratory) increased in relative abundance following completion of the Oldman Dam (Lima *at al*. 2016), including White Sucker, Longnose Sucker, Longnose Dace, Brook Stickleback and Northern Pike. Although Brown Trout, Mountain Whitefish and Lake Whitefish are present within the area (Moore *et al.* 1993, Campen 2016), no records of species/population abundance could be found in the public record.

In summary, the Castle and Crowsnest watersheds have experienced past and existing activity since the late 1800s, with 25% being altered by human development. The influence of historic mining on water quality is undetermined, and there is little potential for selenium loading from irrigation runoff in this area.

Certain and Reasonably Foreseeable Projects and Activities

Certain and reasonably foreseeable projects and activities were reviewed to determine which activities could interact cumulatively with past and existing activities on selenium loading within the Oldman Reservoir. Those activities and projects include:

- Baldy Ridge Mine Expansion by Teck Coal Ltd. – This project was not included in this cumulative effects assessment as it is located on the western side of a mountain divide; subsequently, is not associated with the Crowsnest River watershed.
- The Michel Creek Coking Coal Project by North Coal Ltd. – For the same reason as the Teck Bald Ridge Mine Expansion, this project was not included in this cumulative effects assessment.
- Other potential future mining activities: There have been no other coal mine project applications reported to the AER that would qualify to be considered certain or reasonable foreseeable, under the CEAA 2012 definitions. No other coal mining related activities have been carried forward in this cumulative effects assessment.
- Future timber operations on Crown Land – Land use maps indicate that the timber operations and associated activities between 1982 and 1996 characterized the Gold Creek watershed (Addendum 1, CR#6, Appendix A2, CIAR#44) after which there has been essentially no such development in the Gold Creek watershed. In the Blairmore

Creek watershed, a smaller amount of timber operation or forest resource management activities occurred from 1996 to 2015. As discussed in JRP IR-5.31 (Addendum 10, CIAR#251) TSS was the factor under evaluation due to timber operations. Future timber operations are not expected to contribute to selenium loading into aquatic systems, thus future timber activities have not been carried forward in this cumulative effects assessment.

- Future recreation activities were considered but are not expected to contribute to selenium loading in the Oldman Reservoir. Therefore, these activities were not carried forward in this cumulative effects assessment.
- Alberta Transportation (AT) re-alignment of Highway No. 3 – This project was not included as although AT have identified conceptual alignment, construction of this project is unlikely to occur during the operations of the proposed Grassy Mountain Coal Project, and highways are not expected to be a contributor to selenium loading in the Oldman Reservoir. Therefore, this activity was not carried forward into this cumulative effects assessment.

After review, it was determined that there are no certain or reasonably foreseeable projects within the temporal boundaries that are expected to contribute to future selenium loading in the Oldman Reservoir. Should future projects become more certain and/or develop plans to seek approvals in the future, they would likely be required to conduct cumulative effects assessments.

Summary of Activities

There are past and existing activities that have potential to contribute selenium to the watershed. The discussion of potential cumulative effects below focuses on these past and existing activities and the potential contributions from the Project.

Step 2 - Analysis of Cumulative Effects

The three assessment cases considered for evaluating potential cumulative effects on WSCT from selenium loading include:

- Baseline Case: includes an assessment of the current environmental conditions that considers past and existing activities;
- Application Case: includes the findings and trends of the Baseline Case and incorporates the effects of the proposed Project activities; and
- Planned Development Case: includes the identification of certain and/or reasonably foreseeable projects or activities that could act in combination with the past, existing, and Project activities.

Past and Existing Considerations

Water quality data was reviewed for 2 scenarios: conditions in the Oldman Reservoir and baseline conditions at the Project site.

Baseline conditions for the Oldman Reservoir are described above in parts a) and b). Data on Se concentrations in the Oldman Reservoir do not suggest a current loading of Se.

Baseline surface water quality data from the Project suggest that concentrations of detectable metals were generally within Alberta water quality guidelines, with the exception of total selenium which occasionally exceeded water quality guidelines for the protection of aquatic life. Total selenium only exceeded the guidelines at Gold Creek. Guideline exceedances for selenium were noted in the Crowsnest River baseline data (EIA, Section E.5.2.2, CIAR#42). Water monitoring for the hydrogeological assessment of historic rock dumps and toe springs, and showed some exceedances of selenium for the FWAL guidelines, however it is difficult to determine cause and effect specifically related to historic mining.

Selenium loading from irrigation is not likely a contributor in this area because only 1% of land is irrigated and conditions are not likely to lead to selenium release from irrigation runoff. Little *et al*. (2010) suggested 87% compliance with guidelines for selenium, even in more eastern irrigation districts (Little *et al*. 2010).

Project Considerations

The cumulative effects analysis looks at the Project in combination with past, existing and future activities.

The Project's contribution to selenium loading in the Oldman Reservoir was discussed in part c. Regarding cumulative selenium loading potential in the Oldman Reservoir, the 95th percentile selenium concentration in the reservoir is predicted to be 0.41 µg/L, which is below the Alberta Water Quality guideline of 2 µg/L and the alert concentration of 1 µg/L (Alberta Government 2018). The guideline was developed to be protective against the bio-accumulative effects of selenium in aquatic food webs and particularly sensitive fish.

This loading prediction is the 95th percentile concentration meaning that 95% of the time, selenium loading is predicted to be below this value. As well, this loading is assumed to be continuous over the life of the mine, which is also conservative; therefore, the predicted loading of 0.41 µg/L is considered conservative.

Future Considerations

There are no certain and/or reasonably foreseeable projects within the temporal boundaries for this assessment as discussed above.

In conclusion, as there are no other calculated loadings from future projects, and no other quantitatively defined sources of current Se loading, the cumulative selenium loading is just that from the Project.

Step 3 - Mitigation

Potential impacts to surface water quality have been mitigated on a Project level as part of the Project's Water Management Plan, which includes mitigation for selenium (EIA, Section C.5, CIAR#42).

As the Project's contribution to selenium related cumulative effects in the Oldman Reservoir are low magnitude, no further mitigation is proposed beyond the mitigation measures planned to manage selenium at the Project level.

Step 4 - Significance

There may be a residual cumulative effect on selenium loading into the Oldman Reservoir. The characterization of this residual effect is as follows (following the Evaluation criteria for Water Quality as presented in Table A22-5 in Addendum 4, Attachment 2, CIAR#55):

- Low magnitude –The selenium loading is predicted to be somewhat above typical baseline conditions, but well within the Environmental Quality Guidelines for Alberta Surface Waters.
- Geographic extent is regional because the selenium is predicted to reach the Oldman Reservoir.
- Duration is residual because the effect may last longer than 50 years.
- Frequency is continuous based on the model predictions. However, since this is a 95th percentile value, then the selenium loading should be lower 95% of the time. As such, it is possible that the frequency is periodic.
- Reversibility is reversible in the long term. Effects will remain after cessation of activities and extend for some time into post-closure, but will diminish with time. The water sampling at the historic mining does not show much, indicating that if there was ever anything, then it was reversible.
- Based on this characterization, the residual effect is not significant.

Step 5 - Follow-Up

A Project level follow-up monitoring plan has been developed: Aquatic Monitoring Plan (Appendix 6.23-1). As the Project's contribution to selenium related cumulative effects in the Oldman Reservoir are low, no further mitigation is proposed beyond the mitigation measures planned to manage selenium at the Project level. Adaptive management is a key part of the Aquatic Monitoring Plan, and as such, the monitoring program for selenium will be modified as necessary based on monitoring results observed over time.

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HUMAN HEALTH

Information Request 6.27

Environmental Impact Statement Guidelines. (CIAR #11).

Grassy Mountain Coal Project - Updated Environmental Impact Assessment. Appendix 10b. (CIAR #42).

Information Request Package #4 from the Joint Review Panel to Benga. Information Requests 4.15 (CIAR #212).

Comments from Tsuut'ina Nation. (CIAR #220).

Tenth Addendum to the Environmental Impact Assessment. Response to Information Request 4.12, 4.15 and 5.29. (CIAR #251).

Comments from the Government of Canada - Health Canada submission. (CIAR #283).

The Human Health Risk Assessment (HHRA) conducted by Benga is incomplete, as it does not consider water-based exposure pathways in the LSA, RSA, the Oldman Reservoir or the end pit lake in the post- closure landscape. Water-based pathways may contribute to the risk to human health via drinking water, but most notably, via bioaccumulation of contaminants in aquatic food webs. Bioaccumulation in fish consumed by people, as well as in other aquatic food web components used for traditional purposes such as aquatic plants would be relevant pathways.

The EIS Guidelines (CEAR #11) specify that the proponent will provide, "with respect to Aboriginal peoples, a description and analysis of how changes to the environment caused by the Project will affect: human health, considering, but not limited to, potential changes in air quality, quality and availability of country foods, water quality (drinking and recreational), and noise exposure. When risks to human health due to changes in one or more of these components are predicted, a complete HHRA examining all exposure pathways for pollutants of concern may be necessary to adequately characterise potential risks to human health".

Benga states in Section 5.1.3, Appendix 5 (CIAR #251) that, "The Project is not expected to have any direct effect on water quality or aquatic health". This statement is made despite the fact that water quality modeling conducted by Benga predicts increases in selenium, nitrate, sulphate, zinc and cobalt concentrations in Blairmore Creek and Gold Creek as well as in other mine facilities such as sedimentation ponds and the end pit lake planned for the post-closure period. The predicted concentrations will peak during mine operations and then remain close to peak concentrations over the entire post-closure period modeled (to year 2100) (Appendix 10b, CIAR #42). Also, this statement does not address groundwater-based pathways via alluvial as well as bedrock aquifers as requested in IR 4.15 (CIAR #212). In the response to IR 4.15 (CIAR #251) repeated the assertion that there will be no direct effects on water quality, despite the potentially close connections between surface water and alluvial aquifers. The basis for screening-out water-based pathways in the HHRA is not sufficient.

Tsuut'ina Nation notes (CIAR #220) that the HHRA addresses contaminants of potential concern (COPCs) from aerial deposition but does not consider the potential uptake and bioaccumulation of contaminants from contact water.

The HHRA should include water-based exposure in the Oldman Reservoir because the transport of contaminants of concern to lentic environments can result in a greater degree of bioaccumulation in aquatic food chains. Furthermore, the potential human health risks associated with the end pit lake in the post-closure landscape requires assessment, as noted by Health Canada (CIAR #283).

Revise and resubmit the relevant sections of the HHRA to include the following:

a) An assessment of water-based exposure pathways (both groundwater and surface water) in the LSA (including the end pit lake), RSA and the Oldman Reservoir using predicted concentrations of contaminants of concern in the LSA and RSA from Appendix 10b (CIAR #42) as well as predicted concentrations in the Oldman Reservoir (see IR 6.26). The assessment is to include: an Indigenous- specific conceptual model (e.g. a diagram as to how Indigenous peoples may be exposed to contaminants of concern) which describes source-pathway linkages between the Project and Indigenous use of all aquatic pathways including the end pit lake, Blairmore and Gold Creeks, the Crowsnest River and the Oldman Reservoir in the post closure landscape; and,

Response:

At the request of the JRP, the Project's Human Health Risk Assessment (HHRA) was updated as part of the Tenth Addendum to the Environmental Impact Assessment; response to Information Request 4.9 (Addendum 10, JRP IR-4.9, Appendix 4.9-1, CIAR #251).

In response to this current information request, an assessment of water-based exposure pathways (both groundwater and surface water) in the LSA (including the end pit lake), Crowsnest River, and the Oldman Reservoir using predicted concentrations of contaminants of concern in the LSA and RSA, and predicted concentrations in the Oldman Reservoir is presented as Addendum 1 to the HHRA (Appendix 6.27-1).

The assessment includes an Indigenous-specific conceptual model, which describes source-pathway linkages between the Project and Indigenous use of all aquatic pathways including the end pit lake, Blairmore and Gold Creeks, the Crowsnest River and the Oldman Reservoir in the post closure landscape.

It is important to note that the conclusions of the Addendum 1 to the HHRA do not differ from those presented in the updated HHRA (Addendum 10, JRP IR-4.9, Appendix 4.9-1, CIAR #251).

b) A revised risk characterization that goes beyond a contaminant-by-contaminant table of Health Quotients (HQs) and produces a sum of all HQs which addresses the

cumulative exposure to all COPCs from all pathways, including water-based pathways.

Response:

A revised risk characterization that addresses the cumulative exposure to all COPCs from all pathways, including water-based pathways is also included in Addendum 1 to the HHRA (Appendix 6.27-1).

WILDLIFE HEALTH

Information Request 6.28

Grassy Mountain Coal Project - Updated Environmental Impact Assessment - Appendix 10b, Water and Load Balance Model Report. (CIAR #42).

Grassy Mountain Coal Project - Updated Environmental Impact Assessment – Consultant Report #6, Aquatic Resources. (CIAR #42)

Comments from the Government of Canada - Environment and Climate Change Canada and Fisheries and Oceans Canada submissions. (CIAR #204).

Information Request Package #4 from the Joint Review Panel to Benga, Information Requests 4.15. (CIAR #212).

Comments from Jillian Lynn Lawson. (CIAR #242).

Tenth Addendum to the Environmental Impact Assessment - Appendix H to Appendix 4.9.1, Wildlife Screening Risk Assessment. (CIAR #251).

Benga stated, in the wildlife screening risk assessment, "Since none of the identified COPCs are expected to biomagnify up the food chain and in most cases they are metabolized in higher organisms; exposures are expected to be highest for primary consumers (CCME, 2010; US EPA, 1999)" (CIAR #251). This statement that "most COPC" are metabolized is not supported by Benga with references to literature.

In section 2.3 of its wildlife screening risk assessment (CIAR #251), Benga also states "Project COPC will be emitted to air and direct inhalation of air is expected to be the primary exposure pathway. Maximum predicted air concentrations were used for assessing acute and chronic inhalation exposures for wildlife". Benga indicates in Table H.3 titled Exposure Pathways, that ingestion of fish and ingestion of prey were screened-out because no impacts on surface water are predicted in Consultant Report #6, Aquatic Assessment (CIAR #42), and comparison of predicted deposition of COPC onto surface water indicate estimated surface water concentrations are below guidelines protective of FAL Freshwater Aquatic Life (FAL). Benga further notes that for COPC that do biomagnify up the food chain, this pathway is considered as part of the soil quality guideline.

The screening-out of water-based exposure pathways is not commensurate with the understanding of the importance of bioaccumulation in aquatic food chains (notably for selenium). Water-based pathways cannot be screened-out for wildlife which consume aquatic-based food. Furthermore, risks associated with exposure to COPCs do not result solely from biomagnification, but also from bioaccumulation via uptake from water or sediment to aquatic plants and algae which are then consumed by invertebrates. Aquatic-dependent wildlife such as waterfowl, piscivorous and aquatic- based insectivorous birds (such as Great Blue Heron and American Dipper), or mammals such as bats (which consume invertebrates which emerge as adults from waterbodies) are then exposed to COPC through consumption of these water-based preys.

Comments from Environment and Climate Change Canada, Fisheries and Oceans Canada and members of the public raised concerns regarding wildlife exposure to project-related COPCs from both terrestrial and aquatic environments (CIAR #204, #242). Benga predicts increases in selenium, nitrate, sulphate, zinc and cobalt concentrations in Blairmore Creek and Gold Creek as well as in other mine facilities such as sedimentation ponds and the end pit lake planned for the post-closure period. The predicted concentrations will peak during mine operations and then remain close to peak concentrations over the entire post-closure period modeled (to year 2100) (Appendix 10b, CIAR #42). Therefore, there is potential for exposure of wildlife to elevated concentrations of these COPCs during mine operations as well as during the post-closure period in the LSA and RSA as a result of consumption of drinking water and aquatic-based food pathways. Given this, the wildlife screening risk assessment should also include exposure via consumption of water and aquatic-based food in the Oldman Reservoir as a result of the potential transport of contaminants of concern to this lentic environment.

a) Screen all wildlife health COPC via water-based pathways for the tendency to bioaccumulate in lotic and lentic aquatic systems including Blairmore Creek, Gold Creek, mine facilities such as sedimentation ponds, the planned end pit lake for the post-closure period, and the Oldman Reservoir. Selenium must be included as a COPC. Include explicit consideration of selenium loadings to the Oldman Reservoir and subsequent uptake into aquatic organisms in the Oldman Reservoir. Provide a rationale for any screening-out of other COPC;

b) Include receptors which have diets comprised in whole or in part of aquatic-based prey. These receptors should include all bat species listed as receptors in Table H.6 of Appendix H to Appendix 4.91, as well as representative and sensitive migratory waterfowl, shorebirds, and piscivorous birds such as Great Blue Heron. American dipper should be included as a receptor for Blairmore Creek;

c) Include ingestion of fish and ingestion of prey which are water-based (such as aquatic invertebrates) in the calculation of hazard quotients for COPC which accumulate in aquatic food chains, including, but not necessarily limited to, selenium;

d) Provide the Health Quotients (HQs) for all receptors referenced in b) with an accompanying risk characterization narrative (including an uncertainty analysis); and

e) Provide a multi-media exposure risk characterization for all receptors reference in b); i.e., risk from all exposure pathways listed in Table H.3 of Appendix H to Appendix 4.9.1.

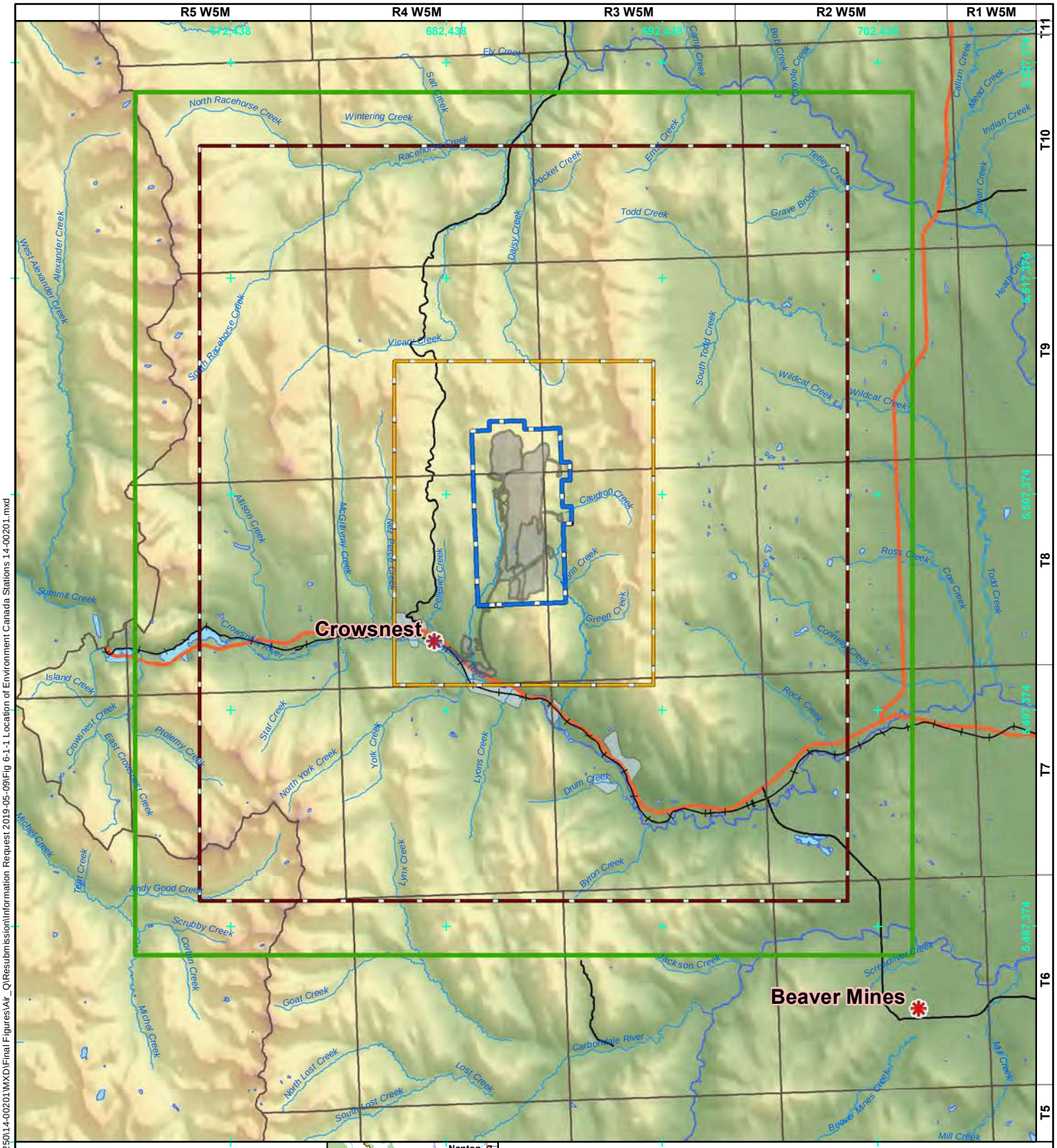
Response:

At the request of the JRP, the Project's Human Health Risk Assessment and Wildlife Risk Assessment was updated as part of the Tenth Addendum to the Environmental Impact

Assessment; response to Information Request 4.9 (Addendum 10, JRP IR-4.9, Appendix 4.9-1, CIAR#251).

Appendix 6.28-1 provides the requested additional information (parts a to e) in an addendum to the wildlife screen risk assessment (WRA).

FIGURES



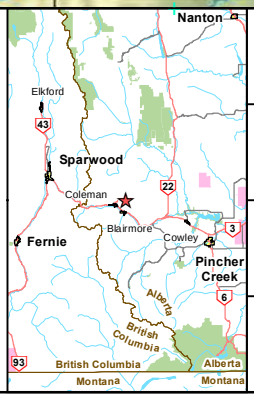
LEGEND

- EC Meteorological Station
- Proposed Mine Permit Boundary
- Project Footprint
- Undisturbed Area
- Air Quality Local Study Area
- Air Quality Regional Study Area
- Model Domain

Topography (masl)

High : 2800

Low : 1250



RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

LOCATION OF CROWSNEST AND BEAVER MINES ENVIRONMENT CANADA STATIONS

AltaLIS, 2019; Geobase, 2019, MEMS, 2019; NRCAN, 2019, Riversdale, 2016

Coordinate System: NAD 1983 UTM Zone 11N

0 5 10

Kilometers

MILLENNIUM EMS Solutions Ltd.

PROJECT: 14-00201

DRAWN BY: JLAMBERTS

CHECKED BY: MB

DATE: DECEMBER 18, 2019

FIGURE

6.1-1

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Air_QIResubmission\Information Request 2019-05-09\Fig 6-1-1 Location of Environment Canada Stations 14-00201.mxd

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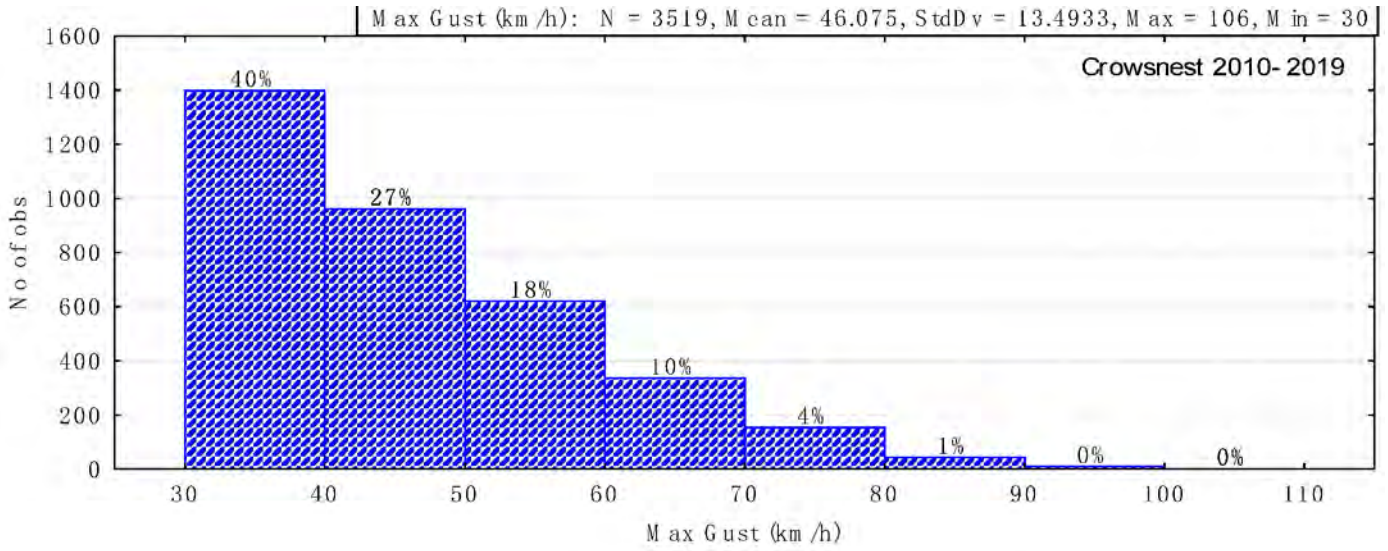

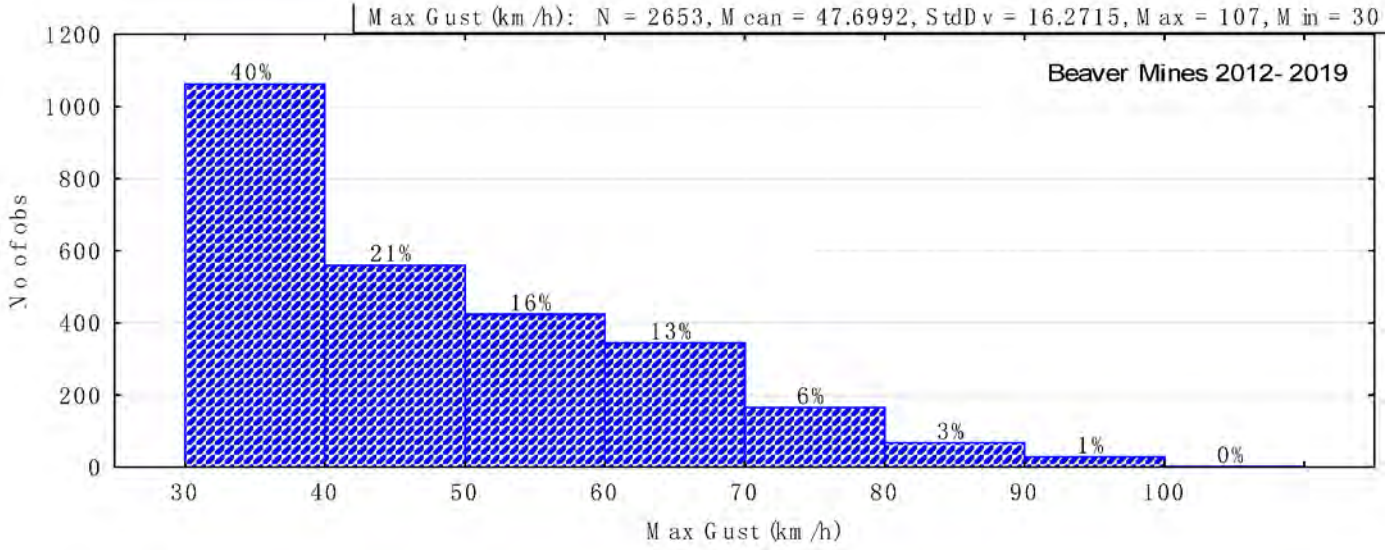

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

FREQUENCY DISTRIBUTION OF DAILY MAX GUST AT CROWSNEST AND BEAVER MINES

Data Source: Environment Canada (2019)

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: DECEMBER 18, 2019

FIGURE
6.1-2

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Air_QI\Resubmission\Information Request 2019-05-09\Fig 6-1-2 Frequency Distribution of Daily Max Gust at Mines 14-00201.mxd

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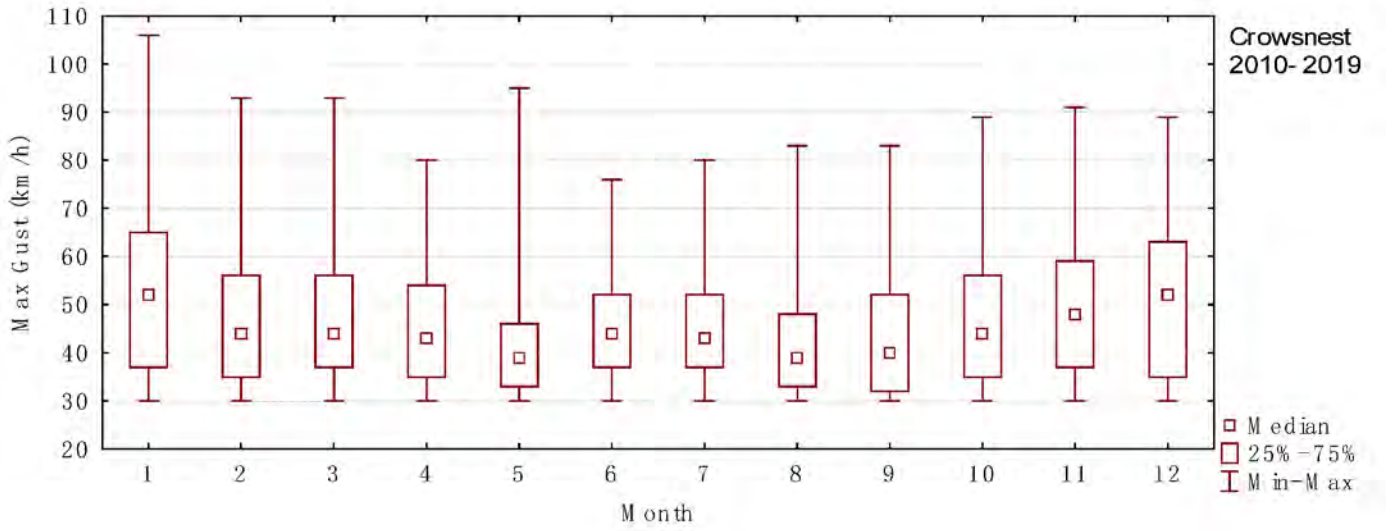

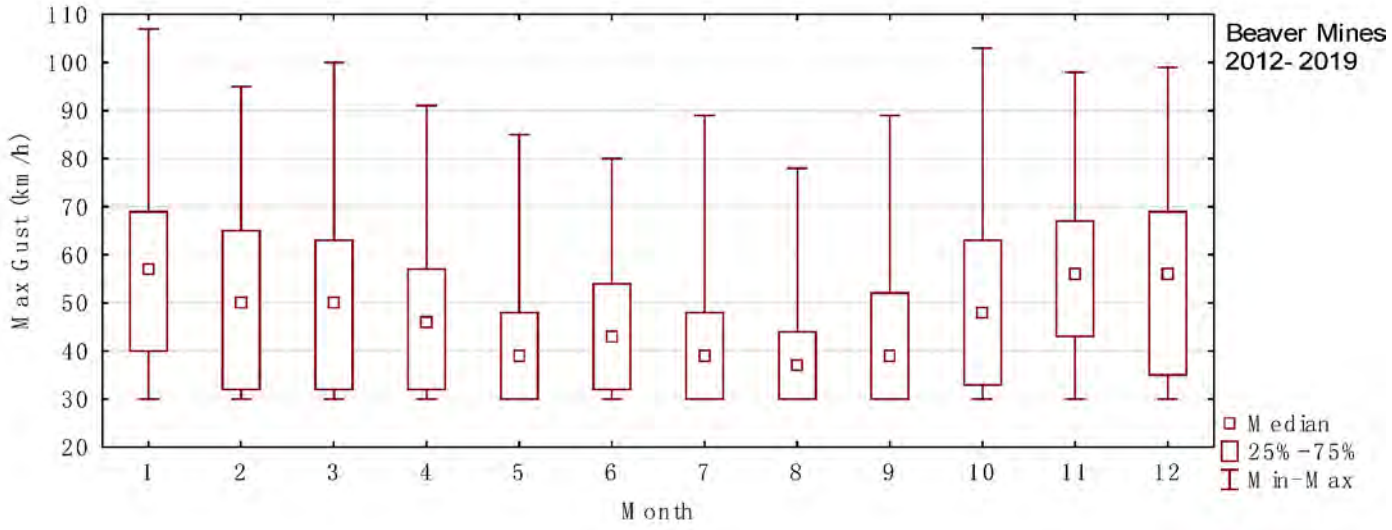

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

SEASONAL VARIATION OF DAILY MAX GUST AT CROWSNEST AND BEAVER MINES

Data Source: Environment Canada (2019)

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: DECEMBER 18, 2019

FIGURE
6.1-3

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Air_QResubmission\Information Request 2019-05-09\Fig 6-1-3 Seasonal Variation of Daily Max Gust at Mines 14-00201.mxd

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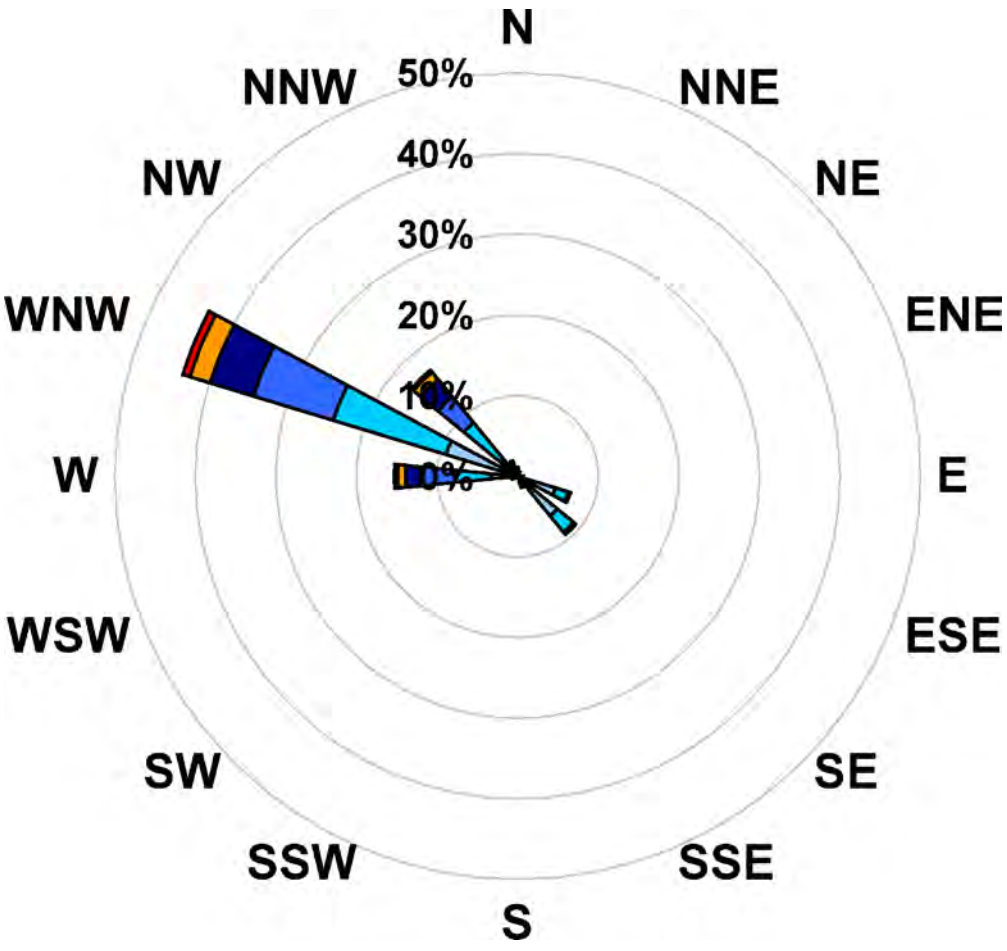

LEGEND

Max Gust (km/h)

- >80
- 70-80
- 60-70
- 50-60
- 40-50
- 30-40

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

WIND ROSE OF DAILY MAX GUST AT CROWSNEST (2010 - 2019)

Data Source: Environment Canada (2019)

MILLENNIUM EMS Solutions Ltd.

PROJECT: 14-00201

DRAWN BY: JLAMBERTS

CHECKED BY: MB

DATE: DECEMBER 18, 2019

FIGURE

6.1-4

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Air_Q\Resubmission\Information Request 2019-05-09\Fig 6-1-4 Wind Rose of Daily Max Gust at Crowsnest 14-00201.mxd

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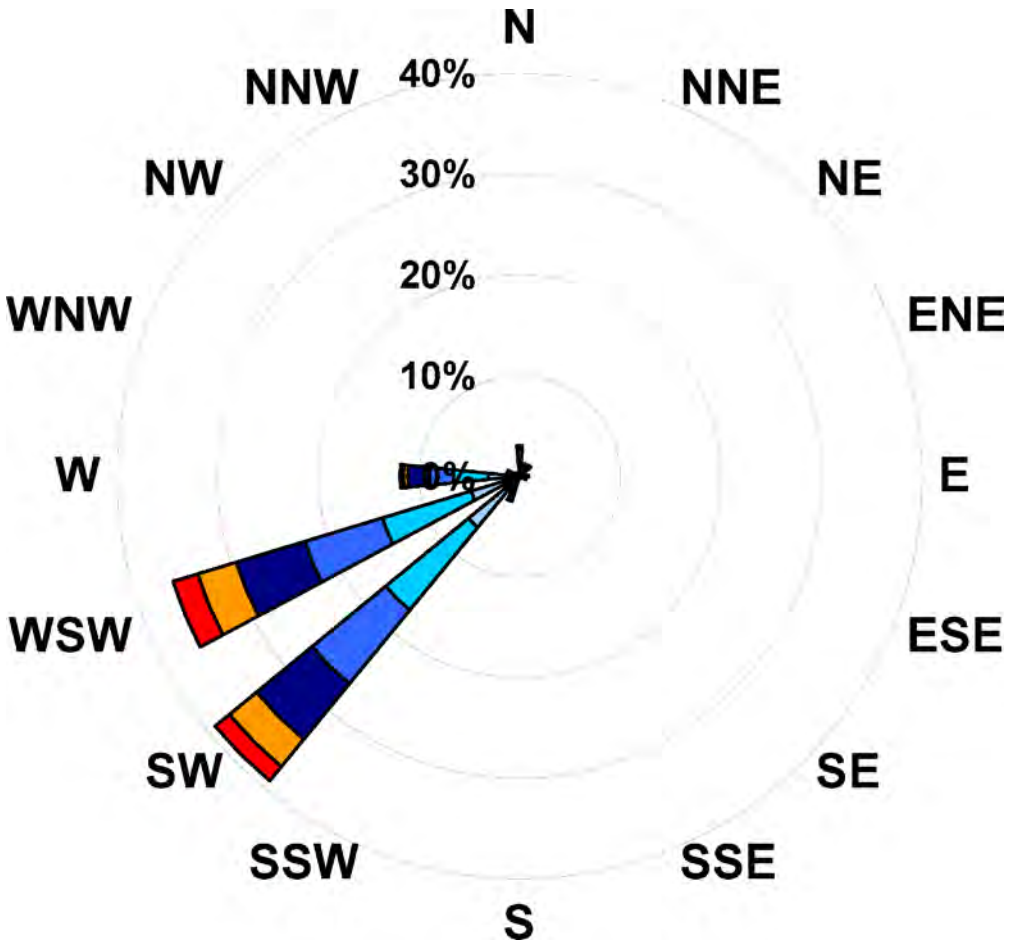

LEGEND

Max Gust (km/h)

- >80
- 70-80
- 60-70
- 50-60
- 40-50
- 30-40

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

WIND ROSE OF DAILY MAX GUST AT BEAVER MINES (2012 - 2019)

Data Source: Environment Canada (2019)

MILLENNIUM EMS Solutions Ltd.

PROJECT:	14-00201
DRAWN BY:	JLAMBERTS
CHECKED BY:	MB
DATE:	DECEMBER 18, 2019
FIGURE	6.1-5

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Air_Q\Resubmission\Information Request 2019-05-09\Fig 6-1-5 Wind Rose of Daily Max Gust at Beaver Mines 14-00201.mxd

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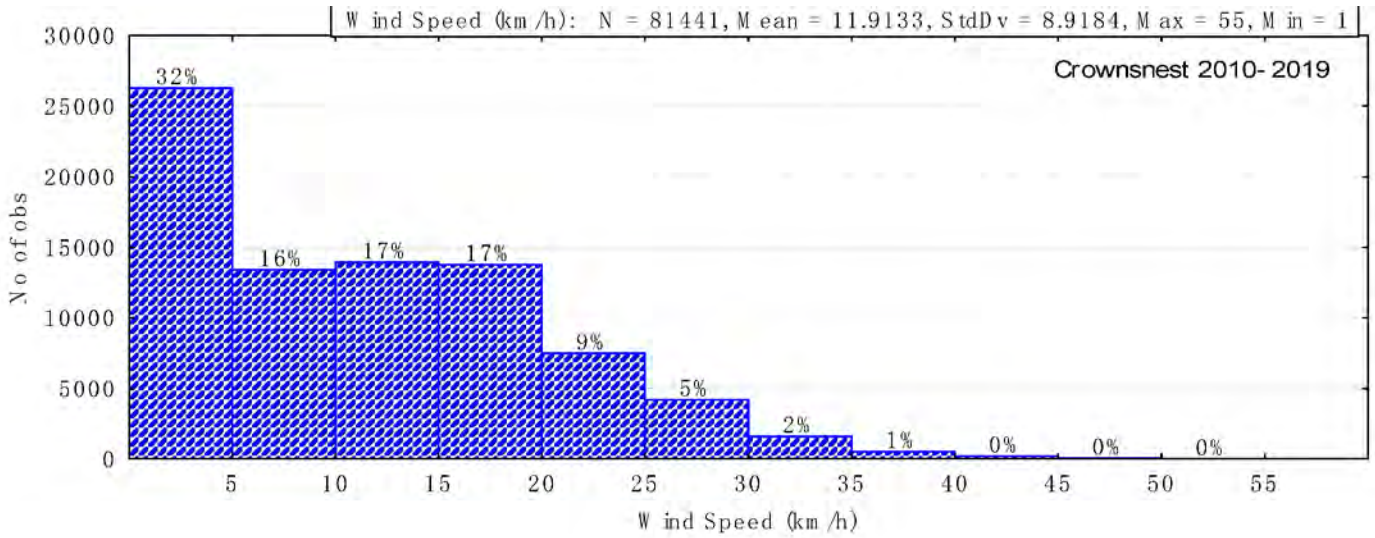

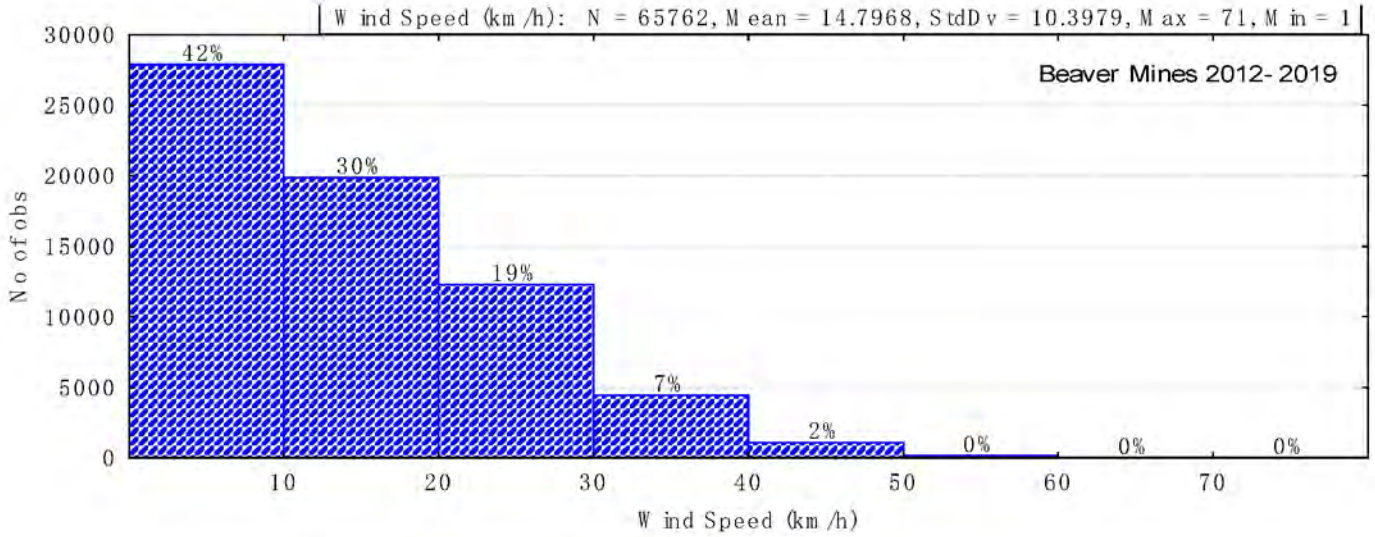

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

FREQUENCY DISTRIBUTION OF HOURLY WIND SPEEDS AT CROWSNEST AND BEAVER MINES

Data Source: Environment Canada (2019)

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: DECEMBER 18, 2019

FIGURE
6.1-6

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Air_QI\Resubmission\Information Request 2019-05-09\Fig 6-1-6 Frequency Distribution of Hourly Wind Speeds at Mines 14-00201.mxd

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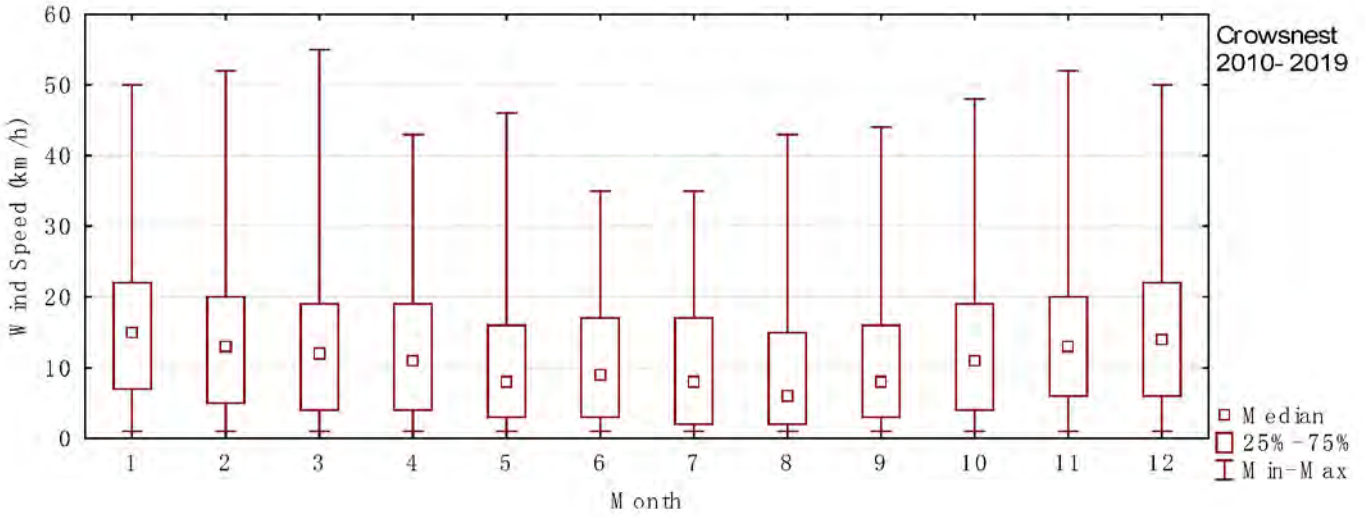

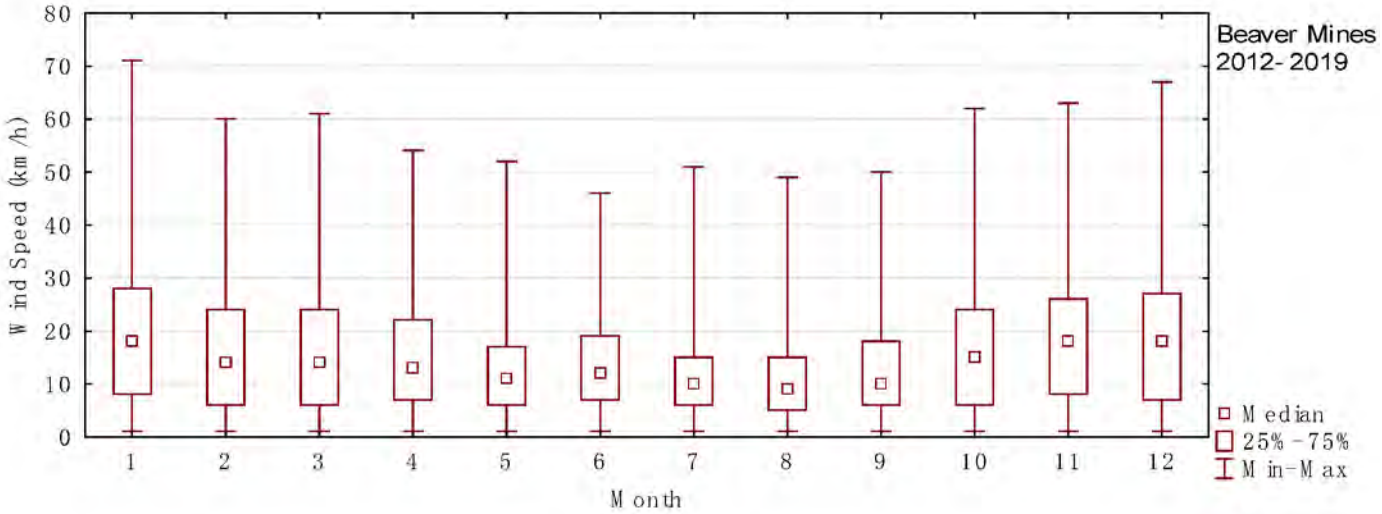

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

SEASONAL VARIATION OF HOURLY WIND SPEEDS AT CROWSNEST AND BEAVER MINES

Data Source: Environment Canada (2019)

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: DECEMBER 18, 2019

FIGURE
6.1-7

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Air_QIResubmission\Information Request 2019-05-09\Fig 6-1-7 Seasonal Variation of Hourly Wind Speeds at Mines 14-00201.mxd

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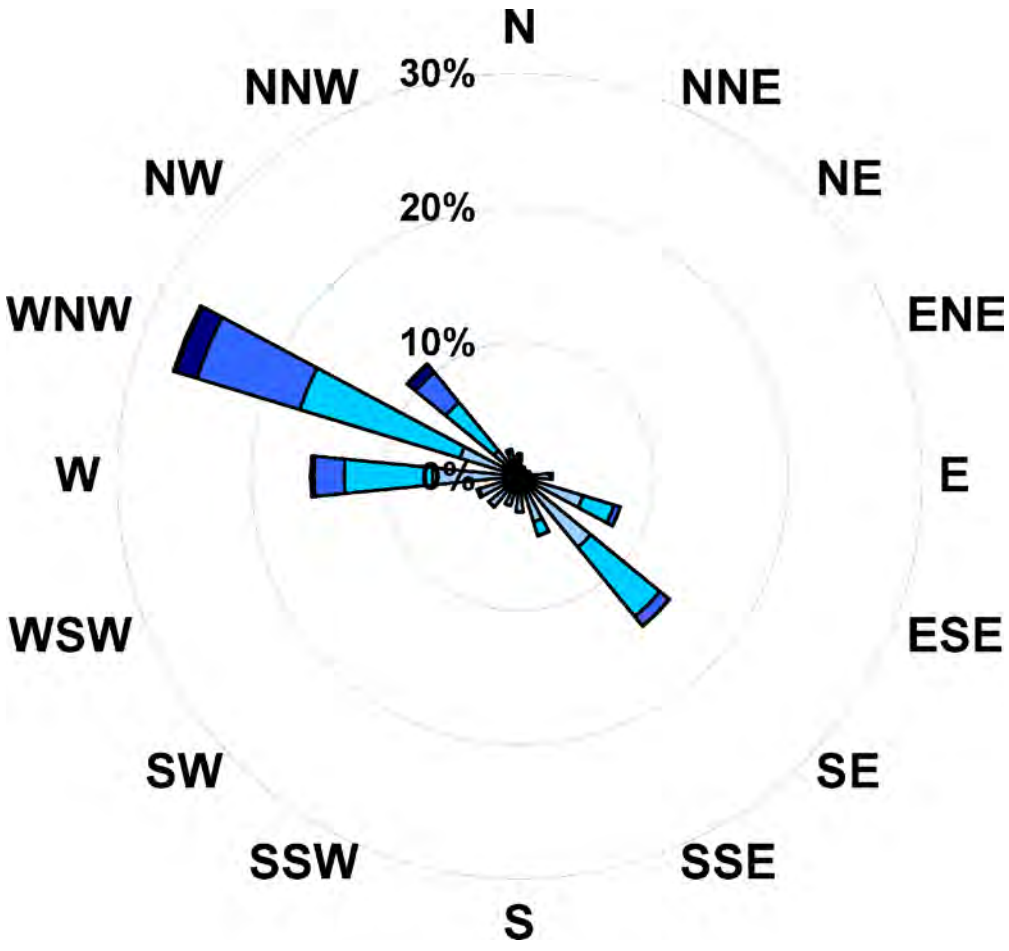

LEGEND

Wind Speed (km/h)

- >50
- 40-50
- 30-40
- 20-30
- 10-20
- 0-10

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

WIND ROSE OF HOURLY WINDS AT CROWSNEST (2010 - 2019)

Data Source: Environment Canada (2019)

MILLENNIUM EMS Solutions Ltd.

PROJECT:	14-00201
DRAWN BY:	JLAMBERTS
CHECKED BY:	MB
DATE:	DECEMBER 18, 2019
FIGURE	6.1-8

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Air_Q\Resubmission\Information Request 2019-05-09\Fig 6-1-8 Wind Rose of Hourly Winds at Crowsnest 14-00201.mxd

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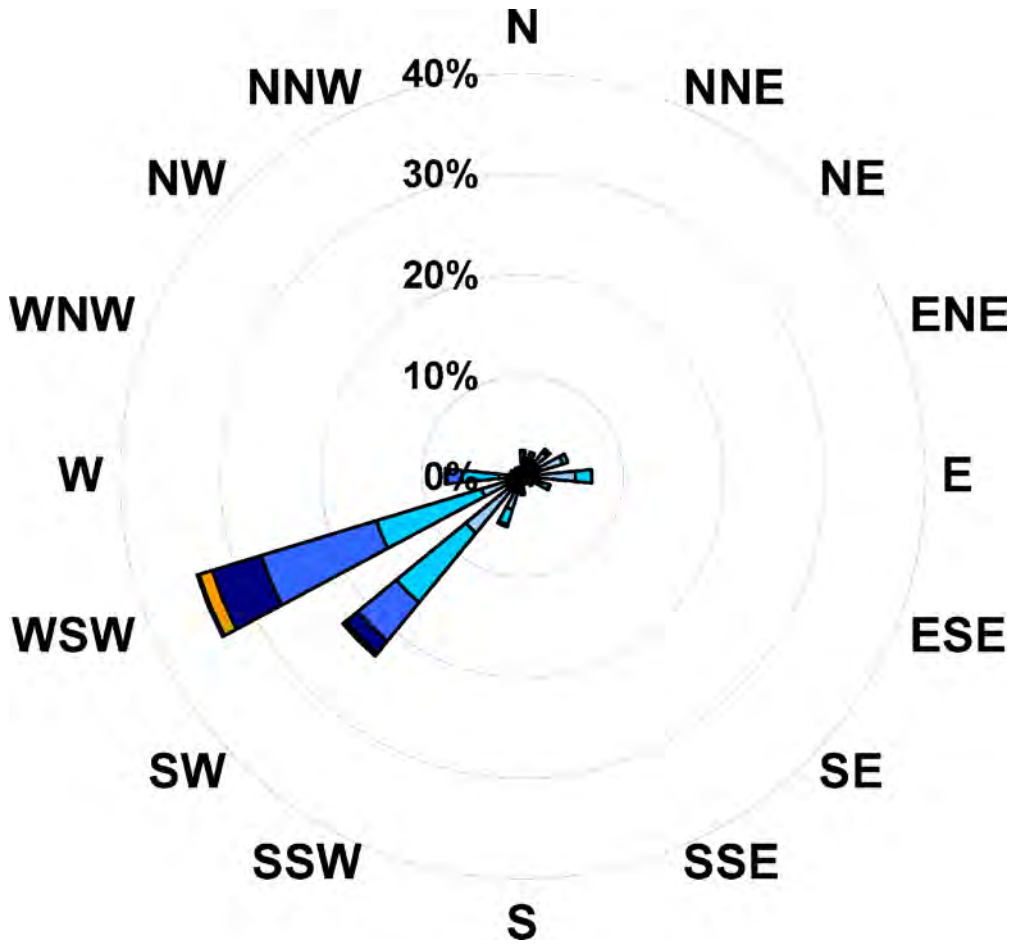

LEGEND

Wind Speed (km/h)

- >50
- 40-50
- 30-40
- 20-30
- 10-20
- 0-10

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

WIND ROSE OF HOURLY WINDS AT BEAVER MINES (2012 - 2019)

Data Source: Environment Canada (2019)

MILLENNIUM EMS Solutions Ltd.

PROJECT: 14-00201

DRAWN BY: JLAMBERTS

CHECKED BY: MB

DATE: DECEMBER 18, 2019

FIGURE

6.1-9

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Air_Q\Resubmission\Information Request 2019-05-09\Fig 6-1-9 Wind Rose of Hourly Winds at Beaver Mines 14-00201.mxd

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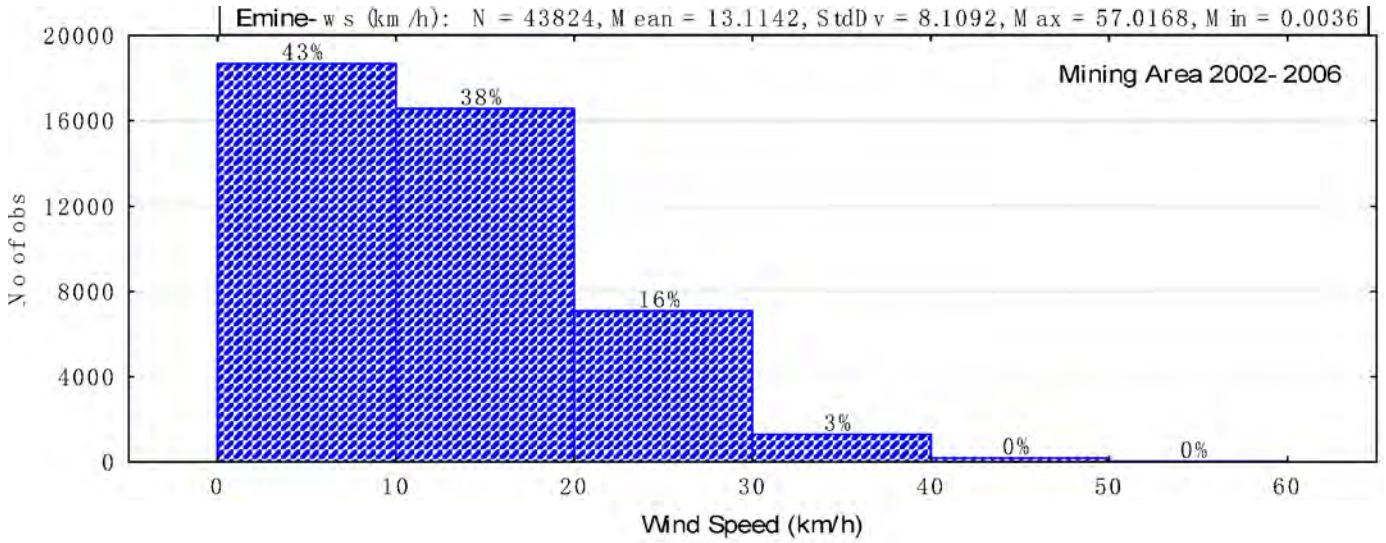

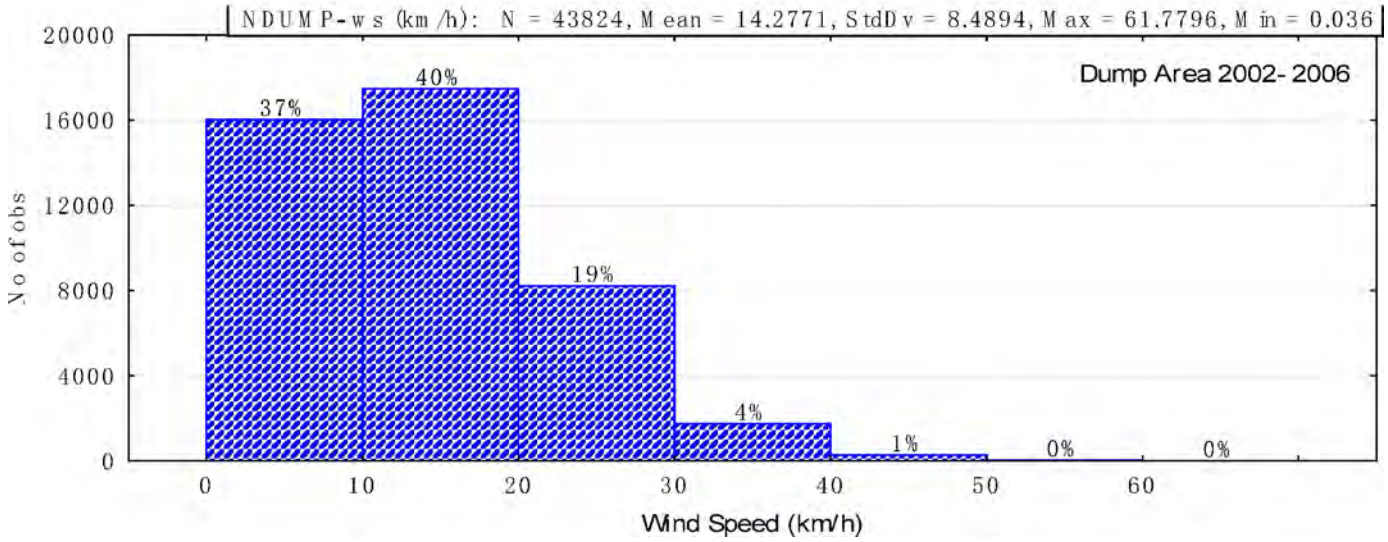

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

FREQUENCY DISTRIBUTION OF CALMET WIND AT MINING AREA AND DUMP AREAS (2002-2006)

Data Source: Environment Canada (2019)

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: DECEMBER 18, 2019

FIGURE
6.1-10

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Air_QRresubmission\Information Request 2019-05-09\Fig 6-1-10 Frequency Distribution of CALMET Wind 14-00201.mxd

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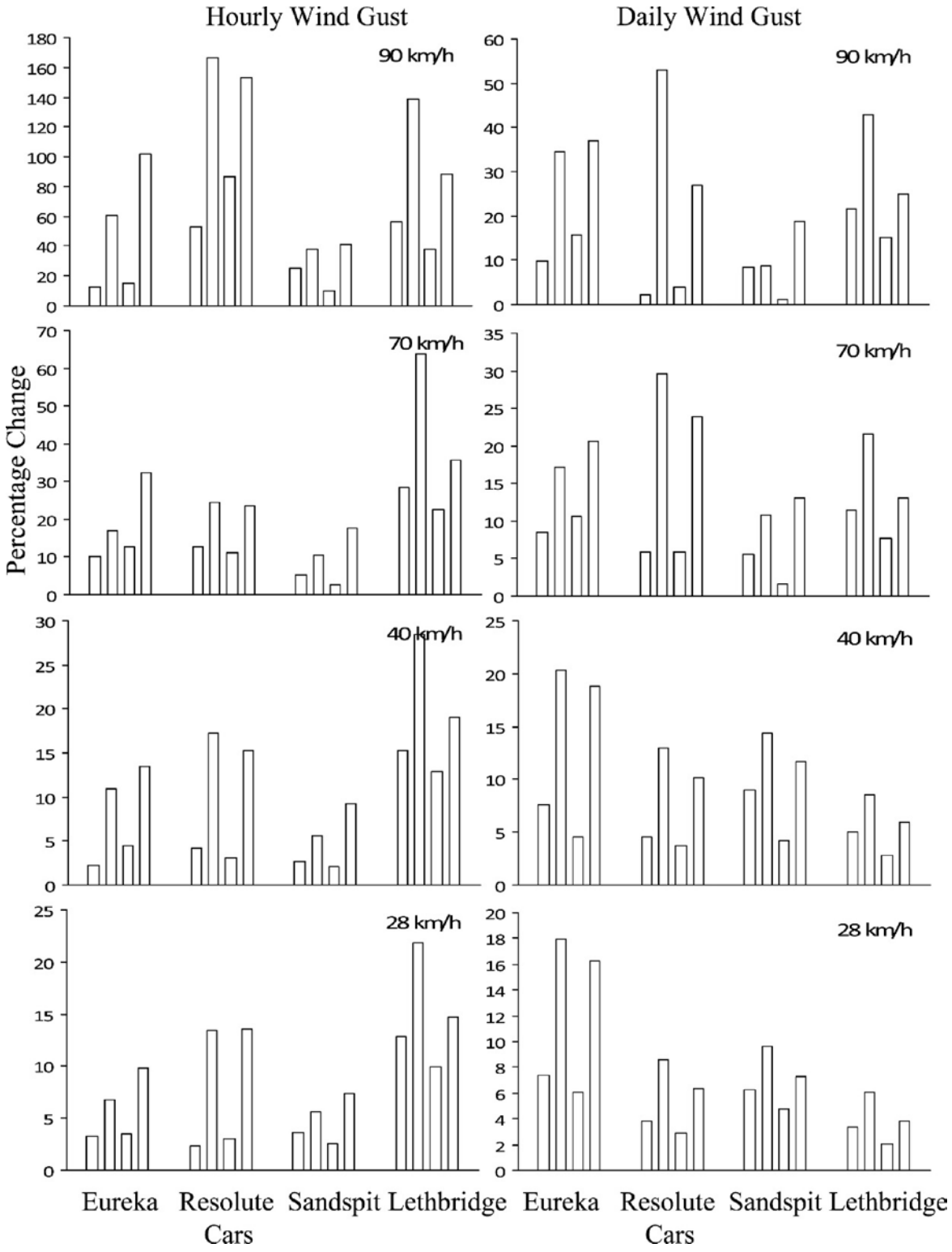

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

PREDICTIONS FOR WIND GUST INCREASES

Data Source: Cheng et al (2014)

MILLENNIUM EMS Solutions Ltd.

PROJECT:	14-00201
DRAWN BY:	JLAMBERTS
CHECKED BY:	RR
DATE:	JANUARY 13, 2020
FIGURE	6.1-11

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Air_QIResubmission\Information Request 2019-05-09\Fig 6-1-11 Wind Gust Increases 14-00201.mxd

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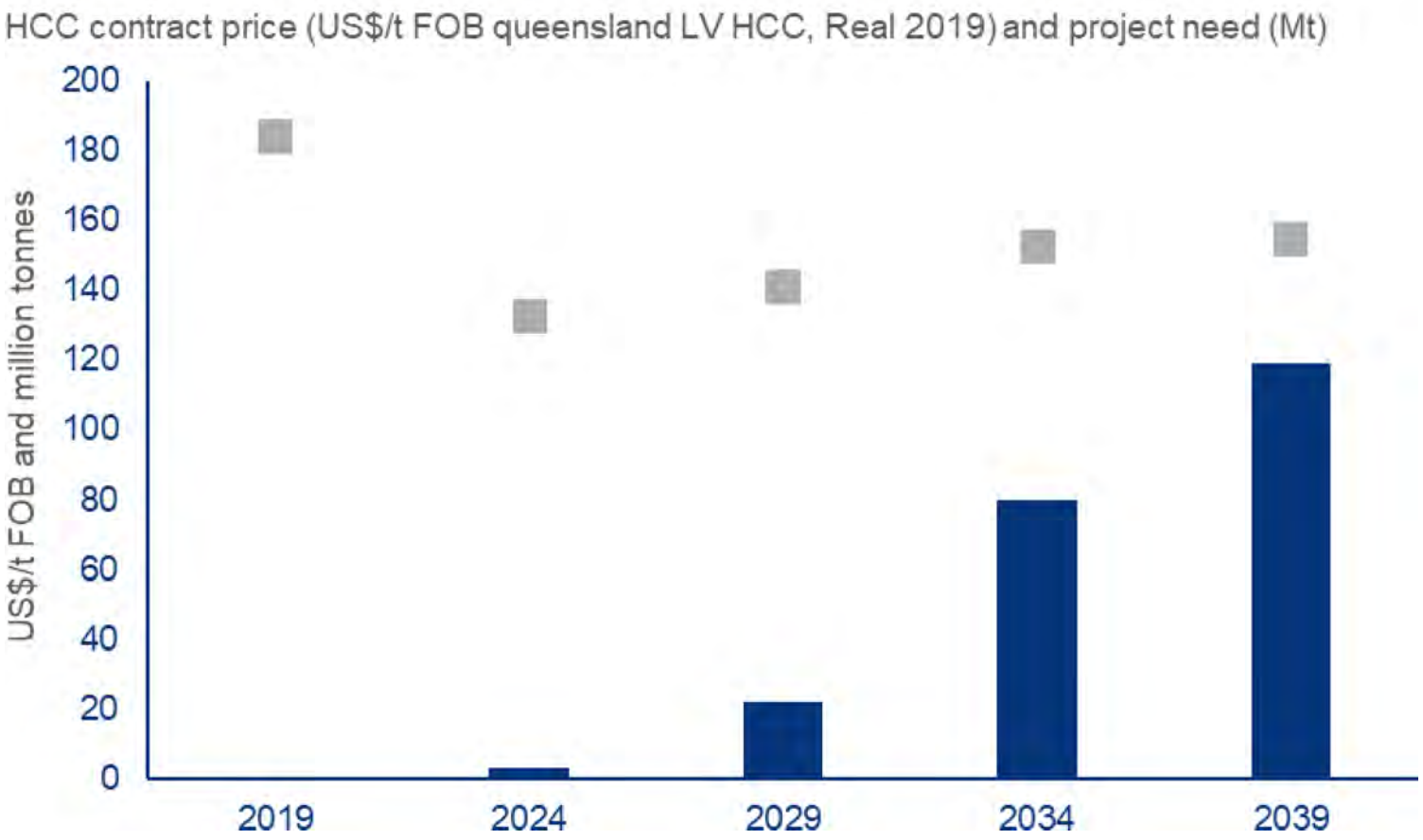
H2 2019 base case price forecast summary



LEGEND

- Project need
- Price LV HCC

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

H2 2019 BASE CASE PRICE FORECAST SUMMARY

Data Source: Wood Mackenzie Coal Market Service

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 24, 2020

FIGURE
6.3-1

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-3-1 H2 2019 Base Case Price Forecast 14-00201.mxd

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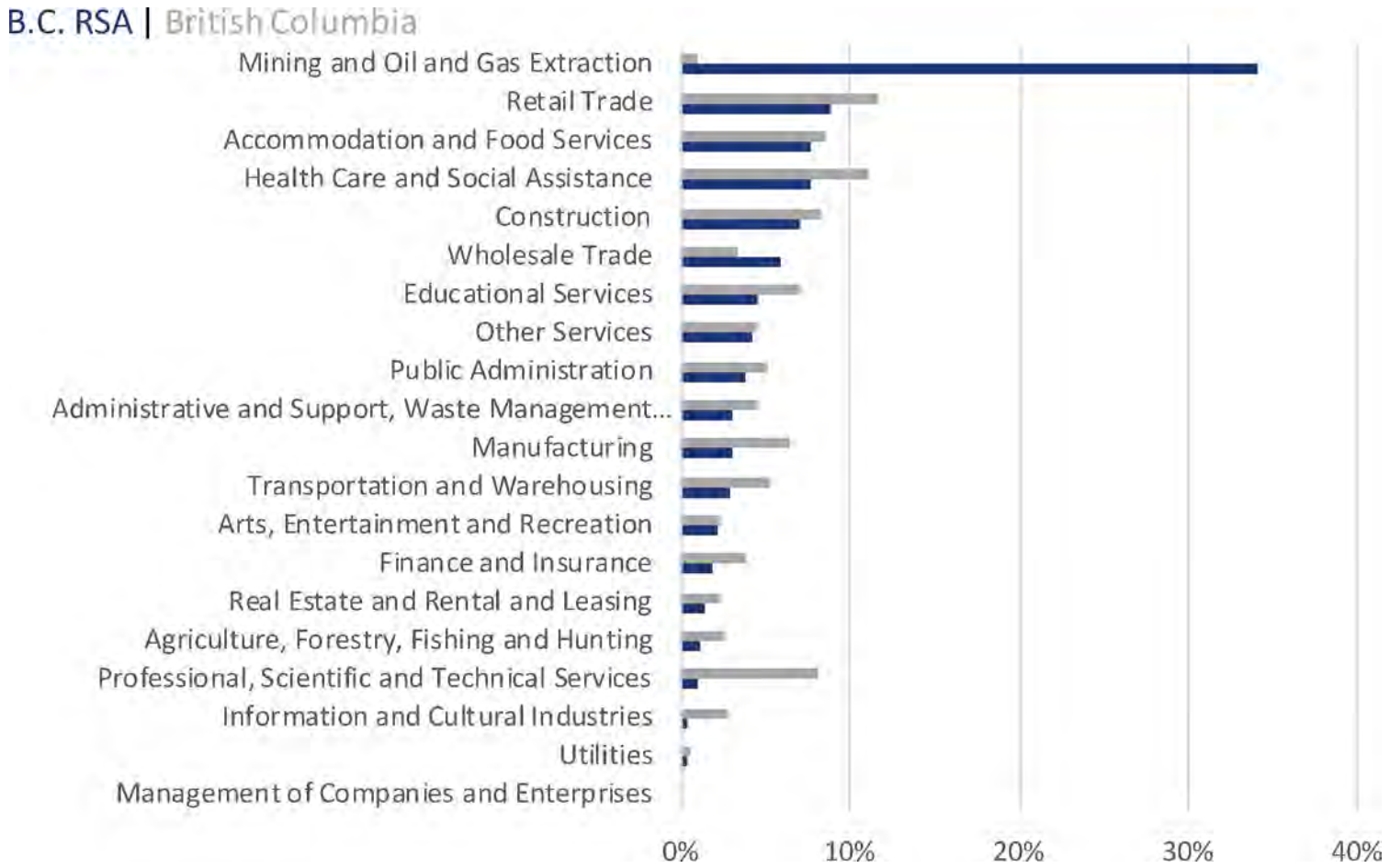

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

B.C. RSA LABOUR FORCE BY INDUSTRY

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 24, 2020

FIGURE
6.3-2

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-3-2 BC Labour Force by Industry14-00201.mxd

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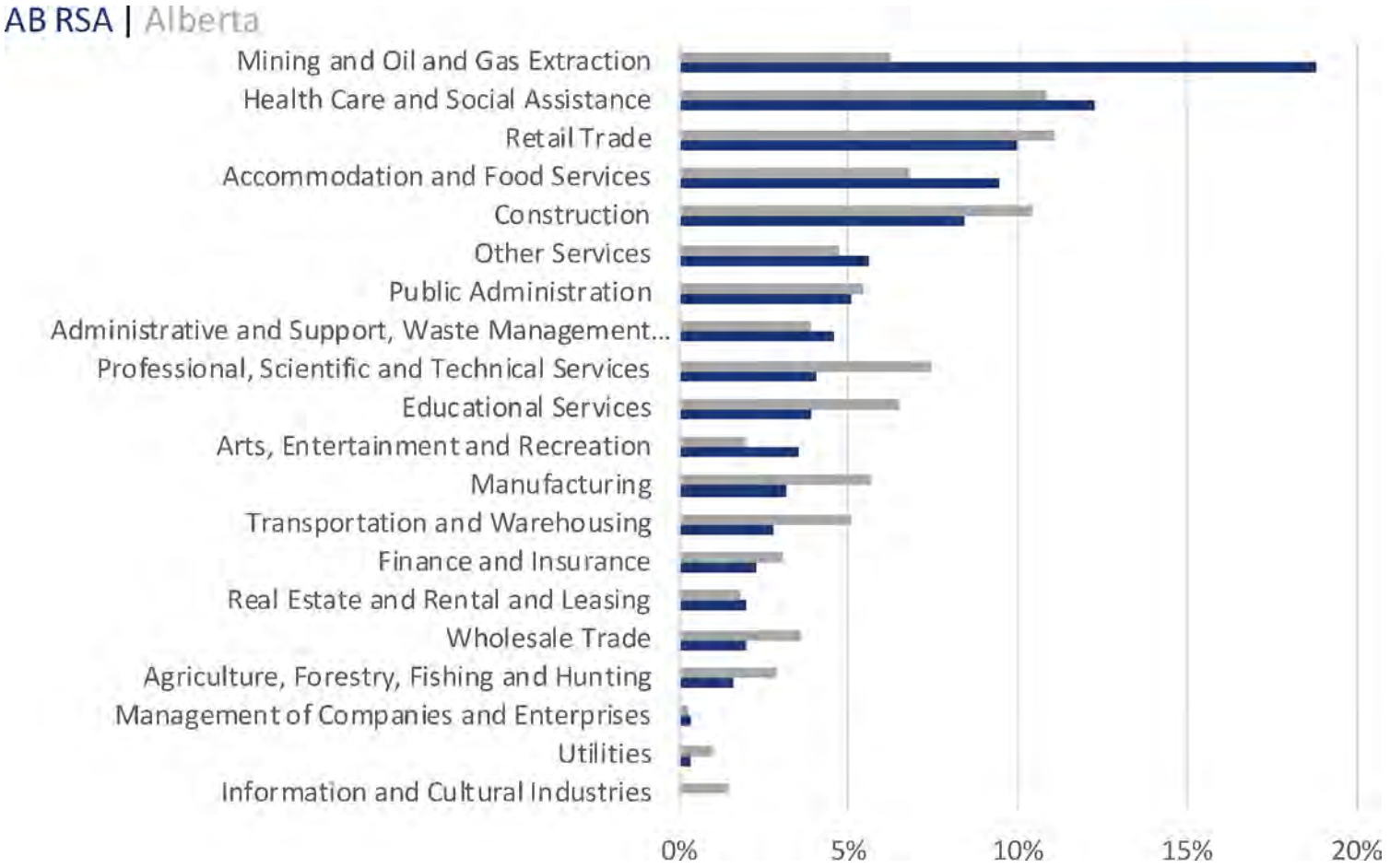

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

ALBERTA RSA LABOUR FORCE BY INDUSTRY

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 24, 2020

FIGURE
6.3-3

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-3-3 Alberta RSA Labour Force by Industry14-00201.mxd

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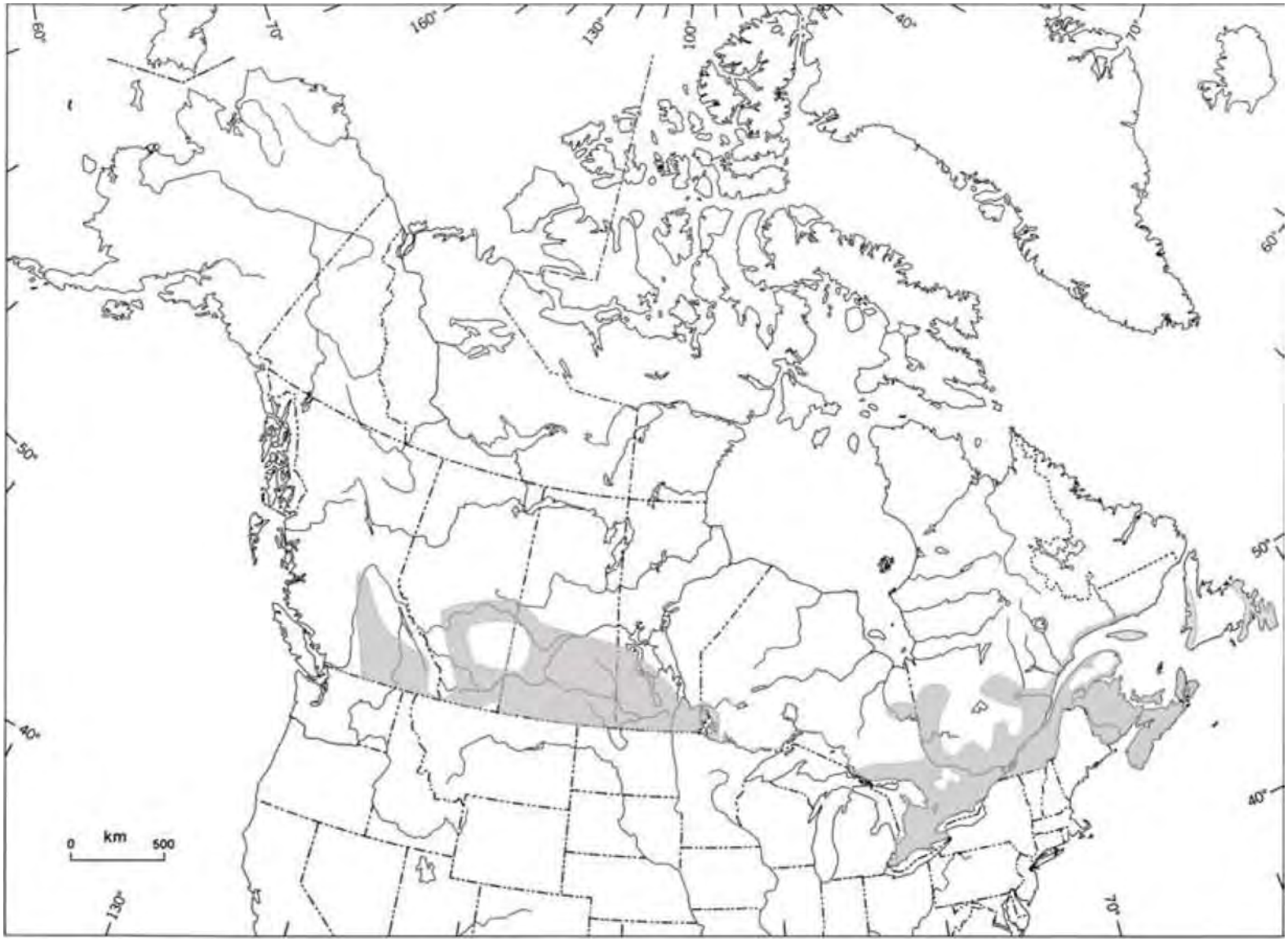

LEGEND

Bobolink Breeding Range

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

DISTRIBUTION OF THE BOBOLINK IN ALBERTA

COSEWIC, 2010

MILLENNIUM EMS Solutions Ltd.

PROJECT: 14-00201

DRAWN BY: JLAMBERTS

CHECKED BY: TB

DATE: FEBRUARY 18, 2020

FIGURE

6.10-1

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-10-1 Bobolink Distribution 14-00201.mxd

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R6 W5M | R5 W5M | R4 W5M | R3 W5M | R2 W5M | R1 W5M | R30 W4M | R29 W4M | R28 W4M

T10 | T9 | T7 | T6 | T5 | T4 | T3

Don Getty Wildland
Mt. Livingstone
Willow Creek
Livingstone Falls
Beehive
Honeymoon Creek
Bob Creek Wildland
British Columbia
Alberta
Oldman River North
Black Creek
Dutch Creek
Racehorse
Maycroft
22
PEIGAN TIMBER LIMIT 147B
Chinook
Crowsnest Pass
40
Island Lake
Coleman
Blairmore
3A
Lundbreck Falls
Cowley
Oldman Dam
3
PIKANI RESERVE NO. 147
Pincher Creek
Lynx Creek
Castle Falls
1635
Castle River Bridge
Beauvais Lake
Syncline
Beaver Mines Lake
West Castle Wetlands
British Columbia
Alberta

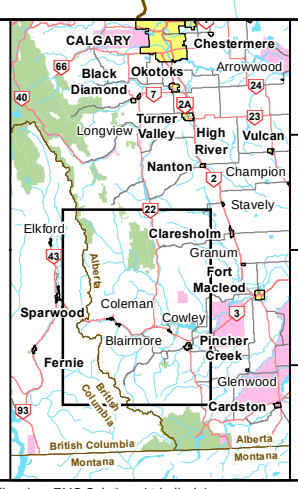
LEGEND

- ABMI Sample Site Location
- Primary Highway
- Secondary Highway
- Watercourse

Breeding Bird Survey Route

- 04-205 Coleman
- 04-304 Summerview
- 04-404 Trout Creek

- Waterbody
- Populated Place
- Indian Reserve/Metis Settlement
- Park/Protected Area
- Grizzly Bear Regional Study Area
- Project Location
- Wildlife Regional Study Area
- Wildlife Local Study Area
- Provincial Boundary



RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

BREEDING BIRD SURVEY ROUTES AND ABMI SAMPLE SITES IN THE VICINITY OF THE PROJECT

ABMI, 2020; AltaLIS, 2020; MEMS, 2020

Coordinate System: NAD 1983 UTM Zone 11N

0 10 20
Kilometres

MILLENNIUM EMS Solutions Ltd.

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: TB
DATE: FEBRUARY 18, 2020

FIGURE
6.10-2

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-10-2 BBS ABMI 14-00201.mxd

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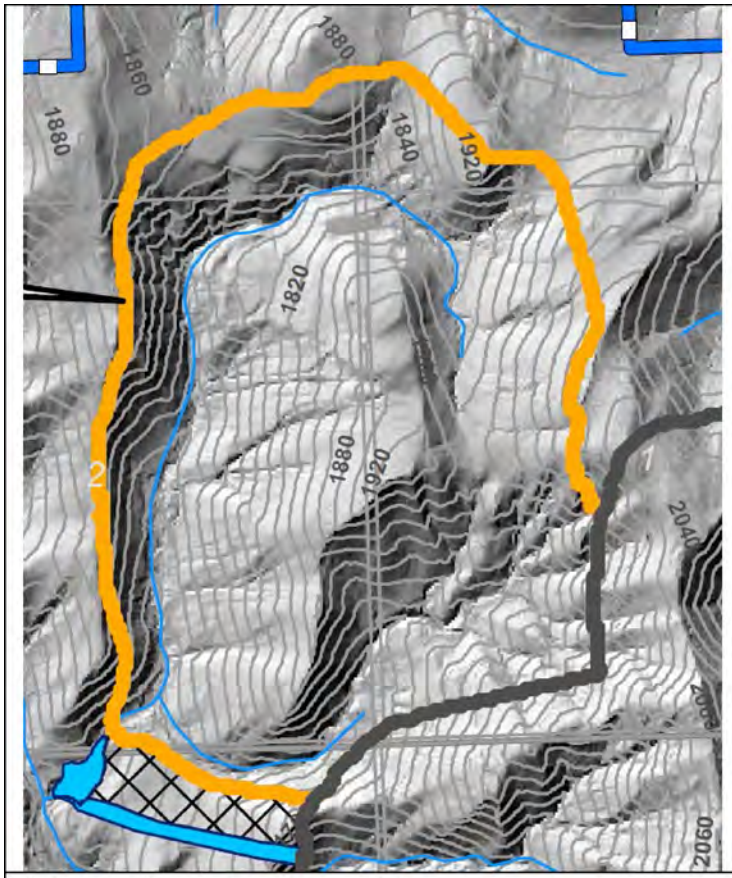

(a) North Rock Disposal Area
EIA Section A Project Introduction. Excerpt from Figure A.1.0-4 (CIAR#42)

(b) South Rock Disposal Area
EIA Section A Project Introduction. Excerpt from Figure A.1.0-4 (CIAR#42)

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

TOPOGRAPHY ASSOCIATED WITH THE PROJECTS PROPOSED EXPIT ROCK DISPOSAL AREAS

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 20, 2020

Data Source: MEMS, 2020

FIGURE
6.12-1

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-12-1 Topography of Rock Disposal Areas 14-00201.mxd

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R4 W5M

R3 W5M

T9

T8

T7

MW14-08-79

MW14-09-129

MW14-10-22

MW14-05-114

MW14-04-12

MW14-04-93

MW14-07-48

MW14-06-32

MW14-06-105

MW16-13-11

MW14-03-28

MW14-03-90

MW14-01-64

MW15-11-09

MW15-11-18.5

MW14-02-73

MW16-14-03

MW15-12-07

MW15-12-14

A

A'

B

B'

C

C'

D

D'

Vicary Creek

Daisy Creek

Caudron Creek

Forestry Trunk Road

Nez Percé Creek

Blairmore Creek

McGillivray Creek

Pelletier Creek

Gold Creek

Morin Creek

Green Creek

Crowsnest River

York Creek

Lyons Creek

Coleman

Blairmore

Frank

3

40

LEGEND

- Monitoring Well Location
- Existing Railway
- Primary Highway
- Secondary Highway
- Hydrogeological Cross-Section Line
- Blairmore Creek; Gold Creek
- Surface Water Drainage
- Surface Water Body
- Proposed Mine Permit Boundary
- LSA
- RSA

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

CROSS-SECTION LOCATIONS

AltaLIS, 2020; MEMS, 2020

Coordinate System: NAD 1983 UTM Zone 11N

0 1 2 Kilometres

MILLENNIUM EMS Solutions Ltd.

PROJECT: 14-00201

DRAWN BY: JLAMBERTS

CHECKED BY: TB

DATE: FEBRUARY 24, 2020

FIGURE 6.12-2

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-12-2 Cross-Section Locations 14-00201.mxd

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A
WEST

A'
EAST

1200m West to MPB

360m East to MPB

MW14-01-64*
(104m South, 1560.9m)

West Release Pond

East Release Pond

Turtle Mountain Thrust

(1506.7)
K = 2.3E-6 m/s

Tributary

Blairmore Creek

Tributary

Gold Creek

1700RL
1600RL
1500RL
1400RL
1300RL
1200RL
1100RL
1000RL
900RL
890RL

1525 m
1550 m
1575 m

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 metres

LEGEND

Geology

- Topography at Baseline
- Reverse Fault
- Blairmore Group
- Cadomin Formation
- Seam 1
- Seam 2
- Seam 4
- Fernie Group
- Kootenay Group

Mine

- Approximate Ultimate Pit Depth

Interpreted Geology

- Reverse Fault
- Blairmore Group
- Cadomin Formation
- Kootenay Group
- Paleozoic
- Fernie Group

MW14-01-64
(1506.7) Groundwater Elevation (m) Measured October 2014
Monitoring Well Screened Interval
K = 2.3E-6 m/s Hydraulic Conductivity

Hydrogeology / Hydrology

- 1575m Potentiometric Contour (Modelled Average Baseline from Numerical Model)
- Flow Direction
- Surface Water (Creek)
- Groundwater Divide

* - Well is Projected into the Cross-Section Line MPB = Mine Permit Boundary

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

HYDROGEOLOGICAL CROSS-SECTION AA' - Baseline

Update to EIA Consultant Report #3, Figure 4.2-5, CIAR#42

MEMS, 2016; Riversdale, 2016; srK, 2016

PROJECT:	14-00201
DRAWN BY:	JDC/JL
CHECKED BY:	CH
DATE:	FEBRUARY 24, 2020

0 100 200 300 400
Metres

FIGURE
6.12-3

K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Groundwater\Figure 9 - Section AA' 1080.dwg

A
WEST

A'
EAST

Ultimate Pit Extent

Saturated Fill Zone

Ultimate Rock Disposal Area Extent

1200m West to MPB

MW14-01-64*
(104m South, 1560.9m)

West Release Pond

East Release Pond

Turtle Mountain Thrust

Dam

SESP

360m East to MPB

Tributary

Blairmore Creek

Tributary

Gold Creek

1700RL
1600RL
1500RL
1400RL
1300RL
1200RL
1100RL
1000RL
900RL
890RL

1450 m
1475 m
1500 m
1525 m
1550 m
1575 m
1600 m

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 metres

K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201MXD\Final Figures\Groundwater\Figure 9 - Section AA' 1080.dwg

LEGEND

Geology

- Topography at Baseline
- Reverse Fault
- Topography at EOM
- Blairmore Group
- Cadomin Formation
- Seam 1
- Seam 2
- Seam 4
- Fernie Group
- Kootenay Group

Mine

- Approximate Ultimate Pit Depth
- Rock Disposal Area

* - Well is Projected into the Cross-Section Line

MPB = Mine Permit Boundary
SESP = South East Surge Pond

Interpreted Geology

- Reverse Fault
- Blairmore Group
- Cadomin Formation
- Kootenay Group
- Paleozoic
- Fernie Group

MW14-01-64 — Monitoring Well

Hydrogeology / Hydrology

- 1575m — Potentiometric Contour (Modelled Average Baseline from Numerical Model)
- Flow Direction
- Groundwater Divide
- Water Level at Southern Saturated Fill Zone
- Surface Water (Creek)

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

HYDROGEOLOGICAL CROSS-SECTION AA' - EOM

Update to EIA Consultant Report #3, Figure 4.2-5, CIAR#42

MEMS, 2016; Riversdale, 2016; srK, 2016

PROJECT:	14-00201
DRAWN BY:	JDC/JL
CHECKED BY:	MB
DATE:	FEBRUARY 24, 2020

FIGURE **6.12-4**

0 100 200 300 400
Metres

A
WEST

A'
EAST

Ultimate Pit Extent

Saturated Fill Zone

Ultimate Rock Disposal Area Extent

1200m West to MPB

MW14-01-64*
(104m South, 1560.9m)

West Release Pond

East Release Pond

Turtle Mountain Thrust

Dam

SESP

360m East to MPB

Tributary

Blairmore Creek

Tributary

Gold Creek

1700RL
1600RL
1500RL
1400RL
1300RL
1200RL
1100RL
1000RL
900RL
890RL

1450 m
1475 m
1500 m
1525 m
1550 m
1575 m
1600 m

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 metres

K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Groundwater\Figure 9 - Section AA' 1080.dwg

LEGEND

Geology

- Topography at Baseline
- Reverse Fault
- Topography at EOM
- Blairmore Group
- Cadomin Formation
- Seam 1
- Seam 2
- Seam 4
- Fernie Group
- Kootenay Group

Mine

- Approximate Ultimate Pit Depth
- Rock Disposal Area

'- Well is Projected into the Cross-Section Line

MPB = Mine Permit Boundary
SESP = South East Surge Pond

Interpreted Geology

- Reverse Fault
- Blairmore Group
- Cadomin Formation
- Kootenay Group
- Paleozoic
- Fernie Group

MW14-01-64
Monitoring Well Screened Interval

Hydrogeology / Hydrology

- 1575m — Potentiometric Contour (Modelled Average Baseline from Numerical Model)
- Flow Direction
- Groundwater Divide
- Water Level at Southern Saturated Fill Zone
- Surface Water (Creek)

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

HYDROGEOLOGICAL CROSS-SECTION AA' - LTC

Update to EIA Consultant Report #3, Figure 4.2-5, CIAR#42

MEMS, 2016; Riversdale, 2016; srK, 2016

PROJECT:	14-00201
DRAWN BY:	JDC/JL
CHECKED BY:	MB
DATE:	FEBRUARY 24, 2020

FIGURE 6.12-5

0 100 200 300 400
Metres

D
WEST

D'
EAST

4170m West to MPB

MPB

MW14-04-12*
(12m North, 1866.5m)
MW14-04-93*
(12m North, 1867.0m)

MW14-05-114*
(193m North, 1945.6m)

(1921.0)
K = 3.6E-8 m/s

MW14-07-48*
(64m North, 1853.5m)

(1838.7)
K = 1.5E-7 m/s

(1844.8)

(1823.8)
K = 1.3E-8 m/s

Tributary

Tributary

Blairmore
Creek

Gold
Creek

2100RL
2000RL
1900RL
1800RL
1700RL
1600RL
1500RL
1400RL
1300RL
1200RL
1100RL

1600 m
1700 m
1725 m
1750 m
1775 m
1800 m
1825 m
1850 m
1875 m
1900 m
1775 m
1750 m
1725 m
1700 m
1675 m
1650 m
1625 m
1600 m
1650 m

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200 3400 3600 3800 metres

K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Groundwater\Figure 12 - Section DD' 2480.dwg

LEGEND

Geology

- Topography at Baseline
- Reverse Fault
- Blairmore Group
- Cadomin Formation
- Seam 1
- Seam 2
- Seam 4
- Fernie Group
- Kootenay Group

Mine

- Approximate Ultimate Pit Depth

Interpreted Geology

- Reverse Fault
- Blairmore Group
- Cadomin Formation
- Kootenay Group
- Paleozoic
- Fernie Group

MW14-04-12
(1506.7) Groundwater Elevation (m)
Measured October 2014
Monitoring Well
Screened Interval

K = 2.3E-6 m/s Hydraulic Conductivity

Hydrogeology / Hydrology

- 1575m — Potentiometric Contour (Modelled Average Baseline from Numerical Model)
- Flow Direction
- Surface Water (Creek)
- Groundwater Divide

* - Well is Projected into the Cross-Section Line MPB = Mine Permit Boundary

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

HYDROGEOLOGICAL CROSS-SECTION DD' - Baseline

Update to EIA Consultant Report #3, Figure 4.2-5, CIAR#42

MEMS, 2016; Riversdale, 2016; srK, 2016

PROJECT:	14-00201
DRAWN BY:	JDC/JL
CHECKED BY:	MB
DATE:	FEBRUARY 24, 2020

0 100 200 400 600
Metres

FIGURE
6.12-6

D
WEST

D'
EAST

Ultimate Pit Extent

4170m West to MPB

MPB

Dam

Undisturbed Area

Saturated Fill Zone

MW14-04-12* (12m North, 1866.5m)

MW14-04-93* (12m North, 1867.0m)

MW14-05-114* (193m North, 1945.6m)

Saturated Fill Zone

MW14-07-48* (64m North, 1853.5m)

Tributary

Tributary

Blairmore Creek

Gold Creek

2100RL
2000RL
1900RL
1800RL
1700RL
1600RL
1500RL
1400RL
1300RL
1200RL
1100RL

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200 3400 3600 3800 metres

K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Groundwater\Figure 12 - Section DD' 2480.dwg

LEGEND

Geology

- Topography at Baseline
- Reverse Fault
- Topography at EOM
- Blairmore Group
- Cadomin Formation
- Seam 1
- Seam 2
- Seam 4
- Fernie Group
- Kootenay Group

Mine

- Approximate Ultimate Pit Depth
- Rock Disposal Area

Interpreted Geology

- Reverse Fault
- Blairmore Group
- Cadomin Formation
- Kootenay Group
- Paleozoic
- Fernie Group
- MW14-04-12 — Monitoring Well Screened Interval

Hydrogeology / Hydrology

- 1575m — Potentiometric Contour (Modelled Average Baseline from Numerical Model)
- Flow Direction
- Groundwater Divide
- Water Level at Southern Saturated Fill Zone
- Surface Water (Creek)

' - Well is Projectec into the Cross-Section Line MPB = Mine Permit Boundary

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

HYDROGEOLOGICAL CROSS-SECTION DD' - EOM

Update to EIA Consultant Report #3, Figure 4.2-5, CIAR#42

MEMS, 2016; Riversdale, 2016; srK, 2016

PROJECT:	14-00201
DRAWN BY:	JDC/JL
CHECKED BY:	MB
DATE:	FEBRUARY 24, 2020

0 100 200 400 600
Metres

FIGURE
6-12.7

D
WEST

D'
EAST

Ultimate Pit Extent

4170m West to MPB

MPB

Dam

Undisturbed Area

Saturated Fill Zone

MW14-04-12* (12m North, 1866.5m)
MW14-04-93* (12m North, 1867.0m)

MW14-05-114* (193m North, 1945.6m)

Saturated Fill Zone

MW14-07-48* (64m North, 1853.5m)

Tributary

Tributary

Blairmore Creek

Gold Creek

2100RL
2000RL
1900RL
1800RL
1700RL
1600RL
1500RL
1400RL
1300RL
1200RL
1100RL

0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200 3400 3600 3800 metres

LEGEND

Geology

- Topography at Baseline
- Reverse Fault
- Topography at EOM
- Blairmore Group
- Cadomin Formation
- Seam 1
- Seam 2
- Seam 4
- Fernie Group
- Kootenay Group

Mine

- Approximate Ultimate Pit Depth
- Rock Disposal Area

Interpreted Geology

- Reverse Fault
- Blairmore Group
- Cadomin Formation
- Kootenay Group
- Paleozoic
- Fernie Group
- MW14-04-12 — Monitoring Well Screened Interval

Hydrogeology / Hydrology

- 1575m — Potentiometric Contour (Modelled Average Baseline from Numerical Model)
- Flow Direction
- Groundwater Divide
- Water Level at Southern Saturated Fill Zone
- Surface Water (Creek)

* - Well is Projected into the Cross-Section Line MPB = Mine Permit Boundary

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

HYDROGEOLOGICAL CROSS-SECTION DD' - LTC

Update to EIA Consultant Report #3, Figure 4.2-5, CIAR#42

MEMS, 2016; Riversdale, 2016; srK, 2016

PROJECT: 14-00201
DRAWN BY: JDC/JL
CHECKED BY: MB
DATE: FEBRUARY 24, 2020

0 100 200 400 600
Metres

FIGURE
6.12-8

K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Groundwater\Figure 12 - Section DD' 2480.dwg

R4 W5M

R3 W5M

T9

T8

MW10-3

MW10-2

MW10-1

MW14-08-79

MW14-09-129

MW14-10-22

Ultimate Pit Extent

End Pit Lake

North Rock Disposal Area

North East Sediment Pond (NESP)

Northwest Surge Pond (NWSP)

MW1-1

MW4-1

MW4-2

West Sediment Pond (WSP)

Saturated Zone - 7 (1634m)

MW14-05-114

Saturated Zone - Lake (1702m)

MW14-04-12

MW14-04-93

MW14-07-48

MW6-1

MW6-2

MW9-1

MW14-06-105

MW14-06-32

East Sediment Pond (ESP)

MW6-3

MW16-13-11

MW5-1

MW5-2

MW14-03-90

MW14-03-28

Southwest Surge Pond (SWSP)

Saturated Zone - 6 (1465m)

MW14-01-64

Southeast Surge Pond (SESP)

MW11-1

MW2-1

MW2-2

MW16-14-03

MW19-16-7

Saturated Zone - 4 (1470m)

MW14-02-74

MW15-11-18.5

MW15-11-09

MW15-12-14

MW15-12-07

Plant Site Sedimentation Pond (PSSP)

MW19-15-9

MW19-15-16

MW7-1

MW12-1

MW7-2

MW14-1

Topsoil Storage

South Rock Disposal Area

Raw Water Pond (RWP)

MW14-2

Blairmore Creek

Gold Creek

Caudron Creek

Morin Creek

LEGEND

- Proposed Monitoring Well Location (N#1B)
- Proposed Monitoring Well Location (N#1S)
- Proposed Monitoring Well Location (N#2)
- Proposed Monitoring Well Location (N#3)
- Monitoring Well Location drilled for baseline EIA (MEMS 2014/2016)
- Release Point
- Groundwater Divide
- Interpreted Groundwater Flow Direction
- Reclaimed Topographic Contour (20m interval)
- Access Road
- Proposed Area for GW Wells
- End-Pit Lake
- Release Pond
- Dam
- Surge Pond (No Release)
- CHPP Facilities
- Proposed Mine Permit Boundary
- Ponds and Ditches
- Saturated Fill Zone

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

PROPOSED GROUNDWATER MONITORING NETWORK

MILLENNIUM EMS Solutions Ltd.

AltaLIS, 2020; MEMS, 2020

Coordinate System: NAD 1983 UTM Zone 11N

0 500 1,000 Metres

PROJECT: 14-00201

DRAWN BY: JLAMBERTS

CHECKED BY: AK

DATE: FEBRUARY 24, 2020

FIGURE 6.12-9

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-12-9 Proposed Groundwater Monitoring Network 14-00201.mxd

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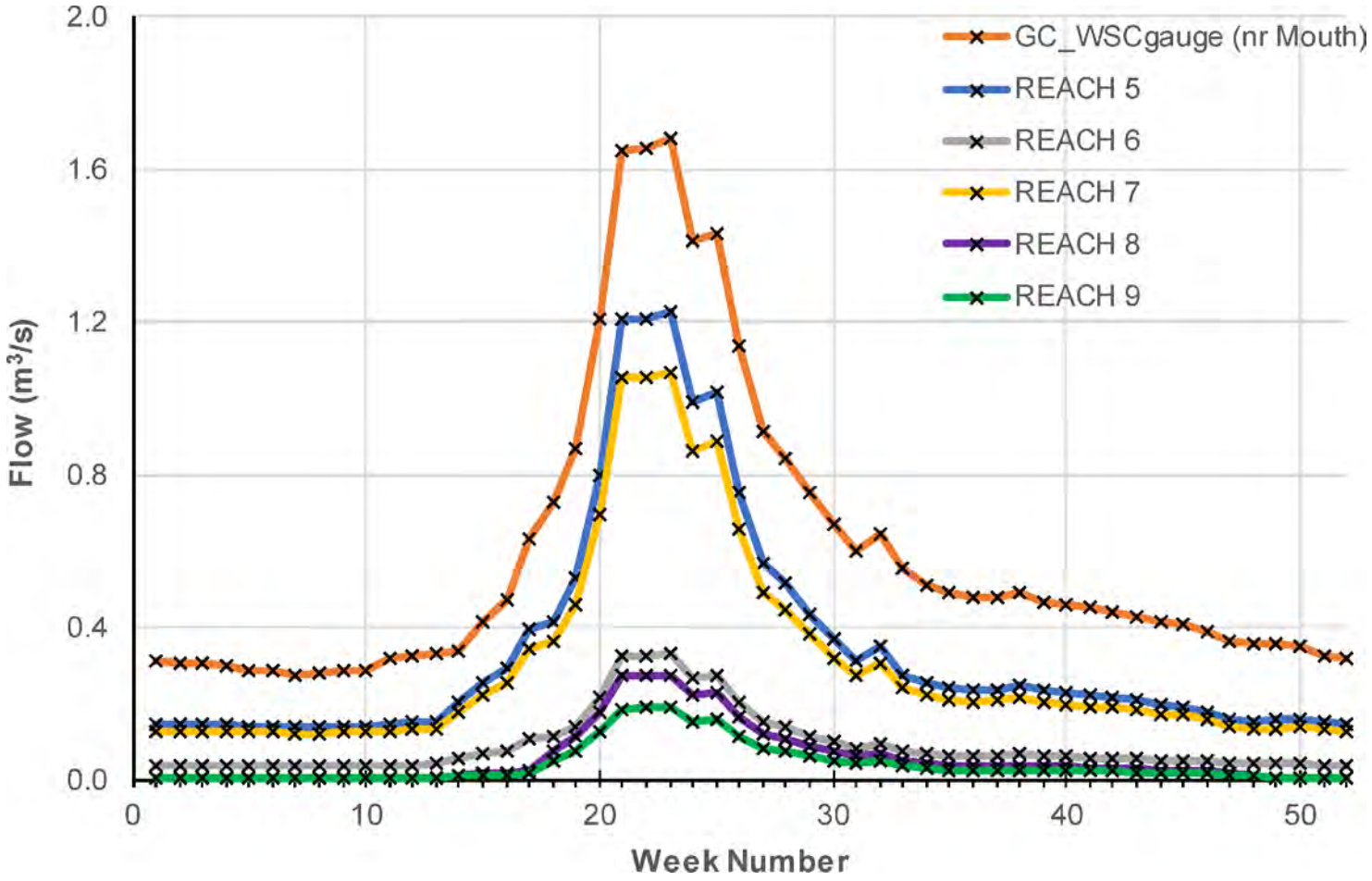

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

IFN VALUES CALCULATED ON WEEKLY GOLD CREEK SYNTHETIC FLOW DATA

Data Source: MEMS, 2020

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 12, 2020

FIGURE
6.13-1

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-13-1 IFN Values Gold Creek 14-00201.mxd

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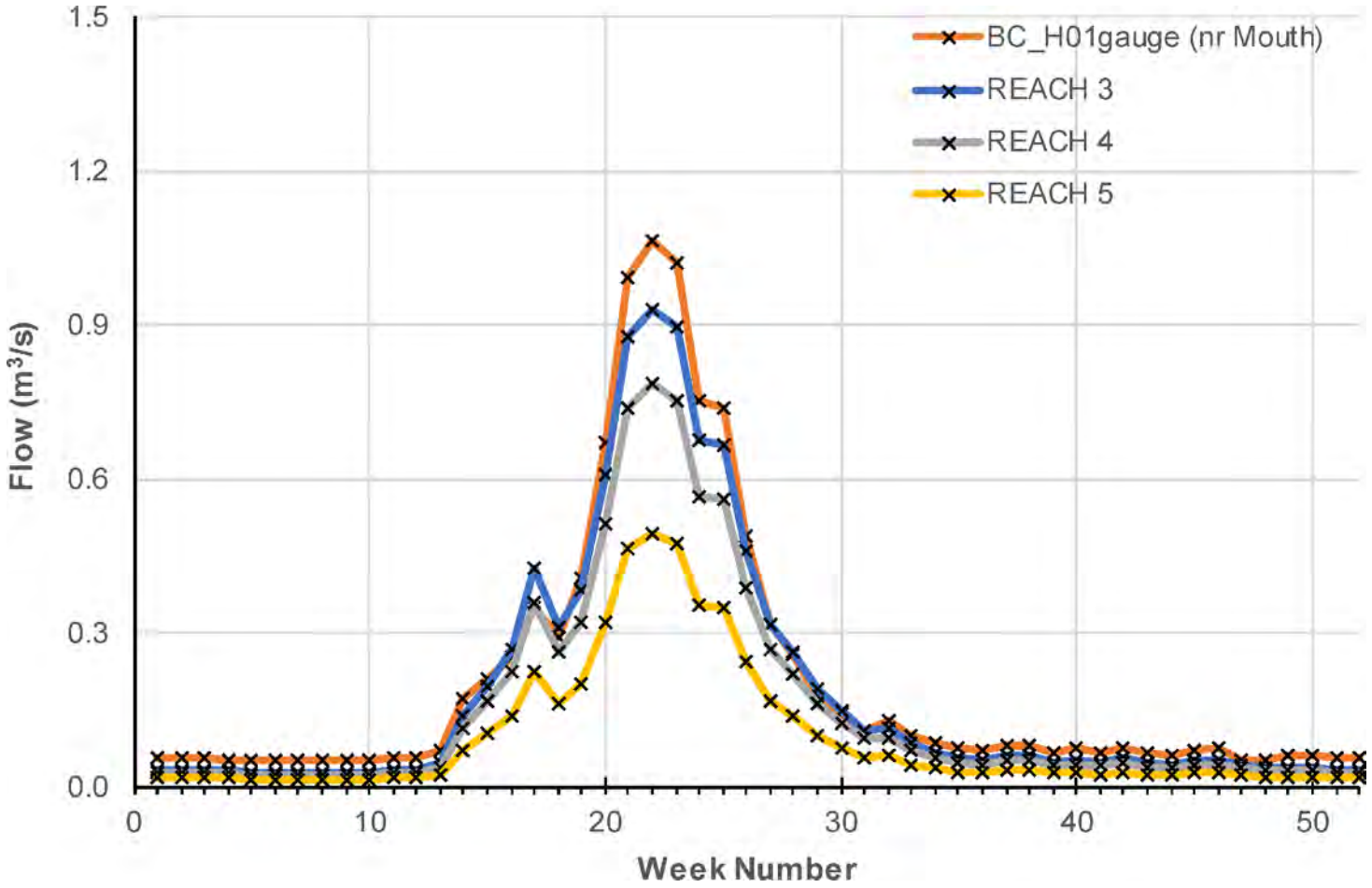

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

IFN VALUES CALCULATED ON WEEKLY BLAIRMORE CREEK SYNTHETIC FLOW DATA

Data Source: MEMS, 2020

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 12, 2020

FIGURE
6.13-2

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-13-2 IFN Values Blairmore Creek 14-00201.mxd

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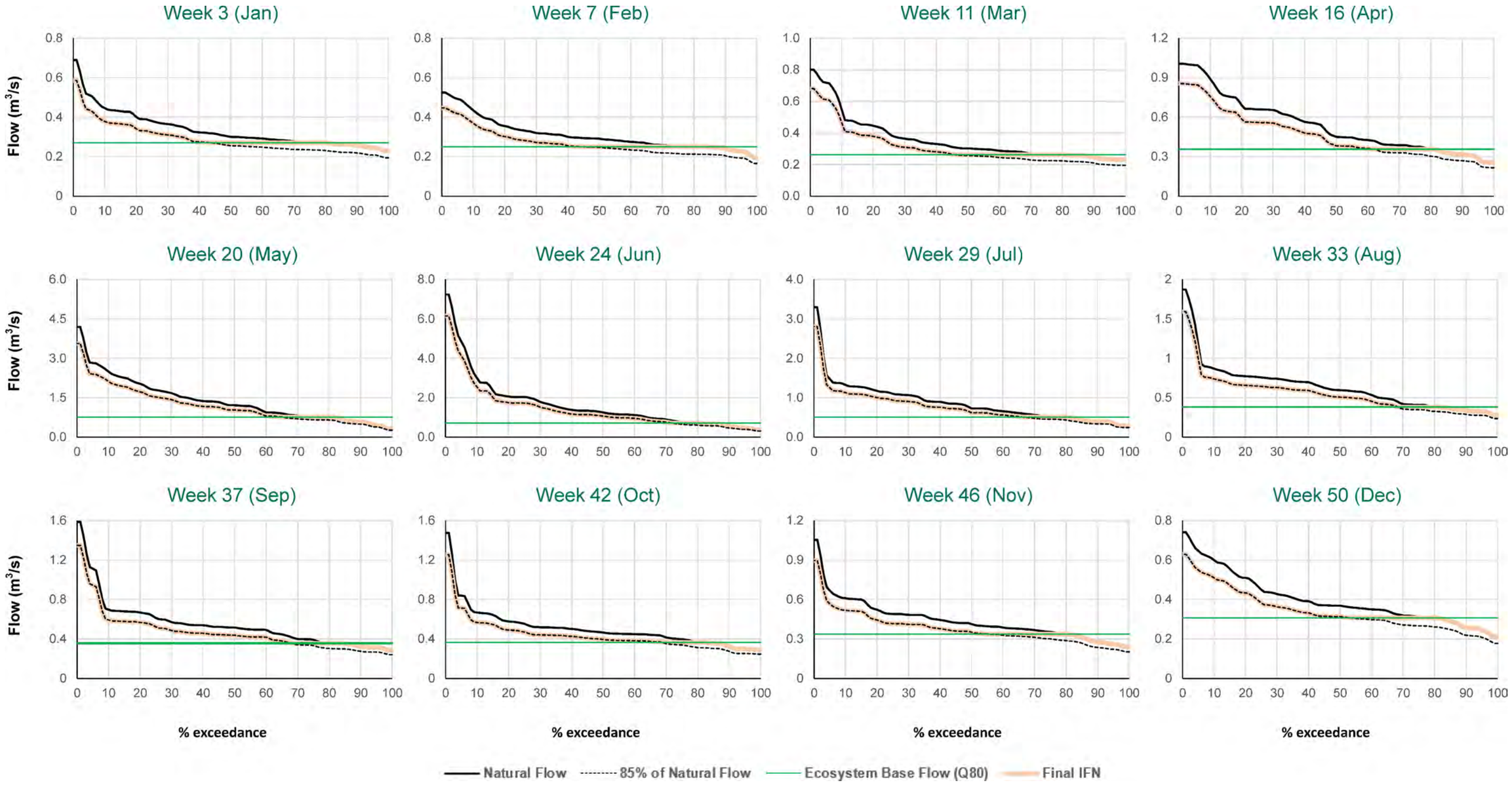


RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

IFN CALCULATIONS USING THE ALBERTA DESKTOP METHOD, FOR MIDDLE-OF-MONTH WEEKS AT GOLD CREEK NEAR MOUTH (WSC GAUGE)

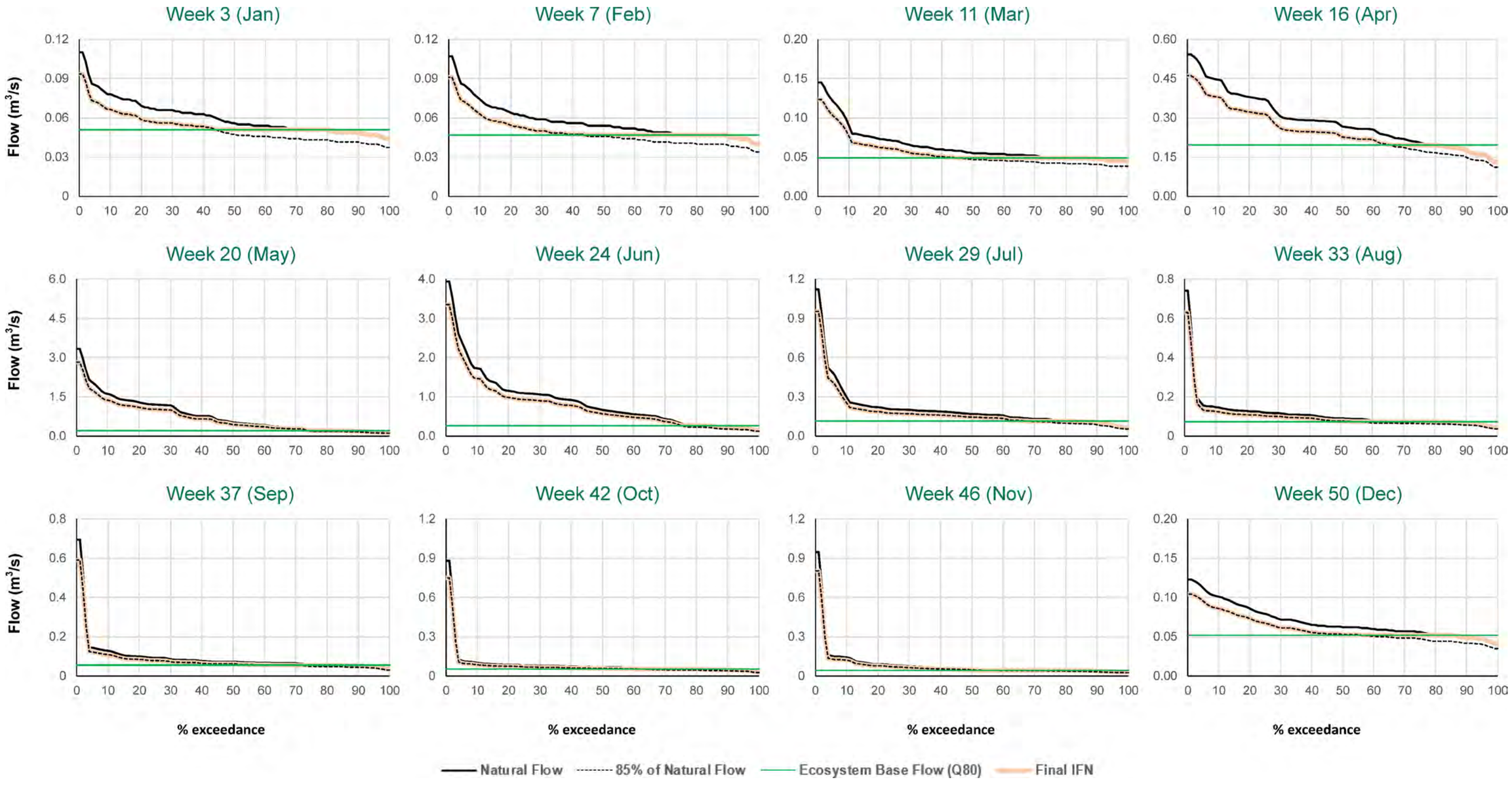
Data Source: MEMS, 2020

MILLENNIUM EMS Solutions Ltd.

PROJECT:	14-00201
DRAWN BY:	JLAMBERTS
CHECKED BY:	MB
DATE:	FEBRUARY 12, 2020
FIGURE	6.13-3

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6.13-3 IFN Calculations Gold Creek 14-00201.mxd

Disclaimer: This figure was derived from multiple data sources and while we make every effort to assure its accuracy, Millennium EMS Solutions Ltd. disclaims any representation or warranty and assumes no liability either for any errors, omission or inaccuracies that may occur.



RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

IFN CALCULATIONS USING THE ALBERTA DESKTOP METHOD, FOR MIDDLE-OF-MONTH WEEKS AT BLAIRMORE CREEK NEAR THE MOUTH (BL-H01 GAUGE)

Data Source: MEMS, 2020

MILLENNIUM EMS Solutions Ltd.

PROJECT:	14-00201
DRAWN BY:	JLAMBERTS
CHECKED BY:	MB
DATE:	FEBRUARY 12, 2020
FIGURE	6.13-4

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6.13-4 IFN Calculations Blairmore Creek 14-00201.mxd

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RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

FLOW CHANGES, RELATIVE TO BASELINE, ALONG GOLD CREEK DURING THE PROJECT (FIGURE 43 FROM SRK2016A)

Data Source: MEMS, 2020

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 12, 2020

FIGURE
6.13-5

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-13-5 Flow Changes Gold Creek 14-00201.mxd

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R4 W5M

R3 W5M

T9

T8

NRDA

Northwest Surge Pond
Year 6

Northeast
Sedimentation Pond
Year 14

Saturated Zone (SZ1636)
Year 20

Saturated Zone (SZ1700)
Year 24

B'

B

A'

A

Pit Area

Horizontal
Boreholes

BC-07

West Sedimentation Pond
Year 2

East
Sedimentation Pond
Year 6

CRDA

Phase 5 (1465m)
Year 12

BL-02

Southeast Surge Pond
Year 0

Southwest Surge Pond
Year 1

Post Closure Discharge Point

SRDA

Plant Site
Sedimentation Pond
Year 0

BC-03

Raw Water Pond
Year 0

Metals Treatment Plant

Caudron Creek

Morin Creek

LEGEND

- Release Point
- Dewatering Well
- Model Node

Distribution of Mature Spawning Habitat

- 0
- 1 - 10
- 11 - 20
- 21 - 30
- 31 - 40
- Reclaimed Topographic Contour
- Surface Water Drainage
- Cross-Section Location
- CHPP Facilities
- Access Road
- Proposed Haul Road
- Release Pond
- Dam
- Surge Pond (No Release)
- Proposed Mine Permit Boundary
- Project Footprint
- Undisturbed Area
- Saturated Fill Zone
- End-Pit Lake
- Water Treatment Plant
- Legacy Underground Mine
- Topsoil Replacement
- Rock Disposal Area
- Active Mining Area
- Disturbed Area

RIVERSDALE RESOURCES

GRASSY MOUNTAION COAL PROJECT

WATER MANAGEMENT INFRASTRUCTURES WITH OBSERVED FISH SPAWNING HABITAT

AltaLIS, 2020; Hatfield, 2020; MEMS, 2020

Coordinate System: NAD 1983 UTM Zone 11N

0 500 1,000
Metres

MILLENNIUM EMS Solutions Ltd.

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: MARCH 11, 2020

FIGURE
6.14-1

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-14-1 Water Management and Fish Spawning Habitat 14-00201.mxd

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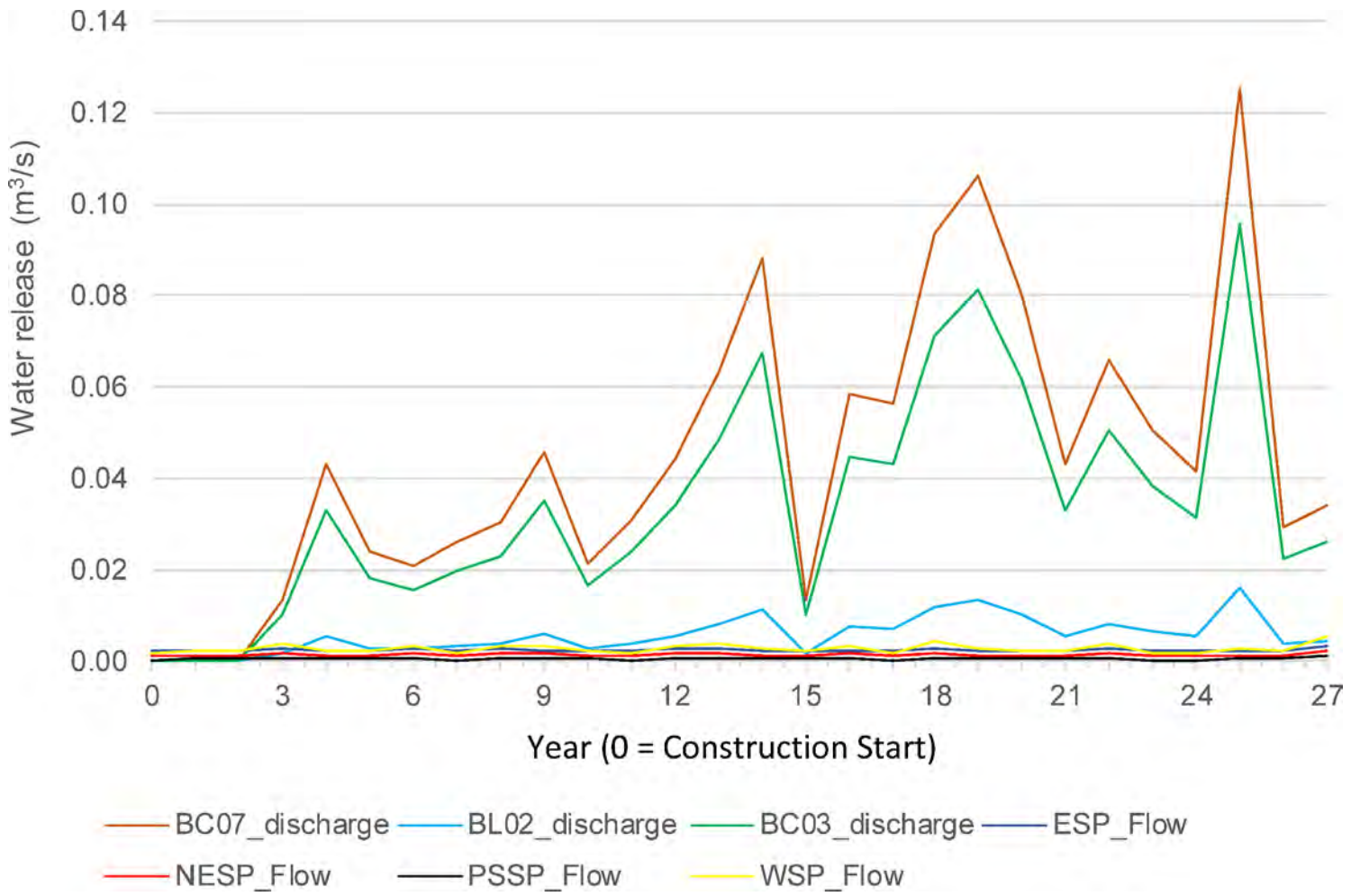

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

MONTHLY-PREDICTED PROJECT WATER RELEASES ACROSS THE PROJECT MINE-LIFE

Data Source: MEMS, 2020

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 20, 2020

FIGURE
6.15-1

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-15-1 Monthly Predicted Water Releases 14-00201.mxd

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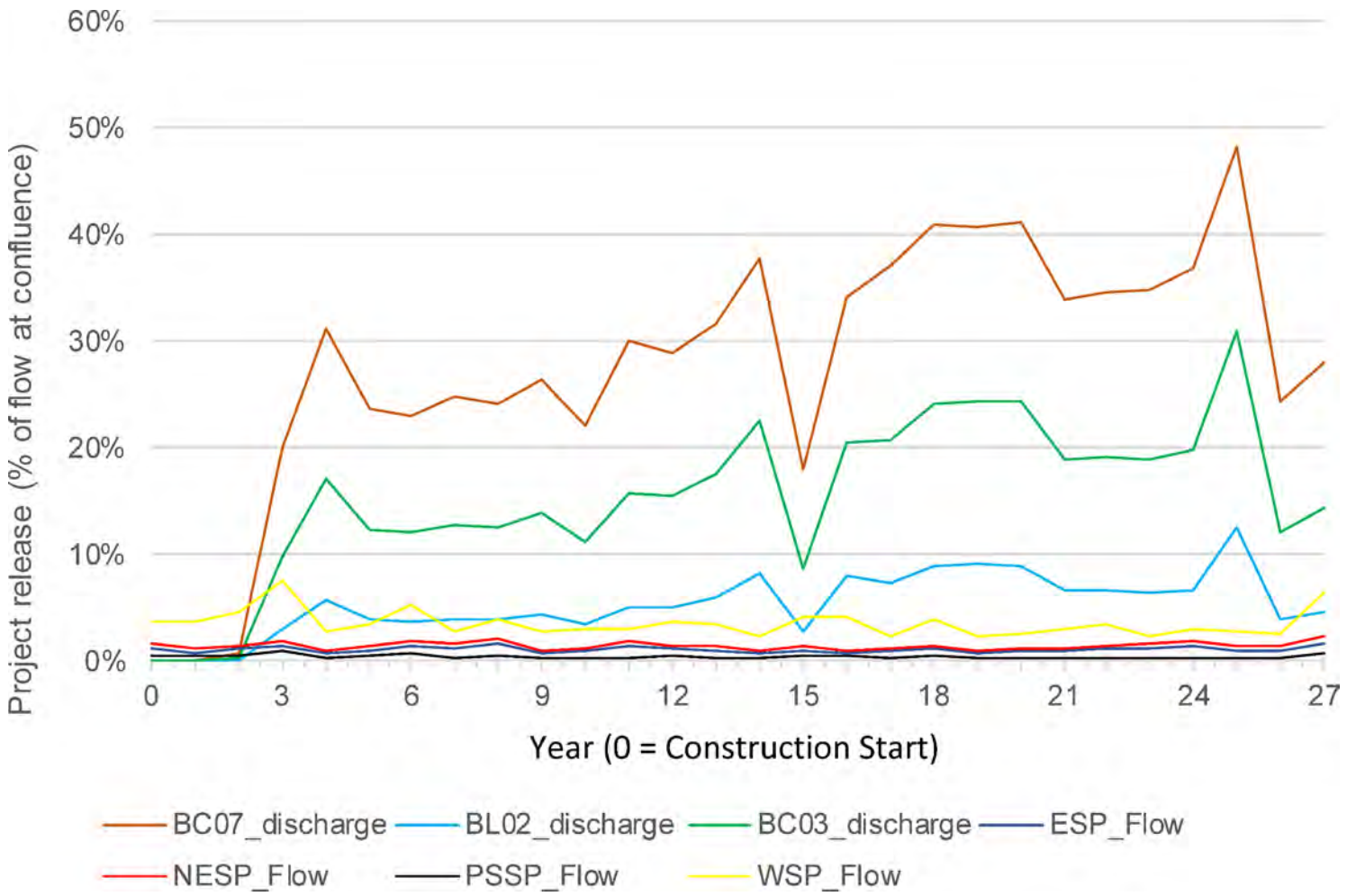

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

ANNUAL-PREDICTED PROJECT FLOW CONTRIBUTIONS FROM WATER MANAGEMENT FEATURES AT EACH CORRESPONDING CREEK CONFLUENCE

Data Source: MEMS, 2020

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 20, 2020

FIGURE
6.15-2

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-15-2 Annual Predicted Flow Contributions 14-00201.mxd

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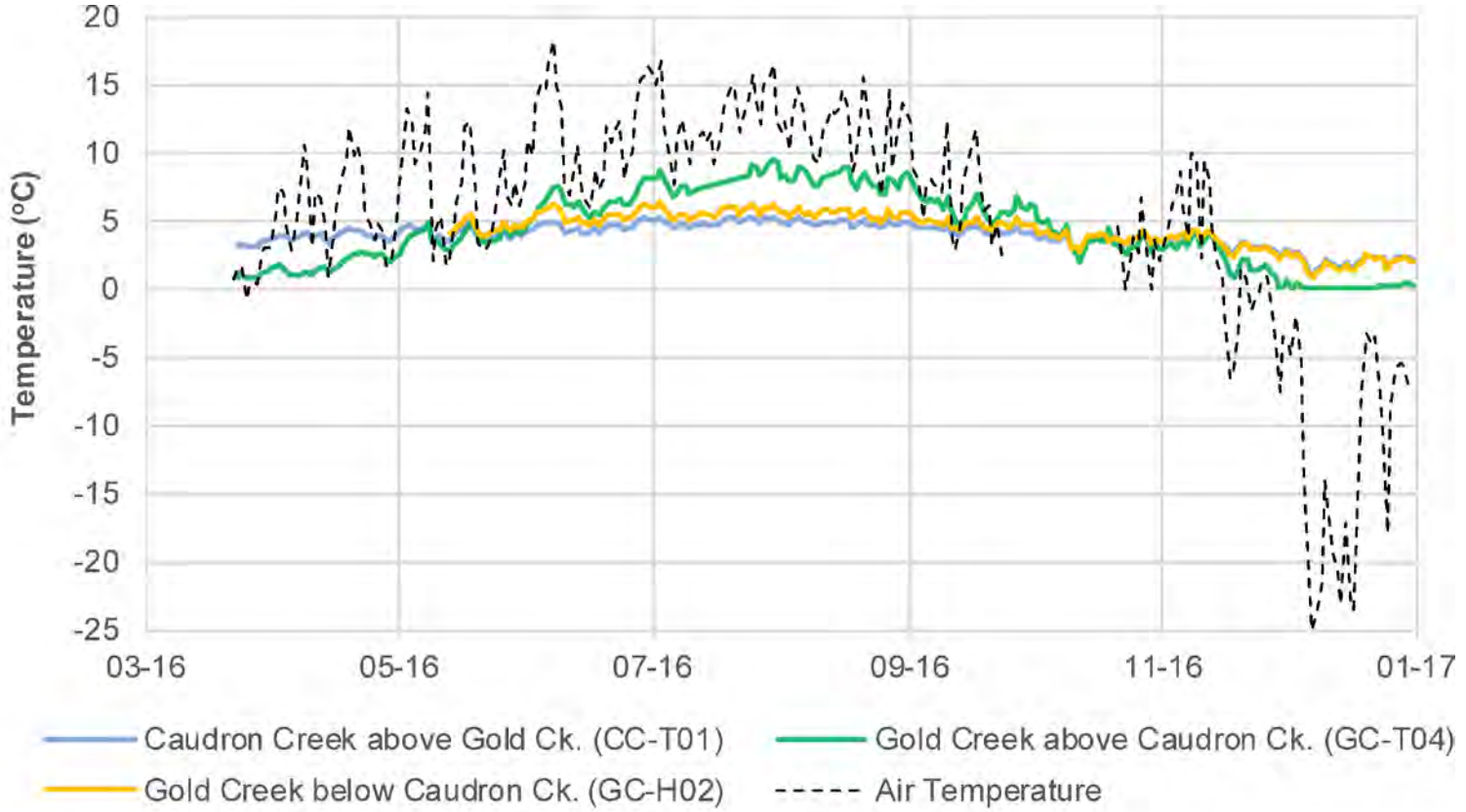

Note: all temperature data measured at temperature loggers except for the GC-H02 hydrometric station data.

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

DAILY MEAN WATER AND AIR TEMPERATURE COMPARISON, GOLD CREEK WATERSHED, 2016

Data Source: MEMS, 2020

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 20, 2020

FIGURE
6.15-3

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-15-3 Daily Mean Water and Air Temperature Gold 14-00201.mxd

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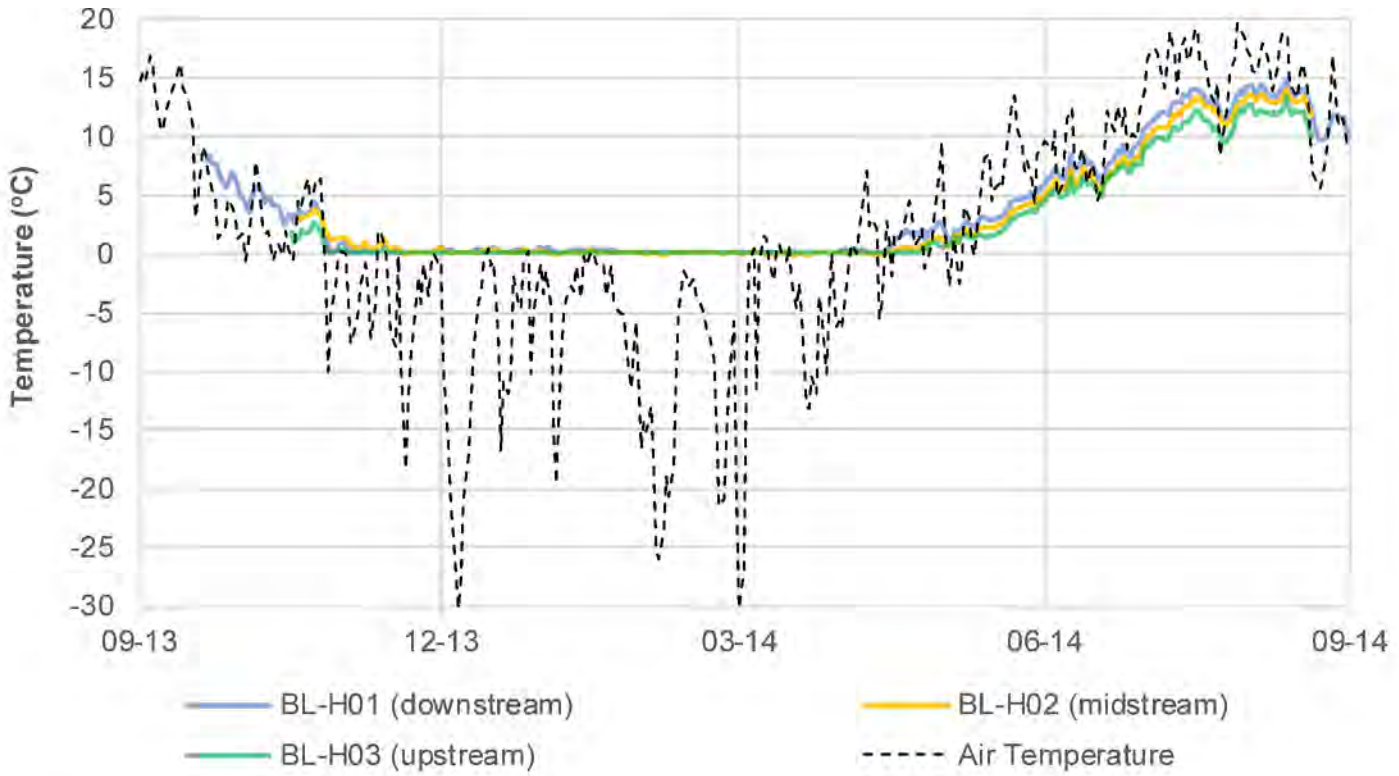

Note: water temperatures measured at 3 hydrometric stations; air temperatures measured at Pelletier Creek AEP weather station, a few kilometres west of BC-07 and approximately equal elevation

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

DAILY MEAN WATER AND AIR TEMPERATURE COMPARISON, BLAIRMORE WATERSHED, 2013-2014

Data Source: MEMS, 2020

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 20, 2020

FIGURE
6.15-4

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-15-4 Daily Mean Water and Air Temperature Blairmore 14-00201.mxd

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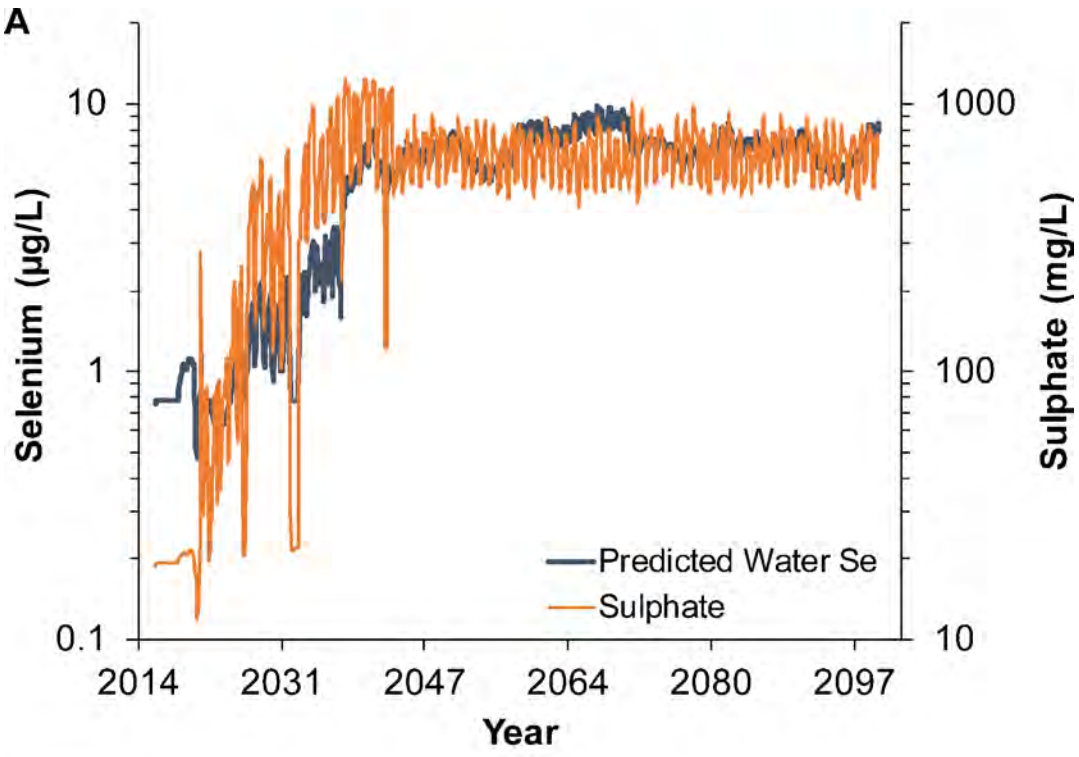

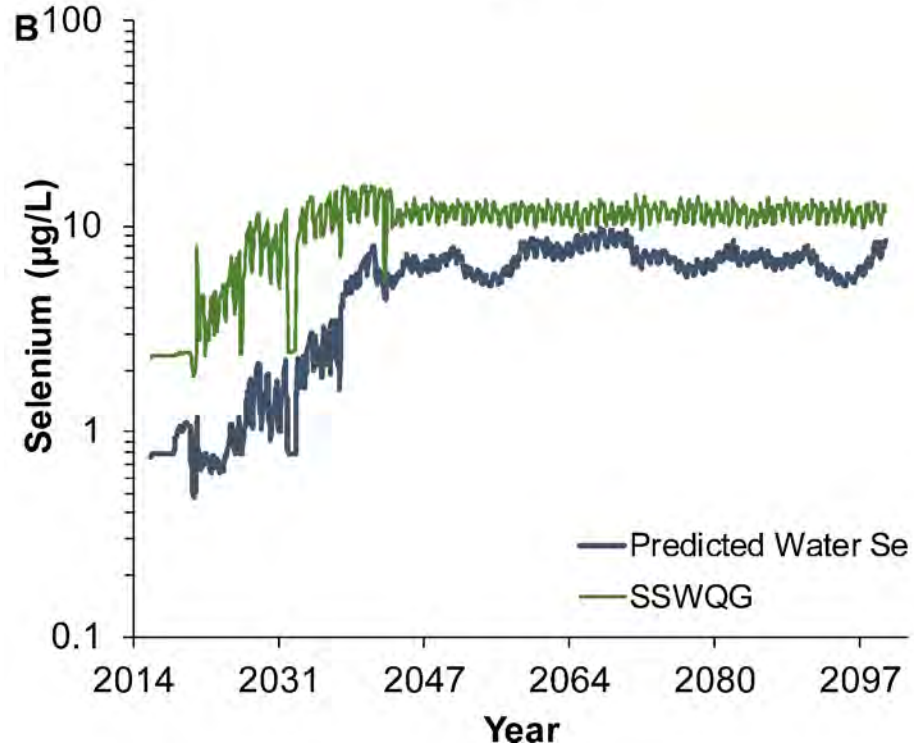

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

COMPARISON OF (A) PREDICTED SULPHATE AND SELENIUM CONCENTRATIONS IN SURFACE WATER AT BC-07; AND (B) PREDICTED SELENIUM CONCENTRATIONS AND THE SULPHATE-DEPENDENT SELENIUM GUIDELINE

Data Source: MEMS, 2020

MILLENNIUM EMS Solutions Ltd.

PROJECT: 14-00201

DRAWN BY: JLAMBERTS

CHECKED BY: MB

DATE: FEBRUARY 20, 2020

FIGURE

6.16-1

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-16-1 Comparison of Predicted Sulphate and Selenium 14-00201.mxd

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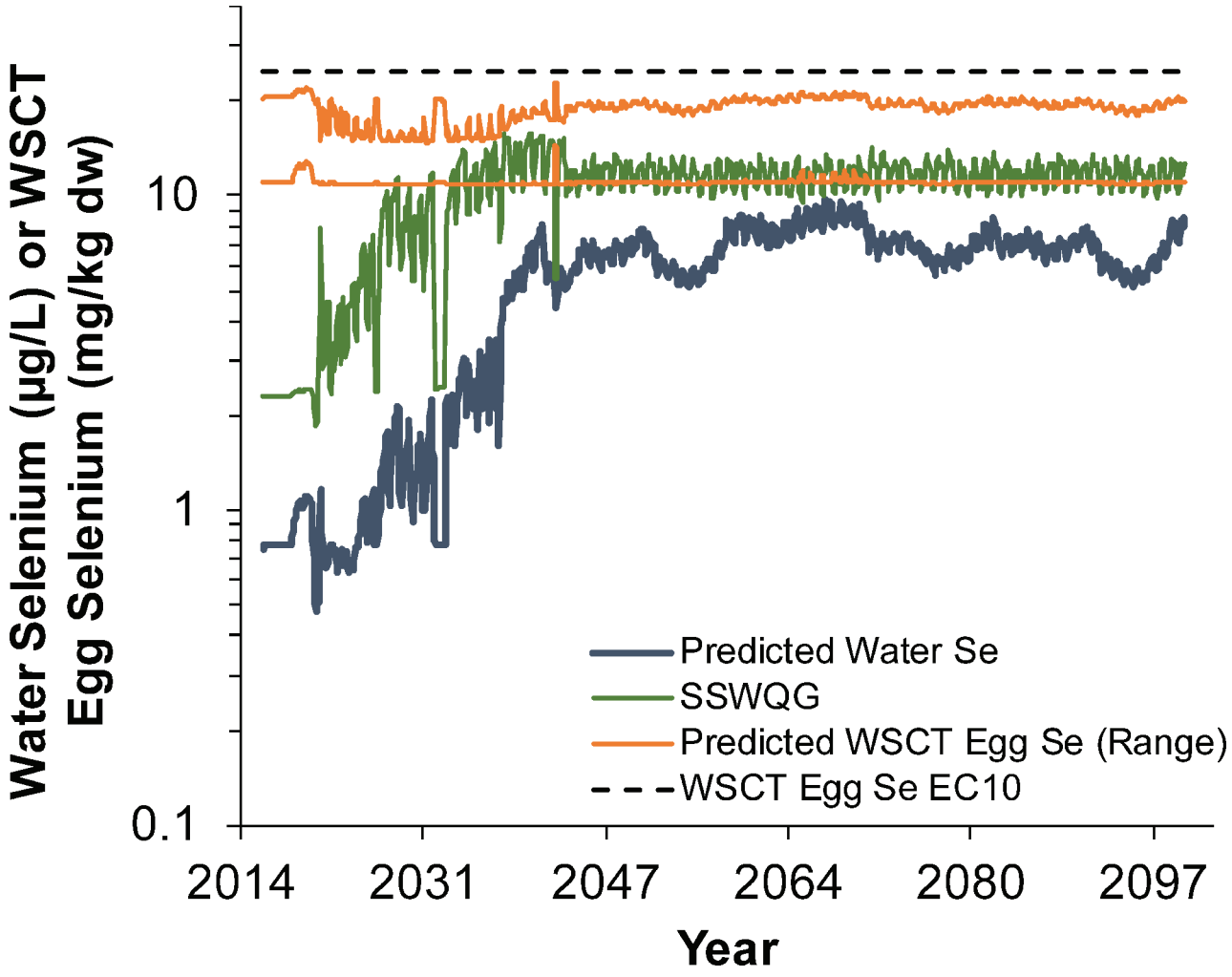

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

COMPARISON OF PREDICTED SELENIUM CONCENTRATIONS, THE SULPHATE-DEPENDENT SELENIUM GUIDELINE, AND PREDICTED WESTSLOPE CUTTHROAT TROUT EGG SELENIUM CONCENTRATIONS

MILLENNIUM EMS Solutions Ltd.

Data Source: MEMS, 2020

Note: The two orange lines bracket the range of predictions from the selenium bioaccumulation model.

PROJECT: 14-00201

DRAWN BY: JLAMBERTS

CHECKED BY: MB

DATE: FEBRUARY 28, 2020

FIGURE

6.16-2

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-16-2 Comparison of Predicted Selenium 14-00201.mxd

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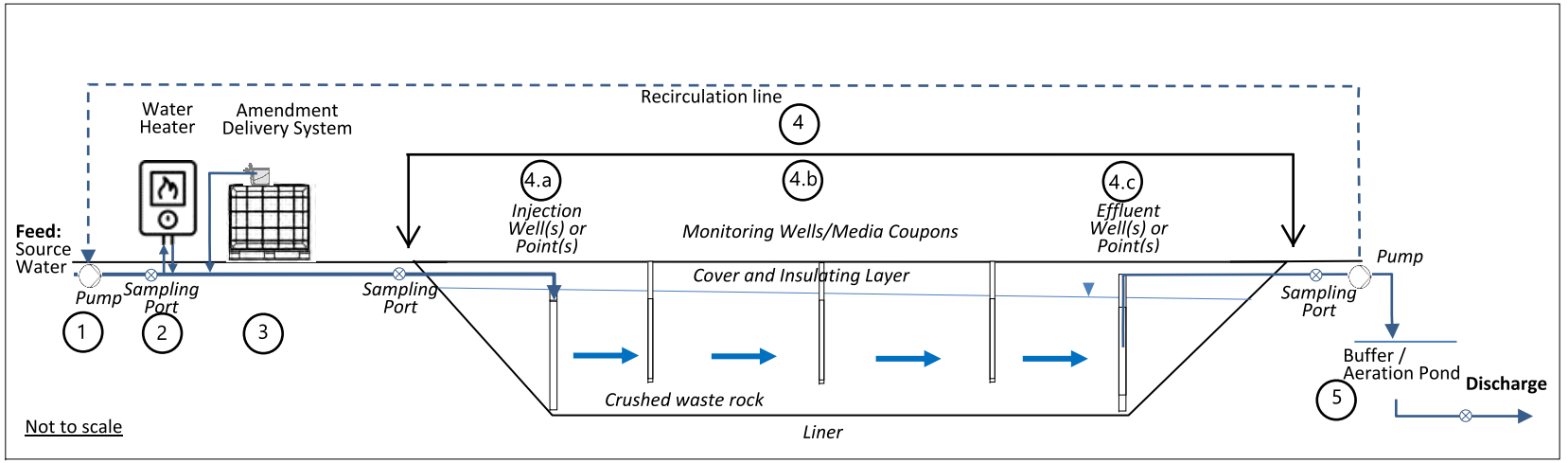


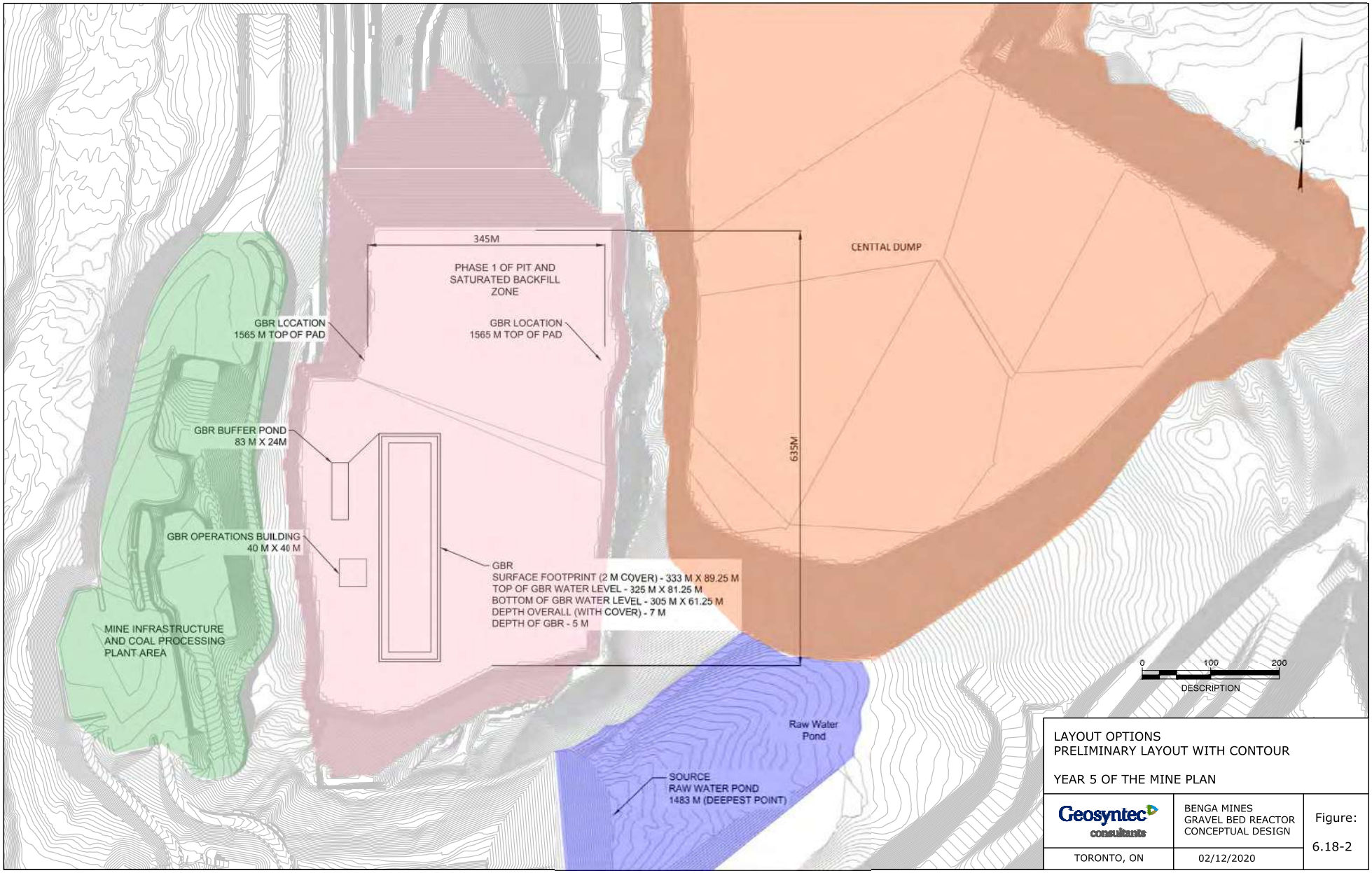
Note: Amendments can include electron donors (e.g., methanol), electron acceptors (e.g., nitrate), nutrients (e.g., phosphate, yeast extract), pH buffers (e.g., acids or bases), conservative tracers (e.g., chloride), and/or anti-scalants

Unit Operations (as described in Conceptual Memo)

1. Source Water
2. Influent Heating
3. Amendment Delivery
4. GBR
   4a. Injection Well(s) or point(s)
   4b. Monitoring wells / Media Coupons
   4c. Effluent Well(s) or point(s)
5. Buffer / Aeration Pond

Cross-Sectional Schematic of a Typical GBR

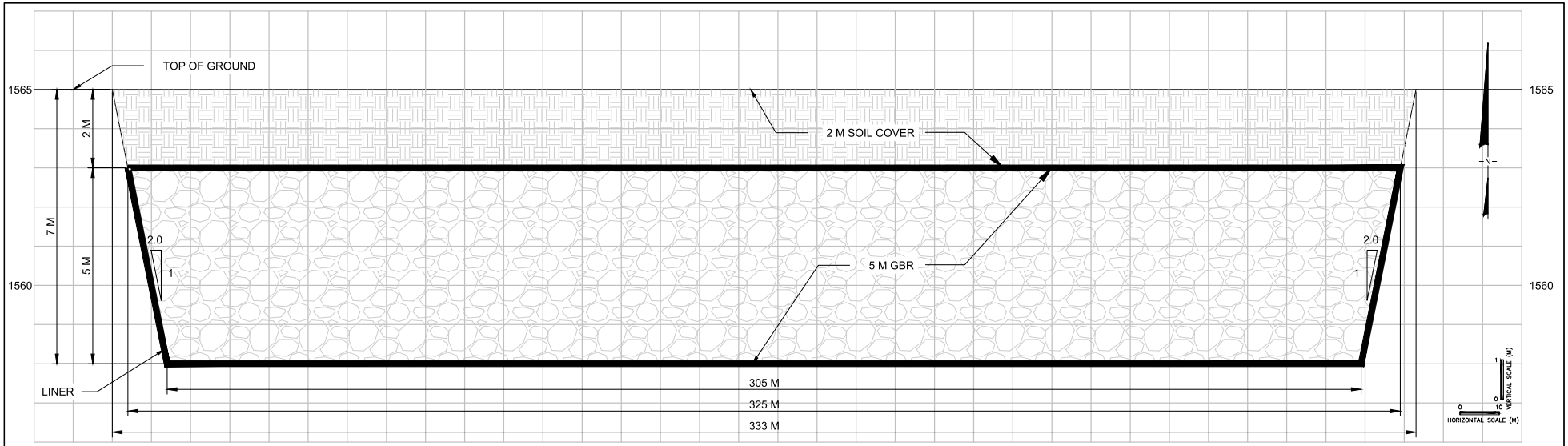
Geosyntec consultants	BENGA MINES GRAVEL BED REACTOR CONCEPTUAL DESIGN	Figure: 6.18-1
TORONTO, ON	02/12/2020	

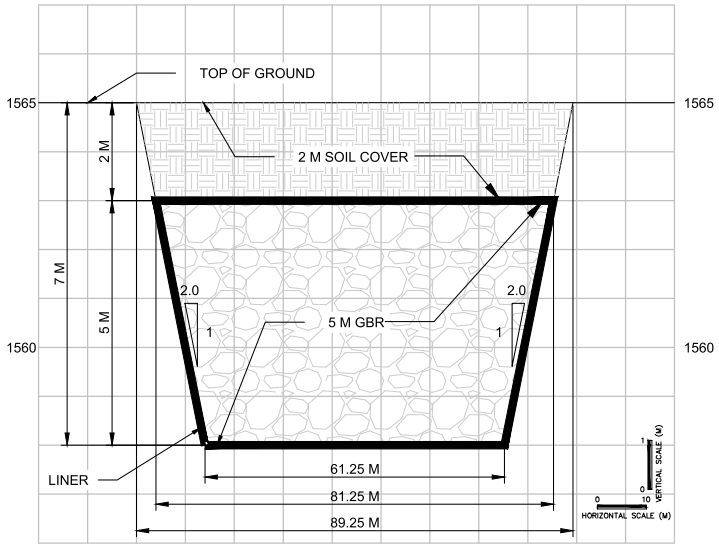


LAYOUT OPTIONS
PRELIMINARY LAYOUT WITH CONTOUR

YEAR 5 OF THE MINE PLAN

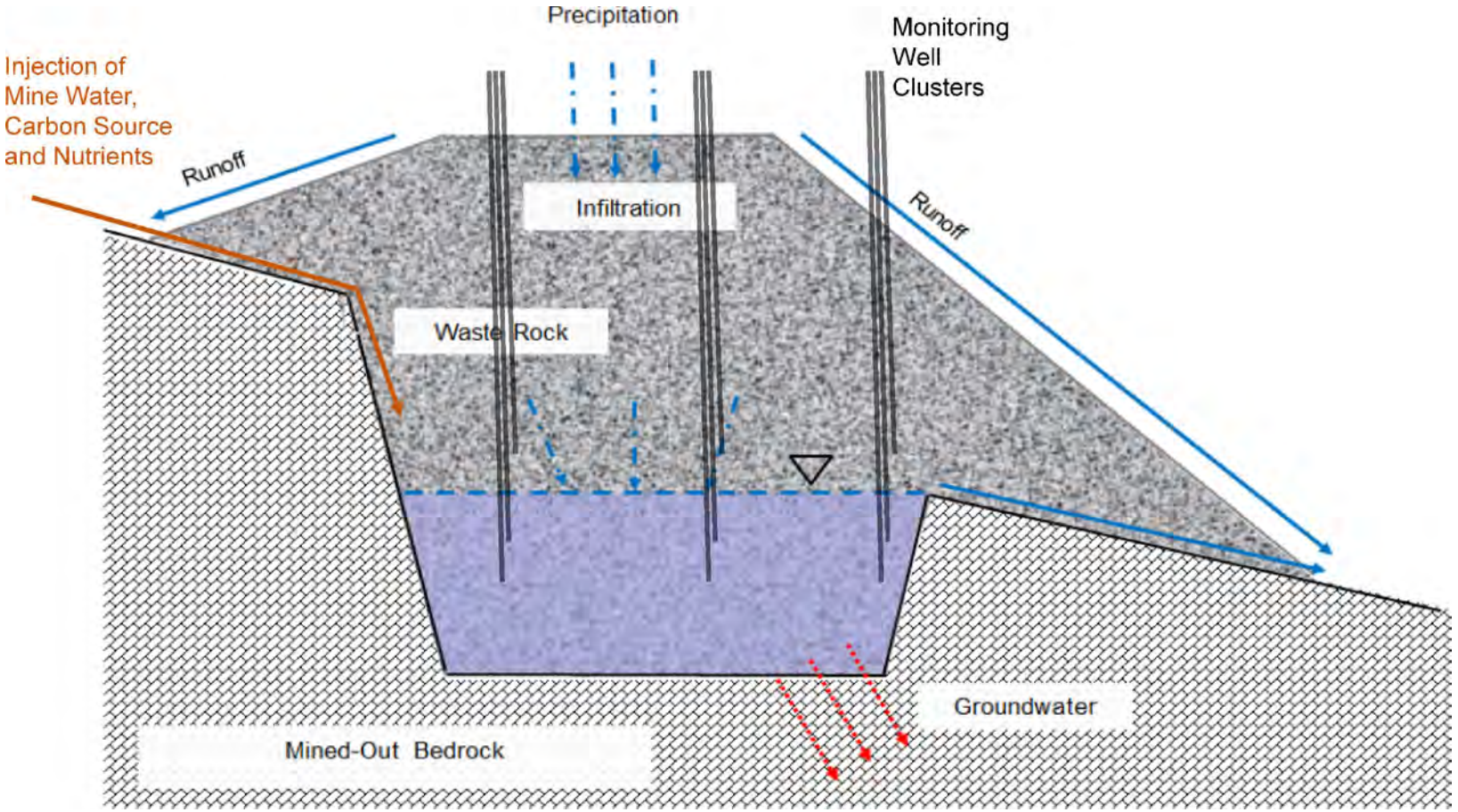
Geosyntec consultants	BENGA MINES GRAVEL BED REACTOR CONCEPTUAL DESIGN	Figure: 6.18-2
TORONTO, ON	02/12/2020	





GRAVEL BED REACTOR SECTION -
CONCEPTUAL CROSS-SECTIONAL LAYOUT

Geosyntec consultants	BENGA MINES GRAVEL BED REACTOR CONCEPTUAL DESIGN	Figure: 6.18-3
TORONTO, ON	02/12/2020	



RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

SCHEMATIC OF MANAGED SATURATED BACKFILL

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 24, 2020

FIGURE
6.21-1

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-21-1 Schematic of Managed Saturated Backfill 14-00201.mxd

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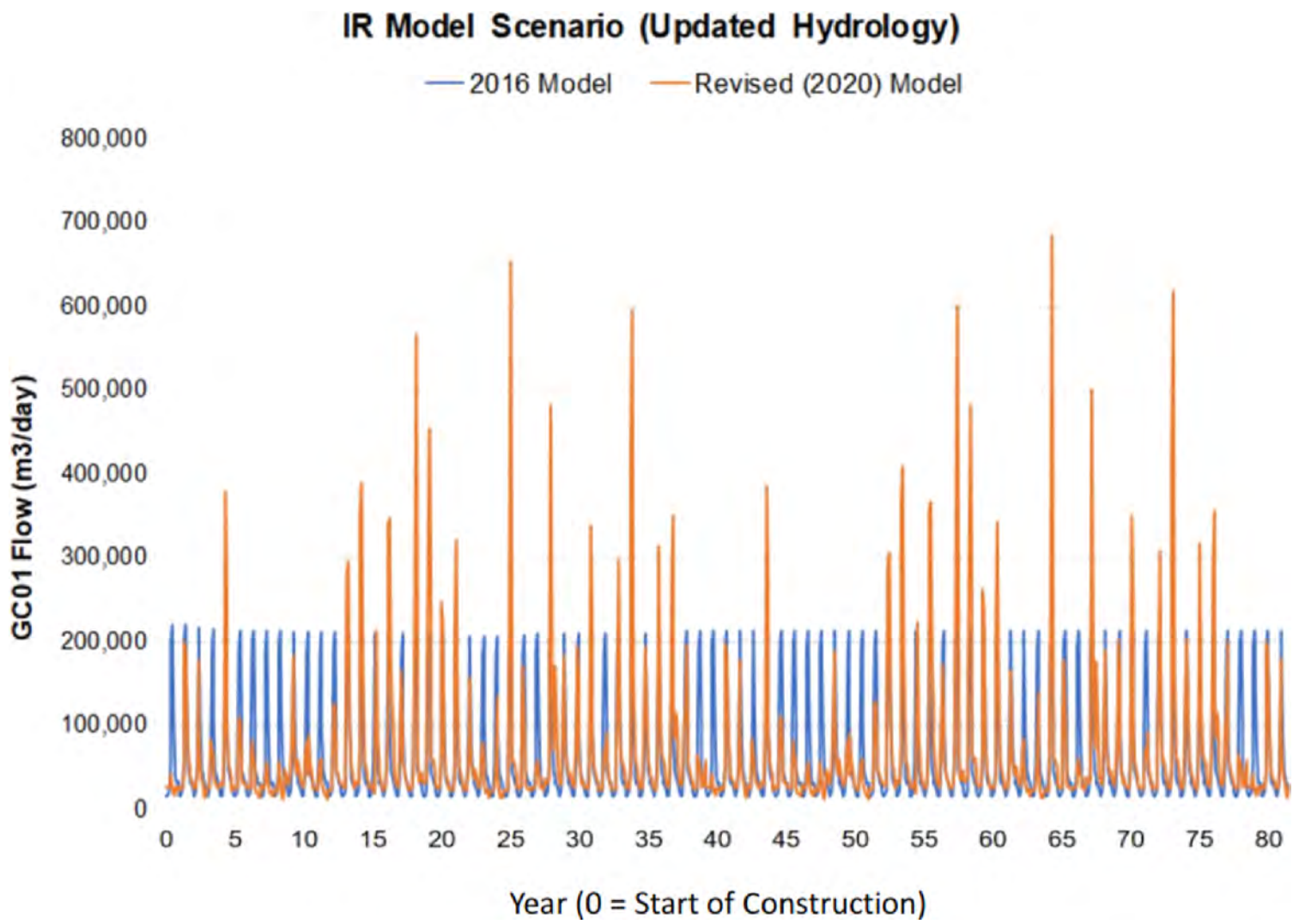

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

GOLD CREEK (GC01) FLOWS USED IN 2016 EA AND IN REVISED (2020) MODEL

Data Source: MEMS, 2020

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 18, 2020

FIGURE
6.25-1

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-25-1 Gold Creek Flows 2016 14-00201.mxd

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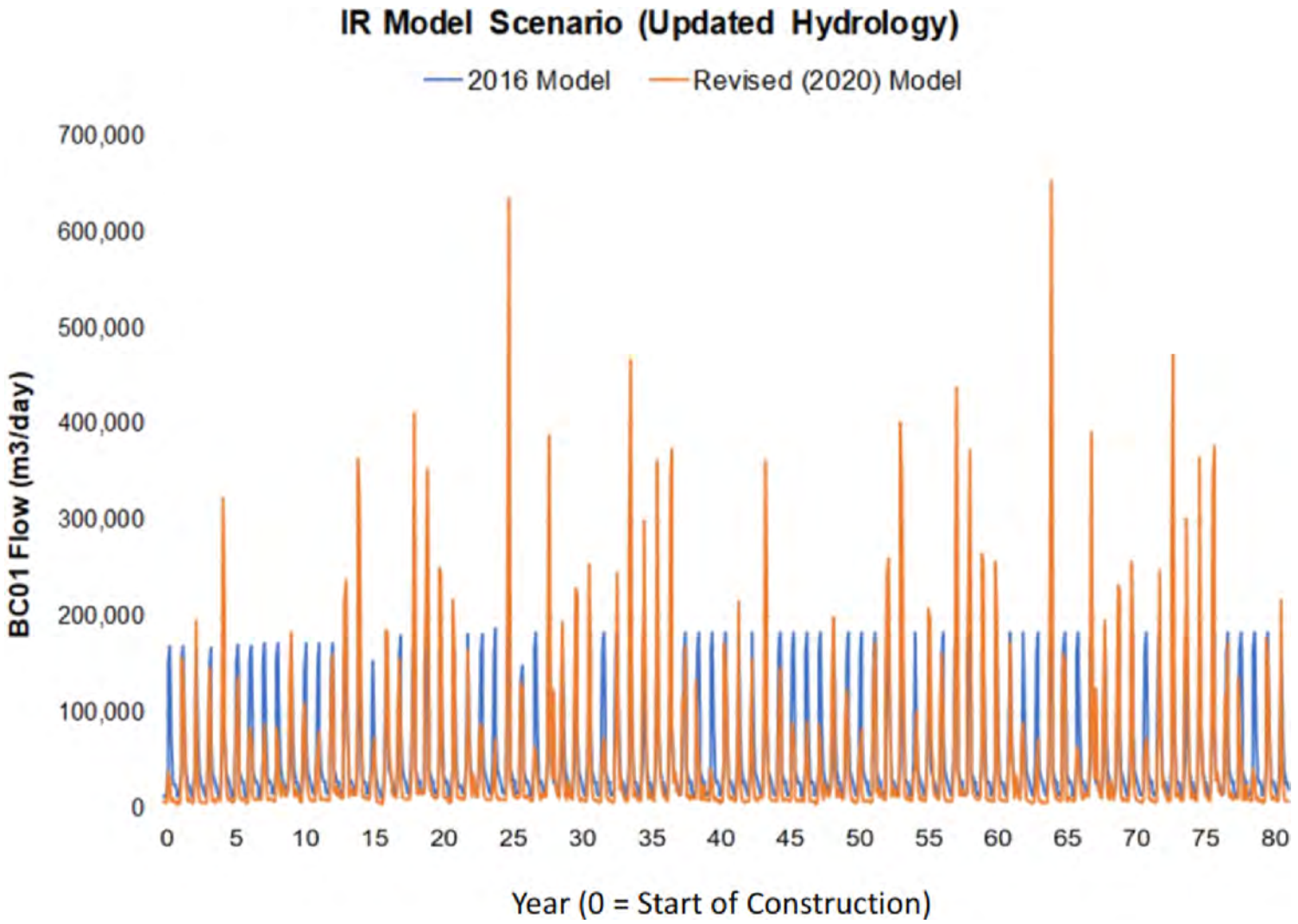

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

BLAIRMORE CREEK (BC01) FLOWS USED IN 2016 EA AND IN REVISED (2020) MODEL

Data Source: MEMS, 2020

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 18, 2020

FIGURE
6.25-2

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-25-2 Blairmore Creek Flows 2016 14-00201.mxd

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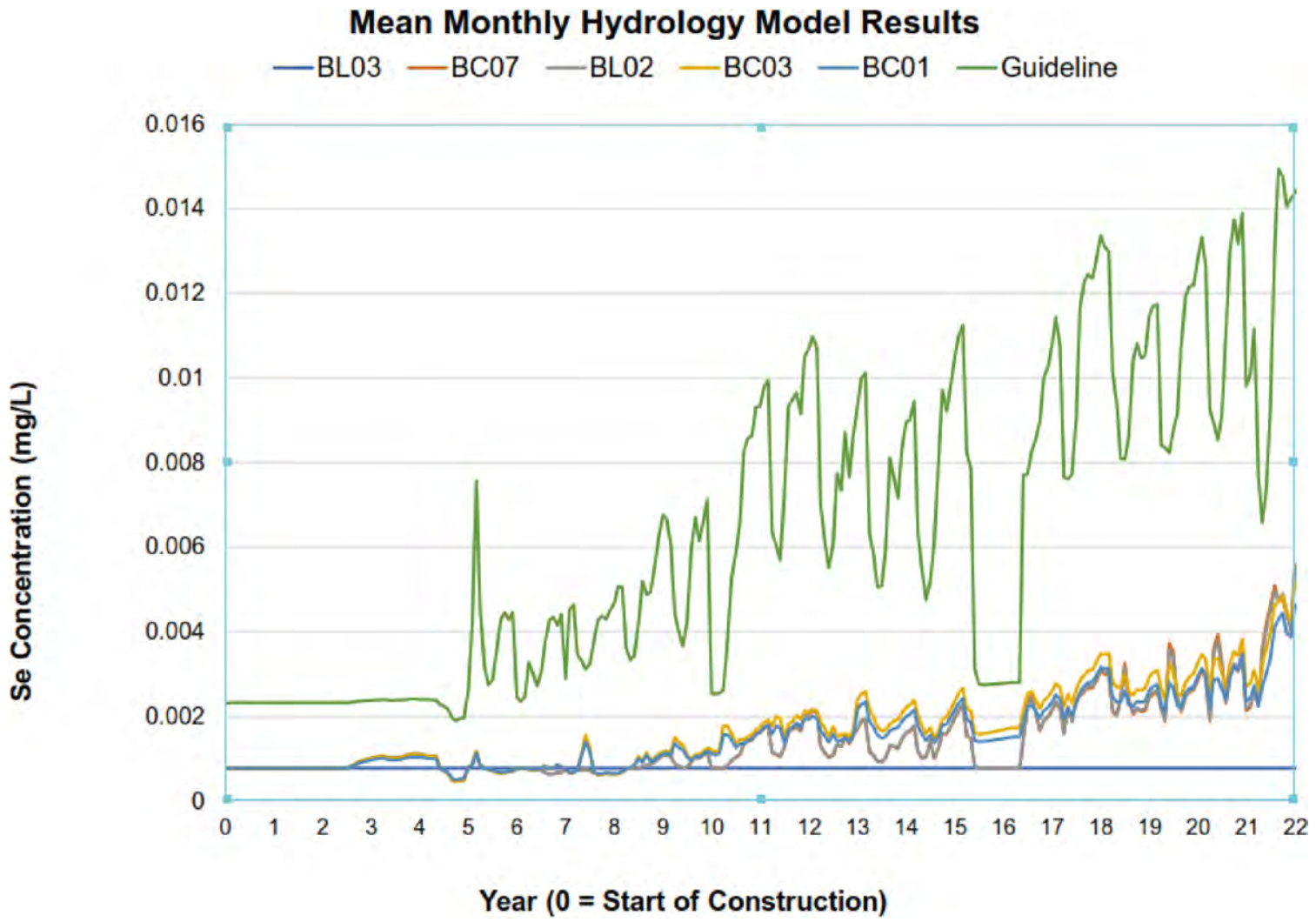

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

TOTAL SELENIUM CONCENTRATIONS IN BLAIRMORE CREEK – 20 YEARS

Data Source: MEMS, 2020

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 18, 2020

FIGURE
6.25-3

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-25-3 Total Selenium in Blairmore Creek 2016 14-00201.mxd

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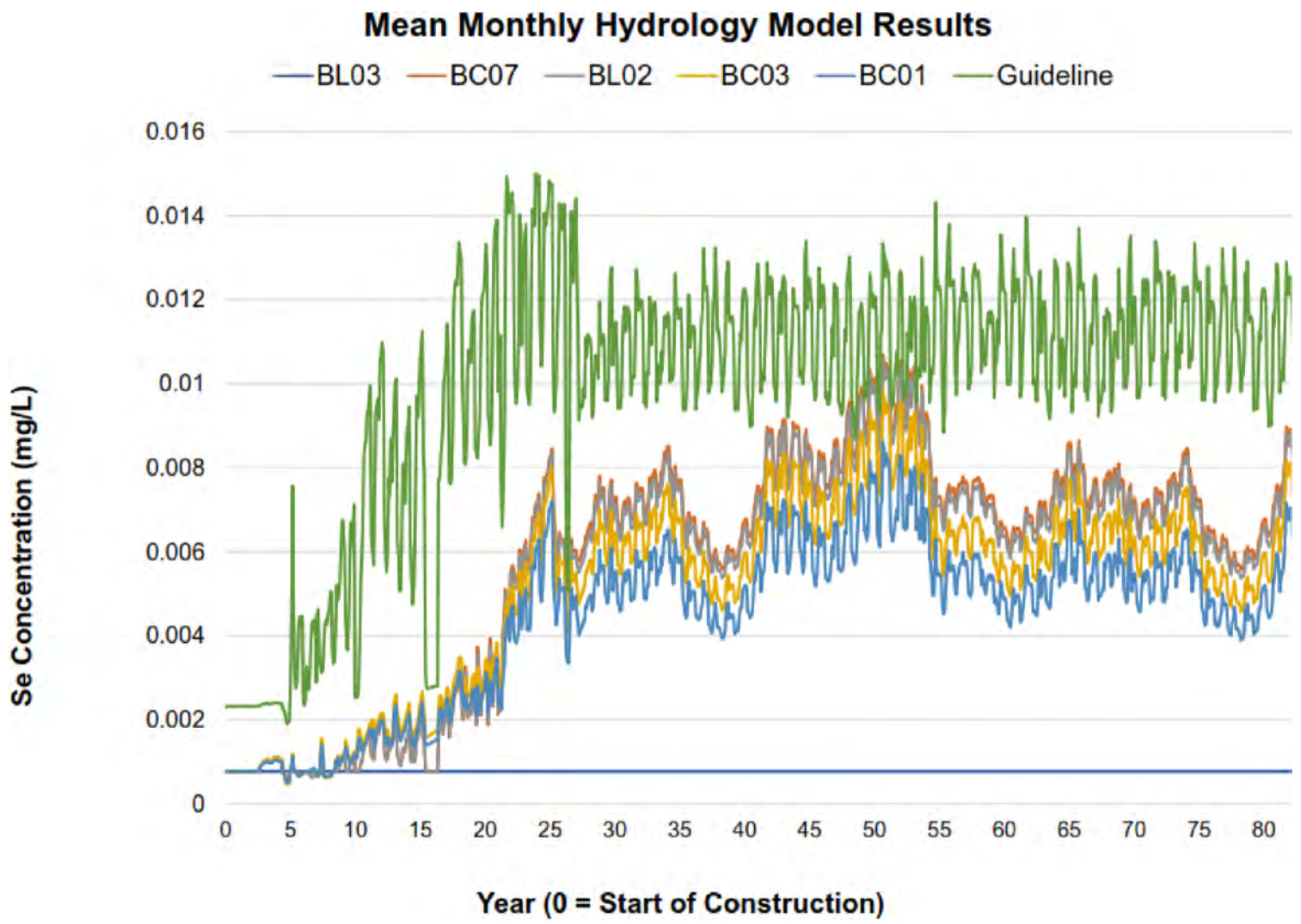

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

TOTAL SELENIUM CONCENTRATIONS IN BLAIRMORE CREEK – 80 YEARS

Data Source: MEMS, 2020

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 18, 2020

FIGURE
6.25-4

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\ResubmissionInformation Request 3\Fig 6-25-4 Total Selenium in Blairmore Creek 80 Years 2016 14-00201.mxd

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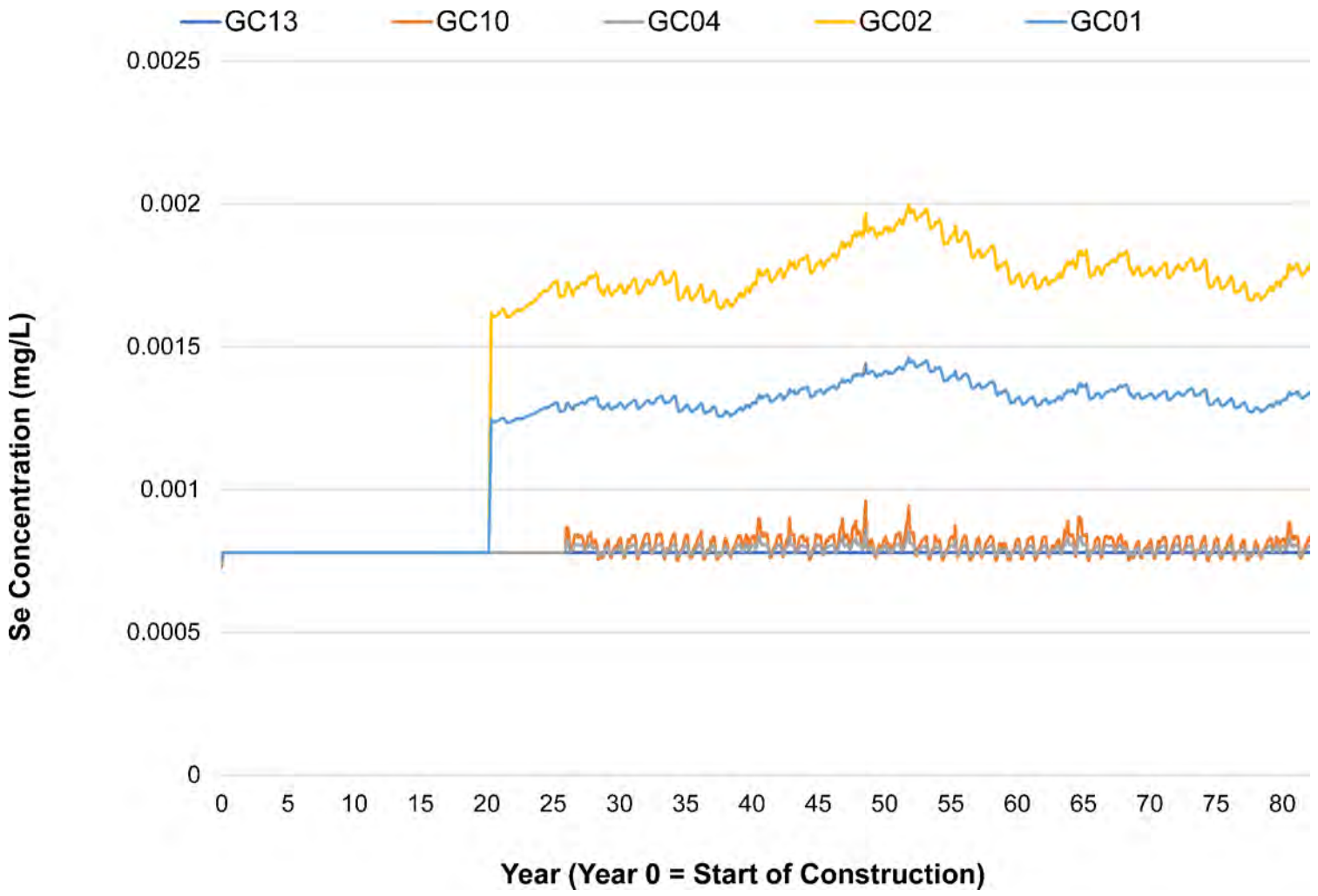

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

TOTAL SELENIUM CONCENTRATIONS IN GOLD CREEK – 80 YEARS

Data Source: MEMS, 2020

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 25, 2020

FIGURE
6.25-5

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-25-5 Total Selenium in Gold Creek 80 Years 2016 14-00201.mxd

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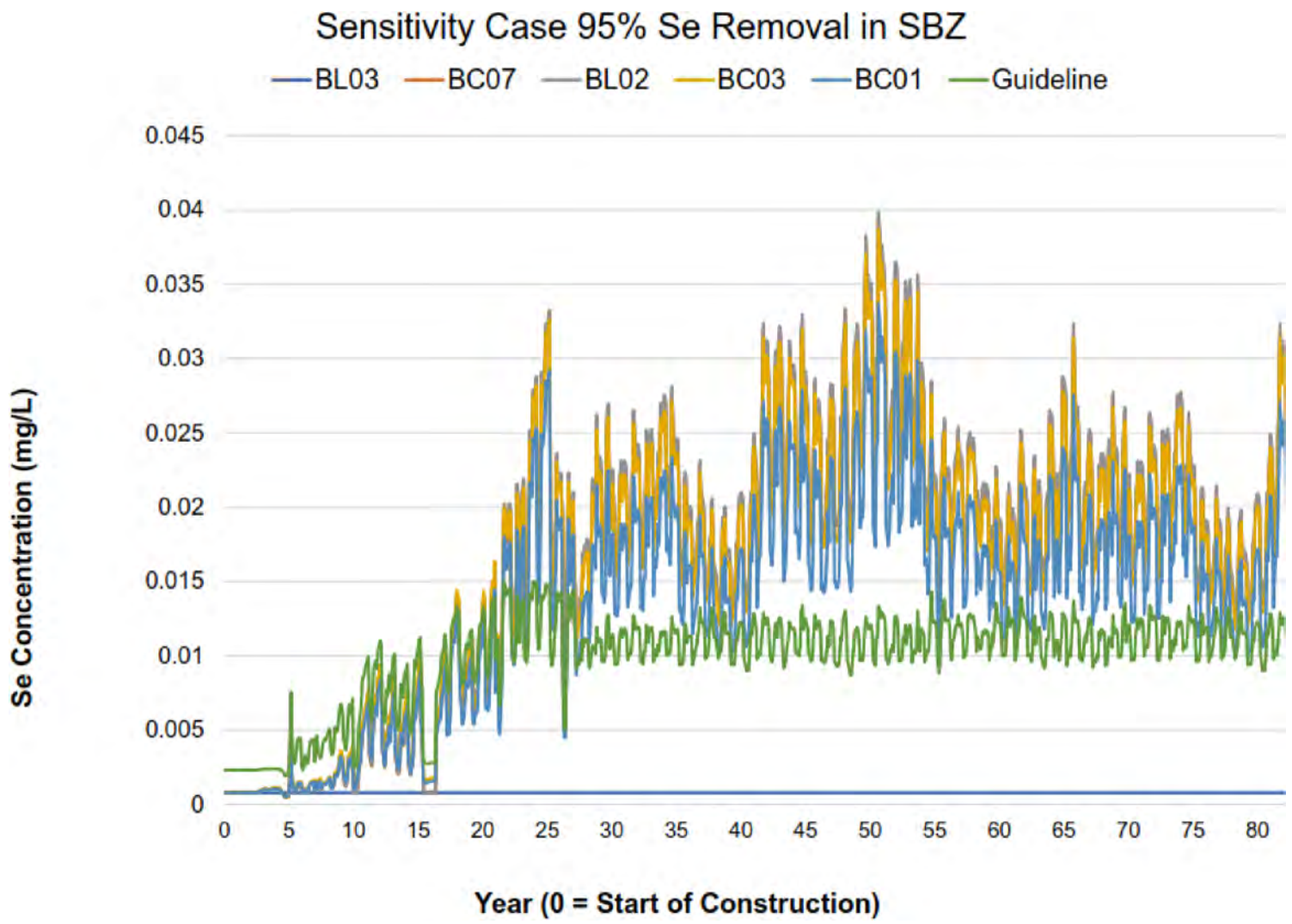

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

TOTAL SELENIUM CONCENTRATIONS IN BLAIRMORE CREEK AT 95% ATTENUATION IN SBZ

Data Source: MEMS, 2020

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 18, 2020

FIGURE
6.25-6

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-25-6 Total Selenium in Blairmore Creek 2016 14-00201.mxd

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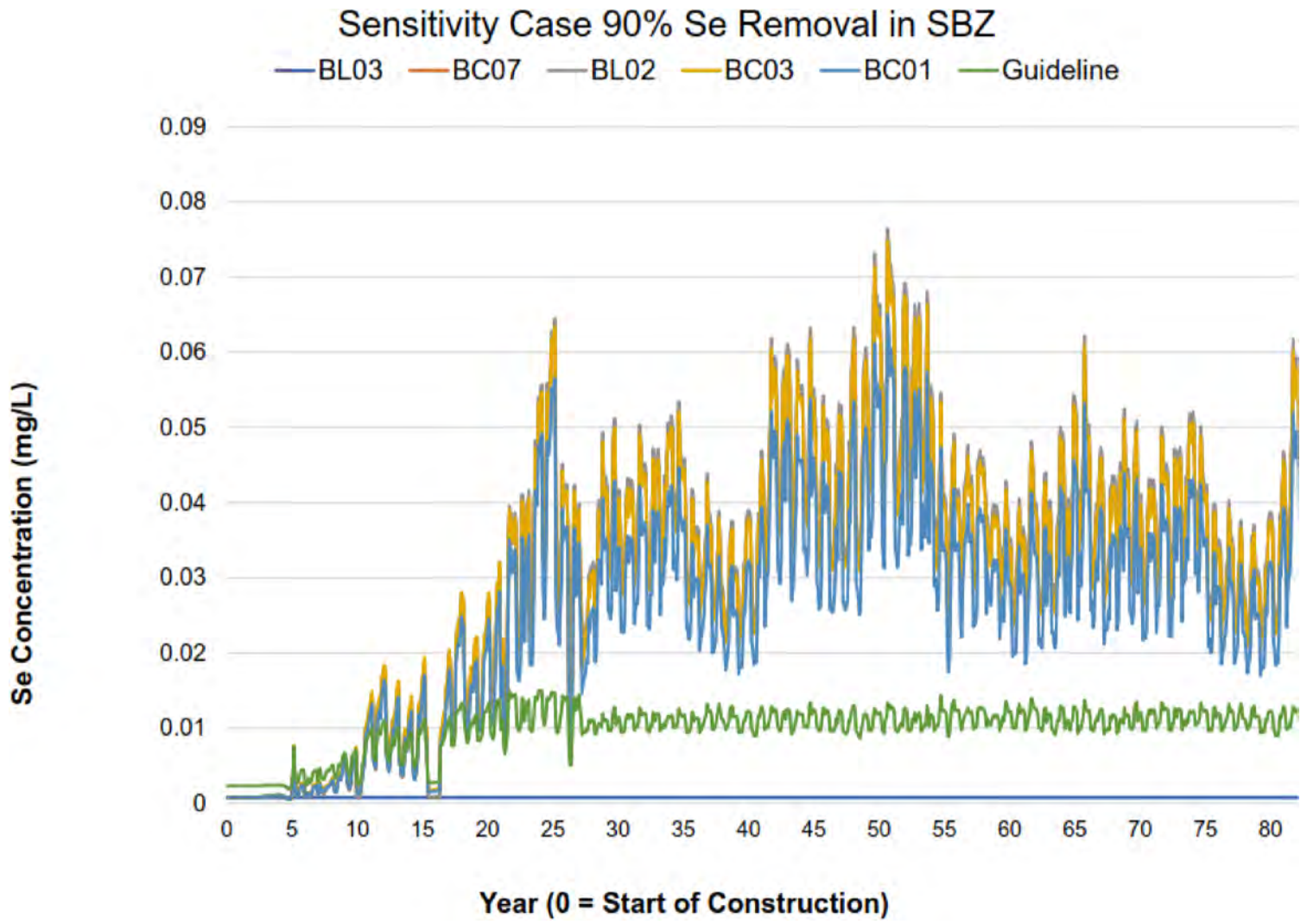

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

TOTAL SELENIUM CONCENTRATIONS IN BLAIRMORE CREEK AT 90% ATTENUATION IN SBZ

Data Source: MEMS, 2020

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 18, 2020

FIGURE
6.25-7

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-25-7 Total Selenium in Blairmore Creek 2016 14-00201.mxd

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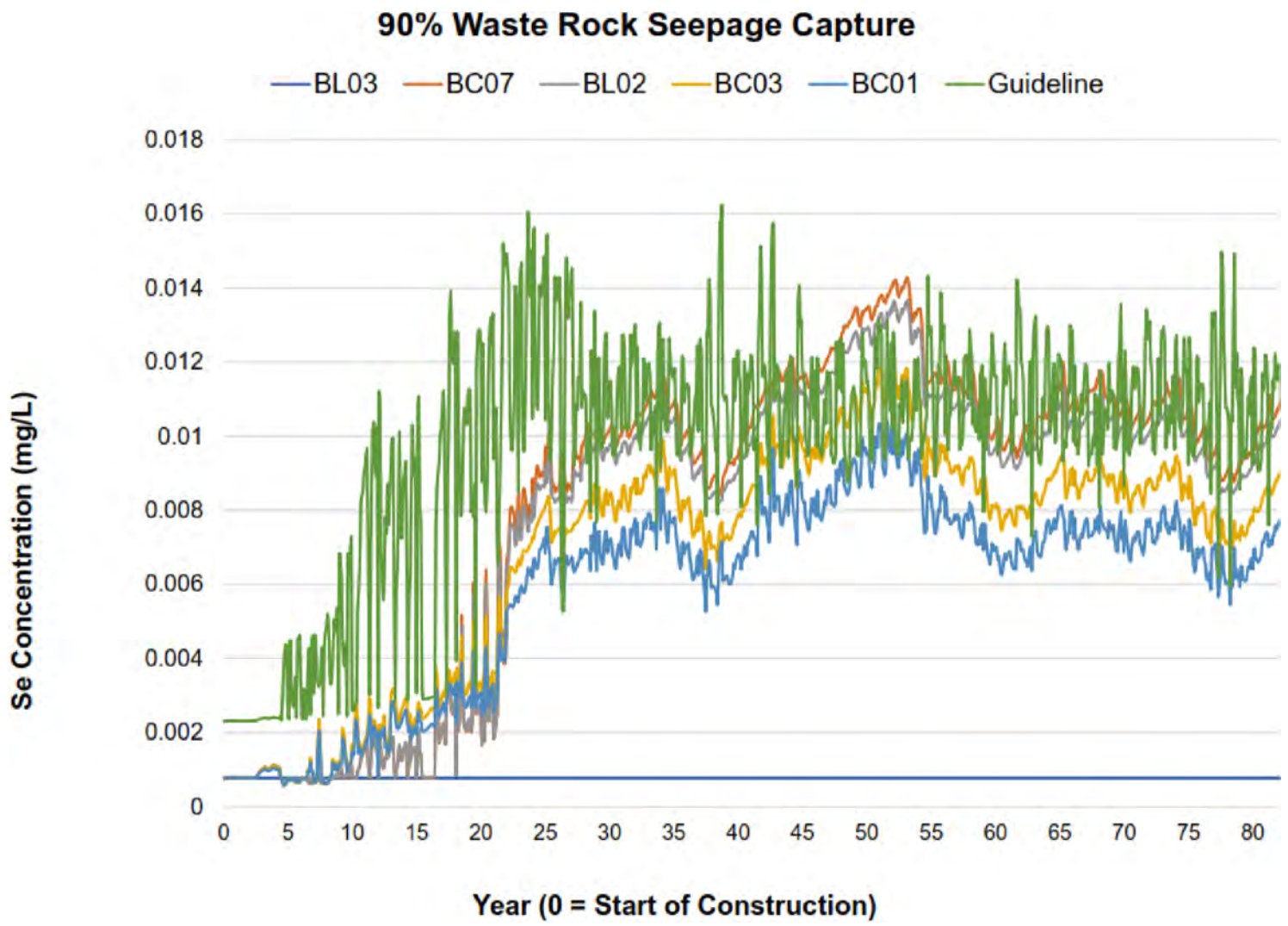

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

TOTAL SELENIUM CONCENTRATIONS IN BLAIRMORE CREEK, 90% CONTACT WATER CAPTURE

Data Source: MEMS, 2020

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 18, 2020

FIGURE
6.25-8

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-25-8 Total Selenium in Blairmore Creek 2016 14-00201.mxd

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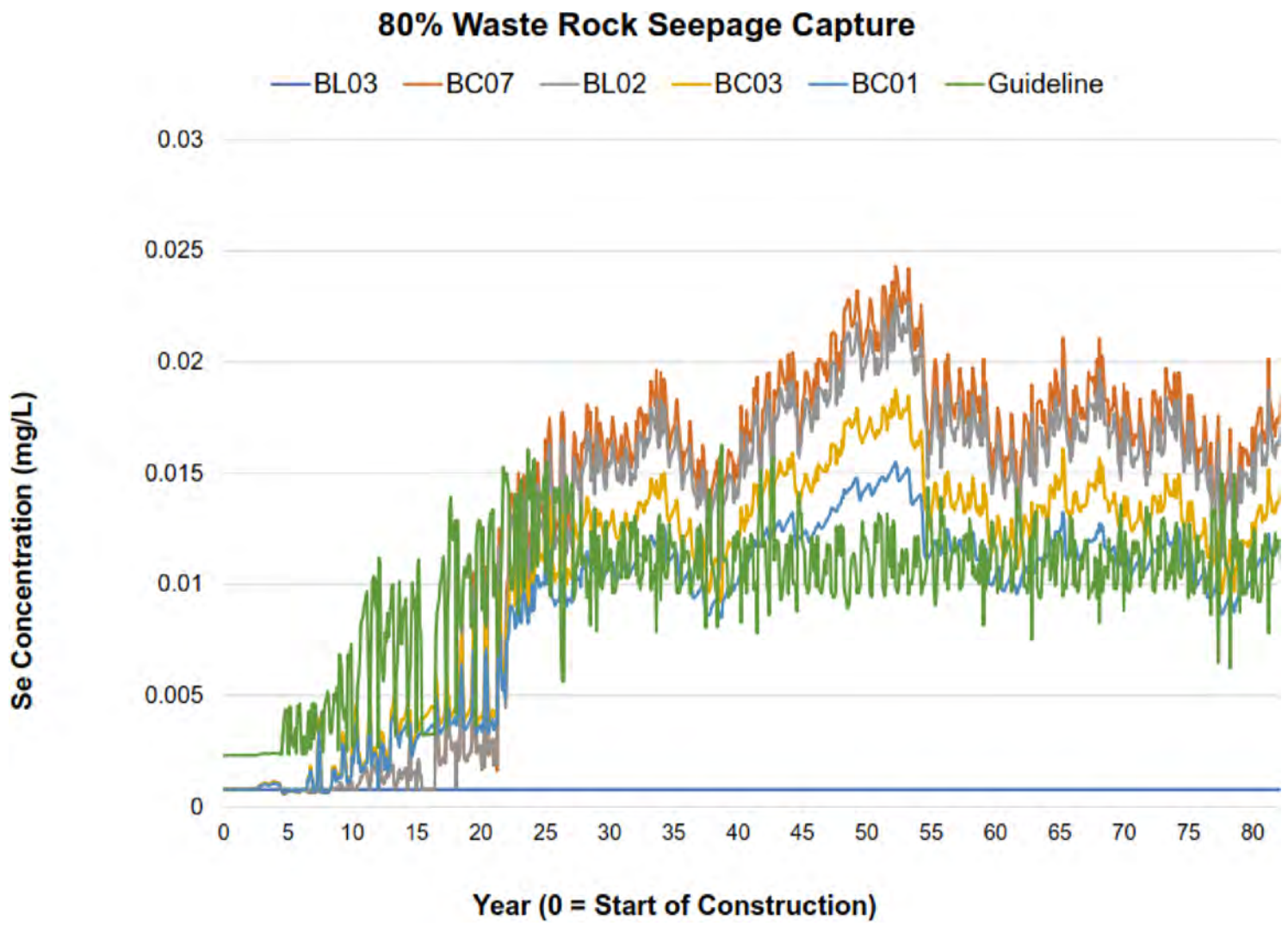

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

TOTAL SELENIUM CONCENTRATIONS IN BLAIRMORE CREEK, 80% CONTACT WATER CAPTURE

Data Source: MEMS, 2020

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 18, 2020

FIGURE
6.25-9

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-25-9 Total Selenium in Blairmore Creek 2016 14-00201.mxd

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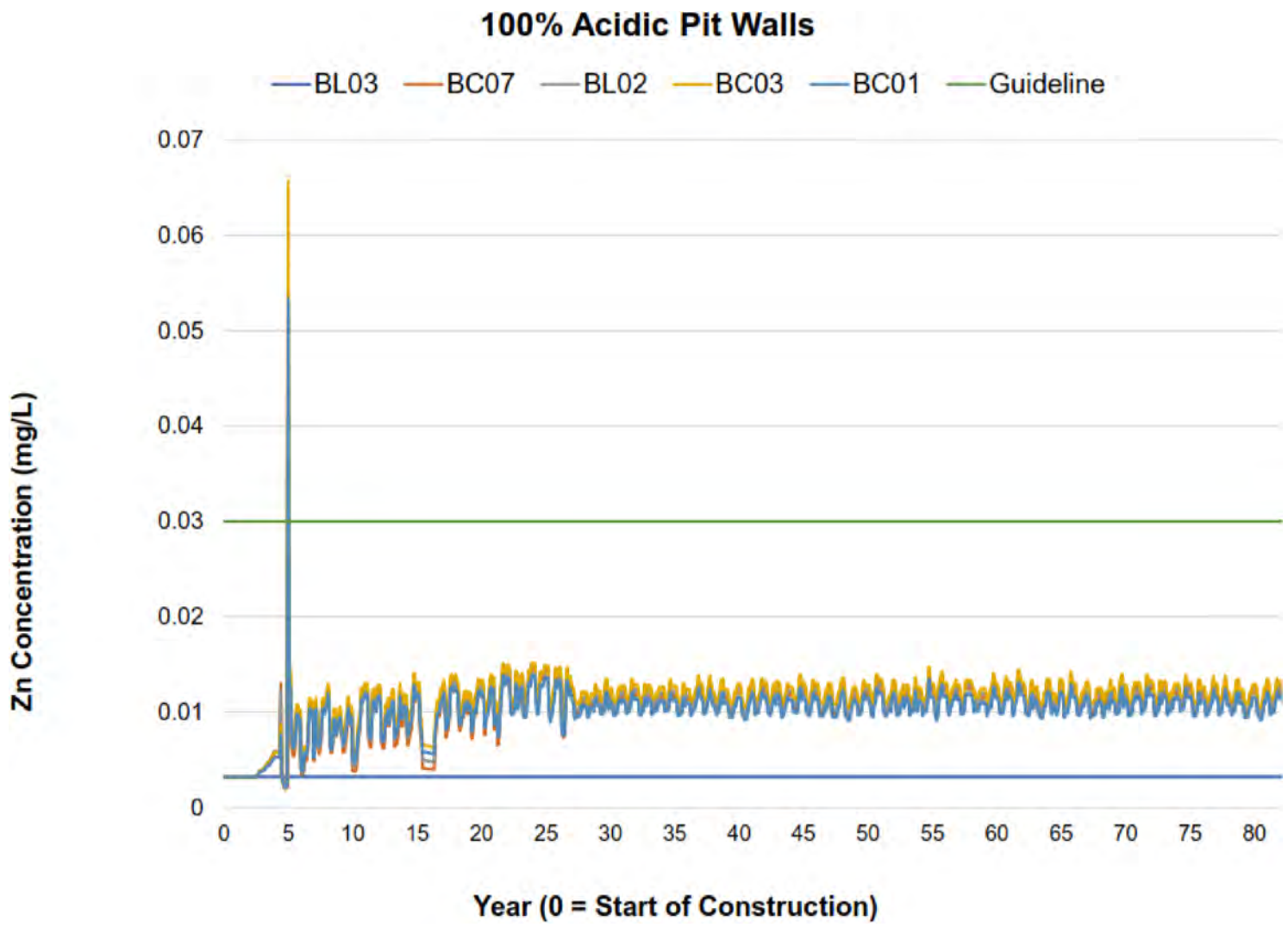

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

TOTAL ZINC CONCENTRATIONS IN BLAIRMORE CREEK, 100% ACIDIC PIT WALLS

Data Source: MEMS, 2020

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 18, 2020

FIGURE
6.25-10

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-25-10 Total Zinc in Blairmore Creek 2016 14-00201.mxd

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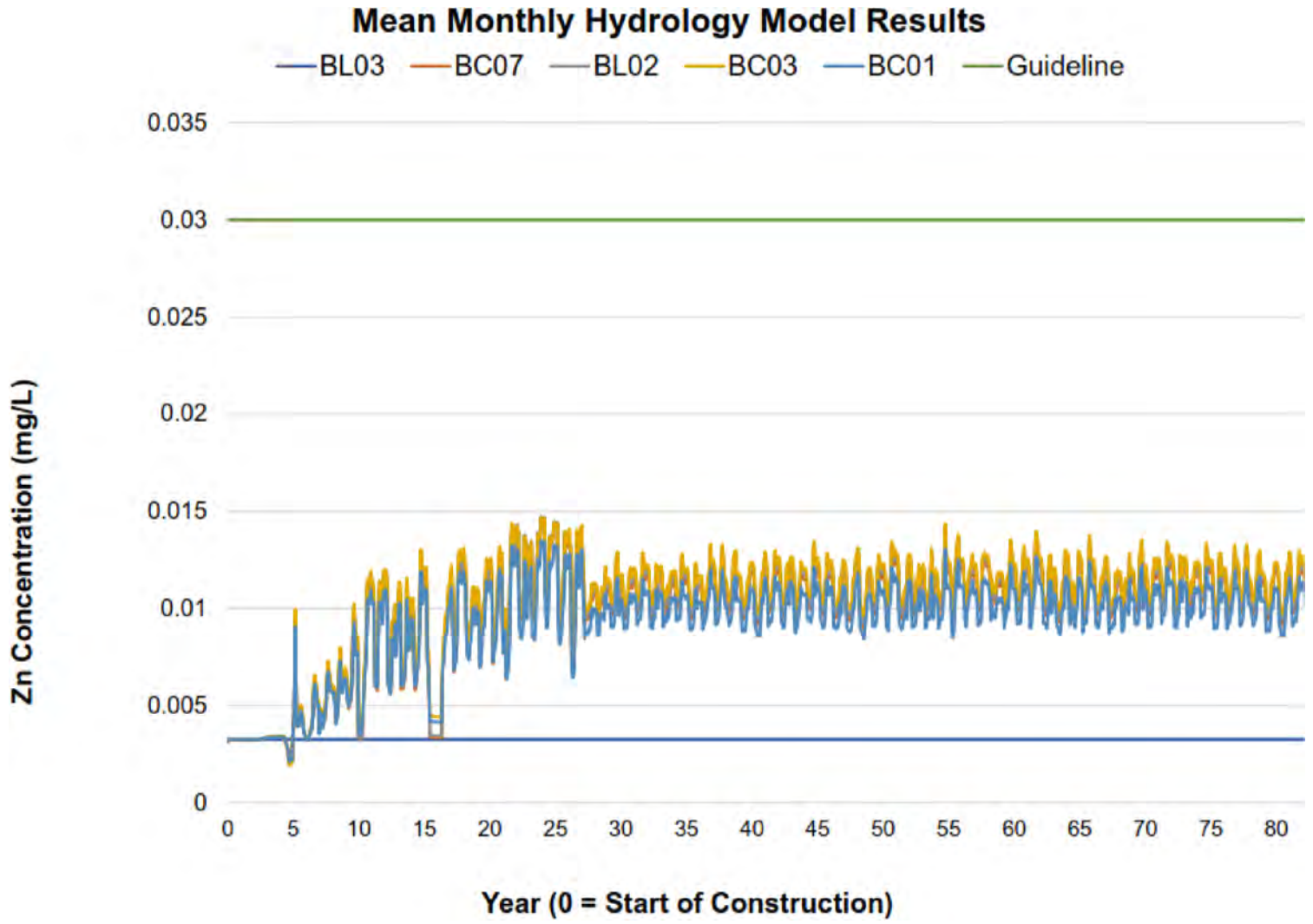

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

TOTAL ZINC CONCENTRATIONS IN BLAIRMORE CREEK, NON-ACIDIC PIT WALLS

Data Source: MEMS, 2020

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 18, 2020

FIGURE
6.25-11

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-25-11 Total Zinc in Blairmore Creek 2016 14-00201.mxd

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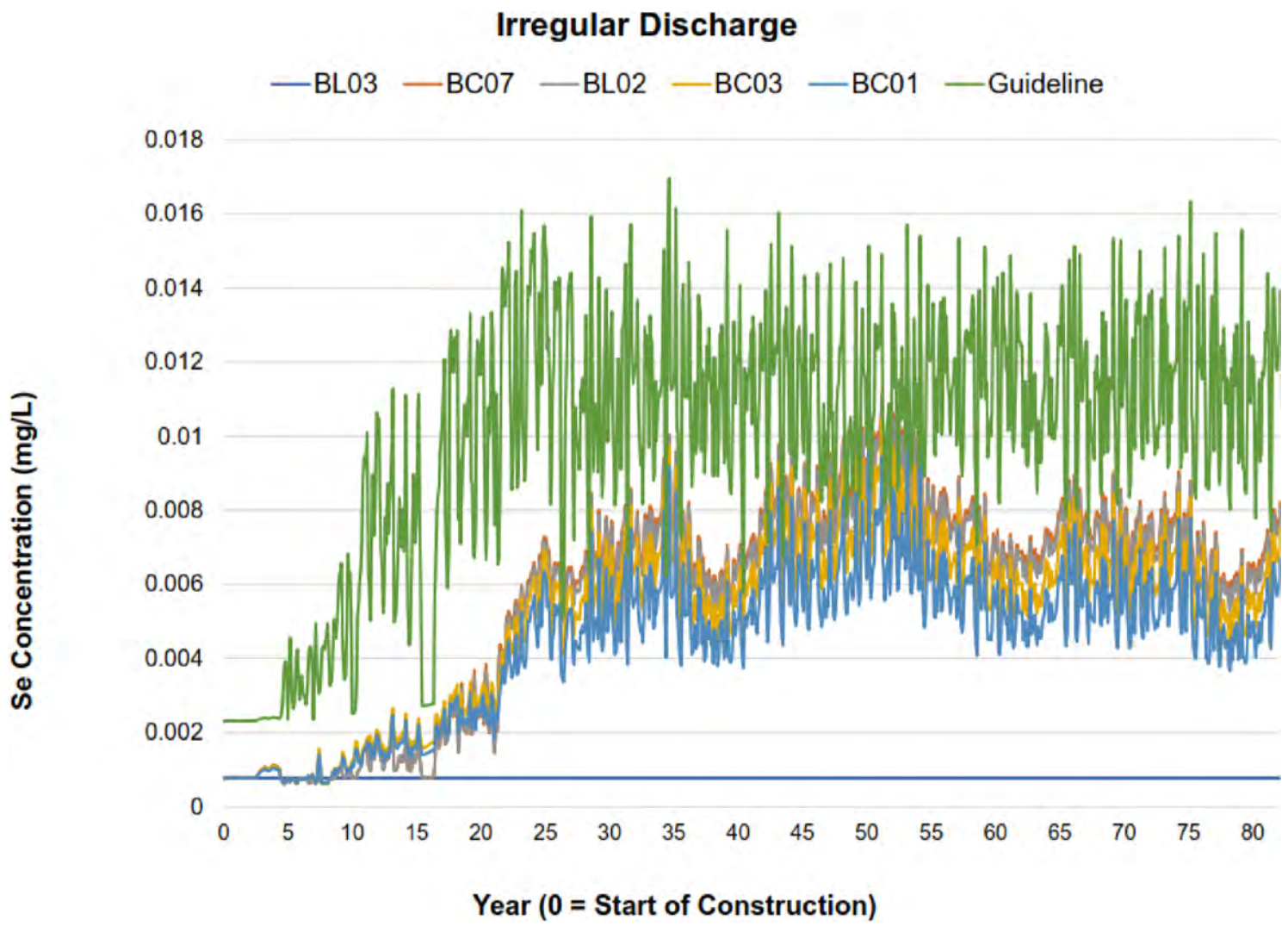

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

TOTAL SELENIUM CONCENTRATIONS IN BLAIRMORE CREEK FOR IRREGULAR DISCHARGE

Data Source: MEMS, 2020

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 18, 2020

FIGURE
6.25-12

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-25-12 Total Selenium in Blairmore Creek 2016 14-00201.mxd

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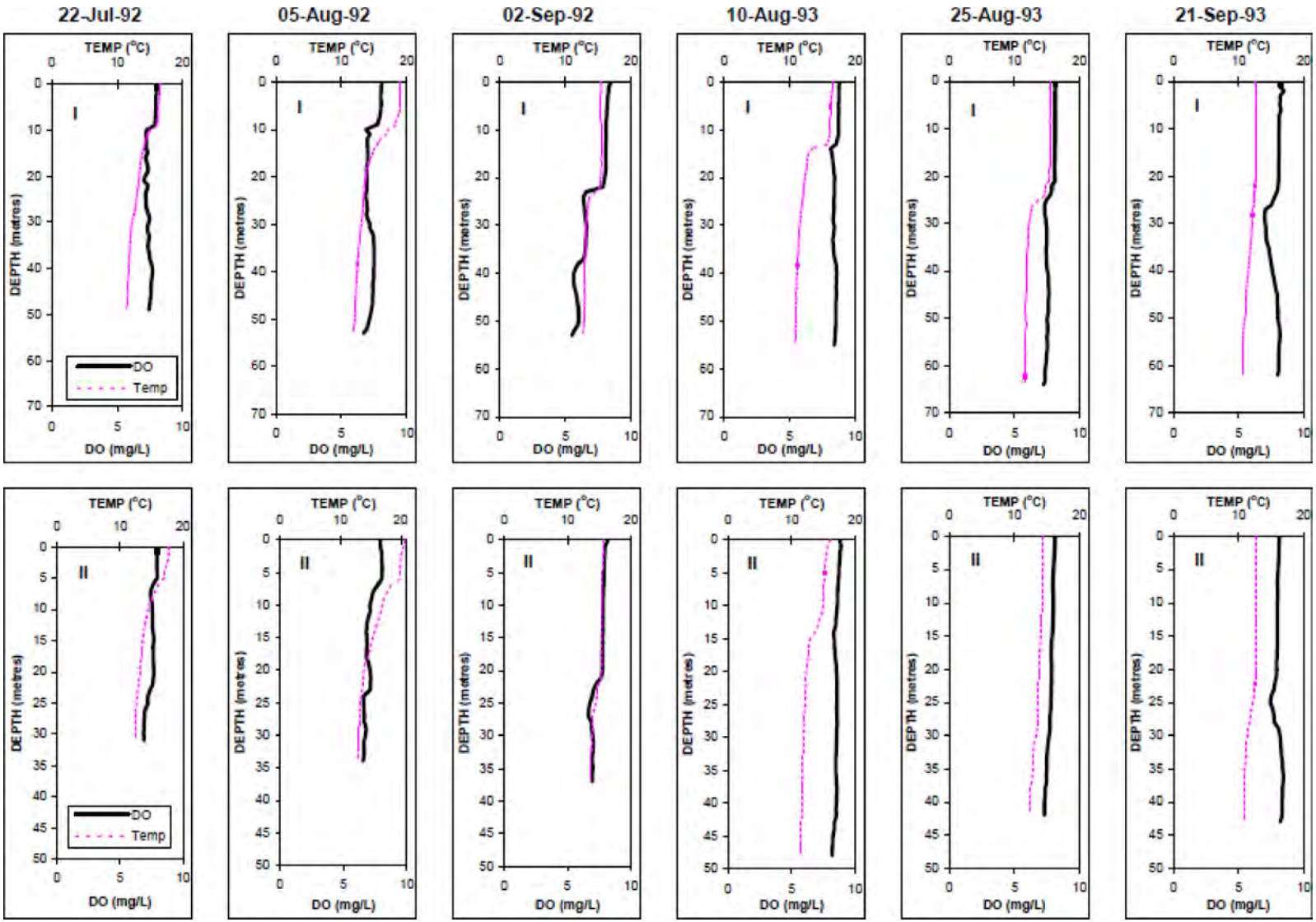

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

TEMPERATURE AND DISSOLVED OXYGEN PROFILES IN THE OLDMAN RESERVOIR, 1992 TO 1996

Data Source: Mitchell, 2001

MILLENNIUM EMS Solutions Ltd.

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 24, 2020

FIGURE
6.26-1A

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-26-1A Temperature and Oxygen in Oldman Reservoir 1992-1996 14-00201.mxd

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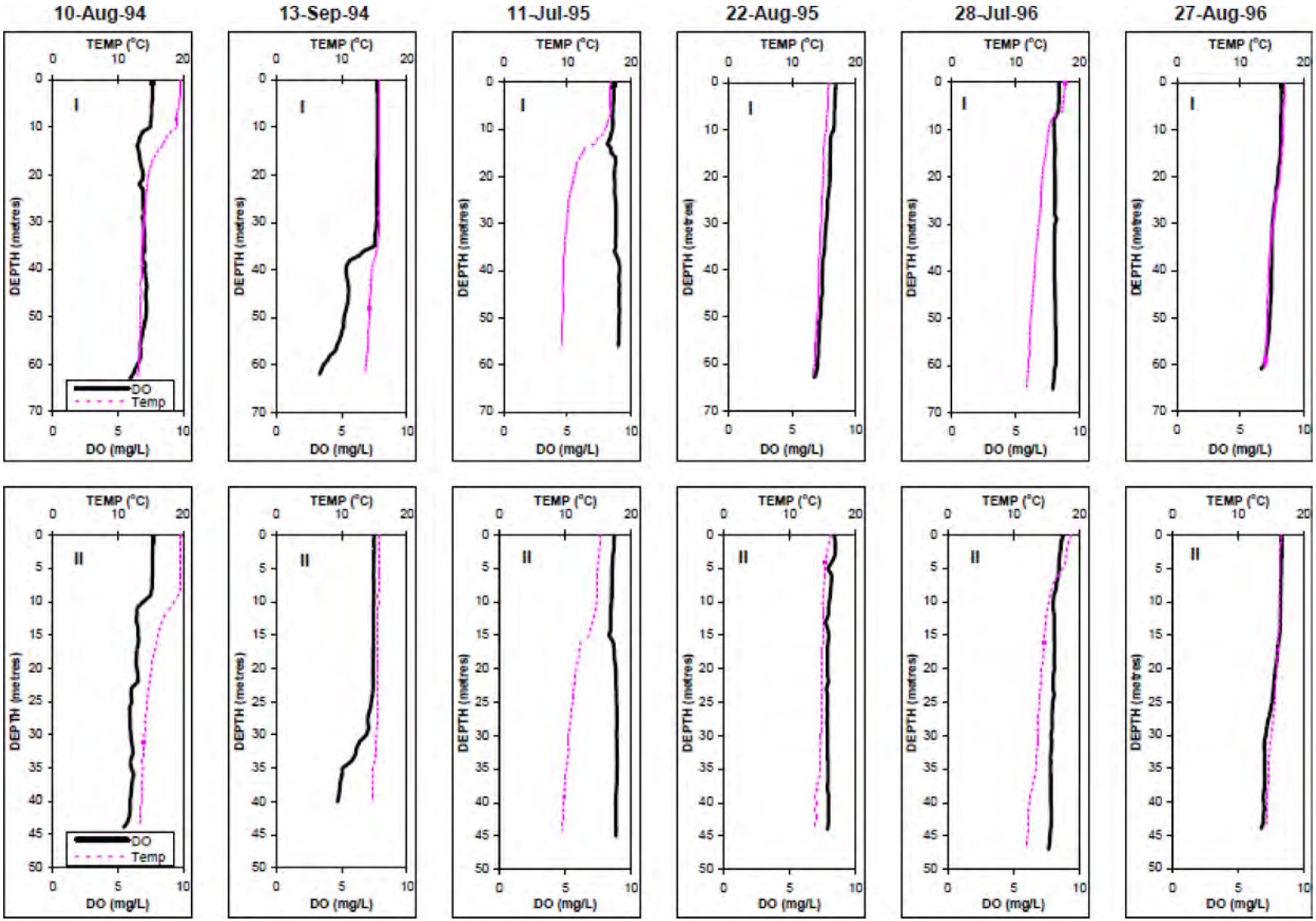

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

TEMPERATURE AND DISSOLVED OXYGEN PROFILES IN THE OLDMAN RESERVOIR, 1992 TO 1996

Data Source: Mitchell, 2001

PROJECT:	14-00201
DRAWN BY:	JLAMBERTS
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DATE:	FEBRUARY 24, 2020
FIGURE	6.26-1B

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-26-1B Temperature and Oxygen in Oldman Reservoir 1992-1996 14-00201.mxd

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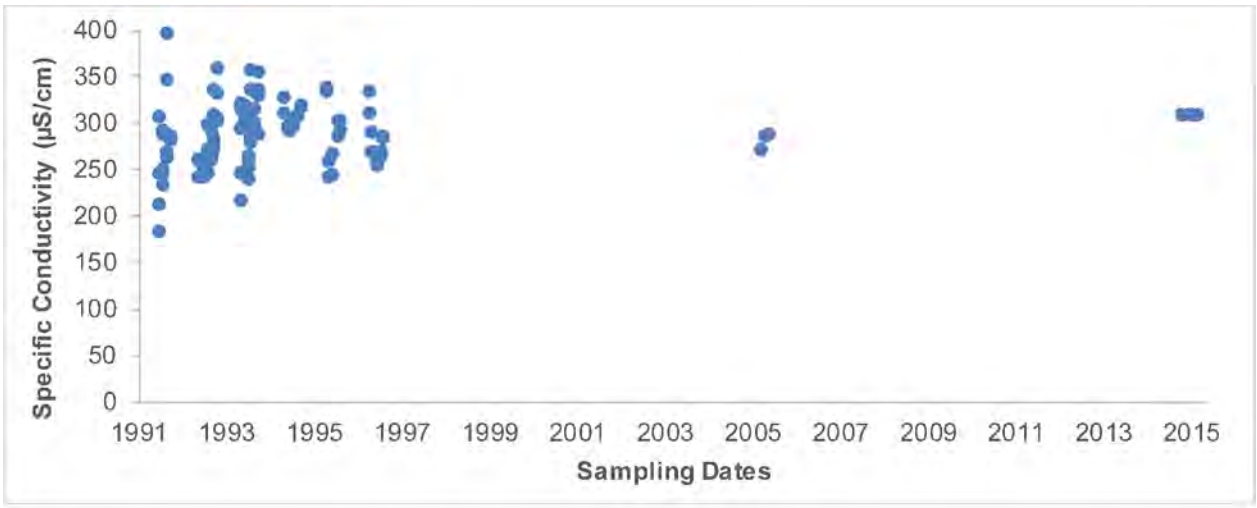

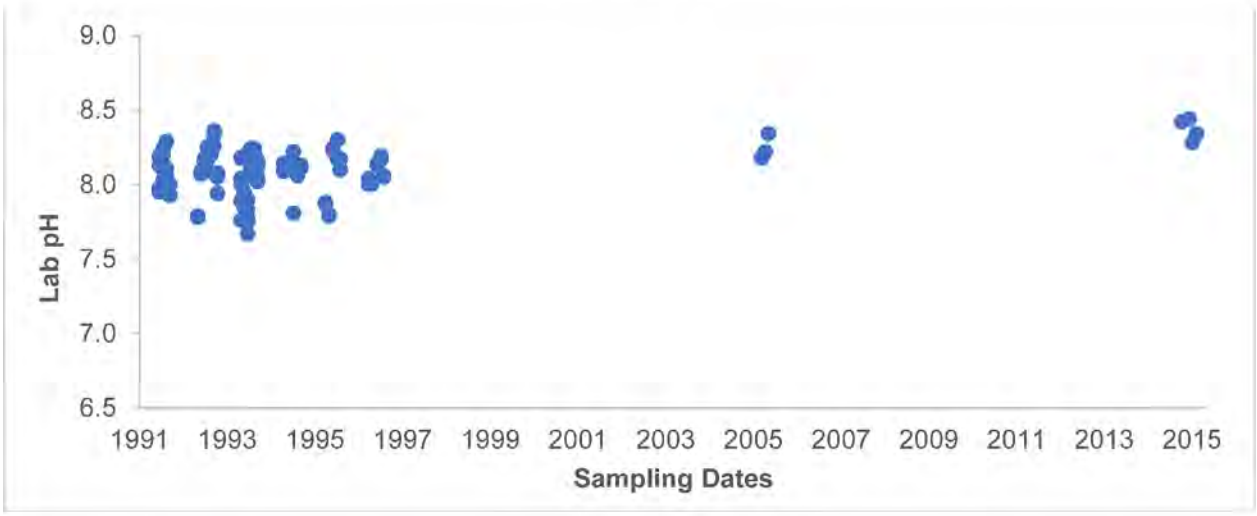

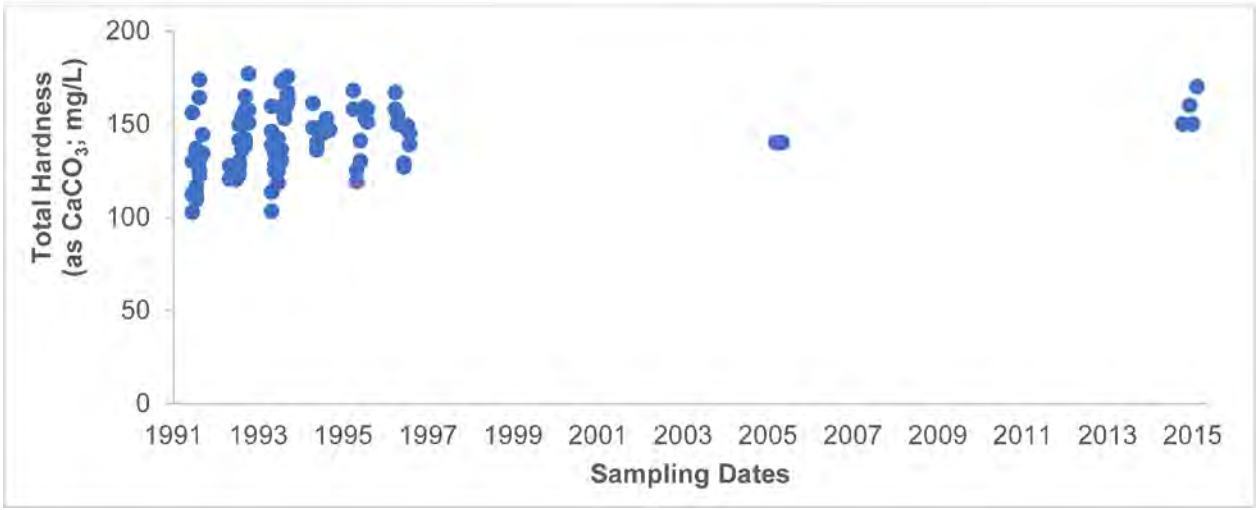

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

TEMPORAL TRENDS OF CONVENTIONAL PHYSICOCHEMICAL VARIABLES IN THE OLDMAN RESERVOIR, 1991 TO 2015

MEMS, 2019

MILLENNIUM EMS Solutions Ltd.

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 24, 2020
FIGURE
6.26-2A

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-26-2A Temporal Trends in Oldman Reservoir 1991-2015 14-00201.mxd

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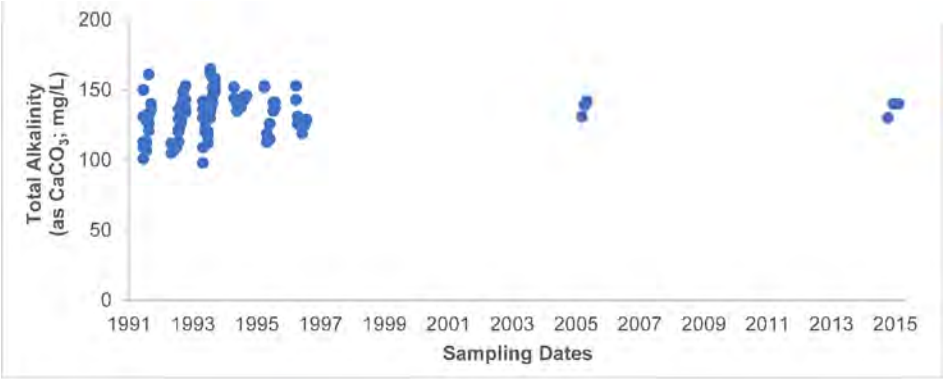

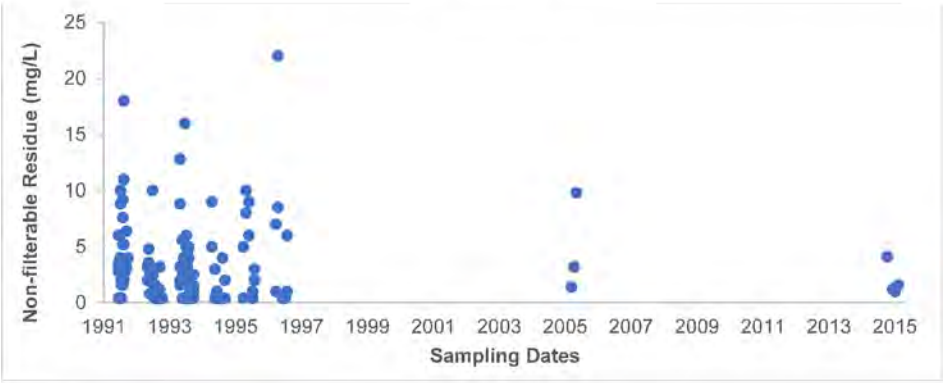

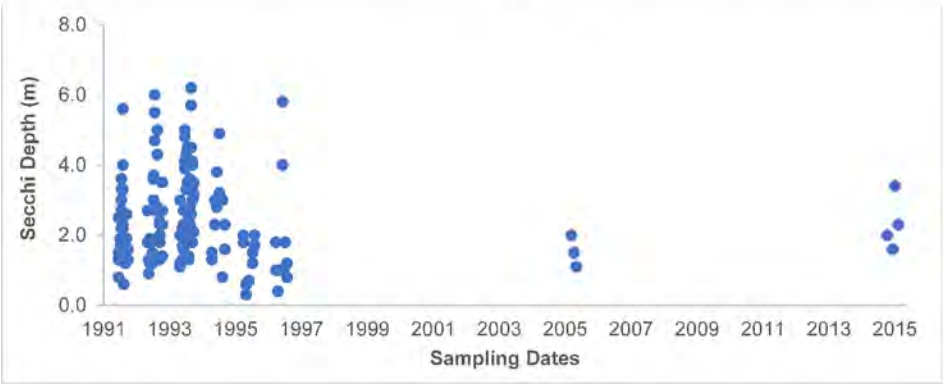

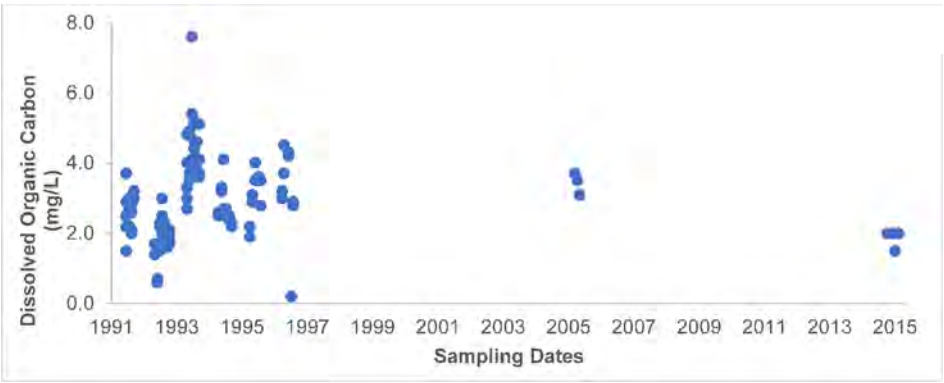

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

TEMPORAL TRENDS OF CONVENTIONAL PHYSICOCHEMICAL VARIABLES IN THE OLDMAN RESERVOIR, 1991 TO 2015

MEMS, 2019

MILLENNIUM EMS Solutions Ltd.

PROJECT: 14-00201

DRAWN BY: JLAMBERTS

CHECKED BY: MB

DATE: FEBRUARY 24, 2020

FIGURE

6.26-2B

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-26-2B Temporal Trends in Oldman Reservoir 1991-2015 14-00201.mxd

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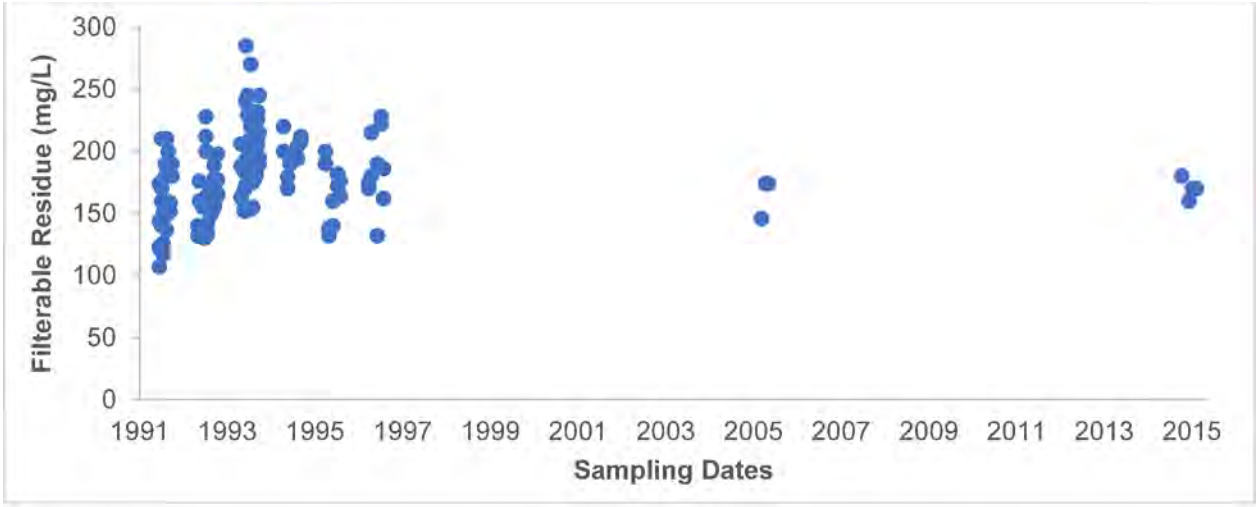

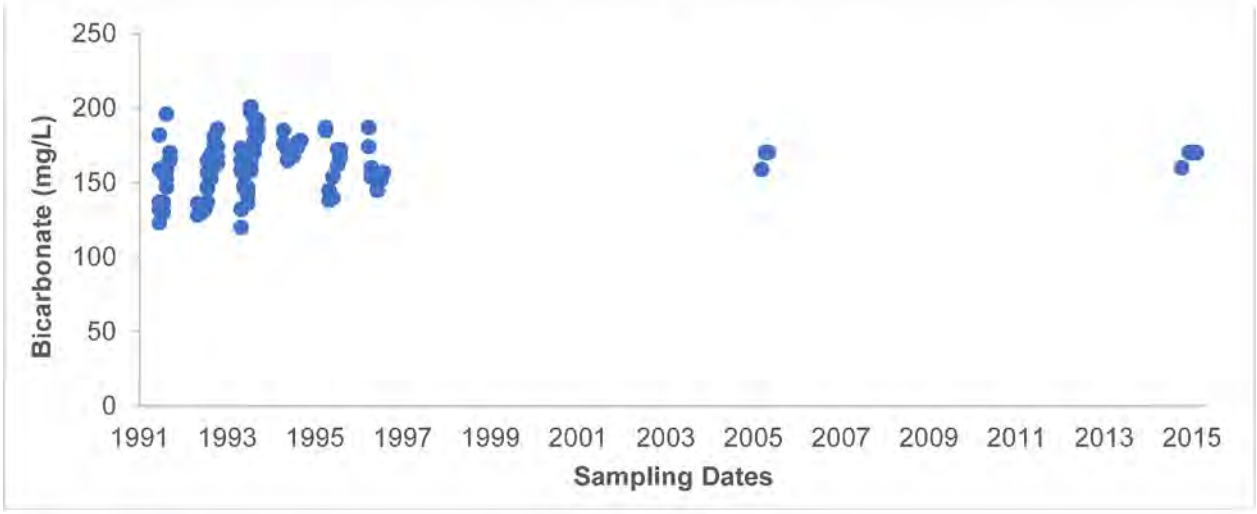

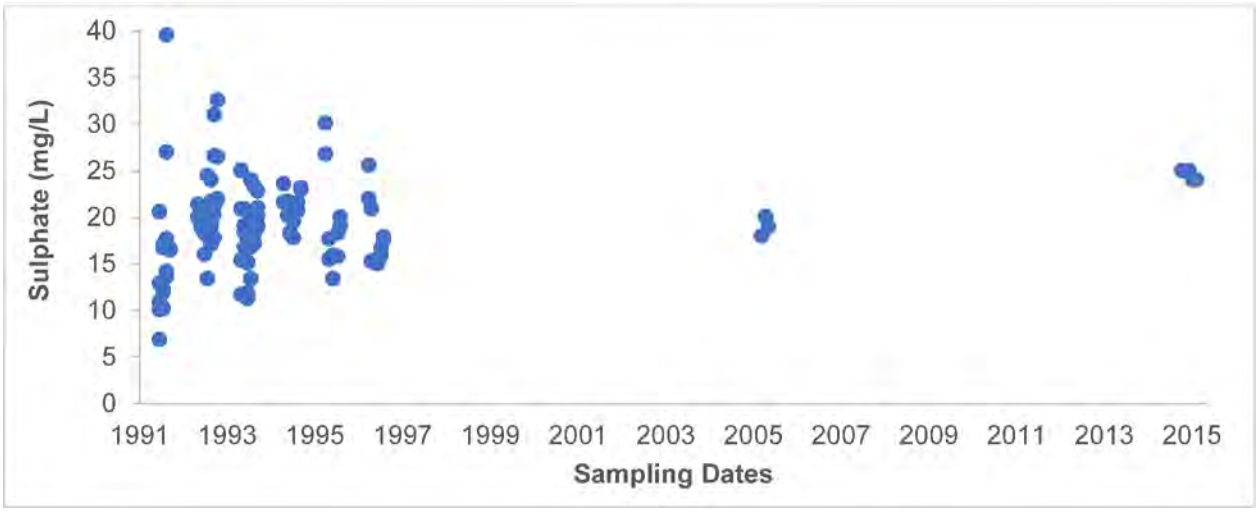

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

TEMPORAL TRENDS OF MAJOR IONS IN THE OLDMAN RESERVOIR, 1991 TO 2015

MEMS, 2019

MILLENNIUM EMS Solutions Ltd.

PROJECT:	14-00201
DRAWN BY:	JLAMBERTS
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DATE:	FEBRUARY 24, 2020
FIGURE	6.26-3A

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-26-3A Temporal Trends Major Ions in Oldman Reservoir 1991-2015 14-00201.mxd

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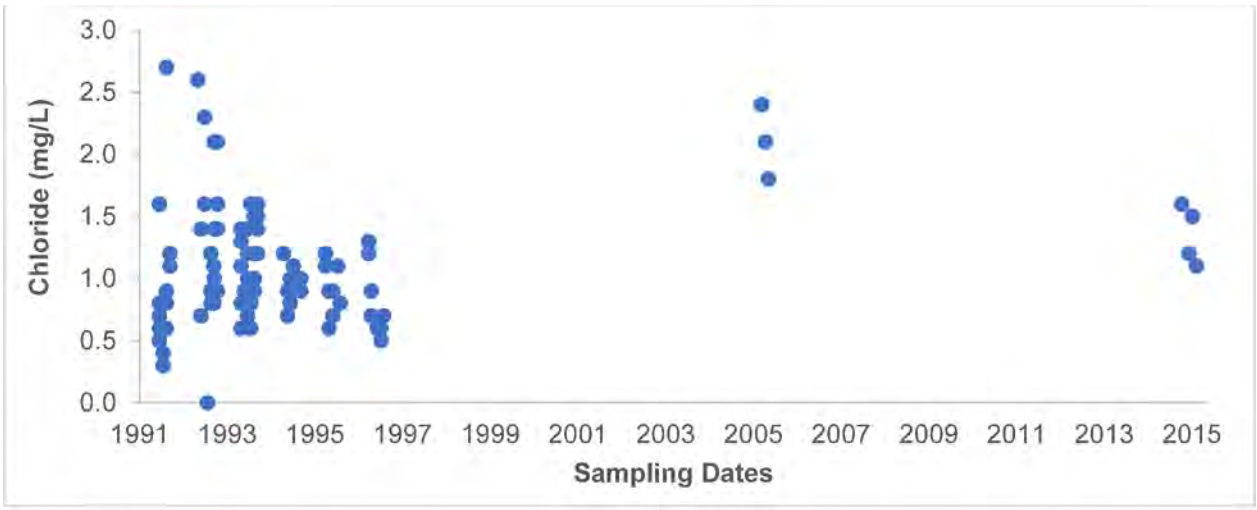

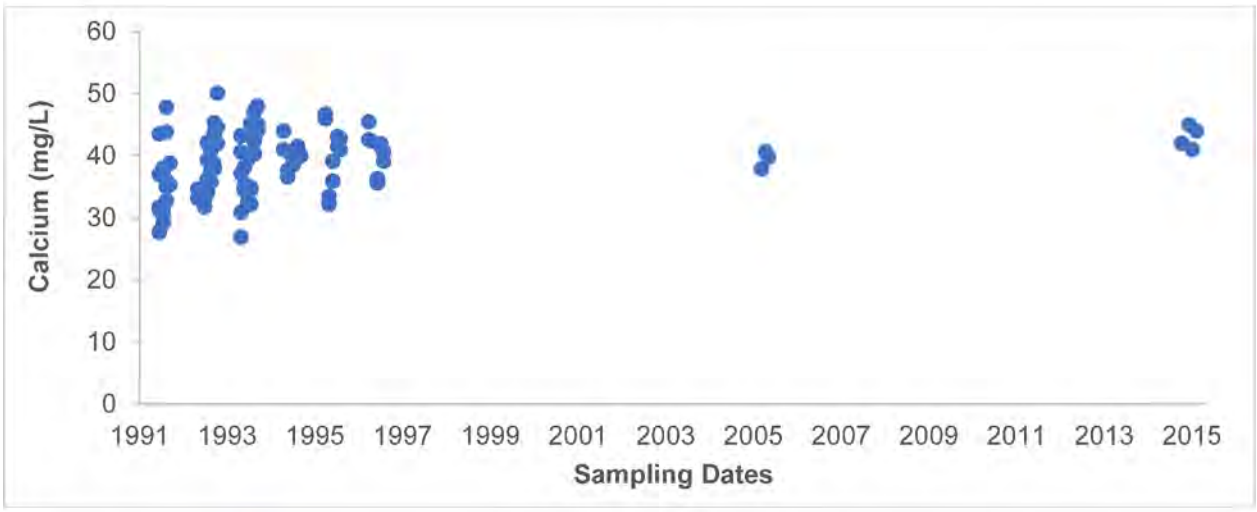

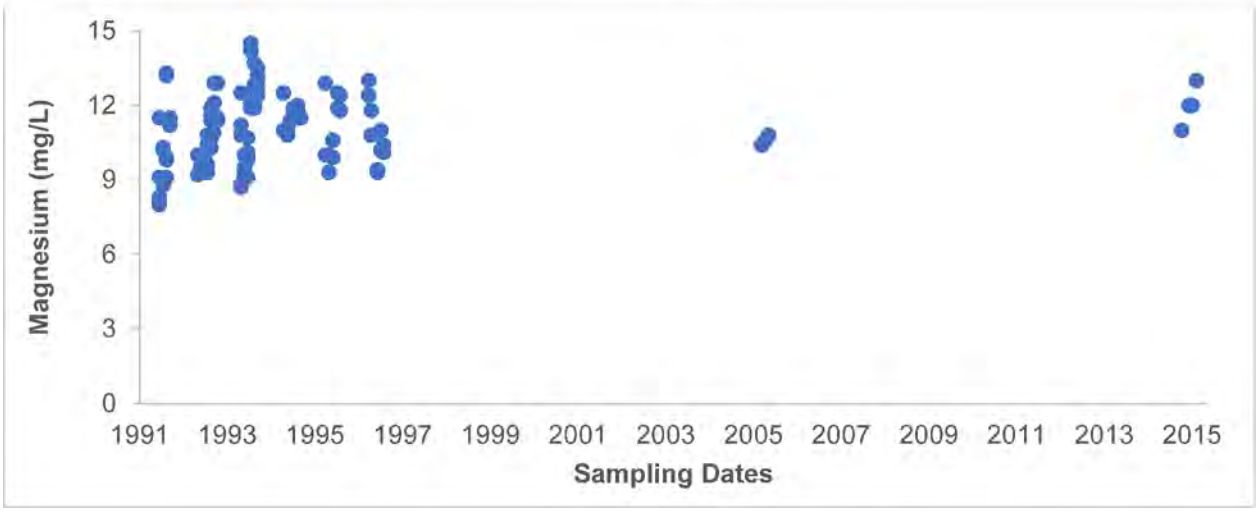

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

TEMPORAL TRENDS OF MAJOR IONS IN THE OLDMAN RESERVOIR, 1991 TO 2015

MEMS, 2019

MILLENNIUM EMS Solutions Ltd.

PROJECT:	14-00201
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DATE:	FEBRUARY 24, 2020
FIGURE	6.26-3B

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-26-3B Temporal Trends Major Ions in Oldman Reservoir 1991-2015 14-00201.mxd

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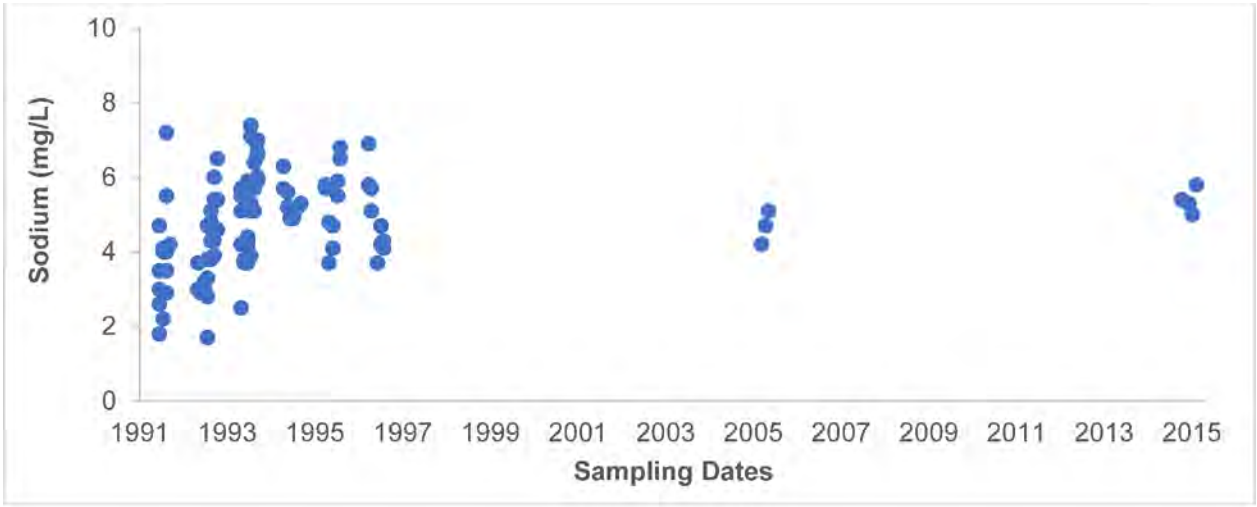

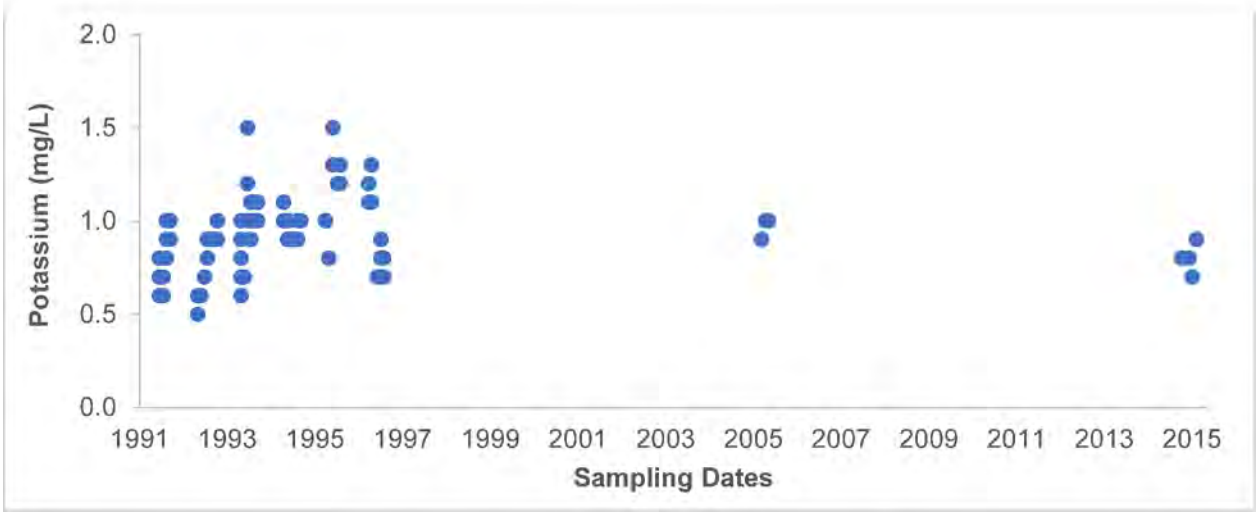

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

TEMPORAL TRENDS OF MAJOR IONS IN THE OLDMAN RESERVOIR, 1991 TO 2015

MEMS, 2019

MILLENNIUM EMS Solutions Ltd.

PROJECT:	14-00201
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DATE:	FEBRUARY 24, 2020
FIGURE	6.26-3C

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-26-3C Temporal Trends Major Ions in Oldman Reservoir 1991-2015 14-00201.mxd

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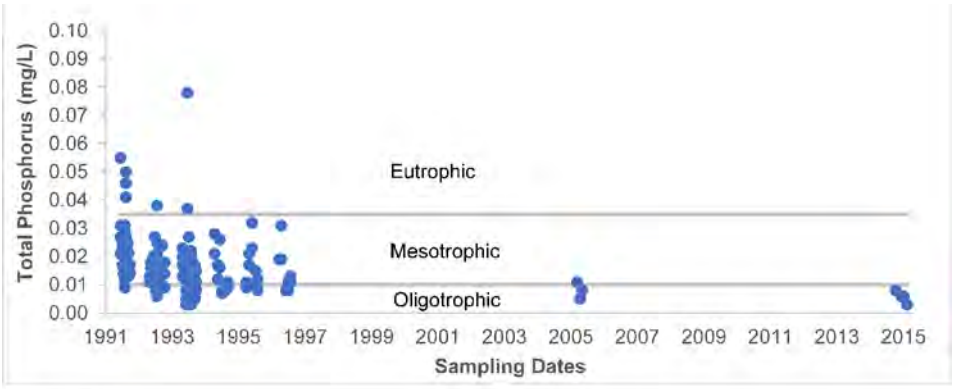

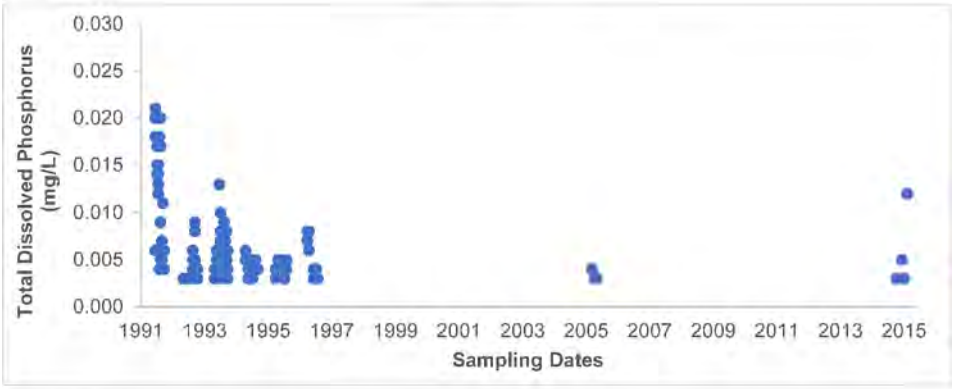

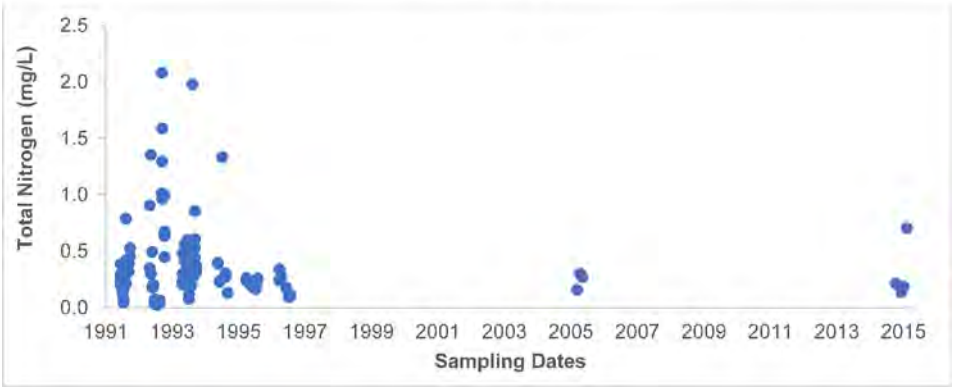

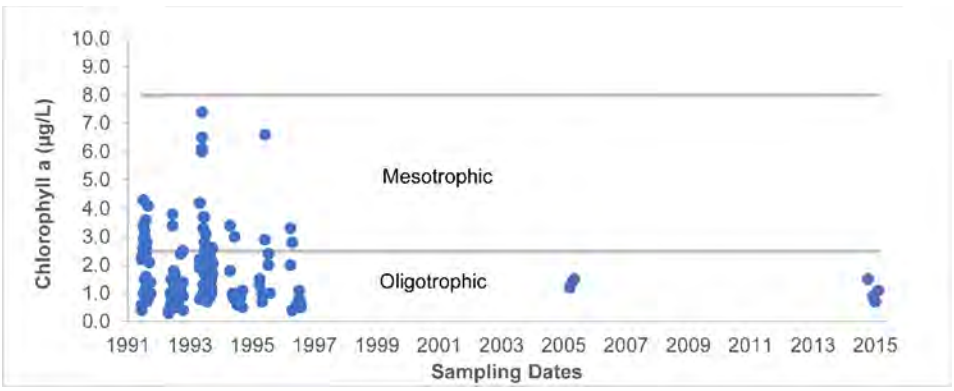

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

TEMPORAL TRENDS OF MAJOR NUTRIENTS AND CHLOROPHYLL A IN THE OLDMAN RESERVOIR, 1991 TO 2015

MEMS, 2019

MILLENNIUM EMS Solutions Ltd.

PROJECT:	14-00201
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DATE:	FEBRUARY 24, 2020
FIGURE	6.26-3D

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-26-3D Temporal Trends Major Nutrients in Oldman Reservoir 1991-2015 14-00201.mxd

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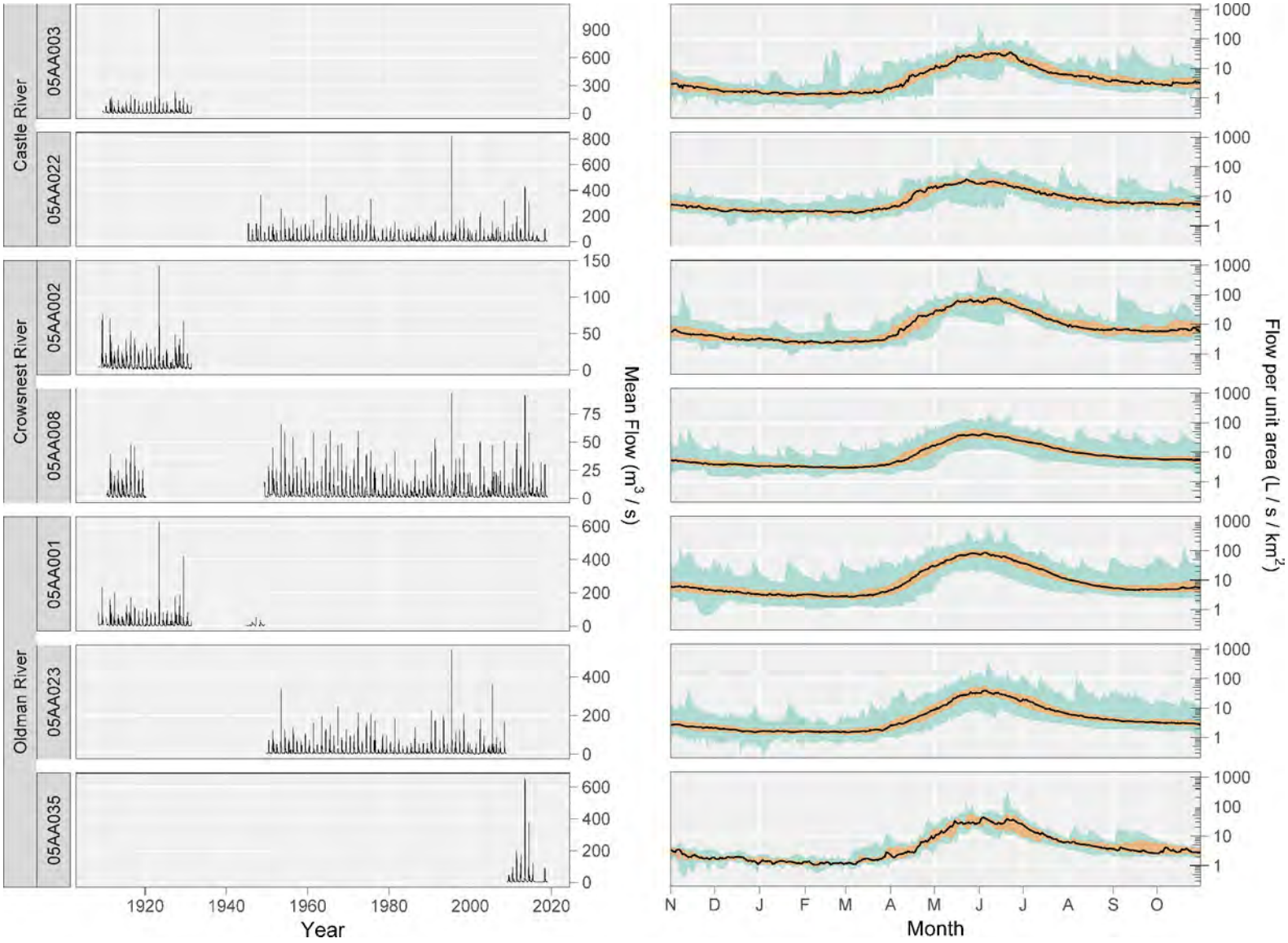

LEGEND

25-75 percentile | Range | Median

Note: daily statistics shown using a common scale to facilitate direct comparison.

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

DAILY FLOW DATA AND STATISTICS FROM THE CROWSNEST, CASTLE AND OLDMAN RIVERS

Data Source: MEMS, 2020

MILLENNIUM EMS Solutions Ltd.

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 24, 2020

FIGURE
6.26-4

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-26-4 Daily Flow from Crowsnest Castle and Oldman Rivers 14-00201.mxd

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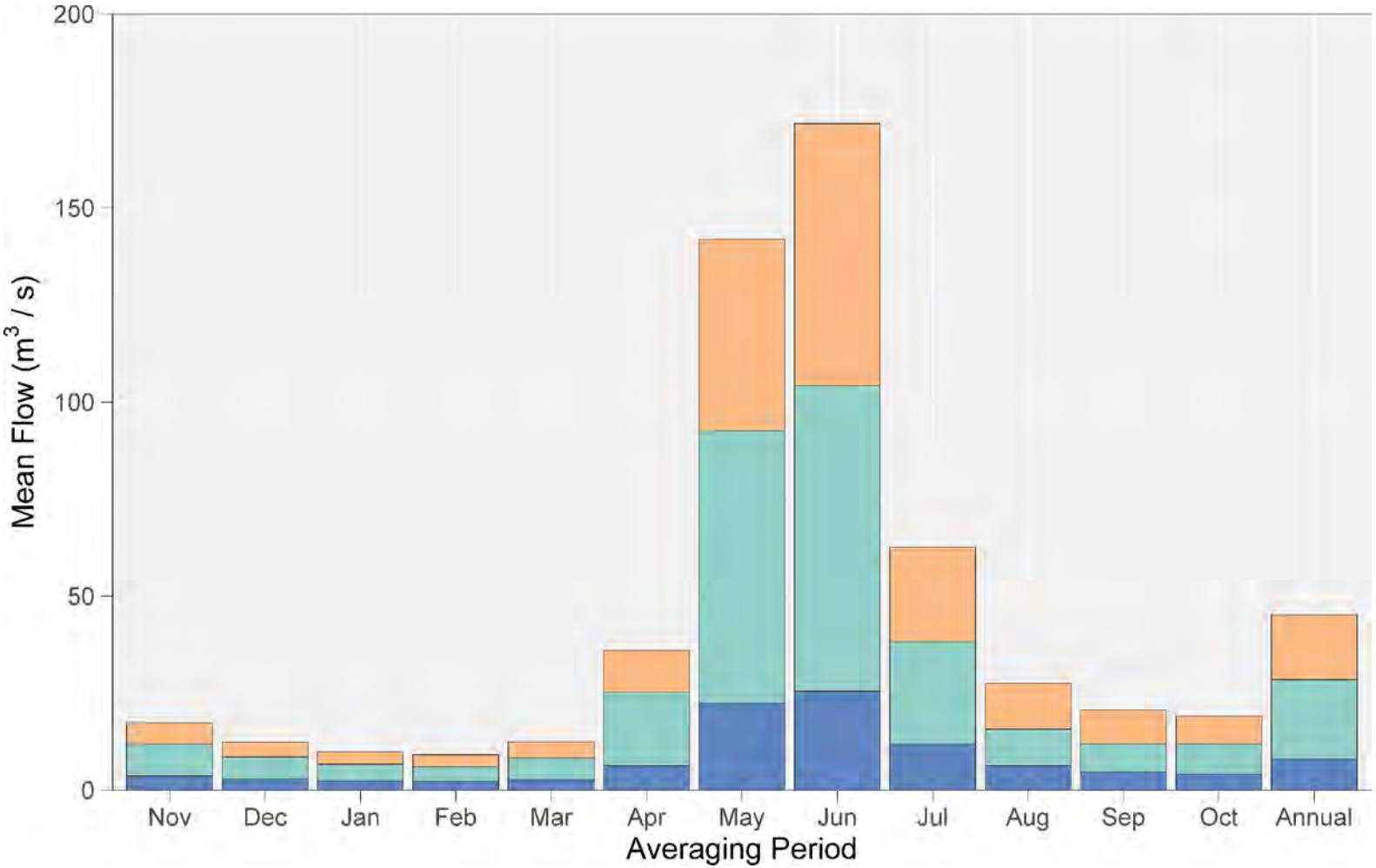

LEGEND

Crowsnest River | Castle River | Oldman River

Note: it is hypothetically assumed the Reservoir was present throughout this 50-year period

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MEAN MONTHLY AND ANNUAL INFLOWS TO OLDMAN RESERVOIR

Data Source: MEMS, 2020

MILLENNIUM EMS Solutions Ltd.

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 24, 2020

FIGURE
6.26-5

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-26-5 Mean Inflows to Oldman Reservoir 14-00201.mxd

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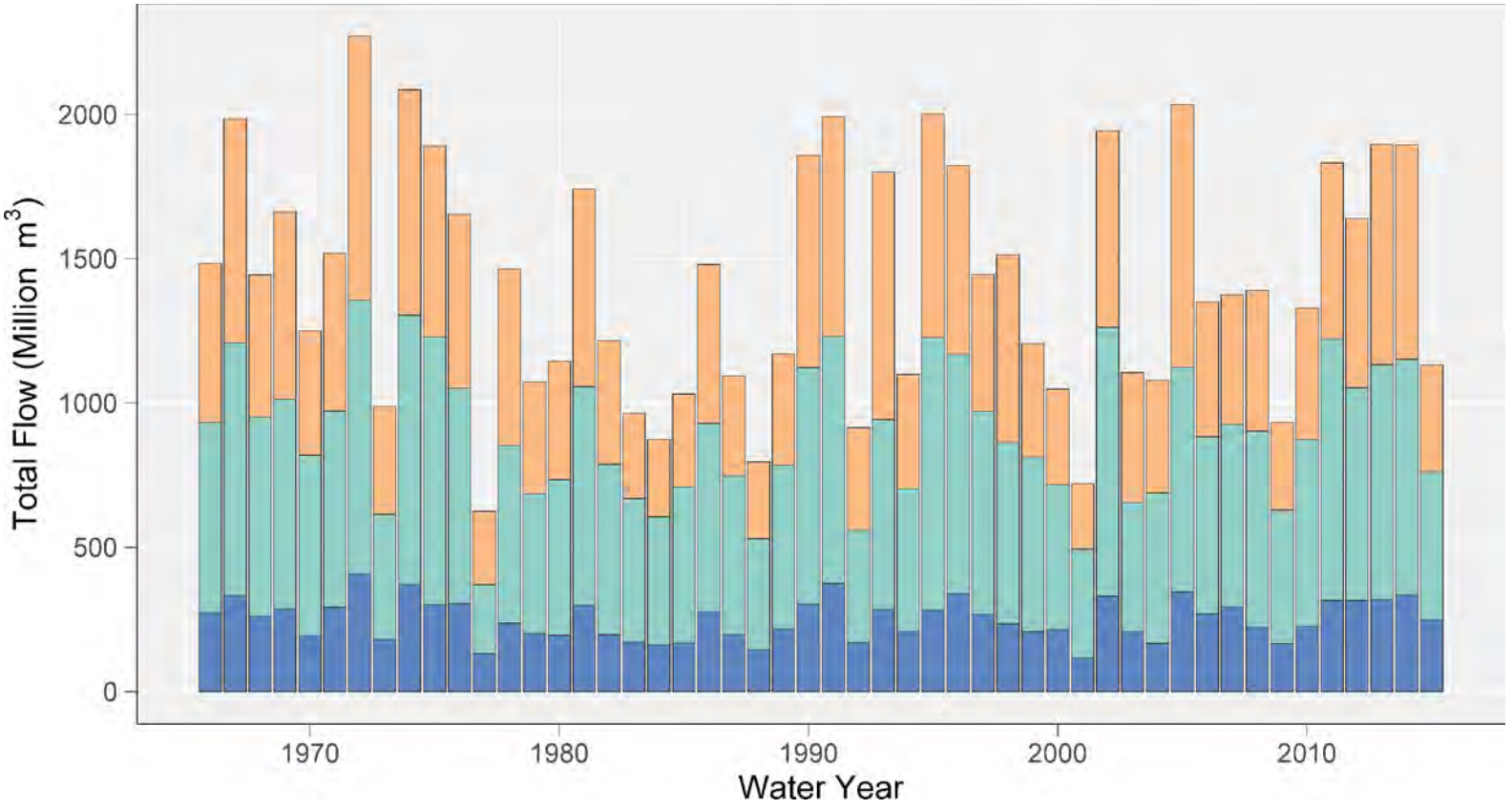

LEGEND

Crowsnest River | Castle River | Oldman River

Note: it is hypothetically assumed the Reservoir was present throughout this 50-year period

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

ANNUAL FLOW CONTRIBUTIONS TO OLDMAN RESERVOIR

Data Source: MEMS, 2020

MILLENNIUM EMS Solutions Ltd.

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
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DATE: FEBRUARY 24, 2020

FIGURE
6.26-6

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-26-6 Mean Inflows to Oldman Reservoir 14-00201.mxd

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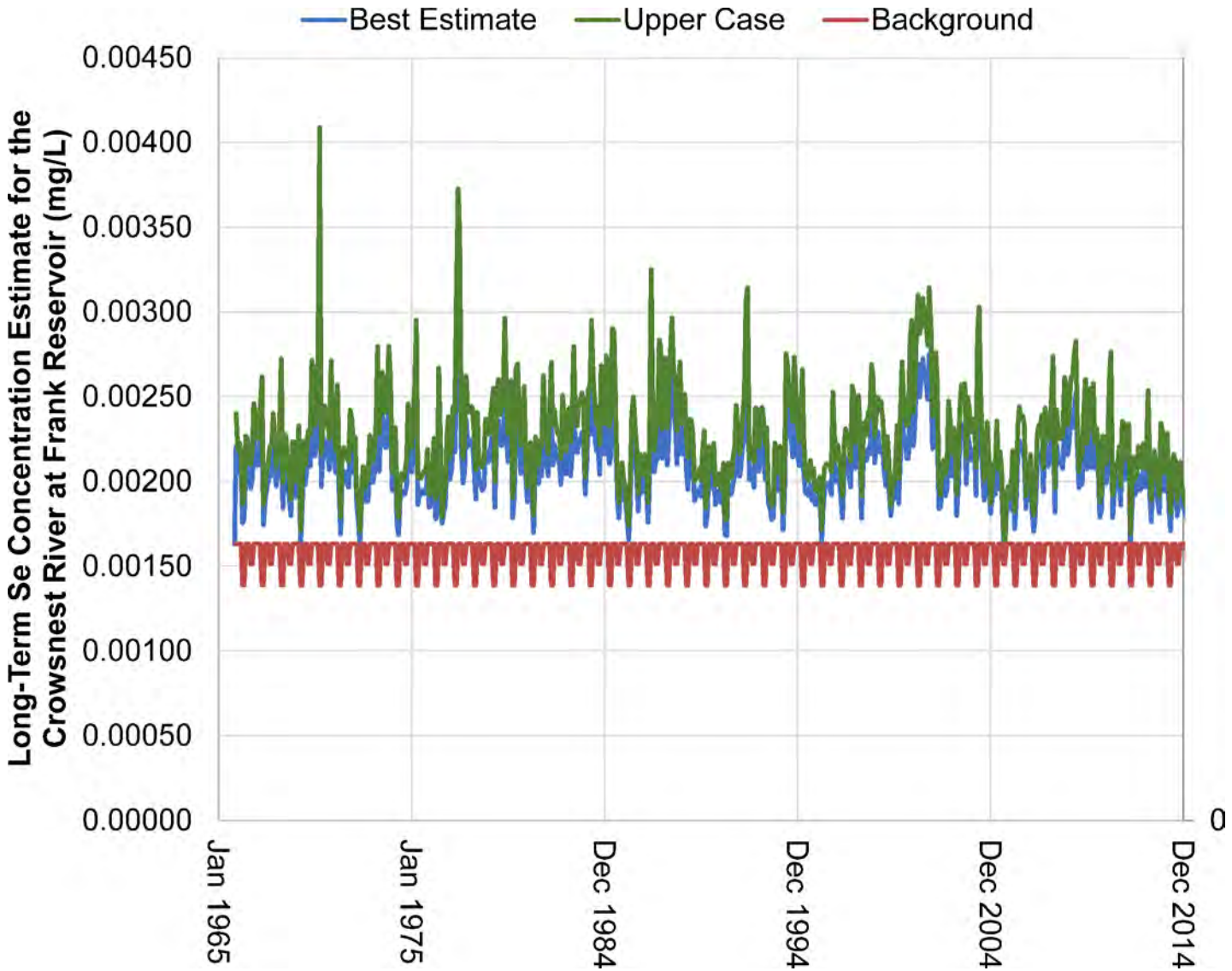

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

LONG-TERM SE CONCENTRATION ESTIMATE FOR THE CROWSNEST RIVER AT FRANK RESERVOIR (MG/L)

Data Source: MEMS, 2020

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 24, 2020

FIGURE
6.26-7

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-26-7 Long Term Se Concentration 14-00201.mxd

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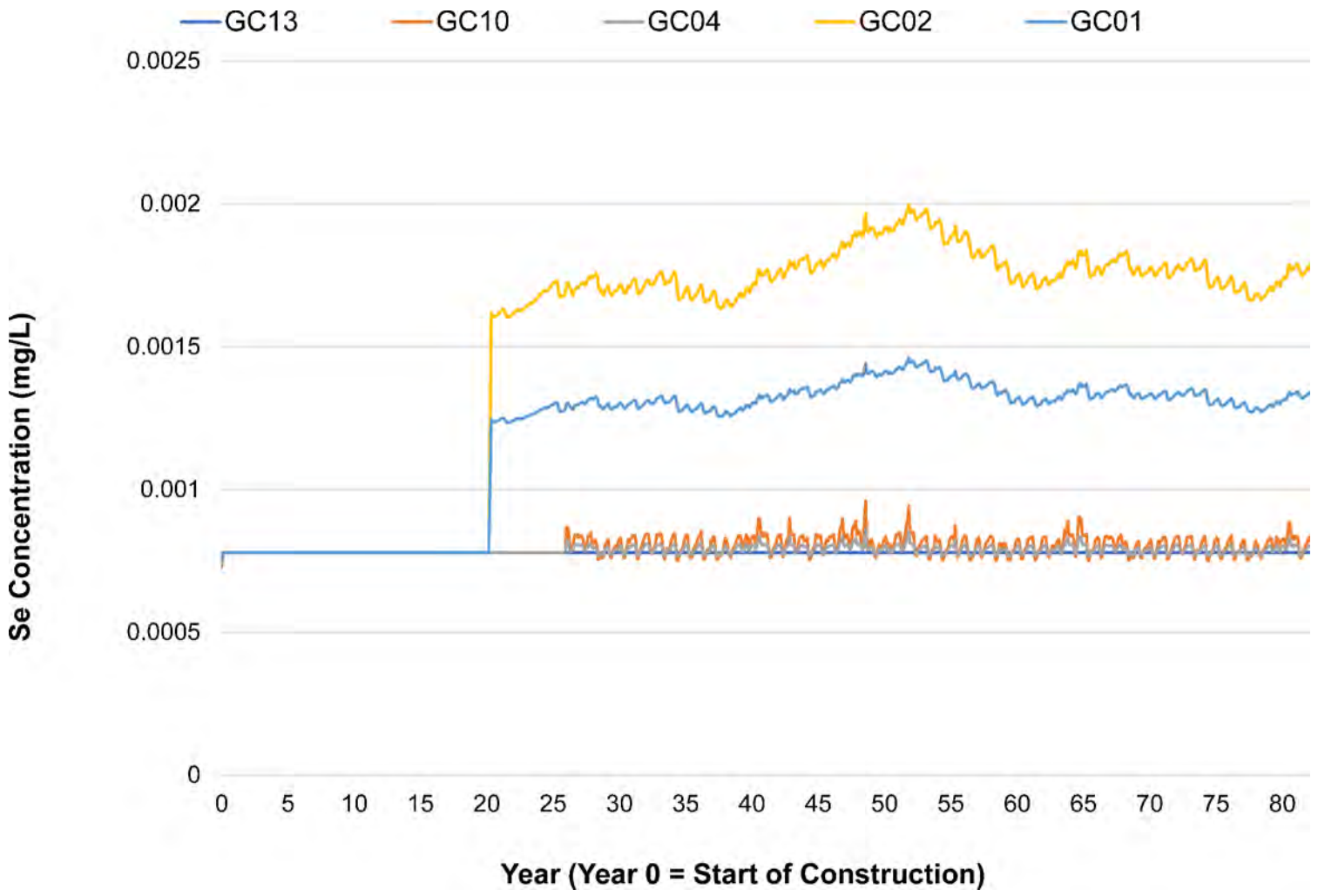

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

SURFACE WATER TOTAL SELENIUM CONCENTRATIONS AT STATION LK2 IN KOOCANUSA RESERVOIR DOWNSTREAM FROM THE ELK RIVER. DATA FROM LOTIC ENVIRONMENTAL (2019)

Data Source: Lotic Environmental, 2019

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 25, 2020

FIGURE
6.26-8

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-26-8 Selenium at Station LK2 14-00201.mxd

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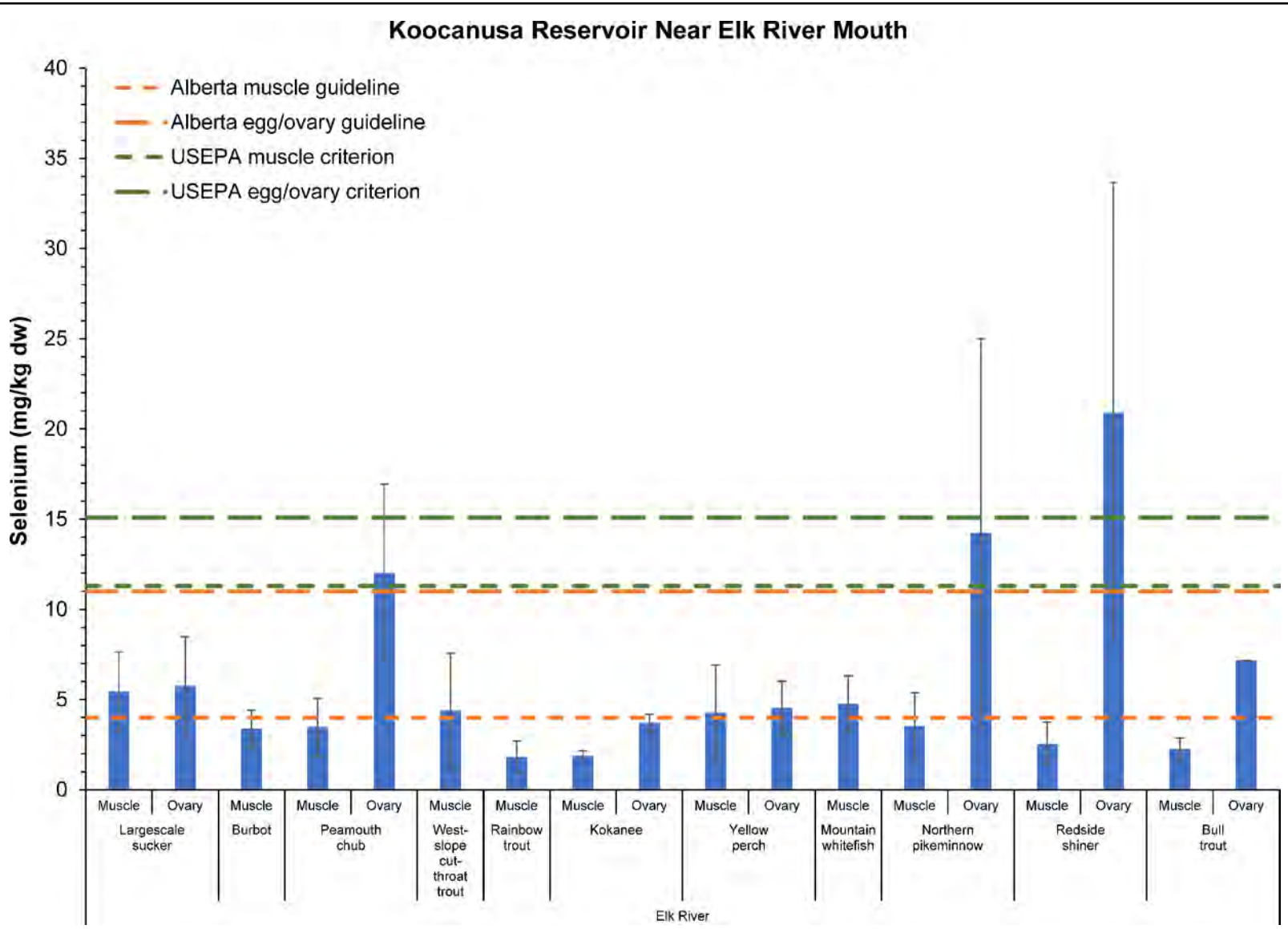

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

MEAN (±SD) SELENIUM CONCENTRATIONS IN FISH COLLECTED NEAR THE MOUTH OF THE ELK RIVER IN KOOCANUSA RESERVOIR

Data Source: Lotic Environmental, 2019

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 25, 2020

FIGURE
6.26-9

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-26-9 Mean Selenium at Elk River 14-00201.mxd

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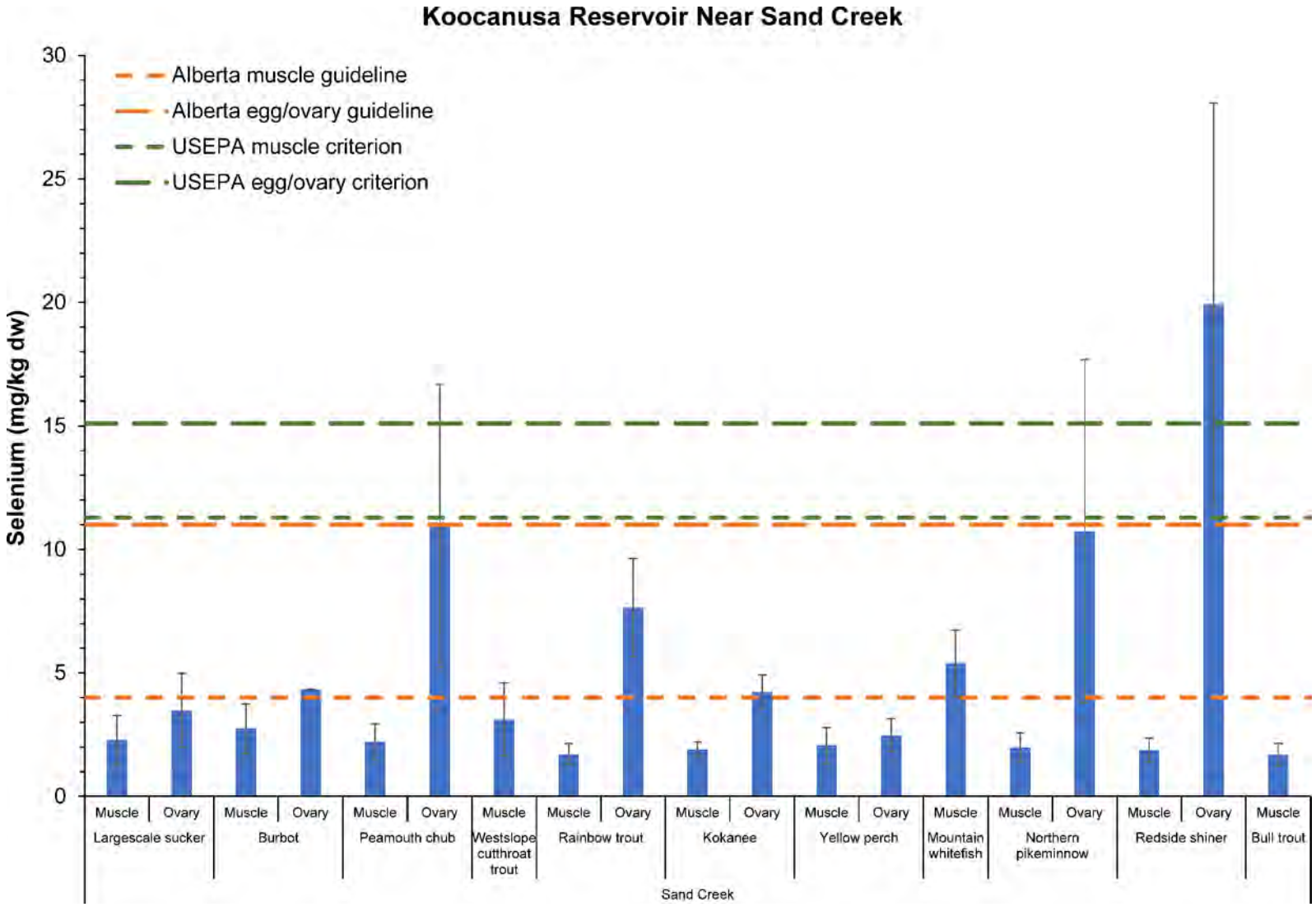

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

MEAN (±SD) SELENIUM CONCENTRATIONS IN FISH COLLECTED NEAR SAND CREEK IN KOOCANUSA RESERVOIR

Data Source: Lotic Environmental, 2019

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 25, 2020

FIGURE
6.26-10

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-26-10 Mean Selenium at Sand Creek 14-00201.mxd

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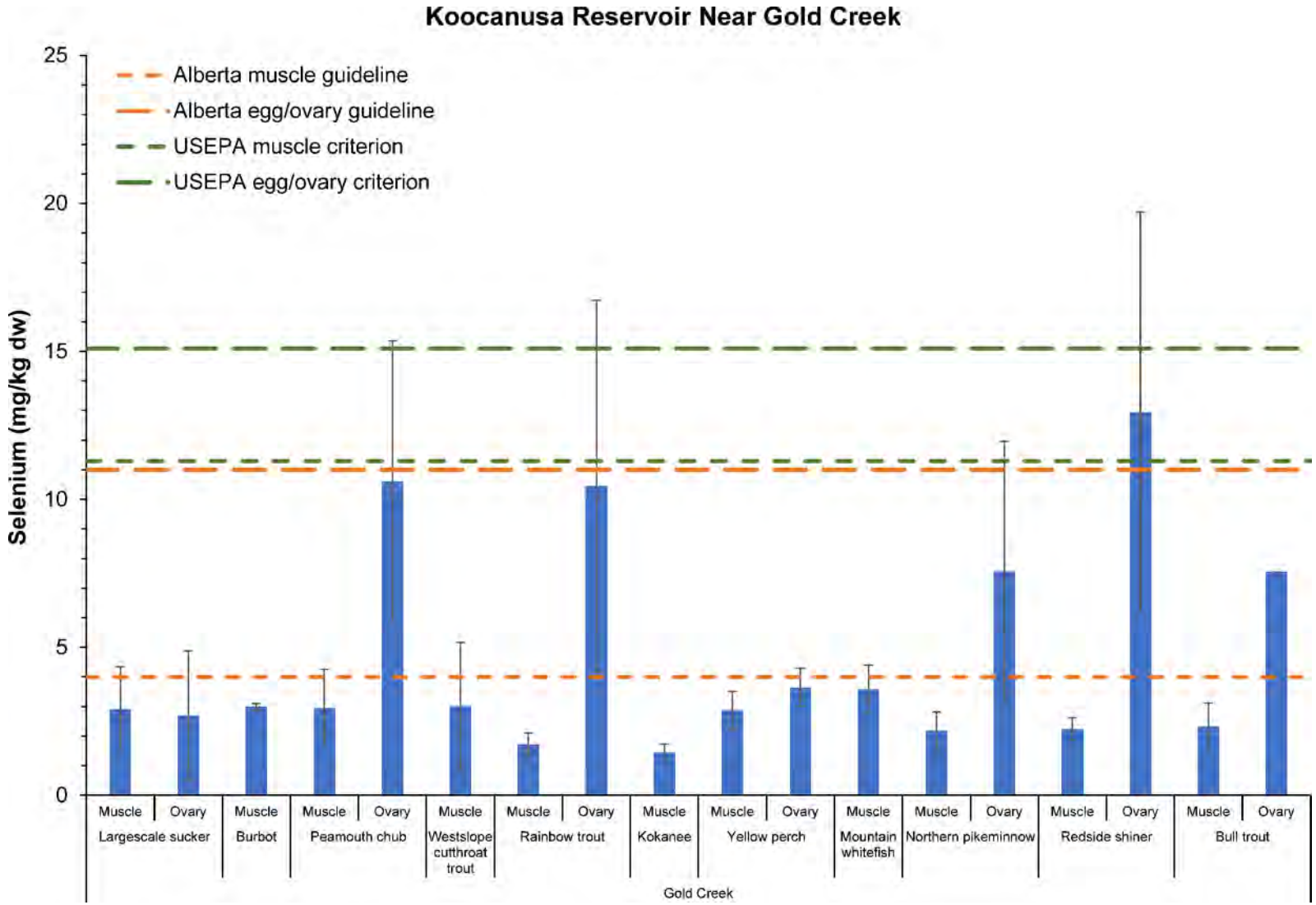

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

MEAN (±SD) SELENIUM CONCENTRATIONS IN FISH COLLECTED NEAR GOLD CREEK IN KOOCANUSA RESERVOIR

Data Source: Lotic Environmental, 2019

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
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DATE: FEBRUARY 25, 2020

FIGURE
6.26-11

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-26-11 Mean Selenium at Gold Creek 14-00201.mxd

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APPENDIX 6.4-1: BENGA'S HISTORICAL RESOURCES ASSESSMENT RECOMMENDATIONS

SUMMARY AND RECOMMENDATIONS

On behalf of the Benga Mining Limited (operating as Riversdale Resources), Bison Historical Services Ltd. conducted a Historical Resources Impact Assessment (HRIA) of the proposed the Benga Mining Limited (Riversdale Resources) Grassy Mountain Coal Project in the Municipality of Crowsnest Pass. Grassy Mountain underwent extensive historic underground and surface stripping mining operations by West Canadian Collieries Ltd. from 1905 to 1968 (Alberta 1981; ERCB 1988).

A pre-field overview study identified 32 previously documented historical resources sites (archaeology and heritage structures) inside or within 100-metres of the Project's footprint. Twenty-five (n=25) High Potential Areas were developed as a means to focus the field survey on certain terrain that had the potential to contained undiscovered archaeological sites based on relationship to water, distinguishing landforms, proximity to known archaeological sites, and landforms that are typically conducive to having such sites.

The field survey was conducted from June to October 2015, and resulted in the documentation of 40 historical resource sites, 24 of which were revisits of previously known sites, and 16 were newly identified sites. Additionally, other areas encountered, besides the High Potential Areas, that were deemed to have potential for historical resources were shovel tested, resulting in the 61 Assessment Areas. A minimum of 210 areas were visually examined resulting in 21 spots that were positive for artifacts, and the excavations of 1,110 subsurface tests, 151 of which contained artifacts. A total of 3,975 artifacts were recovered.

Table 73 summarizes the 20 historical resource sites with no *Historical Resources Act* concerns or *Historical Resources Act* clearance is recommended. Table 74 summarizes the 17 historical resource sites recommended for further historical resources work or *Historical Resource Act* clearance with conditions for the proposed the Benga Mining Limited (Riversdale Resources) Grassy Mountain Coal Project in the Municipality of Crowsnest Pass. **All recommendations are subject to approval from Alberta Culture and Tourism.**

No.	Borden/ HS	Site Name	HRV	Site Type	Pre-contact/ Historic	11U UTM	LSD/ATS	Mining Impact Area	Revisited/ NEW	Environment	Exp.	Shovel Tests	Artifacts	HRIA Results and Further *Historical Resources Act* Recommendations
1	DjPo-31	Hole 8	**0**	Campsite, settlement - concrete foundation	Pre-contact & historic	683897E 5499305N	9, 8-3-8-4-5	Rail and Load-out	No	Within the landscaped golf course.	0	0		Site DjPo-31 has a Historical Resource Value of 0 and was already disturbed from the highway realignment, and the golf course expansion in the 1980s and 1970s respectively. **The site will be disturbed further by the Rail and Load-out circle configuration, and therefore, there is no *Historical Resources Act* concerns regarding site DjPo-31.**
2	DjPo-32	East Ridge Golf Course	**0**	Campsite	Pre-contact	683819E 5499451N	9-3-8-4-5	Rail and Load-out	Revisited	Within the landscaped golf course.	0	0		Site DjPo-32 has a Historical Resource Value of 0 and was already disturbed from the highway realignment and the golf course expansion in the 1970s. **The site will be disturbed further by the Rail and Load-out circle configuration, and therefore, there is no *Historical Resources Act* concerns regarding site DjPo-32.**
3	DjPo-34	Blairmore Clinic	**0**	Campsite	Pre-contact	683121E 5499818N	15-3-8-4-5	Outside & next to the Rail and Load-out	Revisited	Terrace above service road and Highway 3.	0	0		The site is outside of the Rail and Load-out, and will not be impacted. Site DjPo-34 has a Historical Resource Value of 0 and no remnant of the site was identified. **There are no *Historical Resources Act* concerns regarding site DjPo-34.**
4	DjPo-35	Hospital Ridge	**0**	Campsite	Pre-contact	683347E 5499663N	10-3-8-4-5	Outside & next to the Rail and Load-out	Revisited	Terrace above service road and Highway 3.	0	0		Site DjPo-35 has a Historical Resource Value of 0, and outside the footprint of the Rail and Load-out. **There are no *Historical Resources Act* concerns regarding site DjPo-35.**
5	DjPo-37; HS 14639	Blairmore Dairy	**4**	Settlement - building	Historic	683501E 5499392N	7, 10-3-8-4-5	Rail and Load-out	Revisited	Utility corridor, Highway 3, golf course entry, and driveway.	0	0		The Blairmore Dairy structure does not exist, and the site is green space with subsurface utilities, a segment of the highway, and associated ditch. ***Historical Resources Act* clearance is recommended for site DjPo-37.**
6	DjPo-63	Golf Course Terrace	**4**	Campsite, stone feature, workshop	Pre-contact	684007E 5499114N	3, 4, 5, 6-2-8-4-5; 7,8-3-8-4-5	Rail and Load-out	Revisited	Within the landscaped golf course.	4	28 **(3+)**	**42 Total** - 34 Faunal - 7 Lithics - 1 Historic	Site DjPo-63 is within the footprint for the Rail and Load-out, and will be directly impacted. Due to the paucity of temporal-cultural diagnostic artifacts, the disturbed sedimentation from the backhoe deep tests, and the developed landscape from the golf course expansion and the realignment and widening of Highway 3, site DjPo-63 was largely disturbed or destroyed. No further historical resources work is warranted. The opportunity to recovered artifacts from a primary and intact context for the site was completed in 1983 under ASA Permit 83-020. ***Historical Resources Act* clearance is recommended for site DjPo-63.**
7	DjPo-124	Frank & Grassy Railroad	**4**	Railroad	Historic	687965E 5501967N	1,2,3,4-25-8-4-5	South Disposal Area	Revisited	Existing gravel road.	1	28		Only an approximately 1,330-metres segment of site DjPo-124, the Frank and Grassy Mountain Railway within the footprint of the South Disposal Area, and is currently a gravel road often used by locals and recreational users. It is not known exactly what kind of impact will happen to the site, but it appears the road maybe upgraded and used as a means to travel and transport waste materials between various parts of the project area during coal mining operations (Millennium 2015). A considerable portion of the railway going through Gold Creek towards historic Lille from the project boundary will not be impacted. ***Historical Resources Act* clearance is recommended for the segment of site DjPo-124, the Frank and Grassy Mountain Railway within the footprint of the South Disposal Area.**
8	DjPo-156		**0**	Campsite, workshop	Pre-contact	686880E 5504530N	9-24-8-4-5	Transmission ROW	Revisited & Relocated	On slope terrace within transmission corridor.	0	4		Site DjPo-156 is within the existing transmission right-of-way, and the South Disposal Area, and will be impacted. The site has a Historical Resource Value of 0, and is destroyed. **There are no *Historical Resources Act* concerns.**
9	DjPo-182		**0**	Isolated Artifact Find	Pre-contact	687022E 5504717N	13-30-8-4-5	South Disposal Area	Revisited	Undulating rocky landscape.	1	21		The east half of site DjPo-182 is within the footprint of the In-Pit Disposal Area, and will be directly impacted. Site DjPo-182 was heavily disturbed from previous logging activities, and has a Historical Resource Value of 0. **There are no *Historical Resources Act* concerns.**

Table 73: Historical resource sites with no Historical Resources Act concerns and/or clearances recommended.

No.	Borden/ HS	Site Name	HRV	Site Type	Pre-contact/ Historic	11U UTM	LSD/ATS	Mining Impact Area	Revisited/ NEW	Environment	Exp.	Shovel Tests	Artifacts	HRIA Results and Further *Historical Resources Act* Recommendations
10	DjPo-183		**0**	Workshop	Pre-contact	686935E 5504817N	16-24-8-4-5	South Disposal Area	Revisited & Relocated	Undulating rocky landscape.	1	2		The east half of site DjPo-183 is within the footprint of the South Disposal Area, and will be directly impacted. It was disturbed from previous logging activities, and has a Historical Resource Value of 0. **There are no *Historical Resources Act* concerns.**
11	DjPo-184		**4**	Campsite	Pre-contact	686622E 5504617N	9-24-8-4-5	South Disposal Area	Revisited	On gradual north-facing slope, previously logged.	0	29 **(3+)**	**3 Total** - 3 Lithics	Site DjPo-184 is within the footprint of the South Disposal Area, and will be directly impacted. A total of 29 shovel tests were excavated and only three (n=3) flakes were recovered from three shovel tests (T059+, T052+, T049+). The bulk of the shovel tests (n=23) were concentrated in the vicinity where the 20 artifacts were collect under ASA Permit 92-082. Additionally, the site is a north facing gentle slope with a well trampled surface from previous logging activities, which was further confirmed by the compact, mottled, and mixed soil profile to 40 cm below surface in many of the shovel tests. **The site has been satisfactory assessed based on the sloping terrain, the heavily logged context, the disturbed soil profile, and the paucity of artifacts recovered from the 29 shovel tests excavated, and thus, no further historical resource work is warranted. *Historical Resources Act* clearance is recommended for site DjPo-184.**
12	DjPo-185		**0**	Campsite	Pre-contact	686404E 5504712N	10, 15-24-8-4-5	South Disposal Area	Revisited & Relocated	Undulating landscape with gully.	1	3		Site DjPo-185 is within the footprint of the South Disposal Area, and will be directly impacted. It was disturbed from previous logging activities, and has a Historical Resource Value of 0. **There are no *Historical Resources Act* concerns.**
13	DjPo-218		**TBD**	Scatter <10	Pre-contact	686510E 5504407N	10-24-8-4-5	South Disposal Area	New	With a saddle between two rises on a ridgeline.	0	25 **(6+)**	**6 Total** - 6 Lithics	Site DjPo-218 is within the footprint of the South Disposal Area, and will be directly impacted. Due to the paucity of artifacts (n=6) recovered from six out of 25 shovel tests; the site has been satisfactorily well assessed. **The site is considered to have a low to limited historical resource value, and thus, *Historical Resources Act* clearance is recommended.**
14	DjPo-221	Grassy Mountain Trail	**TBD**	Trail	Historic	686330E 5504211N	7-24-8-4-5	South Disposal Area	New	Travels along a forested ridgeline down to a meadow.	1	2		Certain segments of the trail in the east half of 24-8-4-W5M was already disturbed by previous logging activities, and the construction of the transmission right-of-way. The segment of the trail that was visually assessed between the NW of 13-8-4-W5M to NE of 24-8-4-W5M is within the South Disposal Area, and will be impacted. The remaining segment towards NW of 11-8-4-W5M is outside the project's footprint. No artifacts were identified along the trail, and no significant information was discerned regarding the trail. In addition, a considerable segment of the trail within east half of 24-8-4-W5M was already disturbed by previous logging activities, and the construction of the transmission right-of-way. Due to the lack of significant information regarding the trail, and that a considerable segment within east half of 24-8-4-W5M was already disturbed within the project's footprint. ***Historical Resources Act* clearance is recommended for the segment of site DjPo-221 within the project's footprint.**
15	DkPo-13		**0**	Scatter	Pre-contact	687422E 5510018N	14-6-9-3-5; 3-7-9-3-5	Outside & next to the In Pit Disposal Area in Township 9	Revisited	On Teddy's Trail overlooking Gold Creek to the east.	0	0		Site DkPo-13 is outside the footprint of the In-Pit Disposal Area, and will not be impacted. It was destroyed by the vehicle trail, Teddy's Trail, and has a Historical Resource Value of 0. **No *Historical Resources Act* concerns.**
16	DkPo-14		**4**	Campsite	Pre-contact	687322E 5509818N	14-6-9-3-5	Outside & next to the In Pit Disposal Area in Township 9	Revisited	On Teddy's Trail overlooking Gold Creek to the east.	1	0		Site DkPo-14 is adjacent to and outside the footprint of the In-Pit Disposal Area, and will not be impacted. It was destroyed by Teddy's Trail, vehicle trail. **No *Historical Resources Act* concerns.**

Table 73: Historical resource sites with no Historical Resources Act concerns and/or clearances recommended, con't.

No.	Borden/ HS	Site Name	HRV	Site Type	Pre-contact/ Historic	11U UTM	LSD/ATS	Mining Impact Area	Revisited/ NEW	Environment	Exp.	Shovel Tests	Artifacts	HRIA Results and Further *Historical Resources Act* Recommendations
17	DkPo-47		**TBD**	Campsite	Pre-contact	686451E 5504997N	15-24-8-4-5	South Disposal Area	New	On a crescent-shaped knoll in a grassy-tussock floodplain.	0	23 **(4+)**	**6 Total** - 1 Faunal - 2 Lithics - 3 FBR	Site DkPo-47 is within the footprint of the South Disposal Area, and will be directly impacted. Due to the paucity of artifacts (n=6) recovered, and the excavation of 23 shovel tests through very shallow soil deposition, the site has been satisfactorily well assessed. ***Historical Resources Act* clearance is recommended for site DkPo-47.**
18	DkPo-48		**TBD**	Scatter <10	Pre-contact	685917E 5504950N	14-24-8-4-5	South Disposal Area	New	On grassy terrace overlooking the South Disposal Area	0	20 **(2+)**	**2 Total** - 2 Lithics	Site DkPo-48 is within the footprint of the South Disposal Area, and will be directly impacted. Due to the paucity of artifacts (n=2) recovered, and the excavation of 20 shovel tests; the site has been satisfactorily well assessed. **The site is considered to have a low to limited historical resource value, and thus, *Historical Resources Act* clearance is recommended for site DkPo-48.**
19	DkPo-49	T-Road (Taqa Road)	**TBD**	Trail	Historic	684645E 5506689N	15-26-8-4-5 2-35-8-4-5	Coal Handling Processing Plant	New	Most of this trail is an existing vehicle trail. Stems from Grassy Mountain Road.	0	0		A segment of the trail is within the footprint of the Coal Handling Processing Plant, and will be impacted. Most of the trail outside the project's footprint has been disturbed from historic mining activities, and is often used by ATV off-roaders. No artifacts were identified along the trail, and no significant information was discerned regarding the trail. In addition, the segment within the project's footprint was previously widened and disturbed from mining activities and petroleum projects, and is currently being used by vehicles of all sizes to access various areas of the Riversdale Resources properties. ***Historical Resources Act* clearance is recommended for the segment of site DkPo-49 within the project's footprint.**
20	DkPo-50; HS 30781, 26601		**TBD**	2 Historic Mine Structures	Historic	687040E 5508920N	5-6-9-3-5	In Pit Disposal Area	New	On man-made terrace overlooking a forested slope.	1	2		Site DkPo-50 is within the footprint of the In-Pit Disposal Area, and will be directly impacted. There is no significant information regarding the collapsed and dilapidated structures. **The site is considered to have a low to limited historical resource value, and thus, *Historical Resources Act* clearance is recommended.**
21	HS 106691, 106694, 106695, 106696	Galicia's	TBD	4 Historic Structures	Historic	686279E 5503886N	2-24-8-4-5	South Disposal Area	New	On relatively level grassy landscaped lot.	0	0		The Galicia's structures are within the footprint of the South Disposal Area, and will be directly impacted. A literature search found nothing of particular historical significance regarding the property, the structures or the landowners, therefore, the site has limited historical resource significance, and documentation of the structures provided in this final report is considered satisfactory. **The structure is considered to have a low to limited historical resource value, and thus, *Historical Resources Act* clearance is recommended for HS 106691, 106694, 106695, and 106696.**
22	HS 18929, 15221, 24030, 28198	Grassy Top	N/A	4 Historic Mine Structures	Historic	686160E 5506567N	14-25-8-4-5	In Pit Disposal Area	New	Grassy Mountain top and quarry.	0	0		The Grassy Mountain Top structures are within the footprint of the In-Pit Disposal Area, and will be directly impacted. A literature search found nothing of particular historical significance regarding the property, the structures or the landowners, therefore, the site has limited historical resource significance, and documentation of the structures provided in this final report is considered satisfactory. **The structure is considered to have a low to limited historical resource value, and thus, *Historical Resources Act* clearance is recommended for HS 106704, 106705, 106706, 106707, 106708, and 106709.**

Table 73: Historical resource sites with no Historical Resources Act concerns and/or clearances recommended, con't.

No.	Borden/ HS	Site Name	HRV	Site Type	Pre-contact/ Historic	11U UTM	LSD/ATS	Mining Impact Area	Revisited/ NEW	Environment	Exp.	Shovel Tests	Artifacts	HRIA Results and Further *Historical Resources Act* Recommendations
23	HS 106715	Frasers	N/A	1 Historic Structure	Historic	686379E 5504825N	15-24-8-4-5	South Disposal Area	New	On modified and landscaped lot.	0	0		The Fraser's House within the footprint of the South Disposal Area, and will be directly impacted. A literature search found nothing of particular historical significance regarding the property, the structures or the landowners, therefore, the site has limited historical resource significance, and documentation of the structures provided in this final report is considered satisfactory. **The structure is considered to have a low to limited historical resource value, and thus, *Historical Resources Act* clearance is recommended for HS 106715.**
24	HS 106745	Rubble Pile1	N/A	1 Historic Structure & Vent Fan	Historic	685472E 5504313N	12-24-8-4-5	Coal Handling Processing Plant	New	Next to trail on south-facing slope and a quarry pit. Forced air and turbine housing north and up the trail.	0	0		HS 106745 is within the footprint of the In-Pit Disposal Area, and will be directly impacted. A literature search found nothing of particular historical significance regarding the property, the structures or the landowners, therefore, the site has limited historical resource significance, and documentation of the structures provided in this final report is considered satisfactory. **The structure is considered to have no historical resource value, and thus, *Historical Resources Act* clearance is recommended for HS 106745.**
											11	**185 (6+)**	**59**	

Table 73: Historical resource sites with no Historical Resources Act concerns and/or clearances recommended, con't.

No.	Borden/ HS	Site Name	HRV	Site Type	Pre-contact/ Historic	11U UTM	LSD/ATS	Mining Impact Area	Revisited/ NEW	Environment	Exp.	Shovel Tests	Artifacts	HRIA Results and Further *Historical Resources Act* Recommendations and Conditions
1	DjPo-10	Blairmore Creek Campsite	**4**	Campsite	Pre-contact	683521E 5499618N	9, 10-3-8-4-5	Outside & near the Rail and Load-out	Revisited	Terrace above golf course.	1	0	N/A	Site DjPo-10 is approximately 40-metres north and outside of the footprint of the Rail and Load-out, and will not be directly impacted. The Rail and Load-out will impact a grassy utility corridor paralleling Highway 3, which is at the base of the terrace and the eroding slope. **Therefore, there are no *Historical Resources Act* concerns regarding the direct impact to site DjPo-10, however, it is recommended that the erosional slopes of the terrace be fenced off and partitioned from the construction and the operations of the Rail and Load-out.**
2	DjPo-33	Clubhouse Ridge	**4**	Campsite	Pre-contact	683725E 5499470N	9-3-8-4-5	Rail and Load-out	Revisited	Terrace above golf course.	0	0		The southern portion of site DjPo-33 is on the golf course landscaped terrace slope, and will be disturbed by the Rail and Load-out circle configuration. Based on the preliminary plans for the golf course relocation and expansion, it appear the terrace margins will be fenced-off, separating the golf course from the Rail and Load-out circle configuration, and only the landscaped slopes will be directly disturbed whereas, the remaining undisturbed portions of the site will be avoided. ***Historical Resources Act* clearance is recommended for site DjPo-33, as long as the undisturbed portion of the site will be avoided and fenced off from the construction and the operations of the Rail and Load-out circle configuration, as shown on the preliminary plans for the golf course expansion and relocation.**
3	DjPo-38; HS 16330, 17849, 18828, 22949, 26019, 26563, 28187, 29917, 31001, 32395, 81513, 106789, 106792, 17169	Greenhill Mine	**1, 2h, 3a**	Mine Complex and structures	Historic	684495E 5498812N	2, 3, 4, 6, 7-2-8-4-5; 1-3-8-4-5	Rail and Load-out	Revisited	Mine complex.	9	0	N/A	On July 29, 2015, a discussion was initiated between Riversdale Resources and Alberta Culture and Tourism regarding the potential ancillary and direct impacts, and which appears to be ongoing. In regards to Structure 12, the fire equipment storage and garage and the footprint of the Rail and Load-out, the Project plans were received on May 21, 2015 from Riversdale Resources, and the HRIA was planned and conducted accordingly to the given footprint. Based on the results of the HRIA fieldwork, Structure 12, the foundation remains of the fire equipment storage and garage is within the footprint of the Rail and Load-out configuration. A more defined and detailed plan of the Rail and Load-out was received on August 8, 2015 from Riversdale Resources showing impact avoidance to all of the structures and remains of the Greenhill Mine Complex including Structure 12 (HS 32395), the foundation remains of the fire equipment storage and garage. **Based on the more defined plans, Structure 13, the foundation remains of the fire equipment storage and garage will be avoided from impact.** **The proposed Rail and Load-out will impact a portion of site DjPo-38, the Greenhill Mine, a historical resource site with an Historical Resource Value of 1, 2h (historic), and 3a (archaeology), and thus further historical resource work is recommended. On January 11, 2016, the Permit Holder consulted with Fraser Shaw, Heritage Conservation Advisor, Southern Region, Alberta Culture and Tourism regarding the additional HRIA recommendations for site DjPo-38, the Greenhill Mine, and they include:** **1. Increase stability or any other mitigation measures to the fragile state of the compressor house, the wash house, and the office and lamp house.** **2. Any engineered mitigation measures of the Rail and Load-out configuration that may reduce or minimize any ancillary and accumulative impacts that may exacerbate the fragileness of the compressor house, the wash house, and the office and lamp house, such as vibrations and noise from its construction and operations.** 3. **A detailed architectural documentation of the foundation remains of the compressor house, the wash house, and the office and lamp house and garage, and the salvaging of all associated artifacts.**

Table 74: Historical resource sites recommended for further historical resources work.

No.	Borden/ HS	Site Name	HRV	Site Type	Pre-contact/ Historic	11U UTM	LSD/ATS	Mining Impact Area	Revisited/ NEW	Environment	Exp.	Shovel Tests	Artifacts	HRIA Results and Further *Historical Resources Act* Recommendations and Conditions
4	DjPo-98		**4**	Campsite	Pre-contact	684852E 5503751N	2-23-8-4-5	Coal Handling Processing Plant	Revisited & Expanded	Four terraces overlooking Blairmore Creek.	22 **(19+)**	89 **(51+)**	**2,037 Total** -1,068 Faunal - 607 Lithics - 293 FBR - 69 Historics	The Coal Handling Processing Plant will impact a portion of DjPo-98, and it is most likely the entire site will be impacted by the development. A grand total of 2,036 artifacts were recovered between 0 - 50 cm in depth from primary context including the four (n=4) projectile points representing three pre-contact cultural components, as well as the historic period. A total of 1,968 pre-contact artifacts were recovered primary context including 5 projectile points representing three pre-contact cultural components, Early Pre-contact 9,600 - 8,600 B.P., Middle Pre-contact 2,500 - 1,350 B.P., and Late Pre-contact 1,350 - 250 B.P. Additionally, a buried pre-contact hearth was identified, the faunal remains of bison and moose, and the variety of stone tools identified; these findings suggest that a variety of activities occurred at the site. **The site is considered to be of high archaeological significance**. **A Stage 1 mitigative excavation of 120 m^2 is recommended with the removal of levels at 5 cm intervals down to 40 - 50 cm below surface. It is anticipated that the 120 m^2 will be divided among the three terraces as a means to determine how each of the terraces were occupied. The 120 m^2 excavation will represent a sampling strategy of 0.2% of the total site area (280 m^2 x 195 m^2 = 54,600 m^2). Additionally, radiocarbon dating is recommended to correlate the three pre-contact cultural components that were deduced from the seriation of the four projectile points.**
5	DjPo-101; HS 25001, 14575, 18796, 106672, 106674	Boisjoli Mine	**4**	Mine Complex and structures	Historic	685237E 5503726N	4-24-8-4-5; 1,2-23-8-4-5	Coal Handling Processing Plant	Revisited	Mine complex.	1	1	N/A	Site DjPo-101 is within the footprint of the Coal Handling Processing Plant, and will be directly impacted. It was assessed that the integrity of Structure 4 (HS 18796) was most likely weakened after it was buried, and the two wooden A frames (HS 106672 and 106674) have low to limited historical resource value therefore, there are no historical resource concern regarding those three structures. On December 7, 2015, the Permit Holder questioned David R. Leslie, P. Eng., VP of Technical Services for Riversdale Resources regarding their plans for the Generator House, the Fan House, and the Mine Entrance. Riversdale Resources plan to avoid those structures in their project design for the Coal Handling Processing Plant, however those plans will not be definite until later in 2016. **At this point, *Historical Resources Act* clearance is recommended for site DjPo-101, the Boisjoli Mine, as long as the Generator House (HS 106670), the Fan House (HS 106671), and the Mine Entrance (HS 22702) are shown to be avoided in the final construction plans, as well as fencing or monitoring measures to ensure avoidance during construction. If avoidance is not feasible, then further historical resources work is warranted.**
6	DjPo-116; HS 73184, 106735, 106739	Sartoris/ Mannix Sawmill (Grassy Mountain Camp)	**4**	Campsite, settlement - concrete foundation	Pre-contact & historic	685965E 5504165N	5,6-11-24-8-4-5	South Disposal Area	Revisited	Disturbed landscape along Grassy Mountain Road. Former location of a sawmill.	3	44 **(14+)**	**540 Total** - 12 Faunal - 4 Lithics - 1 FBR - 523 Historics	Site DjPo-116 is within the footprint of the South Disposal Area, and will be directly impacted. Five hundred forty (n=540) artifacts recovered from 0 to 60 cm below surface, of which 523 were historical items, and three cement foundations and the remains of a well/pumphouse were identified, which may belong to the former sawmill. **A Stage 1 mitigative excavation 10 m^2 is recommended, two sets of 3 m^2 each for Foundations 1, and 2, and the remaining 4 m^2 at the north side of Grassy Mountain Road in one or two of the shallow depressions. None is recommended for Foundation 3.**

Table 74: Historical resource sites recommended for further historical resources work, con't.

No.	Borden/ HS	Site Name	HRV	Site Type	Pre-contact/ Historic	11U UTM	LSD/ATS	Mining Impact Area	Revisited/ NEW	Environment	Exp.	Shovel Tests	Artifacts	HRIA Results and Further *Historical Resources Act* Recommendations and Conditions
7	DjPo-130		**4**	Campsite	Pre-contact	684801E 5503509N	2-23-8-4-5	Overland Conveyor	Revisited, relocated, & expanded	Forest cut terrace overlooking Blairmore Creek.	1	46 **(9+)**	**585 Total** - 228 Faunal - 6 Lithics - 351 FBR	Site DjPo-130 is within the footprint of the Overland Conveyor. Much of the conveyor will be above ground, but it appears the site will be impacted by the overland conveyor support structures, specifically the construction of the pilings and footings. Five hundred eighty-five (n=585) artifacts were recovered from 0 to 50 cm below surface, including 351 FBR and 228 faunal remains, many of which were burnt and calcinated fragments. This strongly suggests a pre-contact campsite concentrated at the south end of the site. **A Stage 1 mitigative excavation of 15 m^2 is recommended with 10 m^2 at the artifact concentration, and the remaining 5 m^2 in proximity to the shovel tests that were positive for flakes.**
8	DjPo-214		**TBD**	Campsite	Pre-contact	684636E 5503290N	14-14-8-4-5	Overland Conveyor	New	A forested terrace overlooking Blairmore Creek to the west.	0	34 **(7+)**	**46 Total** - 39 Faunal - 4 Lithics - 3 FBR	Site DjPo-214 is within the footprint of the Overland Conveyor. The Overland Conveyor is an above ground structure, and it appears that the site will be impacted by the overland conveyor support structures, specifically the pilings and footings. Forty-six (n=46) pre-contact artifacts were identified from seven shovel tests from a terrace landform overlooking Blairmore Creek. **A Stage 1 mitigative excavation of 10 m^2 is recommended with a focus at the north end of the site, however, if the artifacts recovered from the first 5 m^2 are considered scant, the excavation will end upon consultation with Alberta Culture and Tourism.**
9	DjPo-215; HS 106685, 106687, 106688, 106689	Mannix Camp	**TBD**	Dwelling, Mining Camp	Historic	685658E 5503799N	4-24-8-4-5	South Disposal Area	New	A poorly-drained and marshy area that was terraformed.	4 **(2+)**	15 **(4+)**	**19 Total** - 2 Faunal - 3 FBR - 14 Historics	Site DjPo-215 is within the footprint of the South Disposal Area, and will be directly impacted. The structures face a poorly-drained terrain with a disturbed soil profile context to the north, whereas the spots around and behind the structures and the abandoned vehicle remains are dry. Site DjPo-215, in conjunction with DjPo-116 provides an opportunity to study a historic coal mining camps and thus, further historical resource work is warranted. **A Stage 1 mitigative excavation of 10 m^2 is recommended with a focus at the north end of the site, however, if the artifacts recovered from the first 5 m^2 are considered scant, the excavation will end upon consultation with Alberta Culture and Tourism.**
10	DjPo-216		**TBD**	Campsite	Pre-contact	686533E 5503788N	2-24-8-4-5	South Disposal Area	New	Within a gully, along a creek bank.	1	15 **(10+)**	**315 Total** - 314 Faunal - 1 Lithic	Site DjPo-216 is within the footprint of the South Disposal Area, and will be directly impacted. There were 57 burnt and calcinated bone from six shovel tests concentrated within 20-metres of each other, and one (n=1) flake, which suggests a hearth and/or processing spot at that specific locale. **A Stage 1 mitigative excavation of 10 m^2 is recommended at the potential hearth/processing spot, however, if the artifacts recovered from the first 5 m^2 are considered scant, the excavation will end upon consultation with Alberta Culture and Tourism.**
11	DjPo-217		**TBD**	Campsite	Pre-contact	686726E 5504146N	8-24-8-4-5	South Disposal Area	New	Along ridge paralleling a north-south creek.	3	18 **(14+)**	**168 Total** - 85 Faunal - 83 Lithics	Site DjPo-217 is within the footprint of the South Disposal Area, and will be directly impacted. Due to the considerable amount of artifacts recovered along the exposed vehicle tracks, and the associated shovel tests along the ridge, and within the gully, further historical resource work is warranted. **A Stage 1 mitigative excavation of 10 m^2 is recommended, 5 m^2 along the ridge and 5 m^2 within the gully.**

Table 74: Historical resource sites recommended for further historical resources work, con't.

No.	Borden/ HS	Site Name	HRV	Site Type	Pre-contact/ Historic	11U UTM	LSD/ATS	Mining Impact Area	Revisited/ NEW	Environment	Exp.	Shovel Tests	Artifacts	HRIA Results and Further *Historical Resources Act* Recommendations and Conditions
12	DjPo-219		**TBD**	Scatter >10	Pre-contact	686298E 5504694N	10, 15-24-8-4-5	South Disposal Area	New	Along forested ridge.	1	15 **(6+)**	**24 Total** - 24 Lithics	Site DjPo-219 is within the footprint of the South Disposal Area, and will be directly impacted. The 24 flakes recovered were recovered from an apparent isolated undisturbed rise in a quarter section (NE-24-8-4-W5M) that was heavily disturbed from previous logging operations. This site affords an opportunity to examine the pre-contact occupation in this specific locale; an opportunity that was not given to the other archaeological sites in proximity. **A Stage 1 mitigative excavation of 10 m^2 is recommended, however, if the artifacts recovered from the first 5 m^2 are considered scant, the excavation will end upon consultation with Alberta Culture and Tourism.**
13	DjPo-220		**TBD**	Campsite	Pre-contact	685986E 5504701N	11, 14-24-8-4-5	South Disposal Area	New	Within forest area at base of slope overlooking marsh to the east.	1	32 **(16+)**	**179 Total** - 152 Faunal - 18 Lithics - 9 FBR	Site DjPo-220 is within the footprint of the South Disposal Area, and will be directly impacted. **Due to the fact that a considerable amount of artifacts (n=179) recovered on the forested terrace overlooking a broad marsh to the east, a Stage 1 mitigative excavation of 10 m^2 is recommended.**
14	DkPo-7		**4**	Stone feature - cairn	Pre-contact	686222E 5505017N	14, 15-24-8-4-5	South Disposal Area	Revisited	On knoll overlooking Grassy Mountain Road, and the Frank and Grassy Railroad.	2	12 **(1+)**	**1 Total** - 1 Historic	Site DkPo-7 is within the footprint of the South Disposal Area, and will be directly impacted. It is a pre-contact cairn within the Crowsnest Pass, which is considered an uncommon archaeological feature found within this locale, and thus, further historical resources work is warranted. **A mitigative excavation of 1-x-2 metres is recommended to salvage the remaining context of the cairn.**
15	DkPo-41; HS 81564, 81565, 81566, 81562		**4**	Mine Compound	Historic	686822E 5505018N	1-25-8-4-5; 16-24-8-4-5	In Pit Disposal Area	Revisited	On a south-facing forested slope that crosses the Frank and Grassy Railroad. Afterwards, it becomes more gradual with a ridgeline, and a terrain with grassy clearings, marshes, and stands of trees.	5	30 **(1+)**	**2 Total** - 2 Historics	Site DkPo-41 is within the footprint of the In-Pit Disposal Area, and will be directly impacted. Despite the paucity of artifacts (n=2) recovered, a mottled and shallow soil profiles, and the lack of any historical documentation and details. It is not known what is the connection, if there is any between the two mine entrances, the berm, the other two structures, and the Frank and Grassy Mountain Railroad. The Permit Holder believes that the unsophisticated construction of the mines entrances may represent one of the early forays of coal mining or exploration in the Crowsnest Pass, and thus further historical resource work is warranted. **A Stage 1 mitigative excavation of 8 m^2 is recommended in front of both mine entrances. If the artifacts recovered from the first 4 m^2 are considered scant, the excavation will end upon consultation with Alberta Culture.**
16	HS 21169	Hoist #6	**N/A**	Cable Run Foundation (H)	Historic	684385E 5499895N	14-2-8-4-5	Overland Conveyor	New	South facing forested slope. Within the footprint of the Overland Conveyor	0	0	N/A	The cable run foundation (HS 106646) is within the footprint of the Overland Conveyor and will be directly impacted. The rest of the site is outside of the proposed footprint by approximately 15-metres to the west. On December 7, 2015, the Permit Holder asked David R. Leslie, P. Eng., VP of Technical Services for Riversdale Resources to explain the Project plans for the cable run foundation. Riversdale Resources plans to avoid the foundation in their final project design for the Overland Conveyor; it will be above ground, however those plans will not be definite until later in 2016. **At this point, *Historical Resources Act* clearance is recommended for Hoist #6, as long as the cable run foundation (HS 106646) are shown to be avoided in their final construction plans, as well as fencing measures to ensure avoidance from during construction. If avoidance is not feasible, then further historical resources work is warranted.**

Table 74: Historical resource sites recommended for further historical resources work, con't.

No.	Borden/ HS	Site Name	HRV	Site Type	Pre-contact/ Historic	11U UTM	LSD/ATS	Mining Impact Area	Revisited/ NEW	Environment	Exp.	Shovel Tests	Artifacts	HRIA Results and Further *Historical Resources Act* Recommendations and Conditions
17	HS 21397, 16977, 23634, 106702, 27791	Grassy Mountain	N/A	4 Historic Mine Structures	Historic	686634E 5506312N	9-25-8-4-5	In Pit Disposal Area	New	Grassy Mountain east aspect, and mountainous switchback road.	0	0		The Grassy Mountain structures are within the footprint of the In-Pit Disposal Area, and will be directly impacted. A literature search found nothing of particular historical significance regarding the property, the structures or the landowners, therefore, the site has limited historical resource significance, and documentation of the structures provided in this final report is considered satisfactory. **The structures are considered to have a low to limited historical resource value, and thus, *Historical Resources Act* clearance is recommended for HS 106699, 106700, 106701, 106702, and 106703.** Regarding the engine from the hoist house (HS 106703); despite not finding any details regarding the manufacture history of the engine, the Permit Holder believes that such a material item may have artifactual significance to the coal mining history of the Crowsnest Pass. After consultation with Trevor Peck, Archaeologist for the Alberta Survey of Alberta Culture and Tourism on January 12, 2016, it was decided that Alberta Culture and Tourism will make inquiries to the Reynolds-Alberta Museum in Wetaskiwin on whether the engine has any historical significance to the history of Alberta, and whether such an item should be curated.
											54 (21+)	**351 (133+)**	**3,916**	

Table 74: Historical resource sites recommended for further historical resources work, con't.

APPENDIX 6.4-2: ALBERTA CULTURE'S HISTORICAL RESOURCES ACT REQUIREMENTS

Historical Resources Act Requirements

Proponent: Riversdale Resources
12331 - 20th Avenue, Box 660, Blairemore, AB T0K 0E0
Contact: Cal Clark

Agent: Bison Historical Services Ltd.
Contact: Tommy Ng

Project Name: **Benga Mining Limited (Riversdale Resources) Grassy Mountain Coal Project**

Project Components:
- Coal Mine
- Industrial Plant Site
- Access Road
- Powerline
- Soil / Rock Dump
- Storage Site
- Railway
- Other - conveyor alignment

Application Purpose:
- Requesting HRA Approval / Requirements
- Update to Project Name and/or Ownership

Pursuant to Section 37(2) of the *Historical Resources Act*, a Historic Resources Impact Assessment is required for all or portions of those activities described in this application and its attached plan(s)/sketch(es). The Historic Resources Impact Assessment is to be conducted in accordance with the instructions outlined in the following schedule.

David Link
Assistant Deputy Minister

SCHEDULE OF REQUIREMENTS

ARCHAEOLOGICAL RESOURCES

Pursuant to Section 37(2) of the *Historical Resources Act*, additional studies are to be conducted on behalf of the proponent by an archaeologist qualified to hold an archaeological research permit within the Province of Alberta. A permit must be issued by Alberta Culture and Tourism prior to the initiation of any archaeological field investigations. Please allow ten working days for the permit application to be processed.

SCHEDULE OF REQUIREMENTS (continued)

1. The following Historical Resources Act conditions are based on Historic Resources Impact Assessment studies carried out by Bison Historical Services Ltd. under Archaeological Research Permit No. 15-074.

2. The Historic Resources Impact Assessment completed under permit 15-074 is understood to be based on a provisional development footprint. When the development footprint has been finalized, a Historic Resources Application must be submitted through the OPaC system, accompanied by GIS shapefiles. Further requirements may then be issued.

3. Site-specific conditions are itemized below.

SITE	HRV	SITE DESCRIPTION	CONDITIONS/APPROVAL
DjPo-10	4	campsite	All development activities must avoid this site. The use of temporary fencing is required to ensure avoidance during construction.
DjPo-31	0	campsite, settlement	There are no further Historical Resources Act requirements for this site relative to current or future projects. Development may proceed in the area of this site.
DjPo-32	0	campsite	There are no further Historical Resources Act requirements for this site relative to current or future projects. Development may proceed in the area of this site.
DjPo-33	4	campsite	This site requires avoidance or additional studies. If avoidance is not feasible, then areas of potential impact from development must be shovel tested. The use of temporary fencing is required to ensure avoidance of archaeological deposits during construction.
DjPo-34	0	campsite	There are no further Historical Resources Act requirements for this site relative to current or future projects. Development may proceed in the area of this site.
DjPo-35	0	campsite	There are no further Historical Resources Act requirements for this site relative to current or future projects. Development may proceed in the area of this site.
DjPo-37	0	settlement	There are no further Historical Resources Act requirements for this site relative to current or future projects. Development may proceed in the area of this site.
DjPo-38	2	mine	This site requires avoidance or additional archaeological studies. If avoidance is not feasible, then areas of potential impact from development must be shovel tested. The use of temporary fencing is required to ensure avoidance of historic structures and archaeological deposits during construction.

SCHEDULE OF REQUIREMENTS (continued)

DjPo-63	4	campsite, stone feature, workshop	This site requires avoidance or additional archaeological studies. If avoidance is not feasible, then areas of potential impact from development must be shovel tested including eastern and western portions of the site.
DjPo-98	4	campsite	This site requires avoidance or additional studies. If avoidance is not feasible, then the Stage 1 requirements are as follows: • 120 square metres of excavation in 5 cm levels to approximately 50 cm below surface; • excavation units are to be placed so as to assess all three terraces; • radiocarbon dates must be obtained if appropriate materials are found in good context.
DjPo-101	4	mine (coal)	As development plans have not been finalized for this portion of the development area, these requirements for the Boisjoli Mine (DjPo-101) are provisional. The Generator House (HS 106670), the Fan House (HS 106671), and the Mine Entrance (HS 22702) are to be avoided. Once development plans that will affect this site are finalized, they must be submitted for review with an Historic Resources Application through the Online Permitting and Clearance (OPaC) system. More detailed mapping, shovel testing, temporary fencing, and monitoring may be required.
DjPo-116	4	campsite, settlement, industrial	This site requires avoidance or additional studies. If avoidance is not feasible, then the Stage 1 requirements are as follows: • 3 square metres at Foundation 1 (possible pump house); • 3 square metres at Foundation 2 (structure of undetermined function); • 4 square metres in the depressions on the north side of Grassy Mountain Road.
DjPo-124	4	transportation	There are no further archaeological requirements for this site relative to the current project. If additional development occurs in the area, further assessment may be required.
DjPo-130	4	campsite	This site requires avoidance or additional studies. If avoidance is not feasible, then the Stage 1 requirements are as follows: • 10 square metres of excavation at the concentration of positive tests in the south portion of the site; • 5 square metres of excavation in proximity to shovel tests positive for flakes; • radiocarbon dates must be obtained if

SCHEDULE OF REQUIREMENTS (continued)

			appropriate materials are found in good context.
DjPo-156	0	campsite, workshop	There are no further Historical Resources Act requirements for this site relative to current or future projects. Development may proceed in the area of this site.
DjPo-182	0	scatter <10	There are no further Historical Resources Act requirements for this site relative to current or future projects. Development may proceed in the area of this site.
DjPo-183	0	workshop	There are no further Historical Resources Act requirements for this site relative to current or future projects. Development may proceed in the area of this site.
DjPo-184	0	scatter >10	There are no further Historical Resources Act requirements for this site relative to current or future projects. Development may proceed in the area of this site.
DjPo-185	0	scatter <10	There are no further Historical Resources Act requirements for this site relative to current or future projects. Development may proceed in the area of this site.
DjPo-214	4	campsite	This site requires avoidance or additional studies. If avoidance is not feasible, then the Stage 1 requirements are as follows: • 5 square metres of excavation at the south end of the site; • 5 square metres of excavation at the north end of the site; • 5 square metres to be allocated in consultation with the Regional Archaeologist based on the results of the first 10 square metres of excavation.
DjPo-215	4	dwelling	This site requires avoidance or additional studies. If avoidance is not feasible, then the Stage 1 requirements are as follows: • excavation of a 0.5 by 4 metre trench across Structure 1 (HS 106685); • excavation of a 0.5 by 5 metre trench across Structure 2 (HS 106687); • excavation of a 1 by 1 metre unit at the outhouse (HS 106688); • excavation of a 0.5 by 5 metre trench across the depression/fire pit.

SCHEDULE OF REQUIREMENTS (continued)

DjPo-216	4	campsite	This site requires avoidance or additional studies. If avoidance is not feasible, then the Stage 1 requirements are as follows: • 10 square metres of excavation at areas that produced burned bone; • consult with the Regional Archaeologist after the completion of 5 square metres.
DjPo-217	4	campsite	This site requires avoidance or additional studies. If avoidance is not feasible, then the Stage 1 requirements are as follows: • 10 square metres of excavation along the ridge; • 10 square metres of excavation along the gully; • consult with the Regional Archaeologist if either excavation area is not meeting expectations.
DjPo-218	4	scatter <10	This site requires avoidance or additional studies. If avoidance is not feasible, then the Stage 1 requirements are as follows: • 5 square metres of excavation near the southern concentration of positive tests.
DjPo-219	4	scatter >10	This site requires avoidance or additional studies. If avoidance is not feasible, then the Stage 1 requirements are as follows: • 10 square metres of excavation; • consult with the Regional Archaeologist after the completion of 5 square metres if results are not meeting expectations.
DjPo-220	4	campsite	This site requires avoidance or additional studies. If avoidance is not feasible, then the Stage 1 requirements are as follows: • 10 square metres of excavation.
DjPo-221	0	trail	There are no further arcaheological requirements for this site relative to current or future projects. Development may proceed in the area of this site.
DkPo-7	4	stone feature	This site requires avoidance or additional studies. If avoidance is not feasible, then the Stage 1 requirements are as follows: • excavation of 2 square metres to expose this feature; • detailed mapping.

SCHEDULE OF REQUIREMENTS (continued)

DkPo-13	0	scatter	There are no further Historical Resources Act requirements for this site relative to current or future projects. Development may proceed in the area of this site.
DkPo-14	4	campsite	There are no further Historical Resources Act requirements for this site relative to the current project. If additional development occurs in the area, further assessment may be required.
DkPo-41	4	mine	This site requires avoidance or additional studies. If avoidance is not feasible, then the Stage 1 requirements are as follows: • 8 square metres of excavation in front of each of the two mine entrances; • consultation with the Regional Archaeologist after completion of 4 square metres at each mine entrance if results are not meeting expectations.
DkPo-47	0	campsite	There are no further Historical Resources Act requirements for this site relative to current or future projects. Development may proceed in the area of this site.
DkPo-48	0	scatter <10	There are no further Historical Resources Act requirements for this site relative to current or future projects. Development may proceed in the area of this site.
DkPo-49	0	trail	There are no further Historical Resources Act requirements for this site relative to current or future projects. Development may proceed in the area of this site.
DkPo-50	4	mine	This site requires avoidance or additional studies. If avoidance is not feasible, then additional shovel testing is required closer to the identified structures, particularly the crew house.
DjPo-27	4	campsite, homestaed	This site requires avoidance or additional studies. This site was not investigated during the Historic Resources Impact Assessment but appears to be within the development area. If so, archaeological assessment is required.

SCHEDULE OF REQUIREMENTS (continued)

PALAEONTOLOGICAL RESOURCES

Pursuant to Section 37(2) of the *Historical Resources Act*, additional studies are to be conducted on behalf of the proponent by a palaeontologist qualified to hold a palaeontological research permit within the Province of Alberta. The additional requirements consist of a monitoring program. A permit must be issued by Alberta Culture and Tourism prior to the initiation of any palaeontological field investigations. Please allow ten working days for the permit application to be processed.

1. The following Historical Resources Act conditions are informed by the results of Historic Resources Impact Assessment studies carried out by Nautilus Paleontology Inc. under Palaeontological Research Permit No. 16-017.

2. An annual palaeontological monitoring program is required as outlined in the attached Palaeontological Monitoring Program Policy. The monitoring program must include areas of high palaeontological potential; i.e., where bedrock is close to the surface. Should significant palaeontological resources be encountered during the conduct of the monitoring program the Royal Tyrrell Museum of Palaeontology must be contacted. It may then be necessary for Alberta Culture and Tourism to issue further instructions regarding these resources.

ABORIGINAL TRADITIONAL USE SITES

There are no Historical Resources Act requirements associated with Aboriginal traditional use sites of a historic resource nature; however, the proponent must comply with standard conditions under the Historical Resources Act, which are applicable to all land surface disturbance activities in the Province.

HISTORIC STRUCTURES

Historical Resources Act approval is granted in relation to historic structures, subject to the conditions outlined below.

1. Site-specific conditions and approvals for historic structures located outside the boundaries of the Greenhill Mine Registered Historic Resource and the Village of Lille Provincial Historic Resource are itemized below. Additional information is required regarding work in the vicinity of the Greenhill Mine Complex and Town of Lille (see details in the following section).

SITE	HRV	SITE DESCRIPTION	CONDITIONS/APPROVAL
HS 14639	N/A	dairy	This historic structure is no longer extant. No further concerns or work required.
HS 14575	N/A	ventilator fan	All development activities must avoid this site. Fencing to ensure avoidance during construction is required. If avoidance is not possible, further work may be required.
HS 18796	N/A	foundation	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.
HS 30032	N/A	generator room	All development activities must avoid this site. Fencing to ensure avoidance during construction is required. If avoidance is not possible, further work may be required.
HS 106672	N/A	A frame	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.

SCHEDULE OF REQUIREMENTS (continued)

HS 106717	N/A	foundation	The documentation completed for this site is considered to be acceptable, and there are no further requirements for historic structure remains located at this site.
HS 106735	N/A	well	The documentation completed for this site is considered to be acceptable, and there are no further requirements for historic structure remains located at this site.
HS 106739	N/A	foundation	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.
HS 81564	N/A	mine A entrance	The documentation completed for this site is considered to be acceptable, and there are no further requirements for historic structure remains located at this site.
HS 81565	N/A	root cellar	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.
HS 81566	N/A	mine B entrance	The documentation completed for this site is considered to be acceptable, and there are no further requirements for historic structure remains located at this site.
HS 106698	N/A	root cellar	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.
HS 106685	N/A	cabin [Structure 1]	The documentation completed for this site is considered to be acceptable, and there are no further requirements for historic structure remains located at this site.
HS 106687	N/A	structure ruins [Structure 2]	The documentation completed for this site is considered to be acceptable, and there are no further requirements for historic structure remains located at this site.
HS 106688	N/A	structure ruins [Structure 3]	The documentation completed for this site is considered to be acceptable, and there are no further requirements for historic structure remains located at this site.
HS 106689	N/A	structure ruins [Structure 4]	The documentation completed for this site is considered to be acceptable, and there are no further requirements for historic structure remains located at this site.
HS 26601	N/A	outhouse	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.
HS 81471	N/A	crew house	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.
HS 17003	N/A	Hoist #6 Foundation "I"	All development activities must avoid this site. Fencing to ensure avoidance during construction is required.
HS 17891	N/A	Hoist #6 Cable Frame "F"	All development activities must avoid this site. Fencing to ensure avoidance during construction is required.

SCHEDULE OF REQUIREMENTS (continued)

HS 21169	N/A	Hoist #6 Foundation "H"	All development activities must avoid this site. Fencing to ensure avoidance during construction is required. If avoidance is not possible, further work may be required.
HS 23250	N/A	Hoist #6 Accessory Building "E"	All development activities must avoid this site. Fencing to ensure avoidance during construction is required. If avoidance is not possible, further work may be required.
HS 24704	N/A	Hoist #6 Building "A"	All development activities must avoid this site. Fencing to ensure avoidance during construction is required. If avoidance is not possible, further work may be required.
HS 81504	N/A	Hoist #6 Accessory Building "B"	All development activities must avoid this site. Fencing to ensure avoidance during construction is required.
HS 106691	N/A	outbuilding [Structure 1]	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.
HS 106694	N/A	outbuilding [Structure 2]	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.
HS 106695	N/A	outbuilding [Structure 3]	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.
HS 106696	N/A	outbuilding [Structure 4]	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.
HS 16977	N/A	building remains	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.
HS 21397	N/A	coal chute	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.
HS 23634	N/A	building remains	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.
HS 27791	N/A	cable winch and engine / hoist house	All development activities must avoid this site.
HS 106702	N/A	building remains	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.
HS 15521	N/A	mine entrance	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.
HS 18929	N/A	shed	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.

SCHEDULE OF REQUIREMENTS (continued)

HS 24030	N/A	building	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.
HS 29198	N/A	building	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.
HS 106707	N/A	building	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.
HS 106709	N/A	building	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.
HS 106715	N/A	dwelling	The documentation completed for this site is considered to be acceptable, and there are no further requirements for this site.

PROVINCIALLY DESIGNATED HISTORIC RESOURCES

The project area contains the Village of Lille, a Provincial Historic Resource, and the Greenhill Mine site, a Registered Historic Resource. Ministerial Approval is required for interventions impacting the Village of Lille. Requirements for the Greenhill Mine site are itemized below.

1. Clarification is required regarding interventions, if any, proposed for the transmission line right-of-way where it passes through the Village of Lille Provincial Historic Resource (NE 18-8-3-W5M).
2. Final plans also must confirm that there will be no new access through the Village of Lille site.
3. Detailed, finalized plans are required for the proposed work in the vicinity of the Greenhill Mine site. These plans must include detailed information about load-out design (showing grades), cut-and-fill areas and alignment specifics.

SPECIAL CONDITIONS

1. In addition to any specific conditions detailed above, the proponent must abide by all Standard Conditions under the Historical Resources Act.

Lands Affected: All New Lands

Proposed Development Area:

MER	RGE	TWP	SEC	LSD List
5	4	8	26	1,8,9,16
5	3	8	30	13
5	4	8	36	1-16
5	4	8	23	1,2,7-9,16
5	4	8	25	1-16
5	4	8	14	4-6,11,12,14-16

SCHEDULE OF REQUIREMENTS (continued)

5	4	8	2	3-6,11-14
5	3	9	6	4,5,12,13
5	4	8	11	3-5,12,13
5	4	8	3	7-11,13,14
5	4	8	24	1-16
5	4	9	11	1,2
5	4	8	13	13-16
5	3	8	31	4,12,13
5	3	9	7	4
5	3	8	18	1,8-9,16
5	3	8	19	1,2,5-7,12
5	4	8	10	3,4
5	4	8	35	1,8,9,14-16
5	4	9	1	1-6,8-9,11-14,16
5	4	8	9	1
5	4	9	12	1,3,4
5	4	9	2	1-3,7-10,15,16

Documents Attached:

Document Name	Document Type
Palaeontological monitoring program recommendations for mining operations	Miscellaneous
Palaeontological resource discovery protocol	Miscellaneous
Project Plans	Illustrative Material

APPENDIX 6.13-1: WEEKLY FLOW DATA

JRP IR6.13 – Flow Calculations

An excel file (available on request from the Project's Joint Review Panel) has been provided with the underlying calculations to obtain the IFN values as presented for IR 6.13, including Q80 values. As summarized in Table 6.13-A (below), there are three worksheets contained within the provided Excel file, including calculations undertaken and cross-reference to the corresponding section of the Alberta Desktop Method (ADM; Locke and Paul 2011).

The Q80 (i.e., 80% exceedance natural flow for each of 52 weeks over the year) represents Step 2 of the ADM, and is assumed to be the Ecosystem Base Flow, a threshold below which there would be no further out-of-stream use of water. The sources and derivation of each long-term flow dataset is provided in JRP IR 6.13.

A tabulated copy of the requested Q80 (Ecosystem Base Flow) values, for both Gold Creek near the mouth and Blairmore Creek near the mouth, are summarized in Table 6.13-B (below) as copied from the provided Excel file (WeeklyIFNcalcs worksheet; columns J and L).

Table 6.13-A. Summary of Excel File Contents		
Sheet Name	**Processing**	**ADM reference**
DailySyntheticFlowData	Raw daily synthetic data provided for all assessment locations (1975-2016)	na
WeeklyMeanFlowData	Weekly average flow calculated from the above	na
WeeklyIFNcalcs	Weekly flow data (from above) Calculate 85% Natural Flows **Calculate 52 weekly EBF ≡ 80th percentile (from n = ~42yrs)** Assign weekly EBF to each Week of Year throughout record Calculate minimum of natural flow or 80% exceedance flow Calculate maximum of part b (= preceding step) and part a (= 85% natural flow)	Step 1 / Section 4.4.1 **Step 2 / Section 4.4.2** Step 3 / Section 4.4.3 Part (b) of text All text paragraph

Table 6.13-B. Q80 (Ecosystem Base Flow) Values for Gold and Blairmore creeks near the Mouth; step 2 of the Alberta Desktop Method (source: columns J and L of the corresponding excel sheet)

	Q80 = EBF value	
Week Number	**GC-WSC**	**BC-H01**
1	0.267	0.050
2	0.275	0.051
3	0.273	0.051
4	0.265	0.050
5	0.266	0.050
6	0.262	0.049
7	0.251	0.048
8	0.255	0.048
9	0.248	0.047
10	0.252	0.048
11	0.264	0.050
12	0.272	0.051
13	0.267	0.060
14	0.282	0.142
15	0.315	0.159
16	0.359	0.197

Table 6.13-B. Q80 (Ecosystem Base Flow) Values for Gold and Blairmore creeks near the Mouth; step 2 of the Alberta Desktop Method (source: columns J and L of the corresponding excel sheet)

	Q80 = EBF value	
Week Number	**GC-WSC**	**BC-H01**
17	0.405	0.238
18	0.510	0.156
19	0.596	0.159
20	0.765	0.209
21	0.670	0.297
22	0.720	0.404
23	0.778	0.369
24	0.725	0.265
25	0.632	0.220
26	0.650	0.185
27	0.585	0.156
28	0.529	0.134
29	0.517	0.115
30	0.453	0.098
31	0.405	0.082
32	0.407	0.075
33	0.382	0.073
34	0.378	0.066
35	0.377	0.060
36	0.356	0.058
37	0.358	0.056
38	0.386	0.057
39	0.380	0.056
40	0.382	0.057
41	0.367	0.050
42	0.370	0.053
43	0.356	0.050
44	0.352	0.047
45	0.357	0.047
46	0.339	0.043
47	0.317	0.039
48	0.313	0.040
49	0.293	0.051
50	0.308	0.052
51	0.297	0.054
52	0.275	0.052

APPENDIX 6.18-1: GRAVEL BED REACTOR REFERENCED REPORTS

Appendix 6.18-1: Gravel Bed Reactor Referenced Reports

Sobolewski, A. (2005). Evaluation of Treatment Options to Reduce Water-Borne Selenium at Coal Mines in West-Central Alberta. Report prepared for Alberta Environment Water Research Users Group, Edmonton. https://open.alberta.ca/dataset/456eee9c-86d5-46e6-bc2e-e605c6599eba/resource/b96ac61e-78db-4b2c-b0d5-40d9c0bf772e/download/3877073-2006-evaluation-treatment-options-reduce-water-borne-selenium.pdf

Rutkowski, T; Walker, R., Gusek, J., and Baker, M. (2010). Pilot-scale treatment of selenium gravel pit seepage water using biochemical reactor technology. Presented at the 2010 National Meeting of the American Society of Mining and Reclamation, Pittsburgh June 5-11 2010.

Sobolewski, A. (2010). Benefits of using liquid carbon sources for passive treatment systems. Proceedings of the International Mine Water Association Symposium 2010. Sydney, N.S. Sept 5-9. pp. 279-283.

Bianchin, M., Martin, A., Adams, J. (2013). In-Situ Immobilization of Selenium within the Saturated Zones of Backfilled Pits at Coal-Mine Operations, in: 37th Annual British Columbia Mine Reclamation Symposium. Vancouver, BC, 16-19 September 2013, pp. 1–16.

Kirk, L. (2014). In-situ microbial reduction of selenate in backfilled phosphate mine was SE Idaho. Thesis submitted to Montana State University. January 2014.

Luek, A., Brock, C., Rowan, D. J., Rasmussen, J. B. (2014). A simplified anaerobic bioreactor for the treatment of selenium-laden discharges from non-acidic end-pit lakes. Mine Water and the Environment, Volume 33, Issue 4, pp 295-306. December 2014.

Baldwin, S., Mirjafari, P., Rezahdebashi, M., Subedi, G., Taylor, J., Moger, L., McMahen, K., Frye, A. (2015). Start-Up of a Passive Remediation Bioreactor for Sulfate and Selenium Removal from Mine Tailings Water. Proceedings of the 10th International Conference on Acid Rock Drainage & IMWA Annual Conference, April 21-24, 2015, Santiago, Chile.

Deen, S., Bondici, V., Essilie-Dughan, J., Hendry, J., Barbour, L. (2018). Abiotic and Biotic Sequestration of Selenium in Anoxic Coal Waste Rock. Article in Mine Water and the Environment, 27, 815-824.

Conuma (2018). 2017 Annual Reclamation Report: Brule Mine. Annual report prepared for the British Columbia Ministry of Energy and Mines. April 2018.

Heffernan, V., April 2019. Genomics applications to wastewater start proving their worth. Canadian Mining Journal.

Mancini, S., E. Cox, L. deVlaming, K. Bechard, R. James, A. Przepiora, and F. Risacher. 2019. Gravel Bed Reactors: A Water Treatment Technology for Industrial and Mining Applications. British Columbia Environment Industry Association. Available at: http://bceia.com/wp-content/uploads/2019/05/BCEIA_2019_final_op_linked.pdf. Accessed June 2019.

Evaluation of Treatment Options to Reduce Water-Borne Selenium at Coal Mines in West-Central Alberta

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Any comments, questions or suggestions regarding the content of this document may be directed to:

Environmental Policy Branch
Alberta Environment
4th Floor, Oxbridge Place
9820 – 106 Street
Edmonton, Alberta, T5K 2J6
Fax: (780) 422 – 4192

Additional copies of this document may be obtained by contacting:

Information Centre
Alberta Environment
Main Floor, Oxbridge Place
9820 – 106 Street
Edmonton, Alberta, T5K 2J6
Phone: (780) 427 – 2700
Fax: (780) 422 – 4086
Email: env.infocent@gov.ab.ca

PO Box 193
Roberts Creek, B.C. V0N 2W0
604 885-0568 phone
604 885-0598 fax

Microbial Technologies, Inc.

Evaluation of Treatment Options to Reduce Water-Borne Selenium at Coal Mines in West-Central Alberta

Report prepared for Alberta Environment
Water Research Users Group
Edmonton

Contact: Dr André Sobolewski
andre@microbialtech.com

Executive Summary

Microbial Technologies, Inc. reviewed the environmental chemistry of selenium and technologies for its treatment at three mountain coal mines in West-Central Alberta. These mines have recently been shown to release selenium to adjacent water bodies, resulting in its uptake into the food chain.

Based on limited data from the Alberta mines, selenium is found in the dissolved form (mostly as selenate) in surface waters, a form that from a chemical perspective is relatively unreactive. Selanate can be reduced to selenite, a form more readily removed (chemically) from solution, or (biologically) to elemental selenium, an insoluble form. Currently, the expected duration of selenium release at the Alberta coal mines is not known.

Notwithstanding the advantages or disadvantages of treatment technologies, preventative measures such as submerging seleniferous sulphides or covering waste rock are recognized as an integral component of any management plan for selenium at coal mines in West-Central Alberta. These measures are not fully reviewed in this document. However, a manual of Best Management Practices for seleniferous mining wastes is currently being developed in Idaho and is expected to provide practical guidance with regards to such preventative measures.

Eleven technologies were reviewed in detail. These include physically-based technologies (reverse osmosis, nanofiltration, and ion exchange), chemically-based technologies (iron precipitation and catalyzed cementation), and biologically-based technologies (algal volatilization, biological treatment plant, in-situ treatment, Biopass and other passive treatment systems, treatment wetlands, and evaporation ponds). Several of these technologies have been tested at a pilot-scale or implemented as treatment facilities.

The above technologies varied considerably with regards to their ability to remove selenate from solution cost-effectively. Several of them could not meet a treatment objective of 5 µg/L. Treatment costs ranged from less than USD$1.00/1,000 gallons for in-situ treatment to over $10.00/1,000 gallons for reverse osmosis and iron precipitation. Some technologies employ very straightforward processes, with simple process flowsheets (e.g., in-situ treatment or constructed wetlands), whereas others rely on more complex processes (e.g., iron precipitation). In addition, some technologies are handicapped by the necessity to manage residues from treatment, such as brines or wash solutions for membrane filtration and ion exchange, or sludges resulting from iron precipitation.

These different technologies were evaluated using a scoring system based on nine separate factors relevant to coal mines in West-Central Alberta. Two technologies stood out from the others as being most suited: in-situ treatment and bioreactors (biological treatment plant). Four other technologies might possibly be appropriate to some of the sites if favoured by some site-specific factors: reverse osmosis, nanofiltration, the Biopass/passive treatment systems and treatment wetlands. The other technologies were deemed too underdeveloped or inappropriate for application at coal mines in West-Central Alberta.

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1 Introduction

Concerns about selenium (Se) toxicity were galvanized by its effects observed in the Kesterson Reservoir, San Joaquin Valley, California. Field studies in the early 1980's documented dramatic losses in migratory bird populations and specifically attributed to Se the decline in reproduction of waterfowl, shorebirds and other aquatic birds (1). One other case of Se ecotoxicity had already been documented earlier at Belews Lake, and more reservoirs exhibiting impacts from Se were identified later on, indicating that this was not an isolated incident. Se ecotoxicity in aquatic ecosystems was thus uncovered as a new ecological problem.

Although knowledge of Se poisoning of cattle had existed for some time (2), the striking finding following these new environmental disasters was that ecotoxicity occurred at very low Se concentrations. Little was known about how it acted at such low doses, and this prompted an accelerated program of investigation to understand its fate and behavior in aquatic ecosystems and its toxicological mode of action. Although much has since been learned about its ecotoxicity, there are still knowledge gaps, particularly for cold water environments - compared to warm water environments.

Monitoring data in the late1990's indicate that selenium concentrations have increased in surface waters downstream from mountain coal mines in West-Central Alberta (3). This is a problem that appears to be specific to coal mines in the upper McLeod and Smoky river basins. This study confirmed that selenium concentrations exceeded the Canadian and US-EPA water quality guidelines for the protection of freshwater aquatic life (i.e., 1 and 5 ug Se/L, respectively) in various streams and one end pit lake influenced by active coal mines. In contrast, selenium was usually below the most stringent guideline (i.e., Canadian or CCME) at the reference sites. Moreover, selenium in fish muscles and eggs was significantly more elevated at sites impacted by coal mines compared with reference sites (except for one reference site). This survey also showed selenium is elevated in fish tissues from sites downstream of the mines, compared to reference sites. Concurrent monitoring at the mines confirmed the above findings of elevated selenium in waters draining coal mines (4). Background or upstream Se concentrations in water bodies draining the mines averaged 0.7 µg/L (N=56) compared with 9.1 µg/L (N=126) at downstream sampling stations. Se concentrations in end pit lakes, rock dump springs, and settling pond effluents averaged 19.8, 115, and 42.7 µg/L, respectively, well above the water quality guidelines. Long-term temporal trends for selenium loadings or subsequent selenium concentrations in water bodies influenced by the mines is not currently known.

Based on available data, lowest selenium concentrations in streams occurred in the spring compared to summer and fall. Lower concentrations in spring may be due a dilution effect from snowmelt and runoff. Limited data for chemical speciation of selenium indicated that it was present mostly in the dissolved form (as selenate).

Elevated selenium in surface waters of western North America have been associated with various activities including irrigation of seleniferous soils, and at phosphate and coal mines in Idaho, Wyoming and British Columbia (e.g., 2, 3, 10). Geological sources particularily Cretaceous marine shales appear to be an important source of selenium in these areas. Elevated selenium in surface waters has also been associated with gold deposits and is occasionally a problem at gold mines. Gold mine effluents that contain selenium typically also contain other contaminant, such as ammonium, arsenic, cyanide, and nitrate (e.g., Zortman-Landusky Mines, Gilt Edge), and possibly antimony and mercury. This is important because the problems – and solutions – associated with selenium treatment for gold mine effluents may be different from those associated for coal mine effluents. Similarly, some refineries in the United States (e.g., Chevron's Richmond, CA refinery) produce process-affected water that contains selenium and are required to treat it prior to discharge. In this case, treatment solutions must account for the low concentration/high volumes scenario typical of refinery effluents. Finally, coal-burning power plants may

generate a selenium-contaminated leachate from uncovered coal ash landfills (e.g., Reliant Energy's W.A. Parish coal ash disposal area, TX), leachate that may require treatment. In each case, a unique solution needs to be developed to treat the contaminated water.

A number of treatment technologies have been developed to remove selenium from contaminated water. These include physical methods (e.g., ion-exchange, reverse-osmosis), chemical methods (e.g., ferric iron precipitation), and biological methods (e.g., bioreactors/treatment plants, treatment wetlands). All these technologies vary in their characteristics, such as treatment efficiency (i.e., percent removal), achievable final effluent concentrations, volumes of water that can be treated economically, temperature-sensitivity, etc. This variation presents some difficulties to compare these technologies and identify the most appropriate solution for coal mines in Alberta.

This document presents the current state-of-the-art on treatment technologies for reducing selenium levels in water. Its main objectives are to:

- Review scientific literature and obtain expert opinion on available treatment technologies to reduce selenium in water;
- Using similar criteria, evaluate the technical feasibility of each technology;
- Recommend treatment options that might be used to reduce selenium in surface water at Alberta mines.

It is expected that new developments on the horizon will amplify or add to this information, but that the fundamental knowledge presented herein will not change.

.

2 Selenium chemistry

Understanding the characteristics and reactions of selenium provides a context for the potential use and choice of treatment technologies presented in Section 4. Thus, Se chemistry will be briefly reviewed here.

2.1 Physical Properties

Selenium was first identified as an element in 1817 by Swedish chemists J.J. Berzelius and J.G. Gahn. Its atomic number is 34, mass is 78.96, melting point 271°C, boiling point 685°C, and density 4.26-4.79. Se is in Group VIA of the periodic table between sulfur and tellurium. Its electron distribution is similar to that of sulfur, a fact reflected by the similarities of their chemical properties. Like sulfur, selenium occurs in oxidation states II-, 0, II+, IV+, VI+, although the II+ oxidation state is not known to exist in nature. Se is considered a metalloid because it possesses both metallic properties (e.g., semi-conductor) and non-metallic properties (e.g., elemental Se is dull, without metallic shine).

Se is present in the environment in both inorganic and organic forms. The inorganic forms are elemental Se (Se°), selenite (Se[IV], SeO_3^{2-}), selenate (Se[VI], SeO_4^{2-}), and hydrogen selenide (Se[-II], H_2Se) (See Figure 2). The oxidized forms of Se exist as soluble oxyanions in aqueous environments, with selenate dominant in freshwater and selenite dominant in seawater. Neither of these anions react with cations (e.g., Ca, Mg) under normal ambient conditions, thus remaining soluble in most water bodies. Elemental Se is found in either an amorphous state (an easily identifiable crimson red form, see Figure 1) or in one of three crystalline states. Most stable is the gray, semi-metallic crystalline form which exhibits photoconductive properties and has various industrial uses.

Figure 1. Elemental selenium formed by bacterial reduction of selenate.

Reduced Se species include inorganic forms, such as hydrogen selenide (H_2Se), and organic forms such as volatile methylselenides and nonvolatile organic compounds. Methylated forms are volatile, sparingly soluble and comparatively non-toxic. The Henry's Law constant for dimethyl selenide, the most commonly volatilized species, has been reported as 0.058 (5) and 0.0879 (for both dimethyl selenide and dimethyl diselenide, 6). Most organic non-volatile organoselenides have not been characterized. These species have direct carbon-Se bonds and are biologically active as selenoamino acids and selenoproteins. Two of these compounds are selenocysteine and selenomethionine, which are highly toxic analogs of the sulfur-bearing amino acids cysteine and methionine.

Se is almost exclusively associated with sulfur in endogenic processes (those occurring inside the earth), but differences in melting and boiling points and in redox potentials mean that they follow different paths

in exogenic processes. The similarities in ionic radius (198 pm for Se vs. 184 pm for S) allow for ionic substitution of Se(II-) for sulfur in sulfur minerals. Mineral selenides are usually found in association with sulfur minerals such as chalcopyrite ($CuFeS_2$), pyrite (FeS_2), and galena (PbS), forming seleno-counterparts to these sulfur minerals, such as selenopyrite (SeFeS). Elemental Se can also react directly with reduced sulfur compounds to form insoluble selenosulphides, e.g., Se_2S_3.

Selenates and sulfates have similar colors, ease of crystallization and water solubility, but have different decomposition pathways. While sulfates decompose to give the metal oxide, sulfur dioxide and oxygen, the equivalent mineral selenates typically decompose to give the metal-selenite and oxygen. This results from the greater stability of salts in the selenite-selenate system. Selenides of heavy metals such as mercury, silver, copper and cadmium are highly insoluble, which may explain an association between selenite and decreased heavy metal toxicity.

In coal, Se is one of the most strongly enriched element, being present as an organoselenium compound, in solid solution with pyrite and other sulfides, and as lead selenide (7, 8). It is primarily associated with the organic constituents and micron-sized sulfides and selenides, but is highly variable as a result of the variability of its sources.

Se is used extensively in the production of glass, pigments, rubber, metal alloys, textiles, petroleum, and photoelectric applications. The use of Se-based pesticides has been curtailed largely due to their stability in soils and resultant contamination of food crops, and their toxicity to mammals and birds (2).

2.2 Chemical Properties and Reactions

The many possible oxidation states of Se make for a complex chemistry. Interactions are further complicated by biologically mediated oxidation-reduction reactions. Speciation in soil solution is governed by various physico-chemical factors expressed in terms of pH, dissociation constants, solubility products, and oxidation-reduction potentials (9).

2.2.1 *Oxidation/Reduction and Solubility*

Se speciation is highly influenced by reduction/oxidation (redox) chemistry. This is especially important because Se oxyanions (sele*nite*: Se(IV) and sele*nate*: Se(VI)) are highly soluble, while the reduced forms (elemental selenium: Se° and sele*nide*: Se(II-)) are insoluble. It is the solubility of the oxidized forms that allows for their mobility in the environment and their biological uptake. As with sulphur compounds, selenite is quite reactive and is more easily reduced to elemental Se. Most selenite salts are less soluble than the corresponding selenates. The extremely low solubility of ferric selenite $Fe_2(SeO_3)_3$ ($K_s = 2.0 \pm 1.7 \times 10^{-31}$), and of the basic ferric selenite $Fe_2(OH)_4SeO_3$ ($K_s = 10^{-61.7}$), is important to the environmental cycling of selenium, as well as providing a basis for treatment (10).

Figure 2 shows the areas of thermodynamic stability for the Se-H_2O system in relation to redox potential (Eh) and hydrogen ion potential (pH). Typical redox potentials for environmental media are in the following ranges: Surface water (pe 1 to 6); groundwater (pe -1 to 1); wetland sediments (pe -4 to 1).

These distributions assume that equilibrium is established, a condition that is rarely met. Thus, the reduction of selenate to selenite is thermodynamically favoured but this reaction is very slow (days) and is rarely complete. In contrast, selenite is reduced to insoluble forms in a matter of hours at low redox potential (11). In fact, selenate, selenite, and biselenite ($HSeO_3^{2-}$) are commonly found outside of their predicted zones of thermodynamic stability. Both H_2Se and HSe^- also occur but are comparatively uncommon.

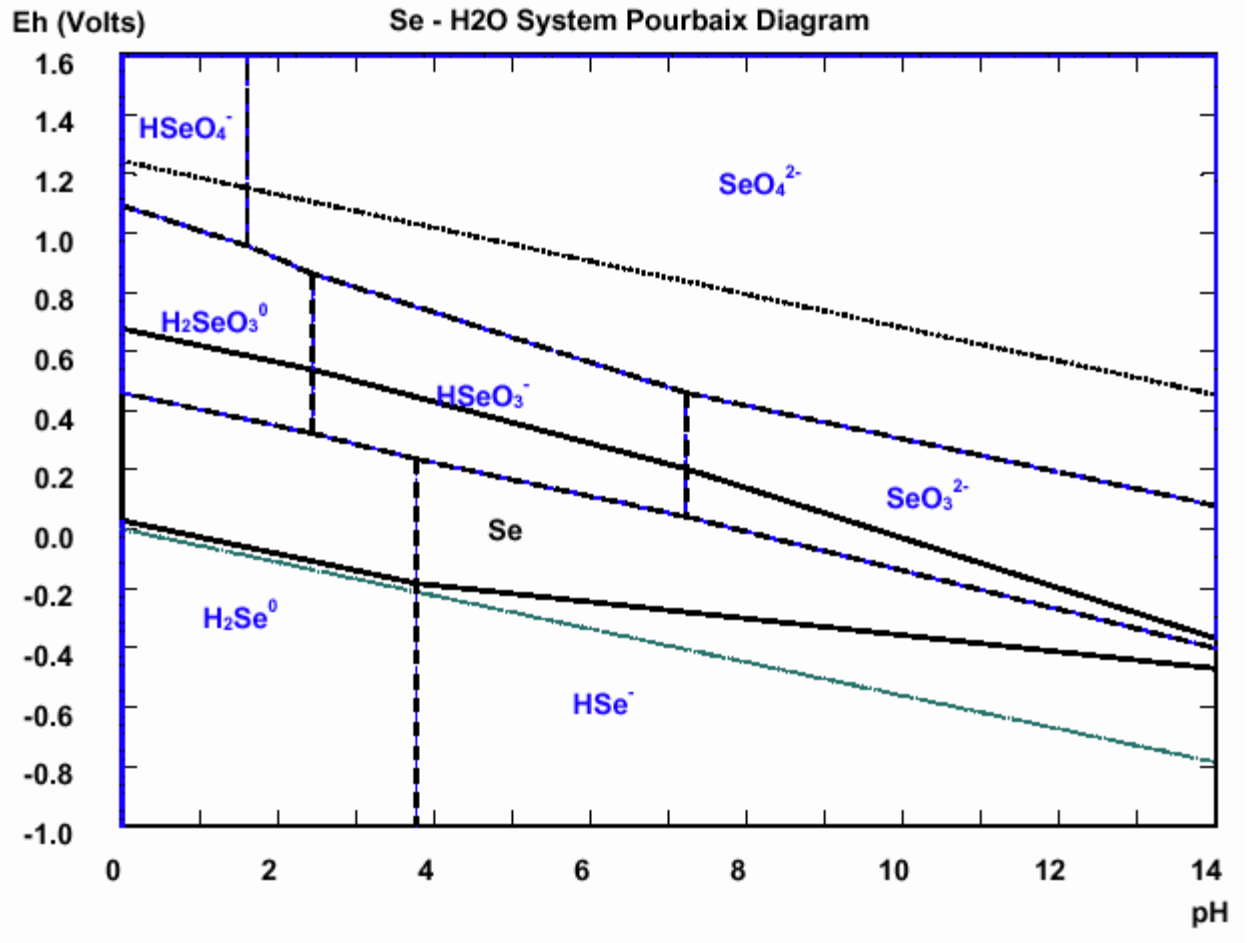

Figure 2. Eh-pH diagram for Se-H_2O system.

The transformation of selenate to selenite, while thermodynamically favoured, occurs slowly because the activation energy for this reaction is very high. ***The feasibility and/or economics of different treatment systems often revolves around this fact.*** Typically, chemically-based treatment processes require an initial reduction of selenate (stable) to selenite (reactive) using strong reductants (e.g., zinc powder). In contrast, microbes catalyze this reduction at ambient conditions, a strength of biologically-based processes.

Calculated reaction equilibria and constants at environmentally-relevant oxidized or moderately reduced conditions indicate that metal-selenite and metal-selenate minerals are too soluble to persist in soils and sediments (12). Under these redox conditions, Se solubility appears to be governed by an adsorption-type mechanism rather than precipitation/dissolution reactions. At low redox potentials, elemental Se or a metal selenide are predicted to limit Se solubility. Since hydrogen selenide (H_2Se) is a highly reactive species, it will be transformed into metal selenides such as FeSe and $FeSe_2$, or ionically substituted into metallic sulfide minerals such as chalcopyrite ($CuFeS_2$) and pyrite (FeS_2). Either elemental Se or these insoluble minerals could act as potential sinks for Se.

Naturally, as redox conditions change, reduced compounds could become sources of soluble selenium. Oxidation of elemental selenium and Se-containing pyrite was credited as a source of increased soluble Se concentrations in Kesterson Reservoir sediment suspensions (13). Similarly, the continued release of selenium in the British Columbia and Wyoming coal fields, and in the Idaho phosphate region, has been shown to arise from the oxidation of Se-containing pyrite (14, 15). The former examples are relevant to the Alberta foothill coal mines, because they likely share common geological origins, including

Cretaceous marine shales, which may have high Se concentrations (16). It suggests that selenium release may persist for decades, as long as the sulphide minerals are exposed to the atmosphere and allowed to weather.

2.2.2 *Methylation and Volatilization*

Dimethyl selenide (DMSe, $(CH_3)_2Se$) and dimethyl diselenide (DMDSe, $(CH3)_2Se_2$) are two volatile species of Se. In natural waters, the production of DMSe is proposed to involve enzymatic and nonenzymatic processes. Methylation is one way for organisms to eliminate excess Se, and aerobic and anaerobic bacteria and fungi capable of doing so have been reported (12). Se volatilization in plants also appears to be a detoxification mechanism and is correlated with tissue Se concentration. Threshold Se concentrations at which volatilization occurs, and rates of volatilization will vary with species for a given water chemistry. DMSe volatilizes rapidly due to its limited water solubility and high vapor pressure. Volatilization rates of Se from soils and plants are also affected by temperature, moisture, time, season, concentration of soluble Se, and microbiological activity. Addition of carbon, alkaline pH values, and oxidation to moderately reduced conditions stimulate biomethylation of Se (12).

Hydrogen selenide (H_2Se) is another volatile species. It may be produced and released in reduced environments, but it oxidizes quickly to elemental Se in the presence of oxygen.

2.2.3 *Other Reactions*

Complexation reactions can also occur with Se, and ion pairs such as $CaSeO_4^{\circ}$, $CaSeO_3^{\circ}$ together with the dissociated SeO_4^{2-} and $HSeO_3^{-}$ species are predicted to be thermodynamically dominant. However, unlike sulfates and sulfites, concentrations are rarely high enough to allow such associations in significant quantities.

Selenite adsorbs to surfaces far more than selenate. Sorption can be onto detritus, clays, Fe- and Mn-oxyhydroxides, or onto soils, and each is pH-dependent (12). Like phosphate and sulfate, the association of selenite with Fe- and Mn-oxyhydroxides is very strong and is described as a ligand exchange reaction, whereby –OH groups on the surface of the mineral are replaced (17). There is a treatment process that exploits this reaction for selenium removal.

An interesting abiotic transformation is the reduction of selenate to elemental Se in the presence of Fe(II,III) oxides known as Green Rust (GR). GRs were initially found as intermediate products of the reduction of iron oxides in aqueous systems, but have recently been found as minerals (i.e., compounds forming in a natural environment). Only in the past few years have the environmental occurrences and implications of GRs been considered. The catalyzation of the selenate redox reaction by GR may represent a pathway for Se cycling which had previously been considered to be mediated by microorganisms. The rapid oxidation of green rust has allowed its presence to be overlooked in the past, but recent studies give evidence of its presence in soils, sediments and porewaters. The reduction reaction can be described as follows:

$$HSeO_4^- + 4Fe_4^{II}Fe_2^{III}(OH)_{12}SO_4{\cdot}3H_2O \Leftrightarrow HSe^- + 8Fe_3O_4 + 4SO_4^{2-} + 8H^+ + 32H_2O$$

This may occur either through coprecipitation and reduction in GR interlayers, or by adsorption on the GR surface. Myeni et al (18) investigated this transformation and found that green rust catalyzed the reduction of selenate in anoxic conditions with pH>5.0. The degree of reduction varied with pH (greater at higher pH), the nature of the reaction (coprecipitation or adsorption), and the initial concentration of Fe(II). Synthetic green rusts have been developed for corrosion studies by oxidizing $Fe(OH)_2$, incorporating Cl^-, SO_4^{2-}, or CO_3^{2-} ions (19). Our understanding of this mechanism is still in its infancy, but investigation into the remedial possibilities for GR in wetlands is certainly warranted.

3 Source Control

The expected length of time for the release of selenium at the mountain coal mines in west-central Alberta is not known at this time. Thus, it is not known how long selenium levels will remain elevated or if selenium levels will increase over time. At the Alberta mines it is possible that selenium mobilisation due to mining activities or disturbance may be a long-term problem. This is expected to be the case at the Elk Valley River coal mines in Southeastern BC because selenium is associated with sulphide minerals (15), which may oxidize for decades. A similar problem exists at many metal mines, which may leach metals for decades after closure. These mines have developed a number of strategies to minimize or mitigate metal release from waste rock. Time and again, it has been shown that preventative measures are the most cost-effective way to mitigate impacts from contaminants leached from waste rock. These measures include preventing or minimizing sulphide oxidation (submerging sulphide minerals, covering waste rock with air or water impermeable soil covers) or managing the contaminants in place (e.g., using *in-situ* treatment, phytoremediation).

In Idaho, both coal and phosphorus mines contain highly seleniferous shales that represent long-term sources of selenium in the environment. Mining companies in that state have collaborated with the US Forest Service (USFS) and Bureau of Land Management (BLM) to develop Best Management Practices (BMP) that minimize the release of selenium from these materials. For example, shales with high Se are identified during mining and are returned to open pits, where they are covered with 8-10 feet chert (non-seleniferous), then capped with top soil, as a means of minimizing Se release (20). This and other BMP are currently being formalized and collated, and are expected to be available by the time this report is published[1].

Two of the most common preventative methods used to minimize Se release will be discussed briefly, since they form a component of the overall treatment solution at mine closure.

3.1 Submerging Sulphide Minerals

Submerging tailings containing sulphide minerals, or “subaqueous disposal”, is practiced at metal mines. The low dissolved oxygen concentrations in the water overlying submerged tailings keeps oxidative rates at a minimum. Furthermore, reducing conditions may develop at depth, near the surface of tailings, thereby halting oxidation altogether.

This approach was extensively studied by metal mining companies. One of the key reports from these studies (21) was that sulphides in tailings either did not release metals, released minor amounts of some metals (e.g., zinc), or release soluble metals (e.g., arsenic) originating from minerals that were oxidized during processing (milling). A companion study that reviewed effects from submerged tailings reported that there are no demonstrable aquatic impacts (22).

Another application of this method is the flooding of underground mines, where metal leaching rates decrease dramatically upon flooding. For instance, zinc concentrations in the Galkeno 900 adit discharge decreased gradually as the underground workings flooded after a concrete plug was installed in the adit (23).

[1] Further information should be available from the USFS, Soda Springs office, or the BLM, Pocatello, ID.

3.2 Soil Covers

In most circumstances, placing engineered soil covers on rock that releases selenium is likely to substantially decrease loadings.

Covers are constructed from natural or man-made materials that retard or divert the movement of water and oxygen into areas containing oxidizing rock[2]. Soil covers can achieve substantial reductions in water flow through piles, but generally do not completely stop sulphide oxidation. For instance, a cover placed over waste rock dumps at the former Rum Jungle Mine reduced sulphide oxidation rates by a factor of 2-3, based on 15 years of monitoring (24). These covers are typically designed by soil engineers, based on material availability, climate, anticipated life, treatment objectives and desired performance (25).

There is a great deal of information available on soil covers, but it will not be reviewed here because it is peripheral to the main focus of this document. Much of the research is published in proceedings from mining conferences, such as those of the International Conference on Acid Rock Drainage (ICARD) or the American Society for Surface Mining and Reclamation (ASSMR). Additional information is available from various research groups (e.g., Unsaturated Soils Group, Dept. Civil Engineering, University of Saskatchewan; The Australian Centre for Mining Environmental Research (http://www.acmer.com.au); consulting firms (e.g., O'Kane Consultants Inc. http://www.okane-consultants.com), etc.

[2] Plastic liners are rarely used because covering large volumes of waste with a liner is usually too expensive.

4 Treatment Systems

Although many different processes have been examined for the removal of selenium from surface waters contaminated by selenium, only a few engineered solutions have been shown to be successful on a commercial scale. In the past, the most widely used approach involved chemical co-precipitation with iron salts at an acidic pH. However, this process is only effective with selenite, and it will not consistently decrease Se concentrations to currently existing discharge criteria. Recent advances in membrane technology and biological processes have brought a new generation of treatment systems. These various systems are reviewed below.

Selenium treatment can be divided into physical, chemical, and biological processes, as shown in Table 1.

Table 1. Types of treatment systems available for selenium.

Physical	Chemical	Biological
Reverse Osmosis	Zinc or iron reduction	Volatilization
Nanofiltration	Iron precipitation	"In-situ" treatment
Ion Exchange	Cementation	Bioreactor
Deep Injection/ Evaporation		"Passive system", i.e., Biopass, Reactive Wall
		Treatment wetland

Reverse osmosis (RO), nanofiltration, and ion exchange remove selenium from an effluent by concentrating it into brines or wash solutions. The resulting concentrates must be disposed safely, either by deep-injection, evaporating the solutions, or other methods.

Chemical methods rely on the reactivity of selenite (Se(IV)), whether with iron or other reagent. Typically, a pre-treatment is required to chemically reduce Se(VI) to Se(IV), using (most commonly) elemental iron or zinc. Such a reduction of Se(VI) is not normally required for biological treatment, but other forms of pre-treatment may be required, such as removal of nitrate[3]. These different pre- and post-treatment steps add to the complexity of the system (its design, operation, etc) and they must be included in any calculation of treatment cost.

Technologies are commonly evaluated by comparing the cost for treating 1,000 gallons of mine water. This cost is either explicitly expressed as an operating cost, or is implied as an amortized capital cost + operating cost for a defined period (e.g., ten years).

When comparing different treatment systems, two factors must be kept in mind. First, the system eventually adopted may make sense for that mine or industry, but not elsewhere. Thus, at Lac Mineral's (now Barrick) Richmond Hill Mine, iron reduction followed by iron co-precipitation was selected partly because tanks used for the carbon-in-pulp gold extraction could be marshaled to this task. Similarly, the Biopass system developed at Homestake's (now Barrick) Santa Fe Mine made sense because the

[3] Bacteria that utilize nitrate to oxidize organic matter derive more energy than those that use selenate or selenite. This confers an advantage to them and allows them to outcompete selenate-reducing bacteria. In practice, nitrate will be removed before selenium in any biological treatment system.

drawdown water from the spent heap was to be released for a limited time, flows were limited, other contaminants (e.g., nitrate, mercury) were also treated in the system, and because lined, open ponds were available for this system. Economics greatly favoured these systems because these facilities were available, thereby reducing capital costs.

The only way to compare "apples with apples" is to evaluate side-by-side different technologies that treat the same water. Such an evaluation was conducted recently by the U.S. EPA, and its results will be reviewed.

A second factor to consider is the gap between technology development and adoption. Thus, nanofiltration is a very promising technology, but no one is willing to be the "test case" in the industry. Consequently, this technology sits on the shelf, waiting for someone to give it a try. However, this situation is changing in the U.S.A. because of the stringent regulatory requirements to treat selenium to very low concentrations.

4.1 Physical

Physical methods used for selenium removal include membrane filtration and ion exchange (electrostatic interactions) methods. Membrane filtration does not discriminate between selenate and selenite, but ion exchange does, being only effective on the latter. Thus, a pre-reduction step is required for treatment of selenate-containing water by ion exchange.

Adsorption onto activated carbon has not proven effective for selenium removal, at least in achieving the low concentrations (< 5 ug/L).

Generally, treatment systems based on these processes are expensive, due to the requirement for pre-treatment steps and post-treatment disposal of concentrated reject brines, as discussed below. This has limited their application at mine sites.

4.1.1 *Membrane Filtration*

Reverse osmosis (RO) and nanofiltration are two membrane filtration methods for treating contaminated water. RO is a widely used and tested technology, whereas nanofiltration is relatively new. Both technologies use a membrane that is semi-permeable, allowing the fluid that is being purified to pass through it, while rejecting the contaminants that remain. The membrane for nanofiltration is different from that used in RO, in being charged and having a hydrophobic reject layer, thereby selectively rejecting divalent salts while retaining monovalent salts. Most RO technology uses a process known as crossflow to allow the membrane to continually clean itself. As some of the fluid passes through the membrane the rest continues downstream, sweeping the rejected species away from the membrane.

Membrane filtration requires a driving force to push the fluid through the membrane, and the most common force is pressure from a pump. The higher the pressure, the larger the driving force. As the concentration of the fluid being rejected increases, the driving force required to continue concentrating the fluid increases. The pressure can reach 1,000 psi, and this requirement constitutes a high proportion of the operating cost. In this respect, nanofiltration is attractive because it operates at lower pressures, and therefore costs less to operate.

Their ability to meet acceptable discharge criteria depends on the characteristics of the mine water to be treated. It is generally agreed that complex or hard waters cannot be treated to below 10 ppb (26). Successful treatment requires a water softening plant to pre-treat mine water. In any event, this would normally be required to prevent excessive membrane fouling, as described below.

There are problems inherently associated with these technologies. Fundamentally, treatment is extended until constituents of concern (e.g., Se) reach the desired final concentrations. As solutes are being concentrated, some salts initially present at high concentrations may crystallize, thereby impairing function or damaging membranes. This is particularly true for hard waters containing high calcium and magnesium concentrations. In general, membrane life is expected to be 2-3 years, depending on the Total Dissolved Solids (TDS) of the water being treated.

In addition, the concentrated brine containing the rejected contaminant(s) must be dealt with safely and cost-effectively. This may require an evaporation facility to dispose of the brine, deep-injection, or some other method. These options can be expensive, depending on the volume of brine to be disposed.

Treatment costs are high, which has limited application of this technology at mines. Depending on necessary pre- and post-treatment requirements, operating costs can range from USD$4.7-71/1,000 gallon, with a median around USD$10-15/1,000 gallon. Capital costs can exceed USD$1 million for the RO unit alone, depending on volumes being treated.

At Lac Mineral's (now Barrick) Richmond Hill Mine, reverse osmosis was selected to treat mine water that is incompletely treated by iron reduction and precipitation (described below). The latter decreases Se concentrations from over 100 ppb to 12-22 ppb, whereas RO decreases it further to approximately 2 ppb. The RO unit is operated at 250 psi and up, which contributes substantially to the operating cost. Flows of 200 gpm are fed to the RO unit, and it produces a permeate at 100 gpm and a reject stream at 100 gpm. This brine, which is a Se concentrate, is cycled back to the iron treatment circuit. Given that selenium is produced from 52 acres (21 hectares) of leach pads, water treatment is expected to be required for at least 50 years.

A filtration pre-treatment is necessary to remove TSS. In addition, the operator is currently evaluating the need to remove calcium in a softening plant. Calcium concentrations in the feed have gradually increased to the present 450 ppm, causing gypsum to be deposited on membranes as salts become concentrated. The cost of this additional softening plant is compared against that of the shortened membrane life, which is presently replaced every 1-2 years at USD$30,000, instead of the normal 3 years.

During winter operation, water is heated to 15 ºC to prevent the cold-induced salt crystallization[4] on membranes. The heating cost is approximately $USD5,500/week, and depends on the weather[5] and propane costs.

The capital costs include purchase of a used RO unit at USD$750,000 (a new unit with the same capacity is approximately $1.2 million) and a multimedia pre-filtration unit at $200,000. Overall monthly operating costs are $50,000, or $10/1,000 gallon when the RO unit operates without trouble. The above issues are presently increasing treatment costs to $18/1,000 gallon. Some of these problems stem from changing water chemistry, some are caused by algal growth.

Nanofiltration is potentially less expensive than RO, due to its more selective nature and the lower pressures under which it operates. There are no examples of mines currently using this technology, although Newmont has evaluated its use at the closing Yanacocha Mine, in Peru to remove sulphate and thallium.

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[4] Concentrated salts are less soluble in the cold.

[5] South Dakota winters are comparable to Alberta winters.

The same issues of membrane fouling must be considered: pre-treatment for high TDS, addition of anti-scalants, anti-bacterial agents and Total Suspended Solids (TSS) removal may be necessary. These can add 10-20% to the operating cost of treatment.

Capital costs for a single-stage filtration unit are quoted at USD$2,000/gpm feed: a plant treating 500 gpm would cost $1 million (27).Additional pre-treatment may be 50% of the treatment plant cost, ranging from $300 - 1,000/gpm feed. Operating costs are quoted at approximately $0.50-0.60/1,000 gallons for a nanofiltration unit, with an additional $0.10-0.15/1,000 gallons for additional pre-treatment. This is much lower than operating costs for RO, but there are no operating nanofiltration units from which these costs could be verified. Additional maintenance costs include changing membranes every 2-3 years.

Development time is relatively short. Laboratory scoping studies can last two weeks, followed by a pilot campaign lasting one month, including mobilization and demobilization. System design can take one week, and ordering can take 20-24 weeks. Thus, a plant can be operational within half a year, assuming a fairly simple design. Additional delays will come from the requirement for, design and construction of pre- and post-treatment units.

4.1.2 *Ion Exchange*

Ion exchange is a reversible reaction wherein an ion (an atom or molecule that has lost or gained an electron and thus acquired an electrical charge) from solution is exchanged for a similarly charged ion attached to an immobile solid particle. These solid ion exchange particles are either naturally occurring inorganic zeolites or synthetically produced organic resins. Efforts to use zeolites for selenium removal have met with limited success. The synthetic organic resins are the predominant type used today because their characteristics can be tailored to specific applications.

Selenium removal is accomplished by using a strong base anion ion exchange resin. Se(VI) is extracted much more effectively than Se(IV). The extraction of Se(VI) is decreased by sulphate. Tailored resins show good selectivity for selenium in the presence of sulphate but only laboratory studies have been performed. Further laboratory studies (on mine waters) are required.

Once the capacity of the resin becomes exhausted, it must be regenerated with a strong acidic solution. As with RO and nanofiltration, the disposal of this solution adds to the overall cost of this technology.

Liquid ion exchange has been investigated on a pilot scale for treating gold heap leach solution effluents. The results were encouraging but the technology has been documented at only one site. Further laboratory and pilot test work need to be conducted.

4.2 Chemical

Several chemically-based treatment processes have been investigated, but only iron co-precipitation has met with success on a commercial scale. Precipitation with activated alumina has not met with success, though it has been tested extensively. Precipitation on lanthanum oxides looks promising, but has not yet been tried beyond the laboratory.

4.2.1 *Iron coprecipitation*

Ferrihydrite precipitation with concurrent adsorption of selenium onto the ferrihydrite surface is an USEPA-approved technology for treating selenium-bearing waters. For the coprecipitation to occur, ferric ion (Fe^{+3}) must be present in the water. The chemical reaction for ferrihydrite precipitation of selenium is:

$$Se^{+4} + FeCl_3 + 4H_2O \rightarrow Fe(OH)_3 \bullet Se^{+4} + 8H^+$$

Adsorption on ferrihydrite has been investigated by several researchers. Se(IV) is effectively removed at pH < 8. This technology is not very effective for Se(VI) except at high Fe/Se weight ratios and relatively low pH levels. Reduction of Se(VI) prior to adsorption is required for effective removal. The presence of other aqueous species may have a detrimental influence on the removal of Se(IV) and Se(VI).

In a review of this technology, Tidwell and co-workers (28) indicated that:

- Se(IV) is adsorbed much more effectively than Se(VI);
- Se(IV) adsorption is a function of type of oxyhydroxide present (amorphous ferrihydrite is best, crystalline FeOOH is considerably less effective);
- The initial concentration of Se(IV) in solution is very important (the higher the Se(IV) concentration the more effective the adsorption);
- The best pH for effective Se(IV) adsorption is 4-6 (85-90% removal), adsorption decreases slowly until about 7 (80-85% removal), then decreases drastically to about (20-40% removal)

In early studies on selenium treatment, Merrill and co-workers (29) reported an optimum pH of 6.5 for Se(IV) removal and that the optimum iron dosage was 14 mg/L for a water initially containing 40-60 µg Se/L. The effluent selenium concentration resulting from the treatment of 33 gpm in a continuous pilot facility was < 10 µg/L. The process treatment created 2.1-3.1 kg sludge/kg iron added. The estimated cost of processing 26 million gallons/day (for arsenic, heavy metals and selenium removal) would be USD$ 0.50/1000 gallons. This estimate, which seems very optimistic, is based on a flowsheet consisting of ferric chloride addition to form ferrihydrite, rapid mixing, polymer addition for agglomeration, clarification, sludge thickening and dewatering, and disposal of dewatered sludge in a municipal landfill.

The effect of other anions on the adsorption of selenium has been investigated (30). Certain anions were found to preferentially adsorb onto ferric oxyhydroxide. The order of adsorption at pH 7 was found to be phosphate > silicate = As(V) > bicarbonate/carbonate > Se(IV) > oxalate > fluoride = Se(VI) > sulphate. The order of adsorption at the lower pH used in treatment plants may be different.

The long term aging stability of adsorbed/co-precipitated selenium remains to be demonstrated. Adsorbed Se may be released when amorphous iron oxide crystallizes to the more thermodynamically stable phases of goethite (FeOOH) or hematite (Fe_2O_3).

At Lac Mineral's Richmond Hill Mine, a selenium treatment system was developed in 1994, based on a process using elemental iron to reduce selenate to selenite, followed by ferric sulphate precipitation at pH 4.5, with a copper sulphate catalyst. The resulting slurry is sent to a thickener to produce a peanut-butter-like sludge that is stored in a sludge pond.

The treatment process needed three years to be optimized. Even so, the best that could be achieved is effluent Se concentrations of 12-22 ppb, which is unacceptable for direct discharge to the environment. The treatment system is now used in conjunction with an RO treatment, which together produces an acceptable effluent.

A treatment plant was developed at FMC's (now Meridian) Dry Valley Mine for selenium removal (31). The process used zinc powder as a reductant, converting all the selenium to selenite, followed by iron salt precipitation at acidic pH. A similar plant was designed at a Homestake mine, where (elemental) iron powder and ferrous sulphate were used as reductants and ferric chloride was used to form ferric

hydroxide, which co-precipitates selenite. Again, the reaction was carried out at ~pH 4.5 and requires tight pH control (+/- 0.2 pH units).

Although capital and operating costs could not be found for both operations, their design and operation is comparable to the treatment plant for molybdenum removal at Noranda's former Brenda Mine. That treatment plant operates under very similar conditions and removes molybdenum through the same process (Figure 3), although it has been rated at 2,000-4,000 gpm. It is designed to operate for over 100 years, and reportedly costed over CDN$10 million when it was built in 1998 (32).

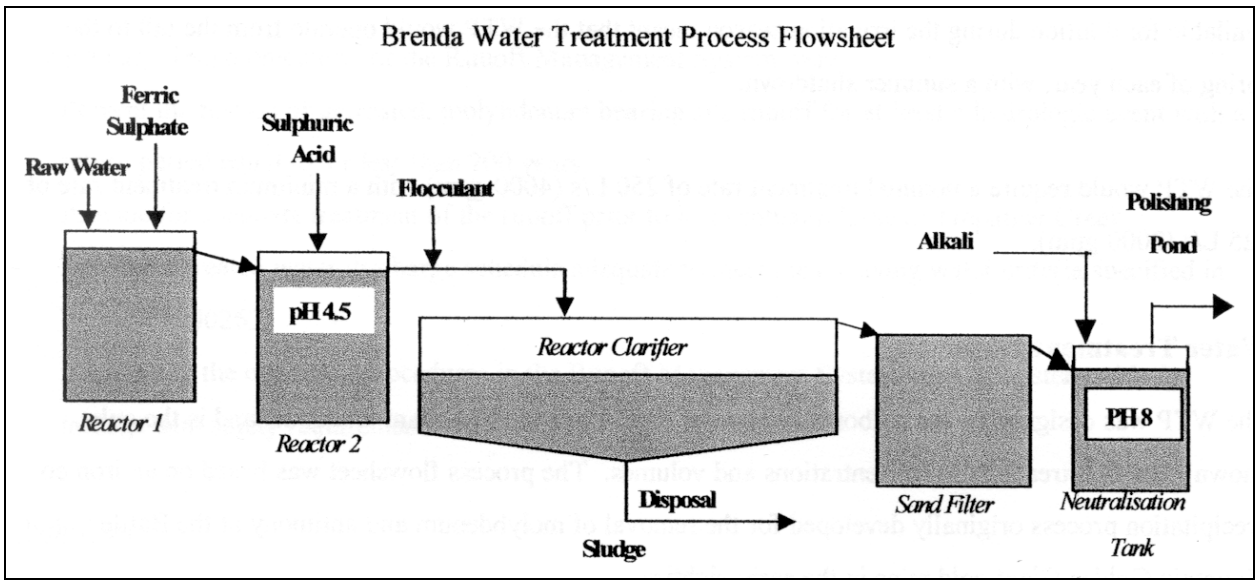


Figure 3. Process flowsheet for the Brenda water treatment plant.

Another chemical process, called catalyzed cementation has been developed by Dr. Larry Tidwell, Montana State University, to remove arsenic, metals and metalloids such as thallium and selenium from water. The term catalyzed cementation describes the process's ability to remove contaminants from solution by cementation (adsorption) onto the iron surface. Catalyzed cementation is expected to treat and remove selenium from solution regardless of its valence state (+6 or +4). To optimize the cementation process, proprietary catalysts are added to increase the removal efficiency of the process[6]. Laboratory tests have shown that selenium concentrations are decreased to below 50 ppb.

This process was tested in a US EPA-sponsored demonstration project at Kennecott Utah Copper Corporation's (KUCC) Garfield Wetlands-Kessler Springs site (33). This demonstration project was established to compare three different technologies side-by-side, thereby collecting comparable performance and cost information.. The site provides water with uniformly high selenium concentrations of 1,600 ppb Se, mostly as Se(VI).

During the test, flows were maintained at 1 gpm. In this process mine water receives iron powder, a proprietary catalyst, and its pH is carefully adjusted to allow for selenate reduction. The iron is recovered for re-use, the solution is pH-adjusted again, another reagent is added, and the cementation reaction is carried out. The suspended solids are thickened and the supernatant is discharged. The entire process is shown in Figure 4.

[6] Terry Mudder indicates that small amounts of copper aid in the adsorption of selenium onto ferrihydrite. This, or another metal, may be the proprietary catalyst.

The catalyzed cementation process could not at first consistently meet the target of 50 ppb Se in the pilot test. However, modification of treatment conditions produced a more acceptable effluent (Figure 5 and Table 2). Additional investigations in the laboratory further improved the treatment process, producing an effluent with selenium concentrations below 5 ppb.

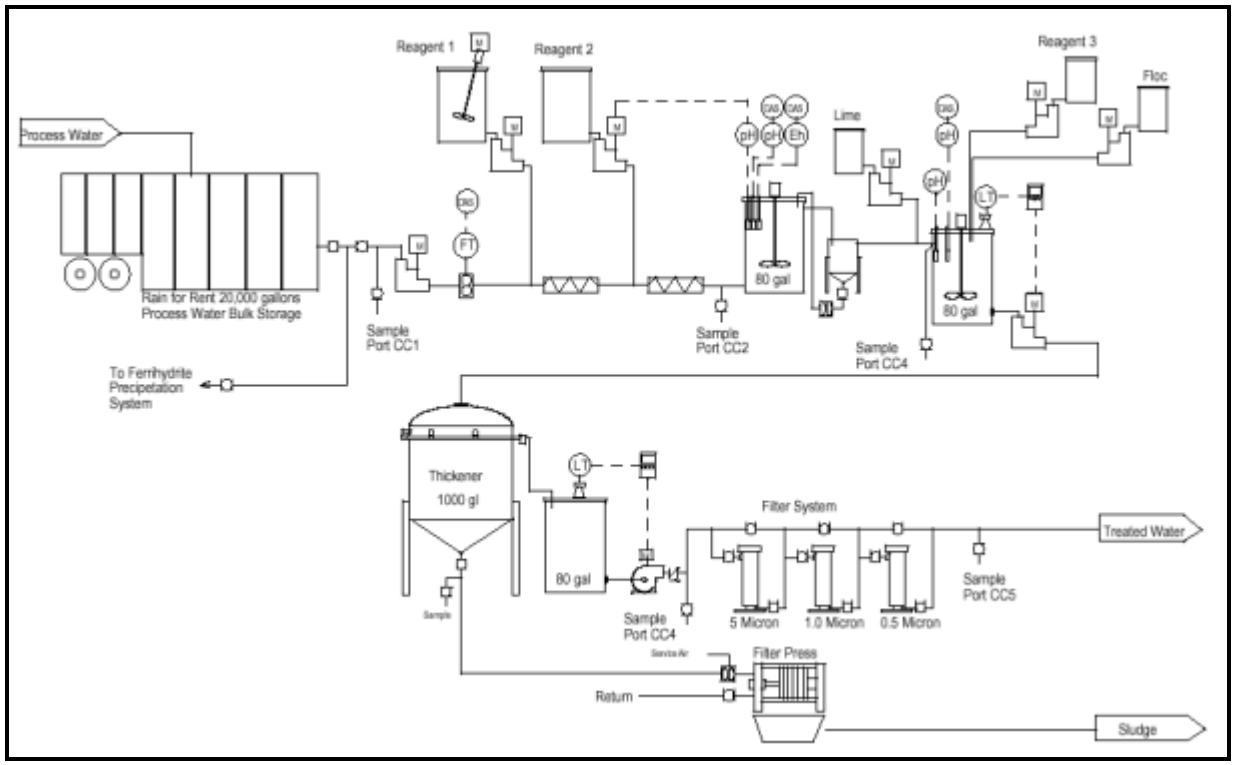


Figure 4. Flowsheet for catalyzed cementation process.

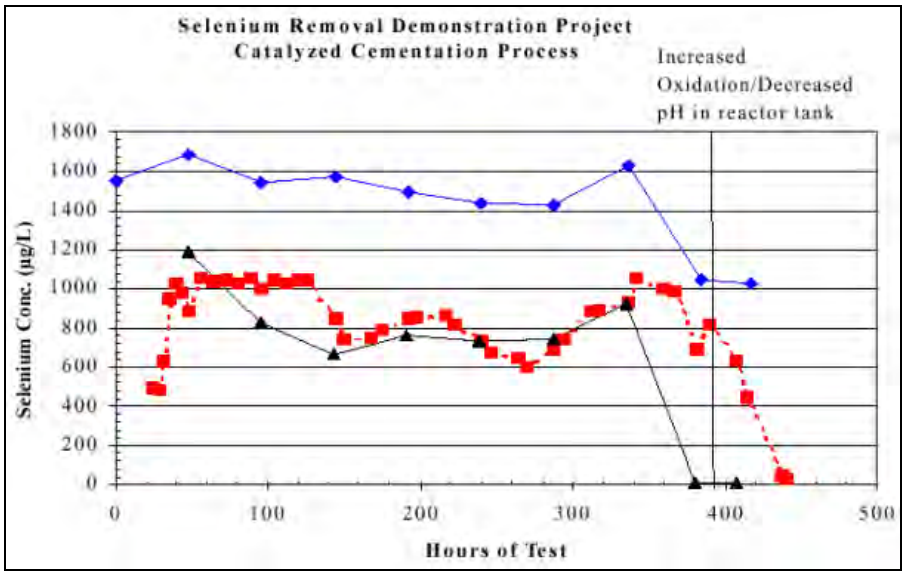


Figure 5. Treatment performance of the catalyzed cementation process at Kennecott.

Table 2. Mean effluent Se concentrations from catalyzed cementation pilot plant.

Treatment Condition	Mean Selenium Effluent Concentration (µg/L) ± Standard Deviation (n = sample size)	Minimum Selenium Effluent Concentration (µg/L)
Catalyzed Cementation	834 µg/L ± 204 (n = 42)	193 µg/L
Catalyzed Cementation with Increased Oxidation/Decreased pH in the reactor tank	35 µg/L (n = 2)	26 µg/L
Additional Testing of Catalyzed Cementation at MSE	3 µg/L 1 ± 4.4 (n = 5)	<1 µg/L

In many respects, catalyzed cementation is very similar to the above conventional iron precipitation technologies. For this reason, the cost comparison with a biological selenium removal technology is instructive. The capital costs for a treatment plant rated at 300 gpm, utilizing some tanks available on site, is calculated to be $1,083,285. Annual operating costs are calculated to be $1,165,358, of which a substantial proportion is accounted by the proprietary catalyst. The treatment cost, amortized over ten years, is calculated to be USD$8.17/1,000 gallons. As will be shown below, this is substantially more than that for biological treatment.

Another iron-based process has been developed at the University of Idaho (34). The process has been piloted and licensed to a company (Bluewater Technologies). Although treatment times are very rapid (10 minutes for low TDS water), final selenium concentrations are still remain higher than acceptable, at a reported 47 ppb. While promising, this technology still requires more development time before it can be evaluated properly for commercial application.

4.3 Biological

Treatment by biologically-based processes relies on the activity of a small group of bacteria that reduce selenate to selenite, then to elemental selenium (Figure 6 and Figure 7). Typically, these bacteria are found in anaerobic sediments, where they use selenium anions to oxidize organic matter. Different bacterial species will form either the red amorphous or the gray metallic form[7]. This may be important since these mineral forms may have different stabilities or susceptibility to oxidation.

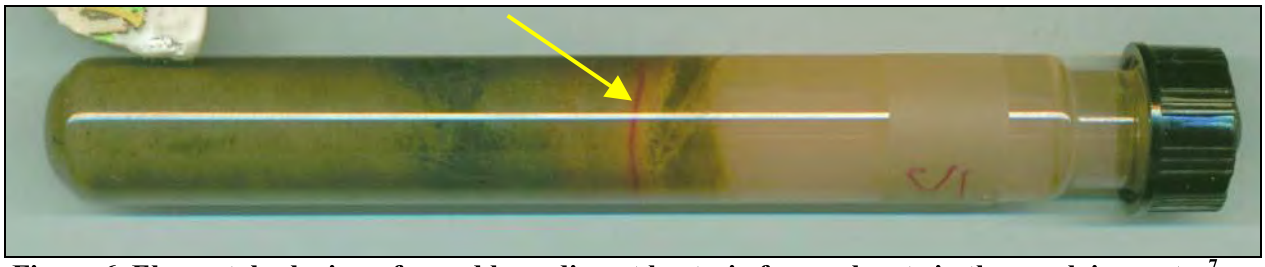


Figure 6. Elemental selenium, formed by sediment bacteria from selenate in the overlying water[7].

[7] André Sobolewski, Microbial Technologies, Inc. Unpublished observation..

Many factors affect their activity, including dissolved oxygen and nitrate concentrations (both are antagonists), temperature, pH, etc. Although it may be beneficial to identify the bacterial species used in a treatment process, this is not always necessary, since it is usually sufficient to identify the conditions that favour maximum activity.

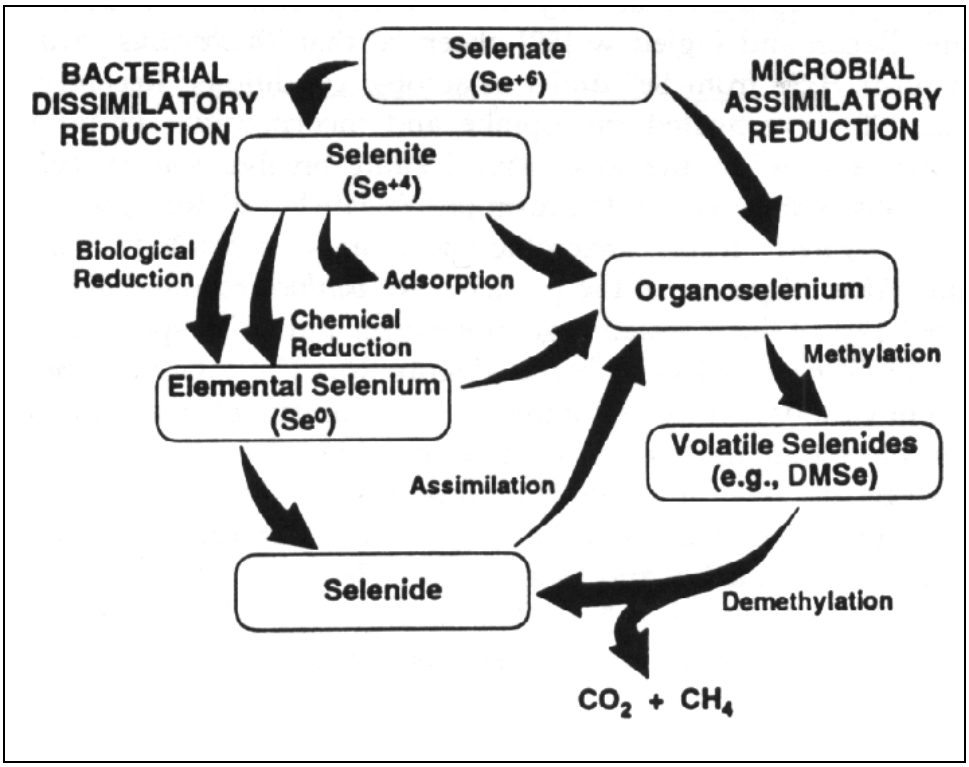


Figure 7. Selenium cycle in anoxic environments. Taken from 35.

The key to successful treatment system design lies in matching bacterial activity (i.e., selenium reduction rate) to the selenium loading rate for a given wastewater stream. This depends principally on the achievable bacterial biomass (more bacteria = higher activity), the supply of nutrients, and temperature.

4.3.1 *Selenium Volatilization*

Frankenberger and Karlson (36) attempted the remediation of sediments from both the Peck and the Kesterson ponds in the West San Joaquin Valley in California. The sediments were amended to stimulate bacterial volatilization of selenium. The Peck pond was bioremediated from a mean of 11.4 mg Se/kg sediment to the goal of 4 mg in 2.6 years. The Kesterson pond was not remediated to the 4 mg goal from 47.8 mg after 8 years, using the same techniques. The results can be explained by examining the distribution of selenium species in these sediments. For Peck the Se distribution was 6.6% Se(VI), 67.6% Se(IV), 18.4% Se(0), 7.3% Se(II-). For Kesterson, it was 5.2% Se(VI), 9.1% Se(IV), 58.0% Se(0), 27.7% Se(II-). Thus, the difference in Se(0) and Se(II-) distributions (25.7% vs. 86%) would suggest that most of the Se in Kesterson sediments was unavailable to microbial volatilization.

4.3.2 *Bioreactors*

Bioreactors are engineered structures that hold selected microbes for wastewater treatment. There are two different types of systems: active systems, essentially conventional treatment plants, in which operational parameters (pH, oxygen concentration, retention time, etc) are tightly controlled, and

passive systems, in which operator intervention is minimal. Both types of bioreactors have been designed for Se removal, as described below.

4.3.2.1 Active Systems

The efforts of the early 1990's to develop bioreactors for treatment of Se in agricultural drainage were reviewed (37). These reactors were mostly small laboratory-scale systems based on anaerobic bacteria that reduce Se oxyanions to elemental Se via the reactions:

$$\text{Se (IV+VI)} + \text{organic carbon} \rightarrow \text{Se (IV)} \rightarrow \text{Se (0)}$$

One of the systems was based on the known selenate reducer *Thauera selenatis*, originally isolated from agricultural drainage (38), whereas the others were seeded with undefined cultures. The reactors utilized either acetate or methanol as carbon sources (methanol being cheaper), and ammonium sulfate as a supplementary nitrogen source. Most of this organic carbon was consumed by bacteria respiring on nitrate (which is abundant in agricultural drainage), outcompeting the selenium-reducing bacteria.

Several reactor configurations were tested, including upflow anaerobic sludge blanket reactors (UASBR), fluidized bed reactors, sequential batch reactors, packed-bed reactors, and slow sand filters (SSF). The latter were found necessary under most configurations because they retained elemental selenium released by treatment bioreactors. Without the SSF, Se concentrations in reactor effluents were typically 30-60 μg/L, whereas they reached 15-30 μg/L with the SSF. These removal rates were achieved with retention times in the order of 10-30 hours. The removal rates were temperature-sensitive.

A common problem identified in most reactors was the formation of calcium carbonate and the potential for plugging. This results directly from the high calcium concentrations present in agricultural drainage and the production of bicarbonate during anaerobic bacteria respiration on nitrate or selenate. Although this makes these treatment systems inherently problematic, it was anticipated that these problems would be addressed during planned pilot tests.

The UASBR pilot plant campaign conducted over a two-year period identified a number of problems. The development of stable biomass took approximately 6 months. This biomass remained stable thereafter, despite variability in sludge volumes retained in the bioreactor. Approximately 90% of Se was removed during the campaign, with influent Se concentrations of 500 μg/L being reduced to 50 μg/L in the discharge. However, this level of treatment was not consistently attained, as effluent Se concentrations occasionally rose over 200 μg/L. This was due to the temperature-sensitivity of the process, as removal rates reached 88% at 15°C, but declined to 35% at 7°C. A partial solution was to insulate reactor tanks for the full-scale treatment system.

Costs were estimated for a full-scale treatment system based on the results from the pilot plant campaign. Operating costs were driven by the relatively high methanol consumption rate, being estimated at USD$1.00-1.30/1,000 gal. The total estimated costs, based on the pilot plant campaign, were USD$1.23-1.48/1,000 gal for a 10 Mgal/day plant, amortized over 20 years. Of course, these costs were derived from the treatment of agricultural drainage and are expected to be different for other types of water.

A number of treatment plants have been constructed and operated at mine sites in the past five years.

At Goldcorp's former Wharf Resources Mine, in Leads, SD, a biological treatment plant has been operated for two years. Mine water containing approximately 30 ppm nitrate (NO_3^-),15 ppb Se (as Se(VI)), and 70 ppb arsenic is collected in a French drain underlying barren rock. Flows are seasonal,

ranging from 40-300 gallons per minute (gpm). All these contaminants are removed during treatment, with NO_3^- decreasing to <1 ppm, Se to < 5 ppb, and As to < 1 ppb.

The plant is operated year-round, with no water heating (except to keep pipes from freezing). Water temperatures range from 1.5-4.0 ºC during the winter, to 15 ºC during the summer. The rate of bacterial activity decreases somewhat during winter operation, which is compensated with the addition of more nutrient. Problems develop when excessive nutrients are added, as the oxidation-reduction potential decreases to very low levels, causing nitrate to be reduced to ammonia. Otherwise, the system requires little maintenance, and has no scaling or odour (from hydrogen sulphide) problems, though it is checked regularly for sliming or other potential issues.

The overall capital cost for the treatment plant was somewhat under USD$1 million, and annual operating costs are USD$40-60,000. The plant made some use of tanks existing on the property, as well as constructing new tanks. The biggest capital cost item was the purchase of activated carbon as support matrix for the bacteria. A total of 800,000 lbs (362 metric tons) of activated carbon was purchased at USD$0.37/lb.

The system was first tested in the laboratory on a bench-scale, followed by a pilot campaign (Summer 2001) that lasted one month. Design, procurement and construction followed through Fall and Winter 2001/2002. The plant was operational in March 2002. The bacterial inoculum was grown in 3-4 weeks, and does not constitute a significant time constrain.

Overall, this treatment plant functions very well, though contaminant loadings are fairly light.

At the former Zortman-Landusky gold mine, in Montana, the acidic water collected from leach pads is treated biologically before discharge by land application. The neutralized influent to the treatment plant contains approximately 200 ppm NO_3^-, 500-700 ppb Se (as Se(VI)), and 300-400 ppb Total cyanide. The effluent contains <10 ppm NO_3^-, 100 ppb Se, and 200 Total cyanide. While this water does not meet state discharge criteria, it is sufficiently treated to allow for its disposal by land application.

The treatment plant consists of 3 x 250,000 gallon insulated (outdoor) tanks filled with activated carbon. It has treated flows of 75-300 gpm year-round for the past two years. Water temperatures vary seasonally, from approximately 1-15 ºC, without affecting treatment performance.

The capital cost for the treatment plant was USD$3 million, for which the highest cost item is the activated carbon (39). Operating costs are somewhat less than USD$250,000/year, and are broken down as follows (Table 3).

Table 3. Operating costs for Zortman-Landusky treatment plant.

Item	Annual Cost
Bacterial nutrients	$100,000
Labour	$43,000
Reagent (lime, etc)	$35,000
Maintenance	$25,000
Power	$15,000
Laboratory analysis	$14,000
Filtration	$10,000
Total	$240,000

A biological treatment system, comparable to the above systems, was tested at Kennecott Utah Copper Corporation's (KUCC) Garfield Wetlands-Kessler Springs site (33). The site provides water with uniformly high selenium concentrations of 1,600 ppb Se, mostly as Se(VI).

The treatment system comprises a series of tanks (total 500 gallon) that contain activated carbon seeded with selected bacteria. The tanks are fed groundwater (temperature = 13 ºC) at a rate of 1 gpm and a nutrient solution. The discharge flows through a slow sand filter to remove elemental selenium produced in the tanks. Treatment performance was excellent at all times (Table 4 and Figure 8). Selenium removal was complete, even with a 5.5 hours retention time.

Table 4. Mean effluent Se concentrations from biological treatment pilot plant.

Residence Time	Mean Selenium Effluent Concentration (µg/L) ±Standard Deviation (n = sample size)	Minimum Selenium Effluent Concentration (µg/L)
12 hrs (Series 1)	8.8 µg/L ±10.2 (n = 17)	<2 µg/L
11 hr (Series 2)	4.9 µg/ L ±4.9 (n = 16)	<2 µg/L
8 hr (Series 3)	<2 µg/L ±2.6 (n = 12)	<2 µg/L
5.5 hr (Series 2)	<2 µg/L ±2.1 (n = 26)	<2 µg/L

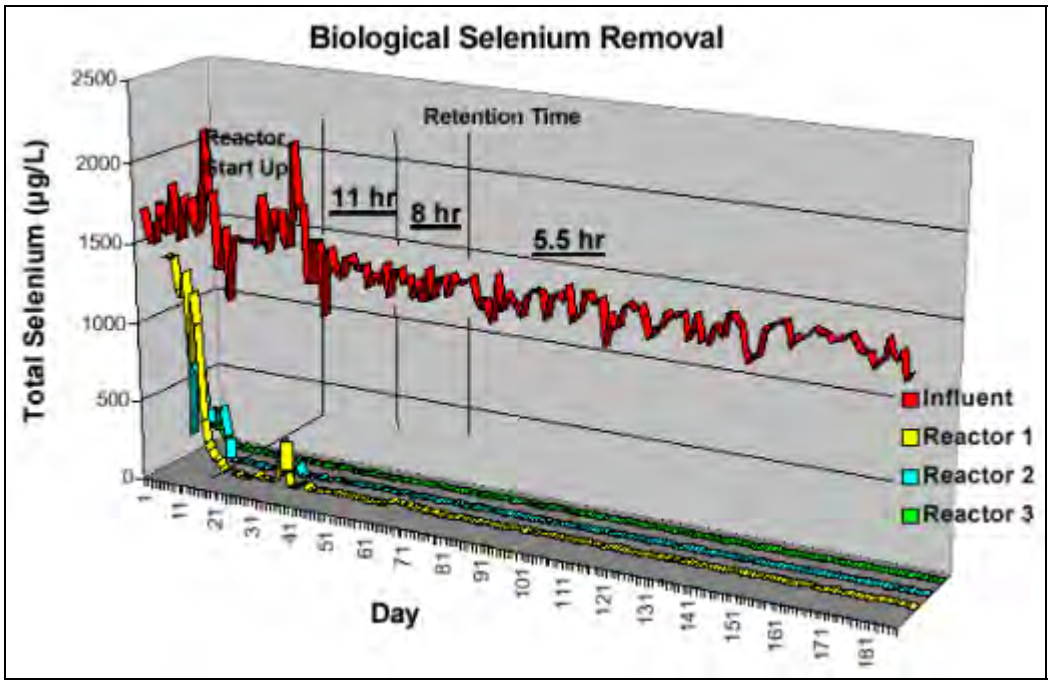


Figure 8. Treatment performance of the biological treatment process at Kennecott.

An economic analysis was carried out to calculate the cost of a full-scale treatment plant receiving 300 gpm of the above groundwater that contains 1,600 ppb selenium (mostly as selenate). The capital costs for such a treatment plant, utilizing some tanks available on site, is calculated to be $603,999. As with the above systems, the bulk of this cost comes from the activated carbon. Annual operating costs are calculated to be $135,029. The treatment cost, amortized over ten years, is calculated to be

USD$1.32/1,000 gallons, a fraction of the catalyzed cementation treatment process. This cost is roughly in line with the costs for the above biological treatment plants.

4.3.2.2 In-Situ Remediation

In-situ remediation involves the treatment of selenium in groundwater through stimulation of bacterial activity. In one typical application, aquifer sediments are sampled for the presence of selenium-reducing bacteria (See Section 4.3) and, if present, they are stimulated by addition of nutrient solutions (40). The reduction of selenate and selenite produces elemental selenium, which is retained in the subsurface.

This approach is been carried out in full-scale at Homestake Mining Co.'s Grants New Mexico Reclamation Project (41). Se present in a groundwater plume at 50-100 µg/L is being decreased through the action of bacteria to <5 µg/L. This process is very cost-effective, at less than USD$1.00/1,000 gallons, due to low capital costs. However, this approach may not be applicable everywhere, due to different aquifer characteristics. Moreover, the potential remobilization of elemental selenium retained in the subsurface has not been conclusively ruled out.

4.3.2.3 Passive System

The Biopass system was developed in the early 1990's for passive treatment of drainage from a reclaimed cyanide heap leach facility at Homestake Mining Company's Santa Fe Mine, in Mineral County, Nevada (42). This system relies on the flow of mine water through decaying organic matter (Figure 9). The system is designed to treat weak acid dissociable (WAD) cyanide (CN), nitrate (NO_3), mercury (Hg), and selenium (Se).

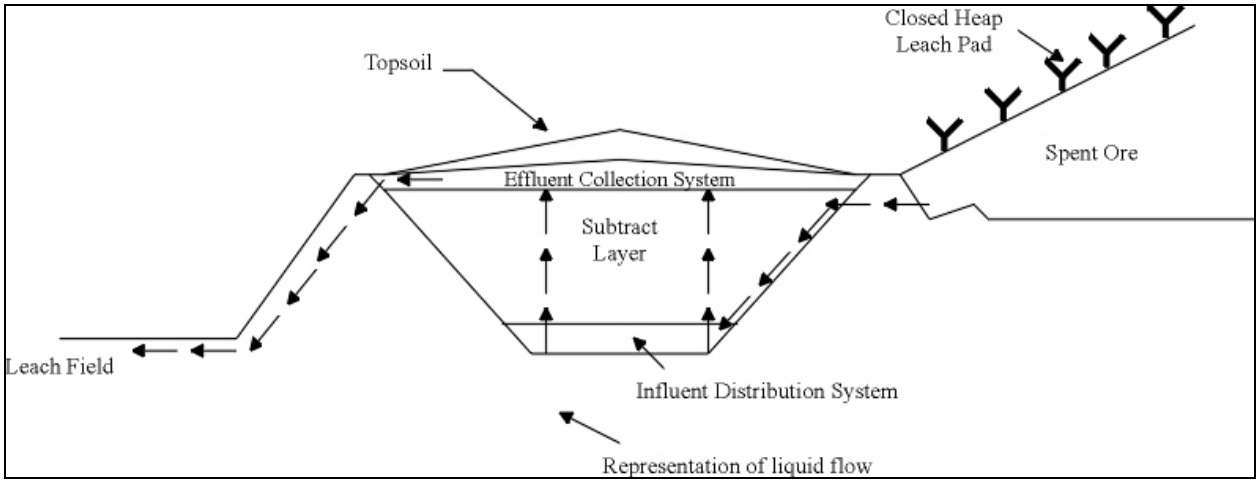


Figure 9. Schematic diagram of the Biopass system.

The Biopass system was constructed in an emptied double geomembrane lined solution pond and consisted of, from the bottom upward: a seepage collection (influent) layer comprised of gravel and perforated pipe, a substrate layer comprised of spent ore gravel and composted cow manure mixture, an effluent collection layer comprised of gravel and perforated pipe, a geotextile cushion, a geomembrane liner, and a vegetative soil cover. Treated solution flows by gravity through a buried pipeline from the effluent layer to a leach field where it is aerobically treated. Anaerobic bacteria in the substrate layer reduce selenium oxyanions to insoluble elemental selenium and form insoluble mercury sulfides. They also remove sulfate from the effluent. Other microorganisms biodegrade cyanide and remove nitrate from the water.

The Biopass system is designed to be sealed and operated passively. As a consequence, living organisms are not exposed to the fixed selenium and metals. However, these contaminants must be prevented from re-oxidizing in the future, or the system must be sealed off to prevent the discharge of re-oxidized contaminants.

Careful attention must be paid to two key considerations in the system design:

- Sizing of organic substrate mass and treatment retention times.
- Design and placement of the substrate layer to minimize consolidation and maintain permeability.

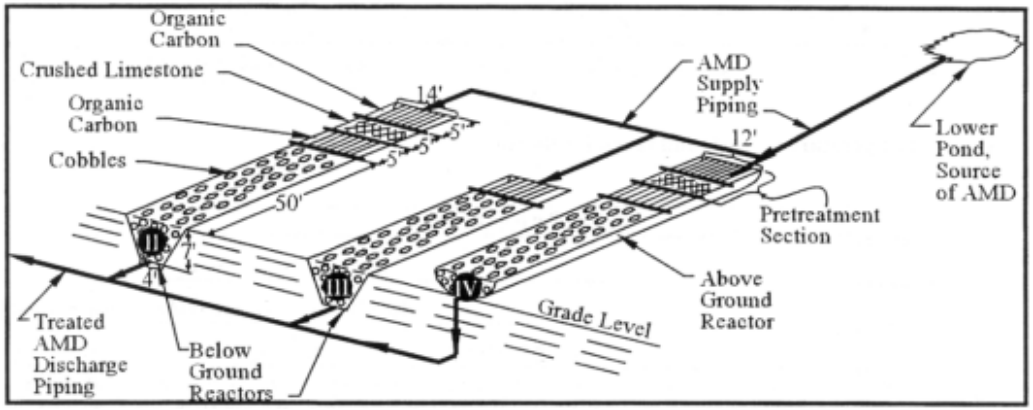
The required mass of organic matter is calculated on the basis of the anticipated sulfate load requiring treatment. A predicted sulfate load is calculated using the average annual flow rates, summed over a 20 year period with two 100 year 24-hour storm events, and an average sulfate concentration of 2,000 mg/L. The mass of organic substrate is determined assuming a conservative ratio of volatile suspended solids that will be consumed per pound of sulfate. Results to date indicate that every contaminant of concern is removed sufficiently for the effluent to meet mandated discharge criteria.

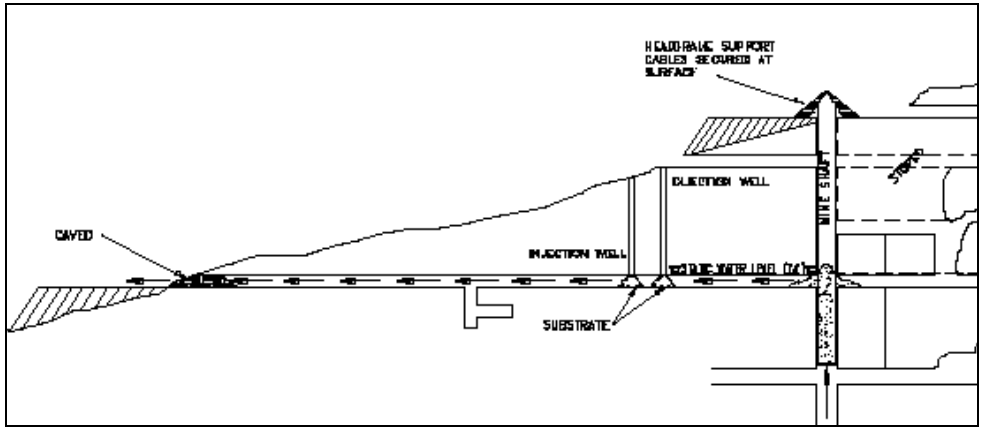
No cost information is available on this treatment system.

The Biopass system is a particular design of a general class of passive treatment systems that has been developed in the past 5-10 years. Such systems that have been used at other mine sites, though they were not designed to treat selenium-contaminated waters (See examples in Figure 10).

In general, they are very compact systems, a distinct benefit in certain settings. The majority of designs rely on the organic matter placed in them to feed the bacteria that provide treatment. Typical materials include alfalfa, manure, mushroom compost, sawdust, straw, etc. The benefit of this design is that organic matter is usually abundant and inexpensive. Its decomposition produces the anaerobic environment required by SRB, nitrate- and selenium-reducers.

The main drawback of this approach is that this material often offers poor or deteriorating system hydraulic, due to gradual decomposition, compaction, sliming, accumulated metals, etc. For that reason, most current designs are best suited for modest flows. Potentially, they represent a “walk-away” scenario, or an inexpensive solution for abandoned mines, specially since some of them have been shown to operate at low temperature.





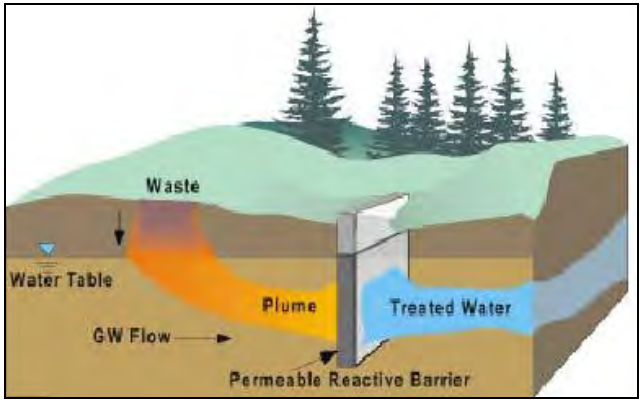


Figure 10. Examples of different bioreactors. Top: aboveground reactors; bottom: underground reactors.

4.3.3 *Treatment Wetlands*

ChevronTexaco's (Chevron's) Richmond, CA refinery, one of the largest on the West Coast, produces a contaminated effluent when selenium is stripped from crude oil during the refining process. The resulting wastewater passes through an oil-water separator, oxidation ponds, and ultimately through restored wetlands which remove Se (43). The 3x30-acre cells (called "passes") wetland system (Figure 11) receives flows of 1,000 gallons per minute (gpm) containing 10-30 ppb (predominantly selenite), a mass loading of 156 ± 13 g/day. Se concentrations are reduced by 60-70% at the outlet on Pass 1 and attain < 5 ppb dissolved Se at the outlet of the wetland complex.

Most of the dissolved Se is retained in the wetland sediments, where it has built up to concentrations of 3-8 mg/dry kg (44). A significant portion of the Se, estimated at 10-30%, is transformed to volatile selenides, which are lost from the system (44). Rates of volatilization in the wetland vary over two orders of magnitude and are a function of time of year and plant coverage (Table 5).

Table 5. Volatilization rates in Chevron's treatment wetlands.

Site	Volatilization Rate µg Se/m^2/day
Vegetated - Rabbitfoot grass	190 ± 150
Vegetated - Cattails	180 ± 100
Vegetated – Saltmarsh bulrush	150 ± 40
Vegetated – Saltgrass	80 ± 40
Vegetated – Brass buttons	60 ± 30
Unvegetated – Inlet channel	170 ± 30
Unvegetated – Fungal mat	110 ± 60
Unvegetated – Algal puddle	50 ± 20
Unvegetated – Uncovered sediments	20 ± 10

The wetland has attracted considerable attention because of its abundance of bird life. The marsh is home to black-necked stilts, Canada geese, Savannah sparrows, endangered California clapper rails, as well as grey foxes, raccoons, skunks, muskrats, mice and moles. Some of the latter carnivores were actively trapped to increase egg survival, thus enhancing bird populations. The National Audubon Society, National Geographic Magazine and the California Department of Fish and Game view it as a role model illustrating how a refinery turned land used to treat industrial effluents back into native habitat. Planted near the mouth of San Pablo Bay in Richmond in the late '80s, the restored wetland grows typical California marsh plants including salt marsh bulrush, cattail and rabbitfoot grass.

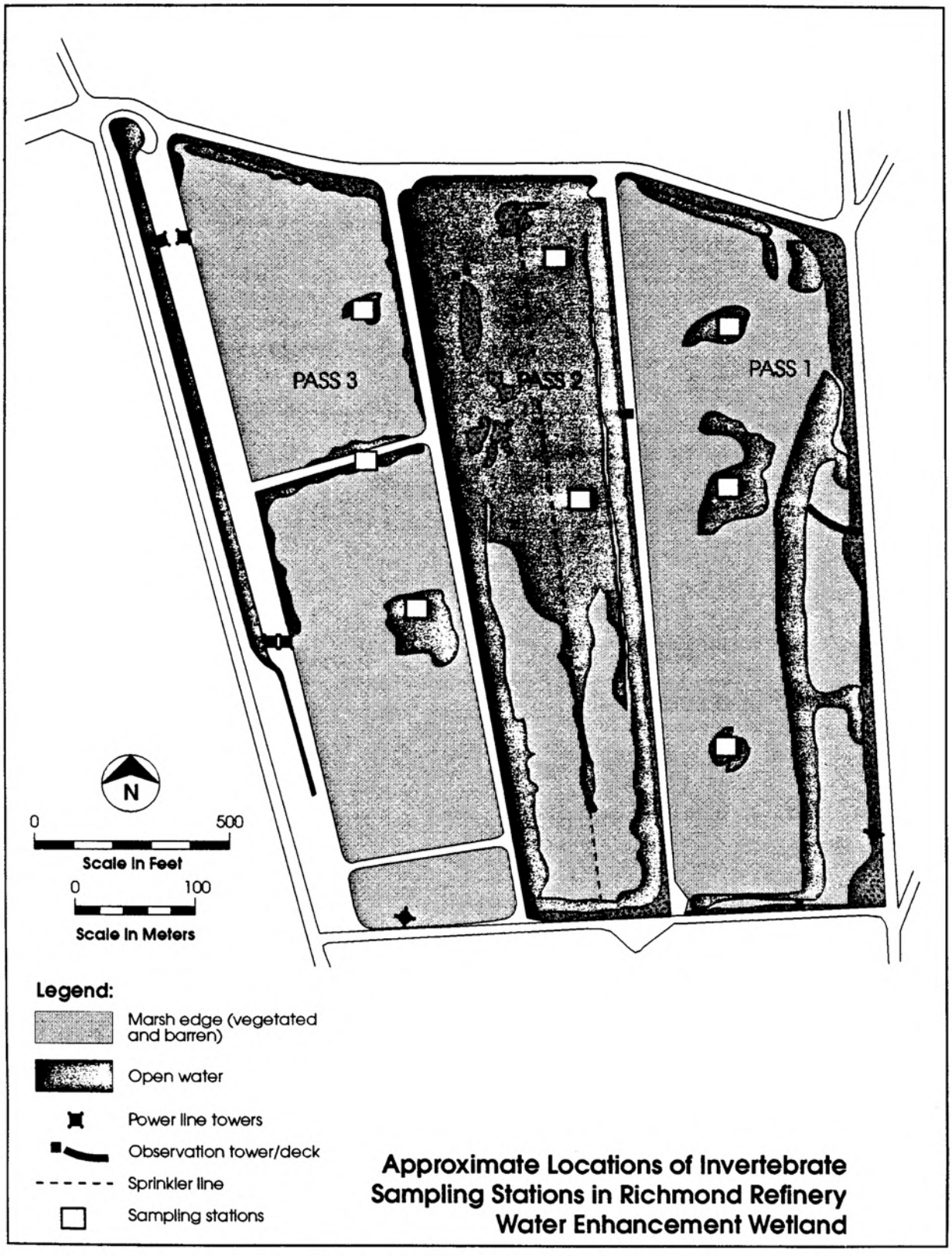


Figure 11. Layout of the Chevron refinery wetland treatment system. Taken from 45.

Se is taken up by organisms living in the wetlands. Se concentrations reach 31.0 µg/dry g in midge larvae (*Chironomus* species), 17.3 µg/dry g in water boatmen and 12.8 µg/dry g in snails (45). These concentrations are twice those predicted from invertebrates living in Tulare Basin evaporation ponds, apparently reflecting the fact that selenate is found in these ponds. Interestingly, tissue Se concentrations do not reflect ambient dissolved Se concentrations, but correlate with the average Se concentrations from the previous 2-3 weeks.

The U.S. Fish and Wildlife Service is concerned that Se is accumulating in the wetlands and causing toxic effects. Se concentrations in black-neck stilt eggs average (geometric mean) 20.4 µg/dry g, a concentration predicted to result in non-viability and/or embryonic deformations (45). These concentrations have increased the rate of deformities in young birds to an estimated 10-30%, whereas the rate of deformities is expected to be less than 1% (46).

To mitigate impacts of Se toxicity on bird populations, Chevron modified the treatment wetland by densely planting the first two passes and modifying their shoreline, both to deter bird usage. These passes was further altered to remain continually submerged, thereby improving treatment performance and preventing accidental drying out of sediments and release of accumulated selenium. Finally, the last pass was modified to enhance bird usage. The result of these modifications is that treatment efficiency is maintained, while selenium content in bird eggs decreased dramatically (47).

Unfortunately, no cost information is available for this system. However, the author's experience suggests that such a system would cost between $1-3 million to design and construct (depending on topography, soils, flow control structures, etc), and approximately $100,000/year to operate (including monitoring costs) and maintain. Such a system could accept up to 2,000 gpm (454 m^3/hr), removing 80-95% of input Se, depending on flows. Operation in a Northern climate would be seasonal, with water stored in an impoundment or reservoir during the winter.

4.3.4 *Natural Attenuation in Evaporation Ponds*

Microalgae and submerged aquatic plants can volatilize significant quantities of selenium from the water column. This ability has been exploited in California to remove Se from contaminated agricultural drainage. Drainage entering the Hacienda Evaporation Basin of the Tulare Lake Drainage District, Corcoran, CA, shows a progressive decrease in Se concentrations despite becoming more concentrated due to water evaporation. Rates of volatilization from planktonic algae for selenium concentrations of 1 µg/g are 220 ng/hour (48). These rates are achieved when conditions in the pond are favorable for plant growth and activity, which include slightly alkaline pH, clear water, non-limiting nutrient (i.e., nitrogen and phosphorus) concentrations, etc. Nevertheless, a retention time of approximately 80 days is sufficient to remove Se completely from agricultural drainage.

Unfortunately, these evaporation basins have caused reproductive impacts to avocets feeding and nesting at these sites. The operators of these basins have modified the design and management of the basins to discourage shorebird use and nesting (49). Modified designs include: greater water depths, steep banks with 3:1 slopes, no islands or windbreaks, level bottoms, and plastic lined or "stacked" rip-rap banks for erosion control. Management strategies include rapid filling and drawdowns of the ponds, intensive hazing during the pre-breeding and breeding seasons, vegetation control on the banks and ponds, and clean, smooth, scraped dikes and banks. Hazing efforts include: propane cannons, cracker shells, bird bombs, mylar flagging, airboat, and vehicles. Other management strategies include modifying sites adjacent to the basin that attracted birds to the basin area or providing a freshwater mitigation wetland adjacent to the evaporation basin. These mitigation efforts have succeeded in reducing bird use and, consequently, Se-induced reproductive failures.

5 Discussion

The chemical properties of selenium help explain several aspects of selenium treatment. Thus, the relatively greater reactivity of selenite (Se(IV)) compared with selenate (Se(VI)) (similarly to the greater reactivity of sulphite compared with sulphate) explains why iron precipitation will readily remove selenite from solution but not selenate.

Any of the technologies reviewed above could be used at the coal mines in West-Central Alberta, but they may not all be well suited. To compare their relative suitability, these technologies are assessed using the criteria listed below[8].

1. Achievable discharge concentrations (12 points)
2. Cost-effectiveness (12 points)
3. Treatment for selenate (8 points)
4. Operational constraints (i.e., land area or power requirement, temperature-dependence, by-product disposal, etc) (8 points)
5. Operational experience, reliability of the technology (6 points)
6. Post-treatment management (Brine disposal, sludge storage/management) (6 points)
7. Maturity of the technology (bench-, pilot-, or full-scale experience) (6 points)
8. Volumes of water that can be treated (4 points)
9. Development time (2 points)

The highest score is given when a criterion is completely met (e.g., effluent Se is 5 µg/L or less) or a technology is best suited (e.g., most cost-effective, requires no post-treatment management of residues). Each technology is assigned points for each criterion, and the technology with the highest score is recommended as that best suited for the coal mines in West-Central Alberta. Operational constraints are factored in Item 4, arising mainly from the long, cold winters and limited availability of flat areas existing at these coal mines. In some cases, professional judgment was applied when there was little or no information to evaluate a technology under a specific criterion.

The results of this evaluation are presented in Table 6. It must be borne in mind that this is a generic evaluation conducted without site-specific information. There may be circumstances at a mine that favour one option over another.

[8] The rationale for the scores assigned to each criterion is as follows. Costs and achievable discharge concentrations are the most important selection criteria by companies and government, respectively. Selenate treatability is important, but a chemical reduction step to selenite, which adds operational complexity and costs, can be used if selenate treatment is poor. Operational experience, post-treatment management, and maturity of the technology are somewhat less important – they are not make-or-break factors – but they are still quite significant in evaluating a technology. Some technologies can only handle limited flows, which handicaps them and should be considered in this evaluation. Finally, a minor issue is the time it takes to develop a technology for a site: development times of two month are preferred over two years.

Table 6. Evaluation of selenium treatment technologies for suitability to Alberta coal mines.

	Achievable[1] discharge [Se]	Cost-effectiveness	Selenate treatability	Operational constraints[3]	Experience, reliability	Post Manag't	Maturity	Water Volume	Dev't Time	**Total Score**
Maximum Points[2]	**12**	**12**	**8**	**8**	**6**	**6**	**6**	**4**	**2**	**64**
Reverse Osmosis	12	2	7	7	6	2	6	2	2	**46**
Nanofiltration	12	6	8	7	5	2	2	2	2	**46**
Ion exchange	8	2	3	8	3	1	1	2	2	**30**
Iron precipitation	3	4	2	7	5	2	5	4	1	**33**
Catalyzed cementation	3	2	3	6	1	3	2	2	1	**23**
Algal volatilization	5	12	6	3	2	6	2	3	1	**40**
Biological treatment plant	12	8	8	7	5	5	5	2	1	**53**
In-situ	12	12	8	5	3	5	2	4	1	**52**
Biopass system	10	10	8	3	4	4	2	2	1	**44**
Treatment wetlands	10	10	8	2	4	4	3	3	1	**45**
Evaporation ponds	6	12	6	2	2	3	2	3	1	**37**

[1] Headings correspond to categories identified in Page 27.
[2] Maximum possible score for each category.
[3] See discussion on Page 27.

Two technologies stand out from the others: In-situ treatment and Bioreactors (biological treatment plant). Both technologies score well with regards to effluent selenium concentrations and cost-effectiveness. Unlike filtration methods, treatment wetlands or evaporation ponds, these technologies can also operate in cold climates without heating. These two technologies appear to be most suitable for coal mines in West-Central Alberta. The fact that biological treatment systems have been favoured in the past five years undoubtedly reflects the above results.

Several consultants have indicated during the interviews that In-situ treatment is the method of choice *if applicable at a site*. As such, it is one of the technologies to consider first. Its applicability is dependent on favourable subsurface conditions.

Bioreactors have proved to be more reliable than expected in treating selenium, as well as a number of other contaminants. Another unexpected characteristic is their apparently good treatment efficiency at cold temperatures (e.g., 2-4 ºC). There are now four biological treatment plants that remove selenium in the USA, suggesting that this technology is becoming more mature. Note that they are located in Western states (e.g., South Dakota, Montana), where winters are comparable with those of West-Central Alberta.

Four other technologies form a second group in the ranking: reverse osmosis, nanofiltration, the Biopass/passive treatment systems and treatment wetlands. These technologies might possibly be appropriate to some of the sites if favoured by some site-specific factors, e.g., suitable land is available for treatment wetland or inexpensive equipment or other factor reduces the cost for RO treatment. Passive technologies, such as the Biopass system or treatment wetlands, might be favoured over others if several dispersed small flows require treatment, if they contribute significant loadings of selenium to receiving waters, and if their continued collection after mine closure proves onerous.

Treatment plants using iron precipitation could be suitable for waters containing low selenite concentrations. However, this does not seem to be the case for the coal mines where selenium speciation has been investigated.

The remaining technologies are too underdeveloped or inappropriate for application in West-Central Alberta.

It should be noted that preventative measures will always be preferred over treatment systems, at least for long-lasting contaminant leaching. Presently, there is not enough information to determine if Se release is a short-term or long-term problem in West-Central Alberta. This is an important issue that should be evaluated since evidence from other mines suggests that it might be a long-term problem. The most common preventative measures were only briefly described above and were not evaluated. However, there is a substantial body of literature that addresses such reclamation techniques, one of which was mentioned earlier[1].

In summary, this evaluation concludes that the two best treatment technologies are in-situ treatment and bioreactors (biological treatment plant), because they can remove selenium down to acceptable levels cost-effectively, even during cold winters comparable to those in West-Central Alberta. Four other technologies – reverse osmosis, nanofiltration, the Biopass/passive treatment systems and treatment wetlands – merit consideration and may be appropriate in certain circumstances at West-Central Alberta coal mines. Notwithstanding the advantages or disadvantages of each technology, preventative measures to minimize selenium release should be implemented as an integral component of any management plan at these mines.

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Appendix I

Topics used for questions during study

Topics used for questions during study

1. Characteristics of the water to be treated
    a. Selenium concentrations; selenite vs selenate
    b. Other constituents, such as nitrate, sulphate, or TDS that might affect treatment performance
    c. Other contaminants for which treatment is required
    d. Flows
2. Description of the treatment system
    a. Necessary pre-treatment
    b. Selenium removal process
    c. Post-treatment
    d. Treatment performance/discharge criteria
    e. Seasonal vs year-round treatment
3. Years of operation
4. Operational issues
    a. Stability of performance
    b. Seasonal/temperature effects, if relevant
    c. Maintenance issues
5. Costs
    a. Capital
    b. Any savings from using available equipment
    c. Operational cost, broken down, if possible
6. Time required for system development

Appendix II

List of people contacted during study

List of people contacted during study

1. Jack Adams, President, Bioremediation & Bioprocess Consulting, LLC. Park City, UT, USA. Tel: (801) 860-8358.
2. Susan Baldwin, Dept Chemical and Biological Engineering, University of BC. Vancouver, BC. Tel: (604) 822-1973.
3. Diana Bless, Program Manager, Mine Waste Technology Program, US Environmental Protection Agency.
4. Gary Benuelos, US Dept of Agriculture. Sacramento Research Station, Sacramento, CA, USA. Tel: (559) 596-2880.
5. Charles Buckham, Manager Analytical Development, Newmont Metallugical Services. Englewood, CO, USA. Tel: (303) 708-4430.
6. Mike Cepak, Mine Reclamation Coordinator, South Dakota Dept of Environment and Natural Resources (DENR). Pierre, SD. USA. Tel: (605) 773-4201.
7. Bill DiRienzo, Watershed Program Supervisor, Wyoming Dept of Environmental Quality (DEQ). WY, USA. Tel: (307) 777-7081.
8. Todd Duex, Project Engineer, Barrick Gold (Homestake). Homestake Mine, Leads, SD, USA. Tel: (605) 722-4875.
9. Tom Durkin, South Dakota SM&T. SD, USA. Tel: (605) 394-1975.
10. Jeff Fuerstaneu, Senior Engineer, Goldcorp. Wharf Resources Mine, SD, USA. Tel: (605) 584-1441.
11. Gene Fuller, Treatment Plant Operator, Barrick Gold (Lac Mineral). Richmond Hill Mine, Richmond Hill, SD, USA. Tel: (605) 578-2138.
12. Lucinda Jackson, Project Manager, ChevronTexaco R&D Co. Richmond, CA, USA. Tel: (510) 242-1047.
13. Laura Kuzel, Montana DEQ (now deceased). Bozeman, MN, USA. Tel: (406) 444-1967.
14. Jay Lombardi, Manager, Harrison-Western. CO, USA. Tel: (303) 234-0273, x205.
15. Bill Maehl, Reclamation Project Manager, Spectrum Engineering. Zortman-Landusky Mines, Billings, MN, USA. Tel: (406) 259-2412.
16. Greg Möller, Professor, Food Science & Toxicology, University of Idaho. Moscow, ID, USA. Tel: (208) 885-7081.
17. Terry Mudder, President, TIMES Ltd. Sheridan, WY, USA. Tel: (307) 674-4844.
18. Jim Myers, ChevronTexaco ETC. Houston, TX, USA. Tel: (713) 432-6689.

19. Ross Smart, Senior Scientist, ChevronTexaco R&D Co. Richmond, CA, USA. Tel: (510) 242-2914.

20. Bill Schafer, President, Schafer Ltd. Bozeman MN, USA. Tel: (406) 587-6100.

21. Mark Strosher, BC Ministry of Environment, Lands, and Parks (MELP). Cranbrook, BC. Tel: (250) 489-8522.

22. Leslie Thompson, V.-P. Research, Pintail Systems. Golden, CO, USA. Tel: (303) 642-3520.

23. Rory Tibbals, Operations Superintendent, Golden Sunlight Mine, Placer-Dome Ltd. Whitehall, MN, USA. Tel: (406) 287-2046.

24. Bruce Winegar, Senior Environmental Manager, Smoky Canyon Mine, J.R. Simplot Co. Afton, WY. Tel: (208) 235-5674.

PILOT-SCALE TREATMENT OF SELENIUM IN GRAVEL PIT SEEPAGE WATER USING BIOCHEMICAL REACTOR TECHNOLOGY[1]

Tom Rutkowski[2], Russ Walker, Jim Gusek, Mike Baker

Abstract. Water quality in the lower Colorado and Gunnison Rivers in western Colorado, and many of their tributaries, is impaired by selenium, which originates from the local Mancos shale. Because of the diffuse and widespread nature of this source, there are limited opportunities to reduce selenium inputs. One option is to treat selenium-contaminated surface water at strategic locations, such as point-source discharges. Gravel extraction is common along these rivers, and treatment of discharges from pit dewatering presents an opportunity for reducing selenium loading. The pilot test goals were: 1) demonstrate that a passive BCR can accomplish high-efficiency selenium removal at the pilot scale 2) determine the relationship between selenium removal efficiency and detention time 3) assesses the influence of seasonal temperature fluctuations on treatment performance 4) determine design parameters for a full-scale system (*i.e.*, one with a footprint on the scale of up to a few acres). A single 4,380 cubic foot pilot BCR was constructed to treat flows ranging from 2 to 24 gallons per minute. The vertical-flow reactor media contains cow manure, hay, sawdust, wood chips, and limestone. Influent was drawn from a dewatering trench in a gravel pit next to the Colorado River near Grand Junction, Colorado. The pilot operated, with varying detention times, over a thirteen-month period from September 2008 until October 2009. The pilot achieved maximum selenium removal rates of 98% with a hydraulic retention time of 2.4 days and a minimum effluent concentration of 0.0005 mg/L (0.5 µg/L). The highest mass removal rate achieved by the BCR was 73 mg/day/m^3 and the cumulative mass of total selenium removal was 600 grams. The BCR treatment process was effective throughout the cold winter months during which total selenium removal rates remained greater than 90%. The total capital cost for the pilot BCR was $39,200 or $0.50 per 1,000 gallons treated. The operations and maintenance costs for a passive BCR system are minimal. Based on the successful operation of the pilot, including high rates of selenium removal and consistent year-round operation, the BCR technology appears to be an effective, low-cost selenium treatment option. This project was funded by the US Bureau of Reclamation Science and Technology Program, Project #4414.

Additional Key Words: BCR, biological treatment

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[2] Tom Rutkowski, P.E. is a senior project engineer at Golder Associates Inc., 44 Union Blvd. Suite 300, Lakewood, CO 80228. Dr. Russ Walker is a professor of Environmental Science at Mesa State College, Grand Junction, CO. Jim Gusek, P.E., is a senior consultant with Golder Associates Inc. Lakewood, CO. Mike Baker is a planning team leader with the U.S. Bureau of Reclamation, Grand Junction, CO.

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Introduction

Selenium in surface and groundwater has generated concern since 1982, when selenium was found responsible for mortality of fish and birds inhabiting the Kesterson National Wildlife Refuge in California (National Research Council, 1989). The western United States is susceptible to Se contamination of ground and surface water due to a combination of geology, climate, and irrigated agriculture. Over 777,000 km^2 (17%) of the total land area in the western U.S. is composed of seleniferous bedrock, much of which is irrigated (Seiler et al, 2003). Selenium is mobilized as irrigation drainage waters leach it from the bedrock and soils. The arid and semi-arid climates promote high rates of evaporation, which can lead to elevated concentrations of Se in surface waters, causing some areas to exceed water quality standards.

Although Se forms the active center of certain enzymes and is thus an essential nutrient, at elevated concentrations it is toxic to invertebrates, fish, birds, and mammals. The oxidation state of Se determines its bioavailability and toxicity (Amweg et al, 2003). Selenium can occur in its elemental form (Se^0), as selenate (SeO_4^{2-}, Se^{6+}), selenite (SeO_3^{2-}, Se^{4+}), and inorganic selenide (Se^{2-}). Elemental Se is insoluble and has little effect on living organisms. The inorganic forms, selenate and selenite, are both soluble and bioavailable, with selenite being the more toxic of the two. Organic selenide is the most bioavailable form of Se, and is utilized by algae 1,000 times more easily than the inorganic forms. Selenium is also bioaccumulative; its concentration may increase in organisms at successively higher levels in the food chain.

The Grand Valley in western Colorado is underlain by the highly seleniferous Mancos shale. Selenium in surface waters here has been measured at concentrations exceeding 100 µg/L (Spahr et al, 2000), which is well above the U.S. Environmental Protection Agency's criterion of 5.0 µg/L as a maximum continuous concentration of total Se for protection of freshwater aquatic life (EPA). Because of the diffuse and widespread occurrence of the Mancos shale, there are limited opportunities to reduce Se inputs to surface waters. One option is to treat selenium-contaminated water at strategic locations, such as point-source discharges (Bureau of Reclamation, 2006). Gravel extraction is common along the Colorado River, and treatment of discharges created by dewatering of groundwater into the pits presents an opportunity for reducing selenium loading to the river.

Selenium-contaminated water can be treated by physical, chemical, and biological treatment methods (Frankenberger *et al.* 2004). Recently, biological treatment has emerged as a leading technology for Se treatment (Microbial Technologies 2005). Biological treatment of Se is accomplished through microbial reduction of oxidized Se species such as selenate and selenite to insoluble elemental Se. In the generalized reactions below, Se serves as an electron acceptor and organic carbon (e.g., BCR substrate, molasses) serves as an electron donor (Fujita et al. 2002).

$$SeO_4^{2-} + \text{Org. Carbon} \longrightarrow SeO_3^{2-} + \text{Org. Carbon} \longrightarrow$$

$$Se^0 + CO_2 + H_20$$

Common electron acceptors that must be removed prior to Se include dissolved oxygen and nitrate.

Biological treatment offers a low cost alternative to more expensive physical and chemical treatment methods and is effective in cold climates (Microbial Technologies 2005). Additionally, it has the proven ability to meet regulatory selenium limits (MSE 2001, Sonstegar 2008). Passive biological treatment systems have been tested extensively at the bench and pilot scale, but have yet to be implemented at full-scale.

Golder Associates Inc. (Golder) and Mesa State College (Mesa State) received U.S. Bureau of Reclamation Science and Technology funding in 2006 to conduct a bench-scale study on biochemical reactor (BCR) treatment of Se. The bench BCR test cells consistently reduced selenium concentrations in the influent water to values below the EPA maximum continuous concentration for protection of aquatic life (Pahler *et al.* 2007, Mesa State College and Golder 2007).

Based on the successful bench results, additional funding was secured to conduct a pilot with the following goals:

1. demonstrate that a passive BCR can accomplish high-efficiency Se removal at the pilot scale
2. determine the relationship between Se removal efficiency and detention time
3. assesses the influence of seasonal temperature fluctuations on treatment performance

4. determine design parameters for a full-scale system (*i.e.*, one with a footprint on the scale of up to a few acres).

Materials and Methods

Site Description

The study was conducted in a gravel pit operation in Grand Junction, Colorado. Groundwater seeps into a dewatering trench along three sides of the gravel pit perimeter and is pumped from this trench into an adjacent agricultural drain, which flows into the Colorado River approximately 45 m (50 yd) away. Selenium concentrations in the groundwater seepage that is discharged to the agricultural drain range from approximately 30 µg/L to 90 µg/L (Kerr 2006).

Materials and Design

The BCR consisted of an above-ground cell contained within an earthen berm (photo 1). The berm slope was 3H:1V from grade to an elevation of 6 ft above grade on both the inside and outside of the structure, with a three-foot wide level crest. The at-grade "floor" within the bermed area measured 7 ft by 7 ft. The overall footprint of the bermed area was 85 ft by 85 ft. The volume of the BCR interior was 4,380 cu ft.

Photo 1. Inside of pilot cell with berms prior to liner placement.

To provide hydraulic control, the inside of the cell was covered by a 6-ounce polypropylene geotextile; overlain by an impermeable 20-mil high-density cross-laminated polyethylene liner (photo 2). The liner and geotextile were Permalon in products from Reef Industries, Inc. of Houston, Texas. Above the liner, 2-inch diameter perforated PVC pipes were placed diagonally

from each corner of the level floor to the center of the cell, where they connect with a below-grade 2-inch diameter PVC pipe that drains treated water from the cell. The drain pipe was connected to a water-level control structure consisting of vertical 2-inch diameter PVC pipes bridged by a horizontal 4-inch diameter PVC pipe (photo 3). The horizontal pipe was initially positioned to establish a water level in the cell 5 feet above the cell floor. Water drained from the level control structure through a 2-inch diameter PVC pipe buried approximately 1-foot below grade to discharge into the dewatering trench approximately 90 ft downstream from intake point for the cell.

Photo 2. Geomembrane liner.

Photo 3. Effluent water level control structure.

The BCR cell was filled with organic substrate which serves as a long-term carbon source for microbial activity. The substrate was a mixture by as-received weight of 30% sawdust, 30% wood chips, 10% grass-alfalfa hay, 10% cow manure, and 20% limestone screener fines. All materials were obtained from local suppliers. Substrate mixing and placement are shown in photos 4 and 5. Perforated, two-inch PVC standpipes were placed in the BCR substrate during construction to serve as substrate sampling ports. Substrate samples were packed into panty hose baggies and inserted into the PVC standpipes. Each baggie was tied off with string that could be retrieved from the top of the standpipe to allow sample removal during pilot operation.

Photo 4. Substrate mixing.

Photo 5. Substrate placement completed. Vertical standpipes are substrate sample ports.

Water was pumped from the dewatering trench to the top of the cell. A pump was placed into a sump created by setting a perforated plastic garbage can on the bottom of the trench (photos 6 and 7). The pump was connected to PVC piping, which ran just below the water level into the side of the trench, then about 1 foot underground from the edge of the trench to the top of the berm. The water was delivered to the cell through a perforated PVC pipe running from the cell edge to the cell center (photo 8).

Photo 6. Influent pumps in pump container.

Photo 7. Influent pump container in the seepage trench with influent pipes.

Photo 8. Influent pipe (white) extends to middle of cell. Drainage pipe cleanout in foreground (white end cap).

In order to insulate the BCR, wood chips were added to the top of the substrate in the cell to create a mound about 2 ft high at the center sloping down to the top of the berm along the sides. A 10-mil high-density cross-laminated polyethylene liner (Permalon™, Reef Industries) was installed on top of the wood chips for insulation and to prevent precipitation from infiltrating into the cell (photo 9).

Photo 9. Influent hose on top of liner cover.

Operation

After filling the cell with water from the trench for the first time, this water was retained in the cell for three weeks to incubate the microorganisms. At the end of this period, the pump was turned on and the study commenced. The first sampling event occurred on 11 September 2008.

Routine operation of the BCR consisted of periodic sampling and analysis (described in the next section), measurement of flow through the cell, and flow rate adjustments. From 11 September 2008 to 27 March 2009, flow was measured as it exited the cell at the water level control structure. Outflow was diverted through a valve in the horizontal pipe (bridging the two vertical pipes) into a calibrated bucket. From 27 March 2009 until the end of data collection on 5 October 2009, flow was measured as it entered the cell using a calibrated bucket and stopwatch.

As the study progressed, Se concentrations in the trench dropped to unacceptably low concentrations (typically less than 20 µg/L). Investigation showed that a separate branch of the dewatering trench draining the west side of the pit had higher Se concentrations. From 11 May 2009 until the end of data collection, water was pumped from this trench through approximately 325 ft of 1.5-inch diameter PVC non-rigid tubing to discharge into a depression excavated in the wood chips at the center top of the cell. A ball valve was used to control the flow rate of the discharge.

Sampling and Analysis

Samples were collected samples and field parameters measured at roughly 10-day intervals (except when the water delivery system was not operating properly) for a total of 32 events. A list of field parameters is provided in Table 1. From 30 September 2008 to 8 June 2009, grab samples of influent were collected and field measurements were performed *in situ* on water in the trench. From 8 June 2009 to the end of the project, influent water was sampled and measured as it pooled and infiltrated at the top of the cell. Grab samples of effluent were collected from the water-level control structure; field parameters were measured here *in situ* as well. All samples were collected into bottles provided by ACZ Laboratories (Steamboat Springs, Colorado) and pre-filled with appropriate preservatives.

Table 1. Field Parameters and Instrumentation

Field Parameter	Instrument
pH	Hach Sension 1 pH meter with automatic temperature compensation; calibrated at beginning of each sampling event
Conductivity	Hach Sension 5 conductivity meter with automatic temperature compensation; calibrated at beginning of each sampling event
Dissolved oxygen	Hach HQ20 oxygen meter with luminescence probe; factory calibrated
Oxidation-reduction potential	Hach HQ20 with platinum combination electrode; calibration verified before each sampling event
Temperature	Each of the three meters listed above; factory calibrated

Samples collected at 10-day intervals were analyzed for total Se and dissolved Se. Samples were collected and analyzed for an extended sampling suite (Table 3) on ten occasions. Substrate samples were collected on four occasions (17 March 2009, 6 August 2009, 16 September 2009, 5 October 2009) and submitted for Toxicity Characteristic Leaching Procedure (TCLP) testing. ACZ Laboratories (Steamboat Springs, Colorado) performed all sample analysis.

Table 2. List of Analytes and Standard Methods

Analyte	Analytical Method
Selenium, total	200.2, 200.8 ICP-MS
Selenium, dissolved	200.2, 200.8 ICP-MS
Selenium (IV)	3114 B, AA-hydride
Selenium (IV) and (VI)	3114 B, AA-hydride
Selenium (VI)	Calculated
Selenium, dissolved	3114 B, AA-hydride
Selenium, organic	calculated
Calcium, total	200.7 ICP
Iron, total	200.7 ICP
Magnesium, total	200.7 ICP
Manganese, total	200.7 ICP
Biochemical oxygen demand (5 day)	5210 B
Total organic carbon	5310 B
Nitrate/nitrite as N	353.2
Nitrogen, total Kjeldahl	351.2
Phosphorous, total	365.1
Sulfate	375.4
Sulfide	376.2
TCLP selenium	1311 extraction 3010A digestion 6010B analysis

Samples to be analyzed for total Se were collected without filtration into laboratory-provided bottles containing enough concentrated HNO_3 acid to lower the sample pH to a value < 2 for preservation. These unfiltered samples are prepared for analysis by digestion, which involves refluxing with HNO_3 and HCl acids to dissolve any Se that may be present in the solid phase within the sample (*e.g.*, sorbed to particulate matter, or in a form that is insoluble under ambient conditions). Samples to be analyzed for dissolved Se were filtered at the time of collection and preserved in a similar manner. The normal laboratory procedure is to analyze the filtered sample directly for Se without digestion.

On some occasions, dissolved Se concentrations were greater than total Se concentrations. A strategy for mitigating the occurrence of dissolved Se exceeding total Se is to digest the filtered samples in the same manner as the unfiltered samples for analysis of total Se. One possible explanation for the success of this modified method is the presence of volatile Se species in effluent samples. The dissolved digestion method is less vigorous and removes a lesser amount

of the volatile Se; the total digestion is more vigorous and removes more volatile Se. Within the first month of sampling, three occurrences of the problem were observed: effluent samples on 11 September 2008 (total Se of 1.5 µg/L, dissolved Se of 14 µg/L); effluent samples on 23 September 2008 (total Se of 1.1 µg/L, dissolved Se of 4 µg/L); and influent samples on 9 October 2008 (total Se of 19.5 µg/L, dissolved Se of 26.6 µg/L). Re-analysis of the filtered samples, following digestion, yielded results that better met expectations. For 11 September 2008, the revised result was 1.1 µg/L (<1.5 µg/L); for 23 September 2008, the revised result was 1.2 µg/L (~1.1 µg/L); and for 9 October 2008, the revised result was 20.8 µg/L (~19.5 µg/L). We adopted the practice of digesting filtered samples for the remainder of the study. Consequently, the problem only occurred in an additional three samples (influent samples on 21 October 2008, 4 April 2009, and 5 May 2009) over 28 remaining sampling events.

BCR treatment results and discussion

Field Parameters

pH. Influent pH ranged from 7.0 to 8.1 s.u. and effluent pH ranged from 6.8 to 7.5 s.u.

Temperature. Influent field temperature ranged from 0.8 to 20.3 degrees Celsius (^{o}C) with an average of 13.6 ^{o}C (Fig. 1). Effluent field temperature ranged from 8.1 to 21.0^{o}C with an average of 14.9^{o}C. During winter months, the influent temperatures are significantly higher than ambient temperatures because the influent water is groundwater seepage. The relatively warm winter-time influent temperatures were likely beneficial in maintaining biological treatment activity.

Oxidation Reduction Potential (ORP).ORP values measured with an Ag/AgCl electrode were corrected to standard hydrogen electrode (SHE) values (Fig. 2). The influent ORP values averaged 261 millivolts (mv); effluent measurements were consistently reducing, with an average of -106 mv. Negative ORP values indicate anaerobic conditions conducive to Se reduction.

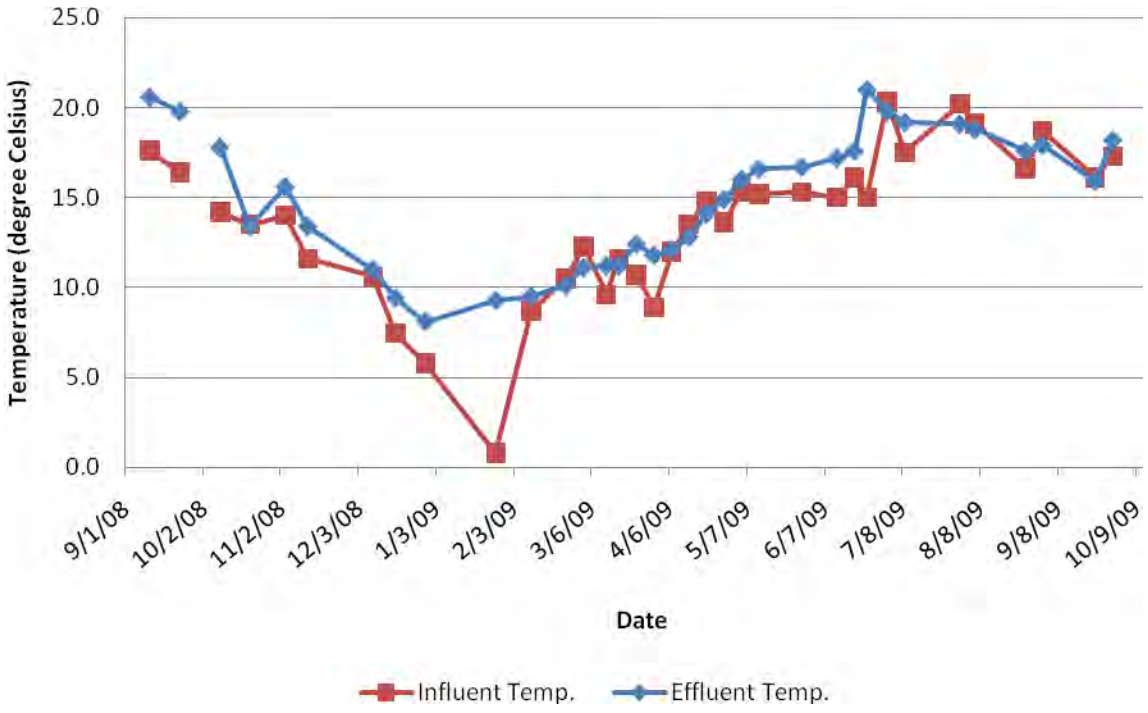

Figure 1. Pilot temperature values.

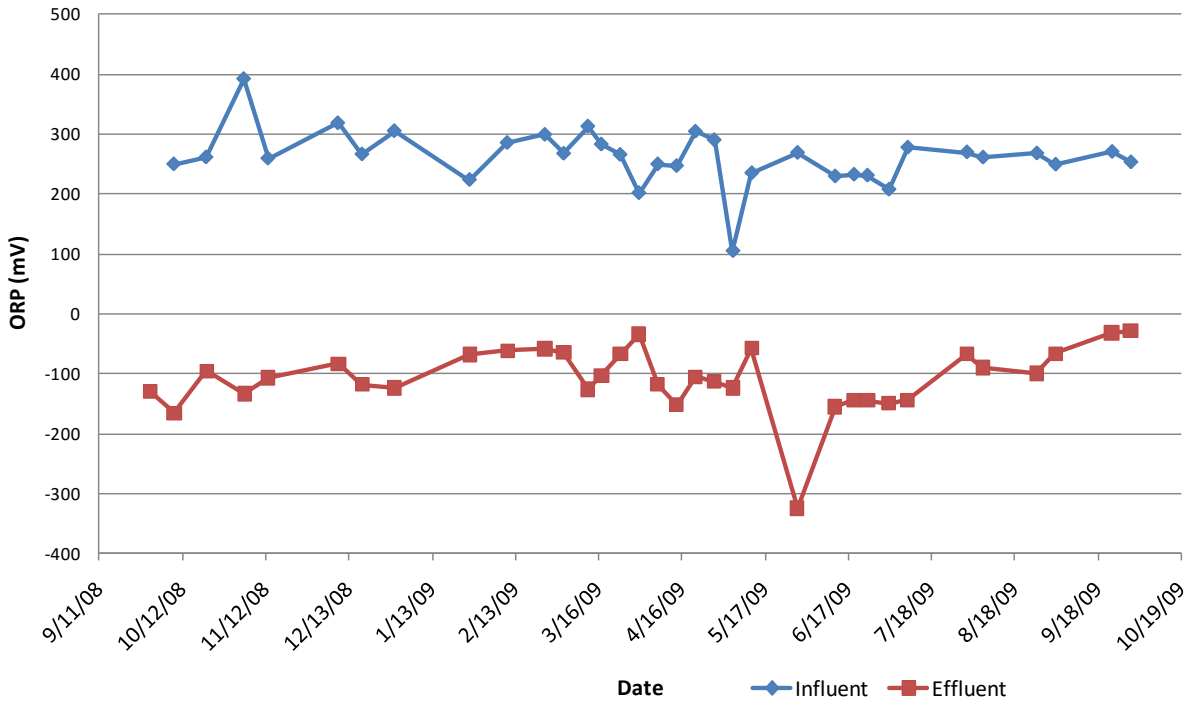

Figure 2. Pilot oxidation reduction potential values.

Dissolved Oxygen**.** Influent dissolved oxygen ranged from 1.2 to 13 mg/L with an average of 5.0 mg/L. BCR effluent dissolved oxygen ranged from 0.0 to 1.3 mg/L with an average of 0.3 mg/L. The consistently low effluent dissolved oxygen values are consistent with the negative ORP values and indicate that the BCR effluent was consistently anaerobic.

Flow and Hydraulic Retention Time. The pilot flow rate ranged from 1.7 gallons per minute (gpm) to 24 gpm (7 to 91 Liters per minute). Hydraulic retention time (HRT) was calculated based on flow rate and an estimated BCR pore space volume of 57 cubic yards. HRT ranged from 0.4 days (10 hours) to 6.1 days. Flow rate and HRT values, which are inversely related, are shown on Fig. 3. One goal of the pilot study was to optimize performance by varying Se loading rates. As such, the influent flow rate was continually increased during the last three months of the study in order to gauge Se treatment performance under different loading rates.

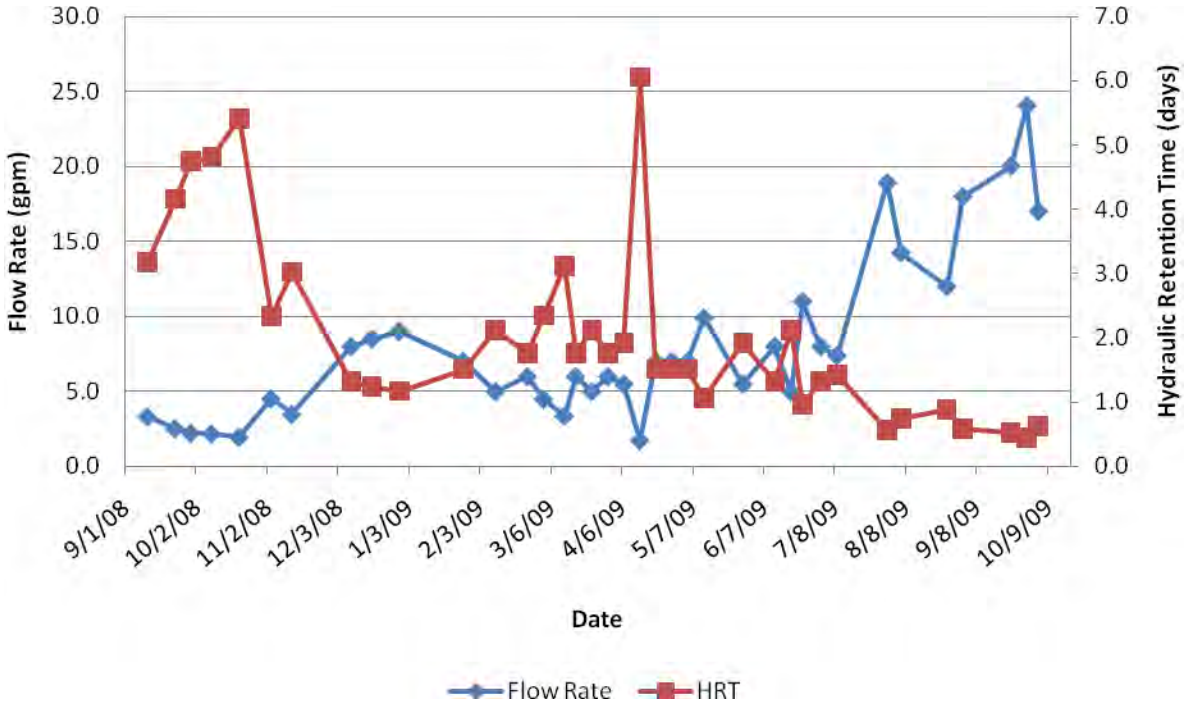

Figure 3. Pilot flow rate and hydraulic retention time (hrt).

Alternate Electron Acceptors

The rate of microbial reduction of Se can be affected by the presence of alternate electron acceptors such as nitrate and sulfate (Masschelyn and Patrick 1993). Nitrate is a more favorable electron acceptor than selenate and typically must be completely removed before significant Se

reduction can occur. Sulfate, on the other hand, is a less favorable electron acceptor than selenate. In theory, sulfate reduction should be minimized in a Se-reducing BCR to minimize carbon (*i.e.*, substrate) utilization and sulfide generation.

Nitrate/nitrite. Influent nitrate/nitrite values were variable, ranging from 0.4 to 17.1 mg/L as N with an average of 7.1 mg/L as N. Effluent nitrate/nitrite values ranged from 0.1 to 9.7 mg/L as N with an average of 3.1 mg/L as N. Nitrate/nitrite removal occurs via denitrification which reduces nitrate/nitrite to nitrogen gas. Percent nitrate/nitrite removal values are shown on Fig. 4, which provides a comparison of nitrate/nitrite, Se, and sulfate removal.

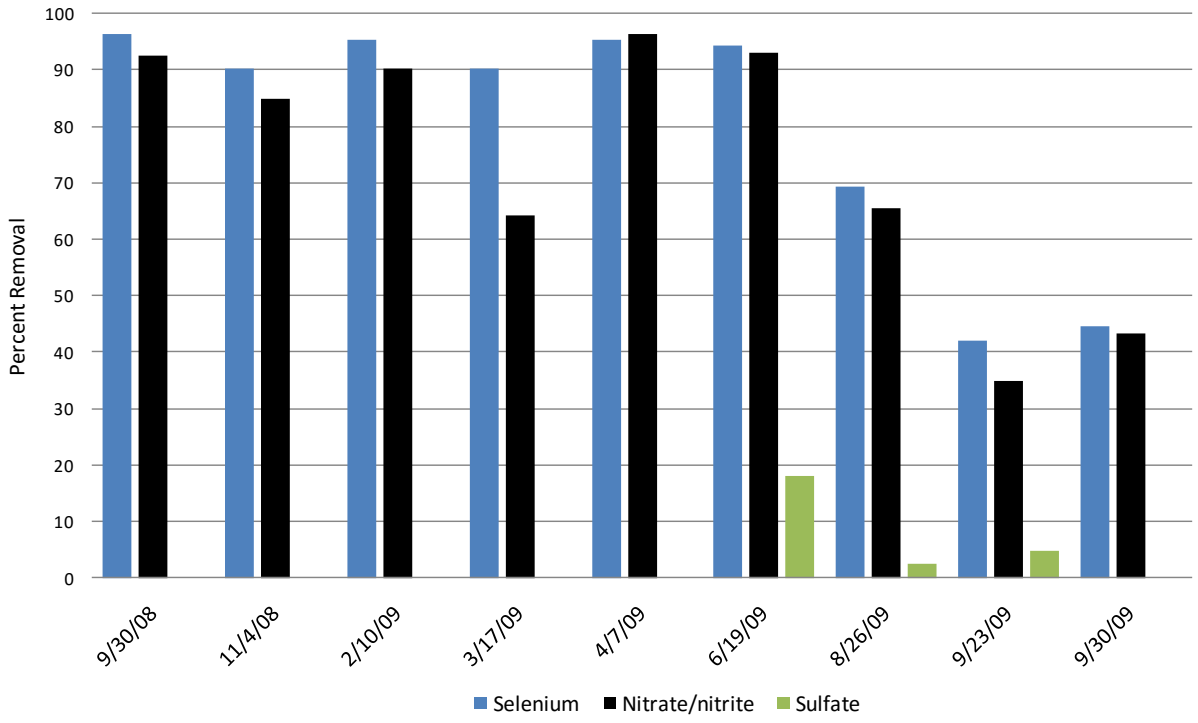

Figure 4. Selenium, Nitrate/Nitrite, and Sulfate Percent Removals.

Sulfate and sulfide. Influent sulfate ranged from 410 to 2700 mg/L with an average of 1495 mg/L. Initial effluent concentrations (30 September 2008 through 28 April 2009), analyzed by gravimetric method (SM 4500), were higher than influent concentrations which is unlikely given anaerobic conditions demonstrated by negative ORP values and the observed increase in sulfide concentrations in the BCR effluent. Influent sulfide concentrations were consistently below the laboratory detection limit of 0.01 mg/L; effluent sulfide concentrations averaged 18.7 mg/L. Beginning with samples collected on 19 June 2008, sulfate samples were analyzed by

two additional methods: turbidimetry (EPA 375.4) and ion chromatography (EPA 300.0). The turbidimetry and ion chromatography methods provided more consistent results indicating varying levels of sulfate removal.

Selenium

Total Selenium. Influent total Se concentrations varied considerably from 0.005 to 0.080 mg/L with an average of 0.034 mg/L (Fig. 5). Effluent concentrations ranged from 0.001 to 0.031 mg/L with an average of 0.005 mg/L. The percent removal for total Se ranged from 32 to 98% as shown on Fig. 5. Removal rates equal to or greater than 98% were achieved with a hydraulic retention times ranging from 12 hours to 2.4 days (Fig. 6). This large range in performance is discussed below in the Se loading section. A consistent Se removal rate greater than 90% was typically achieved with a HRT greater than 2 days. Total Se concentrations and percent removal values are provided in Table 4. The percent removal rate was consistently above 90% during winter months; Se removal was not adversely affected by cold winter-time temperatures.

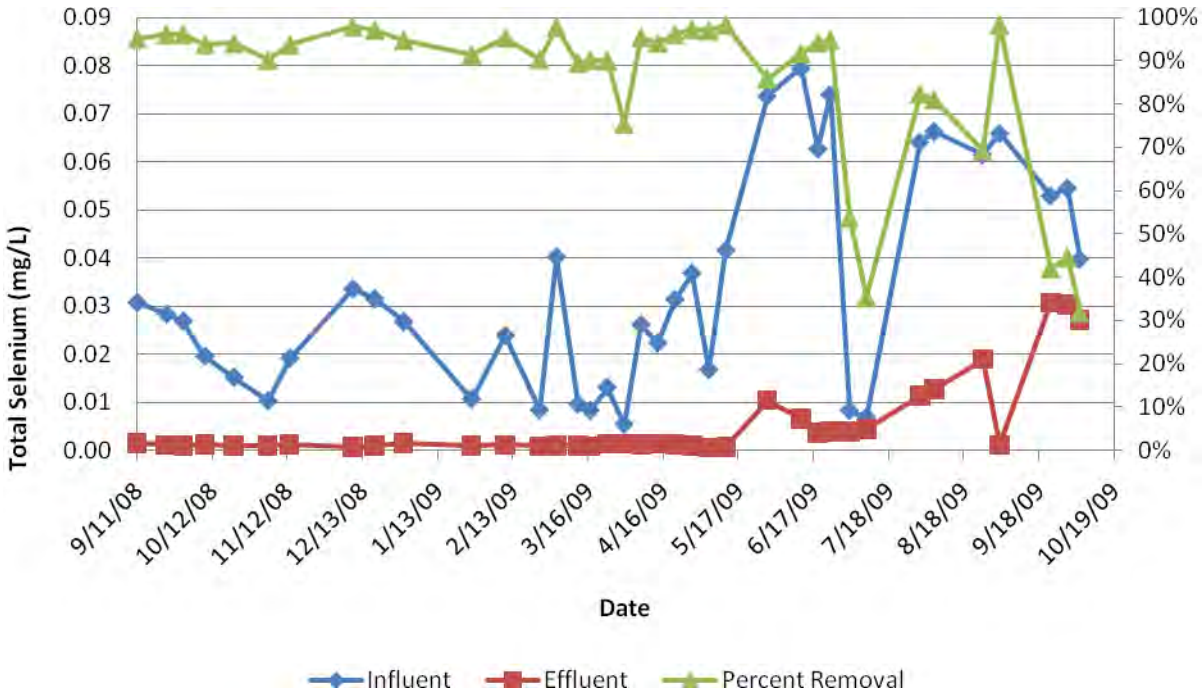

Figure 5. Total selenium concentrations and percent removal.

Table 4. Total Selenium Concentrations by ICP-MS Method

Date	Laboratory Detection Limit mg/L	Influent mg/L	Effluent mg/L	Removal Efficiency
9/11/2008	0.0005	0.0307	0.0015	95%
9/23/2008	0.0005	0.0283	0.0011	96%
9/30/2008	0.0001	0.0268	0.0010	96%
10/9/2008	0.0001	0.0195	0.0012	94%
10/21/2008	0.0001	0.0151	0.0009	94%
11/4/2008	0.0001	0.0102	0.0010	90%
11/13/2008	0.0001	0.0191	0.0012	94%
12/9/2008	0.0001	0.0335	0.0007	98%
12/18/2008	0.0001	0.0315	0.0009	97%
12/30/2008	0.0001	0.0267	0.0014	95%
1/27/2009	0.0001	0.0106	0.0009	92%
2/10/2009	0.0001	0.0238	0.0011	95%
2/24/2009	0.0001	0.0083	0.0008	90%
3/3/2009	0.0001	0.0402	0.0009	98%
3/12/2009	0.0001	0.0095	0.0010	89%
3/17/2009	0.0001	0.0082	0.0008	90%
3/24/2009	0.0001	0.0130	0.0013	90%
3/31/2009	0.0001	0.0053	0.0013	75%
4/7/2009	0.0001	0.0261	0.0012	95%
4/14/2009	0.0001	0.0223	0.0013	94%
4/21/2009	0.0001	0.0313	0.0012	96%
4/28/2009	0.0001	0.0368	0.0010	97%
5/5/2009	0.0001	0.0167	0.0005	97%
5/12/2009	0.0001	0.0416	0.0007	98%
5/29/2009	0.0001	0.0737	0.0104	86%
6/12/2009	0.0001	0.0795	0.0066	92%
6/19/2009	0.0001	0.0627	0.0036	94%
6/24/2009	0.0001	0.0740	0.0038	95%
7/2/2009	0.0001	0.0082	0.0038	54%
7/9/2009	0.0001	0.0068	0.0044	35%
7/31/2009	0.0001	0.0641	0.0113	82%
8/6/2009	0.0001	0.0663	0.0126	81%
8/26/2009	0.0001	0.0615	0.0189	69%
9/2/2009	0.0001	0.0659	0.0011	98%
9/23/2009	0.0001	0.0529	0.0307	42%
9/30/2009	0.0001	0.0545	0.0302	45%
10/5/2009	0.0001	0.0397	0.0271	32%

Dissolved Selenium. Influent dissolved Se concentrations ranged from 0.005 to 0.077 mg/L with an average of 0.036 mg/L (Fig. 6). The similarity between dissolved and total concentrations indicates that nearly all influent Se was present as dissolved. Effluent concentrations ranged from 0.0004 to 0.030 mg/L with an average of 0.006 mg/L. The percent removal for dissolved Se ranged from 36.7 to 98.7% as shown on Fig. 6. Dissolved Se concentrations and percent removal values are provided in Table 5.

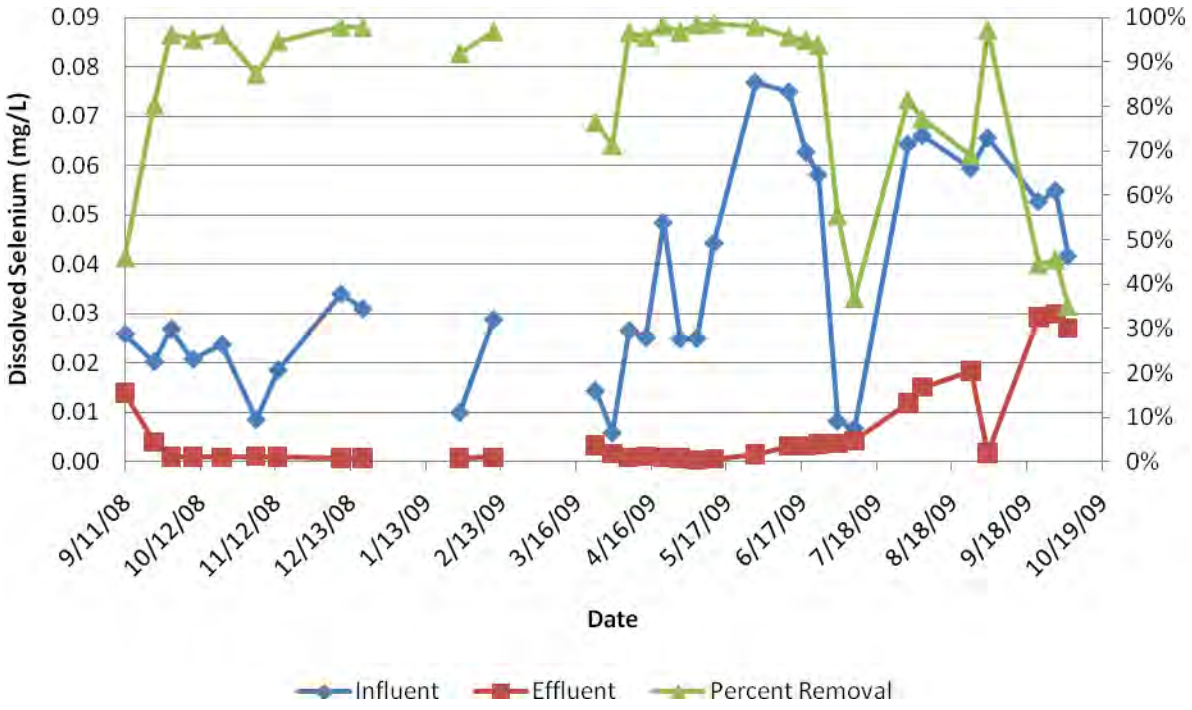

Figure 6. Dissolved selenium concentrations and percent removal.

Selenium Speciation. Influent and effluent speciation results are provided on Tables 6 and 7, respectively. The dissolved Se results by method SM3114B (Tables 6 and 7) differ somewhat from the dissolved Se results by ICP-MS (Table 5). Selenate was the predominant influent species with consistently low concentrations of selenite. The influent selenide concentrations were elevated and also varied considerably between sampling events. Although the data are limited, the BCR process does not appear to increase the more toxic concentrations of reduced Se species (*i.e.*, selenite, selenide); effluent selenite and selenide concentrations were lower than influent concentrations and the majority of effluent selenide concentrations were below the detection limit. Furthermore, the effluent concentrations show consistent selenide removal

Table 5. Dissolved Selenium Concentrations by ICP-MS Method

Date	Laboratory Detection Limit	Influent Dissolved Selenium Concentration (mg/L)	Effluent Dissolved Selenium Concentration (mg/L)	Removal Efficiency
9/11/2008	0.002	0.0259	0.014	45.9%
9/23/2008	0.001	0.0203	0.004	80.3%
9/30/2008	0.002	0.0269	*<0.002*	96.3%
10/9/2008	0.002	0.0208	*<0.002*	95.2%
10/21/2008	0.0001	0.0238	0.0009	96.2%
11/4/2008	0.0001	0.0086	0.0011	87.2%
11/13/2008	0.0001	0.0186	0.0010	94.6%
12/9/2008	0.0001	0.0340	0.0007	97.9%
12/18/2008	0.0001	0.0310	0.0007	97.7%
12/30/2008	NS	NS	NS	NS
1/27/2009	0.0001	0.0100	0.0008	92.0%
2/10/2009	0.0001	0.0288	0.0009	96.9%
2/24/2009	NS	NS	NS	NS
3/3/2009	NS	NS	NS	NS
3/12/2009	NS	NS	NS	NS
3/17/2009	NS	NS	NS	NS
3/24/2009	0.0001	0.0144	0.0034	76.4%
3/31/2009	0.0001	0.0059	0.0017	71.2%
4/7/2009	0.0001	0.0266	0.0009	96.6%
4/14/2009	0.0001	0.0252	0.0011	95.6%
4/21/2009	0.0001	0.0484	0.0009	98.1%
4/28/2009	0.0001	0.0249	0.0008	96.8%
5/5/2009	0.0001	0.025	0.0004	98.4%
5/12/2009	0.0001	0.0443	0.0006	98.6%
5/29/2009	0.0001	0.0768	0.0015	98.0%
6/12/2009	0.0001	0.0749	0.0032	95.7%
6/19/2009	0.0001	0.0627	0.0032	94.9%
6/24/2009	0.0001	0.0581	0.0036	93.8%
7/2/2009	0.0001	0.0083	0.0037	55.4%
7/9/2009	0.0001	0.0068	0.0043	36.8%
7/31/2009	0.0001	0.0643	0.0119	81.5%
8/6/2009	0.0001	0.0661	0.0151	77.2%
8/26/2009	0.0001	0.0594	0.0184	69.0%
9/2/2009	0.0001	0.0656	0.0018	97.3%
9/23/2009	0.0001	0.0527	0.0293	44.4%
9/30/2009	0.0001	0.0549	0.0299	45.5%
10/5/2009	0.0001	0.0417	0.0271	35.0%
10/5/2009	0.0001	0.0417	0.0271	35.0%

Note:

NS - Dissolved Se was not sampled.

Values below the detection limit are shown as preceded with a less than symbol (<). Percent removal calculations for these values below the detection limit were made with a value of one-half the detection limit.

within the BCR when appreciable levels of influent selenide are present (*i.e.*, 7 April 2009, 28 April 2009, 19 June 2009, 26 August 2009). One potential selenide removal mechanism is precipitation of metal selenides such as iron selenide.

Table 6. Influent Selenium Speciation Data based on SM3114B, AA-Hydride Method.

Date	Dissolved Selenium, (µg/L)	Selenate (+VI), (µg/L)	Selenate as percent of dissolved selenium	Selenite (+IV), (µg/L)	Selenite as percent of dissolved selenium	Selenide (-II), (µg/L)	Selenide as percent of dissolved selenium	Sum of selenium species as percent of dissolved selenium
9/30/2008	19.0	8.0	42%	5	26%	6.0	32%	100%
11/4/2008	8	4	50%	2	25%	2.0	25%	100%
2/10/2009	14	12	86%	2	14%	<1	NA	100%
3/17/2009	4	<1	NA	4	100%	<1	NA	100%
4/7/2009	24	7	29%	6	25%	11.0	46%	100%
4/28/2009	21	10	48%	4	19%	7.0	33%	100%
6/19/2009	51	34	67%	3	6%	14.0	27%	100%
8/26/2009	46	27	59%	3	7%	16.0	35%	100%
9/23/2009	41	36	88%	3	7%	2.0	5%	100%
9/30/2009	44	39	89%	3	7%	2.0	5%	100%

Table 7. Effluent Selenium Speciation Data based on SM3114B, AA-Hydride Method

Date	Dissolved Selenium (µg/L)	Selenate (+VI) (µg/L)	Selenate as percent of dissolved selenium	Selenite (+IV) (µg/L)	Selenite as percent of dissolved selenium	Selenide (-II) (µg/L)	Selenide as percent of dissolved selenium	Sum of selenium species as percent of dissolved selenium[1]
9/30/2008	<1	<1	NA	3	NA	<1	NA	NA
11/4/2008	<1	<1	NA	1	NA	<1	NA	NA
2/10/2009	<1	2	NA	<1	NA	<1	NA	NA
3/17/2009	<1	<1	NA	2	NA	<1	NA	NA
4/7/2009	1	<1	NA	3	300%	<1	NA	300%
4/28/2009	1	1	100%	1	100%	<1	NA	200%
6/19/2009	3	<1	NA	3	100%	1.0	33%	133%
8/26/2009	15	9	60%	2	13%	4.0	27%	100%
9/23/2009	23	20	87%	2	9%	1.0	4%	100%
9/30/2009	25	22	NA	1	4%	2.0	8%	100%

Note:

1 - The Se species as a percent of the dissolved Se are greater than 100% when dissolved Se concentrations are very low (*i.e.*, < 5 µg/L) and the analytical precision is insufficient to a detect the various Se species.

Selenium Mass Removal. Selenium mass removal varied from 0.097 grams per day (g/day) to 6.4 g/d and the cumulative Se removal (Fig. 7) over the 13-month operating period was about 600 grams.

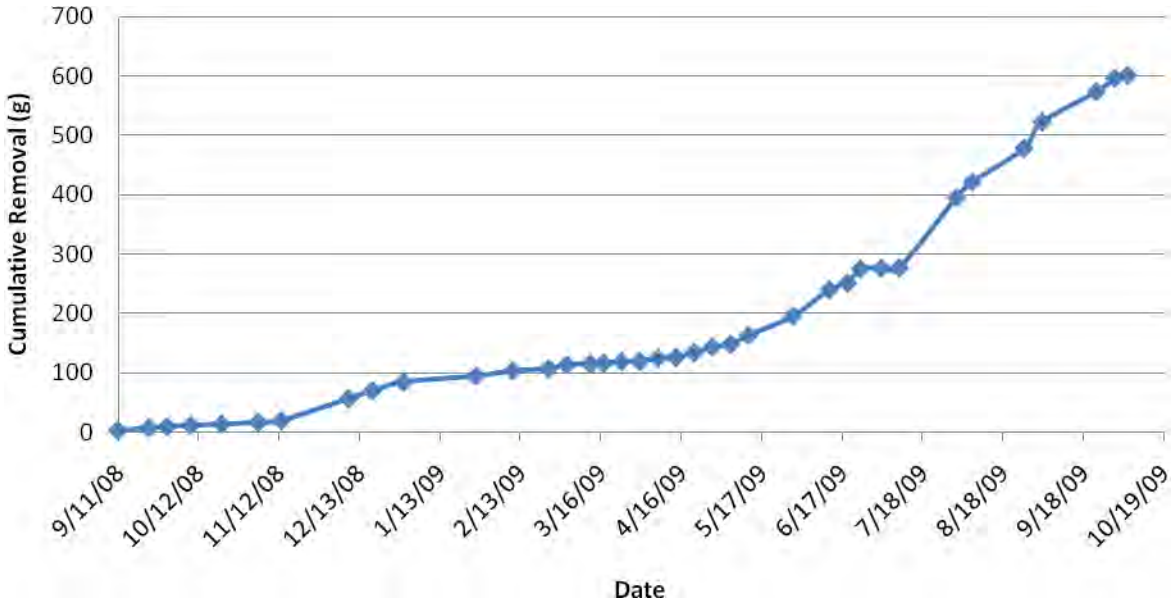

Figure 7. Cumulative total selenium removal.

Selenium Loading. Selenium loading and removal (milligrams per day per cubic meter of substrate) is shown on Fig. 8. The loading graph values are calculated based on influent and effluent Se concentrations and flow rate only. In general, the majority of data points follow a linear trend with a slight decrease in slope at higher loading rates. The maximum removal rate was 73 milligrams per day per cubic meter of BCR media (mg/d/m^3) and the average rate was 16 mg/d/m^3. The three data points that do not fit the trend are circled on the figure. These three points correspond to high influent nitrate concentrations which likely partially explain the decrease in treatment performance. The relative scatter of the loading graph values is likely due to other factors which can affect the removal rate, including temperature and presence of alternate electron acceptors (*i.e.*, nitrate), which are not included in the calculated values. A nitrate/nitrite loading graph was also developed and is shown in Fig. 9. Although nitrate/nitrite data are somewhat limited, the highest calculated nitrate removal rate is about 10 g/d/m^3. The design of future BCR systems should consider both Se and nitrate/nitrite loading criteria.

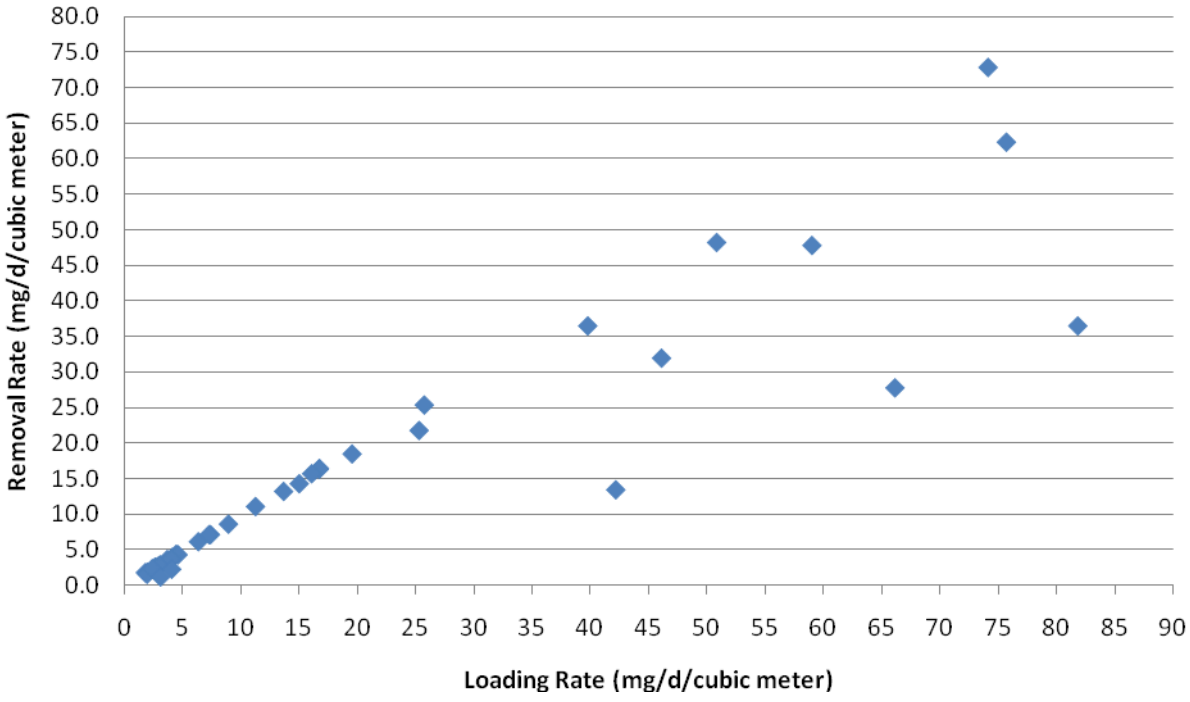

Figure 8. Selenium loading.

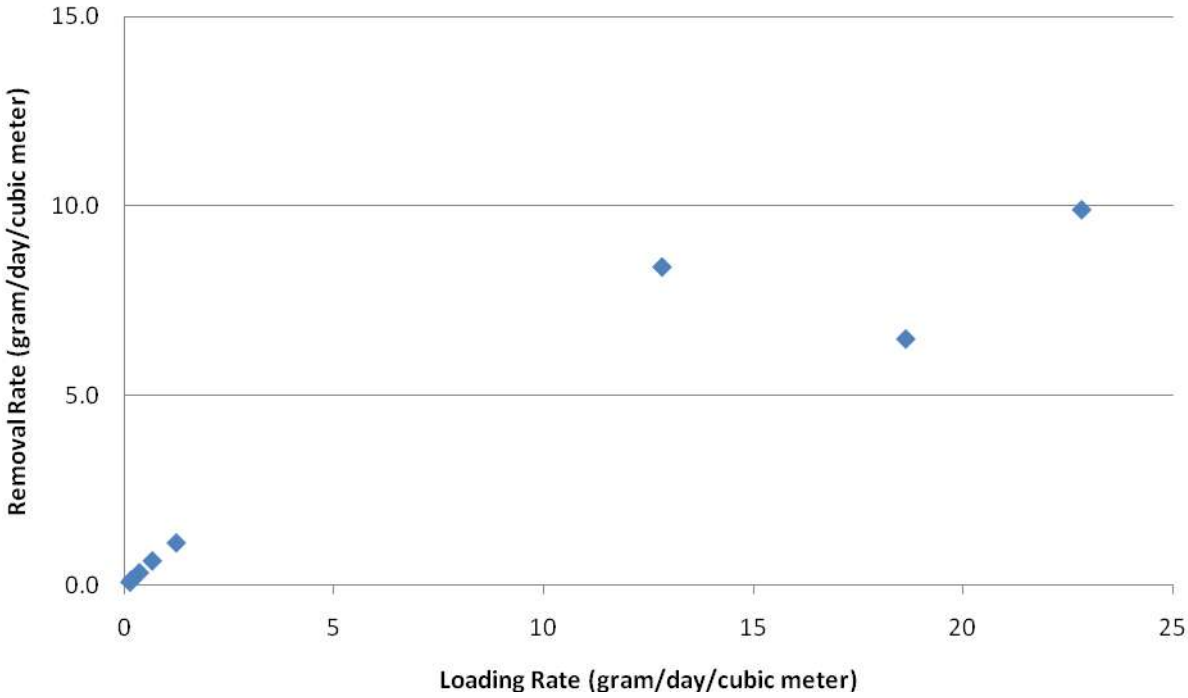

Figure 9. Nitrate + Nitrite Loading

Residual Nutrients. Initial effluent concentrations (9 September 2008) of total organic carbon (TOC), total kjedhal nitrogen (TKN), and phosphorus were 437 mg/L, 11.1 mg/L as N, and 6.4 mg/L, respectively; after thirteen months of operation (30 September 2009), effluent concentrations decreased to 13 mg/L, 1.6 mg/L as N, and 0.05 mg/L, respectively. This large decrease is likely due to flushing of easily degradable organic matter (i.e., manure) and nutrients from the cell.

Fecal coliform. Fecal coliform bacteria are an indicator of fecal contamination. Since animal manure was used as a BCR substrate ingredient, two BCR effluent samples (30 September 2009, 5 October 2009) were collected near the end of the study and analyzed for fecal coliform concentrations. During both sampling events, the effluent fecal coliforms were less than influent concentrations; the effluent concentration on 5 October 2009 was 0 colony forming units per 100 mL. Similar to the concentration trends of the residual nutrients discussed above, the fecal coliform concentrations were likely elevated during startup and decreased throughout the pilot test.

Toxicity Characteristic Leaching Procedure (TCLP) Testing

TCLP testing was performed in order to evaluate disposal options for BCR substrate. All substrate TCLP samples were below the method detection limit for Se. The method detection limit (0.1 mg/L) is well below the hazardous waste regulatory limit (1.0 mg/l) for TCLP Se concentrations (40 CFR 261, Appendix II, 1993 ed., as amended by 58 FR 46040, August 31, 1993). The selenium-negative TCLP results occurred after only 1 year of operation which does not provide a conclusive indication of TCLP results from a system which operates for the lifetime of the carbon substrate (approx. 10 to 20 years). However, given the trace concentrations of Se in the influent water and the buffering capacity of the BCR limestone content, it is likely that a BCR could operate for multiple years prior to exceeding the TCLP Se limit.

Treatment Costs

The capital costs for the pilot cell include materials (*e.g.*, geomembrane liner, piping, pumps, wood chips, and hay), engineering, and construction labor. A significant portion of the construction effort included heavy equipment operation for berm construction and substrate mixing and placement and was provided in-kind by United Sand and Gravel Operations. This portion of the construction cost has been estimated and is included in the capital costs. The total capital cost estimate for the pilot was $39,200 and can roughly be divided into $15,000 for engineering, $8,000 for materials, and $15,700 for labor. Assuming a flow rate of 10 gpm and an operating life of 15 years, the capital cost is equivalent to $0.50 per 1,000 gallons of water treated. Assuming 600 grams of Se removal per year, the pilot BCR would remove 9 kilograms of Se over a 15 year operating life which equates to a mass removal cost of $4,400 per kilogram of Se. The operating costs consisted of electricity for the influent pump, laboratory analysis of water quality samples, and the labor required maintaining flow to the cell. At sites where BCR systems do not require any pumping and operate via gravity flow, operational costs are minimal. The disadvantages of a BCR are the large area required and uncertainty regarding long-term performance.

Conclusions

The 13-month pilot BCR study test was successful in removing Se on a consistent year-round basis. The BCR achieved a maximum total Se removal rate of 98% and a minimum effluent

concentration of 0.0005 mg/L (0.5 µg/L). The maximum percent removal rate of 98% was achieved with a range of hydraulic retention times of 12 hours to 2.4 days. The variability in Se removal as a function of HRT is likely due to varying concentrations of Se and nitrate and temperature. In general, a HRT of 2 days is recommended to consistently achieve removal rates greater than 90% for the site. A HRT of at least two days is recommended for future treatment efforts at the site. Other sites would require testing to determine an appropriate HRT; a reasonable estimate of HRT can be made based on dissolved oxygen, nitrate, and Se concentrations. In terms of Se mass removal, the highest mass removal rate achieved by the BCR was 73 mg/day/m3 and the cumulative mass of total Se removal was 600 grams.

In order for significant Se removal to occur, nitrate/nitrite must first be removed. The highest measured nitrate/nitrite removal rate was approximately 10 $g/d/m^3$. The treatment or nitrate is an ancillary benefit to biological treatment of Se. The BCR treatment process was effective throughout the cold winter months during which total Se removal rates remained greater than 90%.

Based on the TCLP results, the BCR substrate is not toxic with respect to Se and passive treatment residues can be disposed of in a non-hazardous waste landfill. The BCR effluent contains residual nutrients and bacteria that must be considered in the design of a full-scale treatment system. These parameters can be removed in a polishing process such as an aerobic lagoon or wetland. The total capital cost for the pilot BCR was $39,200 or $0.50 per 1,000 gallons treated. The operations and maintenance costs for a passive BCR system are minimal. Based on the successful operation of the pilot, including high rates of Se removal and consistent year-round operation, the BCR technology appears to be an effective, low-cost Se treatment option. The disadvantages of a BCR are the large area required and uncertainty regarding long-term performance.

Acknowledgments

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Benefits of using liquid carbon sources for passive treatment systems

André Sobolewski

AMEC, 111 Dunsmuir St, Vancouver, BC, V6B 5W3

Abstract Using liquid carbon sources provides tangible benefits for bioreactors treating mine water. Microbial activity can be maintained at <4°C, which allows bioreactors to function in cold climates, as shown for bioreactors at the Tulsequah Chief and Smoky River Coal mines. Such carbon sources do not restrict the choice of matrices supporting bacterial growth. This benefit is illustrated in another bioreactor designed to avoid plugging problems associated with decomposing organic matter. The latter is widely perceived as a cheap and sustained carbon source for microbial growth. However, liquid carbon sources overcome its limitations imposed by temperature and susceptibility to plugging.

Key Words bioreactors, liquid carbon, temperature, plugging

Introduction

Passive treatment systems are often idealized as "walk-away" solutions: systems that treat water without an operator and little to no maintenance. In part, this ideal draws after natural wetlands that were shown to detoxify mine drainage, at times for decades (Sobolewski, 1997). The promise of a walk-away solution is especially appealing at closed mines in remote locations where access is difficult and power is typically unavailable.

One type of passive treatment system is the bioreactor, which relies on microbial processes to detoxify mine water. Bioreactor design is strongly guided by the walk-away ideal, typically using a compost/manure mix that slowly decomposes to supports the requisite microbial processes. The key weaknesses of this design are a propensity to become plugged and reduced function at low temperatures. The most successful bioreactors have been operated in warm climates (e.g., Cellan et al., 1997) or have resolved the problems of residual management (e.g., Kepler and McLeary, 1997).

One approach to circumvent these limitations is to supply liquid carbon, such as alcohol, rather than rely on organic matter decomposition. These bioreactors are termed "enhanced" passive systems, though the distinction is academic. This approach has been strongly promoted by Tsukamoto and Miller (e.g., 2002), but it has been used by others in the past twenty years (e.g., Reinsel and Plumb, 1999). Despite its advantages, use of liquid carbon for bioreactors is not prevalent, perhaps because of the perception that such bioreactors cannot become walk-away systems.

Low temperature treatment

Use of a liquid carbon source proved crucial for the successful operation of a bioreactor at the Tulsequah Chief Mine, in Northern BC, Canada. This polymetallic (Cu, Pb/Zn) underground mine was abandoned in the late 1980's and discharged ARD into the Tulsequah River. The highly acidic water (Table 1) flowed from the lowest portal at 5—7 L/sec. Environment Canada required the new owner to treat water during mine exploration, an understandable but onerous demand for the cash-strapped junior.

Treatment options were severely constrained by limitations imposed by the site. The two main portals discharged on the side of a steep, remote mountain, with little flat land available. Access was by helicopter, power was provided by a small diesel generator and equipment was very limited. There was no room for a conventional lime treatment, which, in any event, would have been prohibitively expensive. A bioreactor was eventually developed inside the lowest adit: it combined limestone to neutralize acidity and remove aluminum and iron, and sulfate-reducing bacteria (SRB) to remove other metals. Its design was intended to provide treatment during exploration and until mine start up, when better financing and cash flow would allow the development of a more robust solution.

A 66m^3 pilot-scale bioreactor was first constructed and tested inside the adit. Unfortunately, wood mulch decomposition was too slow at 6—8°C (ambient temperature) to keep the bioreactor anaerobic, with dissolved oxygen (DO) concentrations remaining at 8—9 mg/L. Ethylene glycol (EG) was supplied to mine water, which quickly decreased dissolved oxygen concentrations to

Table 1 Metal concentrations in drainage and discharge from Tulsequah Chief bioreactors

Parameter	ARD	Pilot-scale bioreactor (after EG addition)	Full-scale bioreactor (Limestone cells only)	Full-scale bioreactor (Limestone + SRB)
pH	3.0-3.7	6.0-6.7	4.0-6.0	6.1-6.7
Al (mg/L)	10-30	0.1-1.0	0.9-7.7	0.06-2.5
Cd (mg/L)	0.22-0.47	<0.050	0.22-0.38	0.07-0.30
Cu (mg/L)	16-30	0.1-1.0	9-13	2-7
Fe (mg/L)	20-120	0.1-2.0	0.03-0.7	0.04-4.0
Zn (mg/L)	56-120	30-50	56-118	42-77

near zero. SRB started being active soon thereafter, as evident by detection of hydrogen sulfide and the concomitant removal of cadmium and copper (Table 1).

Based on this trial, a 200m long, 5 cell bioreactor was constructed inside the lowest mine adit. The first three cells received a wood chip/limestone mix to neutralize pH and remove aluminum and iron. The last two cells also received sulfur prills to promote SRB activity. Ethylene glycol was dripped into Cell 1 (to remove oxygen) and Cell 4 (to support SRB activity).

The front limestone cells gradually failed (over four years) from accumulated sludge, yet consistently removed aluminum and iron, while the SRB cell removed cadmium, copper, and some zinc (Table 1). Most remarkable, the bioreactor operated without human intervention from October to April, when the site was shut down and inaccessible. Despite the (expected) cell failures, the bioreactor provided low cost (≈ $50,000/yr for EG) treatment and enabled the company to successfully complete its exploration program.

Another bioreactor that relied on EG was constructed at the Smoky River Coal mine, which produces selenium contaminated drainage. Again, the lack of power and cost constraints dictated the choice of a bioreactor for passive treatment, but the design challenge was to provide year-round treatment.

A trial was conducted in 2008, using two parallel 5 m^3 pilot-scale bioreactors (5 m long x 1 m^2) that received a mix of crushed gravel, wood chip/manure, lime and bone meal. The objective of the trial was to determine treatment performance during summer and winter operation and to derive design parameters for a full-scale bioreactor. The bioreactors were inoculated with selenium-reducing bacteria and received EG. Although they were constructed at the surface, it was intended that the full-scale bioreactor would be constructed below the frost line so that it could operate year-round.

The bioreactors proved very effective in removing selenium (Figure 1). They received drainage with selenium at 80—90 µg/L and consistently discharged it at 1—5 µg/L. Treatment performance was unaffected by temperature, even when it decreased to 2°C.

Unfortunately, Alberta Environment terminated the trials in 2008 and did not proceed to construction of the full-scale treatment system.

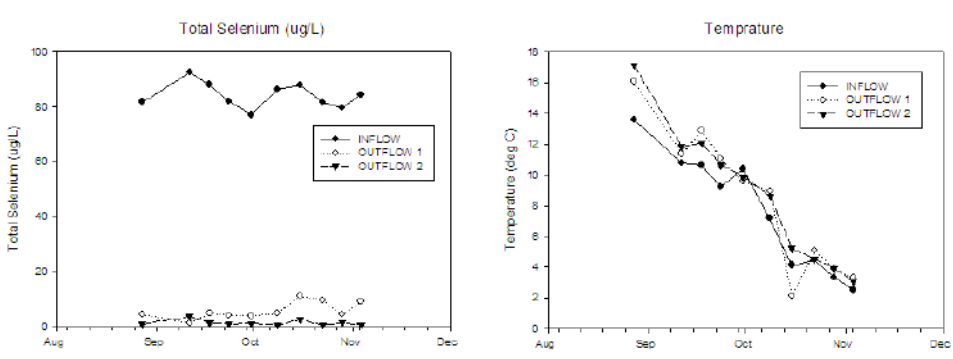

Figure 1 Selenium removal as a function of temperature at Smoky River Coal

Design to prevent plugging

It was not surprising that the bioreactor at Tulsequah Chief would become plugged because the design did not allow for effective removal of aluminum and iron. However, the design allowed for continual operation in spite of accumulating metal sludge, which was adequate for a temporary treatment system. A more porous medium might have prevented metal accumulation, but it may not have provided enough reactive surface area for proper treatment. This trade-off between high reactive surface and high porosity is at the crux of bioreactor design.

The US EPA sponsored a number of studies to develop designs that overcome the plugging problems associated with decomposing organic matter. Different SRB-based bioreactors were tested at the Calliope Mine by holding the organic substrate and cobble in a cellular containment system (Terracell™) to prevent channeling and uneven settling (MSE, 2002). Despite careful construction, substrate compaction and plugging problems developed in some of the bioreactors. Subsequent projects helped to improve design (Bless et al., 2008).

Trading off permeability with flow rates is a problem inherent to the use of decomposing organic matter. Unfortunately, this was not possible in the case of an operating underground lead/zinc (confidential) mine. The neutral underground drainage was contaminated with low concentrations of blasting residues (largely nitrate) and zinc, but proximity to a fish-bearing lake prevented its direct discharge. The restricted space underground and high volumes of drainage meant that high permeability and high reactive surface area were both necessary.

The solution involved designing a high-rate bioreactor that could be shoehorned into a sump at the bottom of the mine. This bioreactor used a matrix comprising elemental sulfur, crushed limestone and Raschig rings (ceramic saddles with high surface area). Its design involved a two-part treatment of mine water: a front section with sulfur-based denitrifiers to remove oxygen and nitrate, and to produce sulfate, and a back section seeded with SRB that received ethanol and removed zinc.

This bioreactor design was evaluated using two 2.5 m long columns inside the mine. The columns were fed mine water and operated with decreasing residence times.

Although dissolved oxygen concentrations were not measured, measurements of oxidation-reduction potential (ORP) indicated that oxygen was entirely removed in the first column (Table 2). Similarly, nitrate was rapidly removed in the first column, even though the retention time in that column was (at its lowest) 1.5 hours. Nitrate removal was clearly effected by sulfur-based denitrification, because sulfate concentrations in the column discharge increased by an average of 100 mg/L, very close to theoretically-predicted concentrations based on stoichiometry.

Inflow into the SRB column was anaerobic, but it received ethanol to support SRB activity. Despite increasing influent zinc concentrations and decreasing overall retention time, zinc removal in the second column produced a discharge with average concentrations of 0.029 mg/L (Figure 2). This consistency was maintained throughout the entire four month trial, indicating that the bioreactor was robust. Its fast performance can be attributed to the high surface area of the matrix used in the columns, although warm underground temperatures (21—22°C) helped. Unfortunately, the client opted for a different treatment system, so it was not possible to determine the performance of a full-scale system.

Conclusions

Arguably, bioreactor designs that use liquid carbon provide improved performance and reliability. As the Tulsequah Chief bioreactor demonstrates, even such "enhanced" passive treatment systems can be operated unattended for prolonged periods at remote mine sites. Moreover, the low temperatures at which they can operate, as shown at Tulsequah and with the Smoky River Coal pilot-scale bioreactor, indicate that they can provide year-round treatment in cold climates. This

Table 2 *Changes in key parameters during column treatment of mine water*

Parameter	Inlet	Outlet first column	Outlet second column
pH	6.6	6.3	6.6
ORP (mV)	124	-5.9	-110
Nitrate (mg/L)	17.4	0.68	<0.05

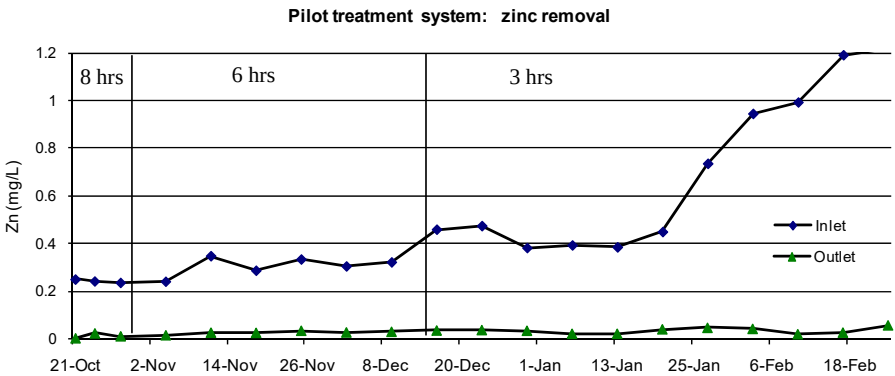

Figure 2 *Dissolved zinc concentrations in a bioreactor operated at different retention times and zinc loadings*

is difficult for bioreactors relying on organic matter decomposition. Conceivably, supplying ethanol or ethylene glycol to such bioreactors or constructed wetlands could sustain treatment during the winter in cold climates.

The reagent costs for operating these bioreactors were modest, rendering moot the argument that decomposing organic matter is preferable because it is a cheaper source of organic carbon. Taking away this argument, the choice of carbon source should be dictated by availability, year-round performance and reliability in treatment. In many circumstances, this gives the advantage to systems using liquid carbon sources.

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IN-SITU IMMOBILIZATION OF SELENIUM WITHIN THE SATURATED ZONES OF BACKFILLED PITS AT COAL-MINE OPERATIONS

Mario Bianchin, Ph.D.[1]
Alan Martin, M.Sc., [1]
Jack Adams, Ph.D.[3]

[1]Lorax Environmental Services Ltd., 2289 Burrard Street, Vancouver, B.C. V6J 3H9
[2]Inotec Environmental Innovations, 85 S Ft. Douglas Blvd. Salt Lake City, UT 84112

ABSTRACT

The removal of selenium (Se) from water using passive technologies at mine sites is challenging as a result of associated high flow rates. However, the chemical and hydraulic conditions of backfilled pits offer a potential means to bioremediate large volumes of water passively. Specifically, the oxidation demand associated carbonaceous waste materials in conjunction with long water residence times within backfilled pits can produce the suboxic conditions required to support the removal of Se from solution through a suite of microbially-mediated processes. Evidence for Se removal is provided from a study of a backfilled pit at a coal mine in Northern Canada. Redox conditions within the saturated backfill are mildly-suboxic, as inferred from low levels of oxygen, nitrate and the presence of dissolved Mn and Fe. Results show pronounced removal of dissolved Se within the saturated backfill, with concentrations decreasing from 40 µg/L (upgradient of saturated zone) to <1 µg/L within the saturated waste rock zone. The reduction in Se concentration was accompanied by a shift in Se speciation from dominantly selenate (Se^{VI}) to selenite (Se^{IV}) along the flow path. Nitrate-N values are also reduced to values below detection (<0.05 mg/L) in the saturated backfill. The data suggest that this relatively small backfilled pit achieves a Se removal rate ranging from 0.03 to 0.3 mg/day/$m^3_{wasterock}$ with a hydraulic residence time of 0.3 to 3 years. Collectively, the data imply that the saturated backfilled zones are serving as an effective site for the bioremediation of Se under mildly suboxic conditions.

KEY WORDS

Selenium removal rate, bioremediation, passive treatment

INTRODUCTION

The bioremediation of selenium (Se) from mine waters using passive systems (e.g., subsurface-flow biological reactors and permeable reactive barriers) has received considerable attention owing to the prevalence of elevated Se concentrations in coal-mine drainages (CH2MHill, 2013). Selenium is naturally abundant in rocks with sedimentary facies hosting carbonaceous shales and shales having particularly high levels; natural ranges documented are 206-280 mg kg^{-1} and 1–675 mg kg^{-1}, respectively (Fernández-Martinez and Charlet, 2009). These rock types typically make up a fraction of the waste rock material at coal mines and constitute a major source of selenium to groundwater and surface water receptors. Toxicity is manifested as reproductive impairment due to maternal transfer resulting in juvenile abnormality or embryo death (Chapman et al., 2009).

In coal mine wastes, Se may be associated with both reduced sulphur species (e.g., pyrite) and as discrete reduced Se compounds (e.g., elemental Se and selenides). The release of Selenium from source rocks is hypothesized through the following reactions:

Oxidation of selenide to selenite

$$FeSe_{(s)} + 3O_2 + 3H^+ + 5e^- \rightarrow SeO_3^{2-} + Fe(OH)_3 \quad (1)$$

Oxidation of selenite to selenate

$$SeO_3^{2-} + O_2 \rightarrow SeO_4^{2-} \quad (2)$$

Both selenite and selenate have an affinity to absorb onto ferric oxyhydroxides; however, the selenate molecule has a lower sorptive affinity rendering it more mobile (Su and Suarez, 2000, Lo and Chen, 1997, Zhang and Sparks, 1990).

The backfilling of wasterock into the voids of open pits offers considerable potential for Se management with respect to both remobilization and attenuation. From a remobilization perspective, the backfilling of waste rock below the water table in open pits will act to shut down oxidation mechanisms responsible for the release of Se to solution. In saturated settings, the oxidation of these reduced species is effectively curtailed, thereby reducing the potential for Se remobilization. This relates to the tendency of oxygen to become depleted in saturated pore spaces, and more importantly, to the diffusion-controlled replacement of dissolved oxygen to reaction sites, which is very slow. In terms of attenuation, the presence of suboxic conditions is a pre-requisite for effective Se attenuation in saturated settings, whereby the removal of Se can occur via: 1) adsorption of selenite; 2) precipitation of elemental Se; 3) precipitation of Se as inorganic/organic selenides; and 4) co-precipitation of Se with reduced sulphur. Suboxia is also required to reduce nitrate, the presence of which can inhibit Se reduction and selenite sorption (Dhillon and Dhillon, 2000). Since backfilled-pit environments have the potential to develop suboxia, these systems offer significant potential with regards to Se attenuation.

This paper summarizes the findings of a field-based hydrogeologic program that assessed the nature of Se behaviour in the saturated backfilled portion of a relatively small pit located in the Rocky Mountain Foothill region of northeastern British Columbia, Canada. The results have broad-scale application to the management of and treatment Se at coal mines and other mining environments that are characterized by Se enrichment (e.g., phosphate mines, metal mines).

SITE DESCRIPTION AND METHODS

The investigation was conducted at an active coal mining operation located in the Rocky Mountain Foothills in the northeastern portion of British Columbia, Canada. The Rocky Mountain Foothills are part of the continental-scale Foreland Fold and Thrust Belt forming the eastern margin of the North American Cordillera. Elevations range from 1,830 m to 2,130 m while precipitation ranges from 500 to 1,000 mm annually with more than 60 % falling as snow. The hydrogeology of the region consists of a shallow

water table (unconfined) system within the overlying surficial (quaternary-aged) sediments where present, and a bedrock system in fractured sedimentary rocks with hydraulic conductivity ranging from 10^{-10} ms^{-1} for a low-permeability shale to 10^{-3} ms^{-1} for a vuggy limestone. The foothills are underlain by a succession of marine and non-marine sedimentary rocks (B.C. Environment, 1994). This section provides a description of the pit shell physiology, characteristics of the backfilled (waste rock) material, the design of the porewater/groundwater monitoring network, methods for collecting and analyzing porewater samples.

Backfilled Pit Physiology

The coal reserve associated with the study site is situated on a small synclinal structure minimizing the strip ratio which resulted in the development of an elongated shallow open pit approximately ~1000 m long, ~150 to 200 m wide and ~50 m deep. Approximately 1.6 million tonnes of pulverized coal injection (PCI) grade coal was excavated from the pit using typical surface mining techniques relying on blasting and shovel methods. Mining of the pit was completed by 2006 and backfilling of the pit occurred in 2011. A total of 4.8 Mm^3 of waste rock was backfilled into the pit, and of this approximately 0.2 Mm^3 is saturated. The maximum depth of the waste rock in pit is on the order of 50 m (mean depth of about 28 m) with saturated thickness of approximately 22 m. The pit shell configuration and the placement of backfilled waste rock is shown in Figure 1. Table 1 summarizes the dimensions of the pit shell, as well as total and saturated backfilled waste rock material.

Monitoring Network

In November 2011, eleven (11) monitoring wells were installed with seven (7) of the wells completed as two monitoring well nests (MW11-01 and MW11-02). A dual rotary (Barber) rig was used to advance the boreholes through waste rock and bedrock and to install the monitoring wells. All monitoring wells consist of 2-inch schedule 80 polyvinylchloride (PVC). Table 2 summarizes the details of the monitoring well installations. Water quality profiling within the saturated portion of the in-pit dump was accomplished with the use of nested monitoring wells with 5-foot long screens (1.5 m) (Elci et al. 2001). The location of these wells with respect to the in-pit dump is shown on Figure 1. The monitoring wells were placed along the centerline of the pit shell bottom as determined from a 2011 Lidar survey. MW11-01 and MW11-02 consist of four (4) and three (3) nested wells, respectively, installed within the saturated backfilled waste rock. MW11-04 is screened across the bedrock/wasterock interface upgradient of the saturated zone, and it is assumed that groundwater within this well is representative of water flowing along the bottom of the backfilled pit and representative of non-attenuated source waste rock water. MW11-03 and MW11-06 were installed within bedrock adjacent to the pit to characterize background water quality and water levels.

Table 1. Summary of Backfilled Pit Characteristics

Description	Dimension	Units	Size
Pit Shell	Length	(m)	1100
	Width	(m)	125-205
	Depth	(m)	~50
	Area	(m^2)	171,792
	Volume	(Mm^3)	4,709,000
Waste Rock	Area	(m^2)	168,871
	Volume	(Mm^3)	4,761,000
Saturated Waste Rock	Depth (mean)	(m)	18.8[1]-20.3[2]
	Area	(m^2)	22,728[1]-23,973[2]
	Volume	(m^3)	197,000[1]-232,000[2]

Notes:
[1] winter low groundwater level; [2] freshet high groundwater level

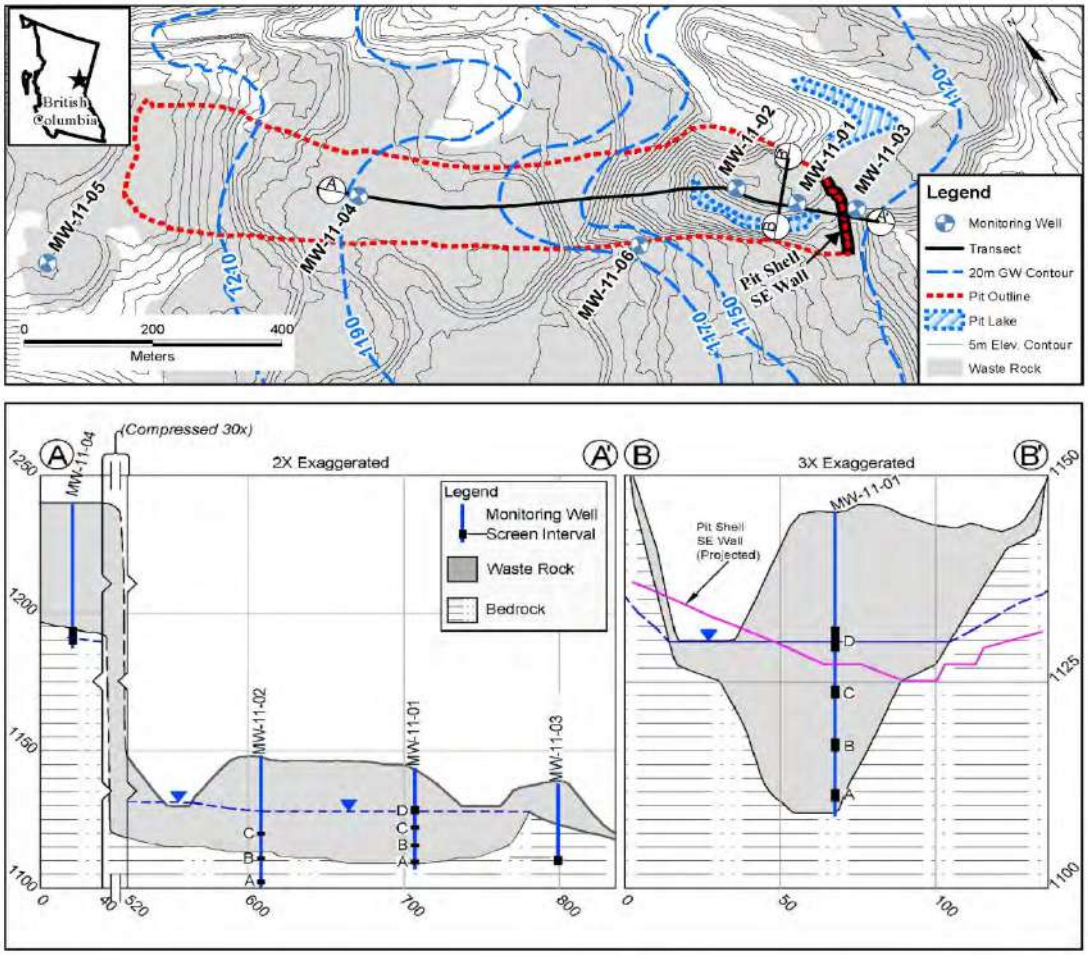

Figure 1. Study site map showing the physiology of the backfilled pit, instrumentation and water table surface map.

Table 2. Summary of monitoring well installations.

Monitoring Well	Screened interval	Instrumentation
Upgradient Well		
MW11-04	Waste rock	Levelogger®
Saturated Backfill		
MW11-02B	Waste rock/bedrock interface	-
MW11-02C	Waste rock, mid pit	HOBO® Levelogger®
MW11-01A	Waste rock/bedrock interface	HOBO®
MW11-01B	Waste rock, lower pit	Levelogger®
MW11-01C	Waste rock, water table	HOBO®
MW11-01D	Waste rock, water table	HOBO® Levelogger®
Peripheral Bedrock		
MW11-02A	Bedrock	HOBO® Levelogger®
MW11-03	Pit wall (southwest)	HOBO®
MW11-06	Pit wall (southeast)	Levelogger®

Notes: HOBO sensors provide hourly fluid conductivity data.

Porewater Monitoring and Sampling

Select monitoring wells were installed with Solnist Leveloggers® water level sensors and onset® HOBO® conductivity loggers for continuous (hourly) monitoring from November 2011 to March 2013. Table 2 summarizes the distribution of instrumentation among the wells. Manual measurements of water level and fluid conductivity were conducted during each groundwater sampling round. Three (3) rounds of sampling were conducted coinciding with anticipated variations in groundwater level associated with a freshet-dominated hydrologic system. As such, sampling occurred as follows: December 2011 coincident with fall low water levels; July 2012 representing freshet high water levels; and March 2013 representing the stream base flow and lowest water levels. All groundwater wells went through the process of development, purging and sampling. Wells were developed by the drillers using compressed air and air lift system. To minimize artifacts of sampling associated sample quality variability and error, monitoring wells were purged and sampled using the Low-Flow technique (Varljen et al., 2006; Elci et al. 2001). All monitoring wells with the exception MW11-03 were sampled using the QED bladder pump. MW11-03 was sampled using a Waterra inertial pump.

Porewater Sample Analysis

Groundwater samples were collected for bulk chemistry, anions, dissolved metals, Se speciation and microbial analyses. Samples for the general aqueous analyses were sent to ALS Laboratories of Burnaby, BC. Se speciation in water was completed at the Trent Water Quality Centre, Trent University similar to the method by Petrov et al. (2012). The ion chromatography-separation method for Se species followed

that of Wallschläger and Roehl (2001). Samples for screening of Se-reducing microbes were sent to Department of Metallurgical Engineering, University of Utah. Microbes from collected samples were analyzed by classical solid media (plating) and liquid culture techniques modified to enumerate both total microbes and Se reducers present.

RESULTS

Backfilled Pit Hydrogeology

Continuous water level readings from MW11-01D along with continuous fluid conductance readings from MW11-01D and MW11-01A are presented in Figure 2 for the period December 2011 to May 2013. Water level records show that freshet leads to an increase of 2 m in saturated thickness within the waste rock pile. Porewater conductance at the MW11-01D is approximately 300 µS/cm lower than observed at MW11-01A (800 uS/cm), likely an effect of recharge events through the waste rock. The effect of recharge, particularly during freshet, appears to reduce the fluid conductance within the saturated backfilled. However, the effect is more pronounced at the bottom of the pit (i.e., at MW11-01D). These data indicate there could a preferential flow path for water at the interface of the waste rock and pit bottom.

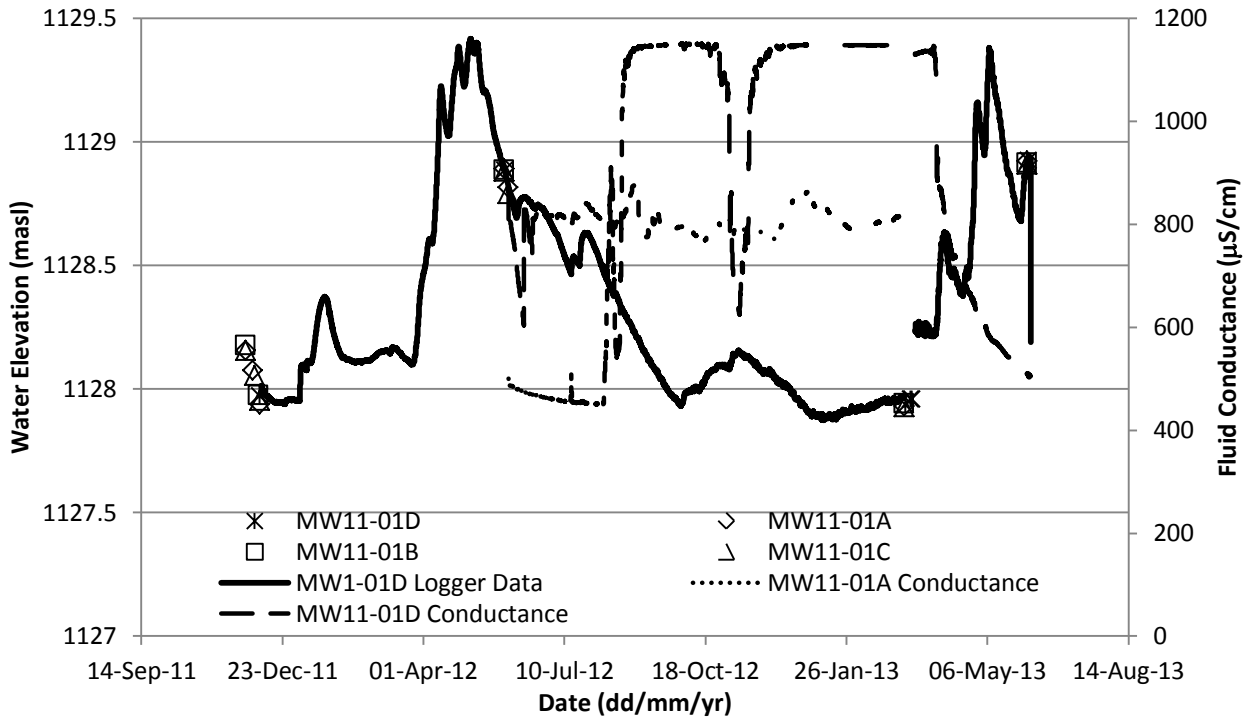

Figure 2. Water levels readings measured at MW11-01. Continuous readings are shown for MW11-01D which is screened across the water table. Manual measurements are also shown for MW11-01A,-01B, -01C and -01D.

The water table surface map shown in Figure 1 was generated using the manual water measurements observed during March 2013. In general, groundwater flow follows a south-easterly direction with deviations in flow patterns at a smaller scale due to influence of the pits. Within the saturated backfilled waste rock, water is predicted to flow relatively rapidly from the upper unsaturated zone to the downstream zone of saturation (~20 m in thickness). The water level within the lower saturated section of the pit is controlled by the southern pit wall which acts as decant point. This remnant bedrock wall produces the "bath tub" conditions within the lower portion of the in-pit dump. The greatest gradient, ranging from 10% to 20%, occurs between MW11-04 and MW11-01 due to the topographic relief between these two monitoring wells (see Table 3). The horizontal groundwater gradient between MW11-01 and MW11-02 is negligible, however; the variation in elevation between the in-pit water level and southern pit wall at MW11-03 is 1.4 % and 2.5% for winter and freshet conditions, respectively.

The groundwater heads within the bedrock at MW11-02A and -02B are 0.25 m lower than that within wasterock at MW11-02C, indicating groundwater flow is downward (data not presented). The gradient at MW11-02 was calculated to be 1.6%. The water elevation in MW11-03 is higher than MW11-01 and MW11-02 indicating an upward gradient in the southern pit wall on the order of 1%.

Conceptually, water flow through the pit consists of rainfall infiltrating downward through the waste rock and collecting along the pit bottom. Ponded water then follows along the pit floor to lower elevation where it pools in the lower portion of the pit within the 20 m-thick saturated zone. Groundwater exits the pit in two ways: 1) spillage over the bedrock ridge at the southeastern of the pit (see Section B-B' in Figure 1); and 2) downward flow through the underlying bedrock. Groundwater velocities along these flows paths are predicted to be markedly different as the hydraulic conductivity of bedrock making up the pit floor is likely three 3 to 4 orders of magnitude lower than that of the waste rock material. An estimate of waste rock hydraulic conductivity based on literature values for gravel yields a range of 10^{-4} to 10^{-5} m s^{-1} whereas, the hydraulic conductivity of the siltstone is predicted to be on the order of 10^{-7} to 10^{-10} m s^{-1} (Freeze and Cherry, 1979).

The groundwater flux through the lower pit floor (area = 24,000 m^2 see Table 1) is estimated to be 3.3 m^3/day (~0.04 L/s). Overflow at the decant point is dependent on the porosity of the waste rock material, an uncertainty in flow estimates. It is generally accepted that the porosity of end-dumped waste rock material could vary considerably thus varying the hydraulic conductivity. Estimates of the horizontal flux through the pit assumed a porosity that ranges from 25% to 40% and a hydraulic conductivity of 10^{-4} to 10^{-5} ms^{-1}. During winter, the horizontal flux component range from 43 to 430 m^3day^{-1}, whereas during freshet, the flux ranges from 80 to 800 m^3day^{-1}. Accordingly, the hydraulic residence time of the saturated backfilled pit ranges from 0.5 to 3 years during winter, and from 0.3 to 2 years during freshet (See Table 3).

Pit Water Quality

In general, water quality observed during the first round is artificially elevated as a result of drilling-related impacts. The disruption to the ambient geochemical environment by mechanical forces and injection of air during drilling can result in sampling artifacts associated with parameters associated with

sulfides (e.g., Se), as well as redox-sensitive parameters. Indeed, well development was insufficient to remove all artifacts of drilling for the first round of sampling. As a result of drilling artifacts in the first round of sampling, the following discussion considers only the results of the 2nd and 3rd sampling rounds (May 2012 and March 2013).

Redox reactions are integral to the biogeochemical processes controlling the attenuation of Se (Masscheleyn et al. 1993; Martin et al., 2011). Redox-sensitive parameters include dissolved oxygen (DO), dissolved nitrate (NO_3^-), dissolved manganese (Mn), dissolved iron (Fe), sulfate (SO_4^{2-}), and hydrogen sulfide ($\Sigma H2S = S^{2-}$, HS^- and H_2S). Inspection of the data in Table 4 for DO, nitrate, dissolved Fe, dissolved Mn show evidence of mild suboxia within the saturated portions of the backfilled pit. Dissolved oxygen concentrations were consistently elevated in the upgradient groundwater (MW11-04) ranging from 2 to 6.3 mg/L but for the remainder of the wells concentrations were generally below 0.7 mg/L. The presence of dissolved iron in the saturated backfill groundwater would mean that DO is less than observed. Likewise, nitrate levels at MW11-04 was observed at 1 mg/L and at less than detection limits for the peripheral and bedrock wells. Dissolved Mn values for wells screened in backfill (e.g., MW11-04, MW11-02C, MW11-01-A/B/C) show values ranging from 0.3 to 0.9 mg/L. Such values are likely indicative of Mn(IV)-oxide reduction. Similarly, the presence of slightly elevated dissolved Fe is indicative of suboxia.

Table 3. Hydrogeological parameters and estimates of flow through backfilled pit.

Well Pair	Gradient by Well Pairs (%)			Lithology	K[5]	Average Width of Pit	Saturated Thickness @ MW-11-01	Saturated Waste Rock Volume[6]	Porosity[5]	Saturated Waste Rock Pore Volume	GW Q	Pit Residence Time
	MW11-04: MW11-02C	MW11-02C : MW11-01C	MW11-1C: Seep		(m s^{-1})	(m)	(m)	(Mm^3)	(%)	(Mm^3)	(m^3/day)	(years)
Baseflow[1]												
MW11-04	19											
MW11-02C		-0.06										
MW11-01C			1.4	Wasterock[4]	1E-05	200	17.77	0.20	25	0.05	42.7	3
Spill Point - Seep[3]			1.4	Wasterock[4]	1E-04	200	17.77	0.20	40	0.08	426.7	0.5
Freshet[2]												
MW11-04	11											
MW11-02C		-0.05										
MW11-01C			2.5	Wasterock[4]	1E-05	200	18.75	0.20	25	0.05	80.4	2
Spill Point - Seep[3]			2.5	Wasterock[4]	1E-04	200	18.75	0.20	40	0.08	803.8	0.3

Notes:

[1] water levels observed on 8-Mar-13 during low winter low flow period

[2] water levels observed on 3-Jun-13 during mid-freshet flow period

[3] elevation of top of pit wall at MW11-03; active flow out of pit is assumed to occur as spill over remnant southern pit wall.

[4] waste rock assumed to have consistency of gravel.

[5] range of hydraulic conductivity and porosity values expected for gravel. Data from Freeze & Cherry 1979.

[6] value based on estimate derived from 1m resolution maps of original ground, mined out pit and waste rock surface (Lidar surveys).

Table 4. Porewater chemistry for general parameters and redox indicators for upgradient pit water, saturated backfill and peripheral bedrock. Data represent geometric means samples collected in December 2011, May 2012 and March 2013.

Parameter[1]	pH	Conductivity	Temp.	DO	ORP	Alkalinity[2]	DOC	NO_3^-	SO_4^{2-}	H_2S[3]	Mn-D	Fe-D
Units	(pH)	(uS/cm)	(°C)	(mg/L)	(mV)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Upgradient Pit Water												
MW11-04	7.1	1524	7.3	4.8	14	289	2.4	1.47	652	<0.001	0.0704	0.5370
Saturated Backfill												
MW11-02-B	7.1	1888	7.1	1.3	[4]11	286	3.7	0.447	893	<0.001	0.8268	0.1671
MW11-02-C	7.1	1725	7.0	0.6	[4]59	308	2.2	0.208	785	<0.001	0.4295	0.1180
MW11-01A	7.0	1327	5.7	1.4	90	329	3.3	0.116	443	<0.001	0.2577	0.0999
MW11-01B	6.8	1636	5.6	0.2	[4]59	345	4.3	0.200	781	<0.001	0.6321	0.1274
MW11-01-C	6.9	1664	6.6	[4]0.3	[4]-96	426	1.8	0.082	715	<0.001	0.4828	0.5342
Peripheral Bedrock												
MW11-02-A	7.1	1700	7.7	0.9	[4]-29	325	8.7	0.102	691	0.004	3.3168	0.8552
MW11-01-D	7.1	1151	7.5	0.4	[4]-90	379	4.8	0.085	282	0.002	0.6112	0.2858
MW11-03	7.2	581	3.2	0.3	[4]-118	338	3.9	<0.005	10	0.003	0.3944	4.5303
MW11-06	7.1	1080	4.3	1.1	[4]-88	565	4.7	0.096	25	0.005	0.0485	0.1278

Notes:
[1]Where concentration was below the method detection limit, concentration was set equal to detection limit value for statistical calculations
[2]Alkalinity = total ($CaCO_3$)
[3] H_2S as S
[4]Arithmetic mean shown due to negative values in dataset

Conversely, H_2S concentrations do not reveal evidence of SO_4^{2-} reduction as levels are below the limits of analytical detection (<0.002 mg/L) in all samples with the exception of the peripheral bedrock wells. Dissolved organic carbon (DOC) is present within the porewater of the backfilled pit, although at approximately half the concentrations observed within the peripheral wells. Under the current redox regime, sulphate represents a suitable proxy for waste rock drainage, and concentrations of this parameter can be used to further assess pit hydraulics. Figure 3 summarizes the sulphate levels during the three rounds of sampling. The sulphate levels in those wells screened across the wasterock-pitfloor interface, namely, MW11-01A and MW11-04, are considerably lower during the May 2012 sampling round under freshet recharge conditions. These fluctuations correlate well with the variations observed in the fluid conductance data in Figure 2 indicating that preferential flow paths along the pit floor may exist. Further, elevated sulphate levels in bedrock at MW11-02 (A/B) support the interpretation of water levels at this location which indicate a downward vertical gradient as background sulfate concentrations are typically less than 100 mg/L, as observed at MW11-03 and MW11-06.

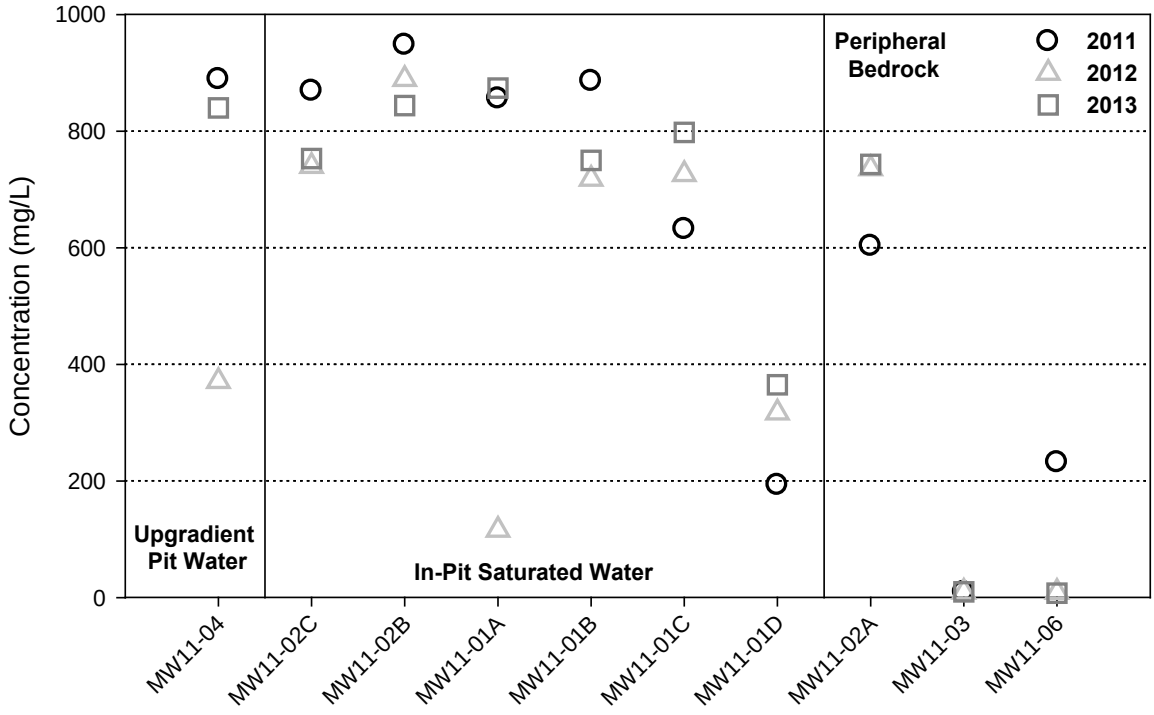

Figure 3. Sulfate concentrations measured in water for December 2011, May 2012 and March 2013 sampling rounds for upgradient pit water, saturated backfill and peripheral bedrock.

Selenium

Total Se, Se^{IV} and Se^{VI} concentrations measured during for each sampling round are summarized in Figure 4 while the mean concentrations 2nd and 3rd sampling rounds are shown in Figure 5. The highest Se levels are observed upgradient of the saturated zone (MW11-04), while the lowest values are observed in the peripheral bedrock wells. The Se levels in the in-pit saturated water are consistently below 1 µg/L. Inspection of the data shows a predominance of Se^{VI} at MW11-04, comprising on average 95% of the total Se inventory. The reduced form Se^{IV} is present, albeit at low levels (less than 2%). In contrast, the in-pit saturated water shows a predominance of Se^{IV}, on average making up 74% of the total Se inventory. Se^{IV} is also the dominant species within the peripheral bedrock making up 71% of the inventory. The in-pit saturated water contains less than 1% of the Se-T observed at MW11-04 suggesting that 99% of the Se-T entering the in-pit saturated zone is lost by attenuation through mechanisms which may include adsorption of Se^{IV}, precipitation of elemental Se, or precipitation of metal/organic selenides. This conclusion is supported in the shift in dominant Se species from Se^{VI} in the source water to Se^{IV} within the in-pit saturated water. The reduction in Se concentrations within the backfilled pit cannot be attributed to dilutionary processes, as revealed by the persistence of elevated SO_4 levels and inferred groundwater flow paths which do not indicate significant recharge of more dilute groundwater sources. In this regard, the backfilled pit can be viewed as a passive bioreactor, where suboxic redox processes promote denitrifcation and immobilization of Se.

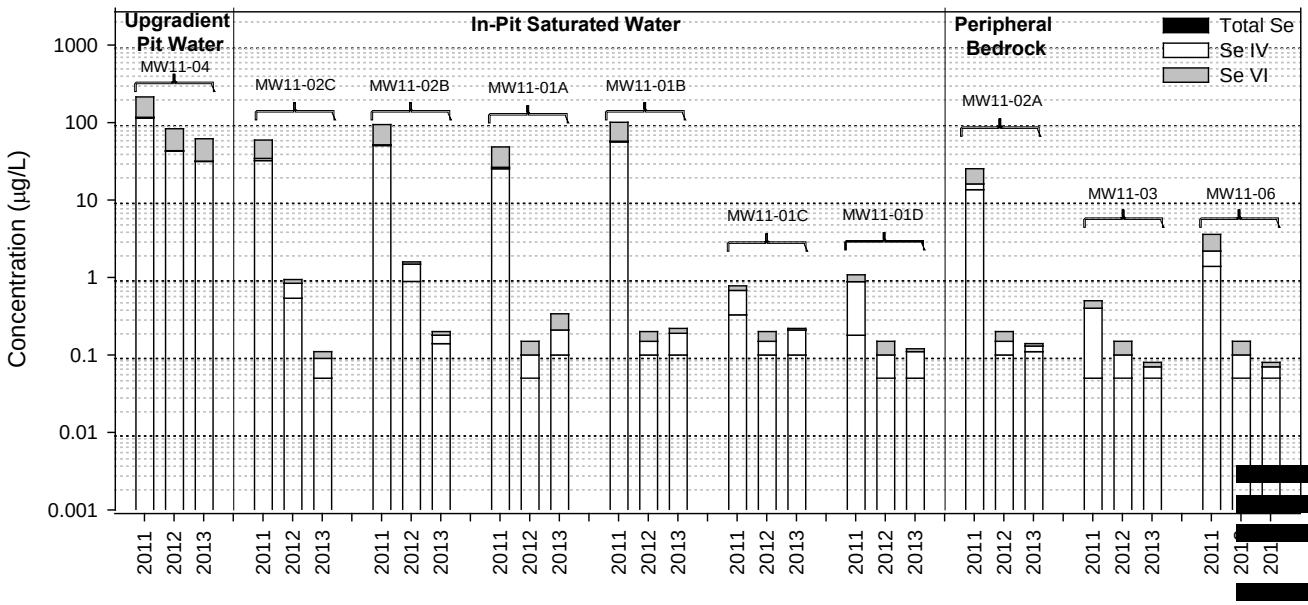

Figure 4. Summary of total selenium and selenium species concentrations in groundwater for upgradient pit water, saturated backfill and peripheral bedrock. All values in µg/L.

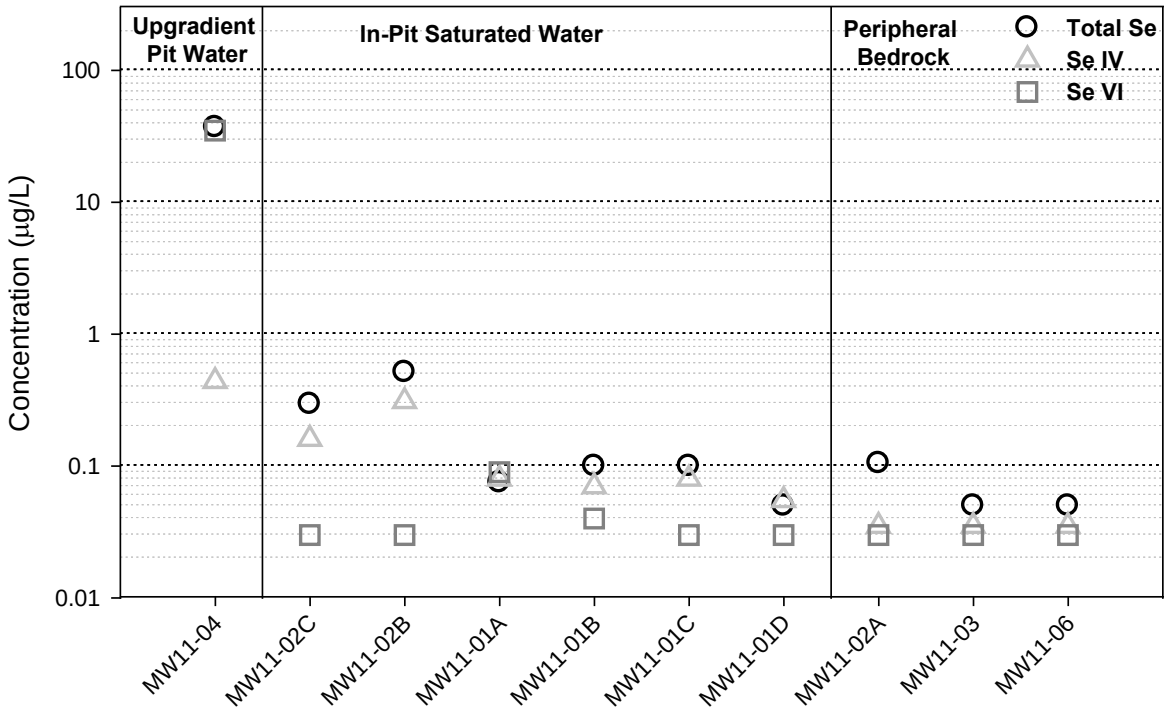

Figure 5. Geometric mean Se-T, Se^{VI} and Se^{IV} concentrations in groundwater of May 2012 and March 2013 sampling rounds for upgradient pit water, saturated backfill and peripheral bedrock.

Microbial Communities

Results of total microbial and Se-reducer counts in groundwater samples are summarized in Figure 6. Total microbial counts provide an indication of microbe population viability at time of sampling. The

microbial counts over the three sampling periods demonstrate variability in both saturated backfilled and peripheral groundwater wells. Se-reducers were recorded in only two samples in December 2011 (MW11-02C-FD) and March 2013 (MW11-04-FD). Although specific counts of Se-reducers were low and varied between sampling events, the potential for selenium reduction in the saturated backfilled is better characterized taken into account the results of the selenium containing media microbial analysis. Se precipitation was observed following two weeks of incubation in samples from MW11-02C-FD and MW11-04. Following a month of incubation, Se reduction was also detected, albeit at much lower levels, in samples MW11-02B and MW-11-03.

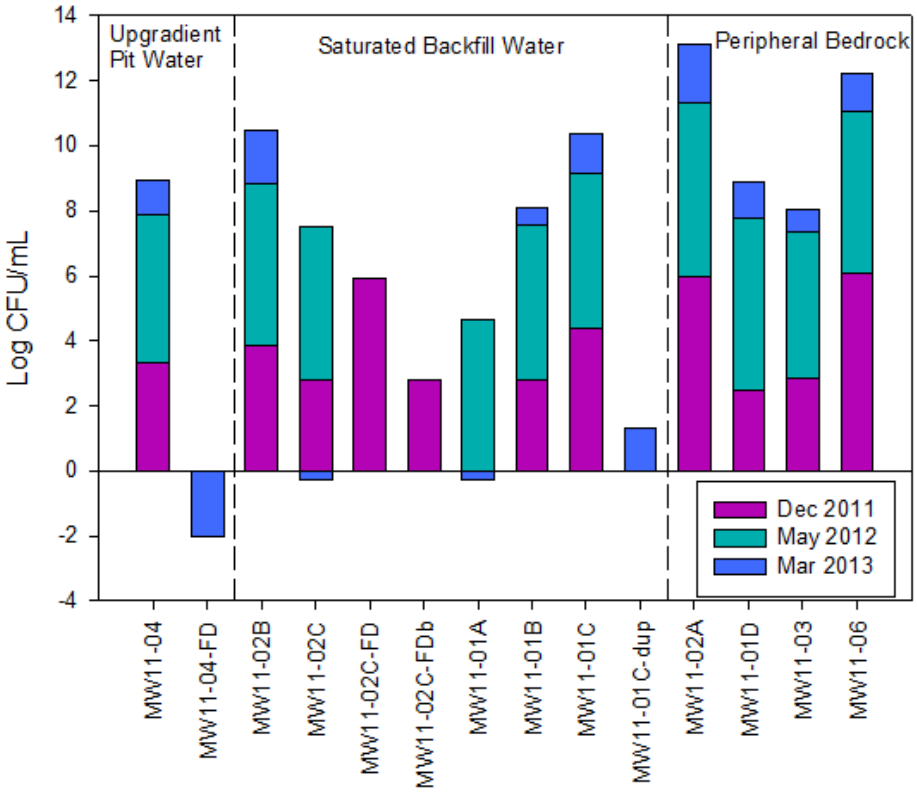

Figure 6. Summary of microbial plates counts for upgradient pit water, saturated backfill and peripheral bedrock.

Estimates of Selenium Removal Rates

Estimates a Se removal rates are not well constrained due to uncertainty in the upper concentration end member and flow through rate (i.e., water residence time). Nonetheless, in-situ Se removal rates were calculated based on the observed difference in total dissolved Se (Se-T) concentration between MW11-04 (upgradient pit water) and saturated backfilled porewater during both low (winter) and high (freshet) flow periods. The parameters for the Se removal rate estimates are summarized in Table 5. The mean Se-T concentration observed at MW11-04 for the May 2012 and March 2013 sampling rounds was 38 µg/L, and the mean concentration within the saturated backfilled porewater was less than 0.1 µg/L. As

discussed previously, pit flow through rate varies due to uncertainly in waste rock porosity values; accordingly a range of possible flow rates were considered. Overall, removal rates were calculated to range from 0.03 to 0.17 mg/day/m^3 of waste rock (winter low flow) and 0.06 to 0.33 mg/day/m^3 of waste rock (freshet flow) (Table 5).

Table 5. Summary of Se removal rates

Waste Rock Volume	Porosity	Flow Rate	Residence Time	[Se-T] In	[Se-T] Out	Se Loading Rate	Se Removal Rate
(m^3)	(%)	(m^3/day)	(years)	(µg/L)	(µg/L)	(mg/d)	(mg/d/m^3)
197000	25	42.7	3	38	0.1	1618	0.03
232000	40	426.7	0.5	38	0.1	16172	0.17
197000	25	80.4	2	38	0.1	3047	0.06
232000	40	803.8	0.3	38	0.1	30464	0.33

CONCLUSIONS

This paper represents the first known study of its kind in northeastern B.C. to rigorously examine Se behaviour in the saturated zone of a backfilled pit. The monitoring methods employed have specifically allowed delineation of the transport characteristics and bioremediation potential of Se within suboxic zones of the waste rock backfill. The results provide direct evidence of in situ Se reduction under mildly suboxic conditions, commensurate with nitrate reduction. Overall, the data suggest that a significant degree of Se attenuation is occurring within the backfilled pit under relatively short residence times. These results have direct application to coal mines globally that employ pit backfill as part of water/waste management planning. The data also suggest that for larger backfilled systems characterized by longer groundwater retention time, a higher magnitude of Se attenuation could be achieved. In this regard, this form of in situ bioremediation represents a possible means to treat large water volumes not accommodated by traditionally forms of passive treatment (e.g., wetlands, permeable reactive barriers).

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IN SITU MICROBIAL REDUCTION OF SELENATE IN BACKFILLED PHOSPHATE MINE WASTE, S.E. IDAHO

by

Lisa Marie Bithell Kirk

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

Doctor of Philosophy

in

Land Resources and Environmental Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

January 2014

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APPROVAL

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Lisa Marie Bithell Kirk

This dissertation has been read by each member of the dissertation committee and has been found to be satisfactory regarding content, English usage, format, citation, bibliographic style, and consistency, and is ready for submission to The Graduate School.

Dr. Tracy M. Sterling (Co-chair)

Dr. Brent M. Peyton (Co-chair)

Approved for the Department Land Resources and Environmental Sciences

Dr. Tracy M. Sterling

Approved for The Graduate School

Dr. Karlene A. Hoo

DEDICATION

To those who make things work….and those who make it worth working.

Most especially, to

My beloved husband, Allan and our daughters, Meghan and Molly Kirk

With gratitude for all of your patient support,
without which this would not have been possible.

"Whatever you do, or dream you can, begin it.
Boldness has genius and power and magic in it."
J.W. von Goethe

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ABSTRACT

The reduction of selenium (Se) by microbes is controlled by oxygen (O_2)-availability within mixed deposits of shale, chert, and mudstone mined from the Phosphoria Formation in S.E. Idaho. Waste rock and groundwater from backfilled mine pits, which have been studied using geochemical, microbial cultivation, and molecular methods, host native populations of selenate-(SeO_4^{2-}) and selenite-(SeO_3^{2-}) reducing bacteria that are highly similar to the genera *Dechloromonas*, *Stenotrophomonas*, *Anaeromyxobacter,* and *Ralstonia*. These bacteria rapidly reduced more than 95% of soluble SeO_4^{2-} concentrations. Reduction occurred within a consortium of slow-growing, cold-tolerant, hydrocarbon-degrading, and nitrate-(NO_3^-), iron-(Fe^{3+}), and manganese-(Mn^{4+}) reducing bacteria, including the genera *Polaromonas* and *Rhodoferax*, which appeared to use the naturally-occurring hydrocarbon present in the rock. Most-probable number estimates of SeO_4^{2-}-reducers were highest in saturated sediments and in unsaturated shale, and were very low in unsaturated chert and mudstone. Selenium reduction was studied in microaerophilic, saturated native chert, shale, and mixed run-of-mine sediments inoculated with live groundwater cultures, with sampling and analysis of total Se, Fe, Mn; Se speciation; NO_3^- and sulfate (SO_4^{2-}); dissolved organic carbon and total nitrogen(N); and mineralogy. Following an O_2- and N-dependent lag, SeO_4^{2-} was reduced within 100 hours under saturated, suboxic conditions at rates that varied depending on lithotype and temperature. The microbial community shifted during reduction as well, from phylotypes associated with the Fe-reducing *Rhodoferax* and HC-degrading *Sphingomonas* and SeO_4^{2-}-reducing *Dechloromonas* genera to include members of the SeO_3^{2-}-reducing genus *Ralstonia*. A unique biogeochemical Se reduction pathway was suggested in chert experiments, where Se reduction proceeded more rapidly and produced SeO_3^{2-} and elemental Se products, relative to the shale, wherein reduction was slower and produced more reduced selenide minerals. Results of these experiments offer insight into the results of *in situ* monitoring in backfill at multiple locations in S.E. Idaho, and potentially explain differences in Se solubility at these locations. Strategic management of rock and water in constructed mine wastefacilities to limit O_2 recharge can thus promote SeO_4^{2-} reduction by communities of indigenous organisms using available carbon and other electron donors. This offers a sustainable, design-based approach to natural attenuation of Se in mined rock.

CHAPTER ONE

INTRODUCTION

Selenium (Se) release associated with weathering of phosphate mine waste is recognized as a risk for human health and the environment in the S.E. Idaho Phosphate Resource Area (Figure 1). Bioaccumulation of Se released by mined phosphate waste rock has resulted in toxicosis in horses and sheep grazed on affected vegetation, and increased concentrations of Se water have been measured at some locations [3, 4]. Awareness of this risk has prompted significant efforts on the part of phosphate producers, state and federal agencies, and other investigators to describe mechanisms of Se release and attenuation associated with mined phosphate wastes. Various research initiatives have addressed questions of health and environmental risk [5], mineralogy [6-10], Se speciation [11-13], and microbial communities in Se-affected sediments [14] of the S.E. Idaho Phosphate Resource Area. Results of these studies have offered insight into the biogeochemical processes that influence Se release from surficial deposits of phosphate waste rock. This study describes the Se biogeochemistry of mined phosphate overburden under subsurface conditions and evaluates factors influencing the extent of native microbial reduction of selenate (SeO_4^{2-}) as a potential method of operational source control in backfilled mine waste.

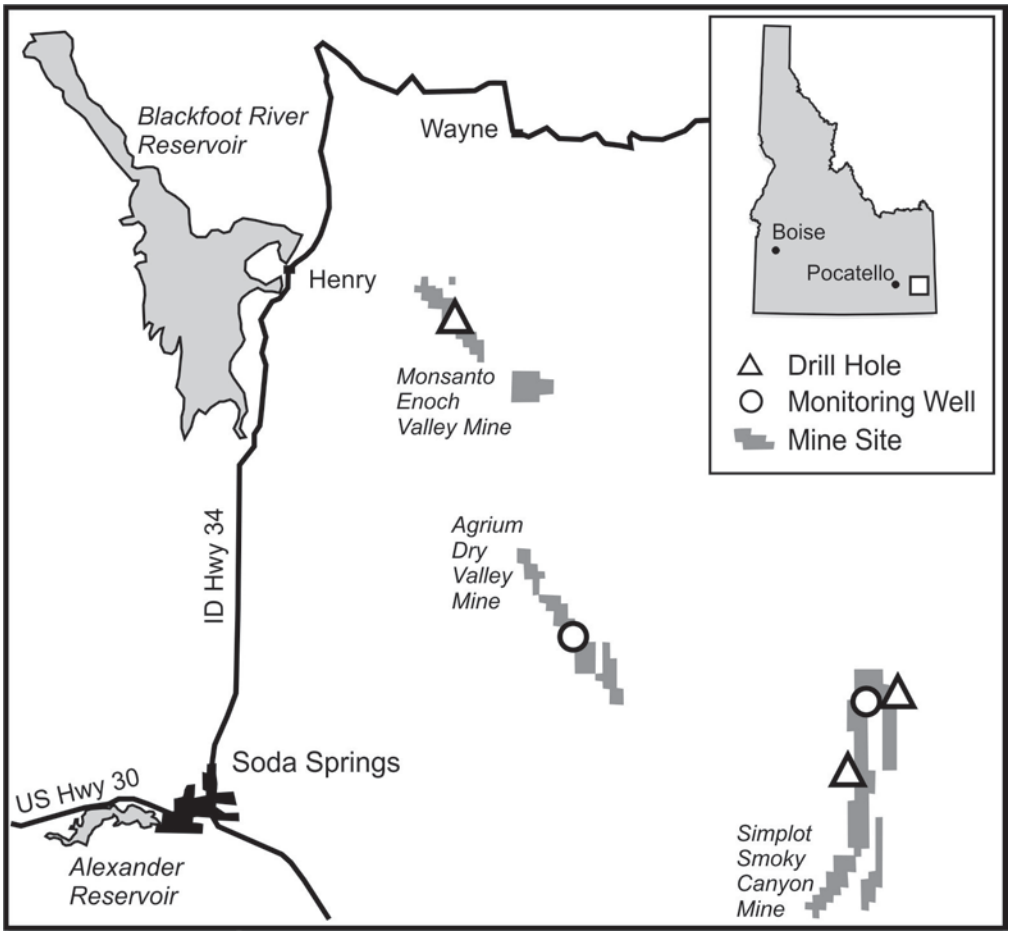

Figure 1. Location of S.E. Idaho Phosphate Resource Area, showing Enoch Valley, Dry Valley and Smoky Canyon mines with studied drillholes and monitoring wells.

Project History and Location

Results of *in situ* monitoring and laboratory testing show that Se hydrogeochemistry in the S.E. Idaho Phosphate Resource Area varies, depending on waste rock mineralogy and composition, placement and location of waste rock, site hydrology and geochemical weathering processes [2, 15, 16]. The central finding that prompted this research was that concentrations of Se in groundwater within backfilled mine waste at Agrium Nu-West Industries, Inc.'s (Agrium) Dry Valley Mine are

relatively low, in contrast to values measured in surface seeps from external mine waste rock dumps [17], near surface lysimeters [2], and shallow monitoring wells [2], as well as backfill monitored at other mine sites [15].

At the Dry Valley Mine (Figure 1), low Se concentrations were measured in a monitoring well that was placed in randomly-distributed mine backfill [2]. The mine waste backfill deposit at this location had been reclaimed and covered with a vegetated cover, but had been intermittatly saturation with nitrate (NO_3^-)- and SeO_4^{2-}-bearing water that was pumped out of an active mine pit over a period of a few years. Nitrate and SeO_4^{2-} concentrations monitored in the well increased initially, but dropped quickly following each application of pit water (Figure 2). Following the discharge of water onto the backfill, the groundwater returned to its original elevation, leaving rock above the water table in an unsaturated state. In spite of the lack of saturated conditions in the upper backfill, groundwater Se concentrations in monitoring well GW7D have remained at or below the Idaho groundwater standard of 50 µg/L. (http://adm.idaho.gov/adminrules/rules/idapa58/0102.pdf).

Data from Dry Valley (Figure 2) show low concentrations of SeO_4^{2-}, NO_3^-, and total dissolved iron (Fe) at consistent pH, with elevated concentrations of SO_4^{2-} and total dissolved manganese (Mn). Low concentrations of dissolved oxygen (O_2) were measured at this location (see Chapter 3). In contrast, groundwater samples collected from a monitoring well (GW11), completed in comparable mixed (run-of-mine) backfilled waste rock at J.R. Simplot Company's (J.R. Simplot) Smoky Canyon Mine, showed higher concentrations of SeO_4^{2-}, with measurable dissolved O_2, under variably saturated

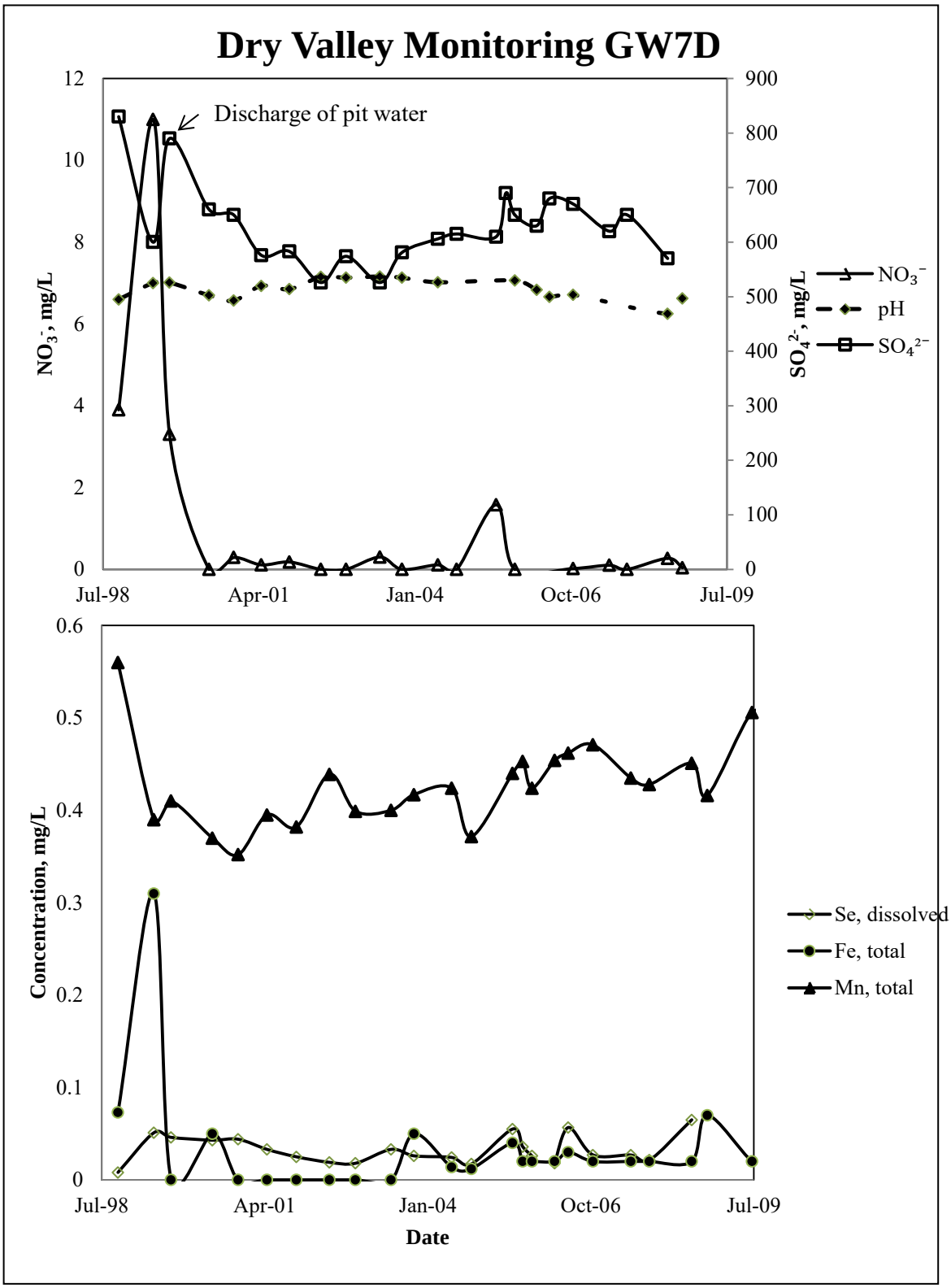

Figure 2. Monitored chemistry in B panel backfill at Dry Valley, groundwater well GW7D [18].

conditions.

Efforts to explain the greater SeO_4^{2-} release from backfill monitored at Smoky Canyon, relative to that observed at Dry Valley, based solely on abiotic mechanisms were unsuccessful and led to the hypothesis that microbial reduction of SeO_4^{2-} to more reduced, less soluble SeO_3^{2-}, Se^0, or Se^{2-} minerals by indigenous organisms, using native carbon (C), may play an important role in controlling SeO_4^{2-} mobility in backfilled phosphate mine waste deposits. Improved understanding of how extensive and/or consistent this process might be within the S.E. Idaho Phosphate Resource Area, and whether microbial reduction of SeO_4^{2-} within backfills can be promoted to reduce impact on downgradient water resources, will benefit operational Se management strategies. Development of operational source control strategies that make effective use of microbial ecology to stabilize waste *in situ* by controlling the flux of water and O_2 to promote the formation of suboxic zones, through placement of key lithotypes to control texture and geochemistry, thereby influencing the potential for stabilization of solutes, has significant implications for sustainable mine waste management across a variety of mineral commodity sectors, well beyond Se control or phosphate production.

Research Goals

The research presented in this dissertation seeks to address the following questions:

- Which, and how many, SeO_4^{2-}-reducing microbes are present in phosphate mine waste? In groundwater from backfilled mine waste?
- Which lithologies support native communities of SeO_4^{2-}-reducing organisms?

- What moisture, oxygen, and temperature conditions support SeO_4^{2-} reduction by native organisms using naturally available C?
- How do moisture, oxygen, and temperature conditions affect the microbial community diversity and capacity for SeO_4^{2-} reduction?
- How fast does SeO_4^{2-} reduction proceed under saturated anaerobic conditions in mine waste? What variables control the rate of Se reduction *in situ*?
- What concentration and species of Se, C, N, S, Fe, Mn, as well as microbial community changes, are observed during SeO_4^{2-} reduction?
- What are the end products of SeO_4^{2-} reduction?
- Can indigenous microbes, using native C, reliably support operational source control of Se in mine waste?

Scope of Investigation

This document begins with a review of relevant literature (Chapter 2), in the context of a conceptual model for addressing the questions listed above. This is followed by a description in Chapter 3 of the sites and historical data available describing the S.E. Idaho Phosphate Resource Area. The sampling and analysis of groundwater and waste rock from sonic drill holes and monitoring wells is also reviewed in Chapter 3, supported by *in situ* measurement of O_2, carbon dioxide, moisture content, temperature, and geochemistry [15]. These samples were collected from three mine sites: Agrium's Dry Valley Mine, J.R. Simplot's Smoky Canyon Mine, and Monsanto Company's (Monsanto) Enoch Valley Mine (Figure 1), and were studied to:

1. Identify and enumerate SeO_4^{2-}- reducing microbes, using (a) cultivation-dependent methods and (b) molecular methods of identification using the (c) most probable number method (Chapter 4)

2. Evaluate environmental factors, including lithology, O_2, temperature, and moisture content, that influence the chemistry, extent and rate of microbial SeO_4^{2-} reduction (Chapter 5).

3. Review environmental conditions needed for conceptual design of operational mine facilities to promote SeO_4^{2-} reduction (Chapter 6) and identify questions to be addressed in future work.

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CHAPTER TWO

CONCEPTUAL MODEL OF PHOSPHATE BACKFILL BIOGEOCHEMISTRY

Release of selenium (Se) associated with phosphate mining in the S.E. Idaho Phosphate Resource Area has important environmental and economic consequences. Selenium has a low crustal abundance of 0.05 mg/kg and is measured in low (1-5 µg/L) concentrations in natural water except in association with Se-rich soils or rock [1]. It is readily bio-accumulated from water and sediment via synthesis of organic-Se compounds, including selenocysteine, the 21st amino acid [2, 3]. Selenium is required in amino acids and proteins used in mammals for intracellular signaling, redox homeostasis, and thyroid metabolism [4], as well as production of antioxidant enzymes [5]. Selenium is also potentially toxic, at levels of exposure that vary between receptor organisms [6, 7] and are strongly affected by Se speciation [8, 9]. Selenate (SeO_4^{2-}) is less toxic than the more reduced biselenite ($HSeO_3^-$) and selenite (SeO_3^{2-}) forms, and many organisms methylate Se to further reduce its toxicity. Selenium is therefore known as an "essential toxin," due to the small difference between necessary and toxic concentrations in mammals, and diseases related to both Se-deficiency and acute or chronic Se-exposure are known [1]. One disease related to Se-deficiency is Keshan disease, a lethal form of cardiomyopathy named for the province in China where soils depleted in Se led to thousands of deaths until the need for supplementation was recognized [10]. Conversely, exposure to elevated concentrations of Se from industrial activities or leaching of naturally elevated Se from soils is known to produce a range of toxicosis symptoms

including gastrointestinal disorders, loss of hair and nails, fatigue, irritability and neurological damage [1]. The ecotoxicology of Se varies significantly between organisms, in part due to differences in detoxification mechanisms [9].

Reduction of soluble and toxic SeO_4^{2-} to SeO_3^{2-}/$HSeO_3^-$ or insoluble elemental selenium (Se^0) and selenide (Se^{2-}) compounds significantly reduces Se mobility and bioavailability. While this reduction does occur abiotically, it is slow, especially in the conversion of SeO_4^{2-} to SeO_3^{2-}. This reduction is thus most readily accomplished by a variety of heterotrophic organisms that couple the reduction of Se with the oxidation of a broad spectrum of carbon (C) sources. Much attention has been focused on the study of microbial reduction of Se in promotion of bioremediation strategies for impacted water and sediment, with considerable focus on agriculture-affected settings like the Kesterson Reservoir, California [11]. These processes have also been incorporated into a variety of passive and active water treatment systems that rely on significant C and nutrient amendment [12]. Volatilization of Se^{2-} and phytoremediation have also received considerable attention, and some believe that these methods offer superior remediation capacity as gaseous Se mixes into the atmosphere and does not have potential for reoxidation in sedimentary or aqueous environments [11, 13]. The potential influence of volatilization on mass transfer and sequestration within subsurface phosphate overburden backfill deposits is likely to be relatively low, however. Use of microbial Se reduction in subsurface biobarriers designed for groundwater remediation has also been suggested in recent investigations [14, 15]. The focus of the present research was an evaluation of options for design of backfilled facilities that promote solid phase biomineralization, but

concurrent production of organic and volatile forms of Se in relation to biomineralization processes have also been considered.

Se Biogeochemistry at the Facility Scale

Integration of the hydrogeochemical and biological processes that together influence the mobility of Se within weathering mine waste requires a conceptual understanding of their influence on Se speciation at both the field ("mine facility") and the micro ("pore") scales, as shown in Figures 3 and 4.

Figure 3 illustrates a phosphate mine pit where mineable phosphorite deposits are exposed in the upper and lower portions of the Meade Peak Member of the Phosphoria Formation. The mine pit is partially backfilled with mixed ("run-of-mine") waste rock (Figure 3) and extends below the groundwater table at this location. An arrow is drawn through the mixed backfill to illustrate infiltration of precipitation through the unsaturated rock, with flow towards saturated rock below the groundwater table (Figure 3). Changes in oxygen (O_2) concentration and moisture content are anticipated along this flow path, under the influence of changing lithology, particle size, compaction, and O_2 demand within the facility, resulting in transition from oxidizing and atmospheric to reduced, subsurface conditions. A constructed lift (bench) of mined waste rock is shown in Figure 3 as a conceptual reactive barrier designed to promote the reduction of the most oxidized form Se(VI) which occurs as SeO_4^{2-} , to less soluble Se(IV), Se(0) and or Se(II) forms. The facility scale conceptual model thus considers hydrologic, geologic and

geochemical conditions relevant to subsurface Se reduction within a backfilled phosphate mine pit.

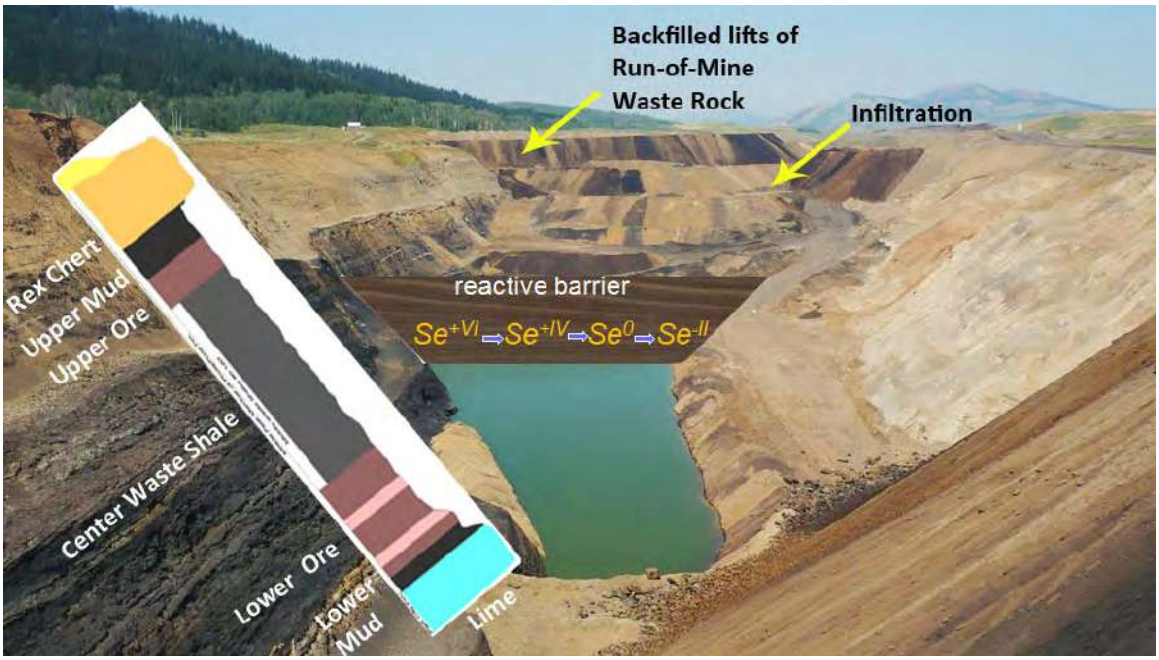


Figure 3. Facility scale conceptual model showing a mined section of the Phosphoria Formation in the S.E. Idaho Phosphate Resource Area in a partially backfilled panel. Geologic section indicates upper and lower phosphorite ore zones with chert, mud, and shale waste rock lithotypes. Lifts of mixed run-of-mine backfill are contrasted with a conceptual biobarrier placed to promote Se reduction within the groundwater flowpath in the middle of the mined panel. Sorted, end-dumped waste rock in foreground.

Phosphate is mined from the Meade Peak Member of the Permian Phosphoria Formation in the S.E. Idaho Phosphate Resource Area, within a section of reduced, fine-grained and organic-rich clastic shale and carbonate sediments [16]. This stratigraphy is illustrated in the column included in Figure 3. These sediments were deposited at the margin of a biologically productive, isolated marine basin, where O_2-depleted, denitrifying conditions allowed preservation of the organic C and phosphorous deposits [17, 18]. Elevated concentrations of biogenic copper (Cu), zinc (Zn), Se, cadmium (Cd),

and molybdenum (Mo), relative to mean crustal abundance, occur in the shale and mudstone of the Meade Peak member [19] and are mobilized to varying degrees when mined rock weathers under oxidizing surface conditions [20].

The Meade Peak shale is comprised of quartz; clay (muscovite, illite); feldspar (albite/orthoclase/buddingtonite), and sulfides (pyrite and sphalerite, containing as much as 5% total sulfide) [21]. Trace element, carbonate, and organic C content of the shale varies depending upon weathering history, with loss of carbonate and organic C, and changes in trace element ratios associated with near-surface alteration by meteoric water over geologic time [17]. Selenium content of the shale ranges from 1 to 1040 mg/kg and averages 65 mg/kg; it occurs as Se^0 or substituted for S in the sulfide host-rock minerals pyrite (FeS_2), vaesite (NiS_2), sphalerite (ZnS), and sulvanite (Cu_3VS_4) [22]. The mineral dzarkenite, $FeSe_2$, has also been identified as a Se-bearing mineral in the S.E. Idaho Phosphate Resource Area mine waste [23]. Selenium has also been shown to occur as organo-Se compounds [22, 23] and as sorbed SeO_3^{2-} complexes on mineral surfaces [23] in weathered portions of the geologic section [24]. Iron oxides occur locally in more oxidized and altered sediments, but no green rust has been reported [17, 22].

Phosphatic sediments are exposed within the S.E. Idaho Phosphate Resource Area along major north-northwest trending fold structures within the Meade Peak overthrust regional structure [16, 17, 25-27]. Waste rock is mined principally from the overlying Rex chert member, the Meade Peak shale member known locally as the “center waste shale” between the upper and lower phosphorite zones, and mudstone mined from the upper and lower contacts of the Meade Peak with the overlying Rex chert (Figure 3).

Locally, the underlying limestone/dolomites of the Wells and Park Formations are also mined (not shown). Mined chert overburden is randomly placed as backfill into mined-out pits with shale and lesser amounts of mudstone. Mixed overburden deposits of black shale, brown mud, and tan chert are stacked in backfill lift deposits at the back of the panel, immediately to the left of the infiltration arrow in Figure 3. The mixed "run-of-mine" composition is approximately 35% chert, 55% shale, and 10% mudstone, which varies locally based on deposit geometry and mining practices. Together, the phosphate overburden lithologies create an alkaline geochemical setting that hosts Ca-HCO_3-SO_4 type groundwater with elevated concentrations of nitrate (NO_3^-) and variable amounts of dissolved organic carbon (see Chapter 3). Leaching rates determined in field and laboratory studies of these mixed waste rock deposits indicate values consistent with the oxidation of Se^0 reported elsewhere, with initially high concentrations that decline to low, steady state levels [28].

Rock is generally placed randomly into backfilled mine pits, without selective handling, compacting, or control of influent water until closure. In some locations, backfill is built in lifts (e.g., benches from the bottom up) and is compacted by haul traffic; in other places, revegetated moisture store-and-release covers are placed as dumps are constructed. Alternatively, waste rock material can be end-dumped along steep embankments over vertical distances of more than 100 feet, where it falls in loose blankets of rock with pronounced sorting as a function of down slope distance [29]. The coarsest rock accumulates at the dump toe, creating zones with greater capacity for air flow. Precipitation infiltrating through the waste rock also transports O_2 into the waste

rock, promoting oxidation of minerals that host Se as a trace element; heat rising within the interior of the dump pulls O_2 into the dump through the coarser toe deposits. Under these conditions, reduced forms of Se are oxidized to the mobile form, SeO_4^{2-}, which persists in alkaline groundwater.

Mined rock typically has a low moisture content of 2 to 4% (weight) water, so that unsaturated conditions within waste backfills are expected to dominate when waste rock is first deposited. Local zones of preferential flow with higher moisture contents are common within fine-grained and compacted material in mine waste, however, and overall moisture content is expected to increase (over tens to hundreds of years, depending upon water management strategies, climate conditions and sediment storage capacity) until unsaturated flow begins. Some backfill deposits in the S.E. Idaho Phosphate Resource Area are located within panels that extend below the local groundwater table, while others confine water within perched aquifers in fine-grained sediments above the regional groundwater table. Air temperature ranges from seasonal highs of 30°C to below freezing, with subsurface temperatures ranging from 8 to 12°C at depths of up to 300 feet. [29].

It is plausible, based on observed conditions within existing backfills which support SeO_4^{2-} reduction, that conditions equally supportive of *in situ* Se stabilization could be intentionally developed on an operational basis within constructed reactive biobarriers. These passive reactive barriers would rely on materials and organisms already present within the backfilled mine waste, with a goal of reducing soluble (and toxic) SeO_4^{2-} to the more strongly sorbed SeO_3^{2-}/$HSeO_3^-$ forms (at neutral pH) or

insoluble Se^0 and Se^{2-}minerals. The potential for bioremediation of organic and metal compounds is well established [30], particularly for Se, and a variety of approaches have been taken to create suitable conditions to promote biological immobilization of contaminants within reactive barriers [31, 32]. Passive reactive barriers have been used to remediate groundwater in a variety of settings, including groundwater with excess NO_3^- [33], SeO_4^{2-} [34], and SeO_3^{2-} [15]. To determine the residence time required for contaminant reduction, and the mass of C required, it is necessary to understand the biogeochemical processes that operate within the barrier. This study examines Se transformation within subsurface overburden deposits in locations like the Dry Valley, Smoky Canyon, and Enoch Valley mines, where reduction is observed, as analogs for possible constructed biobarriers.

Se Biogeochemistry at the Micro-Scale

A conceptual model for Se release and attenuation at the pore scale, where the microbial and abiotic geochemical processes that control mobility and bioavailability occur at the mineral surface, is shown in Figure 4. Se speciation within the pore space is directly influenced by pH, temperature, presence of O_2 and carbon dioxide (CO_2) gas, and biological activity within groundwater and biofilms developed on mineral surfaces. These micro-scale factors are controlled by macro-scale processes that must be described at the facility level. Based on the conditions described within the facility scale conceptual model, pH is expected to remain circumneutral, with temperature ranging between 10 and 25°C. Abiotic factors and biogenic processes likely to influence Se environmental geochemistry under these conditions are discussed below in the context of a conceptual

microscale model.

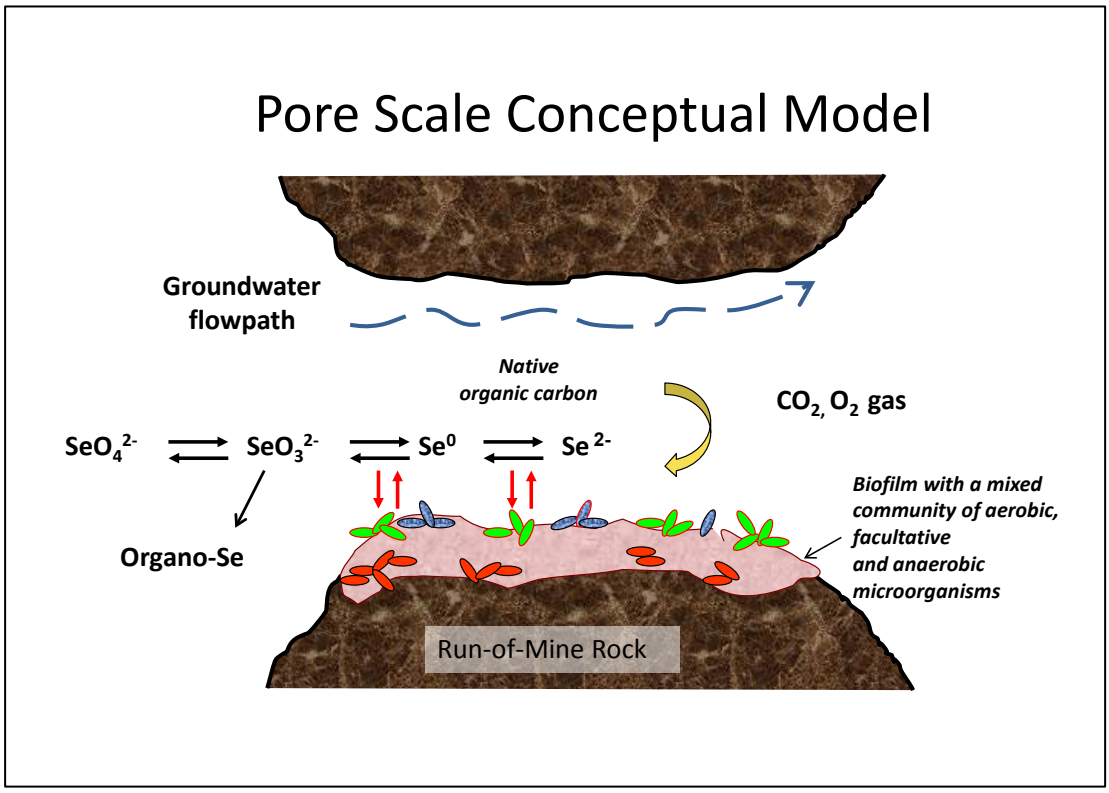
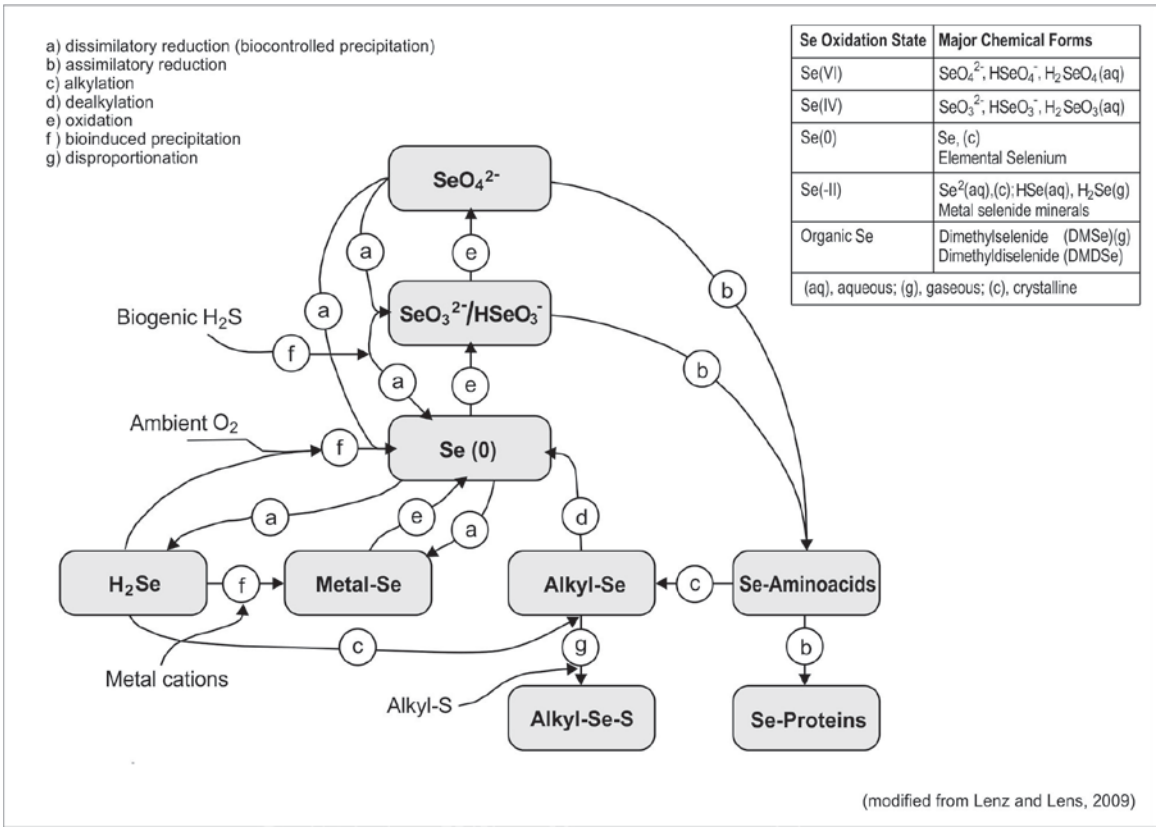


Figure 4. Conceptual model of Se reduction by mixed microbial consortia in groundwater and biofilm developed on mineral surfaces within the pore environment, as influenced by C and O_2 availability, CO_2 production, and moisture content.

Se Geochemistry

Selenium is a chalcogen and is classified as a metalloid [11]. It has four stable oxidation states under ambient conditions, Se(VI), Se(IV), Se(0), and Se(-II) [35] and has six natural stable isotopes, dominated by ^{78}Se and ^{80}Se [36]. As shown in Figure 5, these redox states occur in multiple chemical forms, for simplicity, the chemical forms, rather than the general redox states, are used in this document. Selenium chemical behavior is similar to that of sulfur (S), for which it substitutes in both mineral and organic

compounds [37], and that of arsenic (As), with which it shares similar valence structures, atomic radii, and tendency to form negatively charged oxyanions in solution [5].



Se Oxidation State	Major Chemical Forms
Se(VI)	SeO_4^{2-}, $HSeO_4^-$, H_2SeO_4(aq)
Se(IV)	SeO_3^{2-}, $HSeO_3^-$, H_2SeO_3(aq)
Se(0)	Se, (c) Elemental Selenium
Se(-II)	Se^2(aq),(c); HSe(aq), H_2Se(g) Metal selenide minerals
Organic Se	Dimethylselenide (DMSe)(g) Dimethyldiselenide (DMDSe)
(aq), aqueous; (g), gaseous; (c), crystalline	

Figure 5. Simplified biochemical Se cycle with a) dissimilatory reduction, b) assimilatory reduction, c) alkylation, d) dealkylation, e) oxidation, f) bioinduced precipitation and g) disproportionation, after [4]. Insert table summarizes chemical compounds by oxidation state, after [1].

Selenium occurs as a common trace element in sulfidic coal, shale, and volcanic deposits, and its release is associated with agricultural, mining, and coal combustion activities [4, 38]. Oxidation and dissolution of seleniferous S^{2-} and SO_4^{2-} minerals, as well as organo-Se compounds, releases mobile and potentially toxic forms of Se that may threaten down-gradient water quality and biological resources.

The stability of inorganic Se compounds under changing redox and pH conditions are shown at 1 atm pressure and T=25°C for the system Se-Fe-Ca-H_2O in Figure 6. Selenium occurs in its most oxidized forms in natural water as the oxyanions SeO_4^{2-}, SeO_3^{2-}, or $HSeO_3^-$, whereas more reduced elemental selenium (Se^0) and metal Se^{2-} minerals are relatively insoluble and slow to re-oxidize [32, 39, 40]. Under the neutral to slightly alkaline pH conditions observed in the S.E. Idaho Phosphate Resource Area, which were measured *in situ* between 6.5 to 7.8 (Table 4), dissolved Se(IV) may be present as either SeO_3^{2-} or $HSeO_3^-$.

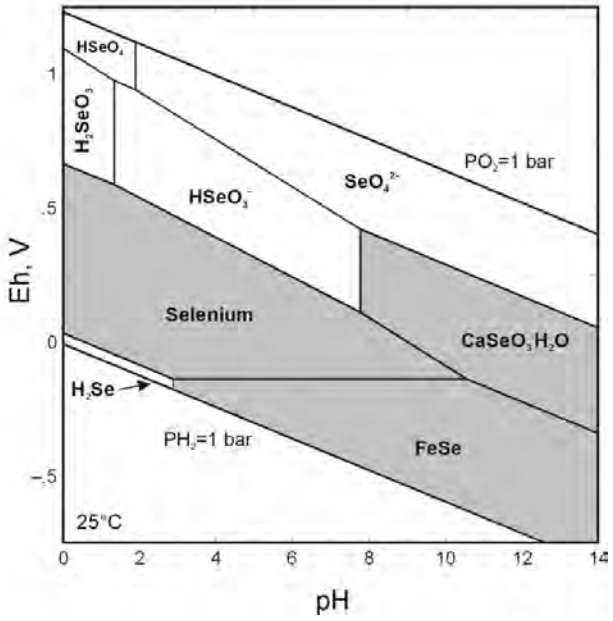


Figure 6. Eh-pH diagram for the system Se-Fe-Ca-H_2O, T= 25°C, p = 1 atm from [32].

Elemental Se has a large stability field under moderately reducing conditions that extends across a wide range of pH conditions in natural water. Above pH 8, where soluble calcium is available, a hydrated calcium selenite mineral is stable, as shown in

Figure 6. Other metal selenite minerals, such as mandarinoite ($Fe_2Se_3O_9 \cdot 6H_2O$), can also occur under oxidizing and metal-rich conditions, but are quite rare in the natural environment. Metal selenide minerals, in addition to the FeSe phase shown in Figure 6, such as penroseite ($NiSe_2$), also occur [23]. There is thus limited solubility control of SeO_4^{2-}, SeO_3^{2-}, and $HSeO_3^-$ under neutral to alkaline and oxidizing conditions in natural environments. Selenium speciation along multiple biotic and abiotic pathways can result in the co-existence of different Se species in any given environment.

A simplified speciation map is shown in Figure 5 after [4] , which illustrates the various biogeochemical pathways involved in Se transformation coupled with a table summarizing the common chemical forms of Se at each oxidation state.

In the following section, biogeochemical pathways controlling SeO_4^{2-} and SeO_3^{2-}/ $HSeO_3^-$ reduction; Se^0 and Se^{2-} precipitation; alkylation and formation of methylated Se compounds; and re-oxidation of reduced Se are described. The potential influence of Se sorption; iron (Fe) and manganese (Mn) biogeochemical cycling; and the organic C speciation and content of the Meade Peak shale are also discussed.

Selenate Reduction

Abiotic reduction of SeO_4^{2-} to SeO_3^{2-}/$HSeO_3^-$ occurs very slowly within circumneutral pH and sub-surface temperatures, creating a kinetic barrier to abiotic reduction [41]. This is explained by a one electron reduction potential barrier imposed by an intermediate Se(V) valence state [42]. Because of this kinetic barrier, most reduction of SeO_4^{2-} to SeO_3^{2-} is thought to be biologically mediated [4, 11, 43-48].

Selenate reduction by green rust, an Fe^{2+}/Fe^{3+} hydroxysulfate that occurs in suboxic sediments, is the best known abiotic mechanism of SeO_4^{2-} reduction [49]. The use of nanoparticle suspensions of zerovalent Fe to reduce SeO_4^{2-} to Se^{2-} compounds has also been reported [50].

Many SeO_4^{2-}-transforming microbes are strict anaerobes, but others are able to tolerate limited O_2 exposure. The important influence of O_2 on microbial reduction of Se oxyanions has been identified in numerous studies [51, 52]. Although most Se reduction occurs under anaerobic or microaerophilic conditions, both obligate and facultative anaerobes are capable of Se reduction [44]. Growth is observed using a variety of electron donors, ranging from acetate and lactate to aromatic compounds [53].

Selenate reduction to Se^0 is energetically favorable, yielding 71 kcal per mole SeO_4^{2-} reduced, when calculated using hydrogen as electron donor at standard state [4]. This yield is less than the energy produced by the reduction of Fe^{3+} to Fe^{2+} (-114 kcal), Mn^{4+} to Mn^{2+} (-106 kcal), and NO_3^- to N_2 (-112 kcal), but greater than that obtained through arsenate reduction toarsenite (-45 kcal) or $SO_4^{2-}$to S^{2-} (-19 kcal) reduction (Figure 5, reaction pathway a), [4].

Biological Selenate Reduction: Anaerobic dissimilatory reduction of SeO_4^{2-} is accomplished by obligate or facultative anaerobes, using one of several specific SeO_4^{2-} reductase enzymes [54, 55]. Reduction of SeO_4^{2-} for detoxification purposes appears to occur using a specific SeO_4^{2-} reductase in *Enterobacter cloacae* SLD1a1 [56], but otherwise is reported to involve non-substrate specific enzymes associated with NO_3^- and nitrite (NO_2^-) [46, 57, 58] or SO_4^{2-} reduction [59, 60].

Much of the research addressing SeO_4^{2-} reduction mechanisms has focused on characterization of the expression of SeO_4^{2-} reductase enzymes and potential inhibition of non-specific SeO_4^{2-} reduction by NO_3^- and NO_2^- reductase enzymes under denitrifying conditions [61-64]. Although the first reports of SeO_4^{2-} reduction associated the process with SO_4^{2-} reduction [43], the energy yield of the SeO_4^{2-} to SeO_3^- and SeO_4^{2-} to Se^0 couples is closer to that of denitrification. Selenium is thus typically reduced and removed from a microaerophilic environmental system (or a water treatment process) well before the anoxic conditions that support SO_4^{2-}-reduction develop. Nevertheless, SO_4^{2-}-reducing bacteria can reduce Se, although some mutual inhibition is reported. In this study, both SeO_4^{2-} and SeO_3^{2-} were shown to be removed from SO_4^{2-}-rich media by a biofilm-selected strain of *Desulfomicrobium*, with variation in end products controlled by the concentration of SO_4^{2-}. Under low SO_4^{2-} growth conditions, S^{2-} was formed, while Se^0 was formed under excess SO_4^{2-} conditions. The SeO_4^{2-} was reduced under SO_4^{2-}-reducing conditions by an unspecified reductase [65], while the SeO_3^{2-} was reduced through abiotic reaction with HS^- produced through SO_4^{2-} reduction [59]. Lenz showed that SeO_4^{2-} reduction to Se^0 was possible in a SO_4^{2-}-reducing bioreactor, with the extent of SO_4^{2-}reduction dependent on the SeO_4^{2-} to SO_4^{2-} ratio, suggesting inhibition of an unspecified common enzyme [66]. Because SO_4^{2-}-reducing conditions are likely to be less important in the microaerophilic backfills of the S.E. Idaho Phosphate Resource Area, the potential role of SO_4^{2-}-reducing organisms is not emphasized here.

Selenate Reductase Enzymes: The first identified Se reductase was the periplasmic SeO_4^{2-} reductase (*Ser*ABCD) described in *Thauera selenatis.* This enzyme is

a member of the DMSO molybdoenzyme family Nar clade, which includes the NO_3^-, chlorate, perchlorate, dimethylsulfide, and dehydrogenase reductase enzymes. Synthesis of *Ser* (which only reduces SeO_4^{2-} to SeO_3^{2-}) is regulated by *T. selenatis* in response to anaerobic conditions and the presence of elevated SeO_4^{2-}concentrations [67]. The SeO_4^{2-} reductase isolated from *T. selenatis* consists of 3 subunits, *serA* (96 kDa), *serB* (40 kDa) and *serC* (23 kDa), with a molecular weight of 159 kDa. The K_m for SeO_4^{2-} is 16 μM and V_{max} is 40 μmol SeO_4^{2-} reduced/min for each mg of protein. Cofactor constituents include Mo, Fe, acid labile S, and a cytochrome b [54]. Santini and Stolz [67] proposed an electron transport chain for the reduction of SeO_4^{2-} to SeO_3^{2-}, involving donation of electrons by the periplasmic cytochrome b to SerC, following receipt of electrons from a membrane-bound cytochrome-bc1 complex or from mobile electron carriers such as quinol. Different reductase characteristics have been described for *Sulfurospirillum barnesii*, wherein the SeO_4^{2-} reductase is membrane bound and much broader in terms of specificity [41, 68], but characterization of this reductase is incomplete. It appears that unique reduction mechanisms result in different biomineralization locations within cells, with Se^0 reported within cytoplasm, periplasm, or as extracellular deposits depending on the organism.

Another well characterized SeO_4^{2-} reductase has been described in *E. cloacae* SLD1a1. Like that of *T. selenatis*, this reductase contains Mo, heme, and non-heme Fe subunits, but it differs in that it is an insoluble membrane bound protein that relies on the global fumarate and nitrate reductase (fnr) regulatory system, as well as the *tatABC* membrane translocation pathway genes, and the menaquinone biosynethic pathway genes

*men*FDHBCE [69]. The fnr regulon controls gene expression in some facultative anaerobic bacteria, allowing them to up-regulate genes controlling the reduction of fumarate, NO_3^-, and other electron acceptors in response to declining O_2 concentrations [70].

A reductase with much broader specificity has been described for *S. barnesii*, [41, 68], and still another has been described for *Bacillus selenatarsenatis SF1* [71]. Recent work by Butler and others addresses the influence of different Se reduction pathways and reductase enzymes on biomineralization end-products and has shown that *T. selenatis* and *E. cloacae* SLD1a-1, which have periplasmic and membrane-bound SeO_4^{2-} reductases, respectively, produce different reduced Se^0 mineral precipitates following unique SeO_3^{2-} reduction pathways [72].

Selenate Reduction to Selenite/Biselenite: Most known SeO_4^{2-}-reducing microbes are *Bacteria*, although *Archaea* and *Eukarya* are known to reduce SeO_4^{2-} as well [4]. Selenate-reducing microorganisms have been identified within the Crenarchaeota, low and high G+C gram positive bacteria, and much of the Proteobacteria [67, 73]. Metabolically and taxonomically diverse communities of SeO_4^{2-}-respiring organisms from the class *Gammaproteobacteria, Betaproteobacteria, Epsilonproteobacteria, Chrysiogenetes, Deferribacteres, Deltaproteobacteria,* and the phylum *Firmicutes* were identified in aquatic sediments from four freshwater environments [44].

Selenate Reduction to Elemental Se: Bacteria known to accomplish anaerobic dissimilatory SeO_4^{2-}reduction to Se^0 (Figure 5, reaction pathway a) include *T. selenatis*

[74], *Geospirillum* SeS-3 [68, 75], *S.barnesii* [46], *B. arsenicoselenatis* and *Selenihalanaerobacter* [76]. *Enterobacter homaechei* was also shown to reduce SeO_4^{2-} to Se^0, although it is not clear whether this was a dissimilatory or a detoxification process [77]. The same is true of several members of the genus *Dechloromonas [78, 79]*. Some bacteria such as *S. barnesii* can reduce SeO_4^{2-} to Se^0 while others like *T. selenatis* and *E. homaechei* can only reduce SeO_4^{2-} to SeO_3^{2-}. Thus, achieving the precipitation of an insoluble Se^0 or Se^{2-} mineral can require the participation of multiple members of the microbial community. In some environmental settings, NO_3^- and SO_4^{2-} were shown to inhibit SeO_4^{2-} reduction to Se^0 [48], perhaps due to inhibition of SeO_3^{2-} reduction by non-Se-specific reductase enzymes with greater specificity for NO_3^- or SO_4^{2-}. However, this is not true in all settings; and NO_3^- has been shown to be consumed concurrently with SeO_4^{2-} reduction in mixed community microcosms.

It appears that unique SeO_3^{2-} reduction mechanisms result from specific SeO_4^{2-}reductase enzyme expression and regulation, which yield characteristic localization of biomineralization, with Se^0 precipitates reported in cytoplasm, periplasm or extracellular deposits for different organisms [72]. The mechanism and location of SeO_4^{2-} reduction thus influences potential biogeochemical pathways for subsequent SeO_3^{2-} reduction.

Selenate Detoxification: Bacterial species that have been shown to reduce SeO_4^{2-} for detoxification purposes (e.g., non-growth dependent reduction) include *E. cloacae* SLD1a-1 [80], *Anaeromyxobacter dehalogenans* [81] and *Desulfovibrio desulfuricans* [43]. Aerobic and microaerophilic non-respiratory reduction of both SeO_4^{2-} and

SeO_3^{2-}oxyanions has also been reported for *Pseudomonas stutzeri* [82-85] and *Azospira oryzae* [86]. *Stenotrophomonas maltophilia* isolated from drainage pond sediment did not grow on Se oxyanions, SO_4^{2-}, or NO_3^-, but was able to reduce SeO_4^{2-} to Se^0 under microaerophilic conditions upon reaching stationary phase; it also produced volatile Se^{2-} compounds [52].

The molecular mechanisms of SeO_4^{2-} detoxification are different from dissimilatory mechanisms. An earlier proposed detoxification mechanism involves maintenance of redox poise through removal of excess electrons by a membrane-bound metal reductase [41]. A more recent study of detoxification in *E. cloacae* [56, 87, 88] identified facultative regulation of SeO_4^{2-} reduction by the global anaerobic regulatory gene fnr, which limits the expression of the SeO_4^{2-} reductase enzyme to low O_2 conditions. Selenate reduction in *E. cloacae* is catalyzed by a unique Mo-dependent, cytoplasmic membrane-bound (periplasm-facing) enzyme that is distinct from the Ser reductase as well as the NO_3^- reductase [89]. This reductase could only sustain very slow growth on SeO_4^{2-} under NO_3^--limited conditions [64].

Selenite Reduction

Although SeO_3^{2-} and $HSeO_3^-$ are less mobile than SeO_4^{2-}, because of a higher tendency to sorb to mineral surfaces under neutral pH conditions, they are more toxic and can bioaccumulate more readily. Review of available literature suggests that factors influencing the SeO_3^{2-} reduction biogeochemical pathways directly influence the ultimate stabilization of Se within mined by-products and thus have obvious bearing on its mobility and toxicity. Potential mineralization end points include formation of sorbed

complexes on mineral surfaces, precipitation of Se^0 or Se^{2-} as minerals, or volatilization of methylated compounds.

Selenite reduction (Figure 5, reaction pathway a) is much less kinetically constrained than SeO_4^{2-} reduction. Abiotic reduction of Se(IV) to Se(0) and/or Se(-II) thus occurs far more readily than Se(VI) reduction, through redox reactions with Fe^{2+}-containing minerals in mixed Fe^{2+}/Fe^{3+} hydroxysulfate green rust [49], freshly precipitated Fe oxide [90], siderite [91], and Fe^{2+} complexed on the surface of montmorillonite [92], clay [93], and calcite [94]. Aqueous Se^{2-} and SeO_3^{2-} have also been shown to undergo abiotic redox reactions with sulfide minerals [95, 96], resulting in the reductive formation of either Se^0 or $FeSe_x$ depending on the oxidation state of the precursor sulfide mineral [97]. Selenite was also shown to co-precipitate with biogenic sulfide within a SO_4^{2-}-reducing biofilm [59].

Mechanisms of Selenite Reduction: Microbial reduction of SeO_3^{2-} to Se^0, and selenide minerals and methylated forms is also common [51,82, 98], in spite of the fact that the reduction of SeO_3^{2-} is not kinetically constrained. Selenite reduction to Se^0 is energetically less favorable than SeO_4^{2-} reduction (-65 kcal/mol, [4]) but offers greater potential energy yield than is offered by SO_4^{2-} reduction [41]. No SeO_3^{2-}-specific reductase has been reported. The mechanisms of biological SeO_3^{2-} reduction appear to be more diverse, involving a variety of reductase enzymes capable of transforming elements including NO_3^-, NO_2^-, tellurite, sulfite and SO_4^{2-}. Specific possibilities include the periplasmic NO_2^- reductase or hydrogenase I [52] and the glutathione reductase [99].

A recent study in *E. coli* showed that SeO_3^{2-} reduction was accelerated by several natural and synthetic quinone compounds that enhance electron transfer in promoting Se reduction both inside and outside microbial cells [100]. Another recent study showed that members of the genera *Enterobacter*, *Bacillus* and *Delftia* had a strong physiological capacity to adapt to high concentrations of SeO_3^{2-} under both aerobic and anaerobic exposure conditions, with resulting changes in cell morphology, fatty acid composition, and intracellular precipitation of Se^0 [101].

Selenite Respiring Microbes: Bacterial species known to respire SeO_3^{2-} include *Cupriavidus metallidurans* [102], *Bacillus selenitireducens* [103], *Shewanella oneidensis* [104], *Aeromonas salmonicida* [105], and *Rhodobacter sphaeroides* [106]. *C. metallidurans* has a unique capacity to accumulate both SeO_4^{2-} and SeO_3^{2-}, but has only been shown to reduce SeO_3^{2-}, to Se^0 [107] and selenomethionine [102, 108]. In 2010, the complete genome for *C. metallidurans* CH34 was reported. It is a model organism for bioremediation with a capacity to withstand millimolar concentrations of over 20 different heavy metal ions, including Se and Cd [109].

Selenite Detoxification: Non-respiratory SeO_3^{2-} reduction has been described for the bacterial species *Klebsiella pneumonia, Pseudomonas fluorescens, Enterobacter amigeneus* [77], and *Stenotrophomonas maltophilia* [52]. Algal species, including *Chlamydomonas reinhardtii* [110], *Spirulina platensis* [111], and *Chlorella vulgaris* [112] can accumulate and reduce SeO_3^{2-}.

Elemental Se and Selenide Precipitation

Precipitation of Se^0 results from the reduction of either SeO_4^{2-} or $SeO_3^{2-}/HSeO_3^-$ (Figure 5). Selenide can be formed via reduction of either $SeO_3^{2-}/HSeO_3^-$ or Se^0 as reported for *B. selenitireducens* by Herbel et al. [103], or through biological transformation of alkylated Se (see Figure 5, reaction pathways a and d). Both Se^0 and Se^{2-} minerals are relatively insoluble and readily precipitate as solid phases. Crystalline Se^0 has a reddish grey color, while biogenic Se^0 has a unique salmon red color and often occurs as framboids or nanospheres [76]. Selenide reacts with metal cations to form insoluble metal complexes (Figure 5, reaction pathway f), such as the mineral isomorphs dzarkenite/ferriselite ($FeSe_2$), or the mineral clausthalite (PbSe). Pearce et al. described the formation of Se^0 and Se^{2-} minerals as a result of the microbial oxyanion reduction of SeO_3^{2-} [113].

Organo-Se Compounds

The assimilation of Se in proteins, and formation of methylated Se compounds, may also influence Se cycling and the formation of stable Se compounds within the phosphate backfill environments in the S.E. Idaho Phosphate Resource Area. Microbial assimilation of Se in organic compounds such as selenocysteine (Figure 5, reaction pathway b) may occur in algal biomass-enriched zones. During assimilation into cells, both SeO_4^{2-} and SeO_3^{2-} can be transported across cell membranes via the SO_4^{2-} ABC transporter using permease enzymes, but there is evidence for multiple uptake systems for the more toxic SeO_3^{2-} compound [5, 11]. Selenium is incorporated into proteins in a manner that is analogous to that observed for S, but it has several unique properties that

result in the production of selenols (as opposed to thiols) and mixed thiol-selenol compounds [114].

Selenium can also be converted into volatile organic compounds, such as dimethylselenide and selenomethionine, by microbes along alkylation pathways as shown in Figure 5, reaction pathway c [11, 13, 115, 116]. Alkylation, the linking of alkyl groups including methyl compounds to Se, is reported to involve reaction of inorganic $SeO_3^{2-}$with S-adenosylmethionine (SAM), forming a series of reaction products including dimethyldiselenide, dimethylselenone, dimethylselenide, and trimethylselenonium [8]. This process increases the volatility of Se compounds and improves membrane transport and therefore microbial excretion. This process also decreases toxicity, but the increased membrane permeability raises potential for environmental accumulation by some species [117]. Methylation is a common detoxification mechanism [11] and both Se(0) and Se(IV) compounds can be methylated. Recent work by Ranjard et al. [118, 119] has identified a bacterial thiopurinemethyltransferase involved in Se biomethylation in freshwater environments. Rapid microalgal metabolism of SeO_4^{2-} to volatile dimethylselenide in freshwater [120] and production of volatile DMSe and DMDSe species by the microfungus *Alternatia alternata* has been described [121]. Seleno-L-methionine was identified as the dominant organo-Se compound produced by the bacterial strain *C. metallidurans* CH34 upon exposure to SeO_4^{2-} or SeO_3^{2-} [108]. The majority of gaseous Se compounds that are stable under the neutral pH conditions typical of phosphate backfill environments are likely to be methylated compounds, since H_2Se gas is only stable under strongly acidic and reducing conditions (Figure 3). Under certain

conditions, volatilization of Se may contribute to a decrease in soluble and bioavailable Se within mine waste facilities.

Several fungi and *Bacteria* are known to contribute to methylation and volatilization under dominantly aerobic and unsaturated conditions (18 to 70% of saturated water content) when sufficient C is provided and where NO_3^- and heavy metal concentrations are low [8, 11]. Bacterial genera with members capable of producing methylated Se compounds include some members of the *Aeromonas, Flavobacterium, Pseudomonas,* and *Rhodocyclus.* Dealkylation (Figure 5, reaction pathway d) by methylotrophic and methanotrophic organisms has also been reported in anaerobic sediments [11].

Selenium Oxidation

Reduced Se^{2-} hosted in sulfide minerals and organo-Se compounds is initially released by oxidation of mined materials. The potential for the reoxidation of reduced and immobile Se compounds is also important to predictions of the long-term effectiveness of *in situ* microbial reduction as a method of source control. Reduced Se often occurs as Se^{2-} substituted in sulfide minerals [122], but also as Se^0 and discrete Se^{2-} mineral phases. Selenium release associated with weathering of mine waste in the S.E. Idaho Phosphate Resource Area is thus commonly due to oxidation of pyrite and other sulfide minerals [123]. As a result, the release of Se follows comparable oxidation pathways to those described for sulfide oxidation, both abiotic and biotic. Under abiotic conditions, O_2 is the most powerful oxidant, but Fe^{3+}, Mn^{4+}, and NO_3^- all have the potential to serve as oxidants in its absence. Sulfide and selenide minerals are known to be oxidized (Figure 5,

reaction pathway e) by the sulfide oxidizing bacteria *Acidiothiobacillus ferrooxidans* [124] and a *Leptothrix sp.* [39].

Selenium in the reduced oxidation states is slow to re-oxidize, although a range of rates are reported. Dowdle and Oremland reported rate constants for Se^0 oxidation that were four orders of magnitude lower than those for dissimilatory SeO_4^{2-} reduction in organic-rich, anoxic sediments [39]. In that study, Se^0 was oxidized mostly to SeO_3^{2-} with smaller quantities of SeO_4^{2-} produced in live soil microcosms where SeO_3^{2-} sorption limited further production of SeO_4^{2-}. However, Tokunaga reported rapid reoxidation of freshly precipitated nanoparticulate Se^0 in ponded sediments when exposed to O_2 [125]. Remobilization of almost half of colloidal biogenic Se^0, which can remain suspended in aerated aquatic systems, has also been demonstrated [126]. Only one bacterial species, *Bacillus megaterium*, has been singled out in the literature for its capacity to oxidize Se^0 to SeO_3^{2-} [127]. Selenite is also reported to be slow to reoxidize abiotically in the presence of O_2 at neutral or alkaline pH and requires stronger oxidation by ultra-violet radiation or redox-active elements such as Fe^{3+} [38] or Mn oxides [128] under more acidic conditions.

Adsorption of Se Species

Adsorption is the dominant abiotic control of Se solubility at neutral pH. A few SeO_3^{2-} minerals are known, such as ferroselite, $Fe_2(OH)_4SeO_3$, and $CaSeO_3$ x H_2O, as shown in Figure 6. These minerals are rare, however, and there are no known insoluble SeO_4^{2-} minerals [1]. Although SeO_4^{2-} sorption is likely to be limited under the neutral to alkaline conditions observed in backfilled phosphate mine waste, SeO_3^{2-} sorption may be

an important attenuation mechanism if sufficient mineral substrate is available. Dissolved concentrations of SeO_4^{2-} and $SeO_3^{2-}/HSeO_3^-$ are controlled abiotically under oxidizing conditions through sorption to metal oxides [129-133], apatite [134], carbonate [135], and clay [136-138] minerals. Adsorption of $SeO_3^{2-}/HSeO_3^-$ to Fe and Mn oxides, carbonate, apatite, and clay minerals is possible within the waste lithologies mined in the S.E. Idaho Phosphate Resource Area. Sorption of the oxyanionic species increases with the increased positive charge of protonated oxide and clay mineral surfaces under acid conditions. At neutral pH, SeO_4^{2-} adsorption is much less efficient than the more significant attenuation of $SeO_3^{2-}/HSeO_3^-$ under mildly reducing conditions. Maximum SeO_4^{2-} sorption requires a pH below 6. In one study, the midpoint of an adsorption isotherm for SeO_4^{2-} to hydrous ferric oxide ranged from pH 5.5 to 6.7 for total Se concentrations between 0.1 and 10 μmol/L; in contrast, the mid-point for SeO_3^{2-}sorption was reported between pH 8.8 and 9 for the same range in concentration [130]. Sorption of Se oxyanions has been described in coal mine environments [139] and modeling parameters have been developed for Se species within the constant capacitance [140] and triple layer models [141]. High concentrations of organic matter in soil also appear to limit the solubility and bioavailability of Se [10], although organic acids may compete for sorption sites on goethite [130]. Sulfate and NO_3^- may also compete with Se oxyanions for sorption sites.

Iron and Manganese Biogeochemistry

Biogeochemical cycling of Fe and Mn by microorganisms potentially influences

Se mobility within the backfilled phosphate environments in the S.E. Idaho Phosphate Resource Area. Iron and Mn-cycling microorganisms may drive the mineralization of complex hydrocarbon compounds present in the Meade Peak sediments and/or alter the availability of oxidized Fe and Mn mineral substrate capable of sorbing SeO_3^{2-}/$HSeO_3^-$. Iron has been shown to be important in abiotic Se sorption and precipitation of ferroselite ($FeSe_2$) [142]. It has been suggested that additional Fe should be added to S.E. Idaho Phosphate Resource Area waste to stabilize Se as an Fe-selenide compound in waste deposits [143]. Because of the high concentration of Mn in the Meade Peak sediments, reduction of Mn oxides by Fe^{2+} (with subsequent cycling of both elements) may play an important role in this system [144].

Microbial oxidation of C coupled to Fe^{3+} reduction is thought to mineralize much of the reduced organic matter in sedimentary and aquatic environments [145, 146]. Organisms capable of this metabolism likely influence the bioavailability of native C to the indigenous consortia of *Bacteria* that affect Se mobility in the Meade Peak sediments. They also influence the presence of reactive Fe^{2+} species in the environment. The importance of Fe and Mn cycling in hydrocarbon degradation has been the subject of numerous investigations [145, 147-151], which are discussed further below and in Chapter 4. Of particular interest to the questions of *in situ* Se reduction using complex bitumen-derived native C in blasted rock within subsurface deposits is the potential for anaerobic, NO_3^--dependent Fe oxidation [152, 153]. The potential role of Fe^{2+}/Fe^{3+} and Mn^{2+}/$Mn^{3+}Mn^{4+}$ as electron shuttles is also interesting in context of SeO_3^{2-} and NO_3^- reduction within the backfill [151, 154]. Given the neutral pH of the phosphate mine

waste, Fe and Mn are likely to form stable oxide minerals, unless reduced through biological activity. Dynamic cycling of Fe and Mn coupled to hydrocarbon reduction creates reducing potential for the subsurface backfill deposit system which balances the flux of oxidants.

Belzile et al. [155] described a multi-scale chemical, biological, and physical process of Se attenuation. Reduced SeO_3^{2-} is sorbed onto Fe-Mn oxyhydroxides, which are dissolved through biotic reduction under progressively reducing conditions developed during diagenesis. Biotic Fe- and Mn-reducing organisms promote mineralization of organic matter, thus driving Se sequestration as Se^0, seleniferous pyrite, and selenide minerals [155].

Organic Geochemistry of the Meade Peak Shale

The organic C content of the phosphate overburden lithologies varies considerably. The dark brown-to-black colored Meade Peak shale sediments are highly carbonaceous, containing up to 15% C by weight [26]. These sediments were source rocks for evolved hydrocarbon, which migrated out of the Meade Peak member during Jurassic time, leaving behind immature kerogen and bitumen residues that reflect a complex thermal maturation history [156, 157]. Extractable, naturally occurring Meade Peak hydrocarbons are asphaltic in composition, ranging from simple alkane and alkene compounds to monocyclic and polycyclic aromatic hydrocarbons. Carbon species naturally present within the Meade Peak shale include toluene, benzene, naphthalene, phenanthrene, and dibenzothiophene (Chapter 3). Conversely, the Rex chert member is

variably argillaceous and oxidized with grey nodular chert concretions in a locally iron-oxide-bearing matrix; it is much less carbonaceous and contains far fewer aromatic compounds (Chapter 3).

Bioavailability of the C that occurs in the phosphate overburden is an important factor that will limit the extent of *in situ* Se reduction by native microbes. In other studies of organic-rich, metal-bearing shales, native *Microbacteria* spp. and *Pseudomonas* spp. have been shown to grow using primary C as the sole C and energy source [158]. Similarly, microbial growth on kerogen in shales has been documented [159, 160]. The ability of native organisms to grow using indigenous C is hypothesized to drive the reduction of Se and other metals in the S.E. Idaho Phosphate Resource Area backfills. In this backfill, application of NO_3^-- and SeO_4^{2-}-rich water appears to have triggered biological reduction of both, without addition of excess C or other modification (e.g., addition of Fe). Based on this observation, C is believed to be bioavailable and present in excess at other subsurface locations where Meade Peak sediments are placed as backfill.

Microbial Degradation of Complex Hydrocarbon Compounds

The goal of this study is to evaluate the potential for native microorganisms to accomplish SeO_4^{2-} reduction as a control on aqueous Se concentrations in backfilled phosphate overburden without amendment, that is to say, relying strictly on the C compounds available in the rock itself. To that end, published literature addressing aerobic and anaerobic subsurface degradation of complex hydrocarbons by bacteria was reviewed in developing a conceptual model for the investigation. There is an extensive

body of literature treating this subject, including several excellent reviews [144, 153, 161]. The identification of native monocyclic and polycyclic aromatic hydrocarbons compounds in analyses of the shale and chert overburden (Chapter 3), as well as identification of bacteria capable of degrading those compounds (Chapter 4), guided the following literature review.

Key physical and chemical factors controlling hydrocarbon degradation include: complexity of C compounds, dispersion or sorption of the hydrocarbon, concentration, temperature, availability of O_2 and nutrients, activity of water, and pH [145]. Based on the variable saturation and O_2 content measured in the backfilled mine pits, it is likely that bacterial mineralization of aromatic hydrocarbons present in the Meade Peak shale proceeds under both aerobic and anaerobic conditions at neutral to slightly alkaline pH. Optimal rates of overall mineralization may reflect both aerobic and anaerobic processes, under conditions ranging from 30 to 90% water saturation [145]. It is likely that both NO_3^- (from blasting) and primary phosphate are present in the overburden, and diesel fuel used in ammonium nitrate-fuel oil (ANFO) compounds for blasting purposes in the less carbonaceous chert may also be used as a C source. Hydrocarbon degradation in the mixed and blasted waste rock may be the result of microbial respiration using O_2, or anaerobic processes involving reduction of Fe^{3+}, Mn^{4+}, NO_3^-, SeO_4^{2-}, SeO_3^{2-}, or SO_4^{2-} [30]. Degradation of organic C under Fe^{3+}-, Mn^{4+}-, and NO_3^--reducing conditions is of particular interest in these transitional redox environments. Because SO_4^{2-} concentrations remain high in monitored, mine-affected water, SO_4^{2-} reduction does not seem to be an important process within the backfills. It is possible that these metabolisms occur within

backfill micro-habitats, due to local development of suboxic conditions as a result of abiotic and biotic consumption of O_2.

A diverse group of microorganisms has been shown to be capable of anaerobic degradation of aromatic hydrocarbons [162]. A mixed benzene-degrading culture that used NO_3^- as an electron acceptor has been described, which was comprised of several *Bacteria* including members of the genus *Dechloromonas [163]*. Degradation of aromatic hydrocarbons via aerobic pathways is energetically more than an order of magnitude more favorable than anaerobic processes [145], with comparable energy yields from Fe^{3+} reduction (-78.7 kJ/e-) and denitrification (-72.2 kJ/e^-) [164]). Energy yield is particularly high for benzene and toluene degradation coupled to NO_3^- or Fe^{3+} reduction [153]. Recently published studies of anaerobic degradation of benzene [165-169], toluene [170], naphthalene [164], and phenanthrene [171] suggests that these processes are more common than previously recognized.

Anaerobic degradation of benzene likely involves hydroxylation, alkylation, or carboxylation to form toluene, hydroxybenzoate, or fumarate [167], with subsequent alkylbenzene degradation via co-A pathways [172] under either SO_4^{2-}- or NO_3^--reducing conditions [153]. Anaerobic benzene degradation was first reported under denitrifying conditions [168], by *Dechloromonas aromatica*. Bacteria having greater than 98% identity to *D. aromatica* have also been isolated from phosphate backfill at both the Smoky Canyon and Dry Valley mines, and shown, in this study, to reduce SeO_4^{2-}.

Many subsurface bacteria survive using anaerobic or facultative metabolisms under low nutrient and temperature conditions and have low metabolic rates [173]. The

rates of mineralization for aromatic compounds are more directly influenced by hydrophobicity compared to rates of mineralization for the more soluble alkane compounds [145]. Denitrification plays an important role in the degradation of monocyclic aromatic benzene and toluene [153], and polycyclic aromatic naphthalene and phenanthrene [173]. An *in situ* study of mixed microaerophilic and anaerobic microbial communities in benzene-contaminated groundwater [174] indicated the presence of phylotypes highly similar to members of the aerobic (or denitrifying) genera *Pseudomonas, Polaromonas, Acidovorax,* and *Rhodoferax*, together with methanogenic organisms, suggesting biodegradation of benzene through paired aerobic and anaerobic metabolism. Anaerobic degradation of benzoate and hydroxybenzoate compounds under SeO_4^{2-}-reducing conditions by diverse members of the *Gamma proteobacteria* has been reported [53].

Conceptual Model of Phosphate
Backfill Se Biogeochemistry

Insight into biogechemical processes that influence Se cycling and mobility based on the preceding literature review allows definition of a conceptual biogeochemical model for *in situ* reduction of Se by native consortia using indigenous C within backfilled mine pit environments at both the mine facility and micro (pore) scales (Figures 3 and 4). Previous investigation has shown that lithology, C content, geochemistry (particularly, NO_3^-, Fe, and Mn), and mineralogy of overburden will influence Se biomineralization. Temperature, pH, Eh, and Se speciation clearly influence the biogeochemical transformation of Se. Availability of water influences biological productivity, O_2 availability, and both the release (e.g., vapor phase Se) and transport of Se (e.g., saturated

vs. unsaturated conditions). Oxygen availability is a particularly important factor influencing styles of microbial metabolism that affect both hydrocarbon degradation and Se speciation. These factors were evaluated through *in situ* monitoring of backfilled phosphate overburden, as described in Chapter 3, and used to identify experimental conditions for sample collection and storage, microbial isolation, and construction of microcosm reactors used in this study.

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CHAPTER THREE

SITE DESCRIPTIONS, SAMPLING METHODS AND EXPERIMENTAL DESIGN

Microbial communities within mine backfill deposits, and their ability to reduce selenium (Se), are directly affected by: 1) lithology and geochemistry of rock; 2) the flux of oxygen (O_2) and water into the subsurface; and 3) resulting groundwater geochemistry. To characterize and quantify these conditions in the S.E. Idaho Phosphate Resource Area, rock and groundwater was sampled and analyzed, together with *in situ* hydrogeochemical measurements of temperature, O_2, and carbon dioxide (CO_2), and moisture. Samples of rock and water, where possible, were collected at the Agrium Nu-West Dry Valley, J.R. Simplot Smoky Canyon, and Monsanto Enoch Valley mines (Figure 7).

Members of the Idaho Mining Association (IMA) Phosphate Working Group have conducted several studies of overburden hydrogeology and Se geochemistry since 1996 [1]. Sampling and analysis of overburden, groundwater, and subsurface conditions in addition to the Tetra Tech/MFG, Inc. work was conducted for this study. This chapter begins with a brief description of backfill at the three mine sites, as well as a summary of previous work characterizing the hydrogeochemistry of Se in these locations [2]. These include overburden sampling and analyses in 2005; drilling, in 2006, and characterization of overburden geochemistry, reported in 2008, conducted in association with this study [2], *in situ* monitoring of backfill hydrogeochemistry, 2007-2010 [2, 3], and groundwater sampling, this study and previous related investigations [4, 5].

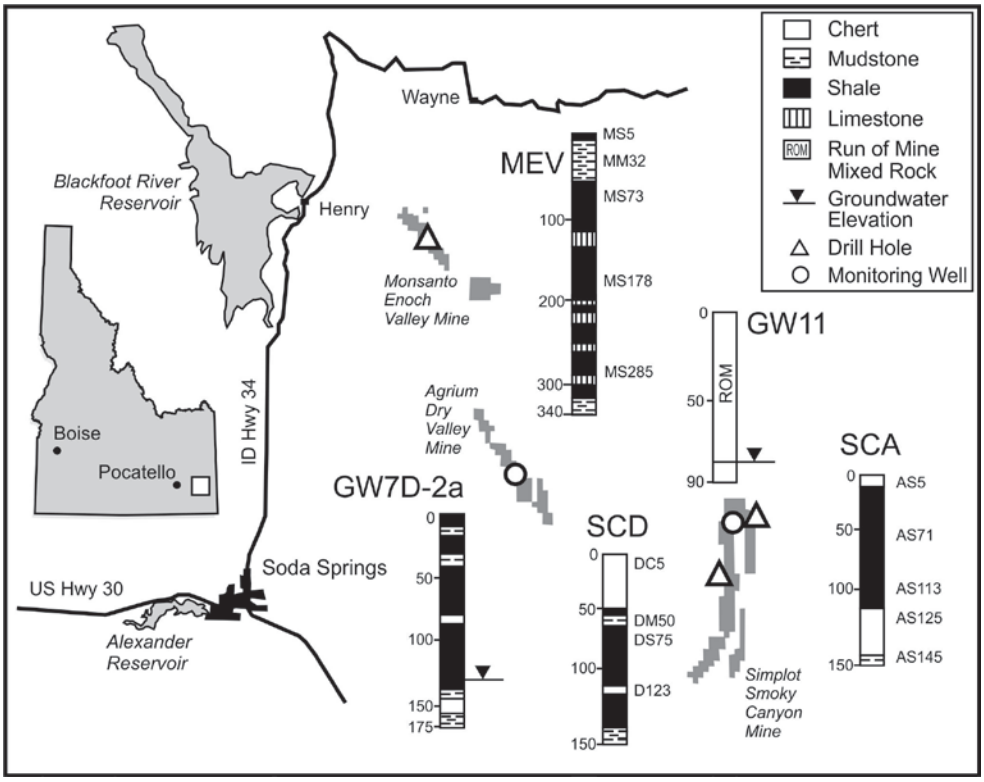

Figure 7. Location of 3 sampled drill holes and 2 monitoring wells in S.E. Idaho Phosphate Resource Area. Depth to exposed lithologies and water in each hole are illustrated. Rock sample locations are indicated to the right of each drill hole at the corresponding sampled depth; the ID reflects the sampling location and rock type, e.g. MS5 represents M for Monsanto's Enoch Valley drillhole MEV, S for Shale, and 5 for 5 feet of depth. Likewise, SCA represents Smoky Canyon drillhole A and SCD represents Smoky Canyon drill hole D. Groundwater monitoring wells are numbered as shown, GW7D-2a (Dry Valley) and GW11 (Smoky Canyon).

Technical reports cited above are publically available from the state of Idaho and/or federal land management agencies, including U.S. Forest Service and U.S. Bureau of Land Management. Some of the reports providing site descriptions cited above or discussed below are provided in Appendix A. Collectively, site conditions are summarized to define experimental design and material requirements for the biogeochemistry experiments presented in Chapters 4 and 5.

Backfilled Mine Panels in S.E. Idaho Phosphate Resource Area

Phosphate ore is mined from regional, NNW-trending folds developed in the Phosphoria Formation within the Meade Peak overthrust. Mine pit (a.k.a. panel) backfills at the Dry Valley, Smoky Canyon, and Enoch Valley mines have been constructed using randomly placed run-of-mine (ROM) waste rock mined from the Meade Peak and Rex chert members of the Phosphoria Formation. At Enoch Valley, more limestone was mined than at both the Dry Valley and Smoky Canyon mines, where more chert was removed. Changes in backfill construction methods, water management, cap construction, and proximity to the regional groundwater table further distinguish backfill conditions at each site. Collectively, these three mines provide an excellent overview of field conditions in S.E. Idaho Phosphate Resource Area backfill.

Agrium Dry Valley Mine

The management history, geology, hydrology, aqueous chemistry, O_2 and CO_2 concentrations, and temperature of backfill at Dry Valley were described by Tetra Tech/Maxim [6]. The B pit backfill at Agrium's Dry Valley Mine was constructed through plug-dumping (rather than end-dumping) by individual trucks on constructed lifts (benches) of fixed height, with random placement of shale, chert, mudstone, and limestone (in descending order of relative tonnage). The pit has a 165 acre footprint, extending nearly 9000 feet along strike and 800 feet across, as shown in Figure 8. Depth is approximately 200 feet below the local ground surface. Pit water was discharged seasonally in 2000 and 2001 into multiple ponds on the surface of the reclaimed B pit

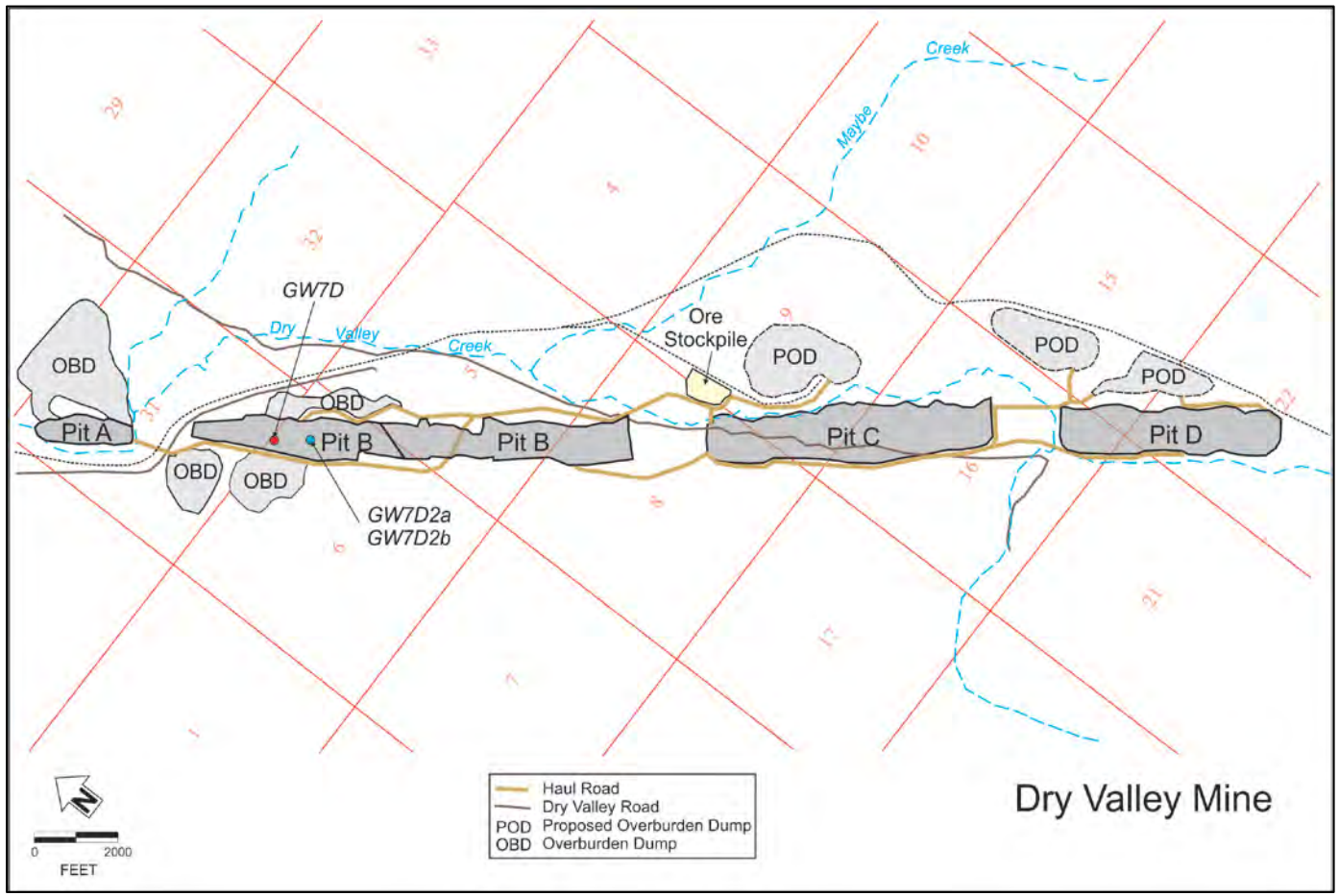

Figure 8. Map of Dry Valley Mine showing backfilled pits A to D and groundwater monitoring wells GW7D, GW7D2a/2b. After Tetra Tech, 2007, [1]

backfill during mining of the adjacent C panel (Figure 8). This resulted in temporary saturation of the backfill with NO_3^-- and SeO_4^{2-}-rich water, followed by draining to field capacity within the upper backfill [6]. A perched zone of saturation exists low in the backfill, which lies above the regional groundwater table in the underlying limestone bedrock (approximately 60 feet below ground surface). The limestone between the saturated backfill and the groundwater is relatively dry, reflecting the confined nature of the groundwater within the backfill. Results suggest that the methods of placement (e.g., constructed lifts rather than end dumping down long waste rock slopes) [2], as well as the temporary saturation of these materials [6] distinguish the physical hydrogeology and therefore the biogeochemistry of these backfills from other S.E. Idaho Phosphate Resource Area backfills.

The cross section shown in Figure 9 illustrates the monitoring wells installed at the Dry Valley Mine in 2003. Groundwater well GW7D was completed in deep backfill at the northern end of reclaimed pit B at the Dry Valley Mine. This well has been monitored for compliance purposes since 1998 and is located within the footprint of historic pit dewatering discharge ponds. A second well was drilled, GW7D2, approximately 500 feet to the north of the GW7D well. Two monitoring wells completed at the second location, one deep (GW7D2a, 180 feet, bottom of backfill) and one more shallow (GW7D2b, 140 feet, the approximate groundwater elevation), have been sampled since October 2002. Water quality data from GW7D and GW7D2a/2b are provided in Appendix A1, Tables A1-1 and Tables A1-2. Near-surface gas vapor points and lysimeters at depths of 5, 10, 20 and 30 feet were also installed (Figure 9). Descriptions

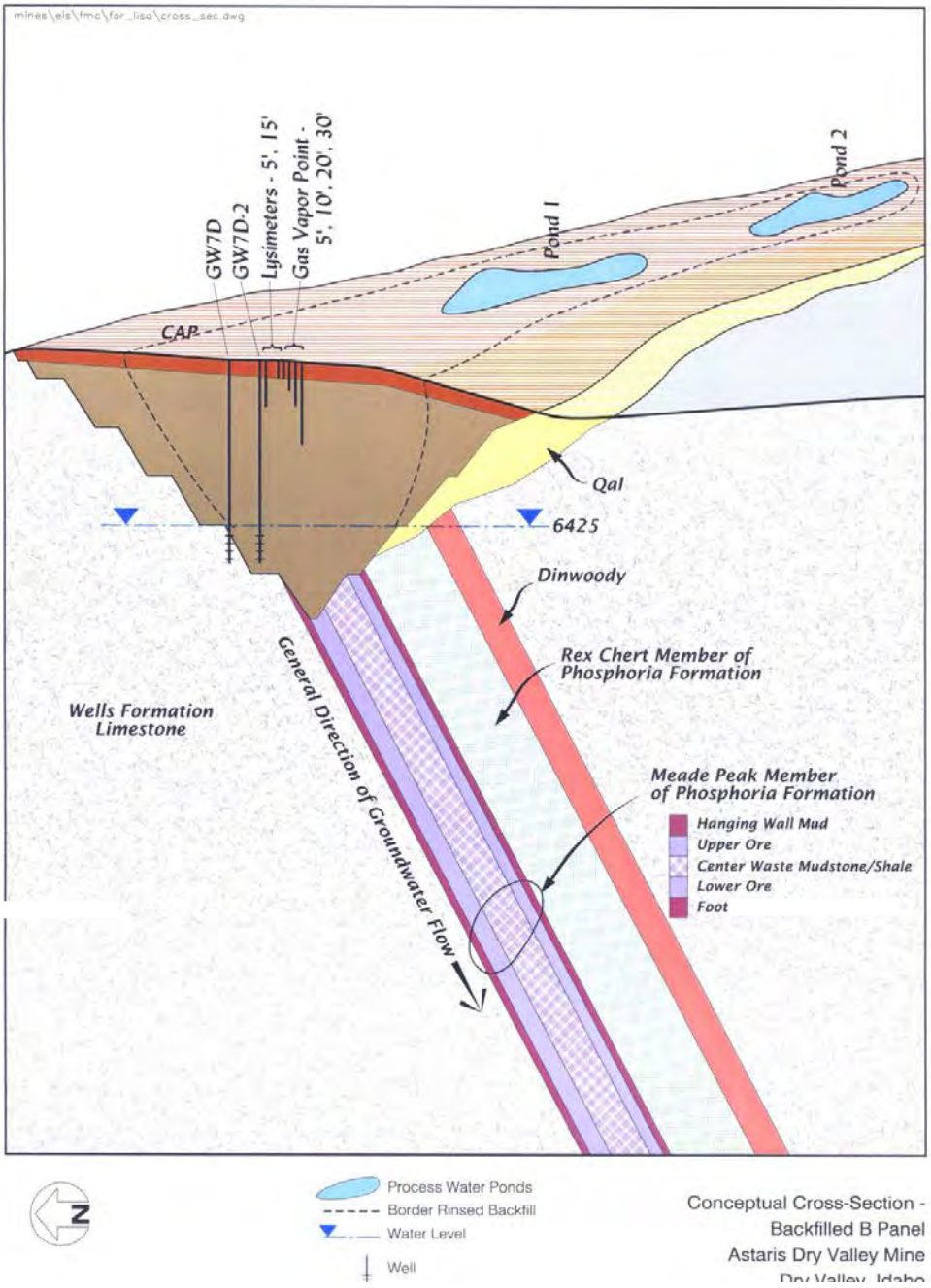

Figure 9. Dry Valley cross section showing monitoring installation, after [7].

of the subsurface monitoring installations, and data collected from them are provided in the Agrium Groundwater Validation study [6], portions of which are also provided in Appendix A1. These data show higher concentrations of total dissolved Se in near-surface (<10 feet) lysimeter samples (mean 0.22 mg/L, with values as high as 0.74 mg/L). Samples collected below a depth of 10 feet in backfill show O_2 depletion (concentration below detection limit (0.1 mg/L), with CO_2 enrichment up to 7% CO_2. Of particular interest are the low soluble concentrations of Se in the two deep wells (GW7D and GW7D2a) at the Dry Valley Mine, which are below the Idaho groundwater standard of 0.05 mg/L. These low Se values correspond with the absence of detectable dissolved O_2 and O_2 gas within backfilled sediments above the water table [6].

J.R. Simplot Smoky Canyon Mine

The hydrogeochemical conditions in backfill at the Smoky Canyon and Enoch Valley mines were described by Tetra Tech/MFG [2]. Three distinct portions of the overburden at the Smoky Canyon Mine have been incorporated into this study, which include the backfilled portions of panels A and D, and the external surface overburden dump located to the southeast of panel A (Figure 10). Most overburden at the Smoky Canyon Mine was placed by end-dumping mine wastes from individual trucks along angle of repose slopes from panel highwall benches (excavated benches that step back from the bottom of a pit or panel in order to create a stable slope on the margins of the pit) or from dump crests (the top of mine waste rock piles). Here, individual truckloads of overburden tend to be distributed along dump faces tens or hundreds of feet in length, where size fractionation occurs by sorting and materials are comingled more completely

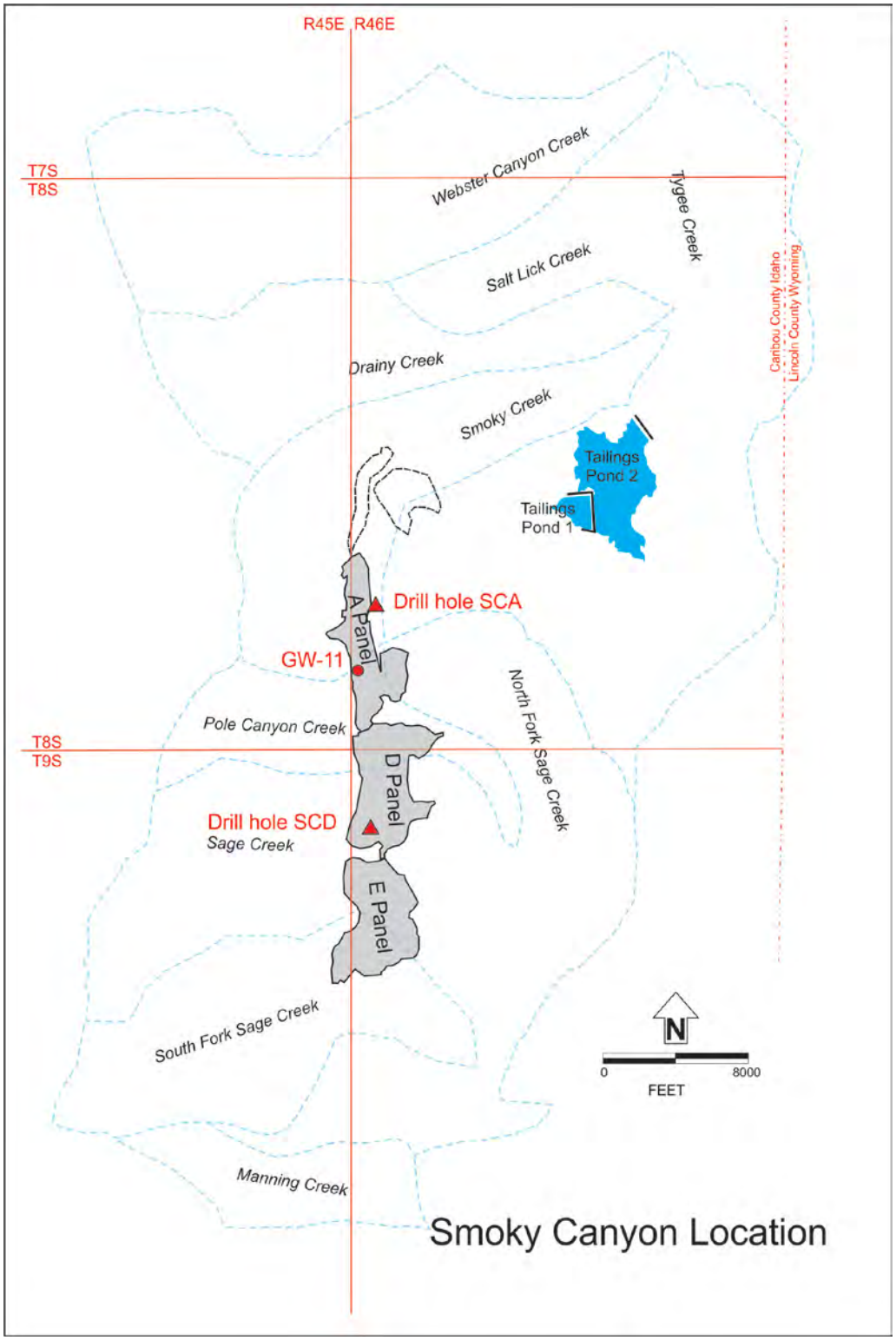

Figure 10. Map of Smoky Canyon Mine showing 2006 drilling locations relative to backfilled panels (pits) A, D and E.

than would occur where individual trucks dump isolated plugs of material that is less well sorted (Dry Valley).

Coarser layers provide conduits for enhanced gas exchange, relative to fine grained layers [8] and also serve as capillary breaks, elevating the saturation and water storage within overlying finer grained zones [9-11]. The D backfill panel extends over a footprint of 370 acres and contains approximately 64 million cubic yards of backfilled overburden. Depth is approximately 220 feet. It was constructed between 1993 and 1997, and the southern third of the facility was capped with chert, graded, and covered with topsoil for re-vegetation in 2004. The northern portion of the D panel was constructed and re-vegetated prior to initiation of chert capping as a best practice for Se management [2].

Panel A (and the associated, free standing external Panel A dump) were constructed beginning in 1984 and are significantly older than the D panel backfills. Panel A backfill is approximately 100 feet thick and extends over a footprint of 120 acres. The Panel A external dump covers some 80 acres and contains 7 million cubic yards of mixed overburden. The external dump was re-graded and covered with topsoil that varies in thickness (3 inches to 3 feet) prior to re-vegetation in 1996; it was not capped with inert rock [2]. The GW11 monitoring well at the Smoky Canyon Mine was completed in approximately 100 feet of backfill along the east side of the A panel, where it was collared (the point at which a well starts at the surface) in a maintenance area located adjacent to the main haul road where the grade was flat. Water ponding in this unreclaimed area resulted in episodic recharge in response to changes in precipitation.

The elevation of ground water was thus variable in GW11 and intermittently dropped below the maximum depth of the well, so that it was not possible to consistently collect water from this well. The well was accessible from 2001 to 2009, after which it was decommissioned to allow for construction of another lift of overburden in that location. Water quality data from GW11 reported in 2002 are provided in Appendix A1, Table A1-3. A description of the groundwater sampling protocol used at GW11 is also provided in Appendix A1.

Monsanto Enoch Valley Mine

The mined pit at the Enoch Valley Mine was backfilled between 2000 and 2002, and reclaimed in 2003. Backfill placed in the lower portion of the facility was end dumped down angle of repose slope distances longer than 50 feet; the upper backfill was constructed with a combination of plug dumping and dozing (pushing of rock with equipment) thereby constructing discrete lifts or tiered benches. This location has a higher proportion of limestone in the backfill than other studied locations. Seleniferous waste materials were isolated within the center of the facility, which does not extend above the original topography. The surface was re-contoured and capped with 4 feet of limestone, and overlain by 18-24 inches of alluvium and chert as topsoil. The backfill lies approximately 128 feet above the regional groundwater table; consequently, it was not possible to sample groundwater at the Enoch Valley Mine (Randy Vranes, Monsanto, personal communication, 2007 and 2011).

Sampling and Analysis Methods

Mined overburden and groundwater from backfilled panels were sampled at multiple time points. Methods used to obtain data and materials for experiments are described below. This study also relied on sampling and analysis conducted by others [4-6], as well as work that was conducted at the same time as this study [2, 3].

Overburden Sampling Program

The majority of rock sampling was completed in March 2005 (Appendix A-2) and March 2006 (Appendix A-3). Initial sampling (2005) was limited to archived drill samples from the Dry Valley Mine (hole GW7D2) and near-surface exposures of bedrock and overburden at the Smoky Canyon Mine. Subsequent drilling (2006) at the Smoky Canyon and Enoch Valley mines provided greater access for subsurface sample collection. The method and timing was largely dictated by access to equipment and drilling schedules, and an effort was made to avoid the most difficult weather and road conditions.

2005 Overburden Sampling: A total of 58 samples of overburden were collected in 2005 at the Dry Valley and Smoky Canyon mines (Figure 7). Specifically, 34 rock samples were collected from an archived core of unconsolidated backfill from the Dry Valley Mine groundwater monitoring well GW7D2; geochemical analyses were reported previously for select samples from this drilled hole, as described in Table A2-1 [6]. An additional 24 samples were collected at the Smoky Canyon Mine by excavating portions of the unreclaimed D & E panel backfills, as shown in the photo log provided in

Appendix A-2. Overburden was exposed and sampled in several locations within the limits of safe excavation practice in unconsolidated material (at a depth of 6 to 10 feet, depending upon topography).

Multiple samples of each rock type were collected to represent the range of mineralogical, textural, and geochemical variation in backfilled pits. A sampling protocol is provided in Appendix A-2. Approximately 4 kilograms (kg) of overburden were collected at each location; samples were air-dried and sieved. Due to formation of hard pan surface and aggregates during the air-drying process, samples were passed through a bench top soil flailer (Custom Laboratory Equipment, Orange City, FL) at the MSU Plant Growth Center prior to sieving. Particle gradation analyses were obtained using standard dry sieving methods (after ASTM C136, 2005) with 2 inch, 1 inch, and no. 10, 20, 40, 60, 80, 100 and 200 mesh screens on a sieve shaker. The relative clay and silt-sized fractions were calculated based on hydrometer measurements of the sub-200 mesh fraction for some of the samples. Results of the particle gradation analyses are provided as Table 2-1 and Figures A2-1 and A2-2.

Material was coned (mounded into a pile on a plastic sheet) and divided into quarter splits, and 100 grams (g) of each individual sample was archived. Sub-1/4 inch material was composited for subsequent experimental use and analyzed for total organic carbon (TOC) (APHA Standard Method 5310) and total element content (aqua regia digestion followed by multi-element Inductively Coupled Plasma (ICP) Mass Spectroscopy (MS)) for the shale and chert composites from both mines at ALS Chemex (Appendix A2). More detailed analysis of organic C speciation was completed for the

chert and shale composites from the Smoky Canyon Mine following EPA method 3350 with Gas Chromatography Mass Spectroscopy (GCMS) by EPA method 8270C at Energy Labs in Billings, MT (Appendix A2).

2006 Drilling, Geochemistry and *In Situ* Monitoring Program: This study was conducted in parallel with a broader regional study of overburden geochemistry conducted throughout the S.E. Idaho Phosphate Resource Area by the IMA Phosphate Working Group and its contractors (Appendix A3, [2]). Subsurface samples were collected in 2006 using sonic drilling methods, with control of gas exposure and aseptic technique (see below) for additional lithological, textural, geochemical, moisture, and microbial community characterization. Specific objectives for Tetra Tech/MFG (contractor to the IMA Phosphate Working Group) included characterizing the O_2 content within overburden deposits; estimating availability of organic carbon (C) as substrate for microbial activity; characterizing total and leachable Se content of samples; producing an acid-base account for overburden waste; assessing grain size distributions; and sampling for microbiological testing (this study). Four holes, drilled at the Smoky Canyon Mine (Smoky Canyon A dump (SCA) and D dump (SCD)), Enoch Valley Mine (Monsanto Enoch Valley (MEV)), and Rasmussen Ridge Luxor Mine (LUX), were situated to intercept maximum thickness of randomly deposited mine waste in deposits with a range of ages, topographical aspects, duration of weathering, and styles of construction/management. Due to limited resources, only three of these drill holes could be sampled for microbiological analyses; two backfill (SCD and MEV) and one external dump (SCA) locations were thus chosen for this microbial study.

A field sampling protocol was developed for this study in coordination with MFG to provide for rapid, in-field aseptic handling and sampling of all cores (Appendix A-3). Samples were collected and stored to preserve temperature, gas, moisture, and redox conditions to the extent possible. A total of 16 samples were collected for microbial community analysis based on depth and lithology following inspection under nitrogen (N_2) gas at the drill site (see photos Appendix A-3). As samples were collected from the core barrel, they were placed into Lexan® plastic bags, labeled and temperature was recorded. Heating of the core within the core barrel varied due to increased friction under rough drilling conditions. Only one sample was excluded from further evaluation based on a temperature that exceeded 37°C. Each interval was placed into the N_2-flooded and sanitized (10% bleach followed by 70% ethanol) glove box on sheets of fresh plastic.

The sample bag was opened under N_2 gas and the lithology was described in hand specimen for mineralogy, moisture, and clastic content, followed by subsequent laboratory analyses by Tetra Tech/MFG [2]. Sampled intervals were chosen to represent the three principal lithologies (chert, mudstone, and shale) at different depths within both backfilled and external dump overburden facilities. To collect a sample for microbial analysis, the internal core was exposed and sub-sampled using sterilized utensils. These sub-samples were composited, split into several containers for mineralogical, microbial, molecular, and geochemical analysis, and preserved under sterile gas headspace conditions, using filtered air and N_2 gas to create oxic and anoxic conditions, respectively. Containers were sealed to conserve moisture and stored in the dark at temperatures at or below the measured average subsurface temperature of 10°C. Samples

stored under aerobic conditions were aerated periodically under sterile conditions or maintained with a filtered port to allow for air exchange.

Samples selected for microbial study from drill holes at the Smoky Canyon Mine backfilled panels D (SCD) and A (SCA), and the Enoch Valley Mine (MEV) were also submitted by Tetra Tech for analysis of TOC (ASA Method 9 29-2.2.4 combustion IR); leachable organic C (EPA SW-846 followed by ASA method above); total Se (EPA SW-846 3050/6020) analyses; leachable Se (EPA SW-846 1312/6020); acid base accounting (EPA M600/2-78-054 1.3); moisture content (ASTM D2216); grain size (ASTM C136, 2005), and soil moisture retention [2].

The holes drilled by MFG were completed with 2-inch PVC well stem in a sand-packed annular space. Nine sections of high density nylon tubing extending to elevations proportional to 10% of the total depth for each hole were attached to the exterior of the PVC casing, for use in monitoring O_2 and CO_2 concentrations (see TetraTech 2008 report in Appendix A3 for completion details). Well stems were also equipped with a single thermistor for *in situ* temperature measurement. Gas and temperature measurements were made in June and December 2006, see [2] in Appendix A-3.

Groundwater Monitoring and Sampling

Groundwater was collected at both the Smoky Canyon and Dry Valley mines, for measurement of *in situ* parameters (temperature, pH, Eh, Specific Conductivity (SC), and dissolved O_2) and geochemistry (multiple parameters). Native groundwater and live cultures were also collected for use in isolation, enrichment, and culturing studies.

Samples were collected periodically from the three wells (GW7D, GW7D2a, GW7D2b) at the Dry Valley Mine, to obtain live cultures, during site visits that occurred between 2004 and 2008. Samples of groundwater were also collected from well GW11 at the Smoky Canyon Mine, between 2002 and 2007.

Chemical analyses of groundwater were reported independently by the Dry Valley and Smoky Canyon Mines. Tables A1-1 through A1-3 in Appendix A1 summarize groundwater chemistry for wells GW7D, GW7D2a/ GW7D2b, and GW11, respectively. Each of these wells has been monitored over several years (1998 to present) for a suite of regulated parameters. Groundwater chemistry samples were collected following standard operating procedures at each mine site, which are consistent with best management practice for regulatory compliance. Generally, this involved low flow pumping to avoid disturbing sediment or degassing of samples, monitoring of physical and chemical parameters, and appropriate filtration and preservation of samples for analysis within required holding times. Data were managed by third-party contractors and disclosed in operational compliance reports [4, 5]. Monitoring continues at the Dry Valley Mine, but ended in 2007 at the Smoky Canyon Mine when the well head was buried as a result of ongoing backfill construction.

Groundwater collected from these monitoring projects allowed collection of samples for microbial cultivation and collection of sediment for molecular biology studies. Samples for microbial work were collected manually, using a new plastic disposable bailer, sealed in a plastic bag, for each sampling event. Each bailer was rinsed several times with groundwater from the well prior to collection of the sample for

analysis. The bailer was used to stir-up water low in the drill hole and to obtain turbid samples containing both sediment and water from each well. Samples were stored in sterile glass bottles, in the dark, with zero headspace at 4°C. A protocol for collection of groundwater microbial samples is provided in Appendix A1.

Results – Backfill Hydrogeochemistry

2005 Overburden Sampling and Analysis

Overburden samples were collected at the Dry Valley and Smoky Canyon mines in 2005, as described in the field notes and photo log of this work provided in Appendix A-2. A total of 4 chert, 21 shale, 7 mudstone, and 2 limestone samples were collected from GW7D2 at the Dry Valley Mine. An additional 24 samples (5 chert, 12 shale, and 7 mudstone) were collected at the Smoky Canyon Mine, using methods described in Appendix A-2.

Gradation data (sorting of material by particle sizes) for all samples are summarized in Table A2-3 and Figures A2-1 and A2-2. Average gradation data for key rock types from both mines are shown in Figure 11, which indicate dominantly gravel and sandy materials with lesser amounts of silt and clay. As anticipated, gravel content is higher in chert than in shale, and mudstone samples contained higher concentrations of fine silt and clay. Chert samples collected from archived sonic cores were finer grained than those collected via excavation at the Smoky Canyon Mine. The overall lower percentage of fine sediments reported in this study (relative to those reported by Tetra

Tech/MFG for samples collected in 2006) likely suggests differences in sample preparation procedures and may reflect the presence of aggregates in these samples.

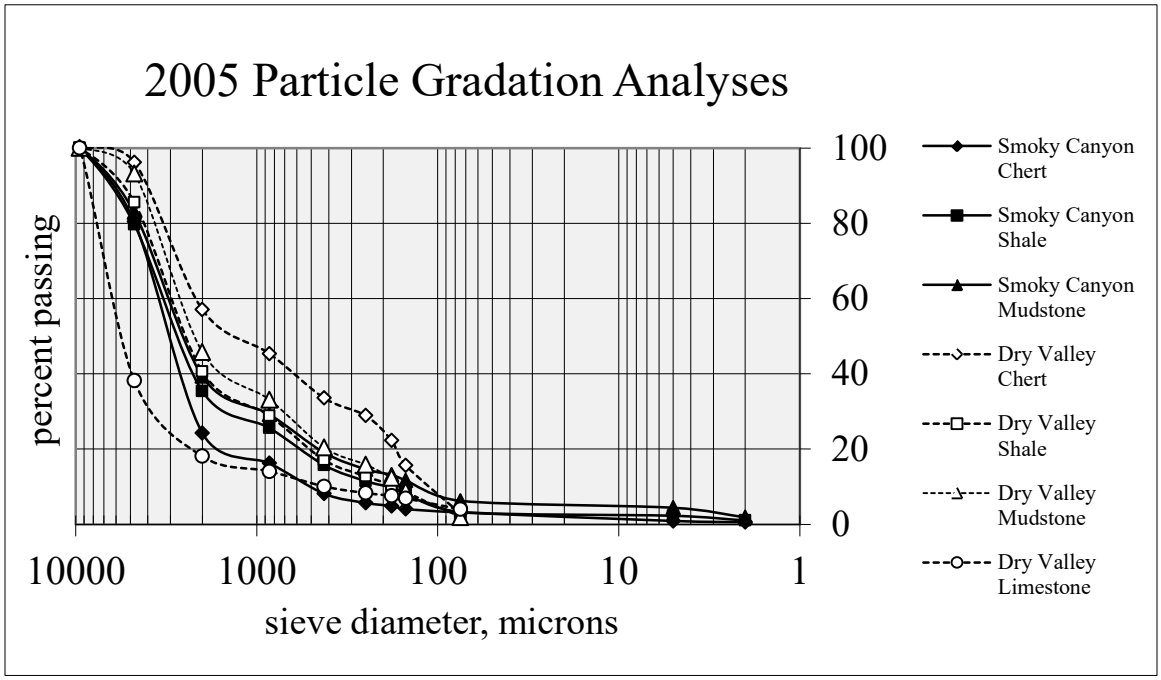

Figure 11. Average particle size distributions for rock samples from Dry Valley and Smoky Canyon mines.

Results of the total element analyses (multi-element ICP following aqua regia digestion) and TOC analyses run for composited chert, shale, and a mixed ROM composite (55% shale, 45% chert, and 10% mudstone) are summarized in Table 1. The data show that shale has higher organic C content than the chert, with values that are comparable between the two mine sites. Sulfur (S) and Se content measured by aqua regia extraction and ICPMS analysis (ALS Chemex) vary between lithology as well, with lower values observed in chert at both mine sites. Iron (Fe) and manganese (Mn) concentrations

extracted by aqua regia vary more subtly between lithology and are consistent between mine sites. Original lab reports for this work are provided in Appendix A2. Analyses of

Table 1. Overburden geochemistry for chert, shale, and run-of-mine rock from Dry Valley Mine and Smoky Canyon Mine D and E panels.

Dry Valley Mine - Well GW7D2A				**chert**	**shale**	**ROM [1]**
No. of Samples				**4**	**21**	Composite
	Method	**Lab**	**Source**			
Se, mg/kg	Aqua Regia/ICPMS MEMS 41	ALS Chemex	a	15	86	56.8
Mn, mg/kg	Aqua Regia/ICPMS MEMS 41	ALS Chemex	a	345	271	314
Fe, wt%	Aqua Regia/ICPMS MEMS 41	ALS Chemex	a	1.61	1.68	1.65
S, wt%	Aqua Regia/ICPMS MEMS 41	ALS Chemex	a	0.17	0.86	0.6
Soluble Se, mg/L	EPA 1312/6020	Energy Labs	b	0.006	0.089	0.054
Soluble Mn, mg/L	EPA 1312/6020	Energy Labs	b	0.228	0.082	0.137
Soluble Fe, mg/L	EPA 1312/6020	Energy Labs	b	2.1	1	1.5
Soluble Nitrate, mg/L	3:1 DI bottle roll extract	MSU Soil Lab	a	44.3	9.2	nm
Soluble Sulfate, mg/L	3:1 DI bottle roll extract	MSU Soil Lab	a	15	413	nm
Leachable Organic Carbon, mg/L	EPA method 5310 GCMS	Energy Labs	b	16.8	72.1	nm
Total Organic Carbon, wt%	Walkley Black	Energy Labs	b	0.37	3.43	nm
Smoky Canyon Mine D and E panel excavation - Well GW11				**chert**	**shale**	**ROM [1]**
No. of Samples				**15**	**12**	**1**
	Method	**Lab**	**Source**			
Se, mg/kg	Aqua Regia/ICPMS MEMS 41	ALS Chemex	a	8	44	28.9
Mn, mg/kg	Aqua Regia/ICPMS MEMS 41	ALS Chemex	a	438	289	393
Fe, wt%	Aqua Regia/ICPMS MEMS 41	ALS Chemex	a	1.15	1.32	1.31
S, wt%	Aqua Regia/ICPMS MEMS 41	ALS Chemex	a	0.08	0.40	0.26
Soluble Se, mg/L	saturated paste extract	Energy Labs	c	<0.01	0.22	0.13
Soluble Mn, mg/L	saturated paste extract	Energy Labs	c	0.15	0.10	0.12
Soluble Fe, mg/L	saturated paste extract	Energy Labs	c	<0.1	<0.1	<0.1
Soluble Nitrate, mg/L	saturated paste extract	Energy Labs	c	1.66	1.75	1.45
Soluble Sulfate, mg/L	saturated paste extract	Energy Labs	c	8	232	135
Leachable Organic Carbon, mg/L	3:1 DI bottle roll extract Method 4500 infrared	MSU	c	43.7	84.5	nm
Total Organic Carbon, wt%	saturated paste extract	Energy Labs	c	0.36	4.63	<0.03

SOURCE: (a) This study, (b) TetraTech/Maxim and Geomatrix 2008, (c) Smoky Canyon B & C EIS. Summary of supporting data in Appendix A2.
nm = not measured.
[1]Composite of 15 chert, 12 shale, and 7 mudstone samples to create ROM rock sample, mixed in proportion to percent lithologic occurrence in run-of-mine placement – 55 shale: 35 chert: 10 mudstone.

texture, organic C, total S, and total element analyses of Cd, Mn, and Se in aqua regia extracts were reported for individual samples by Tetra Tech [6], as summarized in Tables A2-3 in Appendix A2. These results generally agree with those reported for this study in Table 1.

Further analysis of organic C content and speciation was conducted for the chert and shale composite from the Smoky Canyon Mine, as summarized in Table 2. The

Table 2. Methylene-chloride extractable compounds from Phosphoria Formation Meade Peak shale and Rex chert composites, Smoky Canyon Mine, S.E. Idaho.

	Shale *mg/kg*	**Shale** *common compounds*	**Chert** *mg/kg*	**Chert** *common compounds*
Alcohol	*nd*		1.2	hexadecanol
Alkane	32.2	decane, hexane	9.7	decane, eicosane
Alkene	0.6	octadecene	*nd*	octadecene
Amide	7.7	decanamide	3.6	decanamide
Aldehyde	0.5	octadecenal	0.4	dimethyl octenal
Heterocyclic	0.3	azetidine	0.2	tetrahydropyran
Monocyclic aromatic	14.8	phthalate, benzene, toluene	1.9	phthalate, benzene
Diaromatic	9.9	naphthalene	*bdl*	
Polycyclic aromatic	6.0	dibenzothiophene, phenanthrene	*bdl*	
Solvent Extractable Organic Carbon	72.1		16.8	
Non-Aromatic	41.4		15.1	
Aromatic	30.7		1.9	
Ratio Arom/total	43%		12%	
Summary of Energy Laboratories Report B08051823 provided in Appendix A2.			bdl - below detection limit	

methylene chloride-extractable compounds shown were measured using GC-MS and reported in mg/L. These results demonstrate the greater organic C content of the shale, and show that it contains a higher concentration of aromatic hydrocarbons than the chert. Both chert and shale types contain alkane (e.g. decane), amide (decanamide), aldehyde

(octadecanal), and monocyclic aromatic (phthalate and benzene) compounds, but the shale also contains substantial amounts of naturally occurring polycyclic aromatic hydrocarbons (naphthalene, dibenzothiophene, and phenanthrene).

The 2005 overburden sampling program yielded representative bulk composites of shale, chert, and mudstone from the Dry Valley and Smoky Canyon mines with known composition (mineralogy, Se, Mn, Fe, S and organic C). These samples were not collected with the deliberate intent of minimizing microbial contamination between samples and were not preserved to protect the microbial community. Microbial cross-contamination could not be avoided in the sieving process. Rock samples collected in 2005 were thus not appropriate for microbial analysis. These rock samples were autoclaved (steam sterilized 45 minutes at 121°C (250°F) at a minimum of 15 psi), rested for 48 hours, and re-autoclaved to ensure sterilization prior to use as a substrate for rate experiments performed with live cultures collected through groundwater sampling. It is possible that steam sterilization altered the underlying mineralogy to some degree, but this was deemed unavoidable to maintain experimental control with available resources.

As all experiments were treated equally, the influence of this method was likely uniform throughout the study.

2006 Drilling, Microbial Geochemistry, and *In Situ* Monitoring Program

In this study, 15 samples (3 chert, 7 shale, 4 mudstone and 1 limestone) were collected from three of the 2006 sonic drill holes (SCA, SCD, and MEV) for analysis of

Table 3. Overburden samples, *in situ* moisture and O_2 content, and select solid phase geochemistry, after (Tetra Tech 2008).

Location	Sample type	Depth	Lithology	Moisture Content	T	O_2 *	CO_2 *	TOC	Leachable TOC	Tot Se	Leachable Se	Source
		feet		unsaturated, wt%	°C	vol%	vol%	wt%	mg/L	mg/kg	mg/L	
SCD backfill	**DC5**	3	chert	4.6	nm	19.0	0.7	<0.1	<1	3.36	0.0009	b
Smoky Canyon Mine	**DM50**	50	mudstone	5.1	nm	17.7	1.0	0.2	<1	3.23	0.0001	b
	DS75	75	shale	15.8	nm	17.0	1.3	2.6	1	15.70	0.0006	b
	DC123	123	chert	4.7	11.9	13.8	1.5	0.5	<1	3.74	0.0042	b
SCA external dump	**AS5**	5	shale	6.6	nm	19.3	0.8	4.2	<1	106.00	0.0279	b
Smoky Canyon Mine	**AS71**	71	shale	15.4	nm	11.1	5.0	5.5	2	70.80	0.0389	b
	AS113	113	shale	11.5	nm	17.0	0.7	2.7	2	35.20	0.0053	b
	AC125	125	chert	4.3	nm	16.7	1.0	4.3	2	51.00	0.0342	b
	AM145	145	mudstone	14.5	8.5	*nd*	*nd*	0.2	1	8.59	0.0127	b
MEV backfill	**MS5**	5	shale	14.4	nm	*nd*	*nd*	1.0	2	7.82	0.0009	b
Enoch Valley Mine	**MM32**	32	mudstone	18.1	nm	2.2	6.3	<0.1	<1	2.31	0.0005	b
	MS73	73	shale	15.2	nm	0.6	8.8	4.4	<1	63.90	0.0022	b
	MM178	178	mudstone	10.2	nm	0.5	9.7	<0.1	<1	4.28	0.0007	b
	ML 261	261	limestone	12.2	nm	0.6	7.7	<0.1	<1	1.36	0.0037	b
	MS285	285	shale	24.4	10.4	0.6	9.5	2.7	2	32.40	0.0037	b
Dry Valley			**Date**									
	Vapor point	5	Jun-03	unsat	18.2	1.1	7.5	nm	nm	nm	0.1260	a
	Vapor point	10	Jun-03	unsat	16.3	0.0	7.2	nm	nm	nm	nm	a
	Vapor point	20	Jun-03	unsat	14.9	0.0	6.2	nm	nm	nm	0.0260	a
	Vapor point	30	Jun-03	unsat	13.8	0.0	6.2	nm	nm	nm	nm	a
	GW7D2B	130	Jun-03	water table	9.1	1.8	2.0	nm	nm	nm	nm	a
	GW7D2A	130	Jun-03	saturated	12.6	0.6 mg/L	2.6	nm	nm	nm	nm	a
	GW7D	112	Jun-03	saturated	7.5	0.2 mg/L	0.2	nm	nm	nm	nm	a

Source: a Tetra Tech/Maxim, 2007 b Tetra Tech/MFG, 2008 (Appendix A3) *measured by Tetra Tech/MFG 06/2006 nm – not measured nd – not detected

^

their microbial communities via enrichment culturing and isolation, and culture-independent (molecular) techniques. Multiple additional samples were collected and frozen for additional DNA extraction as needed (Table A3.1). These samples are listed in Table 3, with the results of the geochemical analyses and *in situ* moisture, gas, and temperature data that were subsequently collected from these locations by Tetra Tech and O'Kane Consultants.

In situ monitoring data reported for Smoky Canyon from soil suction/temperature sensors, soil moisture content sensors, and lysimeters installed at three *in situ* locations indicate variable moisture content resulting from textural differences between the topsoil and chert layers [3, 11]. Topsoil had elevated water content (18 to 20%), with chert values increasing from 10-12% up to 12-14% (depending upon depth) throughout four months of monitoring between October 2006 and January 2007. Water content in the deepest portion of monitored ROM overburden (at a depth of approximately 72 inches), at a location with relatively low net percolation, the volumetric water content ranged from 18% during the late winter and early spring to a low of 8% during thesummer and fall. Under higher net percolation conditions, the volumetric water content in the deepest sensor ranged from a maximum value of 30% to a low of 16% [12]. More steady state conditions, with less seasonal variation, would be expected with depth, except where changes in grain size and compaction affect capillarity and moisture retention. These data indicate the presence of dominantly unsaturated conditions below the cover at the monitored locations.

Groundwater Monitoring

Multiple analyses of groundwater were reported by Agrium and Simplot for the studied monitoring wells; these results are summarized in Table 4 and provided in greater detail in Tables A1-1 through A1-3 included in Appendix A1. These results show increased SO_4^{2-}, SeO_4^{2-}, and O_2 concentrations in GW11, and lower Fe and pH, relative to the groundwater at the Dry Valley Mine that was measured in wells GW7D, GW7D2a and GW7D2b. Soluble Mn and NO_3^- concentrations were approximately the same.

Discussion – Backfill Hydrogeochemistry

Moisture and gas concentrations varied substantially throughout backfilled overburden in the S.E. Idaho Phosphate Resource Area. Saturated conditions existed deep in the backfill at the Dry Valley Mine, within a confined zone above the regional aquifer. Moisture contents close to or exceeding predicted field capacity based on particle gradation (22-27%) were also identified at the Enoch Valley (24%) and Luxor (22.6%) mines low in the backfill, but above zones of unsaturated rock (with moisture contents ranging from 6 to 14%), suggesting that perched aquifers with suboxic characteristics may also exist within the lower backfill at those locations. Moisture contents for other samples from the four monitored holes studied by Tetra Tech range from 4 to 19% moisture, and are dominantly unsaturated, with some minor variation in water content up to field capacity in rare instances[2]. Higher moisture contents, though still unsaturated, tended to be in the mid-depth intervals. No water was collected from any of the drill holes, although wells were completed for potential future collection of groundwater.

Table 4. Summary of study area hydrogeochemistry.

Site History	**Sample**	**Lithology**	**Well depth**	***In Situ* Parameters[4]**						**Aqueous Chemistry[6]**					
	media type			**GW depth**	**O_2**	**O_2**	**CO_2**	**T**	**Moisture**	**pH**	**SeO_4^{2-}**	**SO_4^{2-}**	**N as NO_3^-**	**Fe[5]**	**Mn[5]**
	name	*in drill hole*	**ft**	**ft**	mg/L	vol%	vol%	**°C**			**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
Dry Valley Mine															
wells in plug-dumped and capped backfill fully saturated in 2000, then drained to field capacity															
GW7D	**gw**	ROM/ mix	172	134	0.35	nm	nm	7.0	Saturated below 172	6.6	0.033	629	1.30	0.05	0.35
GW7D-2a	**gw**	ROM/ mix	180	136	0.20	nm	nm	11.0	Saturated below 150	7.8	0.016	705	0.23	0.20	0.44
saturated below 136 feet, screened below water table															
GW7D-2b	**gw**	ROM/ mix	150	136	0.30	nm	nm	9.8	Saturated below 150	7.6	0.001	834	0.03	12.35	1.77
Screened at water table during completion															
Smoky Canyon Mine															
GW11	**gw**	ROM/shale	85	80	5.50	nm	nm	7.0	Saturated	6.5	1.010	1666	5.58	0.004	0.44
intermittent saturation									field capacity						
SCD Backfill		**Drillhole SCD**		>t.d.	nm	15-20	1-5	8.5	5-18%	Bottle roll chemistry extracts for backfill samples 2.75:1 dilution by mass					
	DC5	chert	5	nm	nm	nm	nm	nm		8.6	1.9	173	0.34	0.01	<0.1
	DM50	mudstone	50	nm	nm	nm	nm	nm		7	1.5	328	0.24	0.15	0. 12
placed as mined, end dumped and capped	**DS75**	shale	75	nm	nm	nm	nm	nm	un-saturated	7.2	1.3	230	2.68	0.07	<0.1
	DC123	chert	123	nm	nm	nm	nm	nm		8.1	1.7	784	0.53	0.04	0.01
SCA External Dump		**Drillhole SCA**		>t.d.	nm	15-20	0.5-2	12.0	5-18%	Bottle roll chemistry extracts for backfill samples 2.75:1 dilution by mass					
	AS5	shale	5	nm	nm	nm	nm	nm		6.9	nd	nd	nd	nd	nd
Run-of-mine rock,	**AS71**	shale	71	nm	nm	nm	nm	nm		7	nd	nd	nd	nd	nd

Table 4. Summary of study area hydrogeochemistry, continued.

Site History	**Sample**	**Lithology**	**Well depth**	***In Situ* Parameters[4]**						**Aqueous Chemistry[6]**					
	media type			**GW depth**	**O_2**	**O_2**	**CO_2**	**T**	**Moisture**	**pH**	**SeO_4^{2-}**	**SO_4^{2-}**	**N as NO_3^-**	**Fe[5]**	**Mn[5]**
	name	*in drill hole*	**ft**	**ft**	mg/L	vol%	vol%	**°C**			**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
end dumped and capped															
	AS113	shale	113	nm	nm	nm	nm	nm	un-saturated	7.7	1.7	1519	0.24	<0.01	0.01
	AC125	chert	125	nm	nm	nm	nm	nm		7.4	1.6	1183	0.22	<0.01	0.01
	AM145	mudstone	145	nm	nm	nm	nm	nm		7.2	1.8	148	0.14	0.02	0.25
Enoch Valley Mine															
MEV backfill		**Drillhole MEV**		>t.d.	nm	<0.5 below 60 ft	5-10	10.4	10-25%	Bottle roll chemistry extracts for backfill samples 2.75:1 dilution by mass					
	MS5	shale	5	nm	nm	nm	nm	nm		7.7	1.7	631	0.09	0.05	0.007
placed as mined, end dumped and capped	**MM32**	mudstone	32	nm	nm	nm	nm	nm	un-saturated	8.6	1.7	797	0.12	<0.01	<0.1
	MS73	shale	73	nm	nm	nm	nm	nm		7.7	nd	nd	nd	nd	nd
	MS178	shale	178	nm	nm	nm	nm	nm		8.2	1.7	624	0.19	0.04	0.008
	MS285	shale	285	nm	nm	[2]nm	nm	nm		7.2	1.7	2465	0.12	0.02	<0.1

[1] from Table 3-1, p. 40, Maxim 2007
[2] from Table 3-3, p. 41, Maxim 2007.
[3] data reported by Simplot for sample collected 10/2003.
[4] from MFG Preliminary Geochemical Characterization of Overburden except Dry Valley data, reported by Maxim, 2007, Appendix F. Values were reported for selected intervals that do not correspond with samples used for this study. For this reason, overall conditions observed in wells are summarized for each well rather than for discrete intervals.
[5] dissolved, filtered 0.45 um, analysis by ICP.
[6]Chemistry reported for rock samples for bottle roll extracts.
nm = not measured; gw = groundwater; <t.d. depth to water greater than total depth of well

Oxygen content varied from atmospheric to non-detectable levels depending on location. Oxygen was measured at generally atmospheric (or slightly lower levels) throughout the overburden at the Smoky Canyon Mine in both SCA and SCD, but was less than 0.2% volume within 10 feet of the overburden surface at the Dry Valley, Enoch Valley, and Luxor mines backfills. This volume is inferred to be due to differences in the method of dump construction, with end-dumped materials more open to barometric pumping and ongoing gas exchange with the atmosphere than dumps constructed in discrete lifts [2]. Dumps that were built in lifts appear to have more limited exchange of O_2 with the atmosphere, and any O_2 introduced during backfill construction has been depleted, presumably through biological or chemical oxidation processes. Temperature at depth in the monitored wells ranged from 8.5 to 11.9°C, which is typical of conditions in the shallow subsurface, with minor seasonal variation.

Geochemical analysis of Se leachability indicated generally low rates of Se release (compared to whole rock Se content) in all of the samples, although there was some variability that could be lithology or moisture dependent. Selenium leachability does not appear to be O_2 dependent (e.g., greater at the Smoky Canyon Mine than at other locations) in the relatively dry materials of the monitored sites. Apparent differences in Se leachability under unsaturated and saturated conditions may also be related to seasonal changes in groundwater flow. They may also reflect microscale changes in redox conditions resulting from biological activity.

The Tetra Tech study provides excellent geochemical background data for this investigation [2]. Acid-base accounting data, which are not summarized here, indicate

low levels of sulfide and abundant carbonate mineralization, with overall net neutralizing conditions throughout the backfill. Although total C varied between lithologies in all three drill holes, the dissolved organic C concentrations were stoichiometrically adequate to support microbial activity based on observed electron acceptor concentrations within the sampled backfill and dump [2]. The trace element and C content of chert and shale differ from one another, but are relatively consistent when compared between locations at the Dry Valley, Smoky Canyon, and Enoch Valley Mines. Key differences between the lithologies include total Se, S, Fe and organic C content (especially, aromatic C content). Backfill seems to have elevated concentrations of both Mn and NO_3^-, with some variability.

Groundwater chemistry described at these sites varied with O_2 availability in the backfill, with higher concentrations of SO_4^{2-} and SeO_4^{2-} (and lower pH and concentrations of Fe) present in water with detectable O_2. Concentrations of SO_4^{2-} and SeO_4^{2-} were higher, and dissolve Fe was lower, at Smoky Canyon in monitoring well GW11 than at Dry Valley, in GW7D or GW7D2a/2b, where O_2 levels were lower.

In Situ Conditions Considered in Experimental Designs

The variation in lithology (including mineralogy, geochemistry, and organic C speciation), moisture content, and O_2 is potentially significant for Se reduction, as described in the conceptual models presented in Chapter 2. Shale, chert, and mudstone were placed randomly as backfill into mined-out panels, and contain variable amounts of total and soluble Se, S, Fe, Mn, and NO_3^-. Sulfate measured in groundwater reflects the

ongoing process of sulfide oxidation within these neutral to alkaline deposits. Oxygen ranged from atmospheric to below detection within backfill, apparently controlled by changes in gas flux at the facility scale and driven by differences in backfill placement methods. Moisture content varied considerably, from the as-mined values of 2 to 4% in coarse cherts to near field capacity in shales, and saturated conditions existed where panels extended below the groundwater table. In fact, the only consistencies between the facilities were the random variation of mixed waste rock mined from the same stratigraphic section of the Meade Peak member of the Phosphoria Formation and the temperatures, which were consistently between 8 and 12°C.

In spite of the complex setting, and the subtle effects of moisture, lithology, and O_2 controls on *in situ* Se biogeochemistry, the combination of conditions developed at the Dry Valley Mine has been sufficient to support *in situ* reduction of soluble Se and NO_3^- for more than ten years. This study explores the biogeochemical processes that influence the rate and extent of this reduction. The potential to develop similarly reducing conditions through intentional design at other mine sites, once the required conditions have been adequately defined, is high. Although hydrocarbon degradation is likely to be slow in cold, subsurface environments, the large mass of available C and the slow flux of water within the backfill environments (with residence time estimated on the order of years) suggests that a sustainable process of C mineralization coupled to anaerobic reduction of NO_3^-, Fe^{3+}, and/or Mn^{4+} could support long-term *in situ* SeO_4^{2-} reduction. Demonstration of natural attenuation as a means of operational source control of Se within phosphate backfill requires documentation of biological processes that promote Se

reduction, within the complex biogeochemical environment of backfilled phosphate overburden. The experiments described in the following chapters were designed to integrate the *in situ* characterization results with a conceptual understanding of Se reduction at both the micro and facility scales. Integration of the *in situ* data with the conceptual models described in Chapter 2 offers a framework, described below, for experimental study of Se reduction within backfilled phosphate overburden in the S.E. Idaho Phosphate Resource Area.

Samples. To address the hypothesis that similar conditions for Se reduction could be developed throughout the S.E. Idaho Phosphate Resource Area, rock and groundwater samples were collected for study at three mine sites located (approximately) along a 30 mile transect from NW to SE through the region.

Lithology and Oxygen as Key Variables. Lithology, C content, trace element geochemistry, and mineralogy of substrate within backfilled mine waste varies, due to random placement of ROM waste rock (55% shale, 35% chert, and 10% mudstone) during mine backfill operations. Rock that is randomly backfilled into mined pits weathers as moisture infiltrates from the surface, transporting O_2 that is progressively consumed through oxidation of reduced mineral phases and aerobic metabolic processes. Changes in pore size within variably graded rock influence gas exchange and the potential for preferential flow. Availability of O_2 is determined by the balance between the relative rate of recharge and consumption processes, and therefore, O_2 availability and moisture content vary within the randomly placed backfill. Shale, with its finer grained texture and higher organic content was hypothesized to support more Se-reducing

bacteria (SeRB) and faster Se reduction than chert. Sampling and experimental protocols for estimating total numbers of SeRB, and for batch reactors, therefore addressed lithology and O_2 availability as primary variables.

Native Rock and Groundwater Substrates. Selenium, along with SO_4^{2-}, is mobilized through oxidation of primary (depositional) sulfide and selenide minerals. Secondary (alteration) Se-hosted minerals and soluble Se oxyanions contribute Se to solution via dissolution and/or desorption from exposed mineral surfaces. Phosphate from phosphorite mineralization may also be soluble, along with Fe and Mn. As these elements have potential to inhibit or support Se reduction by microbes, concentration changes in these elements were monitored as dependent variables in rate experiments. Experiments that address the number and identity of native Se-reducing organisms, under both aerobic and anaerobic conditions, and the rate of Se reduction, were therefore completed using native rock and groundwater to provide representative SO_4^{2-}, NO_3^-, Fe^{3+}, Mn^{4+}, and PO_4^{3-} conditions.

Saturated Experimental Focus. Selenium transport from backfill into groundwater conceptually occurs most significantly under saturated conditions, when SeO_4^{2-} is transported in groundwater from oxidized surface sediments into more reduced and compacted sediments within the backfill. As water moves deeper, O_2 is depleted and denitrifying conditions begin to dominate. Studies of Se reduction rates were therefore conducted under saturated, microaerophilic conditions.

Electron Donors and Acceptors. Hydrocarbon degradation pathways would also be expected to shift from aerobic to denitrifying and anaerobic pathways, with

progressively more involvement of Fe and Mn elemental cycling under anaerobic conditions. Under these hypothesized conditions, redox potential is lower, enhancing the stability of reduced Se phases. Simpler forms of C (such as decane or hexane) formed by degradation of more complex aromatic hydrocarbon compounds would continue to be produced to support SeO_4^{2-} reduction. Transition from aerobic to microaerophilic or anoxic conditions implies the existence of a mixed community of microorganisms capable of aerobic, facultative, or obligate anaerobic metabolisms, using available C compounds as electron donors coupled with the reduction of a variety of possible electron acceptors (O_2, Mn^{4+}, NO_3^-, Fe^{3+}, SeO_4^{2-}, SeO_3^{2-} or SO_4^{2-}). Changes in the microbial community, in response to changing O_2, Mn^{4+}, NO_3^-, Fe^{3+}, and SO_4^{2-} concentrations measured in batch reactors, were described to evaluate this possibility.

Ca-HCO_3-SO_4^{2-} Groundwater Geochemistry. The geochemistry of the phosphate wastes is dominantly alkaline, with Ca-HCO_3-SO_4^{2-} rich groundwater, although sulfide oxidation within the sediments presumably generates local acidity at the pore scale, which is subsequently neutralized by available carbonate. The pH was allowed to vary independently in the experiments presented here. It was documented in bottle roll extracts used to develop media for the enumeration and isolation of microorganisms, as well as batch reactors.

Temperature. Temperatures ranged from an average of 10 °C in the subsurface to 25 °C or more, seasonally, at the land surface. Temperatures of 10 °C and 25 °C were imposed in rate experiments, to evaluate the influence of this range of temperatures on SeO_4^{2-} reduction.

Experimental conditions. The experimental conditions imposed in the microbial isolations, enumeration studies, and rate experiments (Table 5) were designed to account for the observed variation in lithology, O_2, moisture content, pH, soluble SO_4^{2-}, NO^{3-}, Fe, and Mn concentrations.

All three lithotypes (chert, shale and mudstone) were used for these studies. Carbon was added to these experiments to ensure that the maximum possible number of SeO_4^{2-}-reducing organisms was represented. Enrichments were prepared under the

Table 5. Experimental designs based on subsurface backfill conditions.

Experiment	**Lithology**	**Carbon**	**O_2**	**T**	**light**	**moisture**
Rock samples	chert, shale, mudstone	none added	O_2, N_2	<10°C	dark	See table 3
Most probable number	chert, shale, mudstone	2 mM cocktail of lactate-acetate-pyruvate -SeO_4	O_2, N_2	10°C	dark	saturated
Enrichments	chert, shale, mudstone	2 mM cocktail of lactate-acetate-pyruvate -SeO_4	N_2	10°C 25°C	dark	unsaturated, saturated
Rate Experiments	chert, shale, ROM	native only	N_2	10°C, 25°C	dark	saturated

conditions described in Table 5, with a cocktail of simple C compounds including lactate, acetate, and pyruvate to stimulate growth for subsequent molecular studies. The most probable number (MPN) enumeration studies were performed under both aerobic and anaerobic conditions, at the field relevant temperature of 10°C and in the dark. The results of enumeration studies indicated that little, if any, SeO_4^{2-} reduction occurred under aerobic conditions, and showed that the number of SeO_4^{2-}-reducing organisms was lower in unsaturated samples of chert and mudstone than in shale. Based on these MPN

results, subsequent rate experiments focused on anaerobic conditions in chert, shale, and ROM rock.

An understanding of the rate at which native organisms in the different lithologies can reduce SeO_4^{2-} under microaerophilic to anaerobic conditions under controlled temperature conditions is essential to the design of pilot scale facilities with sufficient residence time to support *in situ* reduction as an operational method of Se source control. To address the hypothesis that Se reduction would proceed most rapidly, efficiently, and permanently in shale rather than chert or mixed waste under field temperatures, rate experiments were conducted for individual lithotypes under controlled temperature; known total Fe, Mn, NO_3^-, SO_4^{2-}, and PO_4^3; and variable O_2, pH, and C availability conditions in closed systems.

Measurements of C use and changes in biomass, as well as changes in pH and concentrations of soluble potential competitive electron acceptors, were used to describe the process and capacity for microbial reduction of soluble Se. Similarly, measurements of Se speciation and biomineralization products during the reduction process were made.

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CHAPTER FOUR

SUBSURFACE MICROBIAL SELENIUM REDUCTION BY NATIVE CONSORTIA IN PHOSPHATE MINE WASTE, SE IDAHO

Contribution of Authors and Co-Authors

Manuscript in Chapter 4

Author: Lisa Marie Bithell Kirk

Contributions: principal author.

Co-author: Jared J. Bozeman

Contributions: lab assistant. Developed clone libraries.

Co-author: Susan E. Childers, PhD

Contributions: co-major advisor on microbial ecology, microbiology. Contributed a number of isolates, critical review of molecular work.

Manuscript Information Page

Authors… Lisa Bithell Kirk[1], Jared Bozeman[1], and Susan E. Childers[2]
Department of Land Resources and Environmental Sciences, Montana State University, Bozeman MT[1]

Geological Sciences, University of Idaho, Moscow ID[2]

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Subsurface microbial selenium reduction by native consortia in phosphate mine waste, S.E. Idaho

Lisa Bithell Kirk[1], Jared Bozeman[1], and Susan E. Childers[2]

Department of Land Resources and Environmental Sciences, Montana State University, Bozeman MT[1]

Geological Sciences, University of Idaho, Moscow ID[2]

Abstract

A consortium of native microbes with potential for SeO_4^{2-} reduction in subsurface mine waste at several S.E. Idaho phosphate mines were identified and enumerated under a range of field-relevant oxygen (O_2), moisture, and lithology conditions. Samples of groundwater and unsaturated sediments collected from the subsurface were used to isolate Se-tolerant and Se-reducing microorganisms from the overburden backfill. A most probable number (MPN) method was used to estimate the number of selenium-reducing bacteria (SeRB) in groundwater, chert, shale, and mudstone samples, and both cultivation and molecular methods were used to identify bacteria present in the most dilute positive MPN cultures. Bacterial clone libraries were developed for the two samples of shale with the highest estimated numbers of SeRB, and changes in microbial diversity as a function of lithotype and moisture conditions were compared using denaturing gradient gel electrophoresis (DGGE). The most favorable conditions for Se reduction appear to be in saturated or moist conditions (close to field capacity) where sufficient soluble Se and organic carbon is available to support higher numbers of SeRB. Molecular analysis of community structure in saturated and unsaturated sediments show 16S rRNA sequences with high similarity to known anaerobic and aerobic hydrocarbon-degrading genera *Polaromonas* and *Rhodoferax*. SeRB reduce SeO_4^{2-} using complex naturally-occurring hydrocarbon compounds and potentially other electron donors under Fe^{3+}, Mn^{4+} and NO_3^- reducing conditions. It is proposed that degradation of complex shale hydrocarbons by aerobic and facultative anaerobic members of the community decreases available O_2, thus creating conditions favorable for SeO_4^{2-} reduction by SeRB with high similiarity to the genera *Dechloromonas*, *Stenotrophomona, Anaeromyxobacter* and other hetrotrophic SeRB. This characterization of the indigenous SeO_4^{2-}-reducing community can be used to evaluate design options for *in situ* microbial source control of Se at phosphate mine operations.

Introduction

Control of selenium (Se) concentrations in mine drainage is a concern for phosphate producers at several mine sites in the S.E. Idaho Phosphate Resource Area (Figure 12). Selenium is a naturally-occurring metalloid that is biologically essential in small doses, but toxic at higher concentrations [1]. The Rex chert and Meade Peak shale and mudstone members of the Permian Phosphoria Formation are mined as overburden

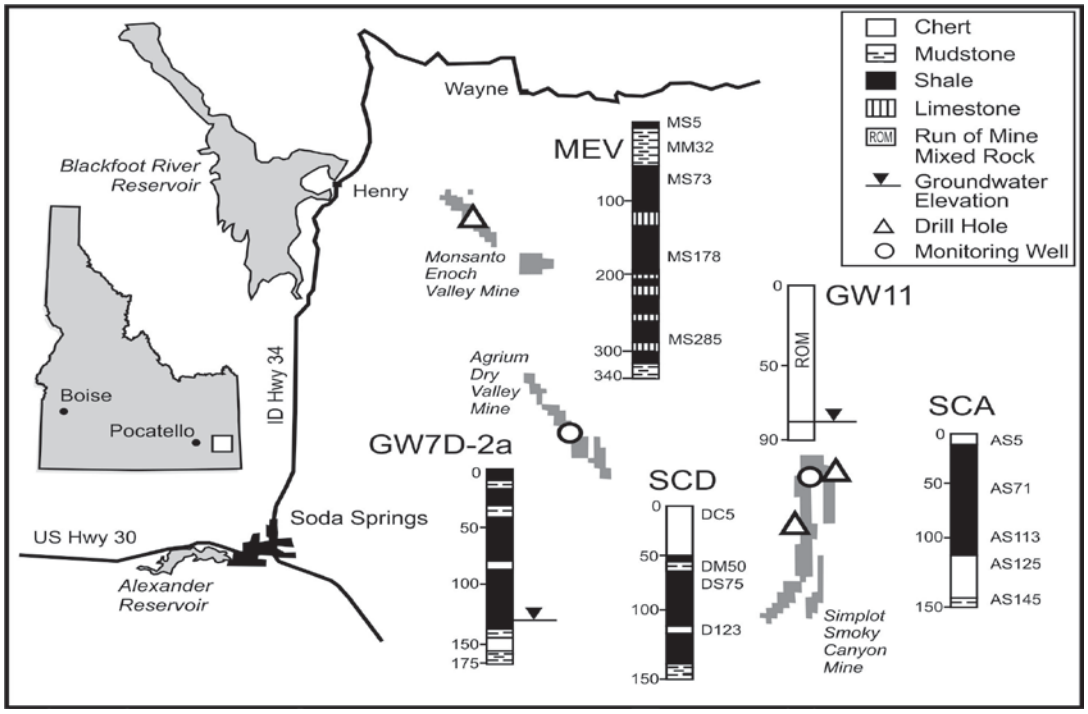

Figure 12. Location of 3 sampled drill holes and 2 monitoring wells in the S.E. Idaho Phosphate Resource Area. Depth in feet to exposed lithologies and water in each hole are illustrated. Rock sample locations are indicated to the right of each drill hole at the corresponding sampled depth; the ID reflects the sampling location and rock type, e.g. MS5 represents M for Monsanto's Enoch Valley drillhole MEV, S for Shale, and 5 for 5 feet of depth. Likewise, SCA represents Smoky Canyon drillhole A and SCD represents Smoky Canyon drill hole D. Groundwater monitoring wells are numbered as shown, GW7D-2a (Dry Valley) and GW11 (Smoky Canyon).

waste during phosphate extraction. Selenium associated with host minerals is released by oxidation and leaching of phosphatic mine overburden and persists as soluble selenate (SeO_4^{2-}) and biselenite-selenite (SeO_3^{2-}-$HSeO_3^-$) species under the neutral to alkaline conditions that characterize the near-surface geochemical environment [2]. Soluble Se concentration in these settings varies, depending on site-specific moisture content, oxygen (O_2) availability and biogeochemistry of overburden lithologies (Table 6) [3].

Groundwater monitoring in backfilled sediments at two mine locations, Smoky Canyon (GW11) and Dry Valley (GW7D2a), exhibited a 50-fold difference in soluble Se concentrations (Table 6) despite the fact that both wells were completed in mixed Phosphoria shale (55%), chert (35%) and mudstone (10%) waste produced using similar mining methods. The average Se concentration was highest in the shale, where Se substituted for sulfur (S) in sulfide minerals in unweathered rock and occurred as sorbed oxyanions or elemental selenium (Se^0) in weathered material. USGS reports Se values ranging from 1 to 1040 mg/kg for the Meade Peak member of the Phosphoria Formation, with an average value of 28 mg/kg in altered rock, and 82 mg/kg in unweathered shale [4]. In contrast, the Rex chert contains between <0.2 and 138 mg/kg Se, with an average value of 7 mg/kg [5]. Carbon content and speciation also varies between lithologies. Although some rock is placed in external dumps, most overburden is randomly placed as internal backfill into mined-out panels (or pits), creating complex subsurface hydrogeochemical environments that vary in moisture and O_2 content (Table 6, after TetraTech, 2008). Abiotic mechanisms known to control concentrations of Se oxyanions are limited in the neutral pH to alkaline pH range relevant in these settings. Mineral

Table 6. Summary of background conditions in S.E. Idaho phosphate overburden, *in situ* groundwater and rock geochemistry

				***in situ* conditions**				**Groundwater Chemistry**					
Location	**Sample**	**Depth feet**	**Rock Type**	**T ˚C**	**Moisture Content**	***in situ* O_2 mg/L**	**pH**	**NO_3^- mg/L**	**Dissolved Se µg/L**	**SO_4^{2-} mg/L**	**DOC mg/L**	**Total Dissolved Fe mg/L**	**Total Dissolved Mn mg/L**
Dry Valley Mine													
GW7D-2a, 6/12/2007	**GW**	**180**	ROM	9.8	Saturated	0.20	7.8	0.3	0.021	710	9.98	0.2	0.47
Smoky Canyon Mine													
GW11, 6/1/2007	**GW**	**90**	ROM	7	Saturated	5.50	6.5	5.60	1.010	1666	nd	0.004	0.44
				***In Situ* Conditions**				**Rock Geochemistry**					
Location	**Sample**	**Depth, feet**	**Rock Type**	**T°C**	**Moisture Content wt%**	**O_2 vol%**	**CO_2 vol%**	**Tot Se mg/kg**	**Leach Se µg/L**	**S wt %**	**DOC mg/L**	**TOC %**	
SCD backfill													
Smoky Canyon Mine	**DC5**	**5**	chert	nd	4.6	atm	atm	3.4	0.9	<0.01	nd	<0.1	
	DM50	**50**	mud	nd	13.0	17.7	1	3.2	0.1	0.06	<1	0.2	
	DS75	**75**	shale	nd	15.8	17.4	1.1	31.8	1.1	0.42	1	3.2	
	DC123	**123**	chert	11.9	4.7	14.8	2.1	3.7	4.2	0.10	<1	0.5	
SCA external dump													
Smoky Canyon Mine	**AS5**	**5**	shale	nd	6.6	atm	atm	70.8	38.9	0.58	2.0	5.5	
	AS71	**71**	shale	nd	15.4	14.1	9.8	35.2	5.3	0.45	2	2.7	
	AS113	**113**	shale	nd	11.5	18.3	0.9	51	34.2	0.54	2	4.3	
	AC125	**125**	chert	nd	4.3	18.2	1.4	8.6	12.7	0.06	1.0	0.5	
	AM145	**145**	mud	8.5	14.5	nd	nd	1.3	0.6	<0.01	1	0.1	
MEV backfill													
Enoch Valley Mine	**MS5**	**5**	shale	nd	15	atm	atm	7.8	0.9	0.06	2.0	1.0	
	MM32	**32**	mud	nd	18.0	9.2	6.6	2.3	0.5	nd	nd	nd	
	MS73	**73**	shale	nd	15.2	0.5	9.4	63.9	2.2	0.64	nd	4.4	
	MM178	**178**	mud	nd	10.2	0.5	9.6	4.3	0.7	nd	nd	nd	
	MS285	**285**	shale	10.4	24.4	0.5	9.8	32.4	3.7	0.38	2	2.7	

nd =not detected atm = atmospheric

ROM is run-of-mine mixture of lithologies incl. shale, chert, and mudstone. Sample ID based on drill hole, material type and depth e.g., SCD chert 5 ft = DC5.

Groundwater chemistry as reported by TetraTech 2007, O_2, CO_2 (vol%) measured in situ Aug 2006[3], Total S% by LECO, Sobek 1978

Total Selenium by method SW-846 3050/6020, Leachable Selenium by method SW-846 1312/6020 [3]

Total Organic Carbon (TOC) by method ASA9-29-2.2.4 [3]

Dissolved Organic Carbon (DOC) by SW-846 followed by ASA 9-29-2.2.4 [3]

solubility is unlikely to control dissolved Se concentrations, and sorption onto metal oxide, carbonate, and clay minerals is likely to be inefficient [6, 7]. Neither mechanism could be shown to fully explain the differences observed between the two wells, suggesting that biotic mechanisms may control soluble Se concentrations.

Abiotic reduction of Se(VI), the oxyanion SeO_4^{2-}, to Se(IV), which occurs as either $HSeO_3^-$ or SeO_3^{2-} depending upon pH, is kinetically limited and proceeds very slowly except when catalyzed by green rust [8, 9] or Se-reducing microorganisms (SeRB)[10]. SeRB are phylogenetically diverse and include many *Bacteria* and some *Archaea* and *Eukarya* that can detoxify or respire SeO_4^{2-} or SeO_3^{2-}. Substantial energy can be gained through respiratory reduction of SeO_4^{2-} to SeO_3^{2-} by strict and facultative anaerobes [11], including *Thauera selenatis* [12], *Sulfurospirillum barnesii* [13], *Pelobacter seleniigenes [14]*, *Selenihalanaerobacter shriftii* [15], *Citrobacter* sp. strain JSA [16], and several *Bacillus* species[17]. Selenium reduction along inducible respiratory pathways is not always growth-dependent [18, 19]. A few bacterial genera capable of aerobic SeO_4^{2-} reduction have also been identified [20, 21]. Reduction of SeO_4^{2-} for detoxification purposes appears to occur using a specific of SeO_4^{2-} reductase in *E. cloacae* SLD1a1 [22], but otherwise involves non-substrate specific enzymes associated with NO_3^- and NO_2^- [19] or SO_4^{2-} reduction[23, 24]. While SeO_3^{2-} reduction to Se(0) or Se(-II) is less energetically favorable than SeO_4^{2-} reduction, this strategy is used for detoxification by a variety of organisms.

Some organisms can reduce SeO_4^{2-} fully to Se(0) or Se(-II), while others will only reduce SeO_4^{2-} to SeO_3^{2-} or SeO_3^{2-} to Se(-II). Complete reduction of soluble oxyanions to

insoluble Se^0 or Se^{2-} minerals can thus depend on community-level interactions between multiple organisms [25].

Previous work on microbial Se transformations in phosphate mine wastes from the Smoky Canyon Mine identified a variety of SeO_4^{2-}-reducing microorganisms using cultivation and molecular methods [26]. Using near surface samples from the Smoky Canyon Mine, the microbial community was evaluated along with its potential to influence Se speciation in response to the application of iron (Fe), compost, and whey amendments as potential bioremediation treatments. A number of isolates were identified, based on their ability to reduce SeO_4^{2-}, and were found to belong primarily to the *Enterobacteriaceae* family, although other gamma- and betaproteobacteria were found, including members of the *Aeromonadaceae, Comamonadaceae, Oxalobacteraceae*, and *Rhodocyclaceae* families. Knotek-Smith, et al. [26] concluded, based on amended column experiments, that Fe amendment to promote the precipitation of insoluble Fe-selenide minerals is the preferred strategy for remediation of SeO_4^{2-} in phosphate waste [27]. Of common interest to the present study was the identification of SeO_4^{2-} reduction by members of the *Rhodoferax* and *Rahnella* genera in laboratory experiments, and the conclusion that further study of microbial populations in environmental samples was needed to resolve questions about SeO_4^{2-} mobility in a mine waste setting [26].

The objectives of the present study were to (1) characterize the indigenous microbial population involved in the Se reduction observed in backfill at the Dry Valley Mine, and (2) to test for SeO_4^{2-} -reducing organisms in subsurface mine waste samples collected from the nearby Smoky Canyon and Enoch Valley phosphate mines, under a

range of conditions identified *in situ*. Here, samples of turbid groundwater and sediment from SeO_4^{2-}-reducing enrichments were used to isolate and enumerate Se-tolerant and Se-reducing microorganisms from groundwater, chert, shale, and mudstone samples. Mixed communities of *Bacteria* in waste rock were described using bacterial clone libraries and denaturing gel gradient electrophoresis (DGGE). Together with data characterizing Se reduction rates in specific lithotypes under controlled O_2 and temperature conditions, and aqueous and mineral Se speciation data (Chapter 5), this characterization of the indigenous SeO_4^{2-} -reducing community can be used to evaluate options for *in situ* microbial source control of Se at phosphate mine operations.

Materials and Methods

Sample Collection and Preservation

Multiple samples of groundwater and overburden were collected for the isolation of SeRB and for the characterization of microbial community diversity using molecular methods. Sampling locations shown in Figure 12 included two groundwater monitoring wells, and multiple depths within three drill holes completed in mined overburden. Groundwater samples were collected from a well completed in saturated backfill at the base of backfilled pit B at the Dry Valley Mine (GW7D2a) and from a well completed in partially (and intermittently) saturated backfill at the Smoky Canyon Mine (GW11). Each well was sampled for major and trace element chemistry, and select results are presented for key elements in Table 6. Water was bailed manually using a new, disposable plastic bailer at each site, weighted to facilitate sediment recovery during sampling. The bailer

was rinsed with groundwater repeatedly prior to sample collection. Samples were transferred immediately into sterile glass or polypropylene bottles and stored at 10°C in the dark under absence of headspace. Groundwater pH, dissolved oxygen (DO) content, and temperature were recorded at the time of sampling. DO was measured using a YSI probe at the Dry Valley Mine, and initially with a Hach kit at the Smoky Canyon Mine and later using an O_2 probe. Sediments associated with the groundwater samples were concentrated by centrifugation at 13000xg for 10 minutes and stored saturated at or below 10°C until use.

Overburden rock samples were collected from existing mine backfill and rock dump facilities at the Smoky Canyon Mine (drill holes SCA and SCD) and Enoch Valley Mine (drill hole MEV) using a sonic drill. A total of 14 samples were selected to represent the range of lithologies encountered within the three drill holes. During the drilling process, samples were quickly preserved to limit (to the extent possible) any changes in temperature, gas, moisture, and redox conditions resulting from exposure of rocks to surface conditions. As samples were removed from the core barrel, they were placed into Lexan® plastics and labeled. The temperature of core samples was measured to avoid collection of overheated (above 37°C) samples as a result of friction between the core barrel and the rock during the drilling process. Each interval was placed on sheets of fresh plastic within a nitrogen (N_2)-flooded and sanitized (10% bleach and 70% ethanol) glove box. Once in the glove box, the sample bag was opened and the mineralogy, moisture, and clastic content were described qualitatively. Afterwards, the internal core was exposed and sub-sampled using sterilized utensils. The sub-samples were

composited, split into several sterile containers for mineralogical, microbial, molecular, and hydrogeochemical analysis, and preserved under both aerobic and anaerobic (20x pore volume flushed N_2 headspace) conditions. Containers were sealed to conserve moisture and stored in the dark at temperatures at or below the measured average subsurface temperature of 10°C. Samples stored under aerobic conditions were aerated periodically or maintained with a 0.22 μm filtered port to allow for atmospheric exchange.

Samples of rock collected for this study were analyzed independently to determine total and leachable organic carbon, Se and S, and moisture content by TetraTech, Inc., an independent contractor who managed the drilling program (summarized in Table 6). Total Se was extracted following EPA method 3050 and leachable Se was extracted using EPA method 1312, followed by Inductively Coupled Plasma- Mass Spectrometry (ICP-MS) analysis using method EPA 6020. Leachable and total organic carbon (TOC) were determined for rock samples using method SW-846 with ASA 9-29-2.2[28]. Total S was measured by LECO furnace with S speciation determined using the modified Sobek method (M600/2-78-054 1.3 [29]. Moisture content was determined by measuring sample weight before and after drying in a 34°C oven [28]. Temperature, O_2, and carbon dioxide (CO_2) concentrations were also measured *in situ* at multiple depths within the drill holes using thermocouples and plastic tubing taped to the outside of the well casing and completed at select depths, as described in the installation report provided in Appendix A3 [3].

Se Reduction by Native Microbes**:** Batch experiments were conducted to verify biotic SeO_4^{2-} reduction in mixed mine overburden. Batch reactors were constructed in triplicate using 30 g of steam-autoclaved rock (mixed rock comprised of 45% shale, 35% chert, and 10% mudstone) and 30 mL of sterile deionized water in 250 mL glass serum bottles. The grain size distribution of these lithologies is described in Figure 11. Rock used in these experiments represented a composite of each lithotype. Hydrocarbon species were extracted from representative samples of shale and chert collected at the Smoky Canyon Mine using methylene chloride, followed by Gas Chromatography-Mass Spectrometry (GC-MS) analysis, to identify the native hydrocarbon compounds that were present in the run-of-mine (ROM) waste. Each reactor was mixed on a shaker table open to the atmosphere for 12 hours to dissolve salts under the aerobic conditions expected to exist within near surface portions of mine waste. Reactors were inoculated with 25.3 mL turbid groundwater (live and autoclaved control), sealed, and residual O_2 removed by flushing bottles with ultrapure N_2 gas through a 0.2 μm sterile filter. Each reactor was spiked with 10 mg/L Se as SeO_4^{2-} (based on maximum field measured concentrations) and incubated at room temperature (approximately 25°C) and 10°C under dark conditions. No external carbon source was added. Samples of mixed water and sediment were collected immediately using a N_2-purged syringe, and every 12 hours for 10 days, and centrifuged at 13,000x g to remove solids. The supernatant was removed and diluted 1:500 with an acid mix comprised of 1.0% HNO_3, 0.5% HCl prior to analysis of total Se, Fe, and Mn using an Agilent 7500ce ICP-MS with the hydrogen (H_2)-gas collision cell following EPA method 200.8 [30]. Samples were removed from the reactor for O_2

measurement using a Hach AQ4 dissolved O_2 meter (Loveland, CO) and pH measurement using an Acumet AB15 pH meter with a probe model no. 13-620-AP (Cole Parmer).

Enrichments and Cultivation: Enrichment cultures were prepared to obtain SeRB from rock samples. Isolations of SeRB were also performed using the most dilute positive most probable number (MPN) cultures (see method, Appendix B). Enrichment and isolation methods are summarized in Appendix C1. Media consisted of filter sterilized groundwater containing 0.01% yeast extract to provide trace vitamins and nutrients and 0.2 to 20 mM SeO_4^{2-}. Carbon sources included native carbon extracted from rock, or lactate, acetate, and/or pyruvate individually or combined, or a cocktail containing all of the above, at total concentrations that were in approximate molar proportion to the amount of added SeO_4^{2-}. The native carbon that was present in the rock varied, both in chemistry and concentration (Table 7), and its extractability in deionized water differed between lithotypes. A mixture of shale, chert, and mudstone was thus used to make media in a ratio based on the relative proportion of shale:chert:mudstone lithotypes typical of mined overburden (55:35:10). The concentration of carbon that could be extracted from rock samples varied, unlike that of lactate, acetate, and pyruvate, which was used in constant molar proportion. Enrichments were prepared in a glove box with a headspace of 2%H_2/98%N_2 and kept in sealed bottles under a N_2 headspace. Enrichments for autotrophic SeRB were similarly prepared except half of the N_2 headspace was replaced with a 1:1 mixture of H_2-CO_2 and no exogenous carbon sources or yeast extract were added. Enrichments were incubated for 6 to 8 weeks at 10°C or until

a red precipitate was noted visually. The cultures were sampled periodically for changes in turbidity and color.

Table 7. MPN solution chemistry (in bottle roll extracts)

Parameter	Method	Detection Limit	Average Chert	Average Shale	Average Mudstone
pH, standard units	EPA 150.1	0.1	8.4	7.7	8.0
NO_3^-, mg/L	EPA Method 6010c	0.5	1.7	1.8	0.9
Total N, mg/L	Standard Method 4500, Shimadzu	0.1	34.7	15.1	12.0
SO_4^{2-}, mg/L	EPA300.0	1	8.0	232.0	18.0
DOC, mg/L	Standard Method 5310 Shimadzu infrared	0.1	84.5	96.9	77.7
Volatile Hydrocarbons in Aqueous Phase, relative%	Head Space-Solid Phase MicroExtraction Gas Chromatography (qualitative only)	Alkanes	64	87	nm
		Alkenes	nd	2.8	nm
		Aromatic	15	5.3	nm
		Cyclic	21	5.6	nm
Total dissolved Fe, mg/L	EPA 200.8	0.01	36.1	1.8	36.1
Total dissolved Mn, mg/L	EPA 200.8	0.01	3.2	0.0	0.9
Dissolved SeO_4^{2-}, µg/L	EPA7131-A GFAA-hydride	2	1751	1609	1655
Dissolved SeO_3^{2-}, µg/L	EPA7131-A GFAA-hydride	2	436	386	425

nd= not detected nm=not measured
Averages taken from Tables B.1 and B.2, Appendix B1.

Samples of turbid groundwater and MPN-diluted rock samples were directly plated onto solid media to obtain SeRB. Agar (3% by weight) was added to the enrichment media described above, and plates were poured and allowed to solidify in the glove box. Groundwater samples (0.1 ml) were spread onto solid media and plates were kept anaerobic using an Anaeropak™ system under a 21% CO_2 atmosphere (Fisher Scientific). Samples from drill holes MEV, SCA, and SCD were serially diluted to 10^{-4}, 10^{-5} and 10^{-6} in 5 mM carbon-specific filter-sterilized groundwater media (e.g., native

carbon or lactate or acetate or pyruvate) and 0.1ml of each dilution was plated onto solid media in the glove box. Colonies showing unique morphologies were isolated by streaking onto solid media until pure. Pure cultures were then maintained in aqueous medium comprised of filter-sterilized site specific groundwater containing 0.03 mM native carbon (extracted from ROM rock using deionized water in a bottle roll for digestion), to which 0.01% yeast extract, 2 mM SeO_4^{2-}, and 2 mM each of lactate, pyruvate, and acetate were added to create the enrichment cocktail. Notes and photographs describing the enrichment process are provided in Appendix C1.

Enumeration of SeO_4^{2-}-Reducing Microorganisms: An MPN approach [31] was used to estimate the number of SeRB in each sample. Samples of chert, mudstone, shale, and groundwater were serially diluted with a rock extract solution containing 0.2 mM each of acetate, pyruvate, and lactate, and a field-relevant concentration of 0.1 mM SeO_4^{2-}. The bottle roll rock extract solution was prepared for each rock sample using a gyrator-shaken sample of rock and water (water: rock mass ratio of 2.65:1), covered but open to the atmosphere. After 12 hours, solids were allowed to settle and fines in suspension were pelleted by centrifugation at 13,000xg for 10 minutes. The rock extract was then filter-sterilized using a 0.22 μm filter, the pH was recorded, and sulfate (SO_4^{2-}), total dissolved organic carbon (DOC), NO_3^-, SeO_4^{2-}, and SeO_3^{2-}, were analyzed (Table 7). Ion chromatography was used to measure anion concentrations using a Dionex model DX500 equipped with an IonPac AS-9-HC (4 x 250 mm) anion column and a CD 20 detector. Samples (25μL) were injected into an 11 mM Na_2CO_3 mobile phase flowing at 0.9 mL/min, both at full strength to measure low concentrations of most ions and diluted

25X with deionized water to measure higher concentrations of SO_4^{2-}. Solvent extractable organic carbon was extracted using methylene chloride by EPA method 3550B and analyzed by GC-MS following EPA Method 8270C [32]. Dissolved organic carbon was measured by Shimadzu infrared, following standard method 5310. Dilutions were performed following a standard test protocol with 10-fold dilutions carried out to 10^{-8} dilution. The resulting solutions were then divided into aliquot tubes, which contained 10 ml each. MPN cultures were prepared both aerobically in capped test tubes, and anaerobically in sealed serum bottles, with a 50% N_2, 25% H_2 and 25% CO_2 headspace, and were kept at 10°C. The chemical analyses of bottle roll extracts (pH, NO_3^-, total N, SO_4^{2-}, DOC, total dissolved Fe and Mn, SeO_4^{2-}, and SeO_3^{2-}) are provided in Table 7.

Due to the strong humic content of the phosphatic shales, and dark color of the rock, it was necessary to replace colorimetric indicators of reduction in MPN tubes with quantitative measurements of total dissolved Se. Samples (1 ml) were removed from each culture and centrifuged at 13,000x g to remove solids. The supernatant was diluted 1:500 with an acid mix comprised of 1.0% HNO_3, 0.5% HCl prior to analysis of total Se using an Agilent 7500ce ICP-MS with the hydrogen-gas collision cell following EPA method 200.8 [30]. Tubes were scored positive if they showed a minimum of 10% reduction in soluble Se concentration. ICP-MS analyses of total Se collected for the approximately 2,600 MPN tubes (16 samples for two O_2 treatments, in duplicate, with 40 tubes per experiment) are listed in Table B.1.4 of Appendix B. The original ICP-MS data are provided on the accompanying CD.

DNA Extractions and PCR**.** Nucleic acids were extracted from enrichments, soil, and groundwater sediment samples. Attempts at direct extraction of DNA from MPN cultures were initially unsuccessful, likely due to the low biomass in the limited culture volume. Therefore, samples from MPN tubes were transferred to fresh media using methods described above to obtain a sufficient volume of biomass for extractions. Nucleic acids were extracted using the Power Soil DNA Isolation Kit ™ (Mo-Bio Laboratories, Carlsbad, CA).

The manufacturer's method was modified by first incubating samples in 20% SDS at 70°C for 1 hour, then vortexing for 20 minutes to breakup any biofilm and detach organisms. After mixing, the entire sample was used for the extraction of nucleic acids as detailed in the protocol provided by the manufacturer. PCR was performed on extracted DNA to amplify 16S rRNA genes using a nested approach to optimize yield [33]. Initially, 10 cycles were run using primers 1070F (5'-ATG GCT GTC GTC AGC T-3') and 1392R (5' ACG GGC GGT GTG TAC-3') [34]. The products from the initial PCR were diluted 1:10 and used as template in a 30 cycle PCR using 1070F and 1392GC. Reactions (50 µl) contained template (2 to 50 ng DNA), 0.2 mM each primer, and PCR mastermix (Promega, Madison, WI, 25 µL), and PCR was performed using an Eppendorf Mastercycler Gradient thermocycler. Conditions were the same for both PCRs and included denaturation at 94°C for 10 min, followed by 10 or 30 cycles of 94°C for 45 sec, 50°C for 45 sec, 72°C for 45 sec, and a final extension at 72°C for 7 min. PCR amplicons were separated on a 0.8% agarose gel and visualized by staining with ethidium bromide.

Colony PCR was used to amplify 16S rRNA genes from isolated SeRB. The resulting PCR products were screened for redundancy using the restriction fragment length polymorphism (RFLP) procedure. Colonies were picked using sterile pipet tips and suspended in nuclease-free deionized water (10 µl). Suspended cells (2 µL) were used as template in a 30 cycle PCR using 334F (5'-CCA GAC TCC TAC GGG AGG CAG C-3') and 926R (5' CCG ICI ATT IIT TTI AGT TT-3') [35]. Reactions (50 µl) contained template (2µl), 0.2 µM primers, and PCR mastermix (Promega) and PCR was performed using a Techne TC-312 thermocycler. PCR conditions were 10 min at 94°C, followed by 30 cycles of denaturation at 94°C for 45 sec, annealing at 50°C for 45 sec, and extension at 72°C for 45 sec. The final extension period was 5 minutes at 72°C. The amplicons were digested for 3 hours at 37°C in a 20 µL volume that contained 10 µL PCR product, 1X reaction buffer and 20U *HaeIII*. Fragments were separated in a 3.5% agarose gel, and digestion patterns were visualized and grouped based on similarity. The PCR amplicon from several colonies representative of each RFLP group were used to obtain 16S rRNA gene sequence information.

DGGE and Sequencing**:** PCR products were separated by electrophoresis in 8-12% acrylamide gels containing a 50-60% urea-formamide gradient at 70 V and 60°C for 20 hours. Gel electrophoresis was performed using a DGGE-2401 system manufactured by CBS Scientific®, based on the general method described by Muyzer et al. [36]. Gels were stained with SYBR Gold (Life Technologies Invitrogen ™) and visualized using UV light. A ladder of PCR amplified products from known isolates was prepared and used to compare with samples. The ladder included PCR amplicons from isolates with

>99% similarity to members of the *Actinobacterium*, *Pseudomonas*, *Rhodoferax, Dechloromonas, Dechloromonas*, *Brevundimonas*, *Rahnella*, *Sphingomonas*, and *Cellulomonas genera*. Individual bands of interest not represented in the ladder were excised from the gel, resuspended in 15 µL of nuclease-free water, and allowed to diffuse from the gel overnight at 60°C. Numerous bands were also cut from the gel to confirm ladder identification. Samples were mixed and acrylamide was pelleted by centrifugation. The resulting supernatant was removed, diluted 1:10 in nuclease free water, and used as template in a 30 cycle PCR using primers 1070F and 1392R as described above. PCR products were purified using a Wizard SV Gel and PCR Cleanup System (Promega) and quantified using a Qbit fluorimeter (Life Technologies Invitrogen™). Samples were submitted to the Idaho State University Molecular Research Core Facility (ISU MRCF, www.isu.edu/bios/MRCF) for sequencing using an Applied Biosystems® 3130XL Genetic Analyzer. The Basic Local Alignment Search Tool (BLAST, NCBI,http://blast.ncbi.nlm.nih.gov) was used to query resulting sequences against a nonredundant database [37]. Images of a number of the gels used for the project are provided in Appendix C4.

Clone Libraries: Clone libraries were constructed for primary enrichments of rock samples AS71 and AS113, which hosted the greatest number of SeO_4^{2-}-reducing organisms as estimated by MPN. 16S rRNA gene fragments were amplified by PCR using bacterial primers 1070F/1392R or archaeal primers Arc 21F (Integrated DNA Technologies, Mfg ID 41725659) and 958R (Integrated DNA Technologies, Mfg ID 41725669) [35]. The bacterial primers were chosen to be consistent with those used for

DGGE in the study. PCR conditions were 94°C for 5 min followed by 30 cycles of 94°C for 45 sec, 55°C for 45 sec, 72°C for 45 sec, and a final extension step at 72°C for 1 minute. PCR products were cloned as described in the Invitrogen TOPO Cloning kit ® protocol, cloned products were transformed into chemically competent *E. coli* cells, and transformants were plated onto solid media and screened by blue-white selection. White colonies were transferred to liquid media (LB), grown overnight, and plasmid DNA was extracted using a QIAprep® Miniprep kit (Qiagen, Valencia, CA). The concentration of plasmid DNA was quantified using the Invitrogen QBit® fluorometer BR dsDNA (broad range double stranded DNA) assay. Cloning methods are summarized in Appendix C3.1.

Plasmid DNA samples were shipped to the ISU MRCF for DNA sequencing.Sequencing results were screened to eliminate samples that were not comprised exclusively of unambiguous bases or greater than 300 base pairs in length. Sequences were aligned using ClustalX, organized into a tree using the program ARB, and compared using Unifrac. Diversity within each library was analyzed using the program DOTUR, a program for defining operational taxonomic units and species richness (Schloss, 2005). Sequences were evaluated using BLAST to identify the closest relative. Further analysis of sequences allowed correction of antisense sequences resulting from inversion of the plasmid insert during the initial ligation, using the program Reverse Complement (Java Boutique, http://javaboutique.internet.com/revcomp/). Bioinformatics data and analyses are summarized in Appendix C3.2.

Results

Sampling and *In Situ* Subsurface Characterization

Sixteen samples were collected from the Smoky Canyon, Dry Valley, and Enoch Valley mines, including two samples of groundwater and fourteen samples of sediment from drill cores of unsaturated and unconsolidated overburden. Groundwater was collected from mixed lithology backfill deposits at the Dry Valley (GW7D2a) and Smoky Canyon (GW11) mines; no groundwater was available from the Enoch Valley Mine. Samples collected from drill cores were chosen to represent the range of observed lithology and moisture conditions observed with depth in holes drilled into the randomly backfilled overburden deposits (Figure 12). Geochemistry (summarized in Table 6) and particle size data (not reported) were measured for the same samples [3].

Table 6 summarizes *in situ* conditions in the groundwater monitoring wells completed in backfilled overburden (GW7D2a, GW11), with conditions at sampled depths in drill holes MEV, SCA, and SCD. Measured pH in groundwater ranged from 6.5 to 7.8 and temperature ranged from 7 to 10°C. The concentration of dissolved Se in Dry Valley well GW7D2a was 0.021 mg/L, considerably below the Idaho groundwater standard of 0.050 mg/L, in contrast to the higher Se concentration of 1 mg/L measured in the Smoky Canyon well GW11. Dissolved oxygen (DO) is non-detectable in groundwater at Dry Valley, in contrast with 5.5 mg/L DO at Smoky Canyon. The highest SO_4^{2-} concentration, 1666 mg/L, correlated with higher DO levels in GW11, and indicates a higher rate of sulfide oxidation relative to GW7D and GW7D2 at the Dry Valley Mine

(See data Chapter 3). NO_3^- in groundwater, likely resulting from blasting residues, ranged from 0.3 to 5.6 mg/L. Levels of soluble Fe (0.004 to 0.2 mg/L) and Mn (0.44 to 0.47 mg/L) were comparable in groundwater monitored at both the Dry Valley and Smoky Canyon Mines. No comparison could be made with the Enoch Valley Mine, where groundwater water quality was not reported.

Table 6 also shows *in situ* conditions and characteristics of rock samples collected from drill holes MEV, SCA, and SCD. Drill hole temperatures ranged from 8 to 12°C. The O_2 concentration was close to atmospheric in both SCA and SCD, but was not detectable below 32 feet in MEV or 10 feet at Dry Valley, apparently reflecting differences in the way rock was dumped during facility construction [3]. Carbon dioxide concentrations ranged from 6.6 to 9.6 volume % in MEV to only 4 volume % in the SCA and SCD holes. Total and dissolved Se, as well as TOC and DOC, varied with lithotype and were consistent with the values reported by the USGS for these sediments [4, 5, 38]. Carbon speciation varied between lithotype in the Phosphoria overburden as well, with shale containing more carbon and higher concentrations of aromatic hydrocarbons, such as benzene, phenanthrene, toluene, and dibenzothiophene relative to chert (Table 8).

Potential for *in situ* Biological Se Reduction

Potential for *in situ* biological reduction of Se was confirmed through comparisons of killed controls with SeO_4^{2-} reduction in live batch reactors of sterile mixed waste rock inoculated with site specific groundwater. Reduction of SeO_4^{2-} to

Table 8 GC-MS analysis of methylene chloride extracted solid phase carbon in overburden samples from Phosphoria Formation. chert and shale.

	Shale		**Chert**	
	mg/kg	*common compounds*	*mg/kg*	*common compounds*
Solvent Extractable Organic Carbon	72.1		16.8	
Non-Aromatic	41.4		15.1	
Aromatic	30.7		1.9	
Ratio Aromatic/Total	43%		12%	
Alcohol	*no data*		1.2	hexadecanol
Alkane	32.2	decane, hexane	9.7	decane, eicosane
Alkene	0.6	Octadecene	*no data*	octadecene
Amide	7.7	Decanamide	3.6	decanamide
Aldehyde	0.5	Octadecenal	0.4	dimethyl octenal
Heterocyclic	0.3	Azetidine	0.2	tetrahydropyran
Monocyclic aromatic	14.8	phthalate, benzene, toluene	1.9	phthalate, benzene
Dicyclic aromatic	9.9	naphthalene	*no data*	
Polyaromatic	6.0	dibenzothiophene, phenanthrene	*no data*	

SeO_3^{2-} and removal of Se from the aqueous phase began in the mixed overburden rate reactors once O_2 was consumed to a concentration below 0.3 mg/L, following an initial lag of approximately 80 hours (Figure 13). Nitrate was also consumed during this phase, although its complete removal was not required for SeO_4^{2-} reduction to proceed. The reduction of SeO_4^{2-} to SeO_3^{2-} and its ultimate removal from solution was associated with an increase in soluble Fe (to an upper limit of 110 mg/L) and Mn (to 4 mg/L), presumably due to concurrent microbial Fe and Mn reduction. The cause of the loss of soluble Fe at 272 hours is not known, but it may be related to the formation of the insoluble mineral ferroselite, $FeSe_2$, which was identified in post reduction mineralogy studies (see chapter 5). Essentially no change was observed in the concentration of PO_4^{3-},

which remained below detection (1 mg/L). The concentration of SO_4^{2-} initially increased from 1035 mg/L to 1390 mg/L and remained constant during the Se reduction process. Se

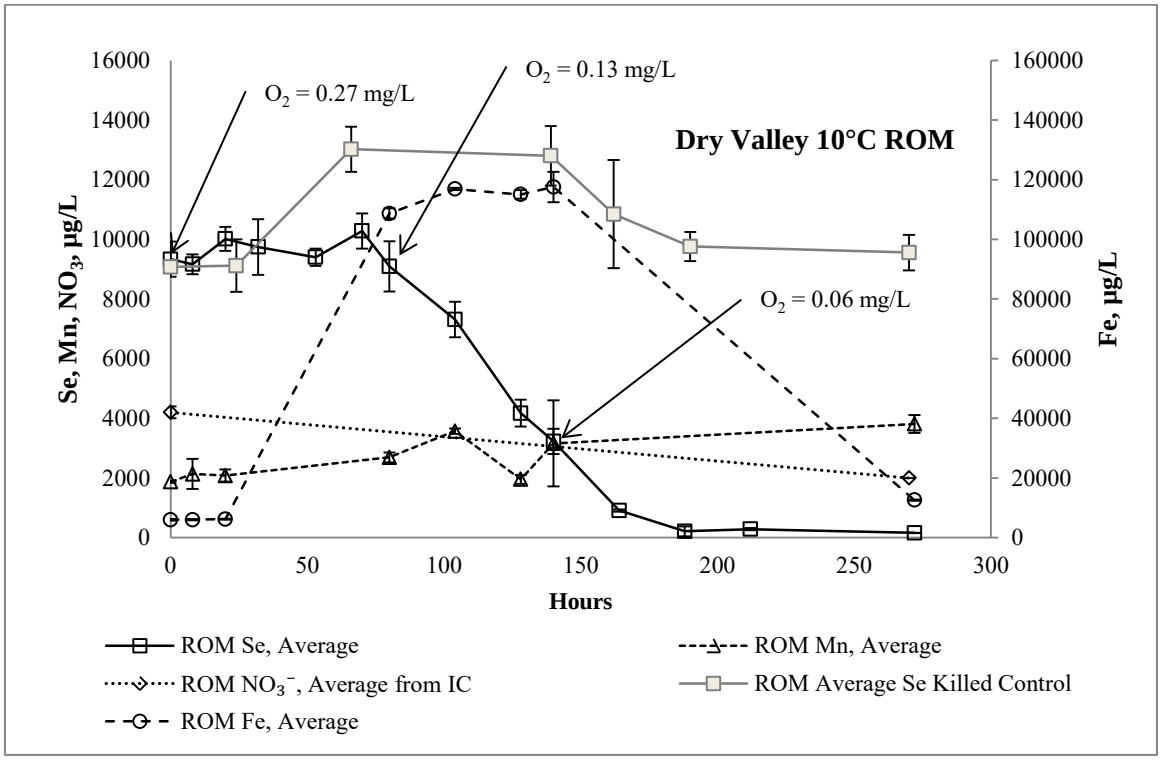

Figure 13. Dissolved Se, Mn, Fe, and NO_3^-concentrations in mixed overburden rate reactor, Dry Valley Mine at 10°C. pH varied from 6.6-6.8 under confined headspace throughout the experiment. ROM is mixed run-of-mine waste rock. Error bars represent +/- standard deviation for triplicate reactors,

speciation data obtained through ion chromatography indicated detectable SeO_3^{2-} mid-way through the reduction process (at 128 hours) as SeO_4^{2-} was removed from solution (Appendices D1 and D2).

Isolation and Identification of SeRB

Direct plating of groundwater and serially diluted rock samples was used to isolate potential SeRB. Colonies exhibited variable morphology and ranged in color from

clear or white to light orange, red and deep brick red. Colonies that exhibited deep orange to red coloration suggested SeO_4^{2-} reduction to Se^0 (see photos Appendix C1). Many of the apparent SeRB were mixed cultures and were observed to be closely associated with, and difficult to separate from, non-SeO_4^{2-} reducing organisms based on microscopy and sequencing results. The bacteria listed in Figure 14 were isolated from the mixed

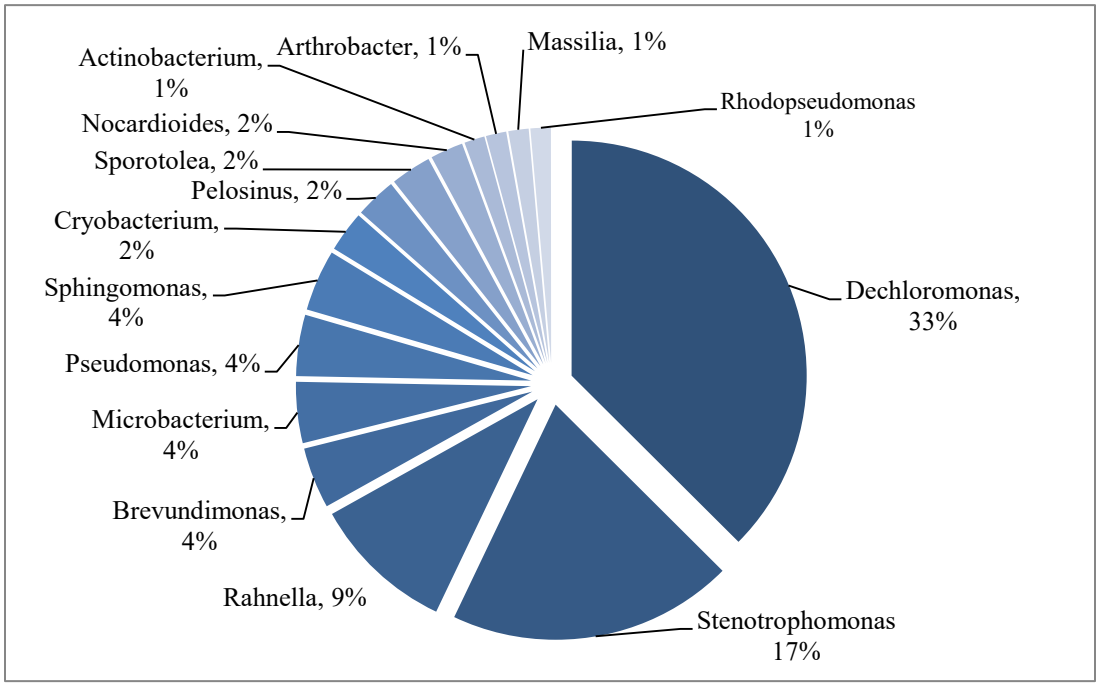

Figure 14. Genera identifications obtained from S.E. Idaho groundwater and rock (percentages reflect frequency of detection in the isolate pool), (n=80).

groundwater and rock cultures while attempting to identify SeO_4^{2-} reducers. Hundreds of colonies were screened in this process and eighty were chosen for identification by sequence analyses of 16S rRNA genes based on visual production of red elemental Se. Growth of isolates was slow at field relevant temperatures of 10°C, but was observed on all carbon substrates tested at various concentrations, and some isolates reduced as much as 10 mM SeO_4^{2-}.

Figure 14 shows the diversity of microorganisms that were isolated. A list is provided as Table C.1.1 in Appendix C1. The majority of phylotypes associated with organisms isolated from samples of groundwater were highly similiar to the genus *Dechloromonas;* these phylotypes comprised more than 33% of the bacterial population. Most sequences obtained for these isolates were >97% identical to members of the *Dechloromonas* genus (based on an average read length of 584 bases), but several sequences were > 96% similar to *D. hortensis, D. denitrificans or Dechloromonas* sp. A-34 (S. Childers, unpublished). Another 17% of the isolate phylotypes were >99% similar to the bacterial genus *Stenotrophomonas* Additional organisms isolated from groundwater were >97% similar to members of the *Rahnella, Brevundimonas, Microbacterium, Pseudomonas, Sphingomonas, Pelosinus, Sporotolea,* and *Nocardioides* genera, based on sequences that ranged in length from 240 to 628 base pairs. A list of the genus level identifications for the microbes isolated during this study is provided in Appendix C1; corresponding sequences are provided in Appendix C2.

Organisms most similar to members of the *Rhodoferax* were particularly challenging to isolate, due to their frequent occurrence in co-cultures with organisms that identified closely with members of the *Cellulomonas* and *Actinobacterium* genera. The organisms producing sequences that identified highly with the genera *Massilia*, *Sporotolea, Arthrobacter*, *Actinobacterium*, *Rhodopseudomonas, Oleomonas*, and *Sporosarcina* were less commonly isolated.

Enumeration of SeRB

A MPN approach [31] was used to estimate the number of SeRB present in groundwater and in the individual lithology specific samples. The results of ICP-MS analyses of total Se used for the MPN analysis are summarized in Table B1.3; the data source files are listed in Table B1.5 and provided electronically.

Table 9 shows that the estimated number of SeRB was greatest in MPN tubes prepared and maintained under anaerobic conditions. Although aerobic tubes showed growth as evidenced by visible turbidity, little to no SeO_4^{2-} reduction was evident. Sediments from Dry Valley GW7D groundwater samples incubated under anaerobic conditions averaged 4.6×10^6 SeRB per gram of rock. Of the various rock lithotypes, higher numbers of SeRB were associated with shales than with cherts or mudstones, and more SeRB were present in the external Smoky Canyon panel A rock dump than in the backfilled overburden in Smoky Canyon panel D or at the Enoch Valley Mine (Table 9). The shale samples AS71 and AS113 had the highest number of estimated SeO_4^{2-} reducers, with values ranging between 10^5 and 10^6 organisms per gram of sediment. In contrast, fewer than 10^3 SeRB were present in mudstone or chert.

Table 9. MPN results and dominant bands cut from DGGE for most dilute positive MPN cultures.

Location	Sample type	Lithology	MPN estimated No. SeO_4^{2-} Reducers per gram[+]		*Bacteria* with greatest similarity to 16S rRNA sequences for DGGE dominant bands for MPN samples
			Anaerobic	Aerobic	
GW7D-2a	**Groundwater**	ROM mix	**$4.67*10^6$**	**846**	*Pseudomonas, Rhodoferax, Dechloromonas* spp.
Dry Valley Mine					
GW11	**Groundwater**	ROM shale	**$1.67*10^4$**	**$1.1*10^4$**	*Pseudomonas, Rhodoferax, Dechloromonas* spp.
Smoky Canyon Mine					
SCD backfill	**ROM rock**				
Smoky Canyon Mine	DC5	chert	**360**	**15.5**	*Pseudomonas, Dechloromonas* sp.*Commamonas, Actinobacterium, Pelosinus, Sphingomonas*
	DM50	mudstone	**188**	**3.25**	nd
	DS75	shale	**$1.4*10^3$**	**18**	*Dechloromonas, Polaromonas*
	DC123	chert	**271**	**1**	nd
SCA external dump	**ROM rock**				
Smoky Canyon Mine	AS5	shale	**$1.7*10^4$**	**6.5**	*Commamonas, Pseudomonas, Rhodoferax, Dechloromonas* spp., *Polaromonas, Pelosinus*
	AS71	shale	**$5.2*10^6$**	**1**	*Pseudomonas, Rhodoferax, Dechloromonas* spp., *Polaromonas*
	AS113	shale	**$3.2*10^5$**	**1**	*Pseudomonas, Rhodoferax, Dechloromonas* spp, *actinobacteria, Cellulomonas*
	AC125	chert	**57**	**8.9**	nd
	AM145	mudstone	**$1.7*10^3$**	**77**	*Rhodoferax, Pelosinus, Pseudomonas*
MEV backfill	**ROM rock**				
Enoch Valley Mine	MS5	shale	**$4.3*10^3$**	**19**	*Pseudomonas, Rhodoferax*
	MM32	mudstone	**309**	**3**	*Pseudomonas, Rhodoferax, Dechloromonas* sp. *Pelosinus, actinobacteria*
	MS73	shale	**$1.2*10^4$**	**220**	*Pseudomonas, Rhodoferax, Pelosinus*
	MM178	mudstone	**238**	**21.9**	nd
	MS285	shale	**$1.6*10^5$**	**229**	*Rhodoferax, Dechloromonas* spp. *Sphingomonas, actinobacteria*

reported MPN values are an average of two replicates , [+]MPN data provided in Appendix B, Table B1-3
ROM = Run-of-mine, nd = not detected

SeRB Community Diversity in
Saturated and Unsaturated Sediments

Community diversity was measured using clone libraries, DGGE, and 454 pyrosequencing of the anaerobic MPN dilutions for samples of the lithotypes with the highest numbest of estimated SeO_4^{2-} reducing organisms. The most dilute positive MPN enrichments for select shale samples were compared with single samples of mudstone and chert using DGGE. Figure 15 shows a moderate level of diversity with 5-10 bands evident for each sample; chert had greater diversity than shales as indicated by the greater number of bands in the upper gel. The shale samples AS71 and AS113, which had the greatest number of SeRB in MPN estimates, showed somewhat less diversity and generally consistent community characteristics when compared with other shales or mudstone.

Comparative sequence analysis of excised DGGE bands (see Figure B1.1 and Table B1.4, Appendix B1), yielded the limited number of phylotypes shown in Table 9. Comparison of samples in Figure 15 with a ladder (left) constructed using DNA from microbes isolated during this study suggests that the majority of rock samples contain phylotypes that are strongly similar to members of the genera *Pseudomonas* (>99%, 260-280 bp) and *Rhodoferax* (>99%, 250-310 bp). Faint bands that align with one or more of the three *Dechloromonas* isolates are evident in shale samples, whereas the most dilute chert and mudstone MPN samples show bands that align with the amplicon for the isolate *Dechloromonas* sp. A-34 only. The identity of microorganisms represented by these bands could not be confirmed because they were too faint to cut. Phylotypes listed in italics in Figure 15, which were not included in the isolate ladder, were identified using

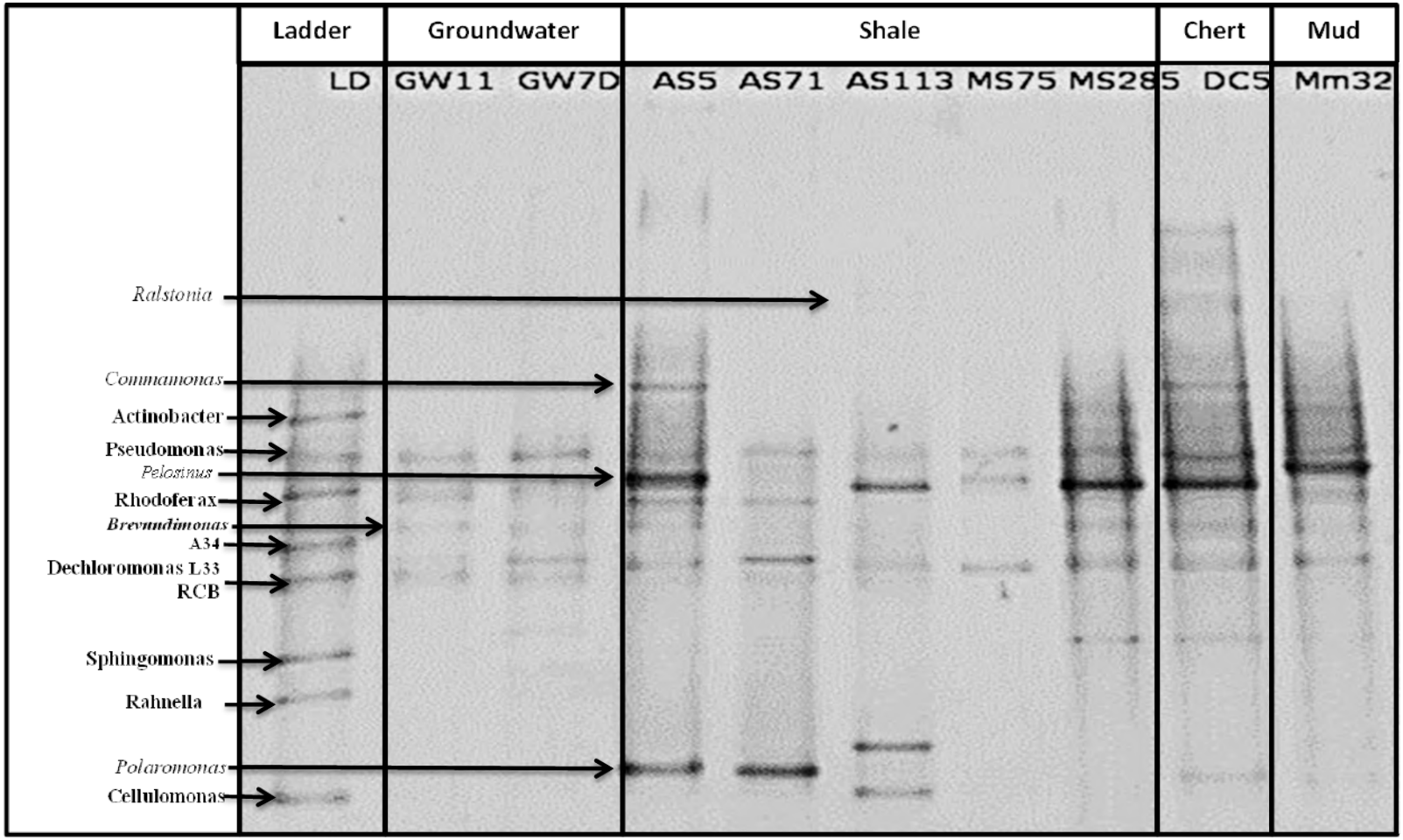

Figure 15. DGGE profiles comparing isolate ladder with groundwater and waste rock samples from Smoky Canyon, Dry Valley, and Enoch Valley mines, S.E. Idaho.

bands cut from gels where visualization and cutting of the bands was possible. While certain bands may have visually aligned, this does not necessarily guarantee that the bands came from the same population. To confirm that the ladder was servicing its purpose, a number of bands aligning with the isolate ladder were cut and submitted for sequence confirmation.

Groundwater samples from backfills at the Smoky Canyon and Dry Valley mines were also compared with one another, the sediment samples, and the isolate ladder in Figure 15. DNA was extracted directly from the biomass collected from these groundwater samples. Groundwater DNA samples yielded bands that were confirmed by comparative sequence analysis and also aligned with the ladder isolates of *Rhodoferax* (>99%), *Dechloromonas* A-34 (>98%), *D. hortensis L-33* (>96%), and *D. aromatica* RCB (>99%). Other bands in samples of groundwater from GW7D2a that were cut, extracted and sequenced had strong similarity to phylotypes associated with the genera *Brevundimonas, Rhodoferax* (>97%), *Polaromonas* (>99%) and *Acidovorax* (>98%).

Shale samples AS71 and AS113 had high estimated numbers of SeRB and contained phylotopes that were > 97% similar to known genera. Phylotypes sequenced from gel bands were closely related to several *Rhodoferax* species, including *R. fermentans[39], Rhodoferax sp.* AsD (>98%), and *R. ferrireducens* T118 (>98%, [40]). Members of the *Polaromonas* (>98%) and *Pseudomonas* (>99%) genera were also identified. Though bands suggestive of several *Dechloromonas* species were apparent based on ladder alignment, these phylotypes could not be confirmed because bands were too faint to be excised and/or did not amplify successfully from excised bands.

Comparable diversity patterns are evident between shale samples (AS5, MS 5, MS73, and MS 285) in Figure 15, and samples also contained phylotypes highly similar to representatives of the genera *Pseudomonas*, *Rhodoferax*, and *Pelosinus*. Supporting data are provided for isolates (Appendix C1), DNA sequences (Appendix C2), clone libraries (Appendix C3), and DGGE images (Appendix C4).

Clone Libraries

Clone libraries were constructed for both *Archaea* and *Bacteria* using primary enrichments of shale samples AS 71 and AS113 (Appendix C3). Bacterial clone libraries constructed for samples AS71 and AS113 contained 72 and 46 clones, respectively, as listed in Tables C3-1 and C3-2, respectively. Species richness and rarefaction curves from DOTUR (Appendix C3, Figures C3.1-3) indicate that clone sample diversity approached actual diversity. The bacterial library for AS71 had 30 OTUs (operational taxonomic units), out of 72 sequences at the 95% confidence level. The bacterial library for AS113 was less diverse, with 7 OTUs (out of 46 sequences) at the 95% confidence level. The two clone libraries represent statistically different populations based on a Unifrac analysis correlation coefficient of $0.001 < p < 0.01$. Sequence length was typically between 380 and 320 bases in length, allowing genus level identification. Figure 16a shows the bacterial phylotypes occurring at a frequency of 2% or greater in the AS71 library. This sample had the highest number of SeRB based on the MPN results. Nearly two-thirds of the clones had sequences that best matched members of hydrocarbon-degrading, Fe-reducing genera including *Anaeromyxobacter, Pelobacter*, *Polaromonas, Pelosinus*, *Geobacter*, and *Variovorax*. Phylotypes strongly similar to

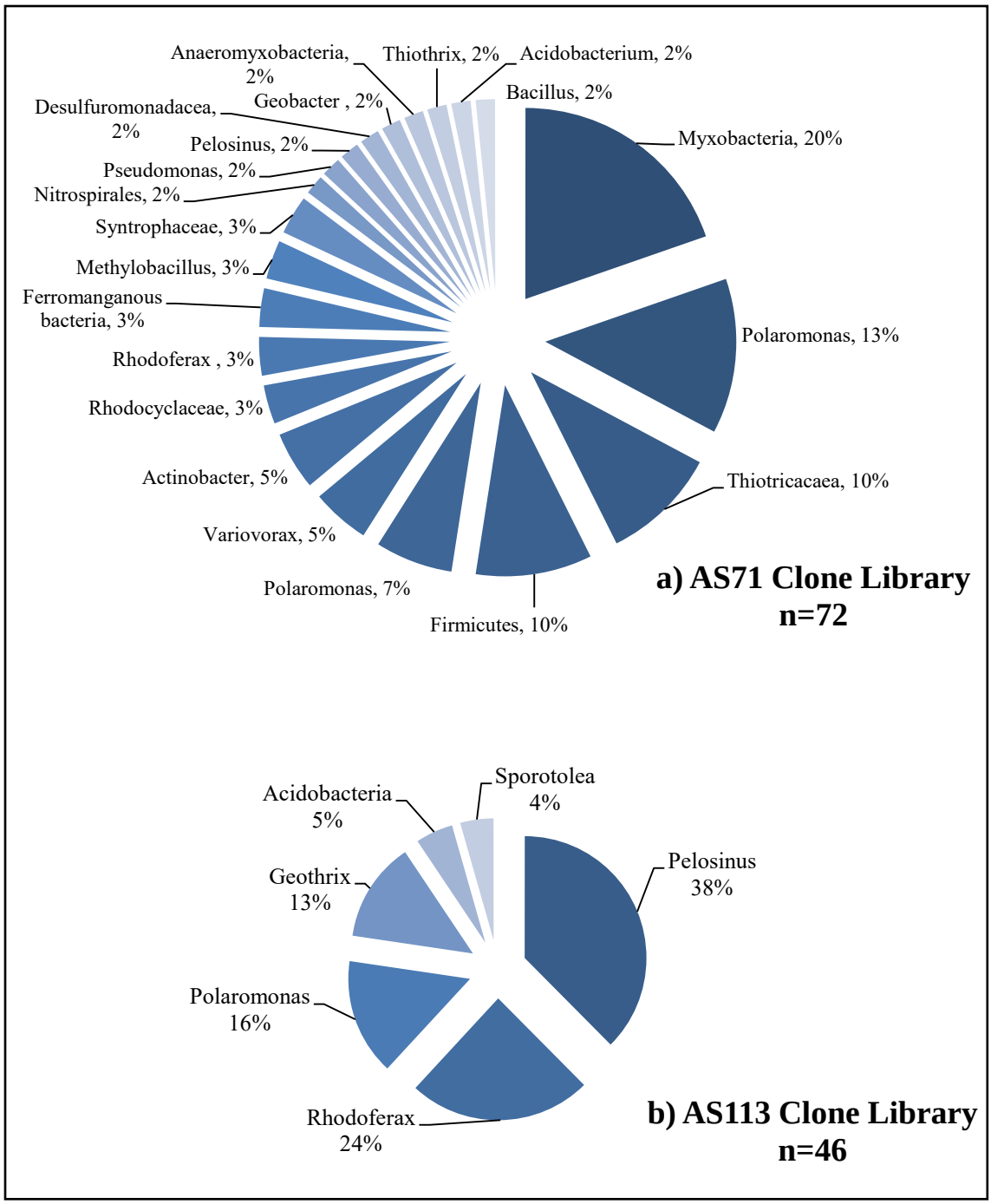

Figure 16. Bacterial clone libraries for overburden samples (a) AS71 and (b) AS113.

Fe- and S-oxidizing members of the *Acidoferrobacter* genus, and the Fe- and S-reducing genera *Desulfuromonas* and *Magnetobacter*, represent another 20% of observed diversity.

Less diversity is evident in the AS113 clone library (Figure 16b), with only 7 principal phylotypes representing the community. Most clones closely (> 97% identity) matched the phylotopes of Fe-reducing, hydrocarbon-degrading genera, including *Pelosinus* (38% of the diversity), *Rhodoferax* (24%), *Polaromonas* (16%), *Geothrix* (13%), *Acidobacteria* (5%), *Sporotalea* (4%) and *Anaeromyxobacter* (2%). The AS113 community is more limited than the AS71 community, but the metabolisms of the microorganisms represented in AS113 are consistent with the dominantly hydrocarbon-oxidizing, Fe-reducing community identified for AS71.

Of the phylotypes identified in the clone libraries, only *Anaeromyxobacter* is known to be a SeO_4^{2-} reducing organism. Interestingly, no *Stenotrophomonas-like phylotypes* were identified in the libraries, consistent with the results of the DGGE molecular work, but not the isolation work. *Dechloromonas* phylotypes were also not identified in the clone libraries.

Results for the *Archaeal* library for AS113, which contained 35 clones, are provided in Appendix C3. The rarefaction curve is also provided as Figure C3.1 in Appendix C3. Creation of an *Archaeal* library for AS71 was unsuccessful due to low DNA yield.

Community Diversity in Saturated and Unsaturated Overburden

Lithotype and moisture content are hypothesized to influence the microbial community composition and capacity for SeO_4^{2-} reduction. DGGE profiles were used to test this hypothesis by comparing changes in community diversity between lithotypes and groundwater samples from saturated backfill (Figure 14). This approach was taken to complement the isolation work by identifying microorganisms that were not readily cultivated. The DGGE banding patterns in the two groundwater samples were nearly identical and reflected less diversity than the unsaturated rock samples. There was considerable similarity between identified communities, however, and bands representing the *Pseudomonas*, *Rhodoferax,* and *Dechloromonas* genera were observed in both saturated and unsaturated sediments. DGGE patterns of the shale samples show a relatively consistent community in that lithotype, whereas the DGGE patterns for the mudstone and chert samples differ somewhat from the shales and from each other.

Discussion

Culture dependent and independent techniques were used to characterize the SeO_4^{2-} reducing microbial populations present in backfill at three phosphate mine sites in S.E. Idaho. The study was undertaken because physical and geochemical monitoring data indicate there are important differences between the overburden deposits at each location, which may influence the release of Se to the surrounding environment.

Subsurface Selenium Biogeochemistry
Supports Potential for Se Reduction

Groundwater chemistry at the Smoky Canyon Mine (GW11), where SeRB numbers were lower, showed lower pH values and higher SeO_4^{2-}, SO_4^{2-}, NO_3^-, and O_2 concentrations compared to conditions at the Dry Valley mine, where SeO_4^{2-} concentrations are below the Idaho groundwater standard of 0.050 mg/L. These data reflect the higher concentration of O_2 at the Smoky Canyon Mine, where increased SO_4^{2-} was measured, and decreased biological reduction of SeO_4^{2-} and NO_3^- was indicated by the relatively higher concentrations of Se and lower numbers of SeRB. The probable importance of microbial reduction of SeO_4^{2-} in the Dry Valley Mine sediments under suboxic conditions is demonstrated by the comparison of live and killed cultures in batch reactors, where concurrent NO_3^-, Fe^{3+} and Mn^{4+} reduction is evident (Figure 13). The Smoky Canyon monitoring well GW11 is intermittently saturated with higher concentrations of O_2, while groundwater in the Dry Valley backfill, where concentrations of SO_4^{2-}, SeO_4^{2-}, and NO_3^- are lower, demonstrates more consistently microaerophilic to anoxic conditions. This condition may be due to prior saturation during pit water discharge onto backfill in 1999 and 2000, but conditions have remained sub- to anoxic even though much of the upper backfill has drained to field capacity moisture content since that time [2]. Elevated concentrations of SO_4^{2-} at both locations suggest that while conditions are moderately reducing, they are too oxidizing to support significant SO_4^{2-} reduction. Iron concentrations in both groundwater wells (<0.2 mg/L) are low relative to higher manganese concentrations (<0.5 mg/L).

Rock sampled from the Smoky Canyon backfill D and external A dumps has variable water content that is consistently below reported moisture retention capacities (Table 6) [3]. At the Enoch Valley Mine site, gas and moisture conditions fall between the partially aerobic, dominantly unsaturated conditions at the Smoky Canyon Mine and the suboxic, more saturated conditions at Dry Valley backfills. Core samples from the Enoch Valley Mine are also unsaturated, but generally have higher water content than the Smoky Canyon Mine samples. Oxygen is not detected in samples collected from below 30 feet of depth at the Enoch Valley Mine, in spite of the unsaturated character of these deposits, reflecting the distinct manner in which the rock was dumped in individual lifts during facility construction. The locations sampled in this study thus offered a representative range of conditions in which to study changes in the SeRB microbial community within mined overburden under field conditions. The *in situ* monitoring data in Table 6 suggest that observed differences in SeO_4^{2-} concentrations between the Dry Valley and Smoky Canyon mines are more likely the result of variations in O_2 levels, moisture content, and lithology (e.g., Se, N and C content and material texture) than differences in temperature or pH, which show little difference between locations. These variables, which can be influenced by mine facility design, were used to further explore changes in microbial community numbers and diversity.

A comparison of the estimated number of SeRB with the physical and chemical parameters of the samples shows that the greatest numbers of SeRB occur in shale or groundwater, where soluble Se and DOC contents are elevated and samples are saturated. Interestingly, measurements of O_2 within the drill hole annulus and/or bulk moisture

contents shown in Table 6 (e.g., at the macro scale) do not correspond directly with SeRB numbers. This is not surprising due to the fine-grained and tightly compacted nature of the hydrocarbon-rich shales, which have a greater capacity to develop anoxic conditions as a result of aerobic hydrocarbon metabolism within partially saturated pore spaces that would not be evident at the macro scale. Significant populations of SeRB were not evident in MPN tubes under aerobic conditions or in samples of chert or mudstone with lower moisture or water soluble organic carbon content, nor were they present in near-surface shales with either low moisture content or low total Se concentrations. As might be expected, greater numbers of SeRB colonize shales where the total Se concentration is higher. For several samples where the SeRB were present in elevated numbers relative to other samples (AS71, DS75, MS5, MS73, and MS285), the ratio of soluble to total Se was (0.03-0.15) reflecting possible microbial influences on net Se solubility.

Identity of SeRB

The phylotypes associated with the SeRB isolated from the majority of SeO_4^{2-} reducing enrichments were more than 99% identical to members of the *Dechloromonas* genus [41]. The *Dechloromonas* OTU's were most similar to *D. aromatica* [42], *D. denitrificans* [43], *D. hortensis* [44],and *Dechloromonas*A-34, a novel organism that was isolated from the Smoky Canyon Mine shales (Childers, unpublished). All of the *Dechloromonas* isolates obtained in this study could respire SeO_4^{2-} (Childers, unpublished) and reduced soluble SeO_4^{2-} to Se^0. Dechloromonads are rod-shaped, gram-negative, non-spore forming, strictly-respiring facultative anaerobes that can couple the oxidation of short chain volatile fatty acids and simple dicarboxylic acids to the reduction

of (per)chlorate, O_2, and in some strains, NO_3^- [45]. Until now, no dechloromonads have been shown to respire SeO_4^{2-}, although some species can respire SO_4^{2-} and NO_3^-. The SeO_4^{2-}-reducing *Decholoromonas* isolates obtained in this study did not grow with chlorate or perchlorate [hereafter referred to as (per)chlorate], indicating they cannot respire (per)chlorate and are physiologically distinct from all known *Dechloromonas* species isolated to date (Childers, in preparation). The majority of SeO_4^{2-}-reducing *Dechloromonas* isolates obtained in this study are most closely related to *D. aromatica* RCB which grows anaerobically by coupling the oxidation of benzene to nitrate or (per)chlorate, and has been shown to oxidize toluene, ethylbenzene, and xylene isomers using nitrate, (per)chlorate or O_2 as electron acceptors [42, 46]. Similar aromatic hydrocarbon compounds, such as benzene, toluene, and anthracene were identified in methylene chloride extractions of shales from the Phosphoria Formation (Table 7) and may provide a substrate for the SeO_4^{2-} reducing dechloromonads present in these sediments.

Organisms from the *Dechloromonas* genus were readily isolated and their 16S rRNA genes amplified from groundwater, and they were detected frequently in culture enrichments. They could not be isolated from the most dilute positive MPN cultures, were not identified in clone libraries, and occurred only as faint bands in DGGE analyses of rock samples, however. This suggests that they may be present in very low numbers in unsaturated rock, or alternatively, that the enrichment and cultivation methods select for these organisms and misrepresent their relative dominance in the enrichment community (Figure 14). It also appears that these dechloromonads thrive under saturated conditions,

as they seem to be more readily isolated from saturated sediment samples collected from groundwater monitoring wells, but were not enriched from samples from unsaturated environments.

The second most frequently isolated SeRB was typically more than 99% identical to a *Stenotrophomonas* member, specifically *S. maltophilia*, and was also only found associated with groundwater rather than unsaturated shale. *S. maltophilia* can reduce SeO_4^{2-} and SeO_3^{2-} to Se^0 during stationary phase under microaerophilic conditions; cells are thus not dependent on SeO_4^{2-} or SeO_3^{2-} for growth [47, 48]. *S. maltophilia* has also been shown to reduce SeO_4^{2-} in a mixed community of SeRB in coal mine tailing pond sediments [25], and was identified as a member of a benzene-degrading microbial consortium [49]. Interestingly, no *Stenotrophomonas* species were isolated from, or identified in the DGGE analysis of the most dilute positive MPNs. Members of this genus were also not identified in the clone libraries suggesting that it, too, may not be numerically important in the rock samples.

None of the other isolates obtained during this study exhibited SeO_4^{2-} reduction independently, under the conditions used in this study. For example, efforts to isolate individual SeRB from the most-dilute positive MPN culture for the AS71 and AS113 samples were unsuccessful (e.g., individual phylotypes similar to organisms known to be capable of reducing SeO_4^{2-} to Se^0), yet members of the *Rhodoferax* and *Cellulomonas* genera and *Actinobacteria* were identified from these samples through cultivation and/or confirmed through comparison with known isolates using DGGE. For this reason, there seems to be additional potential for Se reduction at the community level which could not

be demonstrated here, potentially involving different organisms handling individual steps of the reduction from the SeO_4^{2-} to the Se^0 form. Several *Rahnella* spp. were isolated and although these isolates did not demonstrate SeO_4^{2-} reduction, members of the *Rahnella* genus have been reported to reduce SeO_4^{2-} in sediments from the Nile Delta [50]. *Rahnella* may play a broader community role, in that several members of this genus facilitate phytoremediation of Cd, Pb, Zn, and U [51] and have potential to dissolve hydroxyapatite, a common phosphate mineral [52, 53]. Likewise, the *Rhodoferax* isolates from this study did not reduce SeO_4^{2-} although *R. fermentans* was identified as a SeO_4^{2-}-reducing microorganism in previous work at Smoky Canyon[26].

A mixed culture of one *Rhodoferax* and one *Cellulomonas* isolated from the most dilute AS113 MPN culture did show weak, late growth stage reduction of SeO_4^{2-} to Se^0, but the SeO_4^{2-} reduction was weak compared to the SeO_4^{2-}-reducing capacity of the original MPN culture from which the microorganisms were isolated. The potential capacity of *Rhodoferax* and/or *Rahnella* spp. to reduce SeO_4^{2-} to SeO_3^{2-}, coupled with reduction to insoluble forms by other isolated SeO_3^{2-}-reducing genera such as *Cellulomonas* or *Pseudomonas,* should be further investigated to explain the inability to isolate an individual organism capable of reducing SeO_4^{2-} to Se^0 in the most dilute MPN cultures. *Anaeromyxobacter* is another genus with members that are capable of community level Se reduction. Members of this genus are known to reduce SeO_4^{2-} [54], and this genus was identified in clone libraries for both shale samples in this study, but was not isolated or identified in DGGE work.

The highest numbers of SeRB were associated with hydrocarbon-rich shales, which suggests that SeRB may be capable of coupling the reduction of SeO_4^{2-} directly to the oxidation of complex hydrocarbons. Isolates grew on carbon extracted from the rock, which contained a mix of aliphatic and aromatic compounds of varying complexity, but each isolate has not been tested for growth independently on the individual compounds present in the extracts. However, none of the *Dechloromonas* isolates obtained as part of this study showed an ability to couple SeO_4^{2-} reduction with the oxidation of benzoate.

Selenate-reducing isolates with strong similarity to the genera *Dechloromonas, Stenotrophomonas,*or *Rahnella* could not be isolated from the most-dilute positive MPN tubes of rock samples or identified in the clone libraries, indicating that these organisms are present in low numbers in samples of unsaturated rock but were selected for by the enrichment methods used in this study. The opposite is true for the groundwater samples, as all of the *Dechloromonas, Stenotrophomonas* and *Rahnella* isolates were obtained from groundwater sources. The DOTUR curves (Appendix A3) indicate that the clone libraries, while small, reasonably represent the observed variation in the bacterial community, but the 16S rRNA gene sequences for the SeO_4^{2-}-reducing isolates are absent in the clone libraries. This supports the conclusion that the Se-reducing organisms are rare members of the overall microbial community, and that the reduction of Se is a relatively minor part of the overall biogeochemical activity within the backfills.

A previous study reporting on the isolation of SeRB within phosphate mine wastes in SE Idaho yielded results different from this study [27]. In the earlier study, no *Dechloromonas* representatives were obtained from phosphate overburden nor were any

identified in the DGGE analyses, although uncultivated *Rhodocyclaceae* were reported by Knotek-Smith [55]. Archived samples of overburden used in this previous study were obtained and several members of the *Dechloromonas* genus were successfully isolated from the material, indicating that fundamental differences in the techniques used to isolate SeRB are likely the reason for the discrepancy.

Community Characteristics and Diversity

Results of this study provide a broader understanding of the microbial ecology of these complex overburden deposits. Many of the sequences obtained for microbes isolated from groundwater or enriched rock samples were not SeRB. Phylotypes with a high degree of similarity to denitrifying and hydrocarbon-oxidizing, and Fe^{3+}or Mn^{4+-} reducing organisms appear to dominate the microbial population of these variably saturated, phosphate overburden sediments. In the clone libraries, the only known SeO_4^{2-} -reducing genus that was detected was *Anaeromyxobacter;* the SeO_3^{2-} -reducing genus *Geobacter* was also identified.

Sequences related to S-oxidizing and methanotrophic organisms were also detected in clone libraries. Conversely, phylotypes with high similarity to known SeO_4^{2-} -reducing organisms were more frequently identified in isolates and DGGE-isolated bands than in clone libraries, and were more common in saturated sediments and in unsaturated samples of shale. It is therefore likely that these phylotypes (and the organisms they represent) occur in relatively low abundance within the overall microbial community.

Microbial phylotypes identified in this study indicate the presence of a mixture of aerobes and anaerobes, many closely related to microorganisms that can degrade

hydrocarbons. Degradation of aromatic hydrocarbons, such as benzene, naphthalene, phenanthrene, and other naturally occurring hydrocarbon compounds present in the Meade Peak shale sediments, is most likely to be most efficient under aerobic conditions, but can be stimulated by NO_3^- and Fe^{3+} or Mn^{4+} reduction under anaerobic conditions. Demand for O_2 during such degradation can be sufficient to create locally anaerobic zones within soils [56], and may explain the development of microscale anaerobiosis in shales located within relatively aerobic waste facilities.

Several phylotypes similar to genera that are capable of aerobic or facultative degradation of hydrocarbons were identified. *Sphingomonas* [57], as well as *Anaeromyxobacter* and *Brevundimonas* [58], are heterotrophs and contain species capable of polycyclic aromatic hydrocarbon degradation. Members of the genera *Pseudomonas, Nocardioides,* and *Rhodoccoccus* are similar to the phylotypes identified in this study are also known to degrade aromatic carbon aerobically [59, 60]. Of particular interest is that *Polaromonas*, a genus of aerobes in the *Commamonadacae* family, have high metal tolerance and the capacity for degrading a variety of hydrocarbons, ranging from alkanes to aromatic compounds, under a wide range of metal and salinity exposures [61]. Phylotypes identified in this study were highly similar (>99%) to a *Polaromonas* sp. isolated from a naphthalene contaminated soil sample [62, 63].

Members of the genus *Anaeromyxobacter* are known to oxidize reduced humic acids [6] and can concurrently reduce Se and Fe [64]. Some *Variovorax* spp. can degrade polycyclic aromatic hydrocarbons under aerobic or NO_3^- reducing conditions at low

temperature [65]. Members of the *Acidovorax* and *Pseudomonas* genera were associated with aerobic benzene-degrading communities in a study of O_2 depleted groundwater [56] and *Pseudorhodoferax* spp. are also known hydrocarbon-degrading members of the *Comamonadaceae* family [66]. Of additional interest is the capacity of a comamonad, *Rhodoferax ferrireducens,* to degrade benzoate under both aerobic and anaerobic conditions, as well as its ability to reduce Fe^{3+} and NO_3^- [67].

Hydrocarbon degradation is also fueled by Fe cycling in suboxic environments [68, 69]. Microaerophilic Fe^{2+}oxidation, and anaerobic, NO_3^--dependent re-oxidation of Fe^{2+}, are important contributors to Fe-cycling in carbon-rich sediments [70-72]. Several of the *Bacteria* isolated from these phosphate overburden communities are strongly similar to organisms shown in published studies to couple hydrocarbon degradation to Fe- redox cycling and they are thus inferred to do so in these deposits. For example, *Geobacter metallireducens* was one of the first anaerobes shown to oxidize organic compounds using Fe^{3+} as an electron acceptor [73], and perchlorate and NO_3^- dependent re-oxidation of Fe^{2+} by two species of *Dechloromonas* [42] was shown to occur in anaerobic settings. Abiotic oxidation of Fe^{2+} by Mn^{4+} may also support this process [68], by resupplying Fe^{3+} for reduction by organisms similar to *R. ferrireducens*, a facultative Fe^{3+}-reducer highly similar to the phylotype identified in these sediments [40]. Other organisms similar to phylotypes identified in this study with capacity to reduce Fe^{3+} and Mn^{4+} include members of *Desulfuromonas* [74], G*eobacter* [75, 76], *Rahnella* and *Anaeromyxobacter.* Members of the genus *Pelosinus* are also known to reduce Fe^{3+} and

humic compounds [77, 78]. Members of the *Acidobacteria* and *Acidovorax* genera identified in the backfill are additional potential contributors to Fe^{2+} oxidation [79].

The community analysis suggested additional cycling of S, N, and methane. Both S-oxidizing and -reducing genera were identified in clone libraries, including *Acidoferrobacteria, Desulfuromonas,* and Candidatus *Magnetobacteria*. Methanotrophic genera known to be capable of dentrification (*Acidothermus*) and oxidation of organic compounds (*Methylobacter/Methylotenera*) were also identified in the clone libraries. These *Bacteria* are potentially important members of the community in sulfide-bearing sediments which exhibit elevated levels of NO_3^- and SO_4^{2-} due to NO_3^- compounds used in blasting and the oxidation of sulfide minerals in the mining environment.

Communities with similar microbial diversity and ecology have been described in other low temperature subsurface, hydrocarbon-influenced environments. A consortium comprised of *Acidovorax*, *Pseudomonas, Sphingomonas*, and *Variovorax* species was reported under aerobic and nitrate-reducing conditions in soils where naphthalene, phenanthrene, and fluorene were degraded [65]. Phylotypes with a high degree of similarity to *Polaromonas* spp. were identified with *R. ferrireducens* in a mixed consortium of aerobic and anaerobic benzene-degrading organisms in a groundwater setting [80]. *Polaromonas* spp. were also present with *Acidobacterium* and *Sphingomonas* organisms in a benzene-degrading soil consortium [81]. In an O_2-depleted benzene contaminated groundwater, *Acidovorax*, *Pseudomonas*, and *Rhodococcus* spp. varied in relative abundance based on changes in O_2 availability [56]. An *Acidovorax* sp. was also identified as a member of a benzene-oxidizing, chlorate-reducing consortium

with *Mesorhizobia* and *Dechloromonas* spp. [49]. These studies support the probable role of representatives of the *Acidovorax, Polaromonas, Sphingomonas*, and *Variovorax* genera in hydrocarbon degradation under mixed aerobic/anaerobic conditions in subsurface backfills in S.E. Idaho.

Summary

The diverse community of microorganisms identified in phosphate overburden at three mine sites located across the S.E. Idaho Phosphate Resource area can work together to reduce SeO_4^{2-} under Fe^{3+}, Mn^{4+}, and NO_3^--reducing conditions, using available native hydrocarbon and other available electron donors. With variable O_2 and moisture conditions within the mined overburden, there are opportunities for both aerobic and anaerobic degradation of complex shale hydrocarbons, as suggested by the diversity of organisms identified. Degradation of complex shale hydrocarbons by aerobic members of the community may decrease available O_2, thus creating conditions favorable for SeO_4^{2-} reduction by species of *Dechloromonas* and *Stenotrophomonas*, and perhaps other SeRB such as *Cellulomonas* and *Rahnella* spp. The most favorable conditions appear to be in saturated or moist environments (close to field capacity) where sufficient soluble Se and organic C are available to support growth of SeRB. Opportunities to extend this understanding of biogeochemistry in subsurface phosphate overburden deposits include further evaluation of community level heterotrophic SeO_4^{2-} reduction and evaluation of which native hydrocarbon compounds are being consumed by SeRB in removing Se from solution, as well as controlled studies of how the relative availability of NO_3^- and O_2

affects the reliability of SeRB activity. Field scale monitoring of biogeochemistry and microbial community response to changes in O_2 availability that result from operational changes in mine rock placement and water management is needed to demonstrate how *in situ* microbial reduction of Se performs at the field scale. Based on the results of this study, an effective operational application of *in situ* microbial source control of Se in backfilled phosphate overburden will need to consider the influence of O_2 and NO_3^- concentration, lithology, and water availability on the activity of SeRB, as well as the influence of Fe^{2+} on the native hydrocarbon degrading community.

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CHAPTER FIVE

KINETICS OF SELENATE REDUCTION BY NATIVE MICROBES IN SATURATED PHOSPHATE MINE WASTE

Contribution of Authors and Co-Authors

Manuscript in Chapter 5

Author: Lisa Bithell Kirk

Contributions: Principal investigator, led field work, designed and conducted all experiments and analyses.

Co-Author: Jared J. Bozeman

Contributions: laboratory assistant with all aspects of the project, data reduction, principal investigator as undergraduate scholar responsible for clone library construction and analysis.

Co-Author: Brandy D. Stewart

Contributions: Mineralogical analyses, using XRD, XANES, and S-XRD. Data reduction and interpretation.

Co-Author: Robin Gerlach

Contributions: Advisor, analytical and organic chemistry, chemical engineering. Supervised laboratory research and analyses.

Co-Author: Brent M. Peyton

Contributions: Major Advisor, Biological and Chemical Engineering. Supervised laboratory research and analyses.

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Authors… Lisa Bithell Kirk, Jared J. Bozeman, Brandy D. Stewart, Robin Gerlach and Brent M. Peyton

Center for Biofilm Engineering, Montana State University, Bozeman MT

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KINETICS OF SELENATE REDUCTION BY NATIVE MICROBES IN SATURATED PHOSPHATE MINE WASTE, S.E. IDAHO

Lisa Bithell Kirk, Jared J. Bozeman, Brandy D. Stewart, Robin Gerlach and Brent M. Peyton

Center for Biofilm Engineering, Montana State University, Bozeman MT

ABSTRACT

Selenate (SeO_4^{2-}) reduction by native microbes, using naturally-occurring carbon in chert and shale phosphate overburden, has been studied under temperature, oxygen, and lithological conditions representative of subsurface backfills in S.E. Idaho Phosphate Resource Area. Selenate reduction is a biotic process, wherein SeO_4^{2-} is reduced when trace oxygen (O_2) and nitrate (NO_3^-) in saturated, microaerophilic sediments is consumed by aerobic and denitrifying microbial activity. The rate and biogeochemical reduction pathways are lithology and temperature dependent. Near-complete reduction of SeO_4^{2-} to selenite (SeO_3^{2-}) and elemental Se (Se^0) occurred more rapidly in chert, while SeO_4^{2-} was reduced to selenomethionine, Se^0 and selenide minerals more slowly in shale. Concurrent hydrocarbon oxidation coupled to Fe^{3+}, Mn^{4+}, and NO_3^- reduction was observed, with less than 40% of the available dissolved organic carbon used during the reduction process. Shifts in the community of microbes were observed, from an initial consortium comprised of the genera *Dechloromonas*, *Rhodoferax, Brevundimonas,* and *Sphingomonas* to one containing additional phylotypes associated with the genera *Ralstonia* and *Rahnella*. These results explain field-scale observations of differential Se reduction at different mine site locations due to changes in moisture and oxygen availability, and suggest that design of facilities to achieve *in situ* Se stabilization using native microbes and carbon is possible through management of water, rock, and gas flux.

Introduction

Selenium (Se) release from mine waste may impact water quality and has potential to threaten aquatic ecosystems [1]. Mobility and toxicity depend upon Se speciation in response to complex biogeochemically-driven redox processes [2, 3]. Mine waste deposits host diverse communities of microbes known to influence metal, sulfur (S)[4], and nitrogen (N) geochemistry [5]. Biofilms developed on mineral surfaces within these deposits afford mixed microbial communities opportunities to manage water, carbon (C), nutrient, and oxygen (O_2) budgets [6-10]. The low solubility of Se under moderately reducing conditions has raised broad interest in microbial reduction of Se for bioremediation purposes [11, 12], but intentional development of biogeochemical conditions that foster Se reduction and attenuation within engineered mine waste facilities remains relatively unexplored. This study explores the biogeochemistry, rate, and products of Se reduction by a native consortium of microbes, under saturated microaerophilic conditions, using naturally available C in mined phosphate overburden facilities in S.E. Idaho Phosphate Resource Area. Improved understanding of the microbial ecology of *in situ* Se reduction can guide future efforts to design facilities for *in situ* Se source control.

Selenium exists in four major oxidation states, Se(VI), Se(IV), Se(0), and Se(-II) [13]. It substitutes for S in a variety of minerals, such as pyrite ($Fe(Se^{-II}, S^{-II})_2$) and gypsum, $Ca(Se^{VI}O_4, SO_4)\cdot 2H_2O$, which have potential to release Se when oxidized or leached [14]. Reduced Se minerals can be oxidized through biotic or abiotic processes [15-17]. Under acidic conditions, Se oxyanions are readily sorbed to highly protonated

surfaces of iron (Fe) and manganese (Mn) oxides [18-23], aluminum oxides [24], and clays [25, 26]. At neutral pH, selenate (SeO_4^{2-}) is poorly attenuated and sorption is only efficient for selenite (SeO_3^{2-}) [27, 28]. Alkaline and oxidized mine waste thus release SeO_4^{2-} oxyanions that persist in solution and may bioaccumulate [1].

Kinetic barriers to abiotic SeO_4^{2-} reduction create opportunities for its microbial respiration [29], while other organisms are known to reduce or methylate SeO_3^{2-} for detoxification purposes [30]. Microbial reduction of soluble and potentially toxic SeO_4^{2-} and SeO_3^{2-} to the less soluble Se^0 and Se^{2-} minerals limits Se mobility and bioavailability [31]. Organo-Se compounds, including selenocysteine (SeC) and selenomethionine (SeM), result from Se assimilation [32], and a variety of methylated compounds are produced via detoxification pathways [33, 34]. Facultative or anaerobic Se-reducing microbes range from mesophilic to extremophilic *Bacteria* and *Archaea* that are adapted to extremes of pH, salinity, or temperature [35, 36]. Some can reduce SeO_4^{2-} fully to Se^0, while others are capable only of reducing SeO_4^{2-} to SeO_3^{2-} or SeO_3^{2-} to Se^{2-}. Reduction of soluble oxyanions to the most reduced Se(0) or Se(-II) oxidation states can thus depend on community-level interactions between multiple organisms [37]. The ecology of microbial communities that reduce Se in mine waste is likely to be influenced by O_2 and C availability, as well as cycling of N, S, Fe, and Mn.

Groundwater monitored in backfilled sediments at two S.E. Idaho mines that produce phosphate from the Permian Phosphoria Formation (Figure 17), Dry Valley Mine (well GW7D2a) and Smoky Canyon Mine (well GW11), have significantly different soluble Se concentrations. This is despite the fact that both wells were completed in mixed

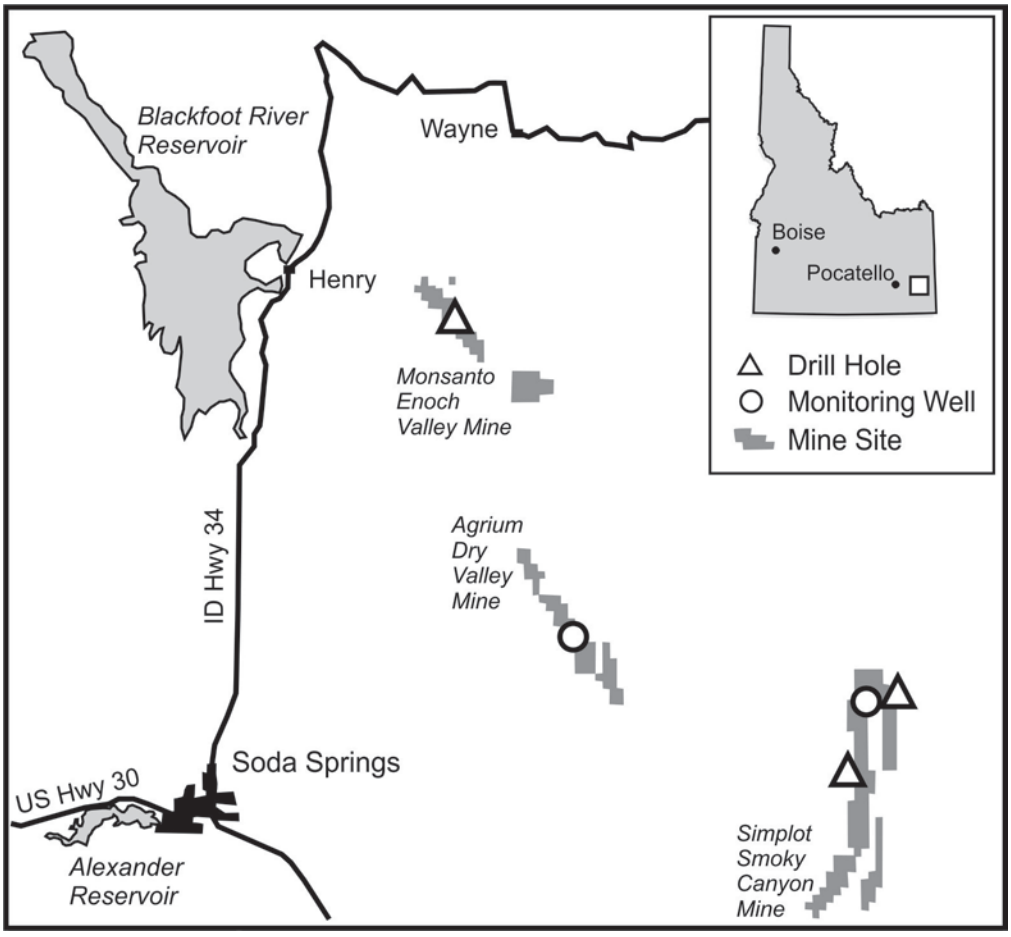

Figure 17. Map showing drill hole and monitoring well sampling locations at the Agrium Dry Valley and Simplot Smoky Canyon Mines, S.E. Idaho.

overburden that was mined from the same geologic formation using similar methods [38]. Concentrations of Se in Ca-HCO_3-SO_4 groundwater at the Dry Valley Mine, where seleniferous rock is saturated in deep backfill, have remained at or below the Idaho groundwater standard of 0.05 mg/L for more than 10 years, suggesting an ongoing process of microbial Se reduction. This is in contrast to concentrations as high as 1 mg/L measured in variably saturated, aerated backfill at the Smoky Canyon Mine. Highly carbonaceous, Se-enriched black shale and a clay-rich, Fe-oxide bearing chert are the dominant overburden lithotypes mined in the S.E. Idaho Phosphate Resource Area, with

lesser amounts of mudstone. The relative percentage of each lithology varies within randomly placed backfilled overburden.

Objectives

In Chapter 4, a consortium of native microbes with potential for SeO_4^{2-} reduction in subsurface mine waste at three S.E. Idaho phosphate mines was identified and enumerated under a range of representative O_2, moisture, and lithology conditions using samples of saturated and unsaturated overburden. A most probable number (MPN) method was used to estimate the number of SeO_4^{2-}-reducing bacteria (SeRB) in groundwater, chert, shale, and mudstone samples, and changes in microbial diversity as a function of lithotype and moisture conditions were compared using clone libraries and denaturing gradient gel electrophoresis (DGGE). The most favorable conditions for Se reduction appear to be in shale, under saturated or moist conditions (close to field capacity) where sufficient soluble Se and organic C is available to support higher numbers of SeRB.

Results reported in Chapter 4 for Se reduction in mixed overburden suggest that variable O_2 and moisture conditions within the mined overburden create opportunities for both aerobic and anaerobic degradation of complex shale hydrocarbon, as reflected by the diversity of identified hydrocarbon-degrading organisms. Results also indicate that SeRB reduce SeO_4^{2-} using naturally-occurring C compounds under Fe^{3+}, Mn^{4+}, and NO_3^- reducing conditions. It is proposed that degradation of complex shale hydrocarbons by aerobic members of the community decreases available O_2, thus creating conditions

favorable for SeO_4^{2-} reduction by the facultative anaerobes identified in Chapter 4 including *Dechloromonas* spp. and *Stenotrophomonas* spp., and perhaps other heterotrophic SeRB.

To explain the observed differences in soluble Se concentrations at the Dry Valley and Smoky Canyon mines, we investigated the rate and extent of Se reduction in saturated batch reactors, under variable temperature and lithological conditions with limited O_2. These experiments address the hypotheses that (1) Se reduction observed in the sediments at the Dry Valley Mine is microbial and not abiotic; (2) reduction is most efficient at elevated temperature after O_2 is depleted; (3) changes in pH, dissolved organic carbon (DOC), and dissolved NO_3^-, SO_4^{2-}, total Mn, and total Fe in chert and shale mine waste are associated with the observed reduction, and (4) creating moist and microaerophilic conditions in sediments will promote Se reduction by native microbes using naturally available C and potentially, other available electron donors.

Experimental

Samples of overburden and groundwater were collected from the Dry Valley and Smoky Canyon mines (Figure 17) and analyzed to describe the mineralogy, metal chemistry, soluble constituents, and C speciation of the materials used to construct reactors (supplement, Tables S1 to S4). Autoclaved samples of the dominant chert and shale lithologies collected from backfill were inoculated with live groundwater cultures from the Dry Valley and Smoky Canyon mines in saturated batch reactors. The rate and extent of SeO_4^{2-} reduction (using naturally-occurring hydrocarbon compounds and other available electron donors) were measured experimentally under the temperature and

lithologic substrate conditions observed during *in situ* monitoring. Changes in dissolved O_2 and DOC, pH, and soluble NO_3^-, SO_4^{2-}, total Fe, and total Mn were measured at key points during the reduction process, including lag, initial reduction, mid-reduction, and post-reduction phases. Changes in Se mineralogy resulting from the monitored reduction process were studied using synchrotron x-ray diffraction (S-XRD) and bulk x-ray adsorption near edge spectroscopy (XANES). The response of the microbial community associated with SeO_4^{2-} reduction was characterized using DGGE.

Saturated Batch Reactor Rate Experiments.

Batch reactors were constructed in triplicate using 30 g of sterilized sub-2 mm shale and chert with 30 mL of sterile deionized water in 250 mL glass serum bottles. The grain size of the sub-2 mm material is described in Appendix A-2. Rock was autoclaved (steam sterilized 45 min at 121°C at a minimum of 15 psi), rested for 48 hours, and re-autoclaved to kill spore-forming organisms prior to reactor construction. A sub-sample of live groundwater was also autoclaved for use in the sterile control experiment. Saturated sediment was stirred in the presence of O_2 for 12 hours to dissolve any existing oxidation products present in the waste rock, which result from weathering under the aerobic conditions known to exist within near surface portions of mine waste. The saturated sediment was then then inoculated with a consortium of native microbes through the addition of turbid site groundwater to bring the reactor to full volume (using fresh and autoclaved groundwater to create a live and killed control reactor, respectively). The sealed bottles were degassed with 0.2 µm filter-sterilized ultra-pure N_2 gas for 1 hour to remove most of the O_2. Each reactor was spiked with Na_2SeO_4 stock solution to a target

concentration of 10 mg/L Se as SeO_4^{2-} and incubated at room temperature (between 20 and 25°C) and 10°C under dark conditions. The actual starting concentration varied in response to Se release from the rock in each reactor. No C was added as electron donor to the hydrocarbon that was naturally present in the rock and groundwater. Samples of mixed water and sediment were collected immediately using a N_2 purged syringe, and every 12 hours until Se reduction was complete (10 to 14 days). Oxygen and pH were measured in the aqueous phase at the beginning, middle, and end of each experiment, using a Hach AQ4 dissolved O_2 meter (Loveland, CO) and an Acumet AB15 pH meter with a probe model no. 13-620-AP (Cole Parmer).

Samples were centrifuged at 13,000x g to remove solids. The supernatant and the solids were separated and frozen for subsequent analysis including total Se, Fe, and Mn by Inductively Coupled Plasma (ICP) Mass Spectroscopy (MS); NO_3^-, SO_4^{2-}, PO_4^{3-}, SeO_4^{2-}, and SeO_3^{2-} by ion chromatography (IC); and analysis of SeO_4^{2-} and SeO_3^{2-} at lower detection limits, together with SeC and SeM, by High Performance Liquid Chromatography (HPLC-ICP-MS). Protein content was measured at select time steps to track changes in biomass, using the Coomassie method [39]. Aqueous samples were also collected following centrifugation to remove solids and were preserved in glass at pH < 2 using phosphoric acid for analysis of DOC and total N. Additionally, samples of sediment were collected at multiple time steps for DNA extraction and mineralogical analysis.

ICP-MS Analysis of Total Se, Fe, and Mn Concentrations: Samples were diluted 1:500 in 1% HNO_3 and 0.5% HCl for measurement of total Se, Fe, and Mn by direct

injection ICP-MS (Agilent 7500ce) following EPA method 200.8 [40]. Total Se was determined with the hydrogen-gas collision cell, to minimize analytical interferences, while Fe and Mn were measured directly without the collision cell. Limits of detection varied slightly within the analytical runs, but were generally 2 µg/L for Se, 1 µg/L for Fe, and 1 µg/L for Mn.

IC Analysis of NO_3^-, SO_4^{2-}, PO_4^{3-}, SeO_4^{2-}, SeO_3^{2}: Anion concentrations were measured by IC using a Dionex instrument with an IonPac AS-9-HC (4 x 250 mM) anion column and a CD 20 detector. Samples (25 µL) were injected into an 11 mM Na_2CO_3 mobile phase flowing at 0.9 mL/min, at full strength to measure low concentrations of SeO_4^{2-} and SeO_3^{2-}, and diluted 25X with deionized water to measure higher concentrations of SO_4^{2-} and NO_3^-.

Se Speciation by HPLC-ICP-MS. Selenium was speciated using an Agilent HPLC and a Hamilton PRPX-100 PEEK anion column with a pH 4.8, 5 mM ammonium citrate mobile phase modified to 2% methanol by weight [41]. The mobile phase was delivered isocratically at 1 ml/min for analysis using an Agilent 7500ce ICP-MS to quantify ^{78}Se using time resolved analysis with a plasma argon (Ar) flow of 15 L/min.

DOC and Total N Analyses: DOC and total N were measured using a Shimadzu TOC-V CSN Carbon/Nitrogen Analyzer (Kyoto, Japan). DOC was measured by standard method 5310 (non-dispersive infrared CO_2 detector) following acidification and two minutes of sparging with zero air (air with less than 0.1 ppm hydrocarbon). Total N was measured using standard method 4500 [42] following treatment with ozone.

Protein Assays: Protein was extracted following 0.5 N NaOH digestion for 10 min at 90°C, followed by neutralization with HCl. Digested samples were assayed using the Pierce Plus Coomassie protein assay method (Pierce no. 23236). Concentrations were measured by absorption at 630 nm using a Biotek Synergy HT multidata microplate reader. Replicate protein assays were attempted using the Pierce Compat-Able Protein assay (Pierce No. 23215) to remove interferences. For comparison, protein measurements were also made using a Qbit fluorimeter with the NanoOrange® Protein Quantitation kit.

XANES and S-XRD of Se Minerals: Se x-ray absorption spectra (XAS) were collected on beamline 4-1 at the Stanford Synchrotron Radiation Laboratory using published methods [43]. Samples were deposited on membranes and sealed with Kapton polyimide film to minimize oxidation. A liquid N_2-cooled Si (220) monochromator was used for energy selection, and higher order harmonics were rejected by detuning 30%. Fluorescence spectra were collected with a Lytle detector for Se. Extended X-ray fine structure (EXAFS) and XANES spectral scans were averaged, with the pre- and post-edge subtracted using SixPACK (Webb, 2005). Synchrotron-based XRD data were collected at SRL on beamline 11-3 and calibrated with lanthanum hexaboride and used to confirm the presence of species identified based on near-edge energy thresholds.

DNA, PCR, DGGE, and Sequencing: Nucleic acids were extracted from 1 g sediment samples taken from enrichment microcosms, or frozen samples of soil and groundwater, using the Power Soil DNA Isolation Kit ™ (MoBio). The method was modified by first incubating 1 g of sediment in 20% SDS at 70°C for 1 hour, followed by 20 minutes in a vortex mixer. After vortexing, the entire sample was used for the

extraction of nucleic acids as detailed in the protocol provided by the manufacturer. PCR was performed on extracts to amplify 16S rRNA genes using a nested approach. Initially, 10 cycles were run using primers 1070F (5'-ATG GCT GTC GTC AGC T-3') and 1392R (5' ACG GGC GGT GTG TAC-3') [44]. The products from the initial PCR were diluted 1:10 and used as template in a 30 cycle PCR using 1070F and 1392R with a 40 base GC clamp. Reactions (50 µl) contained template (2 µl), 10 mM primers (1 µL ea), PCR mastermix (Promega, 25 µL) and were run in an Eppendorf Mastercycler Gradient thermocycler. Conditions included denaturation at 94°C for 10 min, followed by 10 or 30 cycles of 94°C for 45sec, 50°C for 45 sec, 72°C for 45 sec, and a final extension at 72°C for 7 min. Samples of PCR amplicons were visualized by ethidium bromide staining on 0.8% agarose gel.

PCR products were separated by electrophoresis in 8-12% acrylamide gels containing a 50-60% urea-formamide gradient at 70 V and 60°C for 20 hours. Gel electrophoresis was run using a DGGE-2401 system manufactured by CBS Scientific®, based on the general method described by Muyzer et al. [45]. Gels were stained with SYBR Gold and visualized under UV light. Samples were compared with a ladder comprised of DNA from known isolates, and individual bands of interest not present in the ladder were excised from the gel, resuspended in 15 µL of nuclease-free water, and allowed to diffuse from the gel overnight at 60°C. Samples were mixed and acrylamide was pelleted by centrifugation. The resulting supernatant was removed, diluted 1:10 in nuclease free water, and used as template in a 30 cycle PCR using primers 1070F and 1392R as described above. PCR products were purified using a Wizard SV Gel and PCR

Cleanup System (Promega) and quantified using a Qbit fluorimeter (Invitrogen). Samples were submitted to the Molecular Research Core Facility at Idaho State University for sequencing using an Applied Biosystems® 3130XL Genetic Analyzer. BLAST was used to query resulting sequences against the GenBank database [46].

Results and Discussion

Changes in Se, NO_3^-, Fe, Mn, and SO_4^{2-} concentrations, and in the associated microbial community, as well as the minerals produced as a result of Se reduction, are described below. These experiments were conducted in suboxic, saturated chert and shale batch reactors at two temperatures using samples from two mine sites.

Se Reduction in Batch Reactors

Figure 18a and b show results of saturated batch Se reduction rate experiments run at the field relevant temperature of 10°C and room temperature (between 20 and 25°C), using rock and groundwater from the Dry Valley and Smoky Canyon mines. Supporting data are provided as supplemental information in Appendix D, as Tables D1.1 and D1.2 for Dry Valley and D2.1 and D2.2 for Smoky Canyon; analytical data supporting these tables are provided on the accompanying CD. Rate experiments were also run using mixed shale, chert, and mudstone (run-of-mine) samples from both mine sites, which show results that reflect the combined influence of the dominant chert and

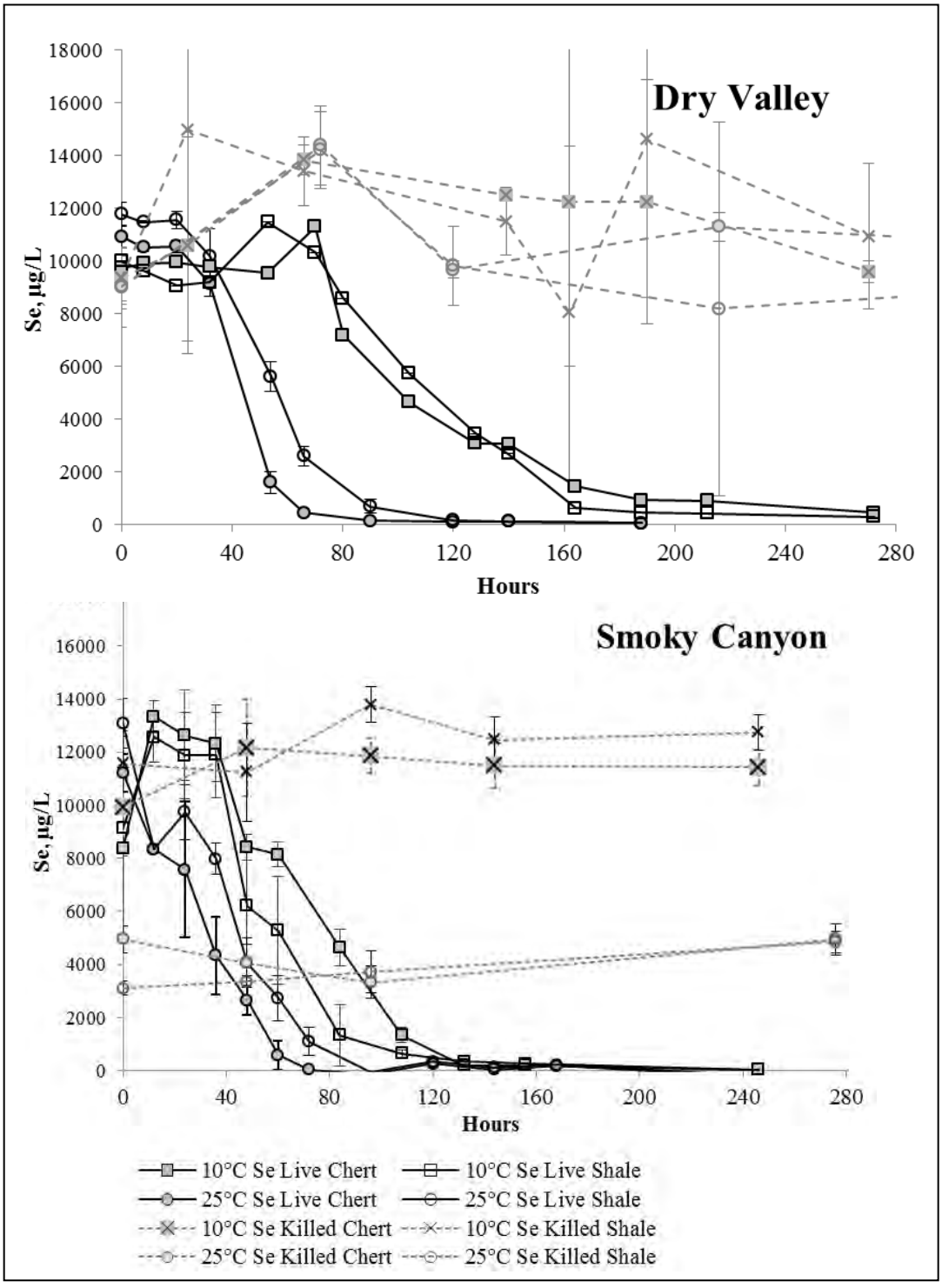

Figure 18. Comparison of Se concentrations in saturated rate experiments for two temperatures and lithologies for the a)Dry Valley and b)Smoky Canyon Mines. Values are averages (n=3), and error bars represent ± 1 standard deviation.

shale lithologies; these results are presented in Chapter 4, with supporting data presented in Appendix D.

Figure 18a shows total dissolved Se measured in live and killed control experiments for both shale and chert from the Dry Valley Mine. Results are given as the average, +/- the standard deviation, of three experimental replicates. Comparable trends in reduction are shown for shale and chert from the Smoky Canyon Mine in Figure 18b. Comparison with killed controls for these experiments shows that reduction did not occur under abiotic conditions in the reactors. In fact, dissolved Se concentrations increased in killed controls initially, above the spiked Se concentration of 10 mg/L, presumably due to abiotic oxidation of reduced Se-bearing sulfide minerals by residual O_2 or, following O_2 depletion, by NO_3^-. Continued dissolution of Se from mineral surfaces following closure and degassing of the reactors is also a possibility. This was less pronounced in live reactors, presumably due to biotic consumption of the available O_2 and NO_3^-.

Following a temperature-dependent lag phase, relatively rapid, near-complete reduction of soluble SeO_4^{2-} was observed at the rates shown in Table 10. These rates were calculated by linear best fit to the steepest part of the reduction curve for each microcosm, using the data between the inflection point and the point at which concentrations become asymptotic at low concentration. In most cases, Se concentration was observed to increase slightly prior to the onset of reduction. There was a shorter lag time prior to initiation of Se reduction in the 10°C microcosms in samples from the Smoky Canyon Mine compared to those from the Dry Valley Mine (Figure 18). In samples from the Dry Valley Mine, Se reduction began sooner and proceeded more

Table 10. Dry Valley and Smoky Canyon mines, Se reduction rates.

Rate of Se Reduction (Average (N=3) ± std dev, µg SeO_4^{2-} reduced /g rock hr)		
Mine Reactor °C	Chert	Shale
Dry Valley 10°C	6.7 ± 1.6	3.0 ± 0.17
Dry Valley 25°C	10.3 ± 0.3	6.3 ± 1.09
Smoky Canyon 10°C	4.3 ± 1	4.3 ± 0.7
Smoky Canyon 25°C	6.0 ± 1.4	5.9 ± 0.5

rapidly in the chert than in shale regardless of incubation temperature. This is in contrast to the Smoky Canyon Mine where the rate of Se reduction in chert was very similar to that measure in shale. Unfortunately, monitoring well GW11, which produced the groundwater used to inoculate the Smoky Canyon reactor, was buried due to subsequent mine development, and it was not possible to repeat the experiment to verify the similarity in rate between lithotypes. It is likely that the more rapid Se removal in the experiments using chert from the Dry Valley Mine resulted from rapid sorption of SeO_3^{2-} onto clay and/or Fe oxide mineral surfaces within the fine-grained, muddy matrix of the chert. This hypothesis is supported by mineralogical analyses reported below.

Se Speciation: Measurable concentrations of SeO_3^{2-} were detected by IC (Tables D2-1 and D2-2, Appendix D2) mid-reduction in all reactors, except the 25°C chert reactor, where reduction proceeded very quickly. Select Dry Valley Mine samples were re-analyzed by HPLC-ICP-MS to more accurately measure SeO_4^{2-}, SeO_3^{2-}, SeC ($C_3H_7NO_2Se$), and SeM ($C_5H_{11}NO_2Se$) (Table 11). Unfortunately, the archived Smoky Canyon samples could not be re-analyzed with this method as they were beyond their holding time for volatile organo-Se compounds by the time the HPLC-ICP-MS analytical

capability became available, and the experiment could not be repeated following burial of the GW-11 well. The HPLC-ICP-MS results (Table 11) show that reduction of SeO_4^{2-} to SeO_3^{2-} was slower in shale than in chert, and was slower at 10°C than 25°C. Selenite was, not surprisingly, more efficiently removed from solution at higher temperatures, regardless of lithology. Measured SeC, an amino acid, was evident during Se reduction; this was most evident in the 10°C reactors. An increase in concentration of SeC reflects an assimilation of Se by bacteria, which appeared to increase under colder temperatures. The reason for this difference is not clear, but these data suggest that intracellular reduction may be favored at low temperatures. The measurement of SeC in supernatant solutions reflects the release of intracellular SeC, perhaps the result of detoxification or cell decomposition. Selenomethionine was observed at only one time step in one of the 1°C shale reactors, mid to late in reduction, along with unidentified organo-Se peaks that did not match standards included in our method. Chasteen and Bentley suggest that such results may indicate the methylation of Se and attributed accumulation of alkylation products to a toxicity response [34]. Such toxicity has been associated with limited capacity for Se reduction within a closed system [47].

The total mass of Se detected by HPLC-ICP-MS analyses from the Dry Valley Mine (Table 11) agrees reasonably well with the total Se analyses by ICP-MS (Figures 18 and 20, and Appendix D), with the dominant measured species being SeO_4^{2-}. Selenite was measured as a transient reduction product at much lower concentrations than SeO_4^{2-}; it is likely to have lower solubility due to its greater potential for sorption. These

Table 11. HPLC-ICP-MS data showing Se speciation for Dry Valley Mine chert and shale reactors at key time steps

T°C	Lithology	Time, hours	Se-SeO_4^{2-}, mg/L	Se-SeO_3^{2-}, mg/L	Se-SeC, mg/L	Se- SeM, mg/L
10	Chert	0	9.56	b.d.	0.045	b.d.
10	Chert	53	8.06	b.d.	0.048	b.d.
S	Chert	104	1.16	0.009	0.050	b.d.
10	Chert	128	1.46	0.001	0.041	b.d.
10	Chert	272	b.d.	b.d.	0.042	b.d.
25	Chert	0	5.84	b.d.	0.022	b.d.
25	Chert	20	9.08	b.d.	0.014	b.d.
25	Chert	66	b.d.	0.007	0.019	b.d.
25	Chert	90	b.d.	b.d.	0.023	b.d.
25	Chert	120	b.d.	b.d.	0.013	b.d.
25	Chert	188	b.d.	b.d.	0.013	b.d.
10	Shale	0	7.64	b.d.	0.051	b.d.
10	Shale	53	7.20	b.d.	0.049	b.d.
10	Shale	104	5.02	0.004	0.060	b.d.
10	Shale	128	2.51	0.014	0.046	0.023
10	Shale	272	bd	0.004	0.042	b.d.
25	Shale	0	6.87	b.d.	0.022	b.d.
25	Shale	20	8.64	b.d.	0.015	b.d.
25	Shale	60	1.94	b.d.	0.016	b.d.
25	Shale	90	b.d.	0.001	0.017	b.d.
25	Shale	120	b.d.	b.d.	0.017	b.d.
25	Shale	188	b.d.	b.d.	0.016	b.d.

Detection limits Se-SeO_4^{2-} =0.001, Se-SeO_3^{2-} = 0.001, Se- SeM= 0.001
b.d. = below detection.

findings point to temperature-dependent shifts in metabolic pathway, but are not completely conclusive. Unfortunately, due to potential loss of volatile compounds during freezing and thawing of stored samples, it was not possible to confidently reproduce these results with archived reactor samples. Analyses of organo-Se compounds should be repeated with fresh samples to confirm the differential production of organo-Se compounds between lithology and temperature treatments.

Major Ion Chemistry During Se Reduction. Concentrations of SO_4^{2-} and PO_4^{3-}, were measured, as well as pH and dissolved O_2, for samples collected at key time steps (lag, inflection, reduction, end of reduction), and are summarized in Table D2.1 of Appendix D2.

Oxygen was initially sparged to low levels with N_2 gas (<1 mg/L), and any residual was subsequently consumed (biotically and abiotically), based on declining concentrations observed in both live and killed control reactors (Figure 19). A temperature-dependent lag time of varying duration was observed in live reactors, which corresponds with consumption of O_2 and some NO_3^- after SeO_4^{2-} reduction was observed. Consumption of O_2 prior to denitrification, followed by metal/metalloid reduction, is typical in microaerophilic induction of anaerobic metabolism by facultative microbes [48]. Nitrate concentrations decreased in all reactors following depletion of O_2 concentrations to < 0.3 mg/L and initiation of SeO_4^{2-} reduction, while SO_4^{2-} was constant or increased slightly. Unfortunately, because O_2 and NO_3^- were not measured for all time steps, it is not possible to separate the influence of the two potential inhibitors to SeO_4^{2-} reduction. Measured pH remained relatively constant in live reactors, but dropped (as much as 0.5 pH units) in killed controls, perhaps reflecting generation of acid by oxidation. Surprisingly, for rock mined from phosphate deposits, soluble PO_4^{3-} was low and detected infrequently (1 mg/L detection limit). Redox-sensitive parameters including NO_3^-, Fe, Mn and Se are compared by temperature for laboratory kinetic experiments

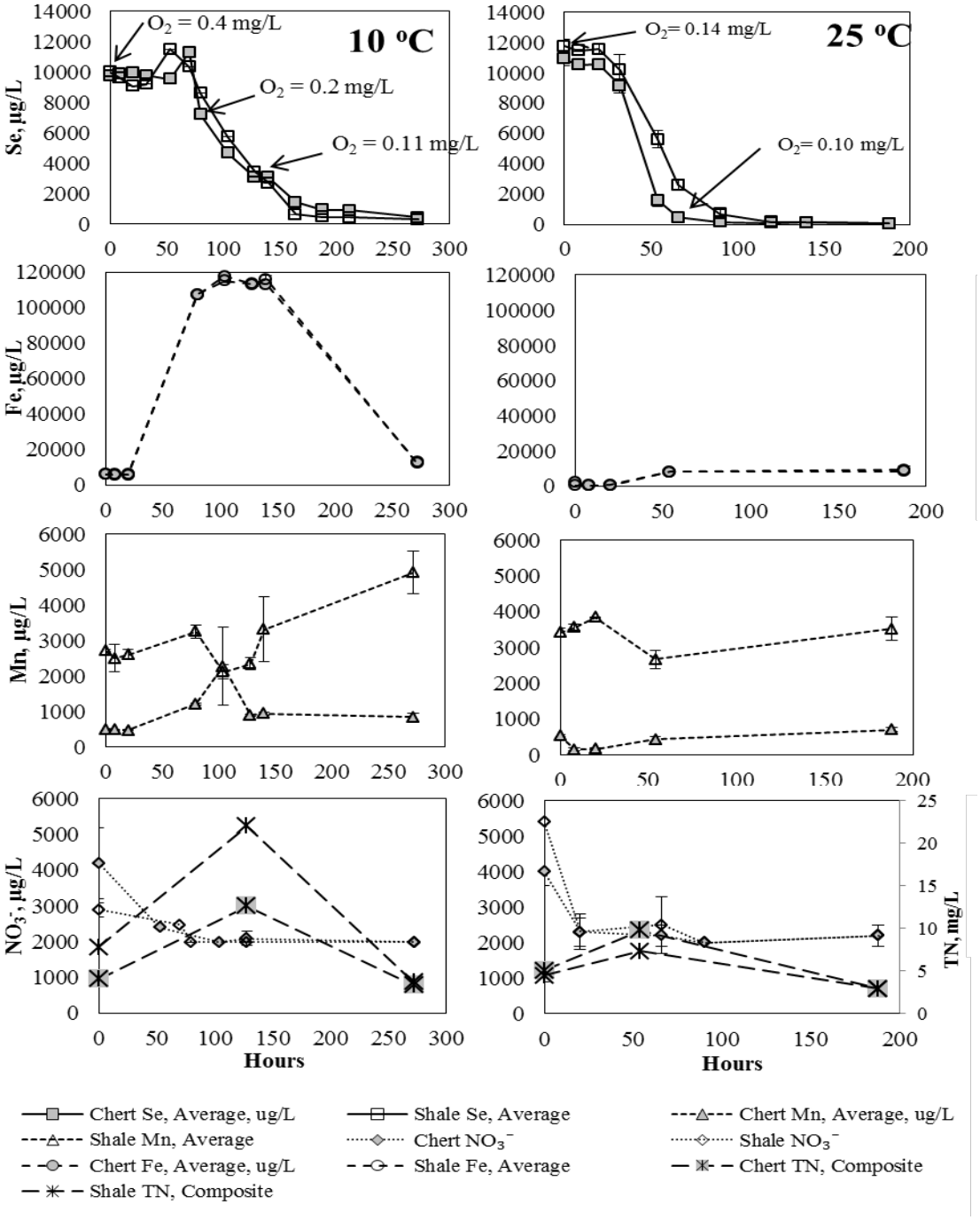

Figure 19. Saturated rate experiments for rock samples from the Dry Valley Mine: Se, Fe, Mn, NO_3^-, and TN concentrations for chert and shale at 10°C (left) and 25°C (right). Values are averages or composites (see legend) of n=3 replicates. Error bars = ±1 standard deviation. O_2 concentrations shown for chert only; see Appendix D2.1 for all O_2 data. Experiments were conducted until Se reduction was complete, thus the length of the 10 and 25°C experiments varied.

using Dry Valley Mine samples in Figure 19 and Smoky Canyon Mine samples in Figure 20.

Iron and Manganese During Se Reduction

Observed increases in Fe, and to a lesser extent, Mn concentration during Se reduction in the Dry Valley and Smoky Canyon mine reactors (Figures 19 and 20) support the hypothesis that Fe and Mn reduction is coupled to hydrocarbon degradation by members of the native microbial community. Concentrations of dissolved Fe shown in Figure 19a, which at pH 7 is most likely Fe^{2+}, rise as O_2 and NO_3^- concentrations drop within the reactors. The dissolved Fe maintains a constant concentration around 120 mg/L throughout the period of Se reduction in the Dry Valley reactor, and then appears to drop at the end of the Se reduction process. The cause and timing of this change is unclear from available data, but this may reflect precipitation of $FeSe_2$ as selenide is produced, consistent with mineralogy analyses presented below. As SO_4^{2-} concentrations were constant in the reactors (see values reported in Appendix D2), it is unlikely that precipitation of pyrite (FeS_2) occurred, and no iron sulfide was identified in mineralogical analyses. A similar increase in dissolved Fe concentration was observed in the Dry Valley Mine 25°C experiment; although the resulting dissolved Fe concentration was considerably lower than that measured in the 10°C microcosm. The lower concentration may reflect a shift in microbial community structure at different incubation temperatures. No subsequent decline in Fe concentration was observed at 25°C, but the experiment was shorter in duration, having been terminated at 180 hours following reduction of the

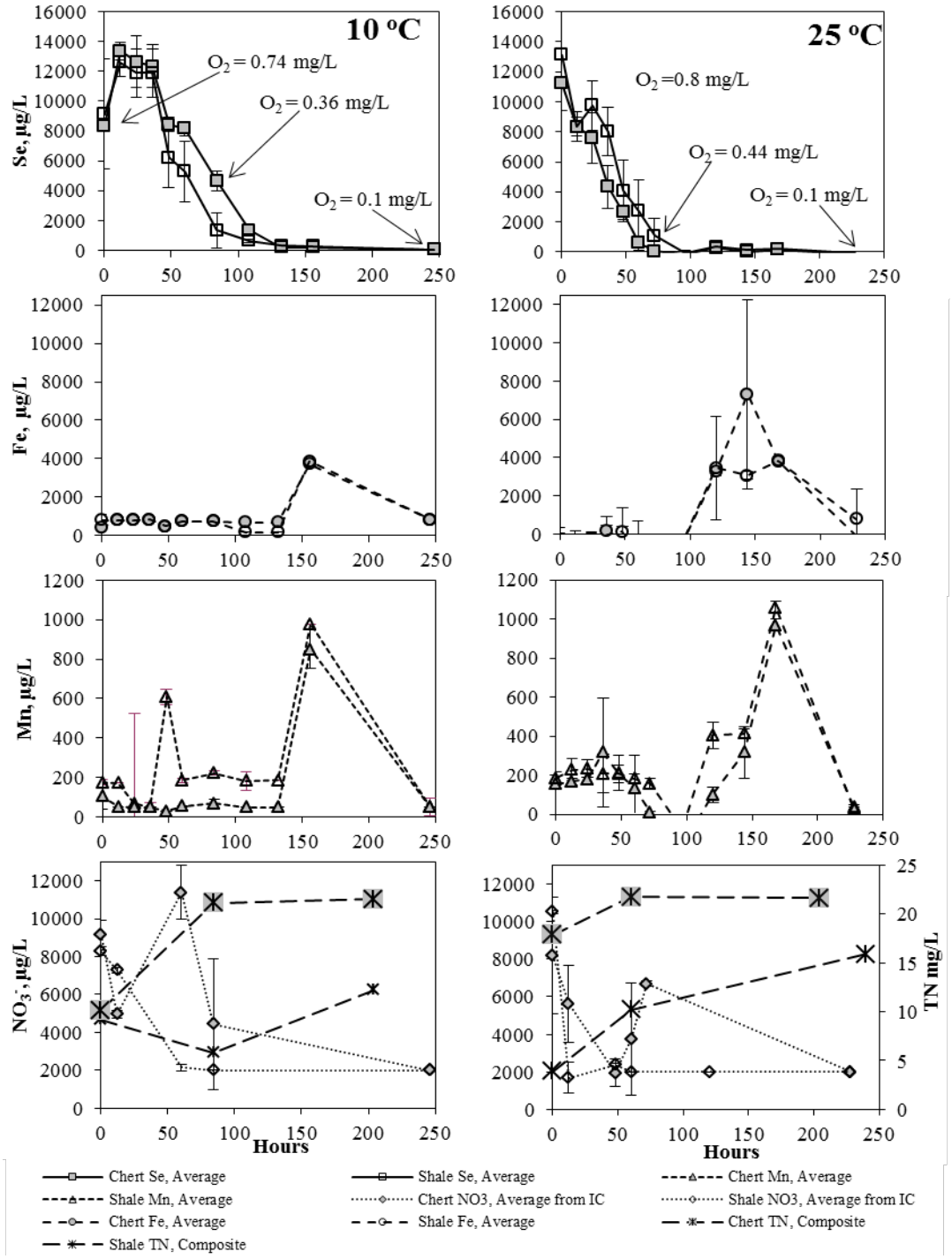

Figure 20. Saturated rate experiments for rock samples from the Smoky Canyon Mine: Se, Fe, Mn, NO_3^-, and TN concentrations for chert and shale at 10°C (left) and 25°C (right). Values are averages or composites (see legend) of n=3 replicates. Error bars = ±1 standard deviation. O_2 concentrations shown for chert only; see Appendix D2.1 for all O_2 data. Experiments were conducted until Se reduction was complete, thus the length of the 10 and 25°C experiments varied.

dissolved SeO_4^{2-}. If the experiment had been carried out to 250 hours, the same drop in dissolved Fe concentration might have been observed.

The observed increase in dissolved Fe is potentially due to the concurrent biological reduction of Fe. Genera known for Fe reduction capability, such as *Rhodoferax,* have been consistently identified with the hydrocarbon-degrading and heterotrophic SeO_4^- reducing bacteria isolated during this study (Chapter 4). Interesting, members of *Rhodoferax* do not themselves have the demonstrated capability to reduce Se (this study; also, [49, 50]). Iron reduction is commonly associated with hydrocarbon degradation in suboxic environments, however [51, 52]. It is also possible that some of the observed Fe release results from redox reaction of the $SeO_3^{2-}/HSeO_3^-$ with primary FeS_2, especially in the Meade Peak shale, resulting in the formation of Se^0 and the release of SO_4^{2-} and Fe^{2+} similar to results reported by Kang et al. [53] and Naveau et al. [54].

Although the data for Mn show a less dramatic increase in concentration than the Fe, a substantial in concentration was observed in both the chert and shale reactors, once O_2 was depleted, especially in the Smoky Canyon Mine data. There were larger differences in the dissolved Mn concentrations between shale and chert in the reactor experiments using Dry Valley Mine samples than were observed with Smoky Canyon Mine samples. This may reflect differences in the Mn-oxidizing microbial communities between the two mine sites or local differences in mineralogy. The occurrence of soluble Mn with low concentrations of Fe under micro-aerophilic, denitrifying conditions (such as those observed in early time steps in the reactors) are consistent with groundwater

chemistry monitored at GW7D and GW11 (Table S5-2). The redox chemistry of Mn in sedimentary pore water is complex, with potential for the intermediate Mn^{3+} to serve as both oxidant and reductant [55-57]. Rapid cycling between Mn^{2+} and Mn^{4+} likely occurs in suboxic sediments at redox boundaries similar to those studied in the backfill environment[58], with consequences for the redox cycling of Fe, and potentially Se [59, 60]. Such changes potentially affect the oxidation state and solubility of Fe and may explain the low concentrations of dissolved Fe late in the experiments (e.g., as Mn^{4+} is reduced, Fe^{2+} is reoxidized, promoting the precipitation of iron oxide minerals). Recognizing that the rapid cycling of Fe drives denitrification and hydrocarbon degradation in suboxic subsurface systems [61, 62], it is possible that microbially mediated, reactive green-rust minerals develop on a transient basis, promoting the abiotic reduction of Se within the suboxic sedimentary environment.

Nitrogen Concentration During Se Reduction: Nitrate and total nitrogen (N) concentrations are plotted in Figures 19 and 20 for the reactors from the Dry Valley and Smoky Canyon mines, respectively. Although NO_3^- concentrations decreased during the lag phase, it was not completely removed from all reactors, and was observed to increase mid reduction phase in some reactors. Total N was observed to increase mid-reduction phase in all reactors. Interestingly, these data suggest that either a fraction of the NO_3^- persists in some reactors or is produced via re-oxidation of reduced N concentrations (2.5 mg/L) mid-reduction (e.g., t= 90 to 188 hours in Smoky Canyon). Results of the rate experiments indicate that NO_3^- was reduced at the same time that SeO_4^{2-} was reduced to SeO_3^{2-}, but because the reactors rely on a mixed community of microbes for biological

reduction, it is not clear whether this was co-metabolism or ongoing NO_3^- reduction that occurred in parallel with SeO_4^{2-} reduction (Table 11). These results suggest that for these systems, NO_3^- does not need to be completely reduced prior to the onset of SeO_4^{2-} reduction. The extent to which the persistence of NO_3^- in the reactors was driven by re-oxidation of reduced N (such as NO_2^- or NH_4^+) cannot be addressed with available data, but the identification of abundant ammonia-oxidizing *Archaea*, specifically *Nitrosphaera* and *Nitrospumilus,* in groundwater (data not presented here) suggest that this is possible.

In all of the Dry Valley Mine reactors, total N was observed to peak mid-reduction phase (Figure 21), but not in the killed controls (data not shown). Interestingly, total N shows a somewhat different pattern of increase in the Smoky Canyon Mine reactors, with total N increasing over time. In order to obtain sufficient volume to measure total N, the replicate reactor samples were composited, so it is not possible to report error for these measurements, and it is therefore difficult to be confident in the limited total N results. These data suggest a more complex N-cycle, with the possible decomposition of N-containing compounds (e.g., proteins) formed during the period of greatest Fe and Mn reduction. Preliminary analyses of volatile hydrocarbon compounds that were measured by HS-SPME-GCMS for a select number of samples indicated that some of the compounds detected in the headspace were nitrogenous, but this analysis was only possible for a limited number of samples and provided only qualitative data (Table S5-5; Appendix E). Alternatively, a change in N fixation during the reduction process may be involved. The fact that Se reduction can proceed in spite of

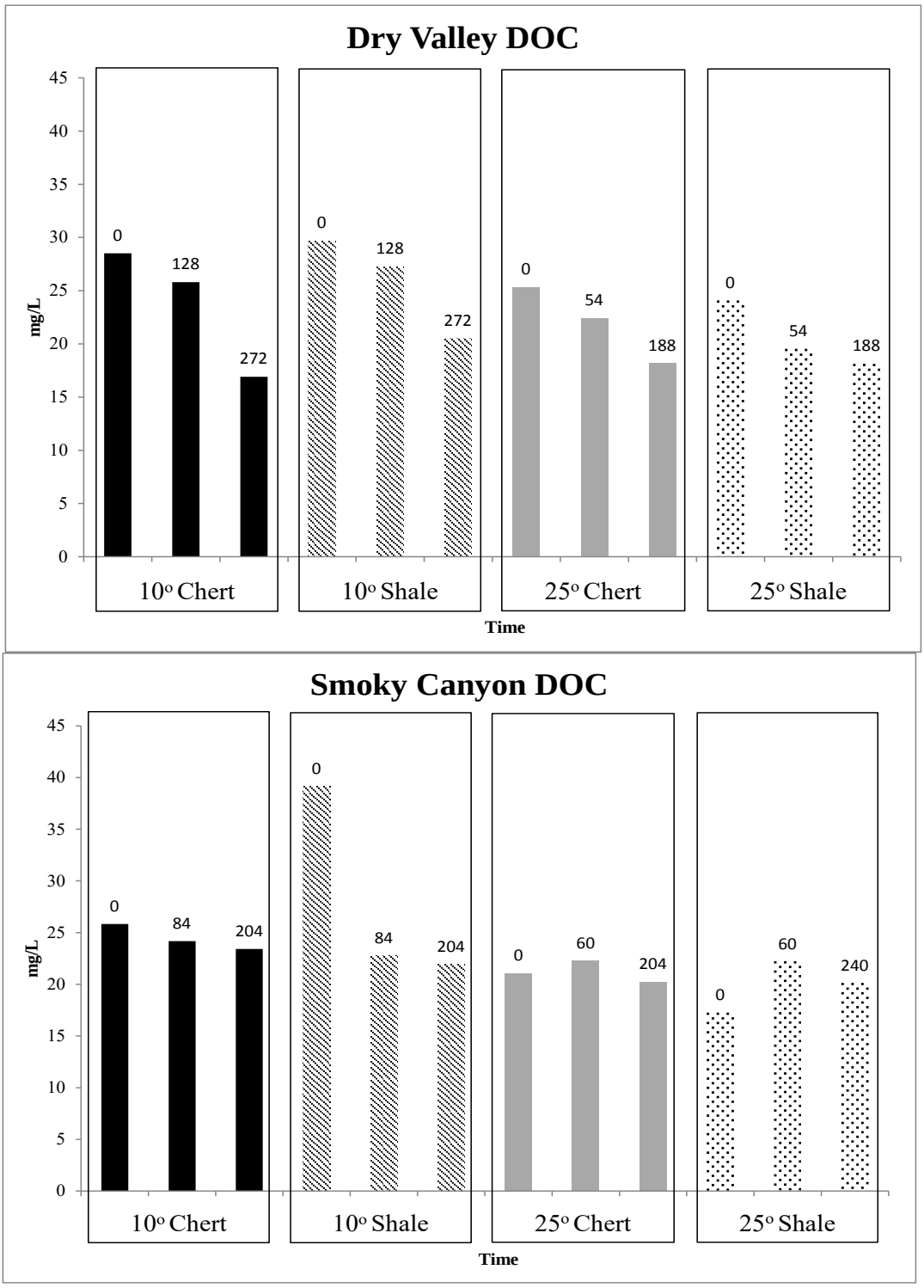

Figure 21. Dissolved organic carbon concentration (mg/L) in rate reactors, for composited sample (n=3) of each lithotype. Numbers above bars indicate time of sampling (in hours).

the presence of soluble N, and NO_3^- in particular, is significant, given its recognized importance as a potential inhibitor of SeO_4^{2-}.

Dissolved Organic Carbon during Se Reduction

Figure 22 shows changes in DOC for the Dry Valley and Smoky Canyon mine reactors, respectively. These samples were composites of water from the replicate reactors (e.g., the sample identified as 10 DCL is a composite of samples from Dry Valley Mine Live Chert reactors 1, 2, and 3 at 10°C). In most reactors, a portion of the available DOC was consumed during the reduction process, but less than 40% of native DOC is shown to be consumed in live reactors; no C was consumed in killed controls, indicating biological consumption of the available C compounds. Evidence of lower DOC following reduction in the rate reactor was also observed in the qualitative SPME data (Table S5-5). Further, an overall shift from complex to simpler hydrocarbon compounds is suggested by the SPME results, as the relative proportion of high molecular weight compounds (e.g., C> 15) measured in the head space was lower for samples of water taken from reactors at the end of the reduction process. The molar ratio of Fe to Se in solution during peak reduction increased by as much as two orders of magnitude in the Dry Valley experiments, with somewhat lower Mn to Se ratios, depending upon mine site and temperature (calculations provided in Appendix D1 on CD). This indicates that a much greater mass of Fe and Mn is reduced than Se in the reactors. Given the lack of demonstrable change in overall reactor biomass based on protein analysis during the Se reduction experiments (Appendix D3), and the relatively low abundance of SeRB noted in the microbial community study (Chapter 4), it seems

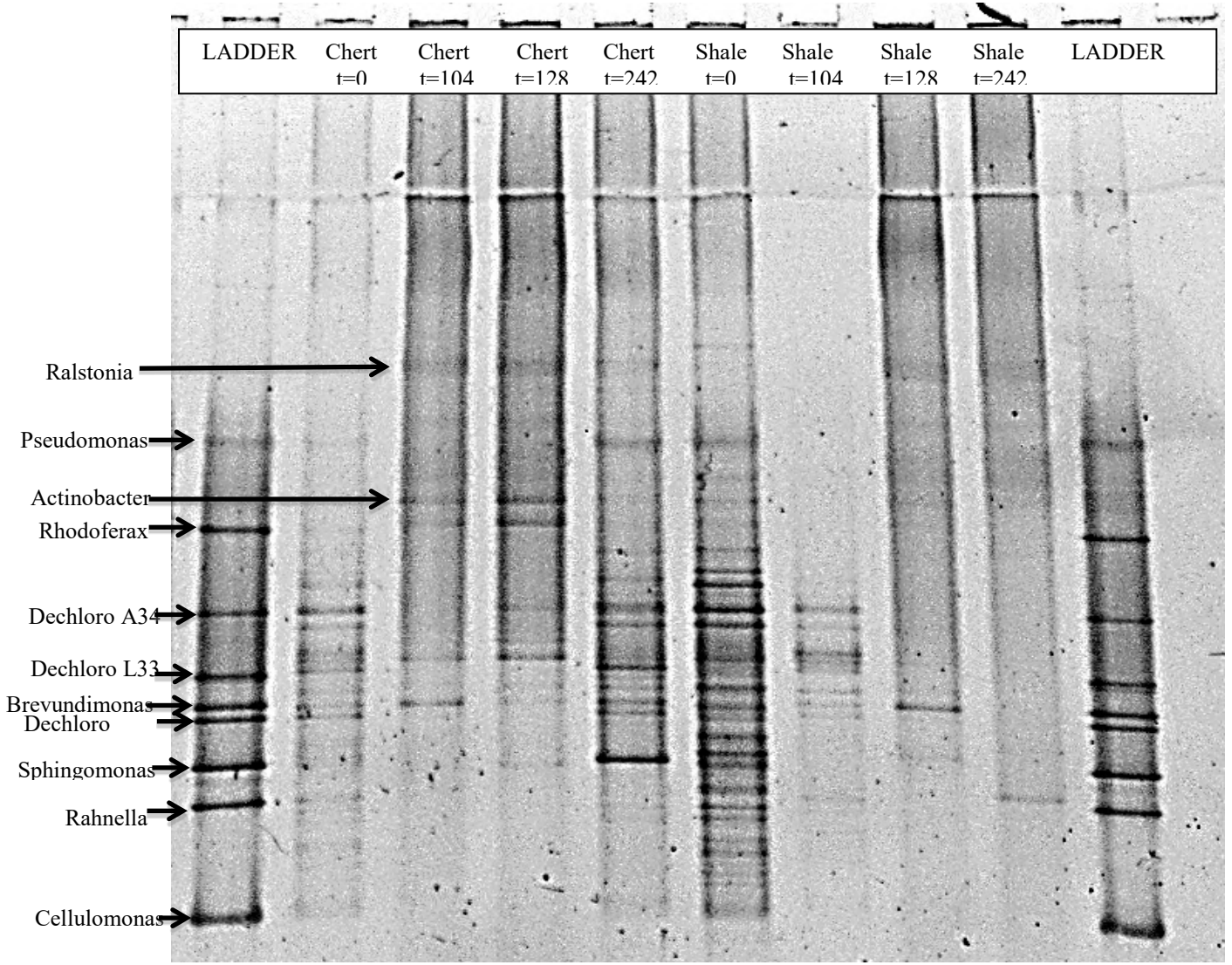

Figure 22. DGGE gel comparing DNA extracted from 10°C reactors, Dry Valley.

multiple members of the native consortium (especially, the Fe and Mn-reducing organisms) and likely not solely coupled to Se reduction. The well-known process of hydrocarbon degradation linked to Fe and Mn reduction under anaerobic conditions [62-64] very likely provides the simpler C compounds that support Se reduction in these reactors, in the absence of added C. Whether the hydrocarbon degradation is directly linked to Se reduction (as opposed to NO_3^-, Mn, or Fe reduction) cannot be determined from available data.

Changes in Biomass in Reactors

Efforts to quantify changes in protein in the Smoky Canyon batch reactors during Se reduction were unsuccessful, potentially due to interference of humic compounds in the organic-rich solutions with the colorimetric assay used in the Coomassie method. Results of these analyses are presented in Appendix D3. Use of the Pierce cleanup kit resulted in low protein yield and did not improve the ability to resolve systematic changes in protein within these native sediment reactors. Alternatively, these findings may simply reflect limited relative growth of SeRB organisms within the reactors during the Se reduction process. Samples were spiked with groundwater containing 10^4 and 10^6 SeRB per gram of rock (Chapter 4) from Smoky Canyon and Dry Valley mines respectively, and it is likely that there was little subsequent increase in population density to measure as the SeO_4^{2-} reduction process in the reactor proceeded. This is supported by the microbial community analysis, which indicated that the number of SeRB in unsaturated chert and shale sediments is lower than in groundwater, and that the microbial community is dominated by hydrocarbon-oxidizing,and Fe^{3+}, Mn^{4+}, and NO_3^- reducing

bacteria, rather than SeRB (see Chapter 4). Regardless, the inability to measure changes in protein limits the ability to report a Se reduction rate relative to biomass.

Se Mineralization in Batch Reactors

Characterizing the mineral products that resulted from the Se reduction process is important in understanding the operational potential of *in situ* stabilization of Se in backfilled panels and/or constructed reactive barriers. Minerals produced through microbial activity may have different potential for re-oxidation or desorption of reduced Se, thereby affecting the capacity for Se attenuation. Results of synchrotron XANES and XRD analyses are presented in Appendix F and summarized below.

Results of S-XRD were somewhat limited due to the complexity of the background sample mineralogy. Quartz and microcline feldspar were confirmed with matches to all peaks in the Jade software standard library, while hematite was probably present in samples of both chert and shale, based on matches to multiple peaks in the region of interest within its diffraction spectra. Zaherite ($Al_{12}(SO_4)_5(OH)_{26}\bullet_{20}H_20$) was also identified in a pre-reduction sample of chert. In post-reduction samples of chert, sodium SeO_3^{2-} was confirmed and ferroselite (an $FeSe_2$ mineral) and copper selenide were probably present, with matches to some peaks in known reference spectra. Samples of shale contained probable Se^0 (based on matches to 3 or more peaks), with likely organo-Se compounds methyline selenafulvene and toluene selenoic acid, as well as $FeSe_2$. No SeO_3^{2-} bearing minerals were identified in the shale.

Efforts to visualize microbes in association with Se minerals following reduction were unsuccessful using Field Emission Scanning Electron Microscopy (FE-SEM), due

to the abundance of fine grained silts in the samples and the detection limit of approximately 0.1 to 1.0 wt% Se for this method relative to low mass of Se potentially precipitated on the mineral surfaces as a result of these experiments.

For these reasons, Se was analyzed using the more sensitive XANES and S-XRD methods at the Stanford Synchrotron Radiation Light Source. Following the previous analyses of Se using XANES [65-67], several standard Se compounds were included in these analyses as listed in Table S5-6. The x-ray absorption energy edge position was measured for several Dry Valley and Smoky Canyon 10°C reactor samples collected at different time steps. The “shale only” and “chert only” samples represent the natural background mineralogy in rock substrate prior to formation of Se minerals in the batch reactor. One additional “live” end sample was studied, which reflected the composition of the reactor at the time it was decommissioned, several months after the Se reduction process had ended in a sample that was incubated at room temperature. This measurement was made to identify stable mineral products of the reduction process. Reduction products were also compared with the Se solid mineral phases present in abiotic control reactors at the end of the experiment.

Comparison of the energy edge (eV) measured for standards with those measured in the background, live reactor, and control samples are summarized in Table S5-6. The geometry of the uniquely shaped spectra shown in Figures 23a (Dry Valley) and Figure 23b (Smoky Canyon) suggests that different end products result from reduction in chert and shale lithotypes. It is difficult to resolve Se^0, SeC, and selenide from one another

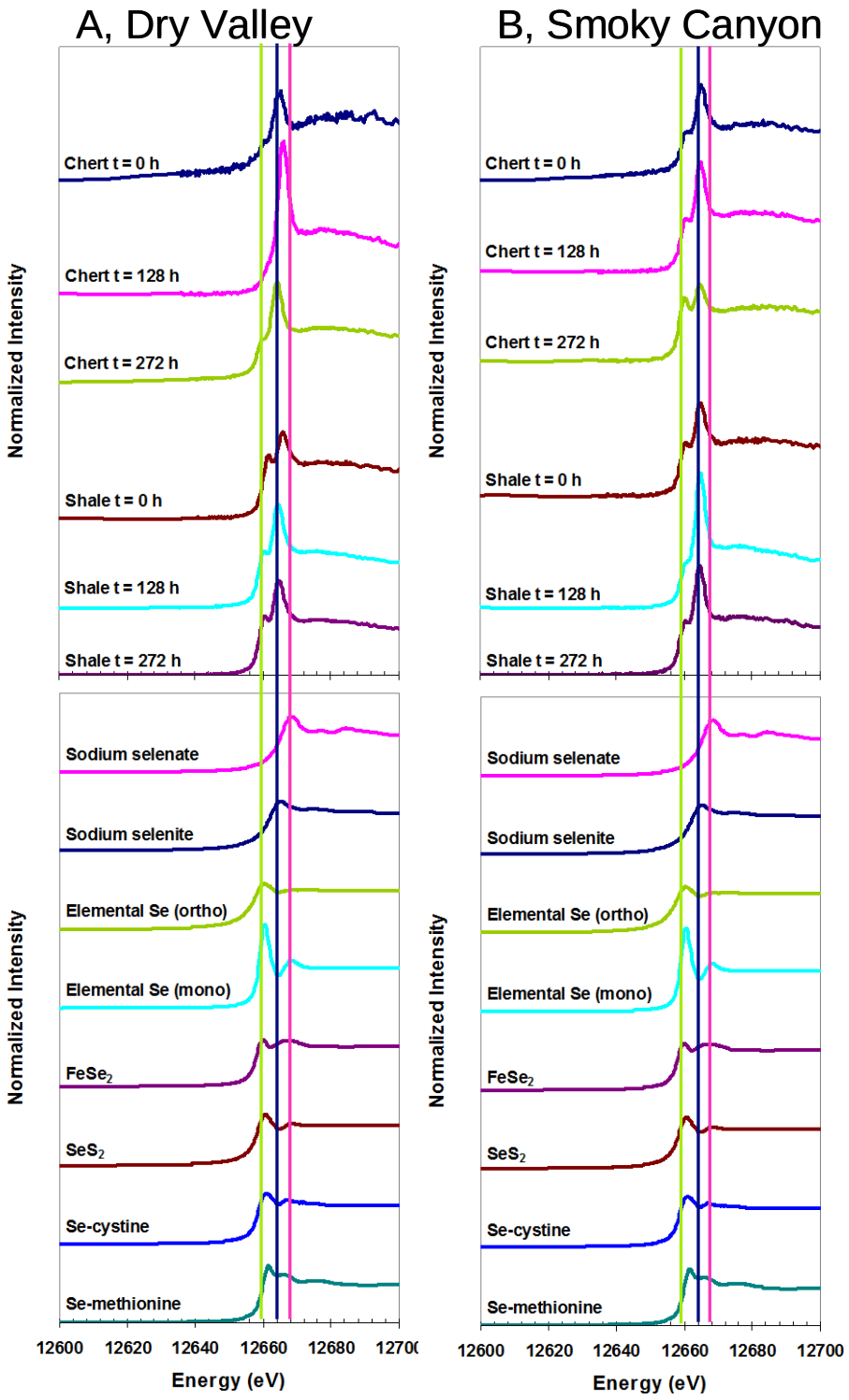

Figure 23. XANES analyses of waste rock from rate reactors for (A) Dry Valley and (B) Smoky Canyon. Colored lines indicate locations of SeO_4^{2-}, SeO_3^{2-}, and Se^0 energy peaks.

based on energy edge alone, so interpretation must also consider the shape of the spectra obtained for each standard.

The energy edge and spectral data in Table S5-6 and Figure 23a show that little if any SeO_4^{2-} was present on the solids in any of the samples, regardless of lithology or mine site studied, and in spite of the elevated concentration known to be present in solution in the reactors at the start of the experiment. This is consistent with the low capacity for SeO_4^{2-} sorption that is reported to exist under neutral to alkaline conditions, which are similar to those that exist in these reactors [18, 20, 28, 68].

Figures 22 a and b show the chert samples from the Dry Valley and Smoky Canyon mines exhibited an overall shift from SeO_3^{2-} to Se^0. In Figure 22a, the background and pre-reduction reactor solid phase had a Se edge that matched SeO_3^{2-}, but as reduction proceeded, the SeO_3^{2-} peak that is strongly in evidence at 12662 eV at t=128 hours is diminished and a peak aligning with Se^0 at 12660 eV appeared on the shoulder of the spectra at t = 272 hours. Selenite (with minor amounts of reduced Se) appears to be the dominant form of Se present in the Smoky Canyon chert in background sediments and pre-reduction samples (t=0). In Figure 22b, the intensity of peaks at 12660 and 12662 eV both increased in mid-reduction phase (t=228), with the SeO_3^{2-} peak at 12662 eV increasing in intensity relative to the reduced phase represented by the “shoulder” peak at 12660 eV. The SeO_3^{2-} peak at 12662 eV declined in intensity relative to the more reduced form in the latest reduction time step (t=272), suggesting a shift toward more reduced Se, although both were present at the end of the reduction process. The rather narrow shape of the more reduced Se peak at 12660 eV suggests the presence of Se^0,

rather than the more reduced forms selenide or SeC, which have energy edge values similar to one another, but a broader shaped spectrum. Thus, in the chert reactors of both sites, Se added as SeO_4^{2-} was reduced to SeO_3^{2-}, which likely sorbed onto mineral surfaces, and then subsequently transformed to the more reduced, insoluble Se^0. From the geometry of the peaks observed in Figure 22, it appears that more Se was transformed to the elemental form in the Smoky Canyon Mine treatments than in the Dry Valley Mine treatments.

The Se characteristics of the shale samples show a somewhat different pattern than those for chert. In background and pre-reduction samples from both mine sites, peaks corresponding to both SeO_3^{2-} at 12662 eV and SeM at 12660 eV are evident. In the Dry Valley Mine reactor (Figure 23a), both peaks grew in intensity in relative proportion to one another, with the "shoulder" peak at 12660 eV shifting towards alignment with the energy edge of the reduced Se^0 mineral at mid reduction phase (t=128). At the end of reduction, the peak appears to shift slightly towards a broader shape that is more characteristic of $FeSe_2$, although subtle differences make it difficult to be conclusive. A similar pattern was observed for the shale sample from the Smoky Canyon Mine reactor (Figure 22b). These results suggest that SeO_4^{2-} added to the shale reactors was reduced to SeO_3^{2-} and SeM, followed by transformation of some of each reaction product to a more reduced $FeSe_2$ compound. Two hypotheses to consider as explanations for the observed differences in alternative biogeochemical pathways include (1) shifts in Se methylation enzyme regulation as a toxicity response to the higher salinity of the shale geochemistry, e.g. elevated SO_4^{2-} or metal content and (2) the reaction of reduced SeO_3^{2-} with primary

FeS_2 present in the shale, thus forming Se^0 and releasing Fe^{2+} into solution [53]. The latter mechanism fits well with the observed increase in dissolved Fe at neutral pH that was observed in association with Se reduction in these experiments.

These results agree with the aqueous speciation data reported in Table 11 for chert and shale, which suggest that SeO_3^{2-} is produced initially and then removed from solution, either through sorption to the solid phase or through further reduction to insoluble Se^0 and selenide minerals.

Within the pH range observed for the Dry Valley chert (7.3-7.5) and shale (6.6-6.8) reactors, the majority of Se(IV) should be present as $HSeO_3^-$. In this range, Se(IV) should sorb strongly to Fe oxyhydroxide minerals [18]. It is important to note, however, that average pH observed in the field at Dry Valley was somewhat higher than this value (7.8, Table S5-4, see also Table A1-1 through 3), closer to the $HSeO_3^{2-}/SeO_3^{2-}$ boundary. The extent of pH-dependent sorption predicted based on results from the reactor could therefore vary somewhat in the field setting. Sorption does not explain the relatively faster reduction of Se by the chert sediments, as the higher pH of the chert should be somewhat less likely than shale to promote sorption of negatively charged oxyanions.

Recent work by Martin and others [69] using x-ray fine structure (XAFS) described distinct SeO_3^{2-} and SeO_4^{2-} and organo-Se reduction profiles in lentic sediments. In these environments, low O_2 concentrations drive similar Fe-N-Mn cycling and Se-redox transformations, with insoluble Se^0 partitioning to the solid phase, and volatile organo-Se and SeO_3^{2-} being released to the aqueous phase. These results are also consistent with those reported by Chen et al. (2009), who described SeO_3^{2-} reduction to

Se^0 under concurrent Fe^{3+}-reducing conditions, releasing sorbed SeO_3^{2-} into solution where it was available for subsequent microbial reduction to Se^0 [70]. It is also possible that desorbed SeO_3^{2-} could be abiotically reduced by biogenically-produced Fe^{2+} [71-73]. The close association of isolated Fe-reducing organisms such as *Rhodoferax* with heterotrophs such as *Cellulomonas* and *Arthobacter* shown to be capable of Se reduction in multiple enrichment cultures from Smoky Canyon and Dry Valley, as well as the elevated Fe^{2+}-concentrations associated with SeO_4^{2-} reduction in experiments conducted with native consortia from both mine sites (Figures 19, 20), suggests the existence of a potentially important mechanistic link between Fe and Se reduction. In the absence of green-rust, the only known abiotic catalyst of SeO_4^{2-} reduction [74, 75], the observed association of Fe and Se in these reactors is inferred to be an Fe^{2+}-SeO_3^{2-} interaction.

Belzile et al. described a very similar, multi-scale process of biological and chemical Se attenuation [76]. They characterized the remobilization of SeO_3^{2-} initially sorbed onto Fe-Mn oxyhydroxides, which were dissolved through biotic reduction under progressively reducing conditions developed during diagenesis. Iron and Mn-reducing organisms promoted mineralization of organic matter in the sediments and supported the formation of Se^0, seleniferous pyrite, and selenides [76].

These results have important implications for the function of a SeO_4^{2-}-reducing reactive barrier or backfill environment within waste rock deposits, in that sorbed SeO_3^{2-}complexes have potential to be desorbed and/or remobilized from reduced iron oxide substrates. The cycling of Fe (and probably Mn) is likely to influence downstream geochemical pathways, wherein the reduced Fe and Mn produced in these suboxic

environments may also play a direct role in subsequent abiotic SeO_3^{2-} reduction. The long term stability of sorbed SeO_3^{2-} complexes is less certain than that of reduced and insoluble Se^0 and Se^{2-} minerals [17, 77]. Although Se reduction may proceed more rapidly in chert due to SeO_3^{2-} sorption, at least initially, the more reduced selenide product observed in the shale potentially offers greater long-term stability.

Changes in Microbial Community During Se Reduction

DNA extracted from Dry Valley samples collected from chert and shale batch reactors for key reduction time steps was compared using DGGE in Figure 23. Samples of sediment from the most field relevant 10°C chert and shale reactors were compared with a ladder comprised of organisms isolated from groundwater and sediment MPNs. Bands were cut where possible to allow sequencing of the DNA fragments, thus identifying phylotypes with high degree of similarity to the genera *Dechloromonas* (>96%), *Rhodoferax* (>98%), *Ralstonia* (>99%), and *Brevundimonas* (>96%). DGGE results allowed community analysis at the genus level; these results are compared with isolates in the ladder, which were identified at both the genus and in a few cases, the species level.

Changes in band intensity representing changes in operational taxonomic unit (OTU) abundance and, by inference community composition, were evident in the rate reactors for chert and shale during the reduction process. Band alignment in the chert suggests an initial community dominated by multiple organisms with a high degree of similarity to members of the genera *Dechloromonas*, *Brevundimonas*, *Sphingomonas*, and

Rahnella, along with other unidentified organisms represented by fainter bands. The community, as suggested by the identified OTUs, appears to transition to a more limited community comprised of genera including *Dechloromonas, Ralstonia, Brevundimonas, Rhodoferax* and members of the *Actinobacteria* class during Se and Fe reduction (t = 104 and 128 hours). Unfortunately, DNA from the earliest time of Se reduction in the chert (e.g., t = 48 hours) was destroyed and was not available for inclusion in this analysis. Community diversity appeared to return to levels comparable to time zero in the chert after the Se was reduced (t = 242 hours). A relatively more diverse community was observed in shale at t=0 in the reactor, which shifted to a much simpler community described by OTUs that aligned with ladder bands from the isolated dechloromanads, which were highly similar to the species *Dechloromonas sp. A34*, *Dechloromonas aromatica*, and *Dechloromonas denitrificans*, along with the *Brevundimonas* spp. isolated at the mid-reduction phase. Faint DNA bands began to appear at t=128 hours that aligned with the band of an isolated *Rhodoferax*. Bands in the shale aligning with a *Brevundimonas* isolate and, to a lesser degree, a *Sphingomona*s isolate, increased in intensity during Se and Fe reduction (t = 104 and 128 hours), while a band aligning with a *Rahnella* isolate intensified at t=242 hours. Community diversity did not appear to return to initial conditions as clearly in the shale at the end of reduction, but the overall faint patterns at t=128 and 242 hours suggest that this may simply reflect lower concentrations of DNA in the gel. Bands that appeared in the upper portion of the gel at t=104 and 128 hours in the chert, and t=128 and 242 hours in the shale, were strongly similar to results obtained in preliminary gels with the genus *Ralstonia.*

The changes in microbial community indicated by the DGGE analysis agree with the aqueous speciation data reported in Table 11 for chert and shale, which show that SeO_3^{2-} is only detected rarely and early in the reduction process. It may be that it is produced initially and then removed from solution, either through sorption to the solid phase or further reduction to insoluble Se^0 and Se^{2-} minerals. Overall, Figure 23 provides an indication of microbial community changes as reduction proceeded in the chert and shale reactors for the Dry Valley Mine, under the field relevant temperature of 10°C. These findings suggest the involvement of microbes known to break down hydrocarbons and reduce SeO_4^{2-}, SeO_3^{2-}, Fe^{3+}, Mn^{4+}, and NO_3^-. Differences in the microbial community appear to exist between the two lithologies, which may in part explain the observed differences in rate, speciation, and reaction pathway. Additional research would be needed to investigate the specifics of these influences. Overall, the phylotypes identified in the DGGE analyses confirm the presence of the otherwise isolated SeO_4^{2-} reducing *Dechloromonas* sp. A34 *(*Childers, unpublished data, this study*)* and a *Rhodoferax* sp. Sequences with a high degree of similarity to the heterotrophic genera *Brevundimonas* and *Sphingomonas,* both of which have members known to degrade aromatic hydrocarbons [78], were identified in chert and shale. Phylotypes strongly similar to the genus *Rahnella*, members of which a reported SeO_4^{2-}-reducer [79], and *Actinobacteria* only appeared in the shale. A phylotype highly similar to a *Pseudomonas*, which was present in the initial community in both chert and shale, was evident again following Se reduction in the chert, but not in the shale. The DNA band associated with

the genus *Ralstonia* [80, 81], members of which have been shown to have the ability to reduce Se, was stronger during the mid-reduction phase for both lithotypes.

Conclusions

Selenate reduction by indigenous microbes using native C in groundwater-saturated phosphate mine overburden was studied under conditions representative of subsurface backfills in S.E. Idaho Phosphate Resource Area, to determine its potential effectiveness for *in situ* source control.

Kinetic experiments were conducted under microaerophilic conditions to evaluate how SeO_4^{2-} reduction proceeds in mineralogically-distinct chert and shale waste lithologies. Analyses of Se, Fe, Mn, N, S, P and C in aqueous and solid phases, together with measurements of pH and O_2. Results indicate that biotic SeO_4^{2} reduction began following biogeochemical reduction of O_2 and some (but possibly not all) NO_3^-, and was significantly associated with concurrent Fe and Mn reduction. Remaining soluble NO_3^- was reduced as SeO_4^{2-} reduction began, but there was an apparent increase in total dissolved N as reduction proceeded. Observed reduction in DOC suggests that carbon obtained through degradation of hydrocarbons present in the rock supported the observed reduction of Se as well as Fe and Mn, with a fraction of the DOC consumed during the reduction process. It is possible that other electron donors also supported the Se reduction. Sulfate was not reduced in either rock type, nor was phosphate measured in solution. The pH was relatively constant within each reactor during the reduction process; pH was lower in shale treatments than in chert at Dry Valley, however.

Selenium was reduced in a step-wise process, from SeO_4^{2-} to SeO_3^{2-} in both chert and shale, at rates influenced by temperature and possibly different SeO_3^{2-} reduction pathways and microbial communities that yielded different mineral products. Reduction occurred more quickly in chert (4.3 to 10.2 µg Se/kg rock/hr), which had lower SO_4^{2-} concentrations (approximately 300 mg/L) and pH values between 7.2 and 7.8, using natural hydrocarbon with relatively fewer aromatic compounds, and produced SeO_3^{2-} and Se^0. Reduction occurred more slowly in shale (3.0 to 6.3 µg Se/kg rock/hour) at concentrations of SO_4^{2-} between 900 and 1300 mg/L and pH values between 6.7 and 6.9, using a mixture of natural aromatic and alkane hydrocarbon, and producing SeO_3^{2-}, methylated Se, and Se^{-2} minerals as reduction products. In spite of differences in rate and end-products, reduction in both lithologies within 100 hours reduced the majority of SeO_4^{2-} to insoluble forms when saturated, low O_2 (less than 0.3 mg/L) conditions were developed.

Changes in the bacterial community were evident between treatments at different temperatures, and to a lesser degree, rock type. Changes in DNA banding patterns indicate that higher numbers of a *Rhodoferax*-like bacterium were present early in the SeO_4^{2-} reduction process. The banding pattern showed increases in phylotypes representative of the genera *Dechloromonas* (known SeO_4^{2-} reducers) in shale and *Ralstonia* (also known SeO_3^{2-} reducers) in both lithologies as reduction proceeded. This analysis of community response to SeO_4^{2-} exposure under microaerophilic conditions suggests hydrocarbon degradation may be coupled with denitrification and Fe-reduction, in association with Se reduction. The biogeochemical factors driving mineralization to

different endpoints should be confirmed with further analysis, perhaps using pyrosequencing and fine scale XAFS tools to better resolve the microbial community and the biomineralization pathways.

Results of these experiments show that facultative members of this microbial community are likely to couple oxidation of native carbon to O_2 reduction, quickly driving the saturated microcosms to microaerophilic and ultimately, conditions that support NO_3^-, Fe, Mn, and Se reduction. Capacity for *in situ* Se reduction by indigenous organisms using electron donors present in the rock was documented using samples from two mine sites, located 15 miles apart, which produce phosphate from the same geological formation. Results of this study explain observed differences in Se concentrations between wells completed in backfill at the two mine sites, which could not previously be explained based solely on solid phase equilibria (TetraTech, 2007). Although lithology affected the reduction rate and mineral end product, Se reduction within either rock type was relatively rapid under low O_2 conditions (on the order of weeks) when compared with the probable residence time of water within a backfilled mine facility, which typically ranges from months to years. Although Se reduction rates and mechanisms differ subtly between the two mine sites in these experiments, likely reflecting different microbial communities and/or abundance resulting from the different *in situ* O_2 conditions, the native microbes from both locations at Dry Valley (GW7D) and Smoky Canyon (GW11) were able to provide effective Se-reducing capacity when grown on either chert or shale under saturated, microaerophilic conditions. It is likely, however, that shale will offer better moisture retention and capacity to consume O_2 within a

backfilled panel or a constructed reactive barrier zone, due to finer grain size and higher organic C content, as well as promote the formation of more reduced mineral products which have lower potential for re-oxidation and remobilization. These results suggest that successful designs relying on microbial reduction as source control within the S.E. Idaho Phosphate Resource Area overburden deposits are possible. Successful designs will depend most significantly on the management of rock and water to develop and maintain suitably microaerophilic and moist conditions.

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Chapter 5 Supplementary Information

Overburden and Groundwater Sampling Methods

Representative samples of overburden and groundwater were collected from backfilled panels at the Dry Valley and Smoky Canyon mines. Multiple samples of shale and chert were collected from sonic drill core and near surface excavations to represent the range of mineralogy, texture, and geochemistry of backfilled overburden deposits. Samples were air-dried, flailed, and graded through sieve and hydrometer analysis. Sub 1/4 inch rock was composited, split, and digested with aqua regia followed by analysis of multiple elements by Inductively Coupled Plasma Mass Spectroscopy (ICP-MS). Methylene chloride extractable organic C species were also identified for two composited samples of chert and shale from the Smoky Canyon Mine using EPA method 3350, followed by Gas Chromotography Mass Spectroscopy (GC-MS) following EPA method 8270C.

Groundwater samples were collected from a well completed in saturated backfill at the base of backfilled panel B at the Dry Valley Mine (GW7D2a) and from a well completed in partially (and intermittently) saturated backfill in panel A at the Smoky Canyon Mine (GW11). Water was bailed manually using a disposable plastic bailer weighted to facilitate sediment recovery during sampling, as a means of collecting both planktonic and attached microbes. Samples were transferred immediately into sterile glass or polypropylene bottles and stored at 10°C in the dark without headspace. Groundwater pH, dissolved O_2 content (Hach model AQ4, Loveland, Colo) and temperature were measured at the time of sampling. Groundwater samples were collected

as close as possible to the start of each series of reactor experiments to limit the effects of storage on chemistry and microbial communities.

Less frequently, samples from each well were submitted for a comprehensive analysis of major and trace element chemistry; chemistries reported in 2007 are provided in Table S5-1. These samples were collected using low flow pumping techniques and preserved without headspace for analysis of dissolved metals using 0.45 μm filtration and nitric acid; total metals using nitric acid; nutrients using hydrochloric acid; and major ions/alkalinity (no filtration or reagent addition). Relative constant chemistry, with minor seasonal variation, has been observed in each of the wells over time. Dissolved organic carbon (DOC, by standard method 5310) and volatile aqueous C species (by Head Space-Solid Phase Micro Extraction-Gas Chromatography-Mass Spectrometry, HS-SPME-GC-MS) were also measured in groundwater collected from GW7D2A.

Total Element Analysis (ICP-MS)
Following Aqua Regia Digestion

Samples of chert, shale, and a run-of-mine mixture containing 55% shale, 35% chert, and 10% mudstone were analyzed for 51 elements by ICP-MS following aqua regia extraction at ALS Chemex laboratories (MEMS41).

Organic Carbon Speciation in Rock

Solvent extractable organic carbon was extracted using methylene chloride by EPA method 3550B and analyzed by EPA Method 8270C at Energy Laboratories in Billings, MT. Chromatographic spectra from unknowns were identified tentatively by comparison with the NIST standard reference database by Energy Laboratories.

Table S5-1. XRD mineralogy of chert and shale used in rate reactors.

CHERT	Quartz Hematite Clay Aluminum sulfate Carbonate
SHALE	Quartz Microcline Hematite Fluoroapatite Zinc Sulfide

Water-extractable Se, Fe, Mn, NO_3^- and DOC

Leachable Se, Fe, Mn, and NO_3^- were measured from bottle-roll extracted solutions by ICP and Ion chromatography. Rock was leached in a 3:1 ratio of distilled water to solid in an aerated 24 hour bottle roll at room temperature. Samples were allowed to stand for 1 hour, followed by centrifugation to remove solids and filtered to 0.20 μM prior to analysis. Total Se, Fe, and Mn were measured by ICP. DOC and total N were measured as described above in the methods section.

Rock and Groundwater Geochemistry Characterization

Representative samples of rock and groundwater used to construct batch reactors were characterized for total and leachable Se, Fe, Mn, SO_4^{2-}, NO_3^-, and organic C content and speciation. A homogenized, representative composite of chert and shale was developed for each of the two mine sites using 24 mono-lithologic samples of overburden collected from backfill excavations at the Smoky Canyon Mine. An additional 34 samples were collected from an archived core of unconsolidated backfill from the Dry

Valley Mine drilled hole GW7D2. The bulk composites were prepared by compositing samples in equal proportions. *In situ* and analytical geochemical data reported previously for select samples from this hole [38] (see also Appendix A1) were used to guide sampling and composite development, in addition to data collected during this study. This provided a homogenized and characterized substrate for experiments that represents the range of mineralogical, textural, and geochemical variation in pit backfill.

XRD Analysis of Rock

Samples of rock used to construct reactors, and samples of rock following reduction of Se in batch reactors, were analyzed using the Scintag Inc. (USA) Advanced diffraction system XL. Randomly packed powder was analyzed from 5 to 75 degrees in 0.02 degree steps, at a power of 1.8 kW using an energy of 45 kV and current set at 40 mA. Spectra were interpreted via comparison using a database of known XRD spectra provided by Scintag.

The bench top XRD analysis provided a baseline analysis of major rock forming minerals, as shown in Table S5-1. Trace quantities of Se phases were identified, but no clear trends with reduction in samples from the batch reactors could be established.

Total Element Analysis (ICP-MS) Following Aqua Regia Digestion: The total (Se, Mn, Fe, in mg/kg and S, in wt%) and extracted soluble Se, Mn, Fe, NO_3^- and organic

Table S5-2. Geochemistry of overburden from Dry Valley and Smoky Canyon mines used in batch reactor rate experiments.

				Dry Valley Mine Well GW7D2A		
				chert	**shale**	**ROM**
No. of Samples				**4**	**21**	composite
	Method	**Lab**	**Source**			composite
Se, mg/kg	Aqua Regia/ICPMS MEMS 41	ALS Chemex	a	15	86	56.8
Mn, mg/kg	Aqua Regia/ICPMS MEMS 41	ALS Chemex	a	345	271	314
Fe, wt%	Aqua Regia/ICPMS MEMS 41	ALS Chemex	a	1.61	1.68	1.65
S, wt%	Aqua Regia/ICPMS MEMS 41	ALS Chemex	a	0.17	0.86	0.6
Soluble Se, mg/L	EPA 1312/6020	Energy Labs	b	0.006	0.089	0.054
Soluble Mn, mg/L	EPA 1312/6020	Energy Labs	b	0.228	0.082	0.137
Soluble Fe, mg/L	EPA 1312/6020	Energy Labs	b	2.1	1	1.5
Soluble Nitrate, mg/L	3:1 DI bottle roll extract Method 4500	MSU	a	44.3	9.2	nd
Soluble Sulfate, mg/L	3:1 DI bottle roll extract method 4500 B	MSU	a	15	413	nd
Leachable Organic Carbon mg/L	EPA method 5310 GCMS	Energy Labs	a	16.8	72.1	nd
TOT Organic Carbon, wt%	Walkley Black	Energy Labs	b	0.37	3.43	nd
				Smoky Canyon Mine D and E panel excavation Well GW11		
				chert	**shale**	**ROM [1]**
No. of Samples				**15**	**12**	composite
	Method	**Lab**	**Source**			
Se, mg/kg	Aqua Regia/ICPMS MEMS 41	ALS Chemex	a	8	44	28.9
Mn, mg/kg	Aqua Regia/ICPMS MEMS 41	ALS Chemex	a	438	289	393
Fe, wt%	Aqua Regia/ICPMS MEMS 41	ALS Chemex	a	1.15	1.32	1.31
S, wt%	Aqua Regia/ICPMS MEMS 41	ALS Chemex	a	0.08	0.40	0.26
Soluble Se, mg/L	saturated paste extract	Energy Labs	c	<0.01	0.22	0.13
Soluble Mn, mg/L	saturated paste extract	Energy Labs	c	0.150	0.100	0.12
Soluble Fe, mg/L	saturated paste extract	Energy Labs	c	nd	nd	nd
Soluble Nitrate, mg/L	saturated paste extract	Energy Labs	c	nd	nd	nd
Soluble Sulfate, mg/L	saturated paste extract	Energy Labs	c	8	232	135
Leachable Organic Carbon mg/L	3:1 DI bottle roll extract Method 4500 infrared	MSU	a	43.7	84.5	nd
TOT Organic Carbon, wt%	saturated paste extract	Energy Labs	c	0.36	4.63	nd

ROM: Run-of-Mine Mixed rock. nd: not determined

SOURCE: supporting data in Appendix A2

a this study, b Tt/Maxim and Geomatrix, 2008, c Smoky Canyon B & C EIS

C content (mg/L) of the shale and chert composites are described in Table S5-2. These results indicate higher total Se, S, and TOC content in shale, compared to chert, with concentrations at the Dry Valley Mine twice those measured at the Smoky Canyon Mine. Comparable concentrations of Fe were observed between rock types (e.g., both chert and shale) at the Smoky Canyon Mine, with values again higher at the Dry Valley Mine. Total Mn concentration was higher in the chert sample than in shale at both mine sites, with slightly higher overall concentrations at the Smoky Canyon Mine. These results are relatively consistent with the variation known to exist within the Phosphoria Formation [82]. At the Smoky Canyon Mine, soluble NO_3^- was relatively consistent in paste extracts between rock units, and significantly lower than the values reported for bottle roll extracts from the Dry Valley Mine. Both are reported. Dissolved organic C was lower in chert than in shale extracts, and comparable between mine sites.

Total organic C (Table S5-3) was an order of magnitude higher in shale than in chert at both mine sites. Leachable organic C was also higher in shale at both mines. At the Smoky Canyon Mine, shale had a higher concentration of aromatic hydrocarbons and an overall higher ratio of aromatic to alkane and alkene compounds (Table S5-4) relative to chert. As the total organic C content in chert and shale was consistent between the two mine sites, and due to the cost of speciation analyses, extractable organic C was speciated only for samples from the Smoky Canyon Mine.

Table S5-4 statistically describes the long term chemistry of groundwater collected at the Dry Valley and Smoky Canyon mines, along with water quality data for samples of groundwater analyzed close to the time that samples were collected for use as

Table S5-3. Hydrocarbon extracted from composited overburden, using methylene chloride extraction followed by GC-MS.

	Shale		**Chert**	
	n = 1 *mg/kg*	*common compounds*	n = 1 *mg/kg*	*common compounds*
Solvent Extractable Organic Carbon	72.1		16.8	
Non-Aromatic	41.4		15.1	
Aromatic	30.7		1.9	
Ratio Aromatic/Total	43%		12%	
Alcohol	*nd*		1.2	hexadecanol
Alkane	32.2	decane, hexane	9.7	decane, eicosane
Alkene	0.6	octadecene	*nd*	octadecene
Amide	7.7	decanamide	3.6	decanamide
Aldehyde	0.5	octadecenal	0.4	dimethyl octenal
Heterocyclic	0.3	azetidine	0.2	tetrahydropyran
Monoaromatic	14.8	phthalate, benzene, toluene	1.9	phthalate, benzene
Diaromatic	9.9	naphthalene	*nd*	
Polyaromatic	6.0	dibenzothiophene, phenanthrene	*nd*	

innoculum in July 2007 (see methods described in Appendix A1). Sediments from the Dry Valley Mine GW7D groundwater samples incubated under anaerobic conditions averaged 4.6 x 10^6 SeRB per gram of rock, values that were considerably higher than the 1.7 x 10^4 SeRB per gram in the Smoky Canyon Mine monitoring well GW11 (Chapter 4).

Dissolved organic C was speciated using HS-SPME-GC-MS for a sample of groundwater from the Dry Valley Mine monitoring well GW7D2a. A sample could not be obtained from GW11 for this analysis, as the well had been abandoned due to construction of additional backfill in this location. Naturally-occurring, volatile organic C compounds detected in the head space are summarized in Appendix E and include benzene, butanone, pentane, furan, and hexadecane. These compounds are reported as a % of C detected in vapor.

Table S5-4. Groundwater chemistry at the Dry Valley and Smoky Canyon mines.

2007 Groundwater samples used in batch reactors		Dry Valley Mine GW7D2A			Smoky Canyon Mine GW11		
	Depth, feet	180			85		
	Lithology	Run-of-mine mix			Run-of-mine mix		
	no. of samples	Average (n=8)			Average (n=3, diss Se only)		
In situ conditions	T°C	9.8			7.7		
	Moisture Content	saturated			saturated		
	In situ O_2, mg/L	0.20			5.5		
	pH	7.8			7.3		
		MIN	*2007*	*MAX*	*MIN*	*2007*	*MAX*
Groundwater Chemistry ICPMS	NO_3^-, mg/L	0.11	0.3	11	nd	0.16	nd
	Diss Se, ug/L	0.01	0.021	0.065	0.299	1.01	1.06
	SO_4^{2-}, mg/L	680	710	830	nd	1666	nd
	Fe, mg/L	0.11	0.20	0.31	nd	3.3	nd
	Mn, mg/L	0.394	0.47	0.55	nd	0.45	nd
DOC, mg/L		10.0			5.57		
Organic C Speciation HS-SPME-GCMS	Example compound	%					
	benzene	16					
	butanone	25					
	pentane	19					
	furan	16					
	hexadecane	24					

nd not determined

Dissolved Organic Carbon Speciation by HS-SPME-GC-MS: Volatile organic C compounds were extracted from acidified aqueous samples by head space-solid phase microextraction (Vas and Veke, 2004) using a Supelco carbox/polydimethylsiloxane fiber, with adsorption time fixed at 45 min with stirring. Analyses were run by the RJ Lee Group, Center for Laboratory Sciences. The fiber was desorbed in the injector at 240°C with helium carrier gas at 1.0 mL/min., followed by GC-MS analysis using EPA Method 8260 BFB tuning criteria. The oven temperature was ramped from 40°C to 230°C at 5°C/min. Although it is possible to quantify volatile organic C compounds based on

equilibrium partitioning coefficients, this was not attempted, as the intended use of the data was qualitative identification of C compounds. HS-SPME-GCMS analyses were run to qualitatively identify volatile C species for eight samples including groundwater, lithology, specific groundwater extracts, and rate reactor water at the start and end of one set of replicate experiments. Compounds were tentatively identified using the NIST05 library[83] and results were edited to remove any compounds introduced with the standards. The tentative identifications provided by the laboratory were reviewed to ensure data quality by limiting identified compounds to well defined peaks with greater than 80% similarity to known compounds, within 0.2 minutes variance of known retention time. The relative amount of identified species was quantified by comparison with a 4-bromofluorobenzene internal standard calibration curve delivered in methanol over the concentration range of 1.2 to 78 ng. Results are summarized in Appendix E.

Volatile C compounds were measured by HS-SPME-GC-MS for samples of groundwater, as well as water from live and killed control reactors for both chert and shale at the end of reduction (Table S5-5). This method allowed qualitative assessment of C speciation in the aqueous headspace only for volatile compounds, based on comparison of peak area with the mass of a known internal standard. These data can only indicate shifts in relative frequency of C species. Also, limited available sample restricted the number of these analyses, unfortunately, so that it was not possible to determine sample reproducibility. As preliminary results, however, the data presented in Table S5-5 suggest that the majority of C in the reactors came from the solid phase, rather than groundwater, which had relatively low initial concentrations of alkane and aromatic compounds. These

data also suggest that relatively larger numbers of shorter chain (fewer C) alkane compounds were initially present in the chert reactor than in the shale reactor and that concentrations of volatile hydrocarbons in the aqueous phase decreased as Se reduction proceeded.

Table S5-5. Dissolved organic carbon speciation by HS-SPME-GC-MS for select samples.

					GW DV7D2A	ROM mix media	SCD chert 5	SCD shale 75	10C control	10C live end	10 S control	10 S live end
	Example Compound	**# Carbons**	**# Nitrogens**	**Chemical Formula**	**ng in vapor**							
Alkane	Ethanol	2	0	C_2H_6O				14.20				
Alkane	ethane, 1,1 -oxybis-	4	0	C_2H_6				40.02				
Alkane	Pentanal	5	0	$C_5H_{10}O$					36.36	13.31		
Alkane	cyclopentane, methyl-	6	0	C_6H_{12}	1.27	7.51	14.68	39.62	49.73	12.63	36.53	28.48
Alkane	Pentane, 3-methyl-	6	0	C_6H_{14}				7.71		11.45		10.60
Alkane	2-pentanone, 4-methyl-	6	0	$C_6H_{12}O$			2.77	1.75	9.16			
Alkane	Hexane	6	0	C_6H_{14}			3.60	23.44	17.46		32.00	13.10
Alkane	2-butanone, 3-hydroxy-3-methyl-	6	0	$C_5H_{10}O_2$	1.27	1.70			18.17			
Alkane	Acetic acid, butyl ester	6	0	$C_6H_{12}O_2$				2.09				
Alkane	Acetic acid, 1,1-dimethylethyl ester	6	0	$C_6H_{12}O_2$			3.58					
Alkane	2-Pentanone, 3-methyl-	6	0	$C_6H_{14}O$				2.17				
Alkane	3- hexanone	6	0	$C_6H_{12}O$					4.94		4.53	4.78
Alkane	Hexane, 3-iodo	6	0	C_6H_{13}		5.81	2.39	2.46		1.18		
Alkane	Propane, 2-ethoxy-2-methyl-	6	0	$C_9H_{14}O$			2.34					
Alkane	3-pentanone, 2,4-dimethyl-	7	0	$C_5H_{10}O$		5.40			31.80			
Alkane	1-pentanol, 2,2-dimethyl-	7	0	$C_7H_{16}O$								
Alkane	2-heptanol, 2-methyl-	8	0	$C_8H_{18}O$					26.11			
Alkane	2-heptanone, 4-methyl-	8	0	$C_8H_{16}O$					17.98			
Alkane	Nonanal	9	0	$C_9H_{18}O$		3.60	7.87		21.63	12.28	7.09	
Alkane	heptane, 4,4-dimethyl-	9		C_9H_{20}		1.45			9.74	1.32		
Alkane	Undecane, 2,4, -dimethyl-	9	0	$C_{11}H_{24}$								
Alkane	3-heptanone, 2,4-dimethyl-	9	0	$C_9H_{18}O$								
Alkane	octanal, 7-hydroxy-3,7-dimethyl-	10	0	$C_{10}H_{20}O_2$					17.27			
Alkane	decanal	10	0	$C_{10}H_{20}O$		4.61	7.97		27.09	1.38	7.40	7.49

Table S5-5. Dissolved Organic Carbon Speciation by HS-SPME-GCMS for Select Samples, continued.

					GW DV7D2A	ROM mix media	SCD chert 5	SCD shale 75	10C control	10C live end	10 S control	10 S live end
	Example Compound	**# Carbons**	**# Nitrogens**	**Chemical Formula**	**ng in vapor**							
Alkane	Dodecane	12	0	$C_{12}H_{26}$				2.32	5.71	0.90	24.21	
Alkane	Dodecane, 1-iodo-	12	0	$C_{12}H_{25}I$							12.29	
Alkane	3-Dodecanol	12	0	$C_{12}H_{26}O$					5.71			
Alkane	3,6- dimethyldecane	12	0	$C_{12}H_{22}$							11.92	
Alkane	Propanoic acid, 2-methyl-, 2-methyl	12	1	$C_{12}H_{15}NO_4$				2.32				
Alkane	9-Undecen-2-one, 6,10-dimethyl-	13	0	$C_{13}H_{24}O$		3.63				1.05	4.85	
Alkane	Undecane, 4,6-dimethyl-	13	0	$C_{13}H_{28}$							4.85	
Alkane	hexane, 1,1-[ehtylidenebis(oxy)	14	0	C_6H_{14}		6.43		2.14	5.27		20.67	
Alkane	Decane, 2,3,5,8-tetramethyl-	14	0	$C_{14}H_{30}$							7.32	
Alkane	Tetradecane	14	0	$CH_3(CH_2)_{12}CH_3$							4.66	
Alkane	Tridecane, 5-methyl-	14	0	$C_{14}H_{30}$		6.43						
Alkane	2-nonanone,9-[(tetrahydro-2h-py	14	0	$C_{14}H_{22}O_2$					5.27			
Alkane	Dodecane, 4,6-dimethyl-	14	0	$C_{14}H_{30}$							8.69	
Alkane	Pentadecane	15	0	$C_{15}H_{32}$							10.79	
Alkane	hexadecane	16	0	$C_{16}H_{34}$	1.21			13.39				
Alkane	Tridecane, 6-propyl-	16	0	$C_{16}H_{34}$				1.88				
Alkane	propanoic acid, 2-methyl-, 1-(1	16	0	$C_{16}H_{32}NO_4$				11.51				
Alkane	octadecane	18	0	$C_{18}H_{38}$							4.89	
Alkane	Tricosane	23	0	$C_{23}H_{48}$							5.09	
Alkane	Octosane	28	0	$C_{28}H_{48}$							7.97	
Alkane	triacontane	30	0	$C_{30}H_{62}$							27.31	
Alkane	hexatriacontane	36	0	$C_{36}H_{74}$							4.64	
Total Alkane					**2.48**	**31.18**	**30.52**	**111.69**	**203.70**	**41.55**	**161.44**	**35.97**

Table S5-5. Dissolved Organic Carbon Speciation by HS-SPME-GCMS for Select Samples, continued.

					GW DV7D2A	ROM mix media	SCD chert 5	SCD shale 75	10C control	10C live end	10 S control	10 S live end
	Example Compound	**# Carbons**	**# Nitrogens**	**Chemical Formula**	**ng in vapor**							
Alkene	1-Pentene, 2,4,4 trimethyl-	8	0	C_5H_{10}						0.77		
Alkene	2-Pentene, 3-ethyl-4,4-dimethyl-	9	0	C_5H_{10}				1.68				
Alkene	1,2,6 Heptatriene, 2,5,5-trimethyl	10	0	C_9H_{12}				1.89				
Alkene	4,4,7,7 -Tetramethyldeca-1,9-dien	14	0	$C_{14}H_{24}O_2$					7.47			
Total Alkene								**3.57**	**7.47**	**0.77**		
Aromatic	Pyrimidine, 5-bromo-	4	2	C_4H3BrN_2;		1.25						
Aromatic	1-H-Pyrazole, 4,5-dihydro-3,5,5-t	6	3	$C_{29}H_{22}F_3N_3O_2$					20.66			
Aromatic	benzene, methyl-	7	0	C_6H_6	0.81			1.77				2.94
Aromatic	Furan, tetrahydro-2,2,5,5-tetram	8	0	C_4H_4O	0.79				17.00		4.36	
Aromatic	Benzenemethanol, 4-hydroxy-.al	9	0	$C_8H_{10}O$		1.20	7.27					
Aromatic	Benzenedicarboxylic acid, di	12	0	$C_8H_6O_4$				2.54				
Aromatic	Benzenedicarboxylic acid, butyl	20	0	$C_7H_6O_2$				2.48				
Total Aromatic					**1.60**	**2.45**	**7.27**	**6.79**	**37.66**	**0.00**	**4.36**	**2.94**
Cyclic	cyclopentane, methyl-	6	0	C_5H_{10}		1.33	6.32	7.26		1.83		9.59
Cyclic	1,2 cyclopentadiol, 1-(1-methyl	8	0	$C_6H_{12}O_2$								7.51
Cyclic	1,8- cineole	10	0	$C_{10}H_{18}O$			3.68		22.53			
Cyclic	fenchone	10	0	$C_{10}H_{16}O$					8.83			
Cyclic	(+)- isomethol	10	0	$C_{10}H_{20}O$					4.87			
Cyclic	Cyclohexane, 1,2-diethyl-3-methy	11	0	C_6H_{12}							16.27	
Cyclic	Cyclohexane, 1-ethyl-2-propyl	11	0	$C_{11}H_{22}$							7.29	

Table S5-5. Dissolved Organic Carbon Speciation by HS-SPME-GCMS for Select Samples, continued.

					GW DV7D2A	ROM mix media	SCD chert 5	SCD shale 75	10C control	10C live end	10 S control	10 S live end
	Example Compound	**# Carbons**	**# Nitrogens**	**Chemical Formula**	**ng in vapor**							
Cyclic	Cyclooctane,butyl-	12	0	C_6H_{12}							6.98	
Cyclic	cyclohexane, octyl-	14	0	$C_{14}H_{28}$					4.90			
Total Cyclic						**1.33**	**10.00**	**7.26**	**41.13**	**1.83**	**30.54**	**17.10**
Amine	2-Propanamine	3	1	C_3H_9N			9.38					
ketone	2-Propanone	3	0	C_3H_6O			2.09					
	Plumbane, tetramethyl-	4	0	$C_4H_{12}Pb$					6.45			2.04
	4-Nitro-1-methylimidazole	4	2	$C_4H_6N_2$					6.45			
Hetero-cyclic	2,2,3,3-Tetramethyl-1-d1-aziridine	4							13.40			13.82
	1,2,3- Oxazaborolane, 2-butyl-	6	1	$C_6H_{14}BNO$								13.82
ketone	Camphor	10	0	$C_{10}H_{16}O$				2.04	14.54			
	Hydroxylamine, o-decyl-	10	1	$C_{10}H_{23}NO$				2.04				
terpene	Farnesol	15	0	$C_{15}H_{26}O$							4.58	

In blank cells, compound was not detected.

These analyses represent GCMS speciation of the aqueous hydrocarbons using SPME methods - volatiles stirred out of aqueous phase, collected on siloxane fiber that is destructively sampled in GCMS. See Appendix E.

This table summarizes #C compounds within each major class of hydrocarbon (alkane, alkene, aromatic, cyclic, misc)

Samples are groundwater GWDV7D2a and aqueous GWTOC extract (bottle roll);two of the bottle roll extracts used for the MPN work, DMSo and DC5; starting (killed) and ending (live) solutions from the 10 Chert and 10 shale (Dry Valley).

Table S5-6. XANES Analysis of Se in Rate Reactor Mineral Samples

Standard	**Edge position (eV)**
Sodium selenite	12 659.5
Sodium selenate	12 662.6
Elemental selenium – red	12 657.5
Elemental selenium – grey	12 655.5
SeS_2	12 656.4
$FeSe_2$	12 657.0
Selenium cysteine	12 657.3
Selenium methionine	12 658.4
Sample	**Edge position (eV)**
Dry Valley Shale	
Shale only	12 658.7
0 h – 10°C	12 658.4
128 h – 10°C	12 658.0
272h – 10°C	12 657.8
Live end – 25°C	12 657.5
Killed end – 25°C	12 657.7
Dry Valley Chert	
Chert only	12 659.1
0 h – 10°C	12 657.6
128 h – 10°C	12 660.6
272 h – 10°C	12 657.4
Live end – 25°C	12 658.5
Killed end – 25°C	12 659.5
Smoky Canyon Shale	
0 h – 10°C	12 658.2
108 h – 10°C	12 658.5
246 h – 10°C	12 657.9
Smoky Canyon Chert	
0 h – 10°C	12 657.8
108 h – 10°C	12 658.1
246 h – 10°C	12 657.8

Data from Appendix F

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CHAPTER SIX

SUMMARY AND CONCLUSIONS FOR SELENIUM SOURCE CONTROL IN MINED OVERBURDEN

Improved capacity for *in situ* source control of selenium (Se) in mine-affected water is of increasing importance to mining operators working in a variety of commodities, including phosphate, coal, and metals [1, 2]. Microbial source control of Se within deposits of phosphate mine waste in the S.E. Idaho Phosphate Resource Area is an important potential strategy for mine waste management and protection of water resources. Observations of apparent *in situ* Se reduction in backfill at multiple locations, and the results of controlled microbiological and kinetic geochemical experiments presented here, support the conclusion that it is possible to intentionally develop conditions within saturated and organic-rich backfilled mine waste that will support Se reduction. Microbes living in backfilled mine overburden deposits can, under conditions that have been documented within full-scale mine backfill and dump facilities, reduce soluble and toxic SeO_4^{2-} and SeO_3^{2-} to insoluble and less toxic Se^0 and Se^{2-} minerals. More than ten years of *in situ* monitoring data from Dry Valley GW7D describing suboxic conditions in partially saturated to saturated backfill demonstrate, at the broadest scale, that this is true. In this study, the biogeochemical conditions observed at this site have been linked with microbial communities and geochemical processes active at the pore scale, and contrasted with those in other S.E. Idaho Phosphate Resource Area waste deposits at Smoky Canyon and Enoch Valley, as a foundation for the design of facilities that integrate biogeochemistry across these scales. The following discussion summarizes

the findings of this study, and outlines the questions it raises regarding the implementation of *in situ* microbial source control of Se within phosphate overburden deposits.

This study applies a variety of existing knowledge regarding the biogeochemistry of Se to questions of mine waste management. For example, the existence of Se-reducing bacteria (SeRB), and the impact they have on the kinetics of Se cycling in the environment, is well documented [3]. A number of microbes capable of reducing Se in the environment are known and many commercial water treatment processes (active or passive) rely on microbial Se reduction with addition of carbon (C) and nutrients [4]. Similarly, the potential for reactive barriers to intercept contaminants in groundwater is also well known [5] and Se remediation using this approach has been the focus of other, ongoing investigations [6]. However, the intentional design of mine facilities (backfills and overburden dumps among others) to act as operational sinks by facilitating biological reduction of Se remains relatively unexplored. This study begins at the hydrogeochemical field scale (Chapter 2 and Figure 3) and works back to a microscale understanding of microbial geochemistry (Figure 4) based on the identity, number, and reduction capabilities of native microbes (including SeRB) under field relevant lithotype, chemistry, and moisture conditions.

This study has identified a variety of native SeRB which function within a community of hydrocarbon-oxidizing and NO_3^-, $Fe^{3+,}$ and Mn^{4+-}reducing, aerobic and facultative anaerobic microbes. The SeRB include several SeO_4^{2-}respiring *Dechloromonads*, as well as other SeRB including *Anaeromyxobacter* spp. and *Stenotrophomonas* spp., also known to reduce SeO_4^{2-} for detoxification or other non-

respiratory reasons. Only *Dechloromonas* was shown to grow on SeO_4^{2-} and reduce it to Se^0 under anaerobic conditions (Childers, unpublished data this study). Also in this study, other SeRB isolates were shown to reduce SeO_3^{2-}, but not SeO_4^{2-}, including members of of the *Arthrobacter, Pseudomonas*, *Cellulomonas*, and *Sphingomonas* genera. Other bacteria genera that were not isolated, but which were identified in molecular work, including *Anaeromyxobacter* and *Ralstonia*, are also known SeO_3^{2-}-reducers.

Results presented here suggest that *Dechloromonas* spp. can reduces SeO_4^{2-} in a stepwise fashion to SeO_3^{2-} and then Se^0, using complex native hydrocarbon and dominates the SeRB community in groundwater samples from both Dry Valley and Smoky Canyon. Based on the absence of dechloromonads in clone libraries and most dilute positive MPN cultures, however, this genus appears to be present in relatively low numbers in unsaturated sediments, where the SeRB were shown to include *Anaeromyxobacter*, *Stenotrophomonas*, and other heterotrophs. Interestingly, phylotypes highly similar to the Fe-reducing genus *Rhodoferax* occur frequently in the clone libraries and DGGE analyses of unsaturated sediment enrichments, in association with the heterotrophic SeRB (Chapter 4), but rarely in the groundwater samples. This raises interesting questions which should be further investigated regarding the role that *Rhodoferax* spp. may play in providing Fe^{2+}- to serve as an electron shuttle in support of biotic Se reduction (or perhaps abiotic SeO_3^{2-} reduction) in unsaturated environments.

A number of opportunities remain to learn more about this complex microbial ecology and its influence on the mineralization endpoints of reduction in this system. A more comprehensive analysis of the diversity and abundance of microorganisms using state-of –the-art methods is essential to obtain a more statistically robust analysis. This

work was conducted at a time when high throughput genomic methods (such as 454 pyrosequencing) were far more expensive than they are today, and these methods were therefore unavailable to this project. The limitations of the DGGE method, relatively small clone libraries, and inconsistencies in identified SeRB between various data subsets (e.g., MPN cultures, isolate populations, and clone libraries), suggest that a more comprehensive approach using methods such as pyrosequencing of rock and groundwater samples would be highly informative.

It would also be interesting to conduct more focused rate experiments using a defined mixed culture consisting of key members of the identified SeRB and a *Rhodoferax* isolate, with one select member of the hydrocarbon-degrading microbial community, under controlled conditions of NO_3^- addition and more carefully tracked changes in NO_3^-, NO_2^-, Mn^{4+}, Mn^{3+}, Mn^{2+}, Fe^{3+}, and Fe^{2+} concentrations. Isolates to be included could be chosen from the community results defined with DGGE. Experiments should be conducted in the presence of known hydrocarbon electron donors and select Fe and Mn mineral substrates, to reduce the complexity of the experimental system. Outstanding questions that could be addressed in these experiments include:

1. Is the observed increase in dissolved Fe^{2+} reproducible, and is it associated with an increase in the *Rhodoferax* (or another Fe/Mn-reducing microbial) population? Does it reflect an abiotic reaction of selenite with primary FeS_2 mineralization?
2. Can the isolated members of the *Rhodoferax* genus, which did not reduce SeO_4^{2-} to Se^0 in culture, be shown to specifically facilitate the ability of other organisms to reduce SeO_4^{2-} to SeO_3^{2-}, and thus contribute to Se

reduction through community level interactions? Does this occur in the presence of specific Fe-oxide substrates?

3. Why does the aqueous total N concentration increase during the middle of the Se reduction process, as suggested by the results shown in Figures 19 and 20? How does this relate to the observed increase in dissolved Fe concentration? Is this associated with increased numbers of N_2-fixing organisms in the microbial community?
4. Are the microbial community changes indicated in Figure 23 reproducible? Or, is there a change in the community within a consistent set of functional microbial niches that correspond with other biogeochemical variables, such as moisture or lithologically-controlled geochemistry? How might the observed biogeochemistry inform the management of such a microbial community in a pilot or field scale facility?

The most favorable conditions for Se reduction appear to be in saturated or moist conditions (close to field capacity) where sufficient soluble Se and organic C is available to support higher numbers of SeRB. The SeRB were present in greatest numbers (5 x 10^6 SeRB per gram of rock) in moist, fine-grained crushed shale that were Se and C rich. The number of SeRB was negligible in chert and mudstone lithotypes ($3x10^2$ SeRB per gram of rock), and no Se reduction was observed in aerobic MPN experiments for any lithotypes.

The greatest numbers of SeRB in sediment collected from turbid groundwater were from the Dry Valley backfill well GW7D2a (4.6 x10^6 SeRB per gram of rock), which had less than 0.2 mg/L initial dissolved O_2. There were approximately 300 times more SeRB at in saturated sediments collected from groundwater Dry Valley than from Smoky Canyon (1.6 x 10^4 SeRB per gram of rock), which had elevated concentrations of dissolved O_2 (5 mg/L). Many of the identified SeRB bacteria are facultative and therefore can use O_2 and/or NO_3^- until they are depleted, and SeO_4^{2-} reduction can occur.

Results of this study indicate that members of the native microbial consortia make use of variable O_2 and moisture conditions within the mined overburden for both aerobic and anaerobic degradation of complex shale hydrocarbons. This is reflected by the diversity of identified organisms, which reduce SeO_4^{2-} using the available, naturally-occurring hydrocarbon compounds under Fe^{3+}, Mn^{4+}, and NO_3^- reducing conditions. Bacteria capable of aerobic hydrocarbon degradation (e.g., *Polaromonas)* and anaerobic hydrocarbon degradation coupled to NO_3^-, Fe^{3+}, and Mn^{4+} reduction (e.g., *Rhodoferax*, *Pelosinus, Geothrix,* and *Dechloromonas*) have been identified. It is likely that degradation of complex shale hydrocarbons by aerobic members of the community decreases available O_2, thus creating conditions favorable for SeO_4^{2-} reduction by facultative anaerobes like *Dechloromonas* and *Stenotrophomonas*, as well as other heterotrophic SeRB.

Experiments to determine rates of O_2, NO_3^-, Fe^{3+}, Mn^{4+} and SO_4^{2-} reduction were conducted under saturated, microaerophilic conditions. The results presented here showed that following depletion of O_2 (via biotic and abiotic mechanisms), biological NO_3^-, Fe^{3+}, and Mn^{4+} reduction occurred together with Se reduction, but SO_4^{2-} reduction

was not observed. Natural C of mixed complexity (including alkanes, cyclic, and aromatic compounds) from the solid phase was solubilized and a fraction (less than 40% of soluble C) was consumed. Reduction of Se occurred more slowly in shale than chert, at Dry Valley, at both temperatures, and was slower at field-relevant 10°C than at room temperature; no difference in rate (Table 10) was observed between lithology at Smoky Canyon experiments. In the experiments conducted for both sites, reduction occurs within 100 hours once low O_2 conditions were developed in both lithotypes. As the residence time of groundwater movement in field scale facilities is likely to be on the order of months or years, rather than days, these data suggest that it is likely possible to design facilities to retain water long enough to deplete residual O_2 and reduce available SeO_4^{2-} and SeO_3^{2-}. The extent to which this is true will depend upon balancing the flux of oxidants into the system against its capacity for reduction, which is in turn dependent on the rate of air (O_2) flow, water flow, and available C, and will need to be considered on a site specific basis. The O_2 demand and replenishment rate can potentially be altered, where necessary, through amendment (e.g., addition of clays) or placement of rock in short, compacted lifts to increase water retention and reduce water flux rates. Other strategies targeting the creation of suboxic zones include the use of textural discontinuities and capillarity [7], construction of efficient store and release covers [8], and addition of C to consume oxygen and thereby promote the development of desired O_2 gradients. Potential health and safety risks associated with CO_2 accumulation and seasonal displacement from constructed facilities could require monitoring and management with institutional controls [9, 10]. This study has not evaluated the potential for re-oxidation of reduced Se minerals, but this risk should be addressed in tandem with

in situ demonstration studies, to consider a realistic flux of oxidants (e.g., O_2 and NO_3^-) as well as potential for re-oxidation by soluble Fe^{3+} and Mn^{4+}.

The aqueous speciation of Se and reduced secondary Se mineralization described in the reactor experiments support chert- and shale-specific biogeochemical pathways at Dry Valley. In the chert reactor, SeO_4^{2-} was reduced to aqueous $HSeO_3^-$ /SeO_3^{2-} that was detected early in the reduction process. The fact that it was not detected subsequently suggests that it was rapidly removed from solution, either through adsorption to a solid phase mineral, probably clay or iron oxide, or through further reduction. The $HSeO_3^-$ /SeO_3^{2-} was subsequently partially reduced to Se^0, although the amount of $HSeO_3^-$ /SeO_3^{2-} reduction to Se^0 varied between the two mine sites; the extent to which this was related to remobilization of $HSeO_3^-$ /SeO_3^{2-} during the concurrent reduction of Fe^{3+} is not clear. It may be that higher concentrations of Fe-oxide and clay minerals present in the chert (Table S5-1) provided greater substrate for initial $HSeO_3^-$ /SeO_3^{2-} sorption, or that differences in pH (Appendix D1) between the two lithotypes subtly influence the extent of $HSeO_3^-$ /SeO_3^{2-} sorption, with consequence for subsequent $HSeO_3^-$ /SeO_3^{2-} availability for reduction. However, it is difficult to determine if sorption is the primary control defining the different pathways between the chert and shale, as in spite of the pH differences between the two lithotypes in reactors at Dry Valley, both have pH below 8 and should support $HSeO_3^-$ /SeO_3^{2-} sorption[11]. The sorption of the $HSeO_3^-$ /SeO_3^{2-} thus has the potential to alter the trajectory of the subsequent biogeochemical reduction pathway. It is also possible that the different concentrations of dissolved SO_4^{2-} between the chert and shale influenced the SeO_3^{2-} reduction pathway, as described by Hockin and Gadd [12]. Another possibility is that there is a difference in the availability of free Ca^{2+}

(as opposed to $CaSO_4^0{}_{aq}$) lithotypes, as a result of the different amount of available SO_4^{2-} between the two lithotypes in the reactors. This could influence the interim solubility of $CaSeO_3xH_2O$ (Figure 5) and have a similar effect on the availability of SeO_3^{2-} for subsequent biological reduction. This would be an interesting question to address from a modeling perspective.

One way to address the significance of these factors on the reduction endpoint could be further examined in batch sorption experiments, with addition of $NaSeO_3$ under a controlled range of pH and SO_4^{2-} concentrations, using defined sorption substrates of known surface area including iron oxide mineral and/or clay. Initial abiotic experiments conducted with speciation of Se, Fe, and Mn, followed by mineralogical analysis to identify surface complexation, could then be inoculated with select members of the Se-, Fe-, and Mn-reducing microbial community to evaluate potential differences in subsequence Se biomineralization.

In the Dry Valley shale, SeO_4^{2-} was more slowly reduced, with some evidence of interim SeO_3^{2-} and selenomethionine (SeM) formation, followed by reduction to Se(-II) and precipitation of $FeSe_2$ as shown by S-XRD and XAFS analyses. It is likely that the Se^0 and Se(-II) reduction products will be less reversible and more stable than adsorbed SeO_3^{2-}. The potential for reoxidation of reduced Se minerals should not be discounted, however, and should be considered in design.

Further study of the biogeochemical pathways that influence the differential production of Se^0 and Se(-II) in chert and shale, respectively, may identify engineering strategies that can optimize the stabilization of Se for most effective long-term remediation. Preliminary aqueous data support the formation of SeM as an interim

reduction product, but these data require replication. The observed decline in dissolved Fe concentration agrees with field scale observations, and is explained by the identification of $FeSe_2$ in shale, but the comparable drop in Fe concentration in chert reactors that do not show evidence for Se(-II) formation at the end of reduction suggests that this should be examined further.

Questions remain about the extent of reduction under unsaturated, but oxygen-depleted conditions, in layered or mixed mine waste. At Enoch Valley, no groundwater saturated conditions were identified, yet suboxic conditions were identified. Much of the Intermountain West hosts mine waste deposits in high evaporation environments where the dominant waste condition is unsaturated. If suboxic conditions can be reliably and cost-effectively created under unsaturated conditions, through the use of capillary break, compaction, organic amendment, or other design parameters, there is significant potential benefit to be gained through NO_3^-, SO_4^{2-} and metal reduction.

Selenium reduction rate experiments were conducted using samples from two mine sites which produce phosphate from the same formation under different hydrologic conditions, located approximately 15 miles apart from one another. In spite of the relatively drier conditions in backfill at Smoky Canyon, zones were identified in the sediments of the panel A dump that hosted relatively higher numbers of SeRB, comparable to those observed in Dry Valley groundwater where Se reduction has been observed *in situ* for over 10 years. Within unsaturated sediments, the number of SeRB varies within the shale, and differences in microbial community are observed both within the shales, and between the chert, shale, and mudstone lithotypes. In spite of these variations, the O_2, moisture, and geochemical conditions identified in this study that were

needed to support biological Se reduction lie within the range of *in situ* conditions identified in phosphate overburden at all three of the studied S.E. Idaho phosphate mine facilities. These results do not indicate a need to add Fe, NO_3^-, or C to promote the *in situ* reduction of Se by native organisms, within a suboxic, steady state low flow environment in backfilled sediments comparable to that developed at Dry Valley.

Collectively, the results of the microbial community, enumeration, and saturated rate reactor studies agree with *in situ* monitoring results, wherein low concentrations of soluble Se exists under dry conditions in unsaturated backfill, with low numbers of associated SeRB, as described at Enoch Valley [13]. Low dissolved concentrations of Se also exist under moist (but, not necessarily saturated) and low O_2, but C-rich conditions, where the number of SeRB is greater, as has been observed at the Dry Valley B pit over time[14]. Higher concentrations of dissolved Se are evident where Se rich shales are exposed to O_2 and water, promoting release of Se that is not locally re-reduced *in situ,* such as Smoky Canyon [15]. In facilities where saturation occurs in deep backfill, O_2 is limited and local Se release following sulfide oxidation is low. In saturated environments, these results demonstrate that although sulfide is oxidized, native microbes can actively reduce soluble Se, Fe, and Mn. When saturation would not be possible, construction of facilities to limit O_2 recharge using placement of rock by individual dump trucks on lifts (as done at Enoch Valley, Dry Valley, and Luxor) or compaction/amendment of Se and C rich shales to promote higher moisture retention and Se reduction (as indicated by the high number of SeRB in the external panel A dump samples AS113 and AS71) may be of value. The extent to which the creation of suboxic conditions can be accomplished operationally, in a cost effective manner, is unclear, but these results suggest that it is

possible and potentially, highly effective. Reduction of Fe and Mn raises potential for changing concentrations of these elements downgradient, but potential for reoxidation of both (as well as precipitation of oxide minerals with capacity for further sorption of other metals) is high and also of potential environmental management value.

Further, our results suggest that the native microbial community is capable of adaptive metabolism, consuming O_2 while degrading hydrocarbons that further support SeRB and other reducing bacteria. When exposed to elevated O_2 concentrations, the SeRB did not efficiently reduce Se in groundwater monitored at GW11. However, fewer facultative bacteria capable of this process were detected at that location and were successfully stimulated in a closed, microaerophilic reactor, demonstrating that operational management of water and rock to create suboxia can make SeRB more efficient. The fact that reduction proceeds within chert when it is saturated with groundwater under anaerobic conditions, in spite of the inherently low numbers of SeRB that exist in that lithotype, suggests that reduction would proceed within mixed lithology backfills.

The ability of the system to tolerate repeated application of high Se water has not been studied in these experiments, but the availability of excess C and the long term monitoring record at Dry Valley suggest that *in situ* reduction of Se within overburden can be stable over a prolonged period of time as long as O_2 levels remain low and water flux rates (hence, O_2 transport) are minimized. Regardless, the goal of the *in situ* stabilization process described here is not to treat multiple volumes of water in rapid succession, but rather to stabilize Se within the mined overburden, thereby preventing the

need for such treatment. Treatment of multiple volumes of water would require consideration of the rate of C transformation to ensure sufficient C supply.

Due to the experimental complexity in the construction and sampling of reactors that maintain partially saturated, anaerobic conditions at field relevant temperatures, and the scale-dependent character of the O_2 consumption and replenishment processes, it seems more appropriate to further demonstrate the potential for *in situ* reduction of Se using paired laboratory and field experiments. This would allow laboratory experiments to reflect field conditions most realistically. Data characterizing scale-dependent parameters, such as those influencing the O_2 consumption and replenishment processes, can be measured in instrumented meso- or full-scale field facilities and used to address questions requiring greater experimental control in column or flow reactor microcosms. Some aspects of the biogeochemical kinetics and microbial community analysis will require further laboratory study, however, but should be conducted using O_2, C, and other oxidant and reductant flux measurements determined from field investigations.

Microbial Ecology in Mine Waste Facility Design

The understanding of the environmental and financial risk posed by mine waste facilities, and their biogeochemistry, continues to evolve. Thirty years ago, mined lands had only begun to be recognized for their potential to affect water resources. Overburden dumps located merely to limit the cost of removing rock from extraction areas began to undergo active design, first to limit risk of hazard due to geotechnical failure, and then to manage water to prevent erosion and downstream sedimentation. More recently, the geochemistry and dynamics of water and gas flux within these facilities has been

characterized through geochemical testing and modeling, to predict the nature of potential impacts and evaluate alternative management options. Increasingly sophisticated yet primarily abiotic conceptual models of elemental fate and transport drive the understanding of future aqueous chemical conditions and subsequent evaluation of environmental and financial risk. Uncertainty about the site-specific efficacy of available, affordable management options continually challenges mining operations because of the inherent difficulty in predicting chemical and hydrodynamic changes across geospatial and temporal dimensions of such magnitude. Ever more comprehensive, complex, and expensive sampling and modeling efforts reflect the industrial and regulatory commitment to overcome these challenges, but do not necessarily provide better answers. Meanwhile, failure to identify risks associated with facility design (however unintentional) has put the social license of the industry to operate and grow in peril. Cast against growing demand for essential raw materials, and escalating environmental expectations, this situation puts the mining industry between a proverbial “rock and a hard place”. Pressure to produce mineral resources, while maintaining the universal availability of clean water, presents mine operators, regulators, and stakeholders with increasingly difficult choices.

A growing commitment to design and manage mining operations “sustainably” appears to offer a meaningful path forward, based on the principle that “ongoing creation of financial and social wealth should protect the future aesthetic and productive capacity of natural capital for future generations” [16, 17]. This concept recognizes the importance of a triple “bottom-line” decision framework that integrates social, environmental, and economic criteria. Decisions made in this context place a premium on options that can

effectively improve facility design for source control, thereby limiting down-gradient impact. Innovative designs that utilize the capacity of native microbial communities of mined materials, relying on management of available rock and water, to influence the biogeochemical processes that control rates of metal release and sequestration, may well become an important component of future mine design.

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APPENDICES

APPENDIX A

OVERBURDEN AND GROUNDWATER CHARACTERIZATION DATA

IDAHO PHOSPHATE MINE

APPENDIX A

OVERBURDEN AND GROUNDWATER CHARACTERIZATION DATA IDAHO PHOSPHATE MINE

A-1: Groundwater Chemistry for Dry Valley and Smoky Canyon
Table A1-1. Monitoring Well GW7D well water quality data
Table A1-2. Monitoring Well GW7D-2 well water quality data
Table A1-3. Monitoring Well GW11 well water quality data

On CD: Excerpts from Agrium 2007 Groundwater Validation study
Groundwater sampling protocol
To request DVD copies contact your local public or university library to place an interlibrary loan request to Montana State University. Questions call 406-994-3161.

A-2 : 2005 Overburden Characterization Data
Figure A2-1. 2005 Smoky Canyon Sieve Analyses
Figure A2-2. 2005 Dry Valley Sieve Analyses
Table A2-1. Dry Valley GW7D2 archived drill core geochemical data
Table A2-2. 2005 Overburden sample sieve results

On CD: Field sampling notes, photos, protocols from 2005
Energy Labs report – GCMS analysis of extracted hydrocarbon
ALS Chemex reports – Aqua Regia digestion, ICPMS analyses
To request DVD copies contact your local public or university library to place an interlibrary loan request to Montana State University. Questions call 406-994-3161.

A-3: 2006 Field Sampling protocol
Table A3-1. Sample Summary

On CD: Photo log (powerpoint) and Field Notes
TetraTech, 2008 – Geochemical Characterization of Phosphate Mining Report, with well installation details for SCA, SCD, and MEV.
To request DVD copies contact your local public or university library to place an interlibrary loan request to Montana State University. Questions call 406-994-3161.

Table A1-1. Dry Valley Monitoring Well GW-7D

	Station ID	GW-7D	GW-7D	GW-7D	GW-7D	GW-7D
	Sample Date	11/1/1998	9/23/1999	11/7/2000	10/30/2001	10/28/2002
	Field Sample ID	GW-7D	GW-7D	GW-7D	GW-7D	GW-7D
	Lab Sample ID					
Parameter	**Result Units**					
Alkalinity (as CaCO3)	mg/l	210	210	231	241	260
Bicarbonate (as CaCO3)	mg/l	210	210	282	241	260
Hardness (as CaCO3)	mg/l	nr	nr	nr	nr	nr
Calcium, dissolved	mg/l	nr	nr	nr	nr	nr
Calcium, total	mg/l	248	286	266	252	244
Magnesium, dissolved	mg/l	nr	nr	nr	nr	nr
Magnesium, total	mg/l	49.5	60.1	54.7	51.3	57.8
Sodium, dissolved	mg/l	nr	nr	nr	nr	nr
Sodium, total	mg/l	13.2	16.2	16.2	13.7	14.4
Potassium, dissolved	mg/l	nr	nr	nr	nr	nr
Potassium, total	mg/l	1.4	1.4	1.4	1.7	2.2
Chloride	mg/l	8	9	7.7	8.6	7.5
Fluoride	mg/l	2.6	0.2	0.1	0.2	0.3
Sulfate	mg/l	830	790	650	583	574
Phosphorus, total as P	mg/l	0.1	0.3	0.1	0.09	0.1
Nitrate as N, dissolved	mg/l	3.9	3.3	0.29	0.18	<0.1
Nitrite as N, dissolved	mg/l	nr	nr	nr	nr	nr
Nitrate/Nitrite as N, dissolved	mg/l	nr	nr	nr	nr	nr
Nitrogen, ammonia	mg/l	<0.6	1.4	<0.6	<0.6	<0.6
Total Dissolved Solids	mg/l	1300	1400	1280	1230	1210
Total Suspended Solids	mg/l	nr	nr	nr	nr	nr
Iron, total	mg/l	0.073	<0.065	<0.05	<0.05	<0.05
Manganese, total	mg/l	0.56	0.41	0.352	0.382	0.399
Selenium, dissolved	mg/l	0.0081	0.046	0.044	0.025	0.018
Selenium, total	mg/l	nr	0.043	nr	nr	nr
Zinc, dissolved	mg/l	nr	nr	nr	nr	nr
Zinc, total	mg/l	1.3	1.5	1.66	1.46	1.36
Temperature, Field	deg C	3.8	8.7	7	7.3	7.4
E.C., Field, 25C	umhos/cm	nr	1580	1492	1386	1281
pH, Field	s.u.	nr	6.6	7.01	6.57	6.85
Dissolved oxygen	mg/l	nr	nr	nr	nr	nr
ORP, Field	millivolts	nr	nr	nr	nr	nr
Depth to Water	ft	nr	nr	nr	nr	nr
Sum of Anions	meq/l	nr	nr	nr	nr	nr
Sum of Cations	meq/l	nr	nr	nr	nr	nr
Cation-Anion Balance	%	nr	nr	nr	nr	nr
TDS (calculated)	mg/l	nr	nr	nr	nr	nr

nr = not reported

Table A1-1. Dry Valley Monitoring Well GW-7D (continued)

	Station ID	GW-7D	GW-7D	GW-7D	GW-7D	GW-7D
	Sample Date	10/22/2003	10/7/2004	10/14/2005	10/23/2006	10/4/2007
	Field Sample ID	GW-7D	GW-7D	GW-7D	GW-7D	GW-7D
	Lab Sample ID			L53888-05	L60021-07	L65749-03
Parameter	**Result Units**					
Alkalinity (as CaCO3)	mg/l	251	252	263	262	267
Bicarbonate (as CaCO3)	mg/l	251	252	263	262	267
Hardness (as CaCO3)	mg/l	nr	nr	922	877	942
Calcium, dissolved	mg/l	nr	nr	272	257	277
Calcium, total	mg/l	257	210	nr	nr	nr
Magnesium, dissolved	mg/l	nr	nr	59	57.1	60.6
Magnesium, total	mg/l	56.8	58	nr	nr	nr
Sodium, dissolved	mg/l	nr	nr	15.4	14.6	15
Sodium, total	mg/l	14.7	16	nr	nr	nr
Potassium, dissolved	mg/l	nr	nr	1.1	1	1.2
Potassium, total	mg/l	<1	1.2	nr	nr	nr
Chloride	mg/l	7.3	8.76	8	8	9
Fluoride	mg/l	0.2	0.21	<0.1	0.3	0.3
Sulfate	mg/l	581	615	650	670	650
Phosphorus, total as P	mg/l	3.3	<0.05	0.15	0.13	0.14
Nitrate as N, dissolved	mg/l	<0.1	<0.03	<0.02	0.02	<0.02
Nitrite as N, dissolved	mg/l	nr	nr	<0.01	<0.01	<0.01
Nitrate/Nitrite as N, dissolved	mg/l	nr	nr	<0.02	0.02	<0.02
Nitrogen, ammonia	mg/l	<0.6	0.31	<0.05	0.16	<0.05
Total Dissolved Solids	mg/l	1220	1200	1250	1220	1210
Total Suspended Solids	mg/l	nr	nr	<5	<5	<5
Iron, total	mg/l	2.88	0.012	<0.02	<0.02	<0.02
Manganese, total	mg/l	0.417	0.3716	0.424	0.471	0.428
Selenium, dissolved	mg/l	0.026	0.0172	0.026	0.027	0.0214
Selenium, total	mg/l	nr	nr	0.019	0.0247	0.0131
Zinc, dissolved	mg/l	nr	nr	nr	nr	nr
Zinc, total	mg/l	1.62	1.062	1.38	1.41	1.1
Temperature, Field	deg C	8	7.6	8.01	8.15	8.24
E.C., Field, 25C	umhos/cm	1164	1211	1035	1610	1529
pH, Field	s.u.	7.13	7.13	6.64	6.83	6.71
Dissolved oxygen	mg/l	nr	nr	0.43	0.18	0.25
ORP, Field	millivolts	nr	nr	nr	nr	nr
Depth to Water	ft	nr	nr	nr	nr	nr
Sum of Anions	meq/l	nr	nr	19.1	19.6	19.3
Sum of Cations	meq/l	nr	nr	19.1	18.2	19.5
Cation-Anion Balance	%	nr	nr	nr	-3.7	0.5
TDS (calculated)	mg/l	nr	nr	1160	1170	1170

nr = not reported

Table A1-1. Dry Valley Monitoring Well GW-7D (continued)

	Station ID	GW-7D	GW-7D
	Sample Date	9/23/2008	10/12/2009
	Field Sample ID	GW-7D	GW-7D
	Lab Sample ID	L70172-05	L78778-02
Parameter	**Result Units**		
Alkalinity (as CaCO3)	mg/l	262	271
Bicarbonate (as CaCO3)	mg/l	262	271
Hardness (as CaCO3)	mg/l	899	959
Calcium, dissolved	mg/l	261	282
Calcium, total	mg/l	nr	nr
Magnesium, dissolved	mg/l	59.9	61.8
Magnesium, total	mg/l	nr	nr
Sodium, dissolved	mg/l	15	15.3
Sodium, total	mg/l	nr	nr
Potassium, dissolved	mg/l	1.1	1.1
Potassium, total	mg/l	nr	nr
Chloride	mg/l	9	8
Fluoride	mg/l	0.3	0.3
Sulfate	mg/l	570	680
Phosphorus, total as P	mg/l	0.2	0.23
Nitrate as N, dissolved	mg/l	0.04	0.04
Nitrite as N, dissolved	mg/l	<0.01	<0.01
Nitrate/Nitrite as N, dissolved	mg/l	0.04	0.04
Nitrogen, ammonia	mg/l	<0.05	<0.05
Total Dissolved Solids	mg/l	1250	1350
Total Suspended Solids	mg/l	<0.05	<5
Iron, total	mg/l	0.07	<0.02
Manganese, total	mg/l	0.416	0.48
Selenium, dissolved	mg/l	0.0292	0.0417
Selenium, total	mg/l	0.0255	0.0382
Zinc, dissolved	mg/l	nr	nr
Zinc, total	mg/l	1.02	1.32
Temperature, Field	deg C	8.24	7.98
E.C., Field, 25C	umhos/cm	1454	nr
pH, Field	s.u.	6.77	6.62
Dissolved oxygen	mg/l	0.35	0.29
ORP, Field	millivolts	nr	122.8
Depth to Water	ft	nr	108.15
Sum of Anions	meq/l	17.5	19.9
Sum of Cations	meq/l	18.7	19.9
Cation-Anion Balance	%	3.3	nr
TDS (calculated)	mg/l	1070	1210

nr = not reported

Table A1-2. Dry Valley Monitoring Well GW7D-2A/2B

	Station ID	GW-7D-2A	GW-7D-2A	GW-7D-2A	GW-7D-2A	GW-7D-2A
	Sample Date	6/15/2005	10/14/2005	3/3/2006	5/25/2006	10/25/2006
	Field Sample ID	GW-7D-2A	GW-7D-2A	GW-7D-2A	GW-7D-2A	GW-7D-2A
	Lab Sample ID	L51895-03	L53888-06	L55672-02	L56910-01	L60021-09
Parameter	**Result Units**					
pH, Lab	s.u.	nr	nr	7.7	7.8	nr
E.C., Lab	umhos/cm	nr	nr	1580	1480	nr
Alkalinity (as CaCO3)	mg/l	225	231	249	230	232
Bicarbonate (as CaCO3)	mg/l	225	231	249	230	232
Carbonate as CaCO3	mg/l	<2	<2	<2	<2	<2
Hydroxide (as CaCO3)	mg/l	<2	<2	<2	<2	<2
Hardness (as CaCO3)	mg/l	1040	920	969	947	936
Calcium, dissolved	mg/l	302	266	279	272	265
Calcium, total	mg/l	nr	nr	nr	nr	nr
Magnesium, dissolved	mg/l	68.8	62	66	65	66.5
Magnesium, total	mg/l	nr	nr	nr	nr	nr
Sodium, dissolved	mg/l	14.5	13.4	14.5	13.7	13.6
Sodium, total	mg/l	nr	nr	nr	nr	nr
Potassium, dissolved	mg/l	1.3	1.5	1.5	1.4	1.7
Potassium, total	mg/l	nr	nr	nr	nr	nr
Chloride	mg/l	5	7	9	7	7
Fluoride	mg/l	0.4	0.2	0.3	0.2	0.4
Sulfate	mg/l	740	690	680	720	690
Sulfide as S, dissolved	mg/l	nr	nr	<0.02	<0.02	nr
Phosphorus, total as P	mg/l	0.47	0.76	0.47	0.55	0.55
Nitrate as N, dissolved	mg/l	0.11	0.2	nr	nr	0.21
Nitrite as N, dissolved	mg/l	<0.01	<0.01	nr	nr	<0.01
Nitrate/Nitrite as N, dissolved	mg/l	0.11	0.2	0.39	0.14	0.21
Nitrogen, ammonia	mg/l	<0.05	<0.05	<0.05	<0.05	0.12
Total Dissolved Solids	mg/l	1360	1240	1250	1330	1240
Total Suspended Solids	mg/l	<5	8	<5	<5	<5
Iron, dissolved	mg/l	nr	nr	0.07	0.1	nr
Iron, total	mg/l	0.12	0.29	0.17	0.11	0.16
Manganese, dissolved	mg/l	nr	nr	0.421	0.438	nr
Manganese, total	mg/l	0.445	0.394	0.41	0.448	0.468
Selenium, dissolved	mg/l	0.026	0.013	0.013	0.0167	0.0102
Selenium, total	mg/l	0.023	0.009	0.0114	0.018	0.0087
Zinc, dissolved	mg/l	nr	nr	nr	nr	nr
Zinc, total	mg/l	0.34	0.28	0.29	0.28	0.27
Sum of Anions	meq/l	20.2	19.3	19.5	19.9	19.4
Sum of Cations	meq/l	21.4	19	20.1	19.6	19.4
Cation-Anion Balance	%	2.9	-0.8	1.5	-0.8	nr
TDS (calculated)	mg/l	1270	1180	nr	nr	1180

nr = not reported

Table A1-2. Dry Valley Monitoring Well GW7D-2A/2B, continued

	Station ID	GW-7D-2A	GW-7D-2A	GW-7D-2B	GW-7D-2B	GW-7D-2B
	Sample Date	6/14/2007	10/4/2007	6/15/2005	10/14/2005	3/3/2006
	Field Sample ID	GW-7D-2A	GW-7D-2A	GW-7D-2B	GW-7D-2B	GW-7D-2B
	Lab Sample ID	L63345-02	L65750-01	L51895-05	L53888-07	L55672-03
Parameter	**Result Units**					
pH, Lab	s.u.	nr	nr	nr	nr	7.8
E.C., Lab	umhos/cm	nr	nr	nr	nr	1570
Alkalinity (as CaCO3)	mg/l	236	241	88	126	143
Bicarbonate (as CaCO3)	mg/l	236	241	82	126	143
Carbonate as CaCO3	mg/l	<2	<2	6	<2	<2
Hydroxide (as CaCO3)	mg/l	<2	<2	<2	<2	<2
Hardness (as CaCO3)	mg/l	915	975	1160	963	905
Calcium, dissolved	mg/l	264	283	344	283	264
Calcium, total	mg/l	nr	nr	nr	nr	nr
Magnesium, dissolved	mg/l	62	65.1	73.6	62.1	59.5
Magnesium, total	mg/l	nr	nr	nr	nr	nr
Sodium, dissolved	mg/l	13.3	13.4	15.5	14.2	13.9
Sodium, total	mg/l	nr	nr	nr	nr	nr
Potassium, dissolved	mg/l	1.6	1.3	1.3	1.5	1.3
Potassium, total	mg/l	nr	nr	nr	nr	nr
Chloride	mg/l	6	7	5	7	8
Fluoride	mg/l	0.4	0.4	1.8	1.6	1.3
Sulfate	mg/l	710	710	940	830	770
Sulfide as S, dissolved	mg/l	nr	nr	nr	nr	0.02
Phosphorus, total as P	mg/l	0.51	0.54	1.36	1.25	1.51
Nitrate as N, dissolved	mg/l	0.3	0.32	<0.02	<0.02	nr
Nitrite as N, dissolved	mg/l	<0.01	<0.01	<0.01	<0.01	nr
Nitrate/Nitrite as N, dissolved	mg/l	0.3	0.32	<0.02	<0.02	0.04
Nitrogen, ammonia	mg/l	<0.05	<0.05	<0.05	<0.05	0.07
Total Dissolved Solids	mg/l	1280	1300	1550	1360	1310
Total Suspended Solids	mg/l	<5	<5	16	14	12
Iron, dissolved	mg/l	nr	nr	nr	nr	7.23
Iron, total	mg/l	0.22	0.21	10.1	8.72	37.9
Manganese, dissolved	mg/l	nr	nr	nr	nr	1.04
Manganese, total	mg/l	0.47	0.462	1.44	1.26	5.27
Selenium, dissolved	mg/l	0.0213	0.0144	0.001	0.001	<0.001
Selenium, total	mg/l	0.0218	0.0163	<0.001	<0.001	0.0003
Zinc, dissolved	mg/l	nr	nr	nr	nr	nr
Zinc, total	mg/l	0.28	0.3	4.29	3.2	10.9
Sum of Anions	meq/l	19.8	20	21.7	20.2	19.3
Sum of Cations	meq/l	18.9	20.1	24	19.9	19.2
Cation-Anion Balance	%	-2.3	0.2	5	-0.7	-0.3
TDS (calculated)	mg/l	1200	1230	1440	1270	nr

nr = not reported

	Station ID	GW-7D-2B	GW-7D-2B	GW-7D-2B
	Sample Date	5/25/2006	6/12/2007	10/4/2007
	Field Sample ID	GW-7D-2B	GW-7D-2B	GW-7D-2B
	Lab Sample ID	L56906-08	L63345-04	L65750-02
Parameter	**Result Units**			
pH, Lab	s.u.	7.5	nr	nr
E.C., Lab	umhos/cm	1570	nr	nr
Alkalinity (as CaCO3)	mg/l	159	160	158
Bicarbonate (as CaCO3)	mg/l	159	160	158
Carbonate as CaCO3	mg/l	<2	<2	<2
Hydroxide (as CaCO3)	mg/l	<2	<2	<2
Hardness (as CaCO3)	mg/l	993	889	954
Calcium, dissolved	mg/l	287	259	280
Calcium, total	mg/l	nr	nr	nr
Magnesium, dissolved	mg/l	67.1	58.8	61.8
Magnesium, total	mg/l	nr	nr	nr
Sodium, dissolved	mg/l	14.9	13.3	13.6
Sodium, total	mg/l	nr	nr	nr
Potassium, dissolved	mg/l	1.6	1.2	1.4
Potassium, total	mg/l	nr	nr	nr
Chloride	mg/l	8	8	8
Fluoride	mg/l	1.2	1.1	1.1
Sulfate	mg/l	850	790	790
Sulfide as S, dissolved	mg/l	<0.02	nr	nr
Phosphorus, total as P	mg/l	1.38	1.32	1.6
Nitrate as N, dissolved	mg/l	nr	0.03	<0.02
Nitrite as N, dissolved	mg/l	nr	<0.01	<0.01
Nitrate/Nitrite as N, dissolved	mg/l	0.02	0.03	<0.02
Nitrogen, ammonia	mg/l	<0.05	<0.05	<0.05
Total Dissolved Solids	mg/l	1460	1330	1340
Total Suspended Solids	mg/l	16	<5	<5
Iron, dissolved	mg/l	7.26	nr	nr
Iron, total	mg/l	7.33	6.29	7.27
Manganese, dissolved	mg/l	1.06	nr	nr
Manganese, total	mg/l	1.09	0.967	1.06
Selenium, dissolved	mg/l	0.0002	0.0001	<0.0001
Selenium, total	mg/l	0.0007	0.0002	0.0001
Zinc, dissolved	mg/l	nr	nr	nr
Zinc, total	mg/l	1.98	1.51	1.58
Sum of Anions	meq/l	21.3	20.1	20
Sum of Cations	meq/l	21	18.4	19.7
Cation-Anion Balance	%	-0.7	-4.4	-0.8
TDS (calculated)	mg/l	nr	1230	1250

nr = not reported

Table A1-3. Smoky Canyon Groundwater Monitoring Well GW11

	Panel A pit backfill well	10/30/2003	IDL	FLAG	3/24/2005
Alkalinity	mg/L	198	1		
Bicarbonate as CaCO3	mg/L	198	1		
Calcium, Dissolved	mg/L	618	0.0083		
Carbonate as CaCO3	mg/L	1	1		
Cation-Anion Balance	%	-0.31	0.01	B	
Chloride	mg/L	109	5		
Iron, Dissolved	mg/L	0.0045	0.0045		
Magnesium, Dissolved	mg/L	118	0.005		
Manganese, Dissolved	mg/L	0.0108	0.0007		
Nitrate + Nitrite (as N)	mg/L	0.16	0.02	J	
Phosphorus, Total	mg/L	38.1	0.01		
Potassium, Dissolved	mg/L	2.2	0.025	J	
Selenium, Dissolved	mg/L	1.01	0.02		
Selenium, Total	mg/L	0.421	0.02		
Sodium, Dissolved	mg/L	16.6	0.0054		
Sulfate (as SO4)	mg/L	1666	30		
Sum of Anions	meq/L	41.73	0.01		
Sum of Cations	meq/L	41.47	0.01		
TDS	mg/L	2470	10	UJ	
Zinc, Dissolved	mg/L	3.85	0.0018	UJ	
Conductivity at 25° C	µmhos/cm	1691		J	3160
DTW	Feet	100.25		UJ	
DTW	Feet	105.6			103
Iron, Ferrous	mg/L	3.3		J	
Iron, Total	mg/L	3.3			
ORP	mV	157.1		J	
Oxygen, Dissolved	mg/L	5.57		J	5
pH	SU	6.5			5.95
Temperature	C	6.9			4
Turbidity	NTU	1000			

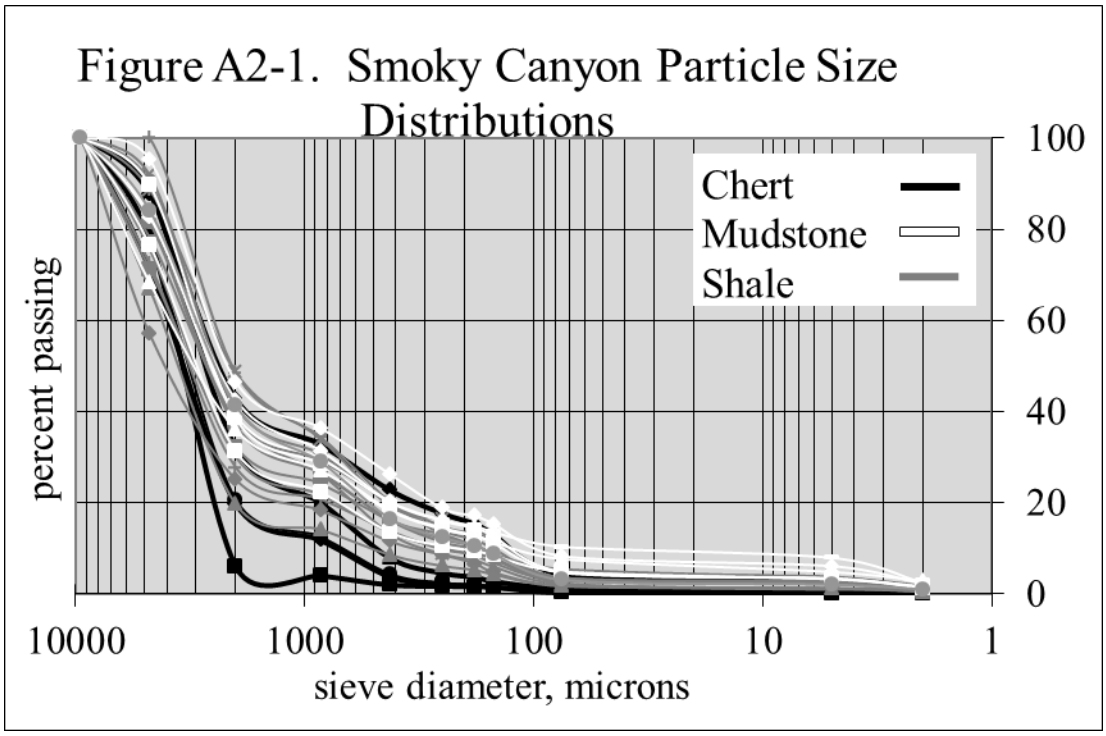


Figure A2-1. Smoky Canyon Particle Size Distributions

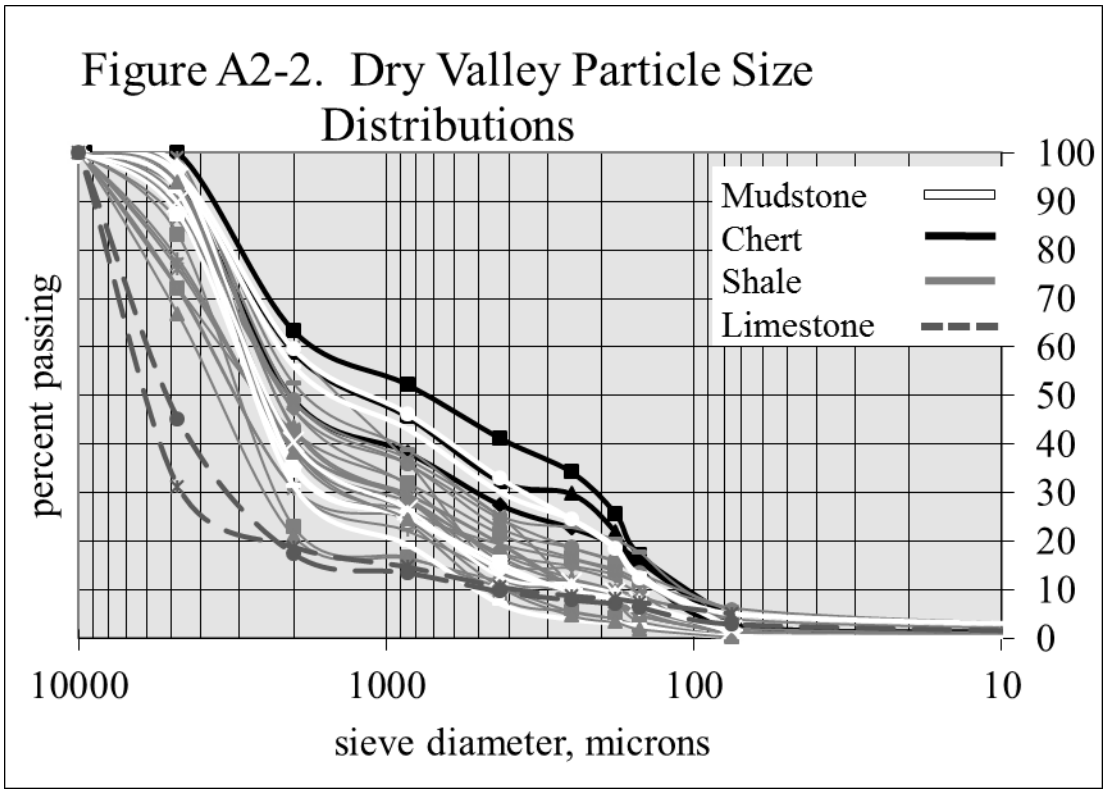


Figure A2-2. Dry Valley Particle Size Distributions

Table A2-1. Dry Valley GW7D2 Drillcore Geochemical Data

Identification	Lith-ology[1]	Clay	Sand	Tex-ture[2]	Organic Carbon	Total Sulfur	Acid/Base Potential	pH	Cadmium	Manganese	Selenium	Cadmium	Manganese	Selenium
								Saturated Paste Extraction				Whole Rock Digestion		
		Wt %	Wt %		Wt %	Wt %	t/kt	s.u.	mk/kg[3]	mk/kg[3]	mk/kg[3]	mk/kg	mk/kg	mk/kg
GW-7D-2-1	Chert	16	50	L	0.37	0.20	417	7.7	< 0.1	< 0.01	0.03	71.8	170	12.8
GW-7D-2-2	HWM	23	44	LS	0.51	0.17	75	7.2	< 0.1	0.1	0.02	59.9	465	11.4
GW-7D-2-3	CWS	6	78	SCL	2.01	0.52	206	7.4	< 0.1	0.3	0.19	8.82	110	34.8
GW-7D-2-4	HWM	11	76	L	0.86	0.39	37	7.2	< 0.1	1.5	0.13	6.22	180	26.8
GW-7D-2-5	Chert	7	80	SL	0.58	0.16	18	6.9	< 0.1	2.0	0.06	2.86	130	9.6
GW-7D-2-6	CWS	11	72	L	0.96	0.34	77	7.3	< 0.1	0.8	0.06	25.2	400	23.4
GW-7D-2-7	CWSr	13	64	SCL	8.25	0.90	81	6.8	< 0.1	< 0.01	1.71	90.2	45	98.4
GW-7D-2-8B	CWSr	11	62	SL	7.26	1.49	50	6.4	< 0.1	0.8	2.70	27.6	95	125.5
GW-7D-2-8G	CWS	15	48	SL	2.76	0.81	56	6.3	< 0.1	0.2	0.43	25.2	145	40.6
GW-7D-2-8R	CWSox	15	58	SL	0.61	0.16	55	7.0	< 0.1	0.2	0.01	21.9	150	14.0
GW-7D-2-9	CWS	9	70	SL	2.14	0.57	407	7.7	< 0.1	0.2	0.14	51.4	275	44.4
GW-7D-2-10	FWM	25	48	L	0.30	0.10	275	7.6	< 0.1	0.1	< 0.01	25.7	180	14.0
GW-7D-2-11	LST	19	51	SL	0.36	0.11	388	7.8	< 0.1	< 0.01	< 0.01	44.0	190	9.8
GW-7D-2-12	Chert	23	52	L	0.16	0.05	91	7.6	< 0.1	< 0.01	< 0.01	31.0	485	16.6

[1] Key to lithologic descriptions: Chert = Rex chert, HWM = hanging wall mud, CWS = center waste shale, CWSr = reduced center waste shale, CWSox = oxidized center waste shale, FWM = footwall mud, LST = Wells/Grandeur limestone.
[2] C = Clay, L = Loam(y), S = Sand(y)
[3] Concentrations expressed as mass of analyte per mass of solid extracted in saturated paste. Mg/kg = milligrams per kilogram.
[4] ALS Chemex method MEMS41, aqua-regia like digestion.

Table A2-2. 2005 Overburden Sample Sieve Analyses.

					gravel		sand						fines					
SUB 1/2 inch			µM	12700	10000	4750	2000	850	425	250	180	150	75	5	2			
				1/2 inch	% pass 0.375in	%pass 4	%pass 10	%pass 20	%pass 40	%pass 60	%pass 80	%pass 100	%pass 200	silt	clay	gravel	sand	silt/ clay
	SCHT1	5	14	100	100	87.9	42.8	32.8	22.8	17.6	15.3	13.1	4.3	3.0	1.3	57	38	4
	SCHT2	5	14	100	100	78.1	6.0	4.0	2.0	1.7	1.6	1.5	0.2	0.1	0.1	94	6	0
	SCHT3	5	1	100	100	88.2	32.0	20.0	7.9	4.6	3.6	2.7	1.2	0.6	0.6	68	31	1
	SCHT4	5	2	100	100	71.4	19.8	11.8	3.8	2.2	1.8	1.4	0.8	0.4	0.4	80	19	1
	SCHT5	5	3	100	100	76.5	20.7	12.6	4.4	2.5	2.0	1.5	0.8	0.4	0.4	79	20	1
AVG	**SCHT**			**100**	**100**	**80.4**	**24.3**	**16.2**	**8.2**	**5.7**	**4.9**	**4.0**	**3.2**	**0.9**	**0.6**	**76**	**21**	**3**
	SCWS1	5	16	100	100	90.5	41.2	30.6	20.0	13.9	11.9	10.0	3.6	2.5	1.1	59	38	4
	SCWS2	5	1	100	100	100.0	48.5	34.4	20.3	13.0	10.6	8.1	2.3	1.0	1.4	51	46	2
	SCWS3	5	23	100	100	75.6	30.1	21.8	13.5	10.1	8.5	6.8	2.9	2.1	0.8	70	27	3
	SCWS4	5	15	100	100	82.0	37.0	26.6	16.3	13.1	10.3	7.6	3.2	2.2	1.0	63	34	3
	SCWS5	5	21	100	100	57.0	25.1	18.3	11.5	8.6	6.6	4.7	1.8	1.3	0.5	75	23	2
	SCWS6	5	3	100	100	71.2	32.2	24.2	16.1	12.1	10.5	9.0	3.5	2.8	0.7	68	29	4
	SCWS7	5	2	100	100	66.9	19.7	14.1	8.5	6.1	5.2	4.3	1.7	1.2	0.5	80	18	2
	SCWS8	5	17	100	100	91.9	39.5	26.4	13.2	8.8	7.4	6.0	2.1	1.2	0.9	61	37	2
	SCWS9	5	21	100	100	88.7	48.6	33.9	19.3	16.3	14.2	12.0	4.9	3.8	1.1	51	44	5
	SCWS10	5	4	100	100	81.5	36.7	26.4	16.2	11.3	10.0	8.6	5.4	3.5	1.9	63	31	5
	SCWS11	5	5	100	100	72.5	27.8	20.8	13.8	9.8	8.8	7.8	3.2	2.3	0.9	72	25	3
	SCWS12	5	22	100	100	78.2	38.2	29.2	20.3	14.8	13.2	11.7	4.9	3.4	1.5	62	33	5
AVG	**SCWS**			**100**	**100**	**79.7**	**35.4**	**25.6**	**15.7**	**11.5**	**9.8**	**8.1**	**3.3**	**2.3**	**1.0**	**65**	**32**	**3**
	SHWM1	5	19	100	100	83.5	39.2	29.7	20.2	16.2	14.9	13.6	10.3	7.9	2.4	61	29	10
	SHWM2	5	9	100	100	95.3	46.5	36.4	26.3	18.8	17.1	15.4	8.3	6.1	2.2	53	38	8
	SHWM3	5	3	100	100	89.7	38.5	28.5	18.5	14.5	12.9	11.3	4.6	3.4	1.3	62	34	5
	SHWM4	5	18	100	100	68.3	36.0	27.1	18.2	14.2	12.8	11.4	7.6	4.8	2.8	64	28	8
	SHWM5	5	13	100	100	76.6	31.2	22.4	13.5	10.5	9.5	8.4	4.9	3.2	1.6	69	26	5
	SHWM6	5	12	100	100	82.7	42.6	31.4	20.2	16.0	14.4	12.8	4.8	3.4	1.5	57	38	5
	SHWM7	5	11	100	100	84.1	41.3	28.9	16.5	12.3	10.6	8.8	3.1	2.0	1.0	59	38	3
AVG	**SHWM**			**100**	**100**	**82.9**	**39.3**	**29.2**	**19.1**	**14.6**	**13.2**	**11.7**	**6.2**	**4.4**	**1.8**	**61**	**33**	**6**
	DCHT1	2.5	5	100	100	93.2	49.1	38.2	27.4	22.7	19.3	15.8	2.1			51	47	2
	DCHT2	150	153	100	100	100.0	63.3	52.2	41.1	34.2	25.6	17.1	3.9			37	59	4

Table A2-2. 2005 Overburden Sample Sieve Analyses, continued

					gravel		sand						fines					
SUB 1/2 inch			µM	12700	10000	4750	2000	850	425	250	180	150	75	5	2			
				1/2 inch	% pass 0.375in	%pass 4	%pass 10	%pass 20	%pass 40	%pass 60	%pass 80	%pass 100	%pass 200	silt	clay	gravel	sand	silt/ clay
	DCHT3	157	160	100	100	95.4	58.9	45.5	32.2	29.7	21.8	14.0	2.7	1.4	1.2	41	56	3
AVG	**DCHT**			**100**	**100**	**96.2**	**57.1**	**45.3**	**33.6**	**28.9**	**22.2**	**15.6**	**2.9**			**43**	**54**	**3**
	DCWS0	36	38	100	100	93.8	38.3	24.4	10.5	4.7	3.3	1.9	0.2			62	38	0
	DCWS1	11	13	100	100	92.6	59.7	36.2	12.7	11.4	10.0	8.6	4.7	1.8	2.9	40	55	5
	DCWS2	13	16	100	100	98.9	43.0	28.7	14.3	10.8	8.9	7.0	1.8			57	41	2
	DCWS3	41	43	100	100	92.1	39.2	23.7	8.2	5.6	3.9	2.3	0.4	0.1	0.3	61	39	0
	DCWS4	43	46	100	100	71.7	30.7	22.1	13.5	11.8	9.2	6.6	2.1	0.9	1.2	69	29	2
	DCWS5	46	48	100	100	88.5	40.9	28.8	16.7	11.2	8.7	6.2	1.4			59	40	1
	DCWS6	48	51	100	100	90.5	39.2	26.3	13.3	10.5	8.0	5.5	1.5	0.6	0.9	61	38	2
	DCWS7	56	58	100	100	93.6	35.1	26.3	17.6	14.9	13.2	11.4	5.8			65	29	6
	DCWS8	60	68	100	100	83.1	22.9	16.7	10.4	5.5	4.1	2.7	0.6			77	22	1
	DCWS9	67	69	100	100	95.6	43.5	28.4	13.3	12.1	9.8	7.4	1.1			56	42	1
	DCWS10	76	79	100	100	77.0	39.9	29.7	19.5	10.8	7.8	4.7	0.9			60	39	1
	DCWS11	76	79	100	100	76.1	39.8	29.5	19.3	10.3	7.4	4.6	1.2			60	39	1
	DCWS12	81	83.5	100	100	96.4	49.1	35.9	22.7	18.6	16.0	13.3	5.6			51	43	6
	DCWS13	96	98.5	100	100	78.1	38.5	28.0	17.4	12.2	8.5	4.8	0.9			61	38	1
	DCWS14	104	106	100	100	93.4	47.1	31.4	15.8	14.4	11.9	9.3	1.3	0.6	0.7	53	46	1
	DCWS15	111	113	100	100	89.7	47.1	35.8	24.6	18.7	15.8	12.9	1.9			53	45	2
	DCWS16	126	128	100	100	97.1	52.5	38.8	25.2	22.8	20.3	17.7	6.3	2.2	4.1	48	46	6
	DCWS17	131	133	100	100	72.1	42.5	32.0	21.4	16.6	14.3	11.9	4.0	1.6	2.4	57	39	4
	DCWS18	141	143	100	100	66.7	21.0	16.4	11.8	9.8	8.9	8.1	4.7			79	16	5
	DCWS19	143	146	100	100	86.2	48.8	36.9	25.0	11.3	7.4	3.5	0.3			51	48	0
	DCWS20	172	174	100	100	72.3	30.9	25.1	19.3	16.2	13.8	11.3	3.9			69	27	4
AVG	**DCWS**			**100**	**100**	**85.6**	**40.6**	**28.8**	**17.1**	**12.8**	**10.4**	**8.0**	**2.5**			**59**	**38**	**3**
	DHWM10	162	167	100	100	96.0	59.5	46.2	32.9	24.5	18.4	12.3	2.1			40	57	2
	DFWM2	167	170	100	100	95.5	63.3	46.9	30.5	27.4	20.1	12.8	1.6	0.7	0.9	37	62	2
	DHWM30	176	178.5	100	100	95.0	56.0	43.0	30.1	24.5	18.8	13.0	5.0	2.3	2.7	44	51	5
	DHWM	7.5	10	100	100	92.2	31.4	19.2	7.0	3.9	3.2	2.5	0.4	0.2	0.2	69	31	0
	DHWM	21	23	100	100	96.7	35.6	25.0	14.4	9.9	8.3	6.8	1.4			64	34	1
	DHWM	83.5	86	100	100	87.3	34.6	25.0	15.4	9.5	8.1	6.8	1.3			65	33	1

Table A2-2. 2005 Overburden Sample Sieve Analyses, continued

					gravel		sand						fines					
SUB 1/2 inch			µM	12700	10000	4750	2000	850	425	250	180	150	75	5	2			
				1/2 inch	% pass 0.375in	%pass 4	%pass 10	%pass 20	%pass 40	%pass 60	%pass 80	%pass 100	%pass 200	silt	clay	gravel	sand	silt/ clay
	DHWM/CHT	26	28	100	100	89.6	40.3	26.5	12.6	11.2	9.3	7.3	1.5			60	39	1
	DMUD			**100**	**100**	**93.2**	**45.8**	**33.1**	**20.4**	**15.8**	**12.3**	**8.8**	**1.9**			**54**	**44**	**2**
	DLST	169	172	100	100	31.2	18.8	14.7	10.5	8.8	8.1	7.4	5.0			81	14	5
	DLST	174	176	100	100	45.1	17.3	13.5	9.6	7.9	7.1	6.4	2.9	1.0	1.9	83	14	3
AVG	**DLST**			**100**	**100**	**38.2**	**18.1**	**14.1**	**10.1**	**8.3**	**7.6**	**6.9**	**4.0**			**82**	**14**	**4**

Table A3-1. 2006 Microbial Geochemistry Sample Summary.

	Smoky Canyon panel D backfill					Smoky Canyon panel A dump					Monsanto Enoch Valley backfill				
	T in hole is		**11.7°C**	**(1 week)**		**T in hole is**		**8.6°C**	**(compl)**						
hole depth	logged lith	DNA samples	T°C sample	interval sampled		logged lith	DNA samples	T°C sample	interval sampled		logged lith	DNA samples	T°C sample	interval sampled	
0	C	cup	nd	3-5	C	soil, C	3,4	7.1			S		nd		
5	C	cht1-3 ?	nd			S	7.5	nd	5-7	S	S		10	5-7	S
10	C		nd			S	10	9.1			M		nd		
15	C		nd			S		nd			M	13,14	nd		
20	C	cht4 ?	nd			S		11.7			M	16	nd		
25	C		nd			S	24				M		nd		
30	C		nd			S		14.5			M		25	32-35	M
35	C	33	nd			S					M	36	nd		
40	C		nd			S		14.9			M	40	nd		
45	C	49.5	nd			S	45				M		nd		
50	M	52.5	14	50-54	M	S		17.3			M	47,50	nd		
55	S		12			S					M	52,58	nd		
60	S	61,62,64	19			S		16.7			S	61	nd		
65	S	69	16			S					S	64	nd		
70	S	70	22			S		17	71-73	S	S		32	73-77	S
75	S	76,79	17	75-77	S	S	74				S	75	nd		
80	S		24.5			S		23.2			S		nd		
85	S	86	24			S	84				S	81	nd		
90	S	94	23.5			S		53.6			S		nd		
95	S		23.4			S	93				S	96,98	nd		
100	S		28.5			S	97	29			S	102,104,	nd		
105	S	109	28.5			S	101, 104				S	108	nd		
110	S		nd			S	108	33.4	113-115	S	S	110, 113	nd		
115	S		nd			S	113, 116				S	117	nd		
120	C	122	27.5	123-125	C	S		28			S	124, 125	nd		
125	S		26.5			C					S		nd		
130	S	130	28			C	130, 132	40	125-127	C	L		nd		
135	S	136	26.2			C	136	68			S		nd		
140	S		82	142-143	S*	C		32			S	143	nd		
145	bedrock	TD	80	143		M	146	36	145-146	M	S	146	32		
150	5,81					bedrock	TD		147		S		54		
155											S	154	35		

Table A3-1. 2006 Microbial Geochemistry Sample Summary, continued

	Smoky Canyon panel D backfill				**Smoky Canyon panel A dump**				**Monsanto Enoch Valley backfill**				
	T in hole is		**11.7°C**	**(1 week)**	**T in hole is**		**8.6°C**	**(compl)**					
hole depth	logged lith	DNA samples	T°C sample	interval sampled	logged lith	DNA samples	T°C sample	interval sampled	logged lith	DNA samples	T°C sample	interval sampled	
160									S	160	38		
165									S		50		
170									S	173	65		
175									L	176	nd		
180									S		35	178-180	M
185									L		nd		
190									S		45		
195									L		nd		
200									S		34		
200									L		54		
205									L		nd		
210									S		nd		
215									L		nd		
220									S		nd		
225									S	226	nd		
230									S	228, 230	nd		
235									S	236	nd		
240									L		nd		
245									L		nd		
250									L		nd		
255									L	258	nd		
260									L		35	261-263	L
265									S		nd		
270									L		nd		
275									S		nd		
280									S		nd		
285									S	288	27	285-287	S
290									S	290	nd		
295									L		nd		
300									L		nd		
305									S	302	nd		
310									S	306	nd		
315									L		nd		

APPENDIX B

MOST PROBABLE NUMBER DATA

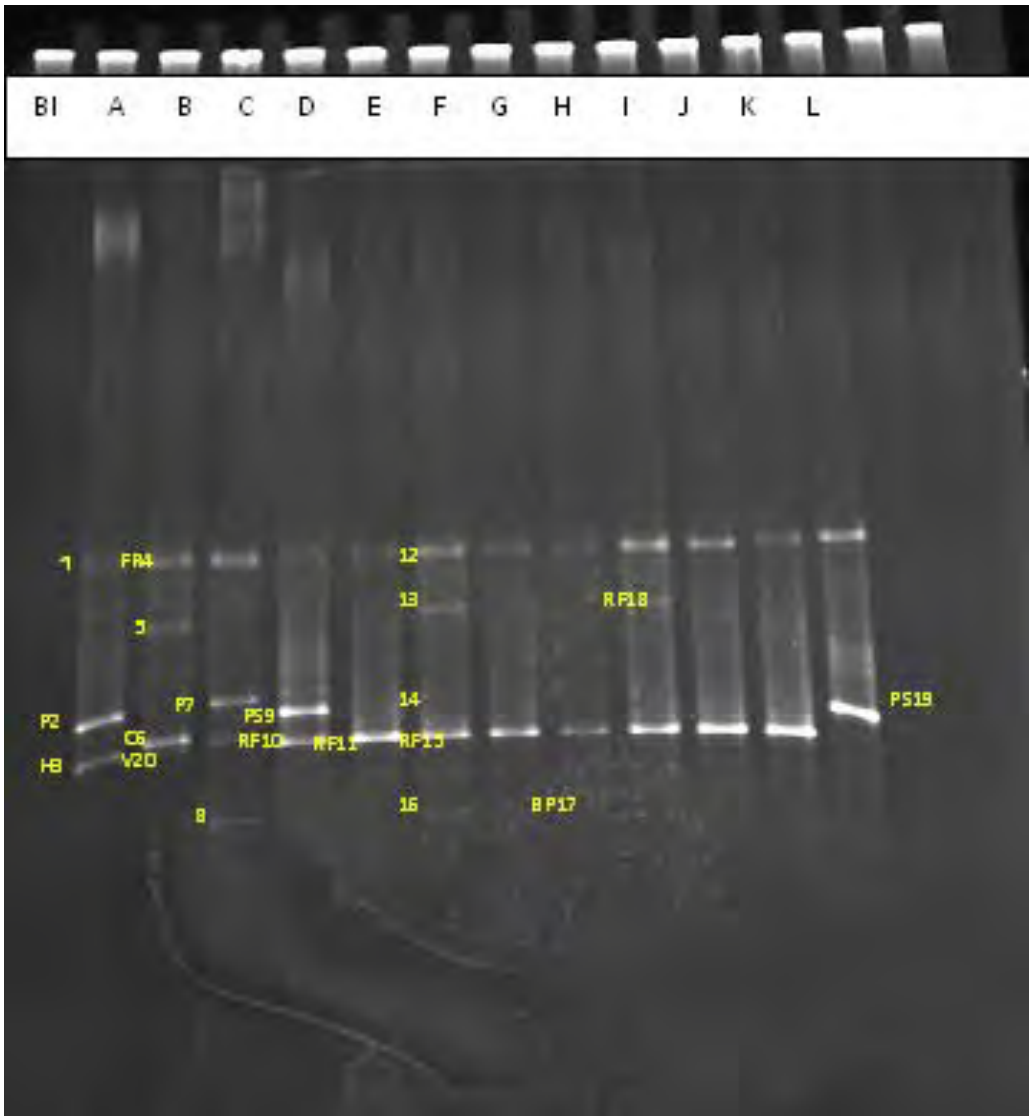
APPENDIX B

MOST PROBABLE NUMBER DATA

B-1: Groundwater Chemistry for Dry Valley and Smoky Canyon
Figure B1-1. DGGE analysis of DNA from MPN Enrichments

Table B1-1. MPN Bottle Roll Extract Selenium Analyses
Table B1-2. MPN Bottle Roll Carbon and Nitrogen Analyses
Table B1-3. Summary of MPN Rankings
Table B1-4. MPN DGGE band DNA sequences
Table B1-5. List of MPN ICP-MS data files on CD

On DVD: ICP-MS data supporting MPN analyses
To request DVD copies contact your local public or university library to place an interlibrary loan request to Montana State University. Questions call 406-994-3161.



Hole ID = Hole_Mine_incubation_dilution_replicate

For example, AS5-A1-4C is from drill hole SCA, Shale at 5 feet of depth, anaerobic incubation replicate 1 – 10-4 diluted replicate C

Bl	blank
A	AS5-A1-4C
B	AS5-A1-5A
C	AS71-A2-3B
D	AS113-A1-3E
E	AS113-A1-7C
F	AS113-A1-8E
G	MS285-A2-7D
H	MS73-A1-6A
I	MS5-A1-5B
J	MS285-N1-8E
K	AM145-N1-3B
L	Mm32

P2, P7	Polaromonas
RF10, RF11, RF15	R. Ferrireducens T118
RF18	Rhodoferax Sp. AsD
FR4	Rhodoferax Fermentans
C6	Comamonadacea
PS9, PS19	Pelosinus
V20	Varivorax
H3	Herminiimonas
BP17	Uncult Betaproteo

Figure B1-1. DGGE analysis of DNA from MPN enrichments.

Table B1-1. Selenium concentration of Rock Extracts Used for MPNs in Experiments.

2006		ppb blank	C125 SCA	SCA S113	SCA M145	SCD M50	SCD S75	SCD C3	SCD C123	MEV S55	MEV M32	MEV M178	MEV L261	MEV S285
4/19	Se74	2.82	na	na	na	na	na	na	na	na	na	na	na	na
4/19	Se76	4.389	na	na	na	na	na	na	na	na	na	na	na	na
4/19	Se77	4.462	na	na	na	na	na	na	na	na	na	na	na	na
4/19	Se78	4.452	na	na	na	na	na	na	na	na	na	na	na	na
4/19	Se80	4.562	na	na	na	na	na	na	na	na	na	na	na	na
4/19	Se82	4.997	na	na	na	na	na	na	na	na	na	na	na	na
4/20	Total Se		2041	2079	2167	1832	1743	2414	2106	2098	2224	2098	1900	2059
4/20	Se IV as Se	ppb	419	371	402	370	404	470	419	414	508	419	380	355
4/20	Se VI as Se	ppb	1622	1708	1765	1462	1339	1944	1687	1684	1716	1679	1520	1704
4/20	SeO4 as Se	mM	0.021	0.022	0.022	0.019	0.017	0.025	0.021	0.021	0.022	0.021	0.019	0.022
4/20	SeO3 as Se	mM	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.006	0.005	0.005	0.004

Extracted at 2.75 : 1 ratio distilled water to rock, filter sterilized 0.22 uM
Contrast with reported maximum SE Idaho field concentration 12 mg/L
na = not analyzed

Table B1-2. MPN Bottle Roll C N Chemistry.

Sample ID	NPOC mg L^{-1}	TN mg L^{-1}	TN peak area	TN corrected mg L^{-1}	TOT C mg L^{-1}	dilution factor	DIC dil factor corrected	NPOC dil factor corrected	TN dil factor corrected
DS 75	23.88	2.946	69.34	3.688	27.6	3.7	13.9	88.36	13.65
DC 3	19.7	2.355	55.44	2.949	20.1	4	1.7	78.80	11.80
DM 50	20.69	2.269	53.42	2.841	21.5	3.4	2.7	70.35	9.66
DC 123	33.88	4.783	112.6	5.989	32.9	2.9	< 0.3	98.25	17.37
AM 145	25.43	3.114	73.3	3.899	31.1	3.9	22.1	99.18	15.21
AC 125	18.22	14.23	334.9	17.814	19.2	4.2	4.1	76.52	74.82
MS 5	24.27	3.529	83.07	4.419	25.2	3.9	3.7	94.65	17.23
MM 32	23.87	2.568	60.45	3.215	25.8	2.5	4.7	59.68	8.04
MM 178	18.53	2.725	64.14	3.412	24.4	4.4	26.0	81.53	15.01
MS 285	23.4	2.511	59.11	3.144	26.3	4.6	13.3	107.64	14.46
ML 261	30.25	3.332	78.43	4.172	29.2	3.2	< 0.3	96.80	13.35

Table B1-3. Summary of MPN Rankings.

Sample ID	Treat-ment	Dilution 10^{-1} abcde	Dilution 10^{-2} abcde	Dilution 10^{-3} abcde	Dilution 10^{-4} abcde	Dilution 10^{-5} abcde	Dilution 10^{-6} abcde	Dilution 10^{-7} abcde	Dilution 10^{-8} abcde	MPN Score	95% c.l.	95% c.l.
ANAEROBIC Most Probable Number Experiments												
GW11	A1	+++++	+++++	+++++	+-++-	-----	-----	+----	+----	16,803	6,451	43,925
GW11	A2	+++++	+++++	+++++	+--+-	+-+--	--+--	-+---	+----	16,730	7,809	35,967
SC-GW7D	A1	+++++	+++++	+++++	+++++	+++++	+++-+	++++-	++++-	837,196	314,433	2,250,783
SC-GW7D	A2	+++++	+++++	+++++	+++++	+++++	+++++	+++++	+----	5,384,114	23,500,511	12,404,417
AS5	A1	+++++	+++++	+++++	-+++-	++++-	-+---	-----	-----	24293	11513	51447
AS5	A2	+++++	+++++	+++++	--+++	--+--	-----	-----	-----	10,676	3883	29,453
AS71	A1	+++++	+++++	+++++	+++++	+++++	+++++	+++++	+++++	10,359,566	5,323,065	20,279,141
AS71	A2	+++++	+++++	-----	-----	-----	-----	-----	-----	230	78	681
AS113	A1	+++++	+++++	+++++	+++++	+++++	--+-+	----+	-----	594,643	206,113	1,723,803
AS113	A2	+++++	+++++	+++++	+++++	-+++-	++++-	-----	+----	260,016	111,469	609,254
AC123	A1	+++++	--+-+	----+	-----	-----	-----	-----	-----	67	22	208
AC123	A2	+++++	---+-	-----	--+--	-----	-----	-----	-----	45	15	136
AM145	A1	+++++	+++++	+++++	-----	-----	-----	-----	-----	2,302	780	6,812
AM145	A2	+++++	+++++	-++++	-----	-----	-----	-----	-----	1,273	497	3,632
DC3	A1	+++++	+++++	--++-	-----	-----	-----	+----	----+	488	154	1553
DC3	A2	++++-	+++++	-----	-----	-----	-----	-----	-----	230	78	681
DM50	A1	+++++	+---+	-----	-----	-----	-----	-----	-----	49	15	155
DM50	A2	+++++	+++++	---+-	-----	-----	-----	-----	-----	327	109	982
DS75	A1	+++++	+++++	-++++	-+---	-+--+	-----	-----	-----	2,576	1,106	6,015
DS75	A2	+++++	+++-+	++-++	+----	-----	-----	-----	-----	334	146	761
DC123	A1	+++++	+++++	-----	-----	-----	----+	-----	-----	311	107	706
DC123	A2	+++++	+++++	-----	-----	-----	-----	-----	-----	230	78	681
MS5	A1	+++++	+++++	+++-+	++++-	-+-+-	-+---	-----	-----	3,165	1,407	7,138,234
MS5	A2	+++++	+++++	+++-+	-++++	+----	-----	-----	-----	3,967	1,807	8,738
MM32	A1	+++++	+++--	+----	-----	-----	-----	-----	-----	107	39	295
MM32	A2	+++++	+++++	-++++	-----	-----	+++--	+----	-----	1,651	635	4,301
MS73	A2	+++++	+++++	+++++	+-+++	-----	-----	-----	-----	756	407	1410
MS73	A1	+++++	+++++	++-++	+-+--	-----	-----	-----	-----	12720	4472	36305
MS285	A1	+++++	+++++	+++++	+++++	+++++	-----	-----	----+	302,742	105,654	871,435
MS285	A2	+++++	+++++	+++++	+++++	+----	-----	+++-+	++---	16461	6342	42876

abcde: 5 replicates
based on calculator using Standard MPN tables
See BAMMPN.xls file in Appendix B.

Table B1-3. Summary of MPN Rankings, continued.

Sample ID	Treat-ment	Dilution 10^{-1} abcde	Dilution 10^{-2} abcde	Dilution 10^{-3} abcde	Dilution 10^{-4} abcde	Dilution 10^{-5} abcde	Dilution 10^{-6} abcde	Dilution 10^{-7} abcde	Dilution 10^{-8} abcde	MPN Score	95% c.l.	95% c.l.
AEROBIC Most Probable Number Experiments												
SC-GW11	01	+++++	++---	+--+-	+-----	----+	-----	-----	-----	4	1	18
SC-GW11	O2	+++++	+++++	++++-	+----	-----	-----	-----	-----	122	79	205
DV-GW7D	02	+++++	+++++	++++-	+----	-----	-----	-----	-----	1,684	649	4,402
DV-GW7D	01	---+-	---++	-----	-----	-----	-----	-+---	-----	8	3	22
AS5	01	+----	-----	-----	-----	-----	-----	-----	-----	2	0.3	14
AS5	02	-+-++	-----	-----	-----	-----	-----	-----	-----	2	0.3	14
AS71	01	-----	-----	-----	-----	-----	-----	-----	-----	0	0	0
AS71	02	-----	-----	-----	-----	-----	-----	-----	-----	0	0	0
AS113	01	+-----	-----	-----	-----	-----	-----	-----	-----	2	0.3	14
AS113	02	-----	-----	-----	-----	-----	-----	-----	-----	0	0	0
AC123	01	+-+--	-----	-----	-----	-----	-----	-----	-----	4	1	18
AC123	02	+--++	+--+-	-----	-----	-----	-----	-----	-----	14	6	35
AM145	01	+++++	---+-	-----	-----	-----	-----	-----	-----	49	15	155
AM145	02	+-+++	+-+-+	----+	-----	-----	--+--	----+	-----	105	38	290
DC3	01	+-+++	-----	-----	-----	-----	-----	-----	-----	13	4	36
DC3	02	+++++	-----	-----	-----	-----	-----	-----	-----	23	8	68
DM50	01	-+--+	-----	-----	-----	-----	-----	-----	-----	4	1	18
DM50	02	-----	-----	-----	-----	-----	-----	-----	-----	0	0	0
DS75	01	+++++	-+-++	-----	-----	-----	-----	-----	-----	78	25	243
DS75	02	+++++	---+-	-----	-----	-----	-----	-----	-----	37	10	98
DC123	01	-----	-----	-----	-----	-----	-----	-----	-----	0	0	0
DC123	02	----+	-----	-----	-----	-----	-----	-----	-----	2	0.3	14
MS5	01	+++-+	---+-	-----	-----	-----	-----	-----	-----	17	6	44
MS5	02	+++++	-+---	---+-	-----	-----	-----	-----	-----	45	15	137
MM32	01	-----	-----	-----	-+---	-+---	-----	-----	-----	4	1	14
MM32	02	+----	-----	-----	-----	-----	++---	-----	-----	1	0	14
MS73	01	+++++	-+++-	-----	-----	-----	-----	-----	-----	230	78	681
MS73	02	+++++	-++++	--+--	-----	+----	-----	-----	+----	210	86	516
MM178	01	+++++	-----	+----	-----	-----	-++--	-++++	+++++	31	10	91
MM178	02	+-+++	-----	--+--	-----	-----	-----	-----	++--+	12	4	36
MS285	01	-++++	-++++	-+++-	----+	-----	-----	-----	-----	61	31	121
MS285	O2	+++++	-++++	++-++	----+	--+-+	----+	-+---	---+-	756	407	1410

abcde: 5 replicates
based on calculator using Standard MPN tables
See BAMMPN.xls file in Appendix B.

Table B1-4. MPN DGGE Band DNA Sequences – July 2009

MPN DGGE bands		ID	Coverage	Identity	in clone library	in sed DGGE
1	Polaromonas sp. UF008	AB426569.1	83%	90%	x	x
2	Polaromonas sp. UF008	AB426569.1	98%	100%	x	x
3	Herminiimonas fonticola	AB512142.1	93%	100%		
4	Rhodoferax fermentans strain FR2	D16212.1	98%	97%	x	
5	Uncultured Betaproteobacteria	CU926297.1	98%	100%		
6	Comamonadaceae bacterium ED16	FJ755906.1	100%	98%		
7	Polaromonas sp. UF008 gene	AB426569.1	100%	100%	x	x
8	Pseudomonas sp. RF-58 16S	GQ205100.1	95%	95%	x	
9	Pelosinus sp. UFO1	EU215386.1	96%	92%	x	x
10	Rhodoferax ferrireducens T118	CP000267.1	99%	99%	x	x
11	Rhodoferax ferrireducens T118	CP000267.1	98%	99%	x	x
12	Uncultured bacterium gene	EU499692.1	99%	96%		
13	Uncultured bacterium gene	AB504940.1	99%	97%		
14	Uncultured bacterium clone 3BH-10FF	EU937983.1	100%	97%		
15	Rhodoferax ferrireducens T118	CP000267.1	100%	97%	x	x
16	Bacterium TG141 gene	AB308367.1	100%	88%		
17	Uncultured beta proteobacterium clone MBMV10	FJ538157.1	99%	97%		
18	Rhodoferax sp. Asd M2A1	FM955857.1	98%	97%	x	x
19	Pelosinus sp. UFO1	EU215386.1	99%	99%	x	x
20	Variovorax paradoxus S110	CP001635.1	100%	99%	x	

Table B1-5. List of MPN ICPMS data files on CD.

File Name (Excel)	Current Location on Kirk CD	Date(s) of analysis	Analytes
101607 Aquant	App B MPN/4_MPN/GW11_7D MPN	10/6/2007	Se 74, 76, 77, 78, 80, and 82
101607 Aquant	App B MPN/4_MPN/GW11_7D MPN	10/6/2007	Se 74, 76, 77, 78, 80, and 82
GW7dC	App B MPN/4_MPN/GW11_7D MPN	7/5, 7/9/2007	Turbid, Sediment, Reduction, None
GW11	App B MPN/4_MPN/GW11_7D MPN	7/5/07 and 7/9/07	Turbid, Sediment, Reduction, None
gw inventory July 2007	App B MPN/4_MPN/GW11_7D MPN	NA	Description of samples collected
MPN Gw7d	App B MPN/4_MPN/GW11_7D MPN	7/13/07, 7/18/2007. 7/20/07, 8/1/07, 8/3/07, 8/6/07, 8/10/07, 8/14/07, 8/20/07, and 8/24/07	Turbid, Sediment, Reduction, None
MPN Gw7D N	App B MPN/4_MPN/GW11_7D MPN	7/13/07, 7/20/07, 8/6/07, and 8/24/07	Turbid, Sediment, Reduction, None
MPN Gw11 N	App B MPN/4_MPN/GW11_7D MPN	7/13/07, 7/20/07, 8/6/07, and 8/24/07	Turbid, Sediment, Reduction, None
MPN gw11	App B MPN/4_MPN/GW11_7D MPN	7/13/07, 7/18/07, 7/20/07, 7/24/07, 8/1/07, 8/3/07, 8/6/07, 8/10/07, 8/14/07, 8/20/07, and 8/24/07	Turbid, Sediment, Reduction, None
070806quant	App B MPN/4_MPN/ICPMS	7/8/2006	Se 74, 76, 77, 78, 80, and 82
092906quant	App B MPN/4_MPN/ICPMS	9/29/2006	Se 74, 76, 77, 78, 80, and 82
092906quant	App B MPN/4_MPN/ICPMS	9/29/2006	Se 74, 76, 77, 78, 80, and 82
093006quant	App B MPN/4_MPN/ICPMS	9/29 and 9/30/06	Se 74, 76, 77, 78, 80, and 82
100406quant	App B MPN/4_MPN/ICPMS	10/4/2006	Se 74, 76, 77, 78, 80, and 82
calib0406	App B MPN/4_MPN/ICPMS	NA	Various dates- Se curves
DCUP	App B MPN/4_MPN/ICPMS	6/26/06, 6/27/06, 7/5/06, 7/10/06, 7/28/06, 7/24/06, and 8/9/06	Turbid, Sediment, Reduction, None
DMup AC	App B MPN/4_MPN/ICPMS	6/27/2006	Turbid, Sediment, Reduction, None
DSUP	App B MPN/4_MPN/ICPMS	6/26/2006	Turbid, Sediment, Reduction, None
extract041606	App B MPN/4_MPN/ICPMS	4/19/2006	Se 78
LA071106quant	App B MPN/4_MPN/ICPMS	7/11/2006	Se 74, 76, 77, 78, 80, and 82
lk010507quant	App B MPN/4_MPN/ICPMS	1/4/2007	Se 74, 76, 77, 78, 80, and 82
lk012307quant	App B MPN/4_MPN/ICPMS	1/26 and 1/27/07	Se 74, 76, 77, 78, 80, and 82
lk012607quant	App B MPN/4_MPN/ICPMS	1/26 and 1/27/07	Se 74, 76, 77, 78, 80, and 82

Table B1-5. List of MPN ICPMS data files on CD, continued.

File Name (Excel)	Current Location on Kirk CD	Date(s) of analysis	Analytes
lk012707quant	App B MPN/4_MPN/ICPMS	1/27/2007	Se 74, 76, 77, 78, 80, and 82
lk012807quant	App B MPN/4_MPN/ICPMS	1/27 and 1/28/07	Se 74, 76, 77, 78, 80, and 82
LK070806quant	App B MPN/4_MPN/ICPMS	7/8/2008	Se 74, 76, 77, 78, 80, and 82
LK071106quant	App B MPN/4_MPN/ICPMS	7/11/2008	Se 74, 76, 77, 78, 80, and 82
LK72006quant	App B MPN/4_MPN/ICPMS	7/20/2006	Se 78 and 82
lk081406quant	App B MPN/4_MPN/ICPMS	8/14 and 8/15/06	Se 74, 76, 77, 78, 80, and 82
lk91206Aquant	App B MPN/4_MPN/ICPMS	9/12 and 9/13/06	Se 74, 76, 77, 78, 80, and 82
LK091206quant	App B MPN/4_MPN/ICPMS	9/12/2006	Se 74, 76, 77, 78, 80, and 82
LK91606Aquant	App B MPN/4_MPN/ICPMS	9/12 and 9/13/06	Se 74, 76, 77, 78, 80, and 82
LK092206quant	App B MPN/4_MPN/ICPMS	9/22/2006	Se 74, 76, 77, 78, 80, and 82
lk092906quant	App B MPN/4_MPN/ICPMS	9/29 and 9/30/06	Se 74, 76, 77, 78, 80, and 82
lk093006quant	App B MPN/4_MPN/ICPMS	9/30/2006	Se 74, 76, 77, 78, 80, and 82
lk100406quant	App B MPN/4_MPN/ICPMS	10/4/2006	Se 74, 76, 77, 78, 80, and 82
lk102306quant	App B MPN/4_MPN/ICPMS	10/22/2006	Se 74, 76, 77, 78, 80, and 82
lk102406quant	App B MPN/4_MPN/ICPMS	10/22 and 10/23/06	Se 74, 76, 77, 78, 80, and 82
lk102606quant	App B MPN/4_MPN/ICPMS	10/26 and 10/27/06	Se 74, 76, 77, 78, 80, and 82
LK102707	App B MPN/4_MPN/ICPMS	NA	List of Samples (no analysis)
lk102806quant	App B MPN/4_MPN/ICPMS	10/28/2006	Se 74, 76, 77, 78, 80, and 82
lk110306quant	App B MPN/4_MPN/ICPMS	11/4/2006	Se 74, 76, 77, 78, 80, and 82
lk110406quant	App B MPN/4_MPN/ICPMS	11/4 and 11/5/06	Se 74, 76, 77, 78, 80, and 82
lk110506quant	App B MPN/4_MPN/ICPMS	11/5/2006	Se 74, 76, 77, 78, 80, and 82
lk111006quant	App B MPN/4_MPN/ICPMS	11/10/2006	Se 74, 76, 77, 78, 80, and 82
lk180906quant	App B MPN/4_MPN/ICPMS	8/9/2006	Se 74, 76, 77, 78, 80, and 82
lk180906quant (2)	App B MPN/4_MPN/ICPMS	NA	Same as lk180906, but with some data copied into new worksheets
lk12110806quant	App B MPN/4_MPN/ICPMS	11/8/2006	Se 74, 76, 77, 78, 80, and 82
lkl1114d6quant	App B MPN/4_MPN/ICPMS	11/14/2006	Se 74, 76, 77, 78, 80, and 82
May282006	App B MPN/4_MPN/ICPMS	NA	Data and figures from may 28 and 29 2006
MPN071506	App B MPN/4_MPN/ICPMS	7/8 and 7/11/06	Se 74, 76, 77, 78, 80, and 82

Table B1-5. List of MPN ICPMS data files on CD, continued.

File Name (Excel)	Current Location on Kirk CD	Date(s) of analysis	Analytes
MPN review	App B MPN/4_MPN/ICPMS	NA	uncertain eactly what this is- appears to be some review of classes of samples.
MPNs saved	App B MPN/4_MPN/ICPMS	NA	Master list of sample IDs?
MPNSUMM	App B MPN/4_MPN/ICPMS	NA	Results sorted with each sample on separate worksheet.
MPNSUMM_A	App B MPN/4_MPN/ICPMS	NA	Results sorted with each sample on separate worksheet.
MPNSUMM_B	App B MPN/4_MPN/ICPMS	NA	Results sorted with each sample on separate worksheet.
MPNSUMM_D	App B MPN/4_MPN/ICPMS	NA	Results sorted with each sample on separate worksheet.
MPNSUMM_M	App B MPN/4_MPN/ICPMS	NA	Results sorted with each sample on separate worksheet.
SCA M145	App B MPN/4_MPN/ICPMS	5/10/2006, 5/15/2006, 5/22/2006, 5/28/2006, 6/26/2006, 7/5/2007, 7/10/2006, 7/18/2006, 7/24/2006	Turbid, Sediment, Reduction, None
SCA M145 (version 1)	App B MPN/4_MPN/ICPMS	5/10/2006, 5/15/2006, 5/22/2006, 5/25/2006, 5/28/2006, 6/26/2006, 7/5/2007, 7/10/2006, 7/18/2006, 7/24/2006	Turbid, Sediment, Reduction, None
Sca S113	App B MPN/4_MPN/ICPMS	5/10/2006, 5/14/2006, 5/15/2006, 5/22/2006, 5/25/2006, 5/26/2006, 5/27/2006, 5/28/2006, 5/31/2006, 6/26/2006, 6/27/2006, 7/5/2007, 7/6/2006, 7/10/2006, 7/18/2006, 7/24/2006	Turbid, Sediment, Reduction, None
Sca S113 (version 1)	App B MPN/4_MPN/ICPMS	5/10/2006, 5/14/2006, 5/15/2006, 5/22/2006, 5/25/2006, 5/26/2006, 5/27/2006, 5/28/2006, 5/31/2006, 6/26/2006, 6/27/2006, 7/5/2007, 7/6/2006, 7/10/2006, 7/18/2006, 7/24/2006	Turbid, Sediment, Reduction, None
SCA Smid	App B MPN/4_MPN/ICPMS	6/26/2006, 7/5/2006, 7/10/2006, 7/18/2006, 7/24/2006, 8/2/2006, 8/7/2006	Turbid, Sediment, Reduction, None
SCA Smid (version 1)	App B MPN/4_MPN/ICPMS	6/26/2006, 7/5/2006, 7/10/2006, 7/18/2006	Turbid, Sediment,

Table B1-5. List of MPN ICPMS data files on CD, continued.

File Name (Excel)	Current Location on Kirk CD	Date(s) of analysis	Analytes
			Reduction, None
SCD Cup	App B MPN/4_MPN/ICPMS	4/26/2006, 4/29/2006, 5/2/2006, 5/5/2006, 5/7/2006, 5/15/2006, 5/22/2006, 5/31/2006, 6/27/2006, 7/5/2006, 7/10/2006, 8/7/2006	Turbid, Sediment, Reduction, None
SCD week 1	App B MPN/4_MPN/ICPMS	NA	Summary of Week 1 data (tables and figures)
SCDCup CO	App B MPN/4_MPN/ICPMS	6/26/2006, 7/5/2006, 7/10/2006, 7/18/2006, 7/24/2006, 7/31/2006	Turbid, Sediment, Reduction, None
070806quant	App B MPN/4_MPN	7/8/2006	Se 74, 76, 77, 78, 80, and 82
BAM-MPN	App B MPN/4_MPN	NA	?
LA071106quant	App B MPN/4_MPN	7/11 and 7/12/2006	Se 74, 76, 77, 78, 80, and 82
LK070806quant	App B MPN/4_MPN	7/8/2006	Se 74, 76, 77, 78, 80, and 82
LK071106quant	App B MPN/4_MPN	7/11/2006	Se 74, 76, 77, 78, 80, and 82
MPN071506	App B MPN/4_MPN	7/8 and 7/11/06	Se 74, 76, 77, 78, 80, and 82
MPNserumchemistry	App B MPN/4_MPN	?	?
rock extracts	App B MPN/4_MPN	?	?
setupinventory	App B MPN/4_MPN	NA	?
setupinventoryv2	App B MPN/4_MPN	NA	?
MPN DGGE library sequences_July2009	App B MPN/4_MPN	NA	?
MPN DNA 5809	App B MPN/4_MPN	2/3/2009, 12/29/2008, 12/5/2009, 1/9/2009, 12/2/2008	?
LK071106quant	App B MPN/4_MPN	7/11 and 7/12/2006	Se 74, 76, 77, 78, 80, and 82
lk1111A6quant	App B MPN/4_MPN/ICPMS/12-20 ICP Files	11/11/2006	Se 74, 76, 77, 78, 80, and 82
lk1111B6quant	App B MPN/4_MPN/ICPMS/12-20 ICP Files	11/11/2006	Se 74, 76, 77, 78, 80, and 82
lk1111C6quant	App B MPN/4_MPN/ICPMS/12-20 ICP Files	11/11/2006	Se 74, 76, 77, 78, 80, and 82
lk1112A6quant	App B MPN/4_MPN/ICPMS/12-20 ICP Files	11/12/2006	Se 74, 76, 77, 78, 80, and 82
lk1112B6quant	App B MPN/4_MPN/ICPMS/12-20 ICP Files	11/12/2006	Se 74, 76, 77, 78, 80, and 82

Table B1-5. List of MPN ICPMS data files on CD, continued.

File Name (Excel)	Current Location on Kirk CD	Date(s) of analysis	Analytes
lk1114A6quant	App B MPN/4_MPN/ICPMS/12-20 ICP Files	11/14/2006	Se 74, 76, 77, 78, 80, and 82
LK070806quant	App B MPN/4_MPN/ICPMS/12-20 ICP Files	7/8/2006	Se 74, 76, 77, 78, 80, and 82
LK72006quant	App B MPN/4_MPN/ICPMS/12-20 ICP Files	7/20/2006	Se 78 and 82
LK91606Aquant	App B MPN/4_MPN/ICPMS/12-20 ICP Files	9/12 and 9/13/06	Se 74, 76, 77, 78, 80, and 82
lk093006quant	App B MPN/4_MPN/ICPMS/12-20 ICP Files	9/30/2006	Se 74, 76, 77, 78, 80, and 82
lkl1114d6quant	App B MPN/4_MPN/ICPMS/12-20 ICP Files	11/14/2006	Se 74, 76, 77, 78, 80, and 82
070809quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	7/8/2006	Se 74, 76, 77, 78, 80, and 82
092906quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	9/29 and 9/30/06	Se 74, 76, 77, 78, 80, and 82
LA071106quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	7/11 and 7/12/2006	Se 74, 76, 77, 78, 80, and 82
lk010507quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	1/4/2007	Se 74, 76, 77, 78, 80, and 82
lk012807quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	1/28 and 1/29/2007	Se 74, 76, 77, 78, 80, and 82
LK070806quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	7/8/2006	Se 74, 76, 77, 78, 80, and 82
LK071106quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	7/11/2006	Se 74, 76, 77, 78, 80, and 82
lk081406quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	8/14 and 8/15/06	Se 74, 76, 77, 78, 80, and 82
lk91206Aquant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	9/12 and 9/13/06	Se 74, 76, 77, 78, 80, and 82
LK092206quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	9/22 and 9/23/2006	Se 74, 76, 77, 78, 80, and 82
LK091206quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	9/12/2006	Se 74, 76, 77, 78, 80, and 82

Table B1-5. List of MPN ICPMS data files on CD, continued.

File Name (Excel)	Current Location on Kirk CD	Date(s) of analysis	Analytes
lk092906quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	9/29 and 9/30/06	Se 74, 76, 77, 78, 80, and 82
lk093006quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	9/30/2006	Se 74, 76, 77, 78, 80, and 82
lk100406quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	10/4/2006	Se 74, 76, 77, 78, 80, and 82
lk102306quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	10/22/2006	Se 74, 76, 77, 78, 80, and 82
lk102406quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	10/22 and 10/23/06	Se 74, 76, 77, 78, 80, and 82
lk102606quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	10/26 and 10/27/06	Se 74, 76, 77, 78, 80, and 82
lk102806quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	10/28/2006	Se 74, 76, 77, 78, 80, and 82
lk110406quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	11/4 and 11/5/06	Se 74, 76, 77, 78, 80, and 82
lk111006quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	11/10/2006	Se 74, 76, 77, 78, 80, and 82
lk180906quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	8/9/2006	Se 74, 76, 77, 78, 80, and 82
lk12110806quant	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	11/8/2006	Se 74, 76, 77, 78, 80, and 82
May282006	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	5/28 and 5/29/2006	?
MPN071506	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	7/8 and 7/11/06	Se 74, 76, 77, 78, 80, and 82
SCD week 1	App B MPN/4_MPN/ICPMS/ICPdata78_711_06	?	?
lk081406quant	App B MPN/4_MPN/MPN2006/Reports52806/LK081406.B	8/14 and 8/15/06	Se 74, 76, 77, 78, 80, and 82
070806quant	App B MPN/4_MPN/MPN2006/NOT FINAL MPNS	7/8/2006	?

Table B1-5. List of MPN ICPMS data files on CD, continued.

File Name (Excel)	Current Location on Kirk CD	Date(s) of analysis	Analytes
070806quant	App B MPN/4_MPN/MPN2006/NOT FINAL MPNS	7/8/2006	?
LA071106quant	App B MPN/4_MPN/MPN2006/NOT FINAL MPNS	7/11 and 7/12/2006	Se 74, 76, 77, 78, 80, and 82
LA071106quant	App B MPN/4_MPN/MPN2006/NOT FINAL MPNS	7/11 and 7/12/2006	Se 74, 76, 77, 78, 80, and 82
LK070806quant	App B MPN/4_MPN/MPN2006/NOT FINAL MPNS	7/8/2006	Se 74, 76, 77, 78, 80, and 82
LK071106quant	App B MPN/4_MPN/MPN2006/NOT FINAL MPNS	7/11/2006	Se 74, 76, 77, 78, 80, and 82
lk100406quant	App B MPN/4_MPN/MPN2006/NOT FINAL MPNS	10/4/2006	Se 74, 76, 77, 78, 80, and 82
LK102707	App B MPN/4_MPN/MPN2006/NOT FINAL MPNS	?	?
lk12110806quant	App B MPN/4_MPN/MPN2006/NOT FINAL MPNS	11/8/2006	Se 74, 76, 77, 78, 80, and 82
AML261	App B MPN/4_MPN/MPN2006/Mpn	7/28/2006	Turbid, Sediment, Reduction, None
AS5 A	App B MPN/4_MPN/MPN2006/Mpn	7/20/2006	Turbid, Sediment, Reduction, None
AS5 O	App B MPN/4_MPN/MPN2006/Mpn	7/28 and 8/8/2006	Turbid, Sediment, Reduction, None
AS113	App B MPN/4_MPN/MPN2006/Mpn	7/28/2006	Turbid, Sediment, Reduction, None
DCUP	App B MPN/4_MPN/MPN2006/Mpn	6/26, 7/5, 7/10, 7/28, 7/24, 8/9/2006	Turbid, Sediment, Reduction, None
Dcup AC	App B MPN/4_MPN/MPN2006/Mpn	7/20 and 7/28/2006	Turbid, Sediment, Reduction, None
DMup A	App B MPN/4_MPN/MPN2006/Mpn	7/20 and 7/28/2006	Turbid, Sediment, Reduction, None
DMup AC	App B MPN/4_MPN/MPN2006/Mpn	6/27/2006	Turbid, Sediment, Reduction, None
DSUP	App B MPN/4_MPN/MPN2006/Mpn	6/26/2006	Turbid, Sediment, Reduction, None
Dsup AC	App B MPN/4_MPN/MPN2006/Mpn	7/20 and 7/28/2006	Turbid, Sediment, Reduction, None

Table B1-5. List of MPN ICPMS data files on CD, continued.

File Name (Excel)	Current Location on Kirk CD	Date(s) of analysis	Analytes
M145 A	App B MPN/4_MPN/MPN2006/Mpn	7/20 and 7/28/2006	Turbid, Sediment, Reduction, None
m145 O1, O2	App B MPN/4_MPN/MPN2006/Mpn	6/28, 7/5, 7/13, 7/19, 7/31, 8/7, 8/15/2006	Turbid, Sediment, Reduction, None
Mev Sup O	App B MPN/4_MPN/MPN2006/Mpn	8/8/2006	Turbid, Sediment, Reduction, None
ML31 Ac	App B MPN/4_MPN/MPN2006/Mpn	7/28/2006	Turbid, Sediment, Reduction, None
ML261 A	App B MPN/4_MPN/MPN2006/Mpn	7/28/2006	Turbid, Sediment, Reduction, None
ML261	App B MPN/4_MPN/MPN2006/Mpn	7/28, 8/8, 8/14/2006	Turbid, Sediment, Reduction, None
MM32 O	App B MPN/4_MPN/MPN2006/Mpn	8/1/2006	Turbid, Sediment, Reduction, None
Mm32	App B MPN/4_MPN/MPN2006/Mpn	7/28/2006	Turbid, Sediment, Reduction, None
mm178 o	App B MPN/4_MPN/MPN2006/Mpn	8/9, 9/14/2006	Turbid, Sediment, Reduction, None
MS5 O	App B MPN/4_MPN/MPN2006/Mpn	7/14/2006	Turbid, Sediment, Reduction, None
MS5	App B MPN/4_MPN/MPN2006/Mpn	Blank	Blank
Ms285 O	App B MPN/4_MPN/MPN2006/Mpn	8/9, 8/24/2006	Turbid, Sediment, Reduction, None
MS 73 O	App B MPN/4_MPN/MPN2006/Mpn	8/8, 8/14/2006	Turbid, Sediment, Reduction, None
SCA C10 (version 1)	App B MPN/4_MPN/MPN2006/Mpn	7/5, 7/10, 7/18, 7/24/2006	Turbid, Sediment, Reduction, None
SCA C10	App B MPN/4_MPN/MPN2006/Mpn	7/5, 7/10, 7/24, 7/30, 8/7, 8/14/2006	Turbid, Sediment, Reduction, None
SCA M145	App B MPN/4_MPN/MPN2006/Mpn	5/10, 5/15, 5/22, 5/25, 5/26, 5/28, 6/26, 7/5, 7/10, 8/1, 8/8, 8/14/2006	Turbid, Sediment, Reduction, None
SCA S113	App B MPN/4_MPN/MPN2006/Mpn	7/5, 7/10, 7/24, 8/2, 8/14/2006	Turbid, Sediment, Reduction, None
SCA Smid	App B MPN/4_MPN/MPN2006/Mpn	6/26, 7/5, 7/10, 7/18, 7/24, 8/2, 8/7, 8/14/2006	Turbid, Sediment, Reduction, None
SCA SUP O1, O2, OC	App B MPN/4_MPN/MPN2006/Mpn	8/8/2006	Turbid, Sediment, Reduction, None

Table B1-5. List of MPN ICPMS data files on CD, continued.

File Name (Excel)	Current Location on Kirk CD	Date(s) of analysis	Analytes
SCD C10, 01, 02	App B MPN/4_MPN/MPN2006/Mpn	4/26, 5/7, 5/15, 6/28, 7/5, 7/13, 7/19, 7/24, 7/31, 8/7, 8/14/2006	Turbid, Sediment, Reduction, None
SCD CLO	App B MPN/4_MPN/MPN2006/Mpn	7/20, 7/24/2006	Turbid, Sediment, Reduction, None
SCD Clo A1, A2	App B MPN/4_MPN/MPN2006/Mpn	7/19/2006	Turbid, Sediment, Reduction, None
SCD MUP 01, 02	App B MPN/4_MPN/MPN2006/Mpn	6/28, 7/5, 7/13, 7/19, 7/25, 7/31, 8/7/2006	Turbid, Sediment, Reduction, None
SCD MUP A	App B MPN/4_MPN/MPN2006/Mpn	7/20, 7/28/2006	Turbid, Sediment, Reduction, None
SCD sup 01, 02	App B MPN/4_MPN/MPN2006/Mpn	4/26, 5/7, 5/23, 6/28, 7/5, 7/13, 7/19, 7/24, 7/31, 8/7/2006	Turbid, Sediment, Reduction, None
lk180906quant	App B MPN/4_MPN/MPN2006/LK180906.B	8/9/2006	Turbid, Sediment, Reduction, None
lk180906quant	App B MPN/4_MPN/MPN2006/ICPdata78_711_06	8/9/2006	Turbid, Sediment, Reduction, None
May282006	App B MPN/4_MPN/MPN2006/ICPdata78_711_06	5/28, 5/29/2006	?
MPN071506	App B MPN/4_MPN/MPN2006/ICPdata78_711_06	7/8, 7/11/2006	Se 74, 76, 77, 78, 80, and 82
SCD week 1	App B MPN/4_MPN/MPN2006/ICPdata78_711_06	?	?
lk180906quant	App B MPN/4_MPN/MPN2006/ICPdata78_711_06/lk180906.B	8/9/2006	Se 74, 76, 77, 78, 80, and 82
092906quant	App B MPN/4_MPN/MPN2006/MPN FINAL DATA	9/30/2006	Se 74, 76, 77, 78, 80, and 82
lk010507quant	App B MPN/4_MPN/MPN2006/MPN FINAL DATA	1/4/2007	Se 74, 76, 77, 78, 80, and 82
lk012307quant	App B MPN/4_MPN/MPN2006/MPN FINAL DATA	1/23, 1/24/2007	Se 74, 76, 77, 78, 80, and 82

Table B1-5. List of MPN ICPMS data files on CD, continued.

File Name (Excel)	Current Location on Kirk CD	Date(s) of analysis	Analytes
lk012707quant	App B MPN/4_MPN/MPN2006/MPN FINAL DATA	1/27/2007	Se 74, 76, 77, 78, 80, and 82
lk012807quant	App B MPN/4_MPN/MPN2006/MPN FINAL DATA	1/28, 1/29/2007	Se 74, 76, 77, 78, 80, and 82
LK091206quant	App B MPN/4_MPN/MPN2006/MPN FINAL DATA	9/12/2006	Se 74, 76, 77, 78, 80, and 82
lk110306quant	App B MPN/4_MPN/MPN2006/MPN FINAL DATA	11/4/2006	Se 74, 76, 77, 78, 80, and 82
lk110506quant	App B MPN/4_MPN/MPN2006/MPN FINAL DATA	11/5/2006	Se 74, 76, 77, 78, 80, and 82
lk111006quant	App B MPN/4_MPN/MPN2006/MPN FINAL DATA	11/10/2006	Se 74, 76, 77, 78, 80, and 82
AML261	App B MPN/4_MPN/MPN by name	7/28/2006	Turbid, Sediment, Reduction, None
AS5 A	App B MPN/4_MPN/MPN by name	7/20/2006	Turbid, Sediment, Reduction, None
AS5 O	App B MPN/4_MPN/MPN by name	7/28, 8/8/2006	Turbid, Sediment, Reduction, None
AS5	App B MPN/4_MPN/MPN by name	10/22, 10/23/2006	Se 74, 76, 77, 78, 80, and 82
AS71	App B MPN/4_MPN/MPN by name	10/28, 11/5/2006	Se 74, 76, 77, 78, 80, and 82
AS113	App B MPN/4_MPN/MPN by name	11/4/2006	Se 74, 76, 77, 78, 80, and 82
DC3	App B MPN/4_MPN/MPN by name	8/9, 8/14, 8/15/2006	Se 74, 76, 77, 78, 80, and 82
DC123	App B MPN/4_MPN/MPN by name	9/29, 9/30, 10/4/2006	Se 74, 76, 77, 78, 80, and 82
DCUP	App B MPN/4_MPN/MPN by name	6/26, 7/5, 7/10, 7/28, 7/24, 8/9/2006	Turbid, Sediment, Reduction, None
Dcup AC	App B MPN/4_MPN/MPN by name	7/20, 7/28/2006	Turbid, Sediment, Reduction, None
DM50	App B MPN/4_MPN/MPN by name	9/12, 9/13, 9/22, 9/23/2006	Turbid, Sediment, Reduction, None
Dmup A	App B MPN/4_MPN/MPN by name	7/20, 7/28/2006	Turbid, Sediment, Reduction, None
Dmup AC	App B MPN/4_MPN/MPN by name	6/27/2006	Turbid, Sediment, Reduction, None
DS75	App B MPN/4_MPN/MPN by name	9/23, 9/29, 9/30/2006	Se 74, 76, 77, 78, 80, and 82
DSUP	App B MPN/4_MPN/MPN by name	6/26/2009	Turbid, Sediment, Reduction, None

Table B1-5. List of MPN ICPMS data files on CD, continued.

File Name (Excel)	Current Location on Kirk CD	Date(s) of analysis	Analytes
Dsup AC	App B MPN/4_MPN/MPN by name	7/20, 7/28/2006	Turbid, Sediment, Reduction, None
M145	App B MPN/4_MPN/MPN by name	7/20, 7/28/2006	Turbid, Sediment, Reduction, None
m145 O1, O2	App B MPN/4_MPN/MPN by name	6/28, 7/5, 7/13, 7/18, 7/25, 7/31, 8/7, 8/15/2006	Turbid, Sediment, Reduction, None
Mev Sup O	App B MPN/4_MPN/MPN by name	8/8/2006	Turbid, Sediment, Reduction, None
ML31 Ac	App B MPN/4_MPN/MPN by name	7/28/2006	Turbid, Sediment, Reduction, None
ML261 A	App B MPN/4_MPN/MPN by name	7/28/2006	Turbid, Sediment, Reduction, None
ML261	App B MPN/4_MPN/MPN by name	1/24, 1/26, 1/27, 1/28, 1/29/2007	Se 74, 76, 77, 78, 80, and 82
MM32 O	App B MPN/4_MPN/MPN by name	7/31, 8/1/2006	Turbid, Sediment, Reduction, None
MM32	App B MPN/4_MPN/MPN by name	1/4, 1/23, 1/24, 1/27/2007	Se 74, 76, 77, 78, 80, and 82
mm178 o	App B MPN/4_MPN/MPN by name	8/9, 8/14/2006	Turbid, Sediment, Reduction, None
MS5 O	App B MPN/4_MPN/MPN by name	7/14, 8/9, 8/14/2006	Turbid, Sediment, Reduction, None
MS5	App B MPN/4_MPN/MPN by name	11/4, 11/5/2006	Se 74, 76, 77, 78, 80, and 82
MS73	App B MPN/4_MPN/MPN by name	1/27/2007	Se 74, 76, 77, 78, 80, and 82
Ms285 O	App B MPN/4_MPN/MPN by name	8/9, 8/14, 8/24/2006	Turbid, Sediment, Reduction, None
MS285	App B MPN/4_MPN/MPN by name	11/10/2006	Se 74, 76, 77, 78, 80, and 82
MS 73 O	App B MPN/4_MPN/MPN by name	8/8, 8/14/2006	Turbid, Sediment, Reduction, None
SCA C10 (version 1)	App B MPN/4_MPN/MPN by name	7/5, 7/10, 7/18, 7/24/2006	Turbid, Sediment, Reduction, None
SCA C10	App B MPN/4_MPN/MPN by name	7/5, 7/10, 7/18, 7/24, 7/30, 8/1, 8/7, 8/14, 8/24/2006	Turbid, Sediment, Reduction, None
SCA M145	App B MPN/4_MPN/MPN by name	5/15, 5/25, 5/26, 5/28, 6/26, 7/5, 7/10, 8/1, 8/10, 8/14/2006	Turbid, Sediment, Reduction, None
Sca S113	App B MPN/4_MPN/MPN by name	5/26, 5/31, 6/27, 7/5, 7/6, 7/10, 7/18, 7/24, 8/2, 8/8, 8/14/2006	Turbid, Sediment, Reduction, None

Table B1-5. List of MPN ICPMS data files on CD, continued.

File Name (Excel)	Current Location on Kirk CD	Date(s) of analysis	Analytes
SCA Smid	App B MPN/4_MPN/MPN by name	6/26, 7/5, 7/10, 7/18, 7/24, 8/2, 8/7, 8/14, 8/15/2006	Turbid, Sediment, Reduction, None
SCA SUP O1, O2, OC	App B MPN/4_MPN/MPN by name	8/1, 8/8/2006	Turbid, Sediment, Reduction, None
SCD C10, 01, 02	App B MPN/4_MPN/MPN by name	4/26, 5/7, 5/15, 6/28, 7/5, 7/13, 7/19, 7/24, 7/31, 8/7, 8/14/2006	Turbid, Sediment, Reduction, None
SCD CLO	App B MPN/4_MPN/MPN by name	7/20, 7/24/2006	Turbid, Sediment, Reduction, None
SCD Clo A1, A2	App B MPN/4_MPN/MPN by name	7/19, 7/20/2006	Turbid, Sediment, Reduction, None
SCD MUP 01, 02	App B MPN/4_MPN/MPN by name	5/7, 5/10, 5/17, 5/20, 5/23, 5/31, 6/28, 7/5, 7/13, 7/19, 7/25, 7/31, 8/7/2006	Turbid, Sediment, Reduction, None
SCD MUP A	App B MPN/4_MPN/MPN by name	7/20, 7/28/2006	Turbid, Sediment, Reduction, None
SCD sup O1, O2	App B MPN/4_MPN/MPN by name	4/26, 5/7, 5/23, 6/28, 7/5, 7/13, 7/19, 7/24, 7/31, 8/7	Turbid, Sediment, Reduction, None
AML261	App B MPN/4_MPN/MPN by name/Mpn	7/26/2006	Turbid, Sediment, Reduction, None
AS5 A	App B MPN/4_MPN/MPN by name/Mpn	7/20/2006	Turbid, Sediment, Reduction, None
AS5 O	App B MPN/4_MPN/MPN by name/Mpn	7/28, 8/8/2006	Turbid, Sediment, Reduction, None
AS113	App B MPN/4_MPN/MPN by name/Mpn	7/28/2006	Turbid, Sediment, Reduction, None
DCUP	App B MPN/4_MPN/MPN by name/Mpn	6/26, 6/27, 7/5, 7/10, 7/28, 7/24, 8/9/2006	Turbid, Sediment, Reduction, None
Dcup AC	App B MPN/4_MPN/MPN by name/Mpn	7/20, 7/28/2006	Turbid, Sediment, Reduction, None
Dmup A	App B MPN/4_MPN/MPN by name/Mpn	7/20, 7/28/2006	Turbid, Sediment, Reduction, None
Dmup AC	App B MPN/4_MPN/MPN by name/Mpn	6/27/2006	Turbid, Sediment, Reduction, None
DSUP	App B MPN/4_MPN/MPN by name/Mpn	6/26/2006	Turbid, Sediment, Reduction, None

Table B1-5. List of MPN ICPMS data files on CD, continued.

File Name (Excel)	Current Location on Kirk CD	Date(s) of analysis	Analytes
Dsup AC	App B MPN/4_MPN/MPN by name/Mpn	7/20, 7/28/2006	Turbid, Sediment, Reduction, None
M145 A	App B MPN/4_MPN/MPN by name/Mpn	7/20, 7/28/2006	Turbid, Sediment, Reduction, None
m145 O1, O2	App B MPN/4_MPN/MPN by name/Mpn	6/28, 7/5, 7/13, 7/18, 7/25, 7/31, 8/7, 8/15/2006	Turbid, Sediment, Reduction, None
Mev Sup O	App B MPN/4_MPN/MPN by name/Mpn	8/8/2006	Turbid, Sediment, Reduction, None
ML31 Ac	App B MPN/4_MPN/MPN by name/Mpn	7/28/2006	Turbid, Sediment, Reduction, None
ML261 A	App B MPN/4_MPN/MPN by name/Mpn	7/28/2006	Turbid, Sediment, Reduction, None
ML261	App B MPN/4_MPN/MPN by name/Mpn	7/28, 8/1, 8/8, 8/14, 2006	Turbid, Sediment, Reduction, None
MM32 O	App B MPN/4_MPN/MPN by name/Mpn	7/31, 8/1/2006	Turbid, Sediment, Reduction, None
MM32	App B MPN/4_MPN/MPN by name/Mpn	7/28/2006	Turbid, Sediment, Reduction, None
mm178 o	App B MPN/4_MPN/MPN by name/Mpn	8/9, 9/14/2006	Turbid, Sediment, Reduction, None
MS5 O	App B MPN/4_MPN/MPN by name/Mpn	7/14, 8/9, 8/14/2006	Turbid, Sediment, Reduction, None
MS5	App B MPN/4_MPN/MPN by name/Mpn	Blank	Blank
Ms285 O	App B MPN/4_MPN/MPN by name/Mpn	8/9, 8/14, 8/24/2006	Turbid, Sediment, Reduction, None
MS 73 O	App B MPN/4_MPN/MPN by name/Mpn	8/8, 8/14/2006	Turbid, Sediment, Reduction, None
SCA C10 (version 1)	App B MPN/4_MPN/MPN by name/Mpn	7/5, 7/10, 7/18, 7/24/2006	Turbid, Sediment, Reduction, None
SCA C10	App B MPN/4_MPN/MPN by name/Mpn	7/5, 7/10, 7/18, 7/24/2006	Turbid, Sediment, Reduction, None
SCA M145	App B MPN/4_MPN/MPN by name/Mpn	5/15, 5/25, 5/26, 5/28, 6/26, 7/5, 7/10, 8/1, 8/8, 8/14/2006	Turbid, Sediment, Reduction, None

Table B1-5. List of MPN ICPMS data files on CD, continued.

File Name (Excel)	Current Location on Kirk CD	Date(s) of analysis	Analytes
Sca S113	App B MPN/4_MPN/MPN by name/Mpn	5/26, 5/31, 6/27, 7/5, 7/10, 7/18, 7/24, 8/2, 8/8, 8/14/2006	Turbid, Sediment, Reduction, None
SCA Smid	App B MPN/4_MPN/MPN by name/Mpn	6/26, 7/5, 7/10, 7/18, 7/24, 8/2, 8/7, 8/14/2006	Turbid, Sediment, Reduction, None
SCA SUP O1, O2, OC	App B MPN/4_MPN/MPN by name/Mpn	8/1, 8/8/2006	Turbid, Sediment, Reduction, None
SCD C10, 01, 02	App B MPN/4_MPN/MPN by name/Mpn	4/26, 5/7, 5/15, 6/28, 7/5, 7/13, 7/19, 7/24, 7/31, 8/7, 8/14/2006	Turbid, Sediment, Reduction, None
SCD CLO	App B MPN/4_MPN/MPN by name/Mpn	7/20, 7/24/2006	Turbid, Sediment, Reduction, None
SCD Clo A1, A2	App B MPN/4_MPN/MPN by name/Mpn	7/19, 7/20/2006	Turbid, Sediment, Reduction, None
SCD MUP 01, 02	App B MPN/4_MPN/MPN by name/Mpn	5/7, 5/10, 5/17, 5/20, 5/23, 5/31, 6/28, 7/5, 7/13, 7/19, 7/25, 7/31, 8/7/2006	Turbid, Sediment, Reduction, None
SCD MUP A	App B MPN/4_MPN/MPN by name/Mpn	7/20, 7/28/2006	Turbid, Sediment, Reduction, None
SCD sup O1, O2	App B MPN/4_MPN/MPN by name/Mpn	4/26, 5/7, 5/23, 6/28, 7/5, 7/13, 7/19, 7/24, 7/31, 8/7/2006	Turbid, Sediment, Reduction, None
070806quant	App B MPN/4_MPN/MPNs	7/8/2006	Se 74, 76, 77, 78, 80, and 82
100406quant	App B MPN/4_MPN/MPNs	10/4/2006	Se 74, 76, 77, 78, 80, and 82
AML261	App B MPN/4_MPN/MPNs	7/28/2006	Turbid, Sediment, Reduction, None
AS5A	App B MPN/4_MPN/MPNs	7/20, 8/22/2006	Turbid, Sediment, Reduction, None
AS5O	App B MPN/4_MPN/MPNs	7/28, 8/8, 9/7, 9/8/2006	Turbid, Sediment, Reduction, None
AS113	App B MPN/4_MPN/MPNs	7/28, 8/22/2006	Turbid, Sediment, Reduction, None
A-S5O	App B MPN/4_MPN/MPNs	7/28, 8/8/2006	Turbid, Sediment, Reduction, None
D-CUP	App B MPN/4_MPN/MPNs	6/26, 6/27, 6/28, 7/5, 7/10, 7/28, 7/31, 8/14, 8/21, 9/1, 9/7, 9/14, 9/22/2006	Turbid, Sediment, Reduction, None
DcupAC	App B MPN/4_MPN/MPNs	7/20, 7/28, 8/22/2006	Turbid, Sediment, Reduction, None
DmupA	App B MPN/4_MPN/MPNs	7/20, 7/28, 8/22/2006	Turbid, Sediment, Reduction, None

Table B1-5. List of MPN ICPMS data files on CD, continued.

File Name (Excel)	Current Location on Kirk CD	Date(s) of analysis	Analytes
Ds-Pac	App B MPN/4_MPN/MPNs	7/20, 7/28/2006	Turbid, Sediment, Reduction, None
DsupAC	App B MPN/4_MPN/MPNs	7/20, 7/28/2006	Turbid, Sediment, Reduction, None
LA071106quant	App B MPN/4_MPN/MPNs	7/11, 7/12/2006	Se 74, 76, 77, 78, 80, and 82
lk010507quant	App B MPN/4_MPN/MPNs	1/4/2007	Se 74, 76, 77, 78, 80, and 82
lk012807quant	App B MPN/4_MPN/MPNs	1/28, 1/29/2007	Se 74, 76, 77, 78, 80, and 82
LK070806quant	App B MPN/4_MPN/MPNs	7/8/2006	Se 74, 76, 77, 78, 80, and 82
LK071106quant	App B MPN/4_MPN/MPNs	7/11/2006	Se 74, 76, 77, 78, 80, and 82
lk081406quant	App B MPN/4_MPN/MPNs	8/14, 8/15/2006	Se 74, 76, 77, 78, 80, and 82
lk91206Aquant	App B MPN/4_MPN/MPNs	9/12, 9/13/2006	Se 74, 76, 77, 78, 80, and 82
LK091206quant	App B MPN/4_MPN/MPNs	9/12/2006	Se 74, 76, 77, 78, 80, and 82
LK092206quant	App B MPN/4_MPN/MPNs	9/22, 9/23/2006	Se 74, 76, 77, 78, 80, and 82
lk092906quant	App B MPN/4_MPN/MPNs	9/29, 9/30/2006	Se 74, 76, 77, 78, 80, and 82
lk093006quant	App B MPN/4_MPN/MPNs	9/30/2006	Se 74, 76, 77, 78, 80, and 82
lk100406quant	App B MPN/4_MPN/MPNs	10/4/2006	Se 74, 76, 77, 78, 80, and 82
lk102306quant	App B MPN/4_MPN/MPNs	10/22/2006	Se 74, 76, 77, 78, 80, and 82
lk102406quant	App B MPN/4_MPN/MPNs	10/22, 10/23/2006	Se 74, 76, 77, 78, 80, and 82
lk102606quant	App B MPN/4_MPN/MPNs	10/26, 10/27/2006	Se 74, 76, 77, 78, 80, and 82
LK102707	App B MPN/4_MPN/MPNs	?	?
lk102806quant	App B MPN/4_MPN/MPNs	10/28/2006	Se 74, 76, 77, 78, 80, and 82
lk110306quant	App B MPN/4_MPN/MPNs	11/4/2006	Se 74, 76, 77, 78, 80, and 82
lk110406quant	App B MPN/4_MPN/MPNs	11/4, 11/5/2006	Se 74, 76, 77, 78, 80, and 82
lk110506quant	App B MPN/4_MPN/MPNs	?	Se 80, 82
lk111006quant	App B MPN/4_MPN/MPNs	11/10/2006	Se 74, 76, 77, 78, 80, and 82
lk180906quant	App B MPN/4_MPN/MPNs	8/9/2006	Se 74, 76, 77, 78, 80, and 82
lk12110806quant	App B MPN/4_MPN/MPNs	11/8/2006	Se 74, 76, 77, 78, 80, and 82
M145A	App B MPN/4_MPN/MPNs	7/20, 7/28, 8/22/2006	Turbid, Sediment, Reduction, None
m145O1, O2	App B MPN/4_MPN/MPNs	6/28, 7/5, 7/13, 7/19, 7/31, 8/7, 8/15, 8/21, 9/1, 9/7, 9/14, 9/22/2006	Turbid, Sediment, Reduction, None
May282006	App B MPN/4_MPN/MPNs	5/28, 5/29/2006	?
MevSupO	App B MPN/4_MPN/MPNs	8/8, 8/21, 9/1, 9/22/2006	Turbid, Sediment, Reduction, None

Table B1-5. List of MPN ICPMS data files on CD, continued.

File Name (Excel)	Current Location on Kirk CD	Date(s) of analysis	Analytes
ML31 Ac	App B MPN/4_MPN/MPNs	7/28/2006	Turbid, Sediment, Reduction, None
ML261	App B MPN/4_MPN/MPNs	7/28, 8/8, 8/14, 8/21, 9/1, 9/8, 9/14, 9/22/2006	Turbid, Sediment, Reduction, None
Ml261A	App B MPN/4_MPN/MPNs	7/28, 8/22/2006	Turbid, Sediment, Reduction, None
Mm32	App B MPN/4_MPN/MPNs	7/28, 8/22/2006	Turbid, Sediment, Reduction, None
MM320	App B MPN/4_MPN/MPNs	8/1, 8/14, 9/1, 9/8, 9/14, 9/22/2006	Turbid, Sediment, Reduction, None
mm178 o	App B MPN/4_MPN/MPNs	8/9, 8/14, 9/1, 9/7, 9/14, 9/22/2006	Turbid, Sediment, Reduction, None
mm-178o	App B MPN/4_MPN/MPNs	8/9, 8/14, 8/21/2006	Turbid, Sediment, Reduction, None
MS5	App B MPN/4_MPN/MPNs	8/22/2006	Turbid, Sediment, Reduction, None
MS5O	App B MPN/4_MPN/MPNs	8/9, 8/14, 8/21, 9/1, 9/7/2006	Turbid, Sediment, Reduction, None
MS73O	App B MPN/4_MPN/MPNs	8/8, 8/14, 8/21, 9/1, 9/8, 9/14, 9/22/2006	Turbid, Sediment, Reduction, None
MS285A	App B MPN/4_MPN/MPNs	8/22/2006	Turbid, Sediment, Reduction, None
Ms285O	App B MPN/4_MPN/MPNs	8/9, 8/14, 8/21, 9/7, 9/8, 9/14, 9/22/2006	Turbid, Sediment, Reduction, None
Ms-285O	App B MPN/4_MPN/MPNs	8/9, 8/14, 8/24, 9/1, 9/8/2006	Turbid, Sediment, Reduction, None
SCAC10(version1)	App B MPN/4_MPN/MPNs	7/5, 7/10, 7/18, 7/24/2006	Turbid, Sediment, Reduction, None
SCAC10	App B MPN/4_MPN/MPNs	7/5, 7/10, 7/24, 7/30, 8/7, 8/14, 9/8, 9/14/2006	Turbid, Sediment, Reduction, None
SCA-C10	App B MPN/4_MPN/MPNs	7/5, 7/10, 7/18, 7/24, 8/1, 8/21, 8/24, 9/14/2006	Turbid, Sediment, Reduction, None
SCAM145	App B MPN/4_MPN/MPNs	5/15, 5/25, 5/26, 5/28, 6/26, 7/5, 7/10, 8/1, 8/8, 8/14, 8/21, 9/1, 9/7, 9/14, 9/22/2006	Turbid, Sediment, Reduction, None
ScaS113	App B MPN/4_MPN/MPNs	5/26, 5/31, 6/27, 7/5, 7/10, 7/18, 7/24, 8/2, 8/8, 8/14, 8/21, 9/1, 9/8, 9/22/2006	Turbid, Sediment, Reduction, None
SCASmid	App B MPN/4_MPN/MPNs	6/26, 7/5, 7/10, 7/18, 7/24, 8/2, 8/7, 8/14, 9/8, 9/14, 9/22/2006	Turbid, Sediment, Reduction, None

Table B1-5. List of MPN ICPMS data files on CD, continued.

File Name (Excel)	Current Location on Kirk CD	Date(s) of analysis	Analytes
SCASUPO1, O2, OC	App B MPN/4_MPN/MPNs	8/1, 8/14, 8/21, 9/1, 9/7, 9/14, 9/22/2006	Turbid, Sediment, Reduction, None
SCDC1002,02	App B MPN/4_MPN/MPNs	6/28, 7/5, 7/13, 7/19, 7/25, 7/31, 8/7, 8/14, 8/21, 9/1, 9/7, 9/14, 9/22/2006	Turbid, Sediment, Reduction, None
SCDCLO	App B MPN/4_MPN/MPNs	7/20, 7/24/2006	Turbid, Sediment, Reduction, None
SCDCloA1, A2	App B MPN/4_MPN/MPNs	7/19, 7/22/2006	Turbid, Sediment, Reduction, None
SCDMUP01.02	App B MPN/4_MPN/MPNs	5/7, 5/10, 5/17, 5/20, 5/23, 5/31, 6/28, 7/5, 7/13, 7/19, 7/25, 7/31, 8/7, 8/14, 8/21, 9/1, 9/7, 9/14, 9/22/2006	Turbid, Sediment, Reduction, None
SCDMUPA	App B MPN/4_MPN/MPNs	7/20, 7/28/2006	Turbid, Sediment, Reduction, None
SCDsupO1, O2	App B MPN/4_MPN/MPNs	6/28, 7/5, 7/13, 7/19, 7/25, 7/31, 8/7, 8/14, 8/21, 9/1, 9/7, 9/14, 9/22/2006	Turbid, Sediment, Reduction, None
Setupinventory	App B MPN/4_MPN/MPNs	?	?
AML261	App B MPN/Mpn	7/28/2006	Turbid, Sediment, Reduction, None
AS5 A	App B MPN/Mpn	7/20/2006	Turbid, Sediment, Reduction, None
AS5 O	App B MPN/Mpn	7/28, 8/8/2006	Turbid, Sediment, Reduction, None
AS113	App B MPN/Mpn	7/28/2006	Turbid, Sediment, Reduction, None
DCUP	App B MPN/Mpn	6/26, 7/5, 7/10, 7/28, 7/24, 8/9/2006	Turbid, Sediment, Reduction, None
Dcup AC	App B MPN/Mpn	7/20, 7/28/2006	Turbid, Sediment, Reduction, None
Dmup A	App B MPN/Mpn	7/20, 7/28/2006	Turbid, Sediment, Reduction, None
Dmup AC	App B MPN/Mpn	6/27/2006	Turbid, Sediment, Reduction, None
DSUP	App B MPN/Mpn	6/26/2006	Turbid, Sediment, Reduction, None
Dsup AC	App B MPN/Mpn	7/20, 7/28/2006	Turbid, Sediment, Reduction, None
M145 A	App B MPN/Mpn	7/20, 7/28/2006	Turbid, Sediment, Reduction, None

Table B1-5. List of MPN ICPMS data files on CD, continued.

File Name (Excel)	Current Location on Kirk CD	Date(s) of analysis	Analytes
m145 O1, O2	App B MPN/Mpn	6/28, 7/5, 7/13, 7/19, 7/31, 8/7, 8/15/2006	Turbid, Sediment, Reduction, None
Mev Sup O	App B MPN/Mpn	8/8/2006	Turbid, Sediment, Reduction, None
ML31 Ac	App B MPN/Mpn	7/28/2006	Turbid, Sediment, Reduction, None
Ml261	App B MPN/Mpn	7/28/2006	Turbid, Sediment, Reduction, None
MM32 O	App B MPN/Mpn	8/21/2006	Turbid, Sediment, Reduction, None
Mm 32	App B MPN/Mpn	7/28/2006	Turbid, Sediment, Reduction, None
mm178 o	App B MPN/Mpn	8/9, 9/14/2006	Turbid, Sediment, Reduction, None
MS5 O	App B MPN/Mpn	7/14, 8/9, 8/14/2006	Turbid, Sediment, Reduction, None
MS5	App B MPN/Mpn	Blank	Blank
Ms285 O	App B MPN/Mpn	8/9, 8/14, 8/24/2006	Turbid, Sediment, Reduction, None
MS 73 O	App B MPN/Mpn	8/8, 8/14/2006	Turbid, Sediment, Reduction, None
SCA C10 (version 1)	App B MPN/Mpn	7/5, 7/10, 7/18, 7/24/2006	Turbid, Sediment, Reduction, None
SCA C10	App B MPN/Mpn	7/5, 7/10, 7/18, 7/24, 8/1, 8/24/2006	Turbid, Sediment, Reduction, None
SCA M145	App B MPN/Mpn	5/15, 5/25, 5/26, 5/28, 6/26, 7/5, 7/10, 8/1, 8/8, 8/14/2006	Turbid, Sediment, Reduction, None
Sca S113	App B MPN/Mpn	5/26, 5/31, 6/27, 7/5, 7/10, 7/18, 7/24, 8/2, 8/8, 8/14/2006	Turbid, Sediment, Reduction, None
SCA Smid	App B MPN/Mpn	6/26, 7/5, 7/10, 7/18, 7/24, 8/2, 8/7, 8/14/2006	Turbid, Sediment, Reduction, None
SCA SUP O1, O2, OC	App B MPN/Mpn	8/1, 8/8/2006	Turbid, Sediment, Reduction, None
SCD C10, 01, 02	App B MPN/Mpn	4/26, 5/7, 5/15, 6/28, 7/5, 7/13, 7/19, 7/24, 7/31, 8/7, 8/14/2006	Turbid, Sediment, Reduction, None
SCD CLO	App B MPN/Mpn	7/20, 7/24/2006	Turbid, Sediment, Reduction, None
SCD Clo A1, A2	App B MPN/Mpn	7/19, 7/20/2006	Turbid, Sediment,

Table B1-5. List of MPN ICPMS data files on CD, continued.

File Name (Excel)	Current Location on Kirk CD	Date(s) of analysis	Analytes
			Reduction, None
SCD MUP 01, 02	App B MPN/Mpn	5/7, 5/10, 5/17, 5/20, 5/23, 5/31, 6/28, 7/5, 7/13, 7/19, 7/25, 7/31, 8/7/2006	Turbid, Sediment, Reduction, None
SCD MUP A	App B MPN/Mpn	7/20, 7/28/2006	Turbid, Sediment, Reduction, None
SCD sup O1, O2	App B MPN/Mpn	4/26, 5/7, 5/23, 6/28, 7/5, 7/13, 7/19, 7/24, 7/31, 8/7/2006	
MPN extract041606	App B MPN/	no file	
rock extracts	App B MPN/	no file	

APPENDIX C

MICROBIAL COMMUNITY CHARACTERIZATION DATA

APPENDIX C

MICROBIAL COMMUNITY CHARACTERIZATION DATA

C-1: Isolates

Table C1-1. Dry Valley GW7D Enrichment Series 1, March 2007
Table C1-2. Dry Valley GW7D Enrichment Series 2, June 2007
Table C1-3. Enrichment Results for Drilling Shale Samples
Table C1-4. Summary of Unique Isolates from this SE Idaho Se Study

On DVD:

C1.1 Isolation
Methods (multiple files with notes, photos)
Results (spreadsheets)

C1.2 Enrichments
Results (photographs)

To request DVD copies contact your local public or university library to place an interlibrary loan request to Montana State University. Questions call 406-994-3161.

C-2: On DVD: DNA Sequence Data

To request DVD copies contact your local public or university library to place an interlibrary loan request to Montana State University. Questions call 406-994-3161.

C-3: Clone Libraries

Figure C3.1 As113 Archaeal Rarefaction Curve for Clone Library
Figure C3.2 As71 Bacterial Rarefaction Curve for Clone Library
Figure C3.3 As113 Bacterial Rarefaction Curve for Clone Library
Table C3-1. Smoky Canyon Sample AS71 Bacterial Clone Library
Table C3-2. Smoky Canyon Sample AS113 Bacterial Clone Library

On DVD:

C3.1 Clone Library Methods and Data
C3.2 Bioinformatics

To request DVD copies contact your local public or university library to place an interlibrary loan request to Montana State University. Questions call 406-994-3161.

C-4: On DVD: DGGE Images

To request DVD copies contact your local public or university library to place an interlibrary loan request to Montana State University. Questions call 406-994-3161.

Table C1-1. Dry Valley GW7D Enrichment Series 1

Dry Valley GW7D Enrichments March 2007
GW diluted serially with filter sterilized GW
Specific electron donor, 3 concentrations

Carbon	Slide	SeO4, mM	-1	-2	-3	-4
NATC	1	0.2	+oj/b	+oj/b	-	-
NATC	1	2	+oj	+oj	++r	+oj
NATC	1	10	+++	++r	++r	+oj
LACT	2	0.2	+b	+	++	+
LACT	2	2	++ro	++r	+lo	++r
LACT	2	10	+oj	+oj	+lo	++ro
ACET	3	0.2	+b	+b	+r	+oj
ACET	3	2	+++r	+++r	++oj	+oj
ACET	3	10	++oj	++oj	+oj	++ro
PYRUV	4	0.2	+pb	+ob	+b	+rb
PYRUV	4	2	broken	+++r	+r	r
PYRUV	4	10	++r	+r	+r	+r
H2/CO2	5	0.2	+oj	+oj	++oj	+oj
H2/CO2	5	2	++oj	+oj	+oj	++++red
H2/CO2	5	10	++oj	++++red	++++red	++oj

- indicates negative for selenate reduction
+ indicates positive for selenate reduction.

		r	*red*
		ro	*red orange*
+	*slight color*	*lo*	*light orange*
++	*mod color*	*b*	*black*
+++	*strong color*	*oj*	*orange*
++++	*str color, turbid*	*rb*	*red black*

*Note: See attached *.ppt slides 1-5*

Table C1-2. Dry Valley GW7D Enrichment Series 2

Dry Valley GW7D Enrichments June 2007

GW diluted serially with filter sterilized GW
Specific electron donor, 3 concentrations

E donor	Slide	SeO4, mM	-1	-2	-3	-4
NATC	6	0.2	+oj/b	-	+oj	-
NATC	6	2	+oj	+ojb	+oj	-
NATC	6	10	++oj	+++oj	++oj	+oj
LACT	7	0.2	++oj	+oj	+roj	++roj
LACT	7	2	+++r	+oj	+oj	+roj
LACT	7	10	+oj	+++oj	+oj	++oj
ACET	8	0.2	++OJ	+r	+p	+p
ACET	8	2	++r	+r	+oj	++oj
ACET	8	10	+++roj	++oj	++oj	++oj
PYRUV	9	0.2	+pb	+ob	+b	+r
PYRUV	9	2	+oj	+oj	+r	+oj
PYRUV	9	10	++r	+r	+r	+r
H2/CO2	10	0.2	+ojb	+oj	+oj	+oj
H2/CO2	10	2	++ojr	+oj	+oj	+oj
H2/CO2	10	10	++oj	+++oj	++++oj	++++oj

- indicates negative for selenate reduction
+ indicates positive for selenate reduction.

		r	*red*
+	*slight color*	*ro*	*red orange*
++	*mod color*	*lo*	*light oj*
+++	*strong color*	*b*	*black*
++++	*str color, turbid*	*oj*	*orange*
		rb	*red black*

*Note: See attached *.ppt slides 5-10*

Table C1-3. Enrichment Results for Drilling Shale Samples.

live shale enrichments started 2/27/07
filter sterilized groundwater with selenate added, 5 mM;
C cocktail (native C, acetate, pyruvate, lactate) 1.25 mM each Σ5 Mm
nitrogen purged headspace with half of volume replaced with 1:1 H2 and CO2.
incubated at 11oC

				2/27/07 enr					4-12-07 dil
ID	Slide*	Mine	Depth	-1	-2	-3	-4	-5	redilute
MS5	11	Monsanto Enoch Valley	5	?	+	+	+	-	+3 1:10, 1:100
MS73	12	Monsanto Enoch Valley	73	?	+	+	+	+	+4 1:100
MS285	13	Monsanto Enoch Valley	285	?	+	+	-/+	-	+3 1:10, 1:100
AS5	14	Smoky Canyon A Dump	5	?	?	+	-	-	+3 1:100
AS71	15	Smoky Canyon A Dump	71	?	+	-	-	-	+3 1:10
AS113	16	Smoky Canyon A Dump	113	?	?	+	+	-	+3 1:10, 1:100
DS75	17	Smoky Canyon D Backfill	75	?	?	-	-	-	

control
control no C added

? Indicates cannot be determined visually
+ indicates positive for selenate reduction, - indicates negative for selenate

Table C1-4. List of Unique Isolates Obtained for this Project in SE Idaho.

Tag	Genus	Se4 Grw	Se4 Rdn	Se6 Grw	Se6 Rdn	Source
A34	Dechloromonas					from H. Knotek-Smith Smoky Canyon sample
L33	Dechloromonas					from H. Knotek-Smith Smoky Canyon sample
L35	Dechloromonas					from H. Knotek-Smith Smoky Canyon sample
LK1	Dechloromonas	+++	red	+++		from Lisa 120728
E51Y	Dechloromonas	+++	slight	+++		from variably weathered shales collected by Lisa in 2005
CMS	Dechloromonas					from variably weathered shales collected by Lisa in 2005
R. ferrireducens		+	weak	++		from Lovley lab
AV1a	Sphingomonas	+++	dk red	+++	none	from Lisa pure culture plate sent to me ("Acidovorax")
AV3	Oleomonas	+++	red	+++	none	from Lisa pure culture plate sent to me ("Acidovorax")
RF3	Sphingobium	+++	med red	+++	none	from Lisa pure culture plate sent to me ("Rhodoferax ferrireducens")
CNT5	Pseudomonas	+++	lt red	+++	none	from Lisa 100768
E5-4a	Cellulomonas	+++	dk red	+++	none	from variably weathered shales collected by Lisa in 2005
DV1a	Cellulomonas	+++	some	+++	none	soil from Dry Valley reclaimed site; collected Aug 2008
DV1b	Nocardiodes	+	weak	++	none	same as above
DV4	Sporosarcina	+	weak	+++	none	same as above
DV5a	Cellulomonas	+++	lt red	+++	none	same as above
DV6	Arthrobacter	+++	dk red	+++	none	same as above
DV9	Arthro. chlorophenolicus	+++	dk red	+++	none	same as above
		*growth determined on R2A plates; aerobic incubation				
P93(pl) C6A	Stenotrophomonas maltophilia					from Lisa's liquid cultures labeled "P93(plate)"--mailed to me
P93(pl) C6B	Stenotrophomonas maltophilia					same as above
P93(pl) C7	Stenotrophomonas maltophilia					same as above
P93(pl) C8	Rahnella					same as above
P93-0 A1	Pseudomonas					from Lisa's liquid culture labeled P93sub0--mailed to me
P93-0 A2	Pseudomonas					same as above
RF1 B3	Stenotrophomonas maltophilia					from Lisa plate of "Rhodoferax ferrireducens" pure culture-sent to UI
RF1 B3a	Stenotrophomonas maltophilia					same as above
RF1 B4a	Rahnella					same as above
RF1 B4b	Rahnella					same as above

Table C1-4. List of Unique Isolates Obtained for this Project in SE Idaho, continued.

Tag	Genus	Se4 Grw	Se4 Rdn	Se6 Grw	Se6 Rdn	Source
RF1 B4c	Rahnella					same as above
RF1 B5	Stenotrophomonas maltophilia					same as above
AS113N1 7E1	Rhodoferax ferrireducens					from MPN culture Lisa sent-AS113N17E
AS113N1 7E2	(Actinobacterium)					from MPN culture Lisa sent-AS113N17E
AS113N1 7E3	Rhodoferax ferrireducens					from MPN culture Lisa sent-AS113N17E
AS113N1 7E4b	Cellulomonas					from MPN culture Lisa sent-AS113N17E
AS113N1 7E4c	Cellulomonas					from MPN culture Lisa sent-AS113N18A
AS113N2 8A1A	Rhodoferax					from MPN culture Lisa sent-AS113N18A
AS113N2 8A1B	Rhodoferax					from MPN culture Lisa sent-AS113N18A
AS113N2 8A2	Actinobacteria					from MPN culture Lisa sent-AS113N18A
AS113N2 8A4a	Cellulomonas					from MPN culture Lisa sent-AS113N18A
AS113N2 8A4c	Cellulomonas					from MPN culture Lisa sent-AS113N18A
L2A1 X	Stenotrophomonas					from Lisa 120929
L2A1 Y	Microbacterium					from Lisa 120929
L2E	Stenotrophomonas					from Lisa 120929
L2P	Stenotrophomonas					from Lisa 120929
L5C1-A	Stenotrophomonas					from Lisa 100768
L5C1-B	Stenotrophomonas					from Lisa 100768
L5C2	Stenotrophomonas					from Lisa 100768
L5E1	Stenotrophomonas					from Lisa 100768
L5R	Microbacterium					from Lisa 100768
L12H	Stenotrophomonas					from Lisa 100715
L12N	Microbacterium					from Lisa 100715
L12F	Sphingobium yanoikuyae					from Lisa 100715
L12W	Rhodopseudomonas palustris					from Lisa 100715
L12J2-A	Brevundimonas					from Lisa 100715
L12J2-B	Brevundimonas					from Lisa 100715

Figure C3-1. Rarefaction curve for archaeal library of AS113.

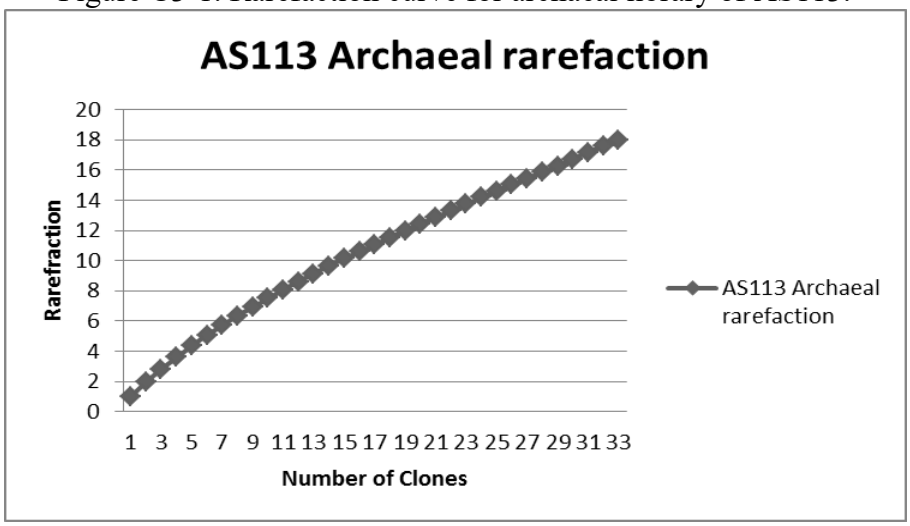


Figure C3-2. Rarefaction Curve for bacterial library of AS71.

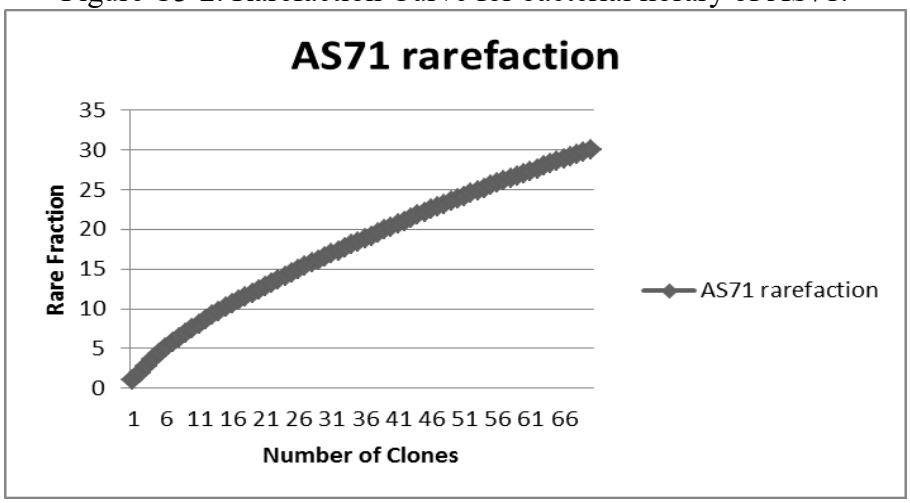


Figure C3-3. Rarefaction Curve for bacterial library of AS113.

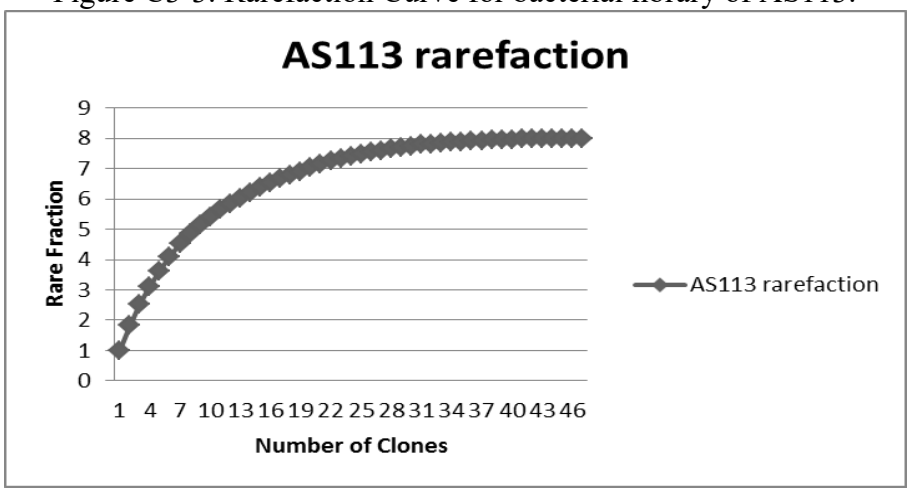


Table C3-1. Smoky Canyon Sample AS71 Clone Library.

Sample ID	Accession	Description	Max Score	Total Score	Query Coverage	E Value	Max Ident
AS71-7	AB166733.1	Thiothrix NKBI-C gene for 16S rRNA, partial sequence	564	564	96%	1.00E-157	95%
AS71-46	AB426569.1	Polaromonas UF008 gene for 16S ribosomal RNA, partial sequence	647	647	96%	0	100%
AS71-56	AB426569.1	Polaromonas UF008 gene for 16S ribosomal RNA, partial sequence	647	647	96%	0.00E+00	100%
AS71-59	AB426569.1	Polaromonas UF008 gene for 16S ribosomal RNA, partial sequence	647	647	96%	0.00E+00	100%
AS71-61	AB426569.1	Polaromonas UF008 gene for 16S ribosomal RNA, partial sequence	647	647	100%	0.00E+00	100%
AS71-63	AB426569.1	Polaromonas UF008 gene for 16S ribosomal RNA, partial sequence	641	641	96%	0.00E+00	99%
AS71-69	AB426569.1	Polaromonas UF008 gene for 16S ribosomal RNA, partial sequence	647	647	97%	0.00E+00	100%
AS71-73	AB426569.1	Polaromonas UF008 gene for 16S ribosomal RNA, partial sequence	647	647	96%	0.00E+00	100%
AS71-74	AB426569.1	Polaromonas UF008 gene for 16S ribosomal RNA, partial sequence	647	647	96%	0.00E+00	100%
AS71-2	AF293013.1	Uncultured Green Bay ferromanganous micronodule bacterium MNA3 16S ribosomal RNA gene, partial sequence	616	616	96%	3.00E-173	98%
AS71-28	AF293013.1	Uncultured Green Bay ferromanganous micronodule bacterium MNA3 16S ribosomal RNA gene, partial sequence	610	610	96%	1.00E-171	98%
AS71-39	AF482687.1	Myxobacterium KC 16S ribosomal RNA gene, partial sequence	625	625	100%	5.00E-176	98%
AS71-43	AF482687.1	Myxobacterium KC 16S ribosomal RNA gene, partial sequence	619	619	100%	2.00E-174	98%
AS71-47	AF482687.1	Myxobacterium KC 16S ribosomal RNA gene, partial sequence	619	619	100%	2.00E-174	100%
AS71-49	AF482687.1	Myxobacterium KC 16S ribosomal RNA gene, partial sequence	630	630	100%	1.00E-177	99%
AS71-50	AF482687.1	Myxobacterium KC 16S ribosomal RNA gene, partial sequence	614	614	100%	1.00E-172	98%
AS71-51	AF482687.1	Myxobacterium KC 16S ribosomal RNA gene, partial sequence	625	625	100%	5.00E-176	98%
AS71-53	AF482687.1	Myxobacterium KC 16S ribosomal RNA gene, partial sequence	630	630	100%	1.00E-177	99%
AS71-54	AF482687.1	Myxobacterium KC 16S ribosomal RNA gene, partial sequence	625	625	100%	5.00E-176	98%
AS71-57	AF482687.1	Myxobacterium KC 16S ribosomal RNA gene, partial sequence	630	630	100%	1.00E-177	99%
AS71-60	AF482687.1	Myxobacterium KC 16S ribosomal RNA gene, partial sequence	627	627	100%	1.00E-176	98%
AS71-68	AF482687.1	Myxobacterium KC 16S ribosomal RNA gene, partial sequence	630	630	100%	1.00E-177	99%
AS71-71	AF482687.1	Myxobacterium KC 16S ribosomal RNA gene, partial sequence	630	630	100%	1.00E-177	99%
AS71-25	AJ414655.1	Methylobacter tundripaludum 16S ribosomal RNA, type strain SV96T	532	532	96%	3.00E-148	92%
AS71-58	AM934876.1	Uncultured Nitrospirales bacterium partial 16S rRNA gene, clone AMJC5	636	636	96%	2.00E-179	99%
AS71-9	AM935618.1	Uncultured Desulfuromonadaceae bacterium partial 16S rRNA gene, clone AMDF7	617	617	92%	9.00E-174	100%
AS71-67	AM936431.1	Uncultured Rhodobacterales bacterium partial 16S rRNA gene, clone CM38A2	608	608	100%	5.00E-171	98%
AS71-62	AM990839.1	Arenimonas MOLA 64 partial 16S rRNA gene, culture collection MOLA:64	619	619	100%	0.00E+00	98%
AS71-10	AY491577.1	Uncultured bacterium clone oc34 16S ribosomal RNA gene, partial sequence	593	593	96%	1.00E-166	96%
AS71-19	CP000698.1	Geobacter uraniireducens Rf4, complete genome	621	1243	96%	7.00E-175	98%
AS71-17	D84568.2	Pseudomonas S21027 gene for 16S ribosomal RNA, partial sequence	448	448	90%	1.00E-122	87%
AS71-38	D84645.2	Variovorax S24561 gene for 16S ribosomal RNA, partial sequence	641	641	96%	0	99%
AS71-44	D84645.2	Variovorax S24561 gene for 16S ribosomal RNA, partial sequence	641	641	96%	0	100%

Table C3-1. Smoky Canyon Sample AS71 Clone Library, continued.

Sample ID	Accession	Description	Max Score	Total Score	Query Coverage	E Value	Max Ident
AS71-45	D84645.2	Variovorax S24561 gene for 16S ribosomal RNA, partial sequence	641	641	96%	0.00E+00	100%
AS71-3	DQ378240.1	Uncultured soil bacterium clone M20_Pitesti 16S ribosomal RNA gene, complete sequence	599	599	96%	3.00E-168	97%
AS71-37	DQ489306.1	Aquabacterium hongkongensis strain CA5 16S ribosomal RNA gene, partial sequence	532	532	85%	4.00E-148	91%
AS71-34	DQ837236.1	Uncultured candidate division OP10 bacterium clone 49S1_2B_10 16S ribosomal RNA gene, partial sequence	619	619	96%	2.00E-174	99%
AS71-13	DQ837241.1	Uncultured Firmicutes bacterium clone 49S1_2B_19 16S ribosomal RNA gene, partial sequence	608	608	96%	5.00E-171	97%
AS71-72	EF220453.1	Uncultured actinobacterium clone FI-2F_H01 16S gene, partial sequence	623	623	96%	2.00E-175	98%
AS71-24	EF467590.1	Uncultured bacterium clone lka50b 16S ribosomal RNA gene, partial sequence	643	643	96%	0	99%
AS71-16	EU194898.1	Methylobacillus M8 16S ribosomal RNA gene, partial sequence	167	281	50%	4.00E-38	98%
AS71-65	EU215386.1	Pelosinus UFO1 16S ribosomal RNA pseudogene, complete sequence	652	652	100%	0.00E+00	100%
AS71-55	EU266783.1	Uncultured Thiotrichaceae bacterium clone D10_10 small subunit riboso	647	647	100%	0.00E+00	100%
AS71-66	FJ711197.1	Afipia KC-IT-F4 16S ribosomal RNA gene, partial sequence	647	647	100%	0.00E+00	100%
AS71-22	FJ713034.1	Uncultured Acidobacteria bacterium clone 49 16S ribosomal RNA gene, partial sequence	652	652	96%	0	100%
AS71-21	FJ823826.1	Uncultured Rhodocyclaceae bacterium clone MFC68E10 16S ribosomal RNA gene, partial sequence	534	534	73%	1.00E-148	91%
AS71-40	FJ939131.1	Anaeromyxobacter IN2 16S ribosomal RNA gene, partial sequence	285	285	90%	5.00E-74	97%
AS71-42	FM955859.1	Polaromonas Asd M3-1 16S rRNA gene, strain Asd M3-1	647	647	96%	0	100%
AS71-52	FM955859.1	Polaromonas Asd M3-1 16S rRNA gene, strain Asd M3-1	647	647	96%	0.00E+00	100%
AS71-64	FM955859.1	Polaromonas Asd M3-1 16S rRNA gene, strain Asd M3-1	625	625	96%	5.00E-176	98%
AS71-70	FM955859.1	Polaromonas Asd M3-1 16S rRNA gene, strain Asd M3-1	647	647	96%	0.00E+00	100%
AS71-33	EF019585.1	Uncultured Mycobacteriaceae bacterium clone Elev_16S_1104 16S ribosomal RNA gene, partial sequence	617	617	95%	9.00E-174	99%
AS71-5	DQ837241.1	Uncultured Firmicutes bacterium clone 49S1_2B_19 16S ribosomal RNA gene, partial sequence	608	608	96%	5.00E-171	97%
AS71-23	DQ837241.1	Uncultured Firmicutes bacterium clone 49S1_2B_19 16S ribosomal RNA gene, partial sequence	597	597	96%	1.00E-167	96%
AS71-27	DQ837241.1	Uncultured Firmicutes bacterium clone 49S1_2B_19 16S ribosomal RNA gene, partial sequence	614	614	96%	1.00E-172	98%
AS71-30	DQ837241.1	Uncultured Firmicutes bacterium clone 49S1_2B_19 16S ribosomal RNA gene, partial sequence	608	608	96%	5.00E-171	97%
AS71-48	AF387301.2	Iron-oxidizing acidophile m-1 16S ribosomal RNA gene, partial sequence	575	575	100%	5.00E-161	96%
AS71-12	AF387301.2	Iron-oxidizing acidophile m-1 16S ribosomal RNA gene, partial sequence	577	577	96%	1.00E-161	96%
AS71-11	AB252945.1	Uncultured Nitrospirae bacterium gene for 16S rRNA, partial sequence, clone: 356	601	601	96%	9.00E-169	97%
AS71-15	AB252945.1	Uncultured Nitrospirae bacterium gene for 16S rRNA, partial sequence, clone: 356	601	601	96%	9.00E-169	97%
AS71-29	EU266874.1	Uncultured Syntrophaceae bacterium clone D15_37 small subunit ribosomal RNA gene, partial sequence	584	584	96%	9.00E-164	95%

Table C3-1. Smoky Canyon Sample AS71 Clone Library, continued.

Sample ID	Accession	Description	Max Score	Total Score	Query Coverage	E Value	Max Ident
AS71-36	EU266874.1	Uncultured Syntrophaceae bacterium clone D15_37 small subunit ribosomal RNA gene, partial sequence	521	622	96%	7.00E-145	100%
AS71-41	EU202763.1	Uncultured Acidobacteriales bacterium clone Plot29-2C11 16S ribosomal RNA gene, partial sequence	599	599	100%	3.00E-168	97%
AS71-31	AM690820.1	Uncultured actinobacterium partial 16S rRNA gene, clone TH1-16	608	608	96%	5.00E-171	97%
AS71-32	AM690820.1	Uncultured actinobacterium partial 16S rRNA gene, clone TH1-16	608	608	96%	5.00E-171	97%
AS71-8	EU266808.1	Uncultured Thiotrichaceae bacterium clone D10_44 small subunit ribosomal RNA gene, partial sequence					
AS71-18	FJ802331.1	Iron-reducing bacterium enrichment culture clone FEA_2_A7 16S ribosomal RNA gene, partial sequence	643	643	96%	0	99%
AS71-4	EU266808.1	Uncultured Thiotrichaceae bacterium clone D10_44 small subunit ribosomal RNA gene, partial sequence	599	599	96%	3.00E-168	97%
AS71-6	EU266808.1	Uncultured Thiotrichaceae bacterium clone D10_44 small subunit ribosomal RNA gene, partial sequence	604	604	96%	7.00E-170	97%
AS71-14	EU266808.1	Uncultured Thiotrichaceae bacterium clone D10_44 small subunit ribosomal RNA gene, partial sequence	604	604	96%	7.00E-170	97%
AS71-26	EU266808.1	Uncultured Thiotrichaceae bacterium clone D10_44 small subunit ribosomal RNA gene, partial sequence					
AS71-20	AB473787.1	Uncultured Rhodoferax gene for 16S rRNA, partial sequence, clone: AA_05_UNI	544	544	96%	1.00E-151	92%

Table C3-2. Smoky Canyon Sample AS113 Clone Library.

Sample ID	Accession	Description	Max Score	Total Score	Query Coverage	E Value	Max Ident
AS113-2	AB426569.1	Polaromonas sp. UF008 gene for 16S ribosomal RNA, partial sequence	647	647	96%	0	100%
AS113-15	AB426569.1	Polaromonas sp. UF008 gene for 16S ribosomal RNA, partial sequence	647	647	96%	0.00E+00	100%
AS113-18	AB426569.1	Polaromonas sp. UF008 gene for 16S ribosomal RNA, partial sequence	647	647	96%	0.00E+00	100%
AS113-24	AB426569.1	Polaromonas sp. UF008 gene for 16S ribosomal RNA, partial sequence	647	647	96%	0.00E+00	100%
AS113-26	AB426569.1	Polaromonas sp. UF008 gene for 16S ribosomal RNA, partial sequence	647	647	96%	0.00E+00	100%
AS113-27	AB426569.1	Polaromonas sp. UF008 gene for 16S ribosomal RNA, partial sequence	641	641	96%	0.00E+00	99%
AS113-37	AB426569.1	Polaromonas sp. UF008 gene for 16S ribosomal RNA, partial sequence	647	647	96%	0.00E+00	100%
AS113-6	AF529125.1	Uncultured Acidobacterium group bacterium clone FTLM5 16S ribosomal RNA gene, partial sequence	652	652	96%	0	100%
AS113-7	AF529125.1	Uncultured Acidobacterium group bacterium clone FTLM5 16S ribosomal RNA gene, partial sequence	652	652	96%	0	100%
AS113-14	AB425279.1	Sporotalea colonica gene for 16S rRNA, partial sequence	652	652	100%	0.00E+00	100%
AS113-10	AM258974.1	Sporotalea propionica partial 16S rRNA gene, strain TmPM3	649	649	96	0	100%
AS113-5	CP000267.1	Rhodoferax ferrireducens T118, complete genome	641	1283	96%	0	99%
AS113-8	CP000267.1	Rhodoferax ferrireducens T118, complete genome	636	1272	96%	2.00E-179	99%
AS113-12	CP000267.1	Rhodoferax ferrireducens T118, complete genome	647	1294	96%	0.00E+00	100%
AS113-23	CP000267.1	Rhodoferax ferrireducens T118, complete genome	647	1294	96%	0.00E+00	100%
AS113-25	CP000267.1	Rhodoferax ferrireducens T118, complete genome	647	1294	96%	0.00E+00	100%
AS113-30	CP000267.1	Rhodoferax ferrireducens T118, complete genome	623	1296	98%	2.00E-175	99%
AS113-31	CP000267.1	Rhodoferax ferrireducens T118, complete genome	647	1294	96%	0.00E+00	100%
AS113-41	CP000267.1	Rhodoferax ferrireducens T118, complete genome	647	1294	96%	0.00E+00	100%
AS113-43	CP000267.1	Rhodoferax ferrireducens T118, complete genome	647	1294	96%	0.00E+00	100%
AS113-44	CP000267.1	Rhodoferax ferrireducens T118, complete genome	647	1294	96%	0.00E+00	100%
AS113-45	CP000267.1	Rhodoferax ferrireducens T118, complete genome	647	1294	96%	0.00E+00	100%
AS113-17	DQ145536.1	Pelosinus fermentans strain R7 16S ribosomal RNA gene, partial sequence	641	641	100%	0.00E+00	99%
AS113-32	DQ145536.1	Pelosinus fermentans strain R7 16S ribosomal RNA gene, partial sequence	652	652	100%	0.00E+00	100%
AS113-36	DQ145536.1	Pelosinus fermentans strain R7 16S ribosomal RNA gene, partial sequence	641	641	100%	0.00E+00	99%
AS113-39	DQ145536.1	Pelosinus fermentans strain R7 16S ribosomal RNA gene, partial sequence	652	652	100%	0.00E+00	100%

Table C3-2. Smoky Canyon Sample AS113 Clone Library, continued.

Sample ID	Accession	Description	Max Score	Total Score	Query Coverage	E Value	Max Ident
AS113-1	EU215386.1	Pelosinus sp. UFO1 16S ribosomal RNA pseudogene, complete sequence	654	654	73%	0	100%
AS113-3	EU215386.1	Pelosinus sp. UFO1 16S ribosomal RNA pseudogene, complete sequence	580	580	98%	1.00E-162	100%
AS113-9	EU215386.1	Pelosinus sp. UFO1 16S ribosomal RNA pseudogene, complete sequence	654	654	96%	0	100%
AS113-11	EU215386.1	Pelosinus sp. UFO1 16S ribosomal RNA pseudogene, complete sequence	654	654	96%	0	100%
AS113-19	EU215386.1	Pelosinus sp. UFO1 16S ribosomal RNA pseudogene, complete sequence	652	652	100%	0.00E+00	100%
AS113-20	EU215386.1	Pelosinus sp. UFO1 16S ribosomal RNA pseudogene, complete sequence	652	652	100%	0.00E+00	100%
AS113-21	EU215386.1	Pelosinus sp. UFO1 16S ribosomal RNA pseudogene, complete sequence	630	630	100%	1.00E-177	98%
AS113-22	EU215386.1	Pelosinus sp. UFO1 16S ribosomal RNA pseudogene, complete sequence	647	647	100%	0.00E+00	99%
AS113-28	EU215386.1	Pelosinus sp. UFO1 16S ribosomal RNA pseudogene, complete sequence	652	652	100%	0.00E+00	100%
AS113-35	EU215386.1	Pelosinus sp. UFO1 16S ribosomal RNA pseudogene, complete sequence	647	647	99%	0.00E+00	99%
AS113-38	EU215386.1	Pelosinus sp. UFO1 16S ribosomal RNA pseudogene, complete sequence	652	652	100%	0.00E+00	100%
AS113-40	EU215386.1	Pelosinus sp. UFO1 16S ribosomal RNA pseudogene, complete sequence	652	652	100%	0.00E+00	100%
AS113-47	EU215386.1	Pelosinus sp. UFO1 16S ribosomal RNA pseudogene, complete sequence	652	652	100%	0.00E+00	100%
AS113-34	FJ939131.1	Anaeromyxobacter sp. IN2 16S ribosomal RNA gene, partial sequence	641	641	100%	0.00E+00	99%
AS113-13	U41563.1	Geothrix fermentans 16S rRNA gene, partial sequence	647	647	96%	0.00E+00	99%
AS113-16	U41563.1	Geothrix fermentans 16S rRNA gene, partial sequence	545	545	100%	4.00E-152	94%
AS113-29	U41563.1	Geothrix fermentans 16S rRNA gene, partial sequence	647	647	96%	0.00E+00	99%
AS113-33	U41563.1	Geothrix fermentans 16S rRNA gene, partial sequence	647	647	96%	0.00E+00	99%
AS113-42	U41563.1	Geothrix fermentans 16S rRNA gene, partial sequence	647	647	96%	0.00E+00	99%
AS113-46	U41563.1	Geothrix fermentans 16S rRNA gene, partial sequence	647	647	96%	0	99%

APPENDIX D

SATURATED RATE EXPERIMENTAL DATA

APPENDIX D

SATURATED RATE EXPERIMENTAL DATA

D1: ICP-MS ANALYSES OF TOTAL Fe, Mn, and Se Concentrations

Tables contain replicate ICP-MS data for the Dry Valley Mine and Smoky Canyon Mine, 10°C and 25°C treatments, and killed controls. Replicates were averaged to create Chapter 4, Figure 13 and Chapter 5, Figures 18-20.

Table D1-1. Selenium ICP-MS data for Dry Valley Mine
- D1-1.1. DV 10 LIVE SELENIUM.
- D1-1.2. DV 25 LIVE SELENIUM.
- D1-1.3. DV 10 KILLED SELENIUM.
- D1-1.4. DV 25 KILLED SELENIUM.

Table D1-2. Iron and Manganese ICP-MS data for Dry Valley Mine
- D1-2.1. DV 10 LIVE IRON/MANGANESE.
- D1-2.2. DV 25 LIVE IRON/MANGANESE.
- D1-2.3. DV 10 KILLED IRON/MANGANESE.
- D1-2.4. DV 25 KILLED IRON/MANGANESE.

Table D1-3. Selenium ICP-MS data for Smoky Canyon Mine
- D1-3.1. SC 10 LIVE SELENIUM.
- D1-3.2. SC 25 LIVE SELENIUM.
- D1-3.3. SC 10 KILLED SELENIUM.
- D1-3.4. SC 25 KILLED SELENIUM.

Table D1-4. Iron and Manganese ICP-MS data for Smoky Canyon Mine
- D1-4.1. SC 10 LIVE IRON/MANGANESE.
- D1-4.2. SC 25 LIVE IRON/MANGANESE.
- D1-4.3. SC 10 KILLED IRON/MANGANESE.
- D1-4.4. SC 25 KILLED IRON/MANGANESE.

D2: ION CHROMATOGRAPHY DATA
- Table D2-1. Dry Valley Ion Chromotography Data
- Table D2-2. Smoky Canyon Ion Chromotography Data

D3: PROTEIN ASSAY DATA
- Table D3-1. Dry Valley Protein Assay – Coomassie/Qbit Method.
- Table D3-2. Smoky Canyon Protein Assay – Coomassie Method.

Table D1-1. Selenium ICP-MS data for Dry Valley Mine Saturated Rate Experiments.
D1-1.1. DV 10 LIVE SELENIUM.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
10DCL1	0	10DCL1-0	9.811	490.5	20.7	0.09	10150	10150	021309cps
10DCL1	8	10DCL1-08	9.812	490.6	20.2	0.09	9923	9923	021309cps
10DCL1	20	10DCL1-20	9.818	490.9	21.1	0.09	10367	10367	021309cps
10DCL1	32	10DCL1-32	9.796	489.8	18.2	0.11	8905	8905	032009SeLtd
10DCL1	53	10DCL1-53	9.841	492.1	19.1	0.21	9404	9404	0214B
10DCL1	70	10DCL1-70	9.606	480.3	23.3	0.84	11171	11171	21509
10DCL1	80	10DCL1-80	9.811	490.6	13.2	0.16	6487	6487	021609Bcps
10DCL1	104	10DCL1-104	9.796	489.8	3.6	0.08	1744	1744	021709cps
10DCL1	128	10DCL1-128	9.795	489.8	1.5	0.16	757	757	021809copy
10DCL1	140	10DCL1-140	9.793	489.6	1.6	0.16	793	793	021809copy
10DCL1	164	10DCL1-164	9.750	487.5	0.4	0.12	210	210	022309cps
10DCL1	188	10DCL1-188	9.788	489.4	0.4	0.12	182	182	022309cps
10DCL1	212	10DCL1-212	9.781	489.1	0.6	0.12	297	297	022309cps
10DCL1	272	10DCL1-272	9.729	486.4	0.4	0.14	178	178	022509Bcps
10DCL2	0	10DCL2-0	9.836	491.8	21.1	0.09	10364	10364	021309cps
10DCL2	8	10DCL2-08	9.827	491.4	20.4	0.09	10046	10046	021309cps
10DCL2	20	10DCL2-20	9.836	491.8	19.5	0.09	9603	9603	021309cps
10DCL2	32	10DCL2-32	9.783	489.1	21.6	0.11	10581	10581	032009SeLtd
10DCL2	53	10DCL2-53	9.840	492.0	20.7	0.21	10179	10179	0214B
10DCL2	70	10DCL2-70	9.773	488.6	24.4	0.84	11908	11908	21509
10DCL2	80	10DCL2-80	9.790	489.5	16.3	0.16	7966	7966	021609Bcps
10DCL2	104	10DCL2-104	9.796	489.8	11.1	0.08	5426	5426	021709cps
10DCL2	128	10DCL2-128	9.797	489.9	3.5	0.16	1731	1731	021809copy
10DCL2	140	10DCL2-140	9.791	489.5	3.9	0.16	1902	1902	021809copy
10DCL2	164	10DCL2-164	9.814	490.7	0.6	0.12	298	298	022309cps
10DCL2	188	10DCL2-188	9.837	491.9	0.3	0.12	172	172	022309cps
10DCL2	212	10DCL2-212	9.797	489.9	0.5	0.12	252	252	022309cps
10DCL2	272	10DCL2-272	9.783	489.2	0.3	0.14	165	165	022509Bcps

D1-1.1. DV 10 LIVE SELENIUM, continued.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
10DCL3	0	10DCL3-0	9.820	491.0	17.6	0.09	8664	8664	021309cps
10DCL3	8	10DCL3-08	9.808	490.4	19.9	0.09	9745	9745	021309cps
10DCL3	20	10DCL3-20	9.808	490.4	20.1	0.09	9876	9876	021309cps
10DCL3	32	10DCL3-32	9.800	490.0	20.0	0.11	9821	9821	032009SeLtd
10DCL3	53	10DCL3-53	9.821	491.0	18.3	0.21	9006	9006	0214B
10DCL3	70	10DCL3-70	9.769	488.5	22.1	0.84	10796	10796	21509
10DCL3	80	10DCL3-80	9.792	489.6	14.5	0.16	7089	7089	021609Bcps
10DCL3	104	10DCL3-104	9.780	489.0	13.9	0.08	6792	6792	021709cps
10DCL3	128	10DCL3-128	9.794	489.7	13.7	0.16	6722	6722	021809copy
10DCL3	140	10DCL3-140	9.790	489.5	13.3	0.16	6491	6491	021809copy
10DCL3	164	10DCL3-164	9.810	490.5	7.8	0.12	3805	3805	022309cps
10DCL3	188	10DCL3-188	9.803	490.1	4.9	0.12	2411	2411	022309cps
10DCL3	212	10DCL3-212	9.783	489.2	4.4	0.12	2130	2130	022309cps
10DCL3	272	10DCL3-272	9.794	489.7	2.0	0.14	978	978	022509Bcps
10DRL1	0	10DRL1-0	9.836	491.8	20.2	0.09	9931	9931	021309cps
10DRL1	8	10DRL1-08	9.828	491.4	18.7	0.09	9202	9202	021309cps
10DRL1	20	10DRL1-20	9.832	491.6	20.5	0.09	10058	10058	021309cps
10DRL1	32	10DRL1-32	9.799	489.9	22.1	0.11	10807	10807	032009SeLtd
10DRL1	53	10DRL1-53	9.828	491.4	18.6	0.21	9142	9142	0214B
10DRL1	70	10DRL1-70	9.755	487.8	22.4	0.84	10928	10928	21509
10DRL1	80	10DRL1-80	9.793	489.6	18.2	0.16	8910	8910	021609Bcps
10DRL1	104	10DRL1-104	9.801	490.0	14.3	0.08	6985	6985	021709cps
10DRL1	128	10DRL1-128	9.771	488.5	7.9	0.16	3861	3861	021809copy
10DRL1	140	10DRL1-140	9.789	489.5	5.6	0.16	2752	2752	021809copy
10DRL1	164	10DRL1-164	9.833	491.7	1.9	0.12	930	930	022309cps
10DRL1	188	10DRL1-188	9.797	489.9	0.7	0.12	338	338	022309cps
10DRL1	212	10DRL1-212	9.798	489.9	0.6	0.12	310	310	022309cps
10DRL1	272	10DRL1-272	9.785	489.2	0.3	0.14	154	154	022509Bcps
10DRL2	0	10DRL2-0	9.840	492.0	18.9	0.09	9318	9318	021309cps
10DRL2	8	10DRL2-08	9.847	492.4	17.9	0.09	8819	8819	021309cps

D1-1.1. DV 10 LIVE SELENIUM, continued.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
10DRL2	20	10DRL2-20	9.830	491.5	19.5	0.09	9590	9590	021309cps
10DRL2	32	10DRL2-32	9.799	489.9	18.5	0.11	9062	9062	032009SeLtd
10DRL2	53	10DRL2-53	9.828	491.4	19.0	0.21	9345	9345	0214B
10DRL2	70	10DRL2-70	9.767	488.4	20.0	0.84	9763	9763	21509
10DRL2	80	10DRL2-80	9.798	489.9	20.4	0.16	10013	10013	021609Bcps
10DRL2	104	10DRL2-104	9.800	490.0	16.3	0.08	8003	8003	021709cps
10DRL2	128	10DRL2-128	9.784	489.2	8.1	0.16	3970	3970	021809copy
10DRL2	140	10DRL2-140	9.799	490.0	6.8	0.16	3354	3354	021809copy
10DRL2	164	10DRL2-164	9.811	490.6	1.8	0.12	865	865	022309cps
10DRL2	188	10DRL2-188	9.796	489.8	0.6	0.12	275	275	022309cps
10DRL2	212	10DRL2-212	9.804	490.2	0.6	0.12	310	310	022309cps
10DRL2	272	10DRL2-272	9.781	489.0	0.3	0.14	156	156	022509Bcps
10DRL3	0	10DRL3-0	9.831	491.6	17.8	0.09	8756	8756	021309cps
10DRL3	8	10DRL3-08	9.823	491.2	19.3	0.09	9482	9482	021309cps
10DRL3	20	10DRL3-20	9.809	490.4	21.2	0.09	10397	10397	021309cps
10DRL3	32	10DRL3-32	9.786	489.3	19.1	0.11	9359	9359	032009SeLtd
10DRL3	53	10DRL3-53	9.822	491.1	19.8	0.21	9718	9718	0214B
10DRL3	70	10DRL3-70	9.805	490.2	20.7	0.84	10153	10153	21509
10DRL3	80	10DRL3-80	9.791	489.6	17.1	0.16	8363	8363	021609Bcps
10DRL3	104	10DRL3-104	9.796	489.8	14.2	0.08	6962	6962	021709cps
10DRL3	128	10DRL3-128	9.799	489.9	9.6	0.16	4694	4694	021809copy
10DRL3	140	10DRL3-140	9.781	489.1	7.3	0.16	3577	3577	021809copy
10DRL3	164	10DRL3-164	9.803	490.2	1.9	0.12	933	933	022309cps
10DRL3	188	10DRL3-188	0.821	41.0	0.6	0.12	24	24	022309cps
10DRL3	212	10DRL3-212	9.800	490.0	0.5	0.12	240	240	022309cps
10DRL3	272	10DRL3-272	9.793	489.7	0.3	0.14	167	167	022509Bcps
10DSL1	0	10DSL1-0	9.728	486.4	20.1	0.09	9773	9773	021309cps
10DSL1	8	10DSL1-08	9.798	489.9	19.4	0.09	9507	9507	021309cps
10DSL1	20	10DSL1-20	9.804	490.2	19.1	0.09	9375	9375	021309cps
10DSL1	32	10DSL1-32	9.789	489.4	16.3	0.11	7997	7997	032009SeLtd

D1-1.1. DV 10 LIVE SELENIUM, continued.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
10DSL1	53	10DSL1-53	9.810	490.5	24.3	0.21	11935	11935	0214B
10DSL1	70	10DSL1-70	9.794	489.7	20.6	0.84	10108	10108	21509
10DSL1	80	10DSL1-80	9.809	490.5	18.6	0.16	9137	9137	021609Bcps
10DSL1	104	10DSL1-104	9.808	490.4	10.8	0.08	5285	5285	021809copy
10DSL1	128	10DSL1-128	9.805	490.3	5.7	0.16	2818	2818	021809copy
10DSL1	140	10DSL1-140	9.721	486.1	4.0	0.16	1954	1954	021809copy
10DSL1	164	10DSL1-164	9.824	491.2	0.8	0.12	415	415	022309cps
10DSL1	188	10DSL1-188	9.805	490.2	0.7	0.12	327	327	022309cps
10DSL1	212	10DSL1-212	9.803	490.2	0.7	0.12	344	344	022309cps
10DSL1	272	10DSL1-272	9.784	489.2	0.4	0.14	220	220	022509Bcps
10DSL2	0	10DSL2-0	9.817	490.8	20.6	0.09	10114	10114	021309cps
10DSL2	8	10DSL2-08	9.822	491.1	19.5	0.09	9589	9589	021309cps
10DSL2	20	10DSL2-20	9.801	490.1	17.0	0.09	8337	8337	021309cps
10DSL2	32	10DSL2-32	9.777	488.9	18.2	0.11	8882	8882	032009SeLtd
10DSL2	53	10DSL2-53	9.807	490.3	24.4	0.21	11950	11950	0214B
10DSL2	70	10DSL2-70	9.763	488.1	21.5	0.84	10509	10509	21509
10DSL2	80	10DSL2-80	9.813	490.6	17.9	0.16	8791	8791	021609Bcps
10DSL2	104	10DSL2-104	9.794	489.7	14.0	0.08	6860	6860	021809copy
10DSL2	128	10DSL2-128	9.791	489.6	8.3	0.16	4054	4054	021809copy
10DSL2	140	10DSL2-140	9.800	490.0	8.6	0.16	4208	4208	021809copy
10DSL2	164	10DSL2-164	9.811	490.6	2.1	0.12	1050	1050	022309cps
10DSL2	188	10DSL2-188	9.811	490.5	1.5	0.12	726	726	022309cps
10DSL2	212	10DSL2-212	9.788	489.4	1.3	0.12	615	615	022309cps
10DSL2	272	10DSL2-272	9.814	490.1	0.6	0.14	277	277	022509Bcps
10DSL3	0	10DSL3-0	9.821	491.1	20.6	0.09	10105	10105	021309cps
10DSL3	8	10DSL3-08	9.828	491.4	19.9	0.09	9798	9798	021309cps
10DSL3	20	10DSL3-20	9.824	491.2	19.3	0.09	9496	9496	021309cps
10DSL3	32	10DSL3-32	9.792	489.6	21.8	0.11	10660	10660	032009SeLtd
10DSL3	53	10DSL3-53	9.793	489.6	21.6	0.21	10562	10562	0214B
10DSL3	70	10DSL3-70	9.793	489.6	21.1	0.84	10327	10327	21509

D1-1.1. DV 10 LIVE SELENIUM, continued.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
10DSL3	80	10DSL3-80	9.810	490.5	16.0	0.16	7827	7827	021609Bcps
10DSL3	104	10DSL3-104	9.806	490.3	10.3	0.08	5033	5033	021809copy
10DSL3	128	10DSL3-128	9.789	489.5	7.0	0.16	3442	3442	021809copy
10DSL3	140	10DSL3-140	9.807	490.4	3.8	0.16	1880	1880	021809copy
10DSL3	164	10DSL3-164	9.804	490.2	0.8	0.12	414	414	022309cps
10DSL3	188	10DSL3-188	9.812	490.6	0.6	0.12	310	310	022309cps
10DSL3	212	10DSL3-212	9.805	490.3	0.7	0.12	327	327	022309cps
10DSL3	272	10DSL3-272	9.803	490.1	0.7	0.14	366	366	022509Bcps

D1-1.2. DV 25 LIVE SELENIUM.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
25DCL1	0	25DCL1-0	9.8	490.5	21.2	0.14	10420	10420	022509Bcps
25DCL1	8	25DCL1-8	9.7	487.4	21.3	0.14	10400	10400	022509Bcps
25DCL1	20	25DCL1-20	9.8	491.8	20.9	0.14	10277	10277	022509Bcps
25DCL1	32	25DCL1-32	9.8	490.2	17.5	0.11	8565	8565	032009SeLtd
25DCL1	54	25DCL1-54	9.8	490.2	2.4	0.11	1173	1173	032009SeFeMn
25DCL1	66	25DCL1-66	9.8	489.6	1.2	0.11	599	599	032009SeLtd
25DCL1	90	25DCL1-90	9.8	490.3	0.3	0.11	168	168	032009SeLtd
25DCL1	120	25DCL1-120	9.8	489.8	0.2	0.11	120	120	032009SeLtd
25DCL1	140	25DCL1-140	9.8	489.9	0.3	0.11	141	141	032009SeLtd
25DCL1	188	25DCL1-188	10.0	499.5	0.10	0.11	49	55	032009SeFeMn
25DCL2	0	25DCL2-0	9.8	491.0	22.7	0.14	11147	11147	022509Bcps
25DCL2	8	25DCL2-8	9.8	490.9	21.8	0.14	10710	10710	022509Bcps
25DCL2	20	25DCL2-20	9.8	491.7	21.7	0.14	10691	10691	022509Bcps
25DCL2	32	25DCL2-32	9.8	488.6	19.3	0.11	9410	9410	032009SeLtd
25DCL2	54	25DCL2-54	9.8	490.2	4.0	0.11	1982	1982	032009SeFeMn
25DCL2	66	25DCL2-66	9.8	489.9	0.6	0.11	285	285	032009SeLtd
25DCL2	90	25DCL2-90	9.8	490.2	0.3	0.11	130	130	032009SeLtd
25DCL2	120	25DCL2-120	9.8	489.9	0.2	0.11	88	88	032009SeLtd
25DCL2	140	25DCL2-140	9.8	490.3	0.3	0.11	168	168	032009SeLtd
25DCL2	188	25DCL2-188	9.8	489.3	0.0	0.11	20	54	032009SeFeMn
25DCL3	0	25DCL3-0	9.8	491.1	22.8	0.14	11216	11216	022509Bcps
25DCL3	8	25DCL3-8	9.8	491.6	21.3	0.14	10453	10453	022509Bcps
25DCL3	20	25DCL3-20	9.8	491.8	21.8	0.14	10717	10717	022509Bcps
25DCL3	32	25DCL3-32	9.8	489.8	19.3	0.11	9443	9443	032009SeLtd
25DCL3	54	25DCL3-54	9.8	489.9	3.4	0.11	1646	1646	032009SeFeMn
25DCL3	66	25DCL3-66	9.8	490.5	0.9	0.11	451	451	032009SeLtd
25DCL3	90	25DCL3-90	9.8	490.9	0.3	0.11	136	136	032009SeLtd
25DCL3	120	25DCL3-120	9.8	490.5	0.2	0.11	77	77	032009SeLtd
25DCL3	140	25DCL3-140	9.7	487.2	0.07	0.11	34	54	032009SeLtd

D1-1.2. DV 25 LIVE SELENIUM, continued.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
25DCL3	188	25DCL3-188	9.8	489.2	0.02	0.11	12	54	032009SeFeMn
25DRL1	0	25DRL1-0	9.8	491.2	21.0	0.14	10298	10298	022509Bcps
25DRL1	8	25DRL1-8	9.8	491.3	20.8	0.14	10231	10231	022509Bcps
25DRL1	20	25DRL1-20	9.8	491.2	20.3	0.14	9975	9975	022509Bcps
25DRL1	32	25DRL1-32	9.8	489.7	18.8	0.11	9223	9223	032009SeLtd
25DRL1	54	25DRL1-54	9.8	489.4	4.8	0.11	2336	2336	032009SeFeMn
25DRL1	66	25DRL1-66	9.8	490.4	0.7	0.11	349	349	032009SeLtd
25DRL1	90	25DRL1-90	9.8	490.5	0.3	0.11	130	130	032009SeLtd
25DRL1	120	25DRL1-120	9.8	490.8	0.15	0.11	72	72	032009SeLtd
25DRL1	140	25DRL1-140	9.8	489.3	0.2	0.11	109	109	032009SeLtd
25DRL1	188	25DRL1-188	9.8	489.9	0.10	0.11	50	54	032009SeFeMn
25DRL2	0	25DRL2-0	9.8	491.6	21.5	0.14	10593	10593	022509Bcps
25DRL2	8	25DRL2-8	9.8	490.1	21.8	0.14	10662	10662	022509Bcps
25DRL2	20	25DRL2-20	9.8	490.9	21.5	0.14	10550	10550	022509Bcps
25DRL2	32	25DRL2-32	9.8	489.1	16.6	0.11	8103	8103	032009SeLtd
25DRL2	54	25DRL2-54	9.8	489.5	5.5	0.11	2704	2704	032009SeFeMn
25DRL2	66	25DRL2-66	9.8	489.2	0.5	0.11	269	269	032009SeLtd
25DRL2	90	25DRL2-90	9.8	490.9	0.2	0.11	120	120	032009SeLtd
25DRL2	120	25DRL2-120	9.8	490.4	0.15	0.11	72	72	032009SeLtd
25DRL2	140	25DRL2-140	9.8	489.9	0.2	0.11	114	114	032009SeLtd
25DRL2	188	25DRL2-188	9.8	490.2	0.066	0.11	33	54	032009SeFeMn
25DRL3	0	25DRL3-0	9.8	490.1	20.8	0.14	10208	10208	022509Bcps
25DRL3	8	25DRL3-8	9.8	492.0	20.9	0.14	10295	10295	022509Bcps
25DRL3	20	25DRL3-20	9.8	491.5	21.2	0.14	10442	10442	022509Bcps
25DRL3	32	25DRL3-32	9.8	489.9	17.5	0.11	8570	8570	032009SeLtd
25DRL3	54	25DRL3-54	9.8	489.4	5.9	0.11	2904	2904	032009SeFeMn
25DRL3	66	25DRL3-66	9.8	490.8	0.9	0.11	457	457	032009SeLtd
25DRL3	90	25DRL3-90	9.8	490.6	0.4	0.11	205	205	032009SeLtd
25DRL3	120	25DRL3-120	9.8	490.4	0.14	0.11	66	66	032009SeLtd
25DRL3	140	25DRL3-140	9.8	489.3	3.0	0.11	1457	1457	032009SeLtd

D1-1.2. DV 25 LIVE SELENIUM, continued.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
25DRL3	188	25DRL3-188	9.8	487.8	0.06	0.11	28	54	032009SeFeMn
25DSL1	0	25DSL1-0	9.8	490.8	23.6	0.14	11592	11592	022509Bcps
25DSL1	8	25DSL1-8	9.8	490.5	23.3	0.14	11426	11426	022509Bcps
25DSL1	20	25DSL1-20	9.8	491.6	24.2	0.14	11883	11883	022509Bcps
25DSL1	32	25DSL1-32	9.8	490.3	22.9	0.11	11246	11246	032009SeLtd
25DSL1	54	25DSL1-54	9.8	489.9	11.8	0.11	5761	5761	032009SeFeMn
25DSL1	66	25DSL1-66	9.8	490.0	5.4	0.11	2622	2622	032009SeLtd
25DSL1	90	25DSL1-90	9.8	490.2	1.3	0.11	632	632	032009SeLtd
25DSL1	120	25DSL1-120	9.8	489.8	0.3	0.11	141	141	032009SeLtd
25DSL1	140	25DSL1-140	9.8	489.7	0.3	0.11	168	168	032009SeLtd
25DSL1	188	25DSL1-188	9.8	490.4	0.04	0.11	18	54	032009SeFeMn
25DSL2	0	25DSL2-0	9.8	491.3	25.0	0.14	12297	12297	022509Bcps
25DSL2	8	25DSL2-8	9.8	491.2	23.5	0.14	11523	11523	022509Bcps
25DSL2	20	25DSL2-20	9.8	491.6	23.5	0.14	11567	11567	022509Bcps
25DSL2	32	25DSL2-32	9.8	490.3	20.7	0.11	10125	10125	032009SeLtd
25DSL2	54	25DSL2-54	9.8	490.3	12.4	0.11	6089	6089	032009SeFeMn
25DSL2	66	25DSL2-66	9.8	489.9	6.0	0.11	2957	2957	032009SeLtd
25DSL2	90	25DSL2-90	9.8	489.8	2.0	0.11	989	989	032009SeLtd
25DSL2	120	25DSL2-120	9.8	489.3	0.4	0.11	189	189	032009SeLtd
25DSL2	140	25DSL2-140	9.8	490.2	0.2	0.11	82	82	032009SeLtd
25DSL2	188	25DSL2-188	9.8	489.9	0.06	0.11	31	54	032009SeFeMn
25DSL3	0	25DSL3-0	9.8	490.6	23.3	0.14	11430	11430	022509Bcps
25DSL3	8	25DSL3-8	9.8	491.7	23.3	0.14	11466	11466	022509Bcps
25DSL3	20	25DSL3-20	9.8	491.0	22.8	0.14	11205	11205	022509Bcps
25DSL3	32	25DSL3-32	9.8	490.3	18.8	0.11	9202	9202	032009SeLtd
25DSL3	54	25DSL3-54	9.8	489.0	10.2	0.11	5009	5009	032009SeFeMn
25DSL3	66	25DSL3-66	9.8	490.1	4.5	0.11	2206	2206	032009SeLtd
25DSL3	90	25DSL3-90	9.8	489.7	0.9	0.11	450	450	032009SeLtd
25DSL3	120	25DSL3-120	9.8	490.1	0.3	0.11	162	162	032009SeLtd
25DSL3	140	25DSL3-140	9.8	489.4	0.3	0.11	130	130	032009SeLtd

D1-1.2. DV 25 LIVE SELENIUM, continued.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
25DSL3	188	25DSL3-188	9.8	489.6	0.10	0.11	48	54	032009SeFeMn

D1-1.3. DV 10 KILLED SELENIUM.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
10DCK1	0	10DCK1-0	9.79	489.6	17.09	0.18	8367	8367	032109cps_SeFeMn
10DCK1	24	10DCK1-24	9.87	493.7	13.33	0.53	6581	6581	040409cps_SeLtdEnd
10DCK1	66	10DCK1-66	9.81	490.5	29.12	0.54	14283	14283	032109cps_SeLtd
10DCK1	139	10DCK1-139	9.80	489.9	25.73	0.54	12602	12602	032109cps_SeLtd
10DCK1	162	10DCK1-162	9.88	493.9	21.11	0.53	10426	10426	040409cps_SeLtdEnd
10DCK1	190	10DCK1-190	9.80	490.1	7.42	0.18	3636	3636	032109cps_SeFeMn
10DCK1	270	10DCK1-270	9.86	493.2	22.04	0.53	10869	10869	040409cps_SeLtdEnd
10DCK2	0	10DCK2-0	9.78	488.9	20.02	0.18	9786	9786	032109cps_SeFeMn
10DCK2	24	10DCK2-24	9.85	492.5	21.11	0.53	10396	10396	040409cps_SeLtdEnd
10DCK2	66	10DCK2-66	9.81	490.3	28.55	0.54	13999	13999	032109cps_SeLtd
10DCK2	139	10DCK2-139	9.82	491.0	25.12	0.54	12335	12335	032109cps_SeLtd
10DCK2	162	10DCK2-162	9.85	492.4	14.44	0.53	7110	7110	040409cps_SeLtdEnd
10DCK2	190	10DCK2-190	9.82	491.1	4.36	0.18	2141	2141	032109cps_SeFeMn
10DCK2	270	10DCK2-270	9.82	490.91	17.2	0.53	8443.7	8444	040409cps_SeLtdEnd
10DCK3	0	10DCK3-0	9.78	488.9	20.22	0.18	9883	9883	032109cps_SeFeMn
10DCK3	24	10DCK3-24	9.86	493.2	30.00	0.53	14797	14797	040409cps_SeLtdEnd
10DCK3	66	10DCK3-66	9.82	490.9	26.87	0.54	13189	13189	032109cps_SeLtd
10DCK3	139	10DCK3-139	9.81	490.4	25.64	0.54	12575	12575	032109cps_SeLtd
10DCK3	162	10DCK3-162	9.85	492.4	38.89	0.53	19151	19151	040409cps_SeLtdEnd
10DCK3	190	10DCK3-190	9.82	491.2	6.15	0.18	3021	3021	032109cps_SeFeMn
10DCK3	270	10DCK3-270	9.88	493.76	35.29	0.53	17425	17425	040409cps_SeLtdEnd
10DRK1	0	10DRK1-0	9.81	490.4	18.55	0.18	9094	9094	032109cps_SeFeMn
10DRK1	24	10DRK1-24	9.86	493.1	6.67	0.53	3289	3289	040409cps_SeLtdEnd
10DRK1	66	10DRK1-66	9.82	491.1	26.91	0.54	13217	13217	032109cps_SeLtd
10DRK1	139	10DRK1-139	9.81	490.7	25.78	0.54	12649	12649	032109cps_SeLtd
10DRK1	162	10DRK1-162	9.85	492.6	17.78	0.53	8759	8759	040409cps_SeLtdEnd
10DRK1	190	10DRK1-190	9.80	489.8	13.23	0.18	6480	6480	032109cps_SeFeMn
10DRK1	270	10DRK1-270	9.82	491.1	19.64	0.53	9647	9647	040409cps_SeLtdEnd
10DRK2	0	10DRK2-0	9.79	489.3	18.93	0.18	9261	9261	032109cps_SeFeMn

D1-1.3. DV 10 KILLED SELENIUM, continued.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
10DRK2	24	10DRK2-24	9.87	493.5	36.67	0.53	18096	18096	040409cps_SeLtdEnd
10DRK2	66	10DRK2-66	9.80	490.0	24.86	0.54	12184	12184	032109cps_SeLtd
10DRK2	139	10DRK2-139	9.81	490.3	28.29	0.54	13870	13870	032109cps_SeLtd
10DRK2	162	10DRK2-162	9.83	491.5	44.45	0.53	21849	21849	040409cps_SeLtdEnd
10DRK2	190	10DRK2-190	9.79	489.5	9.15	0.18	4479	4479	032109cps_SeFeMn
10DRK2	270	10DRK2-270	9.80	490.0	18.32	0.53	8976	8976	040409cps_SeLtdEnd
10DRK3	0	10DRK3-0	9.79	489.7	18.11	0.18	8867	8867	032109cps_SeFeMn
10DRK3	24	10DRK3-24	9.86	492.8	12.22	0.53	6022	6022	040409cps_SeLtdEnd
10DRK3	66	10DRK3-66	9.82	491.0	27.83	0.54	13663	13663	032109cps_SeLtd
10DRK3	139	10DRK3-139	9.82	491.1	24.21	0.54	11887	11887	032109cps_SeLtd
10DRK3	162	10DRK3-162	9.84	492.0	44.45	0.53	21871	21871	040409cps_SeLtdEnd
10DRK3	190	10DRK3-190	9.82	490.9	8.80	0.18	4320	4320	032109cps_SeFeMn
10DRK3	270	10DRK3-270	9.86	493.1	20.37	0.53	10043	10043	040409cps_SeLtdEnd
10DSK1	0	10DSK1-0	9.80	489.8	18.44	0.18	9033	9033	032109cps_SeFeMn
10DSK1	24	10DSK1-24	9.87	493.4	47.78	0.53	23575	23575	040409cps_SeLtdEnd
10DSK1	66	10DSK1-66	9.79	489.6	25.57	0.54	12521	12521	032109cps_SeLtd
10DSK1	139	10DSK1-139	9.82	490.8	24.49	0.54	12016	12016	032109cps_SeLtd
10DSK1	162	10DSK1-162	9.85	492.4	10.00	0.53	4924	4924	040409cps_SeLtdEnd
10DSK1	190	10DSK1-190	9.82	491.0	17.80	0.18	8739	8739	032109cps_SeFeMn
10DSK1	270	10DSK1-270	9.86	493.1	23.89	0.53	11781	11781	040409cps_SeLtdEnd
10DSK2	0	10DSK2-0	9.78	489.2	17.10	0.18	8362	8362	032109cps_SeFeMn
10DSK2	24	10DSK2-24	9.86	493.2	15.56	0.53	7674	7674	040409cps_SeLtdEnd
10DSK2	66	10DSK2-66	9.82	491.2	26.08	0.54	12810	12810	032109cps_SeLtd
10DSK2	139	10DSK2-139	9.82	491.1	20.42	0.54	10029	10029	032109cps_SeLtd
10DSK2	162	10DSK2-162	9.86	493.2	7.78	0.53	3837	3837	040409cps_SeLtdEnd
10DSK2	190	10DSK2-190	9.81	490.3	15.14	0.18	7423	7423	032109cps_SeFeMn
10DSK2	270	10DSK2-270	9.85	492.3	43.67	0.53	21498	21498	040409cps_SeLtdEnd
10DSK3	0	10DSK3-0	9.80	490.1	21.67	0.18	10622	10622	032109cps_SeFeMn
10DSK3	24	10DSK3-24	9.86	493.2	27.78	0.53	13701	13701	040409cps_SeLtdEnd
10DSK3	66	10DSK3-66	9.81	490.7	30.36	0.54	14900	14900	032109cps_SeLtd
10DSK3	139	10DSK3-139	9.82	490.8	25.37	0.54	12451	12451	032109cps_SeLtd

D1-1.3. DV 10 KILLED SELENIUM, continued.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
10DSK3	162	10DSK3-162	9.85	492.7	31.11	0.53	15329	15329	040409cps_SeLtdEnd
10DSK3	190	10DSK3-190	9.82	491.0	21.48	0.18	10546	10546	032109cps_SeFeMn
10DSK3	270	10DSK3-270	9.81	490.7	28.18	0.53	13828	13828	040409cps_SeLtdEnd

D1-1.4. DV 25 KILLED SELENIUM.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
25DCK1	0	25DCK1-0	9.79	489.3	18.65	0.80	9124	9124	020909Aquant
25DCK1	72	25DCK1-72	9.79	489.7	28.95	0.54	14176	14176	032109cps_SeLtd
25DCK1	120	25DCK1-120	9.78	488.9	19.9	0.80	9719	9719	020909Aquant
25DCK1	216	25DCK1-216	9.81	490.7	23.19	0.84	11379	11379	21509
25DCK1	456	25DCK1-456	9.81	490.3	20.45	0.02	10024	10024	032009SeFeMn
25DCK2	0	25DCK2-0	9.75	487.6	21.5	0.80	10476	10476	020909Aquant
25DCK2	72	25DCK2-72	9.81	490.7	32.57	0.54	15982	15982	032109cps_SeLtd
25DCK2	120	25DCK2-120	9.79	489.4	20.4	0.80	9966	9966	020909Aquant
25DCK2	216	25DCK2-216	9.80	490.2	24.08	0.84	11801	11801	21509
25DCK2	456	25DCK2-456	9.81	490.5	22.33	0.02	10953	10953	032009SeFeMn
25DCK3	0	25DCK3-0	9.77	488.5	15.2	0.80	7412	7412	020909Aquant
25DCK3	72	25DCK3-72	9.81	490.7	26.45	0.54	12977	12977	032109cps_SeLtd
25DCK3	120	25DCK3-120	9.77	488.7	19.1	0.80	9313	9313	020909Aquant
25DCK3	216	25DCK3-216	9.81	490.5	21.87	0.84	10725	10725	21509
25DCK3	456	25DCK3-456	9.80	490.2	17.96	0.02	8804	8804	032009SeFeMn
25DRK1	0	25DRK1-0	9.77	488.5	20.4	0.80	9947	9947	020909Aquant
25DRK1	72	25DRK1-72	9.80	489.9	30.60	0.54	14990	14990	032109cps_SeLtd
25DRK1	120	25DRK1-120	9.78	488.8	21.1	0.80	10337	10337	020909Aquant
25DRK1	216	25DRK1-216	9.81	490.4	27.31	0.84	13391	13391	21509
25DRK1	456	25DRK1-456	9.81	490.3	23.01	0.02	11279	11279	032009SeFeMn
25DRK2	0	25DRK2-0	9.78	488.8	19.2	0.80	9406	9406	020909Aquant
25DRK2	72	25DRK2-72	9.81	490.6	26.75	0.54	13124	13124	032109cps_SeLtd
25DRK2	120	25DRK2-120	9.76	488.2	21.9	0.80	10690	10690	020909Aquant

D1-1.4. DV 25 KILLED SELENIUM, continued.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
25DRK2	216	25DRK2-216	9.88	494.1	26.40	0.84	13043	13043	21509
25DRK2	456	25DRK2-456	9.81	490.3	20.28	0.02	9944	9944	032009SeFeMn
25DSK1	0	25DSK1-0	9.78	489.1	19.8	0.80	9704	9704	020909Aquant
25DSK1	72	25DSK1-72	9.80	489.8	29.46	0.54	14426	14426	032109cps_SeLtd
25DSK1	120	25DSK1-120	9.76	488.1	21.6	0.80	10560	10560	020909Aquant
25DSK1	216	25DSK1-216	9.81	490.5	25.13	0.84	12328	12328	21509
25DSK1	456	25DSK1-456	9.80	490.2	16.50	0.02	8089	8089	032009SeFeMn
25DSK2	0	25DSK2-0	9.80	489.9	18.4	0.80	9024	9024	020909Aquant
25DSK2	72	25DSK2-72	9.81	490.3	31.75	0.54	15569	15569	032109cps_SeLtd
25DSK2	120	25DSK2-120	9.78	489.0	16.6	0.80	8096	8096	020909Aquant
25DSK2	216	25DSK2-216	9.81	490.3	24.99	0.84	12250	12250	21509
25DSK2	456	25DSK2-456	9.80	490.0	23.02	0.02	11281	11281	032009SeFeMn
25DSK3	0	25DSK3-0	9.76	488.0	17.1	0.80	8352	8352	020909Aquant
25DSK3	72	25DSK3-72	9.80	489.9	25.87	0.54	12673	12673	032109cps_SeLtd
25DSK3	120	25DSK3-120	9.78	489.0	22.1	0.80	10815	10815	020909Aquant
25DSK3	216	25DSK3-216	9.80	490.0	-0.02	0.84	-10	412	21509
25DSK3	456	25DSK3-456	9.80	490.2	20.63	0.02	10113	10113	032009SeFeMn

Table D1-2. Iron and Manganese ICP-MS data for Dry Valley Mine Saturated Rate Experiments.

D1-2.1. DV 10 LIVE IRON/MANGANESE.

Sample Information					IRON				MANGANESE				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Fe, Measured**	**d.l.**	**Fe, µg/L**	**Fe µg/L, Reported**	**Mn, Measured**	**d.l.**	**Mn, µg/L**	**Mn, µg/L, Reported**	**Fe and Mn Source**
10DCL1	0	10DCL1-0	9.811	490.5	12.70	0.86	6228	6228	1.04	0.35	512	512	021309cps
10DCL1	8	10DCL1-08	9.812	490.6	12.60	0.86	6183	6183	1.00	0.35	490	490	021309cps
10DCL1	20	10DCL1-20	9.818	490.9	12.91	0.86	6338	6338	0.97	0.35	474	474	021309cps
10DCL1	32	10DCL1-32	9.796	489.8									
10DCL1	53	10DCL1-53	9.841	492.1									
10DCL1	70	10DCL1-70	9.606	480.3									
10DCL1	80	10DCL1-80	9.811	490.6	216.37	5.17	106144	106144	2.50	0.16	1224	1224	021609Bcps
10DCL1	104	10DCL1-104	9.796	489.8	240.84	1.31	117965	117965	3.37	0.22	1653	1653	021709cps
10DCL1	128	10DCL1-128	9.795	489.8	229.39	0.03	112346	112346	1.86	0.01	909	909	021809copy
10DCL1	140	10DCL1-140	9.793	489.6	231.19	0.03	113198	113198	2.00	0.01	979	979	021809copy
10DCL1	164	10DCL1-164	9.750	487.5									
10DCL1	188	10DCL1-188	9.788	489.4									
10DCL1	212	10DCL1-212	9.781	489.1									
10DCL1	272	10DCL1-272	9.729	486.4	25.75	1.00	12528	12528	1.71	0.10	832	832	022509Bcps
10DCL2	0	10DCL2-0	9.836	491.8	12.56	0.86	6177	6177	0.99	0.35	487	487	021309cps
10DCL2	8	10DCL2-08	9.827	491.4	12.52	0.86	6149	6149	1.00	0.35	493	493	021309cps
10DCL2	20	10DCL2-20	9.836	491.8	12.47	0.86	6134	6134	0.95	0.35	466	466	021309cps
10DCL2	32	10DCL2-32	9.783	489.1									
10DCL2	53	10DCL2-53	9.840	492.0									
10DCL2	70	10DCL2-70	9.773	488.6									
10DCL2	80	10DCL2-80	9.790	489.5	221.42	5.17	108389	108389	2.48	0.16	1213	1213	021609Bcps
10DCL2	104	10DCL2-104	9.796	489.8	240.35	1.31	117721	117721	3.34	0.22	1636	1636	021709cps
10DCL2	128	10DCL2-128	9.797	489.9	232.80	0.03	114040	114040	1.78	0.01	872	872	021809copy
10DCL2	140	10DCL2-140	9.791	489.5	230.68	0.03	112926	112926	1.92	0.01	942	942	021809copy
10DCL2	164	10DCL2-164	9.814	490.7									
10DCL2	188	10DCL2-188	9.837	491.9									
10DCL2	212	10DCL2-212	9.797	489.9									

D1-2.1. DV 10 LIVE IRON/MANGANESE, continued.

Sample Information					IRON				MANGANESE				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Fe, Measured**	**d.l.**	**Fe, µg/L**	**Fe µg/L, Reported**	**Mn, Measured**	**d.l.**	**Mn, µg/L**	**Mn, µg/L, Reported**	**Fe and Mn Source**
10DCL2	272	10DCL2-272	9.783	489.2	26.04	1.00	12738	12738	1.50	0.10	732	732	022509Bcps
10DCL3	0	10DCL3-0	9.820	491.0	12.04	0.86	5910	5910	0.99	0.35	489	489	021309cps
10DCL3	8	10DCL3-08	9.808	490.4	11.57	0.86	5672	5672	0.99	0.35	486	486	021309cps
10DCL3	20	10DCL3-20	9.808	490.4	11.46	0.86	5622	5622	0.97	0.35	475	475	021309cps
10DCL3	32	10DCL3-32	9.800	490.0									
10DCL3	53	10DCL3-53	9.821	491.0									
10DCL3	70	10DCL3-70	9.769	488.5									
10DCL3	80	10DCL3-80	9.792	489.6	220.20	5.17	107812	107812	2.42	0.16	1184	1184	021609Bcps
10DCL3	104	10DCL3-104	9.780	489.0	241.83	1.31	118259	118259	7.22	0.22	3529	3529	021709cps
10DCL3	128	10DCL3-128	9.794	489.7	231.93	0.03	113572	113572	1.83	0.01	898	898	021809copy
10DCL3	140	10DCL3-140	9.790	489.5	233.40	0.03	114250	114250	1.84	0.01	901	901	021809copy
10DCL3	164	10DCL3-164	9.810	490.5									
10DCL3	188	10DCL3-188	9.803	490.1									
10DCL3	212	10DCL3-212	9.783	489.2									
10DCL3	272	10DCL3-272	9.794	489.7	28.58	1.00	13998	13998	1.93	0.10	944	944	022509Bcps
10DRL1	0	10DRL1-0	9.836	491.8	12.48	0.86	6138	6138	3.89	0.35	1915	1915	021309cps
10DRL1	8	10DRL1-08	9.828	491.4	12.47	0.86	6127	6127	3.88	0.35	1908	1908	021309cps
10DRL1	20	10DRL1-20	9.832	491.6	12.38	0.86	6084	6084	4.32	0.35	2126	2126	021309cps
10DRL1	32	10DRL1-32	9.799	489.9									
10DRL1	53	10DRL1-53	9.828	491.4									
10DRL1	70	10DRL1-70	9.755	487.8									
10DRL1	80	10DRL1-80	9.793	489.6	217.99	5.17	106736	106736	5.14	0.16	2518	2518	021609Bcps
10DRL1	104	10DRL1-104	9.801	490.0	238.26	1.31	116760	116760	7.11	0.22	3483	3483	021709cps
10DRL1	128	10DRL1-128	9.771	488.5	235.37	0.03	114983	114983	4.05	0.01	1978	1978	021809copy
10DRL1	140	10DRL1-140	9.789	489.5	235.23	0.03	115135	115135	4.67	0.01	2285	2285	021809copy
10DRL1	164	10DRL1-164	9.833	491.7									
10DRL1	188	10DRL1-188	9.797	489.9									
10DRL1	212	10DRL1-212	9.798	489.9									
10DRL1	272	10DRL1-272	9.785	489.2	26.20	1.00	12819	12819	8.08	0.10	3952	3952	022509Bcps

D1-2.1. DV 10 LIVE IRON/MANGANESE, continued.

Sample Information					IRON				MANGANESE				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Fe, Measured**	**d.l.**	**Fe, µg/L**	**Fe µg/L, Reported**	**Mn, Measured**	**d.l.**	**Mn, µg/L**	**Mn, µg/L, Reported**	**Fe and Mn Source**
10DRL2	0	10DRL2-0	9.840	492.0	12.54	0.86	6168	6168	3.80	0.35	1871	1871	021309cps
10DRL2	8	10DRL2-08	9.847	492.4	12.47	0.86	6139	6139	3.62	0.35	1781	1781	021309cps
10DRL2	20	10DRL2-20	9.830	491.5	12.60	0.86	6195	6195	3.79	0.35	1861	1861	021309cps
10DRL2	32	10DRL2-32	9.799	489.9									
10DRL2	53	10DRL2-53	9.828	491.4									
10DRL2	70	10DRL2-70	9.767	488.4									
10DRL2	80	10DRL2-80	9.798	489.9	224.71	5.17	110087	110087	5.81	0.16	2847	2847	021609Bcps
10DRL2	104	10DRL2-104	9.800	490.0	239.33	1.31	117270	117270	7.29	0.22	3570	3570	021709cps
10DRL2	128	10DRL2-128	9.784	489.2	232.36	0.03	113665	113665	3.66	0.01	1792	1792	021809copy
10DRL2	140	10DRL2-140	9.799	490.0	251.86	0.03	123399	123399	9.86	0.01	4829	4829	021809copy
10DRL2	164	10DRL2-164	9.811	490.6									
10DRL2	188	10DRL2-188	9.796	489.8									
10DRL2	212	10DRL2-212	9.804	490.2									
10DRL2	272	10DRL2-272	9.781	489.0	25.77	1.00	12604	12604	7.10	0.10	3470	3470	022509Bcps
10DRL3	0	10DRL3-0	9.831	491.6	11.59	0.86	5696	5696	3.73	0.35	1835	1835	021309cps
10DRL3	8	10DRL3-08	9.823	491.2	11.69	0.86	5741	5741	5.52	0.35	2713	2713	021309cps
10DRL3	20	10DRL3-20	9.809	490.4	12.96	0.86	6357	6357	4.61	0.35	2261	2261	021309cps
10DRL3	32	10DRL3-32	9.786	489.3									
10DRL3	53	10DRL3-53	9.822	491.1									
10DRL3	70	10DRL3-70	9.805	490.2									
10DRL3	80	10DRL3-80	9.791	489.6	222.99	5.17	109164	109164	5.55	0.16	2715	2715	021609Bcps
10DRL3	104	10DRL3-104	9.796	489.8	237.98	1.31	116559	116559	7.47	0.22	3659	3659	021709cps
10DRL3	128	10DRL3-128	9.799	489.9	237.90	0.03	116553	116553	4.28	0.01	2097	2097	021809copy
10DRL3	140	10DRL3-140	9.781	489.1	233.43	0.03	114160	114160	4.84	0.01	2368	2368	021809copy
10DRL3	164	10DRL3-164	9.803	490.2									
10DRL3	188	10DRL3-188	0.821	41.0									
10DRL3	212	10DRL3-212	9.800	490.0									
10DRL3	272	10DRL3-272	9.793	489.7	25.24	1.00	12358	12358	8.21	0.10	4019	4019	022509Bcps
10DSL1	0	10DSL1-0	9.728	486.4	13.21	0.86	6428	6428	5.60	0.35	2724	2724	021309cps

D1-2.1. DV 10 LIVE IRON/MANGANESE, continued.

Sample Information					IRON				MANGANESE				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Fe, Measured**	**d.l.**	**Fe, µg/L**	**Fe µg/L, Reported**	**Mn, Measured**	**d.l.**	**Mn, µg/L**	**Mn, µg/L, Reported**	**Fe and Mn Source**
10DSL1	8	10DSL1-08	9.798	489.9	13.67	0.86	6696	6696	5.61	0.35	2746	2746	021309cps
10DSL1	20	10DSL1-20	9.804	490.2	13.09	0.86	6419	6419	5.62	0.35	2757	2757	021309cps
10DSL1	32	10DSL1-32	9.789	489.4									
10DSL1	53	10DSL1-53	9.810	490.5									
10DSL1	70	10DSL1-70	9.794	489.7									
10DSL1	80	10DSL1-80	9.809	490.5	218.43	5.17	107134	107134	6.93	0.16	3397	3397	021609Bcps
10DSL1	104	10DSL1-104	9.808	490.4	236.91	1.31	116181	116181	4.14	0.22	2032	2032	021809copy
10DSL1	128	10DSL1-128	9.805	490.3	231.52	0.03	113506	113506	4.74	0.01	2324	2324	021809copy
10DSL1	140	10DSL1-140	9.721	486.1	243.58	0.03	118393	118393	7.13	0.01	3464	3464	021809copy
10DSL1	164	10DSL1-164	9.824	491.2									
10DSL1	188	10DSL1-188	9.805	490.2									
10DSL1	212	10DSL1-212	9.803	490.2									
10DSL1	272	10DSL1-272	9.784	489.2	25.72	1.00	12582	12582	10.35	0.10	5063	5063	022509Bcps
10DSL2	0	10DSL2-0	9.817	490.8	13.71	0.86	6732	6732	5.57	0.35	2734	2734	021309cps
10DSL2	8	10DSL2-08	9.822	491.1	13.20	0.86	6481	6481	5.47	0.35	2685	2685	021309cps
10DSL2	20	10DSL2-20	9.801	490.1	13.08	0.86	6412	6412	5.01	0.35	2454	2454	021309cps
10DSL2	32	10DSL2-32	9.777	488.9									
10DSL2	53	10DSL2-53	9.807	490.3									
10DSL2	70	10DSL2-70	9.763	488.1									
10DSL2	80	10DSL2-80	9.813	490.6	220.43	5.17	108151	108151	6.74	0.16	3308	3308	021609Bcps
10DSL2	104	10DSL2-104	9.794	489.7	233.80	1.31	114490	114490	4.77	0.22	2336	2336	021809copy
10DSL2	128	10DSL2-128	9.791	489.6	229.19	0.03	112205	112205	5.13	0.01	2511	2511	021809copy
10DSL2	140	10DSL2-140	9.800	490.0	234.91	0.03	115104	115104	4.75	0.01	2329	2329	021809copy
10DSL2	164	10DSL2-164	9.811	490.6									
10DSL2	188	10DSL2-188	9.811	490.5									
10DSL2	212	10DSL2-212	9.788	489.4									
10DSL2	272	10DSL2-272	9.814	490.1	25.68	1.00	12586	12586	8.66	0.10	4243	4243	022509Bcps
10DSL3	0	10DSL3-0	9.821	491.1	11.91	0.86	5851	5851	5.45	0.35	2675	2675	021309cps
10DSL3	8	10DSL3-08	9.828	491.4	11.67	0.86	5736	5736	4.18	0.35	2054	2054	021309cps

D1-2.1. DV 10 LIVE IRON/MANGANESE, continued.

Sample Information					IRON				MANGANESE				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Fe, Measured**	**d.l.**	**Fe, µg/L**	**Fe µg/L, Reported**	**Mn, Measured**	**d.l.**	**Mn, µg/L**	**Mn, µg/L, Reported**	**Fe and Mn Source**
10DSL3	20	10DSL3-20	9.824	491.2	11.99	0.86	5889	5889	5.28	0.35	2594	2594	021309cps
10DSL3	32	10DSL3-32	9.792	489.6									
10DSL3	53	10DSL3-53	9.793	489.6									
10DSL3	70	10DSL3-70	9.793	489.6									
10DSL3	80	10DSL3-80	9.810	490.5	220.15	5.17	107983	107983	6.20	0.16	3042	3042	021609Bcps
10DSL3	104	10DSL3-104	9.806	490.3	234.59	1.31	115024	115024	4.04	0.22	1981	1981	021809copy
10DSL3	128	10DSL3-128	9.789	489.5	235.09	0.03	115067	115067	4.43	0.01	2167	2167	021809copy
10DSL3	140	10DSL3-140	9.807	490.4	235.19	0.03	115331	115331	8.45	0.01	4145	4145	021809copy
10DSL3	164	10DSL3-164	9.804	490.2									
10DSL3	188	10DSL3-188	9.812	490.6									
10DSL3	212	10DSL3-212	9.805	490.3									
10DSL3	272	10DSL3-272	9.803	490.1	25.90	1.00	12695	12695	11.0	0.10	5410	5410	022509Bcps

Shaded fields = data not collected for those samples.

D1-2.2. DV 25 LIVE IRON/MANGANESE.

Sample Information					IRON				MANGANESE				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Fe, Measured**	**d.l.**	**Fe, µg/L**	**Fe µg/L, Reported**	**Mn, Measured**	**d.l.**	**Mn, µg/L**	**Mn, µg/L, Reported**	**Fe and Mn Source**
25DCL1	0	25DCL1-0	9.8	490.5	4.1	1.0	2003	2003	0.3	0.1	163	163	022509Bcps
25DCL1	8	25DCL1-8	9.7	487.4	0.9	1.0	442	487	0.4	0.1	212	212	022509Bcps
25DCL1	20	25DCL1-20	9.8	491.8	-0.4	1.0	-214	492	0.5	0.1	234	234	022509Bcps
25DCL1	32	25DCL1-32	9.8	490.2									
25DCL1	54	25DCL1-54	9.8	490.2	17	2.7	8302	8302	0.86	0.22	420	420	032009SeFeMn
25DCL1	66	25DCL1-66	9.8	489.6									
25DCL1	90	25DCL1-90	9.8	490.3									
25DCL1	120	25DCL1-120	9.8	489.8									
25DCL1	140	25DCL1-140	9.8	489.9									
25DCL1	188	25DCL1-188	10.0	499.5	17	2.7	8308	8308	1.39	0.22	695	695	032009SeFeMn
25DCL2	0	25DCL2-0	9.8	491.0	4.3	1.0	2130	2130	0.3	0.1	167	167	022509Bcps
25DCL2	8	25DCL2-8	9.8	490.9	-0.4	1.0	-218	491	0.4	0.1	173	173	022509Bcps
25DCL2	20	25DCL2-20	9.8	491.7	-0.4	1.0	-196	492	0.4	0.1	218	218	022509Bcps
25DCL2	32	25DCL2-32	9.8	488.6									
25DCL2	54	25DCL2-54	9.8	490.2	16	2.7	7895	7895	0.77	0.22	378	378	032009SeFeMn
25DCL2	66	25DCL2-66	9.8	489.9									
25DCL2	90	25DCL2-90	9.8	490.2									
25DCL2	120	25DCL2-120	9.8	489.9									
25DCL2	140	25DCL2-140	9.8	490.3									
25DCL2	188	25DCL2-188	9.8	489.3	23	2.7	11498	11498	1.59	0.22	778	778	032009SeFeMn
25DCL3	0	25DCL3-0	9.8	491.1	4.5	1.0	2188	2188	0.2	0.1	121	121	022509Bcps
25DCL3	8	25DCL3-8	9.8	491.6	-0.03	1.0	-14	492	0.3	0.1	137	137	022509Bcps
25DCL3	20	25DCL3-20	9.8	491.8	-0.8	1.0	-418	492	0.4	0.1	202	202	022509Bcps
25DCL3	32	25DCL3-32	9.8	489.8									
25DCL3	54	25DCL3-54	9.8	489.9	17	2.7	8361	8361	1.05	0.22	516	516	032009SeFeMn
25DCL3	66	25DCL3-66	9.8	490.5									
25DCL3	90	25DCL3-90	9.8	490.9									
25DCL3	120	25DCL3-120	9.8	490.5									
25DCL3	140	25DCL3-140	9.7	487.2									

D1-2.2. DV 25 LIVE IRON/MANGANESE, continued.

Sample Information					IRON				MANGANESE				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Fe, Measured**	**d.l.**	**Fe, µg/L**	**Fe µg/L, Reported**	**Mn, Measured**	**d.l.**	**Mn, µg/L**	**Mn, µg/L, Reported**	**Fe and Mn Source**
25DCL3	188	25DCL3-188	9.8	489.2	17	2.7	8264	8264	1.37	0.22	672	672	032009SeFeMn
25DRL1	0	25DRL1-0	9.8	491.2	4.1	1.0	2032	2032	4.5	0.1	2200	2200	022509Bcps
25DRL1	8	25DRL1-8	9.8	491.3	-0.6	1.0	-281	491	4.7	0.1	2322	2322	022509Bcps
25DRL1	20	25DRL1-20	9.8	491.2	2.8	1.0	1395	1395	5.2	0.1	2532	2532	022509Bcps
25DRL1	32	25DRL1-32	9.8	489.7									
25DRL1	54	25DRL1-54	9.8	489.4	21	2.7	10332	10332	3.69	0.22	1808	1808	032009SeFeMn
25DRL1	66	25DRL1-66	9.8	490.4									
25DRL1	90	25DRL1-90	9.8	490.5									
25DRL1	120	25DRL1-120	9.8	490.8									
25DRL1	140	25DRL1-140	9.8	489.3									
25DRL1	188	25DRL1-188	9.8	489.9	17	2.7	8226	8226	9.96	0.22	4877	4877	032009SeFeMn
25DRL2	0	25DRL2-0	9.8	491.6	4.1	1.0	2003	2003	4.0	0.1	1969	1969	022509Bcps
25DRL2	8	25DRL2-8	9.8	490.1	1.0	1.0	493	493	4.3	0.1	2092	2092	022509Bcps
25DRL2	20	25DRL2-20	9.8	490.9	-0.5	1.0	-240	491	4.7	0.1	2303	2303	022509Bcps
25DRL2	32	25DRL2-32	9.8	489.1									
25DRL2	54	25DRL2-54	9.8	489.5	16	2.7	7767	7767	3.27	0.22	1601	1601	032009SeFeMn
25DRL2	66	25DRL2-66	9.8	489.2									
25DRL2	90	25DRL2-90	9.8	490.9									
25DRL2	120	25DRL2-120	9.8	490.4									
25DRL2	140	25DRL2-140	9.8	489.9									
25DRL2	188	25DRL2-188	9.8	490.2	17	2.7	8438	8438	6.22	0.22	3048	3048	032009SeFeMn
25DRL3	0	25DRL3-0	9.8	490.1	-0.1	1.0	-28	490	4.5	0.1	2214	2214	022509Bcps
25DRL3	8	25DRL3-8	9.8	492.0	-0.6	1.0	-307	492	4.7	0.1	2326	2326	022509Bcps
25DRL3	20	25DRL3-20	9.8	491.5	-0.7	1.0	-362	492	5.0	0.1	2474	2474	022509Bcps
25DRL3	32	25DRL3-32	9.8	489.9									
25DRL3	54	25DRL3-54	9.8	489.4	16	2.7	7756	7756	3.96	0.22	1936	1936	032009SeFeMn
25DRL3	66	25DRL3-66	9.8	490.8									
25DRL3	90	25DRL3-90	9.8	490.6									
25DRL3	120	25DRL3-120	9.8	490.4									
25DRL3	140	25DRL3-140	9.8	489.3									

D1-2.2. DV 25 LIVE IRON/MANGANESE, continued.

Sample Information					IRON				MANGANESE				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Fe, Measured**	**d.l.**	**Fe, µg/L**	**Fe µg/L, Reported**	**Mn, Measured**	**d.l.**	**Mn, µg/L**	**Mn, µg/L, Reported**	**Fe and Mn Source**
25DRL3	188	25DRL3-188	9.8	487.8	17	2.7	8183	8183	6.14	0.22	2995	2995	032009SeFeMn
25DSL1	0	25DSL1-0	9.8	490.8	-0.4	1.0	-196	491	6.9	0.1	3394	3394	022509Bcps
25DSL1	8	25DSL1-8	9.8	490.5	-0.5	1.0	-260	491	7.2	0.1	3547	3547	022509Bcps
25DSL1	20	25DSL1-20	9.8	491.6	-0.8	1.0	-387	492	7.8	0.1	3831	3831	022509Bcps
25DSL1	32	25DSL1-32	9.8	490.3									
25DSL1	54	25DSL1-54	9.8	489.9	16	2.7	7901	7901	5.31	0.22	2601	2601	032009SeFeMn
25DSL1	66	25DSL1-66	9.8	490.0									
25DSL1	90	25DSL1-90	9.8	490.2									
25DSL1	120	25DSL1-120	9.8	489.8									
25DSL1	140	25DSL1-140	9.8	489.7									
25DSL1	188	25DSL1-188	9.8	490.4	17	2.7	8426	8426	6.65	0.22	3262	3262	032009SeFeMn
25DSL2	0	25DSL2-0	9.8	491.3	-0.6	1.0	-288	491	7.3	0.1	3566	3566	022509Bcps
25DSL2	8	25DSL2-8	9.8	491.2	-0.2	1.0	-86	491	7.5	0.1	3660	3660	022509Bcps
25DSL2	20	25DSL2-20	9.8	491.6	1.5	1.0	740	740	7.8	0.1	3843	3843	022509Bcps
25DSL2	32	25DSL2-32	9.8	490.3									
25DSL2	54	25DSL2-54	9.8	490.3	18	2.7	8687	8687	6.05	0.22	2965	2965	032009SeFeMn
25DSL2	66	25DSL2-66	9.8	489.9									
25DSL2	90	25DSL2-90	9.8	489.8									
25DSL2	120	25DSL2-120	9.8	489.3									
25DSL2	140	25DSL2-140	9.8	490.2									
25DSL2	188	25DSL2-188	9.8	489.9	17	2.7	8391	8391	7.00	0.22	3431	3431	032009SeFeMn
25DSL3	0	25DSL3-0	9.8	490.6	-0.2	1.0	-83	491	6.8	0.1	3325	3325	022509Bcps
25DSL3	8	25DSL3-8	9.8	491.7	-0.3	1.0	-144	492	7.2	0.1	3517	3517	022509Bcps
25DSL3	20	25DSL3-20	9.8	491.0	0.2	1.0	106	491	7.9	0.1	3863	3863	022509Bcps
25DSL3	32	25DSL3-32	9.8	490.3									
25DSL3	54	25DSL3-54	9.8	489.0	16	2.7	7739	7739	5.01	0.22	2449	2449	032009SeFeMn
25DSL3	66	25DSL3-66	9.8	490.1									
25DSL3	90	25DSL3-90	9.8	489.7									
25DSL3	120	25DSL3-120	9.8	490.1									
25DSL3	140	25DSL3-140	9.8	489.4									

D1-2.2. DV 25 LIVE IRON/MANGANESE, continued.

Sample Information					IRON				MANGANESE				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Fe, Measured**	**d.l.**	**Fe, µg/L**	**Fe µg/L, Reported**	**Mn, Measured**	**d.l.**	**Mn, µg/L**	**Mn, µg/L, Reported**	**Fe and Mn Source**
25DSL3	188	25DSL3-188	9.8	489.6	17	2.7	8371	8371	7.94	0.22	3885	3885	032009SeFeMn

Shaded fields = data not collected for those samples.

D1-2.3. DV 10 KILLED IRON/MANGANESE.

Sample Information					IRON				MANGANESE				
Experiment	Time	Name	Weigh t	Dilution	Fe, Measured	d.l.	Fe, µg/L	Fe µg/L, Reported	Mn, Measured	d.l.	Mn, µg/L	Mn, µg/L, Reported	Fe and Mn Source
10DCK1	0	10DCK1-0	9.79	489.6	15.06	1.24	7372	7372	1.12	0.14	548	548	032109cps_SeFeMn
10DCK1	24	10DCK1-24	9.87	493.7									
10DCK1	66	10DCK1-66	9.81	490.5									
10DCK1	139	10DCK1-139	9.80	489.9									
10DCK1	162	10DCK1-162	9.88	493.9									
10DCK1	190	10DCK1-190	9.80	490.1	16.73	1.24	8198	8198	1.18	0.14	577	577	032109cps_SeFeMn
10DCK1	270	10DCK1-270	9.86	493.2									
10DCK2	0	10DCK2-0	9.78	488.9	15.98		7812	7812	1.13	0.14	554	554	032109cps_SeFeMn
10DCK2	24	10DCK2-24	9.85	492.5									
10DCK2	66	10DCK2-66	9.81	490.3									
10DCK2	139	10DCK2-139	9.82	491.0									
10DCK2	162	10DCK2-162	9.85	492.4									
10DCK2	190	10DCK2-190	9.82	491.1	17.63		8657	8657	1.47	0.14	724	724	032109cps_SeFeMn
10DCK2	270	10DCK2-270	9.82	490.91									
10DCK3	0	10DCK3-0	9.78	488.9	15.59		7619	7619	1.09	0.14	535	535	032109cps_SeFeMn
10DCK3	24	10DCK3-24	9.86	493.2									
10DCK3	66	10DCK3-66	9.82	490.9									
10DCK3	139	10DCK3-139	9.81	490.4									
10DCK3	162	10DCK3-162	9.85	492.4									
10DCK3	190	10DCK3-190	9.82	491.2	15.96		7840	7840	1.19	0.14	584	584	032109cps_SeFeMn
10DCK3	270	10DCK3-270	9.88	493.76									
10DRK1	0	10DRK1-0	9.81	490.4	15.79		7745	7745	2.77	0.14	1360	1360	032109cps_SeFeMn
10DRK1	24	10DRK1-24	9.86	493.1									
10DRK1	66	10DRK1-66	9.82	491.1									

D1-2.3. DV 10 KILLED IRON/MANGANESE, continued.

Sample Information					IRON				MANGANESE				
Experiment	Time	Name	Weigh t	Dilution	Fe, Measured	d.l.	Fe, µg/L	Fe µg/L, Reported	Mn, Measured	d.l.	Mn, µg/L	Mn, µg/L, Reported	Fe and Mn Source
10DRK1	139	10DRK1-139	9.81	490.7									
10DRK1	162	10DRK1-162	9.85	492.6									
10DRK1	190	10DRK1-190	9.80	489.8	16.35		8007	8007	3.27	0.14	1601	1601	032109cps_SeFeMn
10DRK1	270	10DRK1-270	9.82	491.1									
10DRK2	0	10DRK2-0	9.79	489.3	15.18		7428	7428	2.89	0.14	1415	1415	032109cps_SeFeMn
10DRK2	24	10DRK2-24	9.87	493.5									
10DRK2	66	10DRK2-66	9.80	490.0									
10DRK2	139	10DRK2-139	9.81	490.3									
10DRK2	162	10DRK2-162	9.83	491.5									
10DRK2	190	10DRK2-190	9.79	489.5	16.01		7839	7839	2.75	0.14	1348	1348	032109cps_SeFeMn
10DRK2	270	10DRK2-270	9.80	490.0									
10DRK3	0	10DRK3-0	9.79	489.7	14.99		7339	7339	3.04	0.14	1489	1489	032109cps_SeFeMn
10DRK3	24	10DRK3-24	9.86	492.8									
10DRK3	66	10DRK3-66	9.82	491.0									
10DRK3	139	10DRK3-139	9.82	491.1									
10DRK3	162	10DRK3-162	9.84	492.0									
10DRK3	190	10DRK3-190	9.82	490.9	16.24		7972	7972	2.60	0.14	1278	1278	032109cps_SeFeMn
10DRK3	270	10DRK3-270	9.86	493.1									
10DSK1	0	10DSK1-0	9.80	489.8	15.76		7721	7721	4.17	0.14	2040	2040	032109cps_SeFeMn
10DSK1	24	10DSK1-24	9.87	493.4									
10DSK1	66	10DSK1-66	9.79	489.6									
10DSK1	139	10DSK1-139	9.82	490.8									
10DSK1	162	10DSK1-162	9.85	492.4									
10DSK1	190	10DSK1-190	9.82	491.0	16.01		7863	7863	4.75	0.14	2331	2331	032109cps_SeFeMn
10DSK1	270	10DSK1-270	9.86	493.1									

D1-2.3. DV 10 KILLED IRON/MANGANESE, continued.

Sample Information					IRON				MANGANESE				
Experiment	Time	Name	Weigh t	Dilution	Fe, Measured	d.l.	Fe, µg/L	Fe µg/L, Reported	Mn, Measured	d.l.	Mn, µg/L	Mn, µg/L, Reported	Fe and Mn Source
10DSK2	0	10DSK2-0	9.78	489.2	15.79		7723	7723	4.12	0.14	2014	2014	032109cps_SeFeMn
10DSK2	24	10DSK2-24	9.86	493.2									
10DSK2	66	10DSK2-66	9.82	491.2									
10DSK2	139	10DSK2-139	9.82	491.1									
10DSK2	162	10DSK2-162	9.86	493.2									
10DSK2	190	10DSK2-190	9.81	490.3	16.64		8159	8159	4.68	0.14	2293	2293	032109cps_SeFeMn
10DSK2	270	10DSK2-270	9.85	492.3									
10DSK3	0	10DSK3-0	9.80	490.1	15.30		7500	7500	4.19	0.14	2054	2054	032109cps_SeFeMn
10DSK3	24	10DSK3-24	9.86	493.2									
10DSK3	66	10DSK3-66	9.81	490.7									
10DSK3	139	10DSK3-139	9.82	490.8									
10DSK3	162	10DSK3-162	9.85	492.7									
10DSK3	190	10DSK3-190	9.82	491.0	16.34		8024	8024	5.06	0.14	2486	2486	032109cps_SeFeMn
10DSK3	270	10DSK3-270	9.81	490.7									

D1-2.4. DV 25 KILLED IRON/MANGANESE.

Sample Information					IRON				MANGANESE				
Experiment	Time	Name	Weight	Dilution	Fe, Measured	d.l.	Fe, µg/L	Fe µg/L, Reported	Mn, Measured	d.l.	Mn, µg/L	Mn, µg/L, Reported	Fe and Mn Source
25DCK1	0	25DCK1-0	9.79	489.3	4.0	0.75	1950	1950	1.07	0.43	525	525	020909Aquant
25DCK1	72	25DCK1-72	9.79	489.7									
25DCK1	120	25DCK1-120	9.78	488.9	3.6	0.75	1777	1777	1.01	0.43	495	495	020909Aquant
25DCK1	216	25DCK1-216	9.81	490.7									
25DCK1	456	25DCK1-456	9.81	490.3	5.47	3.73	2683	2683	1.94	0.15	953	953	032009SeFeMn
25DCK2	0	25DCK2-0	9.75	487.6	3.8	0.75	1854	1854	1.04	0.43	509	509	020909Aquant
25DCK2	72	25DCK2-72	9.81	490.7									
25DCK2	120	25DCK2-120	9.79	489.4	3.6	0.75	1750	1750	1.00	0.43	491	491	020909Aquant
25DCK2	216	25DCK2-216	9.80	490.2									
25DCK2	456	25DCK2-456	9.81	490.5	5.06	3.73	2481	2481	1.81	0.15	889	889	032009SeFeMn
25DCK3	0	25DCK3-0	9.77	488.5	3.9	0.75	1904	1904	1.07	0.43	522	522	020909Aquant
25DCK3	72	25DCK3-72	9.81	490.7									
25DCK3	120	25DCK3-120	9.77	488.7	3.7	0.75	1799	1799	1.01	0.43	495	495	020909Aquant
25DCK3	216	25DCK3-216	9.81	490.5									
25DCK3	456	25DCK3-456	9.80	490.2	5.34	3.73	2617	2617	1.84	0.15	900	900	032009SeFeMn
25DRK1	0	25DRK1-0	9.77	488.5	3.6	0.75	1742	1742	3.15	0.43	1537	1537	020909Aquant
25DRK1	72	25DRK1-72	9.80	489.9									
25DRK1	120	25DRK1-120	9.78	488.8	3.6	0.75	1748	1748	3.45	0.43	1687	1687	020909Aquant
25DRK1	216	25DRK1-216	9.81	490.4									
25DRK1	456	25DRK1-456	9.81	490.3	5.46	3.73	2677	2677	4.43	0.15	2173	2173	032009SeFeMn
25DRK2	0	25DRK2-0	9.78	488.8	3.7	0.75	1817	1817	2.51	0.43	1229	1229	020909Aquant
25DRK2	72	25DRK2-72	9.81	490.6									
25DRK2	120	25DRK2-120	9.76	488.2	3.8	0.75	1862	1862	3.44	0.43	1678	1678	020909Aquant

D1-2.4. DV 25 KILLED IRON/MANGANESE, continued.

Sample Information					IRON				MANGANESE				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Fe, Measured**	**d.l.**	**Fe, µg/L**	**Fe µg/L, Reported**	**Mn, Measured**	**d.l.**	**Mn, µg/L**	**Mn, µg/L, Reported**	**Fe and Mn Source**
25DRK2	216	25DRK2-216	9.88	494.1									
25DRK2	456	25DRK2-456	9.81	490.3	5.27	3.73	2585	2585	4.02	0.15	1972	1972	032009SeFeMn
25DSK1	0	25DSK1-0	9.78	489.1	3.6	0.75	1756	1756	3.09	0.43	1511	1511	020909Aquant
25DSK1	72	25DSK1-72	9.80	489.8									
25DSK1	120	25DSK1-120	9.76	488.1	4.0	0.75	1932	1932	4.35	0.43	2121	2121	020909Aquant
25DSK1	216	25DSK1-216	9.81	490.5									
25DSK1	456	25DSK1-456	9.80	490.2	9.06	3.73	4443	4443	5.17	0.15	2535	2535	032009SeFeMn
25DSK2	0	25DSK2-0	9.80	489.9	3.6	0.75	1769	1769	3.48	0.43	1705	1705	020909Aquant
25DSK2	72	25DSK2-72	9.81	490.3									
25DSK2	120	25DSK2-120	9.78	489.0	3.6	0.75	1752	1752	4.35	0.43	2127	2127	020909Aquant
25DSK2	216	25DSK2-216	9.81	490.3									
25DSK2	456	25DSK2-456	9.80	490.0	5.63	3.73	2759	2759	5.25	0.15	2573	2573	032009SeFeMn
25DSK3	0	25DSK3-0	9.76	488.0	3.8	0.75	1872	1872	3.83	0.43	1869	1869	020909Aquant
25DSK3	72	25DSK3-72	9.80	489.9									
25DSK3	120	25DSK3-120	9.78	489.0	3.6	0.75	1764	1764	4.74	0.43	2316	2316	020909Aquant
25DSK3	216	25DSK3-216	9.80	490.0									
25DSK3	456	25DSK3-456	9.80	490.2	5.05	3.73	2473	2473	4.96	0.15	2430	2430	032009SeFeMn

Shaded fields = data not collected for those samples.

Table D1-3. Selenium ICP-MS data for Smoky Canyon Mine Saturated Rate Experiments.
D1-3.1. SC 10 LIVE SELENIUM.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
10SCL1	0	10SCL1-0	9.80	490.2	17.64	0.08	8647	8647	032309cpsrecalc
10SCL1	12	10SCL1-12	9.89	494.6	14.32	0.08	12647	12647	032309cpsrecalc
10SCL1	24	10SCL1-24	9.84	491.9	18.81	0.04	10655	10655	032309cps\SeLtdcps
10SCL1	36	10SCL1-36	9.86	492.9	13.92	0.04	10677	10677	032309cps\SeLtdcps
10SCL1	48	10SCL1-48	9.81	490.4	16.04	0.04	7914	7914	062008Aquant
10SCL1	60	10SCL1-60	9.86	492.9	13.38	0.3	7600	7600	2008621_M_quant
10SCL1	84	10SCL1-84	9.85	492.4	9.127	0.3	4888	4888	2008621_M_quant
10SCL1	108	10SCL1-108	9.79	489.7	3.01	0.09	1535	1535	062508recalc
10SCL1	132	10SCL1-132	9.85	492.3	0.603	0.09	402	402	062508recalc
10SCL1	156	10SCL1-156	9.85	492.4	0.29	0.09	271	271	062508recalc
10SCL1	246	10SCL1-246	9.82	490.9	-0.1508	0.09	-74	44	071408quant
10SCL2	0	10SCL2-0	9.85	492.6	16.89	0.08	8320	8320	032309cpsrecalc
10SCL2	12	10SCL2-12	9.88	493.8	15.23	0.08	13703	13703	032309cpsrecalc
10SCL2	24	10SCL1-24	9.85	492.4	18.43	0.04	13488	13488	032309cps\SeLtdcps
10SCL2	36	10SCL2-36	9.85	492.7	17.32	0.04	13114	13114	032309cps\SeLtdcps
10SCL2	48	10SCL2-48	9.81	490.7	17.18	0.04	8479	8479	032309cps\SeLtdcps
10SCL2	60	10SCL2-60	9.86	492.9	16.59	0.3	8374	8374	2008621_M_quant
10SCL2	84	10SCL2-84	9.86	492.8	7.355	0.3	3867	3867	2008621_M_quant
10SCL2	108	10SCL2-108	9.77	488.7	1.69	0.09	1027	1027	062508recalc
10SCL2	132	10SCL2-132	9.83	491.6	0.072	0.09	27	44	062508recalc
10SCL2	156	10SCL2-156	9.79	489.7	0.12	0.09	158	158	062508recalc
10SCL2	246	10SCL2-246	9.80	490.1	-0.183	0.09	-90	44	071408quant
10SCL3	0	10SCL3-0	9.85	492.5	16.46	0.08	8108	8108	032309cpsrecalc
10SCL3	12	10SCL3-12	9.87	493.7	17.72	0.08	13671	13671	032309cpsrecalc
10SCL3	24	10SCL1-24	9.84	491.8	21.93	0.04	13741	13741	032309cps\SeLtdcps
10SCL3	36	10SCL3-36	9.86	492.8	16.16	0.04	13203	13203	032309cps\SeLtdcps
10SCL3	48	10SCL3-48	9.79	489.6	17.00	0.04	8862	8862	032309cps\SeLtdcps
10SCL3	60	10SCL3-60	9.86	492.8	18.8	0.3	8471	8471	2008621_M_quant

D1-3.1. SC 10 LIVE SELENIUM, continued.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
10SCL3	84	10SCL3-84	9.85	492.4	10.04	0. 3	5185	5185	2008621_M_quant
10SCL3	108	10SCL3-108	9.79	489.5	2.48	0.09	1475	1475	062508recalc
10SCL3	132	10SCL3-132	9.84	492.2	0.202	0.09	165	165	062508recalc
10SCL3	156	10SCL3-156	9.81	490.6	0.24	0.09	196	196	062508recalc
10SCL3	246	10SCL3-246	9.84	491.8	0.02278	0.09	11	44	071408quant
10SRL1	0	10SRL1-0	9.85	492.4	20.51	0.08	10099	10099	032309cpsrecalc
10SRL1	12	10SRL1-12	9.95	497.3	19.43	0.08	12965	12965	032309cpsrecalc
10SRL1	24	10SRL1-24	9.80	490.0	20.37	0.04	11588	11588	032309cps\SeLtdcps
10SRL1	36	10SRL1-36	9.86	493.0	18.25	0.04	11661	11661	032309cps\SeLtdcps
10SRL1	48	10SRL1-48	9.80	490.0	14.59	0.04	7194	7194	032309cps\SeLtdcps
10SRL1	60	10SRL1-60	9.85	492.6	8.294	0.3	4255	4255	2008621_M_quant
10SRL1	84	10SRL1-84	9.85	492.5	0.881	0.3	1349	1349	2008621_M_quant
10SRL1	108	10SRL1-108	9.78	489.0	1.03	0.09	844	844	062508recalc
10SRL1	132	10SRL1-132	9.83	491.7	0.630	0.09	239	239	062508recalc
10SRL1	156	10SRL1-156	9.82	490.8	0.22	0.09	256	256	062508recalc
10SRL1	246	10SRL1-246	9.82	490.8	-0.2295	0.09	-113	44	071408quant
10SRL2	0	10SRL2-0	9.87	493.5	17.24	0.08	8508	8508	032309cpsrecalc
10SRL2	12	10SRL2-12	9.84	492.1	26.94	0.08	13169	13169	032309cpsrecalc
10SRL2	24	10SRL2-24	9.85	492.5	18.66	0.04	13992	13992	032309cps\SeLtdcps
10SRL2	36	10SRL2-36	9.83	491.6	17.63	0.04	13619	13619	032309cps\SeLtdcps
10SRL2	48	10SRL2-48	9.82	490.8	9.85	0.04	4875	4875	032309cps\SeLtdcps
10SRL2	60	10SRL2-60	9.85	492.6	7.432	0.3	3747	3747	2008621_M_quant
10SRL2	84	10SRL2-84	9.86	492.9	0.9193	0.3	407	407	2008621_M_quant
10SRL2	108	10SRL2-108	9.80	490.2	0.60	0.09	292	292	062508recalc
10SRL2	132	10SRL2-132	9.83	491.5	0.167	0.09	116	116	062508recalc
10SRL2	156	10SRL2-156	9.81	490.7	0.24	0.09	190	190	062508recalc
10SRL2	246	10SRL2-246	9.81	490.3	-0.3031	0.09	-149	44	071408quant
10SRL3	0	10SRL3-0	9.86	493.1	14.91	0.08	7354	7354	032309cpsrecalc
10SRL3	12	10SRL3-12	9.83	491.5	24.55	0.08	14440	14440	032309cpsrecalc
10SRL3	24	10SRL1-24	9.78	488.9	15.83	0.04	15024	15024	032309cps\SeLtdcps

D1-3.1. SC 10 LIVE SELENIUM, continued.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
10SRL3	36	10SRL3-36	9.85	492.6	19.75	0.04	15138	15138	032309cps\SeLtdcps
10SRL3	48	10SRL3-48	9.82	491.2	16.09	0.04	7952	7952	032309cps\SeLtdcps
10SRL3	60	10SRL3-60	9.85	492.7	14.14	0.3	7809	7809	2008621_M_quant
10SRL3	84	10SRL3-84	9.85	492.6	4.072	0.3	2072	2072	2008621_M_quant
10SRL3	108	10SRL3-108	9.78	488.8	0.87	0.09	502	502	062508recalc
10SRL3	132	10SRL3-132	9.83	491.5	0.615	0.09	524	524	062508recalc
10SRL3	156	10SRL3-156	9.81	490.7	0.60	0.09	312	312	062508recalc
10SRL3	246	10SRL3-246	9.82	491.2	-0.1354	0.09	-67	44	071408quant
10SSL1	0	10SSL1-0	9.86	492.8	26.34	0.08	12983	12983	032309cpsrecalc
10SSL1	12	10SSL1-12	9.82	490.8	18.38	0.08	13600	13600	032309cpsrecalc
10SSL1	24	10SSL1-24	9.86	492.9	20.12	0.04	13753	13753	032309cps\SeLtdcps
10SSL1	36	10SSL1-36	9.85	492.6	16.20	0.04	13743	13743	032309cps\SeLtdcps
10SSL1	48	10SSL1-48	9.81	490.4	17.38	0.04	8572	8572	032309cps\SeLtdcps
10SSL1	60	10SSL1-60	9.86	492.8	13.82	0.3	7382	7382	2008621_M_quant
10SSL1	84	10SSL1-84	9.87	493.3	5.209	0.3	2674	2674	2008621_M_quant
10SSL1	108	10SSL1-108	9.50	475.0	1.30	0.09	627	627	062508recalc
10SSL1	132	10SSL1-132	9.83	491.6	0.288	0.09	407	407	062508recalc
10SSL1	156	10SSL1-156	9.81	490.7	0.42	0.09	287	287	062508recalc
10SSL1	246	10SSL1-246	9.80	489.8	-0.0557	0.09	-27	44	071408quant
10SSL2	0	10SSL2-0	9.84	491.8	17.86	0.08	8783	8783	032309cpsrecalc
10SSL2	12	10SSL2-12	9.84	492.0	14.48	0.08	12443	12443	032309cpsrecalc
10SSL2	24	10SSL1-24	9.85	492.3	14.95	0.04	11072	11072	032309cps\SeLtdcps
10SSL2	36	10SSL2-36	9.85	492.7	14.98	0.04	11080	11080	032309cps\SeLtdcps
10SSL2	48	10SSL2-48	9.87	493.7	10.08	0.04	5016	5016	032309cps\SeLtdcps
10SSL2	60	10SSL2-60	9.82	490.9	8.07	0.3	5149	5149	2008621_M_quant
10SSL2	84	10SSL2-84	9.85	492.5	1.32	0.3	620	620	2008621_M_quant
10SSL2	108	10SSL2-108	9.79	489.4	0.96	0.09	767	767	062508recalc
10SSL2	132	10SSL2-132	9.85	492.5	0.646	0.09	317	317	062508recalc
10SSL2	156	10SSL2-156	9.81	490.6	0.36	0.09	241	241	062508recalc
10SSL2	246	10SSL2-246	9.83	491.3	-0.1346	0.09	-66	44	071408quant
10SSL3	0	10SSL3-0	9.85	492.3	11.47	0.08	5649	5649	032309cpsrecalc

D1-3.1. SC 10 LIVE SELENIUM, continued.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
10SSL3	12	10SSL3-12	9.84	492.1	15.39	0.08	11687	11687	032309cpsrecalc
10SSL3	24	10SSL1-24	9.84	491.8	22.32	0.04	10830	10830	032309cps\SeLtdcps
10SSL3	36	10SSL3-36	9.85	492.6	15.72	0.04	10847	10847	032309cps\SeLtdcps
10SSL3	48	10SSL3-48	9.81	490.5	10.23	0.04	5057	5057	032309cps\SeLtdcps
10SSL3	60	10SSL3-60	9.84	492.2	6.766	0.3	3316	3316	2008621_M_quant
10SSL3	84	10SSL3-84	9.85	492.7	1.456	0.3	706	706	2008621_M_quant
10SSL3	108	10SSL3-108	9.78	489.0	0.42	0.09	516	516	062508recalc
10SSL3	132	10SSL3-132	9.77	488.4	0.371	0.09	278	278	062508recalc
10SSL3	156	10SSL3-156	9.81	490.6	0.44	0.09	268	268	062508recalc
10SSL3	246	10SSL3-246	9.84	491.8	-0.07792	0.09	-38	44	071408quant

D1-3.2. SC 25 LIVE SELENIUM.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
25SCL1	0	25SCL1-0	9.802	490.1	21.48	6	10527	10527	010909Bcps
25SCL1	12	25SCL1-12	9.834	491.7	16.95	6	8333	8333	032309cpsrecalcFeMn
25SCL1	24	25SCL1-24	9.854	492.7	11.55	6	5689	5689	040409Bpart1cpssummary
25SCL1	36	25SCL1-36	9.825	491.3	7.75	6	3807	3807	040409Bpart1cpssummary
25SCL1	48	25SCL1-48	9.562	478.1	4.62	6	2208	2869	040409Bpart1cpssummary
25SCL1	60	25SCL1-60	9.833	491.6	0.36	0.30	176	176	062008Aquant
25SCL1	72	25SCL1-72	9.793	489.7	-0.03	0.11	-13	54	062008B25SC 60_72
25SCL1	96	25SCL1-96	9.836	491.8	-0.28	0.19	-135	93	071408quant
25SCL1	120	25SCL1-120	9.780	489.0	0.63	0.10	310	310	062508recalc
25SCL1	144	25SCL1-144	9.856	492.8	0.10	0.10	50	50	062508recalc
25SCL1	168	25SCL1-168	9.798	489.9	0.33	0.10	159	159	062508recalc
25SCL1	228	25SCL1-228	9.829	491.4	-0.27	0.19	-132	93	071408quant
25SCL2	0	25SCL2-0	9.830	491.5	22.81	6	11211	11211	010909Bcps
25SCL2	12	25SCL2-12	9.838	491.9	16.95	6	8337	8337	032309cpsrecalcFeMn
25SCL2	24	25SCL2-24	9.842	492.1	13.36	6	6575	6575	040409Bpart1cpssummary
25SCL2	36	25SCL2-36	9.847	492.3	6.53	6	3216	3216	040409Bpart1cpssummary
25SCL2	48	25SCL2-48	9.852	492.6	5.03	6	2480	2956	040409Bpart1cpssummary
25SCL2	60	25SCL2-60	9.841	492.0	0.73	0.30	360	360	062008Aquant
25SCL2	72	25SCL2-72	9.774	488.7	0.04	0.11	17	54	062008B25SC 60_72
25SCL2	96	25SCL2-96	9.812	490.6	-0.28	0.19	-138	93	071408quant
25SCL2	120	25SCL2-120	9.771	488.5	0.48	0.10	232	232	062508recalc
25SCL2	144	25SCL2-144	9.852	492.6	0.10	0.10	50	50	062508recalc
25SCL2	168	25SCL2-168	9.812	490.6	0.49	0.10	239	239	062508recalc
25SCL2	228	25SCL2-228	9.793	489.7	-0.31	0.19	-150	93	071408quant
25SCL3	0	25SCL3-0	9.820	491.0	24.33	6	11947	11947	010909Bcps
25SCL3	12	25SCL3-12	9.841	492.1	16.95	6	8339	8339	032309cpsrecalcFeMn
25SCL3	24	25SCL3-24	9.846	492.3	21.27	6	10472	10472	040409Bpart1cpssummary
25SCL3	36	25SCL3-36	9.840	492.0	12.17	6	5986	5986	040409Bpart1cpssummary

D1-3.2. SC 25 LIVE SELENIUM, continued.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
25SCL3	48	25SCL3-48	9.805	490.3	6.65	6	3258	3258	040409Bpart1cpssummary
25SCL3	60	25SCL3-60	9.813	490.6	2.48	0.30	1218	1218	062008Aquant
25SCL3	72	25SCL3-72	9.790	489.5	0.24	0.11	119	119	062008B25SC 60_72
25SCL3	96	25SCL3-96	9.829	491.5	-0.26	0.19	-127	**93**	071408quant
25SCL3	120	25SCL3-120	9.771	488.6	0.48	0.10	232	232	062508recalc
25SCL3	144	25SCL3-144	9.817	490.9	0.01	0.10	4	49	062508recalc
25SCL3	168	25SCL3-168	9.813	490.6	0.27	0.10	132	132	062508recalc
25SCL3	228	25SCL3-228	9.815	490.7	-0.23	0.19	-114	93	071408quant
25SRL1	0	25SRL1-0	9.853	492.6	24.05	6	11848	11848	010909Bcps
25SRL1	12	25SRL1-12	9.837	491.9	16.95	6	8336	8336	032309cpsrecalcFeMn
25SRL1	24	25SRL1-24	9.833	491.6	17.24	6	8477	8477	040409Bpart1cpssummary
25SRL1	36	25SRL1-36	9.838	491.9	12.80	6	6298	6298	040409Bpart1cpssummary
25SRL1	48	25SRL1-48	9.829	491.4	7.72	6	3795	3795	040409Bpart1cpssummary
25SRL1	60	25SRL1-60	9.845	492.2	0.46	0.30	224	224	062008Aquant
25SRL1	72	25SRL-1-72	9.780	489.0	0.07	0.11	34	54	062008B25SC 60_72
25SRL1	96	25SRL1-96	9.799	489.9	-0.19	0.19	-92	93	071408quant
25SRL1	120	25SRL1-120	9.796	489.8	0.40	0.10	194	194	062508recalc
25SRL1	144	25SRL1-144	9.848	492.4	0.10	0.10	50	50	062508recalc
25SRL1	168	25SRL1-168	9.816	490.8	0.15	0.10	73	73	062508recalc
25SRL1	228	25SRL1-228	9.822	491.1	-0.21	0.19	-105	93	071408quant
25SRL2	0	25SRL2-0	9.847	492.3	25.68	6	12643	12643	010909Bcps
25SRL2	12	25SRL2-12	9.861	493.1	16.95	6	8356	8356	032309cpsrecalcFeMn
25SRL2	24	25SRL2-24	9.838	491.9	15.84	6	7792	7792	040409Bpart1cpssummary
25SRL2	36	25SRL2-36	9.838	491.9	9.10	6	4476	4476	040409Bpart1cpssummary
25SRL2	48	25SRL2-48	9.842	492.1	1.41	6	696	2953	040409Bpart1cpssummary
25SRL2	60	25SRL2-60	9.829	491.4	0.54	0.30	264	264	062008Aquant
25SRL2	72	25SRL-2-72	9.804	490.2	0.11	0.11	54	54	062008B25SC 60_72
25SRL2	96	25SRL2-96	9.814	490.7	-0.20	0.19	-97	93	071408quant
25SRL2	120	25SRL2-120	9.784	489.2	0.95	0.10	465	465	062508recalc
25SRL2	144	25SRL2-144	9.855	492.7	0.07	0.10	35	49	062508recalc
25SRL2	168	25SRL2-168	9.818	490.9	0.24	0.10	117	117	062508recalc

D1-3.2. SC 25 LIVE SELENIUM, continued.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
25SRL2	228	25SRL2-228	9.831	491.5	-0.27	0.19	-132	93	071408quant
25SRL3	0	25SRL3-0	9.859	492.9	27.79	6	13699	13699	010909Bcps
25SRL3	12	25SRL3-12	9.841	492.1	16.95	6	8339	8339	032309cpsrecalcFeMn
25SRL3	24	25SRL3-24	9.855	492.8	15.30	6	7539	7539	040409Bpart1cpssummary
25SRL3	36	25SRL3-36	9.853	492.7	9.39	6	4624	4624	040409Bpart1cpssummary
25SRL3	48	25SRL3-48	9.843	492.2	3.09	6	1522	2953	040409Bpart1cpssummary
25SRL3	60	25SRL3-60	9.835	491.8	1.37	0.30	672	672	062008Aquant
25SRL3	72	25SRL3-72	9.776	488.8	0.54	0.11	262	262	062008B25SC 60_72
25SRL3	96	25SRL3-96	9.826	491.3	-0.20	0.19	-100	93	071408quant
25SRL3	120	25SRL3-120	9.669	483.5	0.32	0.10	153	153	062508recalc
25SRL3	144	25SRL3-144	9.807	490.3	0.10	0.10	47	49	062508recalc
25SRL3	168	25SRL3-168	9.818	490.9	0.40	0.10	196	196	062508recalc
25SRL3	228	25SRL3-228	9.826	491.3	-0.15	0.19	-72	93	071408quant
25SSL1	0	25SSL1-0	9.772	488.6	26.72	6	13055	13055	010909Bcps
25SSL1	12	25SSL1-12	9.830	491.5	16.95	6	8330	8330	032309cpsrecalcFeMn
25SSL1	24	25SSL1-24	9.829	491.4	19.80	6	9732	9732	040409Bpart1cpssummary
25SSL1	36	25SSL1-36	9.809	490.5	16.14	6	7916	7916	040409Bpart1cpssummary
25SSL1	48	25SSL1-48	9.857	492.9	7.53	6	3711	3711	040409Bpart1cpssummary
25SSL1	60	25SSL1-60	9.853	492.6	6.77	0.30	3337	3337	062008Aquant
25SSL1	72	25SSL-1-72	9.499	475.0	2.83	0.11	1346	1346	062008B25SC 60_72
25SSL1	96	25SSL1-96	9.815	490.8	-0.18	0.19	-86	93	071408quant
25SSL1	120	25SSL1-120	9.820	491.0	0.79	0.10	389	389	062508recalc
25SSL1	144	25SSL1-144	10.130	506.5	0.17	0.10	84	84	062508recalc
25SSL1	168	25SSL1-168	9.819	491.0	0.38	0.10	185	185	062508recalc
25SSL1	228	25SSL1-228	9.819	491.0	-0.22	0.19	-107	93	071408quant
25SSL2	0	25SSL2-0	9.888	494.4	24.66	6	12193	12193	010909Bcps
25SSL2	12	25SSL2-12	9.837	491.9	16.95	6	8336	8336	032309cpsrecalcFeMn
25SSL2	24	25SSL2-24	9.839	492.0	17.73	6	8722	8722	040409Bpart1cpssummary
25SSL2	36	25SSL2-36	9.848	492.4	15.08	6	7427	7427	040409Bpart1cpssummary
25SSL2	48	25SSL2-48	9.855	492.8	6.80	6	3350	3350	040409Bpart1cpssummary

D1-3.2. SC 25 LIVE SELENIUM, continued.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
25SSL2	60	25SSL2-60	9.835	491.8	3. 57	0.30	1757	1757	062008Aquant
25SSL2	72	25SSL-2-72	9.788	489.4	0.97	0.11	476	476	062008B25SC 60_72
25SSL2	96	25SSL2-96	9.820	491.0	-0.08	0.19	-40	93	071408quant
25SSL2	120	25SSL2-120	9.763	488.1	0.71	0.10	348	348	062508recalc
25SSL2	144	25SSL2-144	9.636	481.8	0.18	0.10	88	88	062508recalc
25SSL2	168	25SSL2-168	9.763	488.1	0.44	0.10	216	216	062508recalc
25SSL2	228	25SSL2-228	9.838	491.9	-0.25	0.19	-124	93	071408quant
25SSL3	0	25SSL3-0	9.894	494.7	28.42	6	14059	14059	010909Bcps
25SSL3	12	25SSL3-12	9.845	492.3	16.95	6	8343	8343	032309cpsrecalcFeMn
25SSL3	24	25SSL3-24	9.831	491.6	21.90	6	10763	10763	040409Bpart1cpssummary
25SSL3	36	25SSL3-36	9.857	492.8	17.49	6	8618	8618	040409Bpart1cpssummary
25SSL3	48	25SSL3-48	9.854	492.7	10.40	6	5125	5125	040409Bpart1cpssummary
25SSL3	60	25SSL3-60	9.844	492.2	6.36	0.30	3131	3131	062008Aquant
25SSL3	72	25SSL-3-72	9.780	489.0	3.00	0.11	1467	1467	062008B25SC 60_72
25SSL3	96	25SSL3-96	9.811	490.6	-0.17	0.19	-84	93	071408quant
25SSL3	120	25SSL3-120	9.830	491.5	0.63	0.10	311	311	062508recalc
25SSL3	144	25SSL3-144	9.776	488.8	0.33	0.10	160	160	062508recalc
25SSL3	168	25SSL3-168	9.763	488.1	0.50	0.10	246	246	062508recalc
25SSL3	228	25SSL3-228	9.807	490.4	-0.16	0.19	-79	93	071408quant

D1-3.3. SC 10 KILLED SELENIUM.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
10SCK1	0	10SCK1-0	9.852	492.6	5.6	0.53	2739	2739	040409B-part1cps
10SCK1	48	10SCK1-48	9.8278	491.39	34.5	0.53	16928	16928	040409B-part1cps
10SCK1	96	10SCK1-96	9.8638	493.19	24.5	0.53	12058	12058	040409B-part1cps
10SCK1	144	10SCK1-144	9.835	491.75	21.9	0.09	10764	10764	062508recalc
10SCK2	0	10SCK2-0	8.721	436.05	9.2	0.19	4008	4008	0718quant
10SCK2	48	10SCK2-48	8.27	413.5	8.4	0.19	3480	3480	0718quant
10SCK2	96	10SCK2-96	8.145	407.25	9.1	0.19	3707	3707	0718quant
10SCK2	144	10SCK2-144	9.8342	491.71	18.8	0.09	9222	9222	062508recalc
10SCK3	0	10SCK3-0	8.58	429	9.9	0.19	4238	4238	0718quant
10SCK3	48	10SCK3-48	8.62	431	9.0	0.19	3894	3894	0718quant
10SCK3	96	10SCK3-96	7.441	372.05	7.4	0.19	2741	2741	0718quant
10SCK3	144	10SCK3-144	9.8343	491.715	19.7	0.09	9669	9669	062508recalc
10SRK1	0	10SRK1-0	9.8471	492.355	50.0	0.53	24618	24618	040409B-part1cps
10SRK1	48	10SRK1-48	9.8667	493.335	35.6	0.53	17543	17543	040409B-part1cps
10SRK1	96	10SRK1-96	9.8649	493.245	23.3	0.53	11507	11507	040409B-part1cps
10SRK1	144	10SRK1-144	9.7213	486.065	22.7	0.09	11027	11027	062508recalc
10SRK2	0	10SRK2-0	8.413	420.65	8.6	0.19	3613	3613	0718quant
10SRK2	48	10SRK2-48	8.046	402.3	8.7	0.19	3481	3481	0718quant
10SRK2	96	10SRK2-96	7.989	399.45	8.7	0.19	3458	3458	0718quant
10SRK2	144	10SRK2-144	9.8498	492.49	14.1	0.09	6938	6938	062508recalc
10SRK3	0	10SRK3-0	8.751	437.55	9.1	0.19	3986	3986	0718quant
10SRK3	48	10SRK3-48	7.513	375.65	8.6	0.19	3240	3240	0718quant
10SRK3	96	10SRK3-96	8.034	401.7	9.1	0.19	3658	3658	0718quant
10SRK3	144	10SRK3-144	9.832	491.6	17.7	0.09	8716	8716	062508recalc
10SSK1	0	10SSK1-0	9.8576	492.88	28.9	0.53	14239	14239	040409B-part1cps
10SSK1	48	10SSK1-48	9.8451	492.255	45.6	0.53	22427	22427	040409B-part1cps
10SSK1	96	10SSK1-96	9.851	492.55	58.9	0.53	29006	29006	040409B-part1cps
10SSK1	144	10SSK1-144	9.8572	492.86	17.6	0.09	8653	8653	062508recalc
10SSK2	0	10SSK2-0	8.334	416.7	9.4	0.19	3918	3918	0718quant

D1-3.3. SC 10 KILLED SELENIUM, continued.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
10SSK2	48	10SSK2-48	8.664	433.2	9.3	0.19	4039	4039	0718quant
10SSK2	96	10SSK2-96	7.899	394.95	8.0	0.19	3166	3166	0718quant
10SSK2	144	10SSK2-144	9.845	492.25	18.8	0.09	9262	9262	062508recalc
10SSK3	0	10SSK3-0	8.62	431	9.5	0.19	4096	4096	0718quant
10SSK3	48	10SSK3-48	9.054	452.7	10.1	0.19	4577	4577	0718quant
10SSK3	96	10SSK3-96	7.876	393.8	8.2	0.19	3230	3230	0718quant
10SSK3	144	10SSK3-144	9.8478	492.39	19.9	0.09	9793	9793	062508recalc

D1-3.4. SC 25 KILLED SELENIUM.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
25SCK1	0	25SCK1-0	9.448	472.4	9.98	0.25	4715	4715	0721quant
25SCK1	48	25SCK1-48	8.272	413.6	7.99	0.25	3306	3306	0721quant
25SCK1	96	25SCK1-96	7.916	395.8	8.35	0.25	3303	3303	0721quant
25SCK1	144	25SCK1-144	9.836	491.8	18.31	0.09	9004	9004	062508recalc
25SCK1	276	25SCK1-276	9.912	495.6	10.45	0.25	5179	5179	0721quant
25SCK2	0	25SCK2-0	9.817	490.9	11.26	0.19	5527	5527	0718quant
25SCK2	48	25SCK2-48	9.156	457.8	9.29	0.19	4253	4253	0718quant
25SCK2	96	25SCK2-96	8.473	423.7	9.33	0.19	3953	3953	0718quant
25SCK2	144	25SCK2-144	9.839	491.9	12.92	0.09	6354	6354	062508recalc
25SCK2	276	25SCK2-276	10.400	520.0	10.36	0.25	5387	5387	0721quant
25SCK3	0	25SCK3-0	9.274	463.7	9.92	0.19	4598	4598	0718quant
25SCK3	48	25SCK3-48	9.272	463.6	9.99	0.19	4632	4632	0718quant
25SCK3	96	25SCK3-96	7.268	363.4	7.54	0.19	2740	2740	0718quant
25SCK3	144	25SCK3-144	9.849	492.4	19.85	0.09	9774	9774	062508recalc
25SCK3	276	25SCK3-276	9.347	467.4	9.19	0.25	4293	4293	0721quant
25SRK1	0	25SRK1-0	8.951	447.6	9.34	0.25	4181	4181	0721quant
25SRK1	48	25SRK1-48	8.053	402.7	8.18	0.25	3295	3295	0721quant
25SRK1	96	25SRK1-96	8.596	429.8	8.46	0.25	3636	3636	0721quant
25SRK1	144	25SRK1-144	9.836	491.8	19.89	0.09	9780	9780	062508recalc
25SRK1	276	25SRK1-276	9.525	476.3	10.20	0.25	4858	4858	0721quant
25SRK2	0	25SRK2-0	8.668	433.4	9.23	0.19	3999	3999	0718quant
25SRK2	48	25SRK2-48	7.938	396.9	8.50	0.19	3375	3375	0718quant
25SRK2	96	25SRK2-96	8.626	431.3	8.70	0.19	3754	3754	0718quant
25SRK2	144	25SRK2-144	9.846	492.3	12.15	0.09	5983	5983	062508recalc
25SRK2	276	25SRK2-276	9.425	471.3	9.64	0.25	4541	4541	0721quant
25SRK3	0	25SRK3-0	9.128	456.4	9.41	0.19	4293	4293	0718quant
25SRK3	48	25SRK3-48	8.431	421.6	9.01	0.19	3796	3796	0718quant
25SRK3	96	25SRK3-96	8.919	446.0	10.14	0.19	4522	4522	0718quant
25SRK3	144	25SRK3-144	9.859	492.9	15.94	0.09	7857	7857	062508recalc

D1-3.4. SC 25 KILLED SELENIUM, continued.

Sample Information					SELENIUM				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Se, Measured**	**d.l.**	**Se, µg/L**	**Se µg/L, Reported**	**Se Source**
25SRK3	276	25SRK3-276	9.859	493.0	10.05	0.25	4954	4954	0721quant
25SSK1	0	25SSK1-0	7.853	392.7	8.37	0.25	3286	3286	0721quant
25SSK1	48	25SSK1-48	7.819	391.0	7.89	0.25	3085	3085	0721quant
25SSK1	96	25SSK1-96	7.814	390.7	7.56	0.25	2954	2954	0721quant
25SSK1	144	25SSK1-144	9.778	488.9	16.27	0.09	7955	7955	062508recalc
25SSK1	276	25SSK1-276	9.559	478.0	9.31	0.25	4448	4448	0721quant
25SSK2	0	25SSK2-0	7.325	366.3	7.68	0.19	2812	2812	0718quant
25SSK2	48	25SSK2-48	7.818	390.9	8.83	0.19	3452	3452	0718quant
25SSK2	96	25SSK2-96	8.384	419.2	8.69	0.19	3643	3643	0718quant
25SSK2	144	25SSK2-144	9.842	492.1	17.48	0.09	8600	8600	062508recalc
25SSK2	276	25SSK2-276	9.453	472.7	10.21	0.25	4826	4826	0721quant
25SSK3	0	25SSK3-0	7.675	383.8	8.41	0.19	3226	3226	0718quant
25SSK3	48	25SSK3-48	7.987	399.4	8.77	0.19	3502	3502	0718quant
25SSK3	96	25SSK3-96	9.226	461.3	9.85	0.19	4546	4546	0718quant
25SSK3	144	25SSK3-144	9.800	490.0	14.82	0.09	7262	7262	062508recalc
25SSK3	276	25SSK3-276	10.070	503.5	10.43	0.25	5252	5252	0721quant

Table D1-4. Iron and Manganese ICP-MS data for Smoky Canyon Mine Saturated Rate Experiments.

D1-4.1. SC 10 LIVE IRON/MANGANESE.

Sample Information					IRON				MANGANESE				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Fe, Measured**	**d.l.**	**Fe, µg/L**	**Fe µg/L, Reported**	**Mn, Measured**	**d.l.**	**Mn, µg/L**	**Mn, µg/L, Reported**	**Fe and Mn Source**
10SCL1	0	10SCL1-0	9.80	490.2	-0.8	1.7	-392	809	0.31	0.1	0.0	49	032309cpsrecalc
10SCL1	12	10SCL1-12	9.89	494.6	-0.7	1.7	816	816	0.24	0.1	49	49	032309cpsrecalc
10SCL1	24	10SCL1-24	9.84	491.9	-7.52	1.7	812	812	-0.05	0.1	49	49	2008621_M_quant
10SCL1	36	10SCL1-36	9.86	492.9	-0.85	1.7	838	838	-0.10	0.1	49	49	071408quant
10SCL1	48	10SCL1-48	9.81	490.4	-4.06	1.0	490	490	0.03	0.06	29	29	062008Aquant
10SCL1	60	10SCL1-60	9.86	492.9	-2.33	1.5	739	739	0.11	0.1	53	53	2008621_M_quant
10SCL1	84	10SCL1-84	9.85	492.4	-2.36	1.5	739	739	0.10	0.1	51	51	2008621_M_quant
10SCL1	108	10SCL1-108	9.79	489.7	-0.05	1.4	686	686	-0.05	0.1	49	49	062508recalc
10SCL1	132	10SCL1-132	9.85	492.3	-0.05	1.4	689	689	-0.05	0.1	49	49	062508recalc
10SCL1	156	10SCL1-156	9.85	492.4	7.83	1.4	3855	3855	1.53	0.1	755	755	062508recalc
10SCL1	246	10SCL1-246	9.82	490.9	0.08	1.7	835	835	0.01	0.1	49	49	071408quant
10SCL2	0	10SCL2-0	9.85	492.6	0.6	1.7	813	813	0.17	0.1	86	86	032309cpsrecalc
10SCL2	12	10SCL2-12	9.88	493.8	-1.0	1.7	815	815	0.24	0.1	49	49	032309cpsrecalc
10SCL2	24	10SCL1-24	9.85	492.4	-7.677	1.7	813	813	-0.03	0.1	49	49	2008621_M_quant
10SCL2	36	10SCL2-36	9.85	492.7	0.17	1.7	838	838	-0.12	0.1	49	49	071408quant
10SCL2	48	10SCL2-48	9.81	490.7	-4.92	1.0	491	491	0.02	0.06	29	29	062008Aquant
10SCL2	60	10SCL2-60	9.86	492.9	-2.55	1.5	739	739	0.10	0.1	49	49	062008Aquant
10SCL2	84	10SCL2-84	9.86	492.8	-2.67	1.5	739	739	0.12	0.1	60	60	2008612quantxls
10SCL2	108	10SCL2-108	9.77	488.7	0.00	1.4	684	684	0.00	0.1	49	49	062508recalc
10SCL2	132	10SCL2-132	9.83	491.6	0.00	1.4	688	688	0.00	0.1	49	49	062508recalc
10SCL2	156	10SCL2-156	9.79	489.7	7.51	1.4	3679	3679	1.72	0.1	841	841	062508recalc
10SCL2	246	10SCL2-246	9.80	490.1	-0.27	1.7	833	833	0.02	0.1	49	49	071408quant
10SCL3	0	10SCL3-0	9.85	492.5	-0.9	1.7	813	813	0.14	0.3	173	148	032309cpsrecalc
10SCL3	12	10SCL3-12	9.87	493.7	-1.2	1.7	815	815	0.23	0.1	49	49	032309cpsrecalc
10SCL3	24	10SCL1-24	9.84	491.8	-6.966	1.7	811	811	0.01	0.1	49	49	2008621_M_quant
10SCL3	36	10SCL3-36	9.86	492.8	-0.35	1.7	838	838	-0.12	0.1	49	49	071408quant
10SCL3	48	10SCL3-48	9.79	489.6	-5.27	1.0	490	490	0.02	0.06	29	29	062008Aquant

D1-4.1. SC 10 LIVE IRON/MANGANESE, continued.

Sample Information					IRON				MANGANESE				
Experiment	Time	Name	Weight	Dilution	Fe, Measured	d.l.	Fe, µg/L	Fe µg/L, Reported	Mn, Measured	d.l.	Mn, µg/L	Mn, µg/L, Reported	Fe and Mn Source
10SCL3	60	10SCL3-60	9.86	492.8	-2.64	1.5	739	739	0.11	0.1	56	56	062008Aquant
10SCL3	84	10SCL3-84	9.85	492.4	-1.57	1.5	739	739	0.19	0.1	91	91	2008612quantxls
10SCL3	108	10SCL3-108	9.79	489.5	0.06	1.4	685	685	0.06	0.1	49	49	062508recalc
10SCL3	132	10SCL3-132	9.84	492.2	0.06	1.4	689	689	0.06	0.1	49	49	062508recalc
10SCL3	156	10SCL3-156	9.81	490.6	7.49	1.4	3676	3676	1.94	0.1	953	953	062508recalc
10SCL3	246	10SCL3-246	9.84	491.8	0.03	1.7	836	836	0.05	0.1	49	49	071408quant
10SRL1	0	10SRL1-0	9.85	492.4	-0.8	1.7	812	812	0.20	0.3	173	148	032309cpsrecalc
10SRL1	12	10SRL1-12	9.95	497.3	-1.2	1.7	821	821	0.43	0.1	199	199	032309cpsrecalc
10SRL1	24	10SRL1-24	9.80	490.0	-6.967	1.7	808	808	0.13	0.1	63	63	2008621_M_quant
10SRL1	36	10SRL1-36	9.86	493.0	-0.38	1.7	838	838	-0.06	0.1	49	49	071408quant
10SRL1	48	10SRL1-48	9.80	490.0	-5.41	1.0	490	490	0.25	0.06	121	121	062008Aquant
10SRL1	60	10SRL1-60	9.85	492.6	-1.48	1.5	739	739	0.35	0.1	172	172	062008Aquant
10SRL1	84	10SRL1-84	9.85	492.5	-0.05	1.5	739	739	0.46	0.1	225	225	2008612quantxls
10SRL1	108	10SRL1-108	9.78	489.0	0.44	1.4	214	685	0.44	0.1	214	214	062508recalc
10SRL1	132	10SRL1-132	9.83	491.7	0.44	1.4	216	688	0.44	0.1	216	216	062508recalc
10SRL1	156	10SRL1-156	9.82	490.8	7.43	1.4	3647	3647	1.97	0.1	964	964	062508recalc
10SRL1	246	10SRL1-246	9.82	490.8	-0.23	1.7	834	834	0.03	0.1	49	49	071408quant
10SRL2	0	10SRL2-0	9.87	493.5	-1.1	1.7	814	814	0.21	0.3	174	148	032309cpsrecalc
10SRL2	12	10SRL2-12	9.84	492.1	-1.2	1.7	812	812	0.34	0.1	169	169	032309cpsrecalc
10SRL2	24	10SRL2-24	9.85	492.5	-7.282	1.7	813	813	0.06	0.1	49	49	2008621_M_quant
10SRL2	36	10SRL2-36	9.83	491.6	-0.35	1.7	836	836	-0.08	0.1	49	49	071408quant
10SRL2	48	10SRL2-48	9.82	490.8	-3.26	1.0	491	491	0.16	0.06	78	78	062008Aquant
10SRL2	60	10SRL2-60	9.85	492.6	-2.54	1.5	739	739	0.29	0.1	144	144	062008Aquant
10SRL2	84	10SRL2-84	9.86	492.9	-1.71	1.5	739	739	0.37	0.1	185	185	2008612quantxls
10SRL2	108	10SRL2-108	9.80	490.2	0.34	1.4	167	686	0.34	0.1	167	167	062508recalc
10SRL2	132	10SRL2-132	9.83	491.5	0.34	1.4	167	688	0.34	0.1	167	167	062508recalc
10SRL2	156	10SRL2-156	9.81	490.7	7.65	1.4	3754	3754	1.93	0.1	946	946	062508recalc
10SRL2	246	10SRL2-246	9.81	490.3	-0.27	1.7	834	834	0.03	0.1	49	49	071408quant
10SRL3	0	10SRL3-0	9.86	493.1	-1.0	1.7	814	814	0.29	0.3	174	148	032309cpsrecalc
10SRL3	12	10SRL3-12	9.83	491.5	2.0	1.7	997	997	0.54	0.3	246	246	032309cpsrecalc

D1-4.1. SC 10 LIVE IRON/MANGANESE, continued.

Sample Information					IRON				MANGANESE				
Experiment	Time	Name	Weight	Dilution	Fe, Measured	d.l.	Fe, µg/L	Fe µg/L, Reported	Mn, Measured	d.l.	Mn, µg/L	Mn, µg/L, Reported	Fe and Mn Source
10SRL3	24	10SRL1-24	9.78	488.9	-5.968	1.7	807	807	0.16	0.1	78	78	2008621_M_quant
10SRL3	36	10SRL3-36	9.85	492.6	0.91	1.7	837	837	-0.07	0.1	49	49	071408quant
10SRL3	48	10SRL3-48	9.82	491.2	-4.99	1.0	491	491	0.19	0.06	95	95	062008Aquant
10SRL3	60	10SRL3-60	9.85	492.7	-2.79	1.5	739	739	0.38	0.1	188	188	062008Aquant
10SRL3	84	10SRL3-84	9.85	492.6	-1.26	1.5	739	739	0.53	0.1	263	263	2008612quantxls
10SRL3	108	10SRL3-108	9.78	488.8	0.38	1.4	187	684	0.38	0.1	187	187	062508recalc
10SRL3	132	10SRL3-132	9.83	491.5	0.38	1.4	188	688	0.38	0.1	188	188	062508recalc
10SRL3	156	10SRL3-156	9.81	490.7	7.66	1.4	3756	3756	2.06	0.1	1011	1011	062508recalc
10SRL3	246	10SRL3-246	9.82	491.2	-0.24	1.7	835	835	0.04	0.1	49	49	071408quant
10SSL1	0	10SSL1-0	9.86	492.8	-1.0	1.7	813	813	0.25	0.3	173	148	032309cpsrecalc
10SSL1	12	10SSL1-12	9.82	490.8	-1.2	1.7	810	810	0.41	0.3	196	196	032309cpsrecalc
10SSL1	24	10SSL1-24	9.86	492.9	-5.877	1.7	813	813	0.14	0.1	69	69	2008621_M_quant
10SSL1	36	10SSL1-36	9.85	492.6	0.48	1.7	837	837	-0.07	0.1	49	49	071408quant
10SSL1	48	10SSL1-48	9.81	490.4	0.16	1.0	490	490	1.79	0.06	877	877	062008Aquant
10SSL1	60	10SSL1-60	9.86	492.8	-2.24	1.5	739	739	0.38	0.1	185	185	062008Aquant
10SSL1	84	10SSL1-84	9.87	493.3	1.12	1.5	740	740	0.46	0.1	229	229	2008612quantxls
10SSL1	108	10SSL1-108	9.50	475.0	0.37	1.4	175	665	0.37	0.1	175	175	062508recalc
10SSL1	132	10SSL1-132	9.83	491.6	0.37	1.4	181	688	0.37	0.1	181	181	062508recalc
10SSL1	156	10SSL1-156	9.81	490.7	7.93	1.4	3889	3889	1.87	0.1	920	920	062508recalc
10SSL1	246	10SSL1-246	9.80	489.8	0.11	1.7	833	833	-0.03	0.1	49	49	071408quant
10SSL2	0	10SSL2-0	9.84	491.8	-1.0	1.7	812	812	0.31	0.3	173	173	032309cpsrecalc
10SSL2	12	10SSL2-12	9.84	492.0	-1.3	1.7	812	812	0.32	0.1	157	157	032309cpsrecalc
10SSL2	24	10SSL1-24	9.85	492.3	-3.144	1.7	812	812	0.17	0.1	83	83	2008621_M_quant
10SSL2	36	10SSL2-36	9.85	492.7	-0.13	1.7	838	838	-0.07	0.1	49	49	071408quant
10SSL2	48	10SSL2-48	9.87	493.7	-0.14	1.0	494	494	1.68	0.06	829	829	062008Aquant
10SSL2	60	10SSL2-60	9.82	490.9	-3.27	1.5	736	736	0.36	0.1	177	177	062008Aquant
10SSL2	84	10SSL2-84	9.85	492.5	-1.98	1.5	739	739	0.45	0.1	221	221	2008612quantxls
10SSL2	108	10SSL2-108	9.79	489.4	0.40	1.4	194	685	0.40	0.1	194	194	062508recalc
10SSL2	132	10SSL2-132	9.85	492.5	0.40	1.4	195	690	0.40	0.1	195	195	062508recalc
10SSL2	156	10SSL2-156	9.81	490.6	7.73	1.4	3794	3794	2.05	0.1	1007	1007	062508recalc
10SSL2	246	10SSL2-246	9.83	491.3	-0.19	1.7	835	835	-0.01	0.1	49	49	071408quant

D1-4.1. SC 10 LIVE IRON/MANGANESE, continued.

Sample Information					IRON				MANGANESE				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Fe, Measured**	**d.l.**	**Fe, µg/L**	**Fe µg/L, Reported**	**Mn, Measured**	**d.l.**	**Mn, µg/L**	**Mn, µg/L, Reported**	**Fe and Mn Source**
10SSL3	0	10SSL3-0	9.85	492.3	-1.2	1.7	812	812	0.24	0.3	173	148	032309cpsrecalc
10SSL3	12	10SSL3-12	9.84	492.1	-1.2	1.7	812	812	0.33	0.1	161	161	032309cpsrecalc
10SSL3	24	10SSL1-24	9.84	491.8	-5.823	1.7	811	811	0.09	49	49	24188	2008621_M_quant
10SSL3	36	10SSL3-36	9.85	492.6	-0.03	1.7	837	837	-0.09	0.1	49	49	071408quant
10SSL3	48	10SSL3-48	9.81	490.5	-2.53	1.0	491	491	0.24	0.06	120	120	062008Aquant
10SSL3	60	10SSL3-60	9.84	492.2	-2.28	1.5	738	738	0.38	0.1	188	188	062008Aquant
10SSL3	84	10SSL3-84	9.85	492.7	-2.09	1.5	739	739	0.43	0.1	213	213	2008612quantxls
10SSL3	108	10SSL3-108	9.78	489.0	0.37	1.4	179	685	0.37	0.1	179	179	062508recalc
10SSL3	132	10SSL3-132	9.77	488.4	0.37	1.4	178	684	0.37	0.1	178	178	062508recalc
10SSL3	156	10SSL3-156	9.81	490.6	8.00	1.4	3924	3924	2.05	0.1	1007	1007	062508recalc
10SSL3	246	10SSL3-246	9.84	491.8	-0.09	1.7	836	836	-0.02	0.1	49	49	071408quant

D1-4.2. SC 25 LIVE IRON/MANGANESE.

Sample Information					IRON				MANGANESE				
Experiment	Time	Name	Weight	Dilution	Fe, Measured	d.l.	Fe, µg/L	Fe µg/L, Reported	Mn, Measured	d.l.	Mn, µg/L	Mn, µg/L, Reported	Fe and Mn Source
25SCL1	0	25SCL1-0	9.802	490.1	-0.7	1.65	-346	809	0.3	0.3	157	157	032309cpsrecalcFeMn
25SCL1	12	25SCL1-12	9.834	491.7	-0.8	1.65	-385	811	0.3	0.3	170	170	032309cpsrecalcFeMn
25SCL1	24	25SCL1-24	9.854	492.7	-0.9	1.65	-463	813	0.4	0.3	174	174	032309cpsrecalcFeMn
25SCL1	36	25SCL1-36	9.825	491.3	1.6	1.65	771	811	1.3	0.3	641	641	032309cpsrecalcFeMn
25SCL1	48	25SCL1-48	9.562	478.1	-3.4	1.65	-1616	789	0.3	0.3	142	143	032309cpsrecalcFeMn
25SCL1	60	25SCL1-60	9.833	491.6	-5.4	1.0	-2650	492	0.0	0.06	23	29	062008Aquant
25SCL1	72	25SCL1-72	9.793	489.7	-5.7	0.7	-2781	343	0.0	0.02	13	13	062008B25SC 60_72
25SCL1	96	25SCL1-96	9.836	491.8	-0.4	1.7	-178	836	-0.4	0.10	-178	49	071408quant
25SCL1	120	25SCL1-120	9.780	489.0	6.5	1.4	3176	3176	0.3	0.1	146	146	062508recalc
25SCL1	144	25SCL1-144	9.856	492.8	26.3	1.4	12967	12967	1.0	0.1	471	471	062508recalc
25SCL1	168	25SCL1-168	9.798	489.9	7.7	1.4	3750	3750	2.0	0.1	1004	1004	062508recalc
25SCL1	228	25SCL1-228	9.829	491.4	-0.1	1.7	-47	835	0.1	0.1	48	49	071408quant
25SCL2	0	25SCL2-0	9.830	491.5	-0.8	1.65	-408	811	0.3	0.3	149	149	032309cpsrecalcFeMn
25SCL2	12	25SCL2-12	9.838	491.9	-1.0	1.65	-516	812	0.3	0.3	151	151	032309cpsrecalcFeMn
25SCL2	24	25SCL2-24	9.842	492.1	-1.2	1.65	-575	812	0.3	0.3	153	153	032309cpsrecalcFeMn
25SCL2	36	25SCL2-36	9.847	492.3	-1.2	1.65	-591	812	0.3	0.3	134	148	032309cpsrecalcFeMn
25SCL2	48	25SCL2-48	9.852	492.6	-1.0	1.65	-492	813	0.4	0.3	180	180	032309cpsrecalcFeMn
25SCL2	60	25SCL2-60	9.841	492.0	-1.8	1.0	-896	492	0.7	0.06	331	331	062008Aquant
25SCL2	72	25SCL2-72	9.774	488.7	-5.8	0.7	-2831	342	0.0	0.02	5	10	062008B25SC 60_72
25SCL2	96	25SCL2-96	9.812	490.6	-0.3	1.7	-161	834	-0.3	0.10	-161	49	071408quant
25SCL2	120	25SCL2-120	9.771	488.5	6.3	1.4	3093	3093	0.2	0.1	83	83	062508recalc
25SCL2	144	25SCL2-144	9.852	492.6	10.8	1.4	5299	5299	0.5	0.1	261	261	062508recalc
25SCL2	168	25SCL2-168	9.812	490.6	7.6	1.4	3739	3739	1.9	0.1	946	946	062508recalc
25SCL2	228	25SCL2-228	9.793	489.7	-0.3	1.7	-134	832	0.1	0.1	40	49	071408quant
25SCL3	0	25SCL3-0	9.820	491.0	0.8	1.65	394	810	0.3	0.3	162	162	032309cpsrecalcFeMn
25SCL3	12	25SCL3-12	9.841	492.1	0.4	1.65	202	812	0.4	0.3	185	185	032309cpsrecalcFeMn
25SCL3	24	25SCL3-24	9.846	492.3	0.4	1.65	175	812	0.4	0.3	213	213	032309cpsrecalcFeMn
25SCL3	36	25SCL3-36	9.840	492.0	0.7	1.65	366	812	0.4	0.3	179	179	032309cpsrecalcFeMn

D1-4.2. SC 25 LIVE IRON/MANGANESE, continued.

Sample Information					IRON				MANGANESE				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Fe, Measured**	**d.l.**	**Fe, µg/L**	**Fe µg/L, Reported**	**Mn, Measured**	**d.l.**	**Mn, µg/L**	**Mn, µg/L, Reported**	**Fe and Mn Source**
25SCL3	48	25SCL3-48	9.805	490.3	0.7	1.65	330	809	0.6	0.3	312	312	032309cpsrecalcFeMn
25SCL3	60	25SCL3-60	9.813	490.6	-4.5	1.0	-2187	491	0.1	0.06	52	52	062008Aquant
25SCL3	72	25SCL3-72	9.790	489.5	-5.5	0.7	-2702	343	0.0	0.02	15	15	062008B25SC 60_72
25SCL3	96	25SCL3-96	9.829	491.5	-0.3	1.7	-156	835	-0.3	0.10	-156	49	071408quant
25SCL3	120	25SCL3-120	9.771	488.6	7.1	1.4	3482	3482	0.2	0.1	75	75	062508recalc
25SCL3	144	25SCL3-144	9.817	490.9	7.4	1.4	3642	3642	0.5	0.1	226	226	062508recalc
25SCL3	168	25SCL3-168	9.813	490.6	8.1	1.4	3953	3953	2.0	0.1	963	963	062508recalc
25SCL3	228	25SCL3-228	9.815	490.7	-0.3	1.7	-126	834	0.1	0.1	25	49	071408quant
25SRL1	0	25SRL1-0	9.853	492.6	-1.1	1.65	-558	813	0.3	0.3	160	160	032309cpsrecalcFeMn
25SRL1	12	25SRL1-12	9.837	491.9	-1.1	1.65	-561	812	0.4	0.3	220	220	032309cpsrecalcFeMn
25SRL1	24	25SRL1-24	9.833	491.6	-1.2	1.65	-565	811	0.5	0.3	233	233	032309cpsrecalcFeMn
25SRL1	36	25SRL1-36	9.838	491.9	0.2	1.65	102	812	0.9	0.3	445	445	032309cpsrecalcFeMn
25SRL1	48	25SRL1-48	9.829	491.4	-1.0	1.65	-475	811	0.5	0.3	249	249	032309cpsrecalcFeMn
25SRL1	60	25SRL1-60	9.845	492.2	-5.5	1.0	-2727	492	0.6	0.06	307	307	062008Aquant
25SRL1	72	25SRL-1-72	9.780	489.0	-6.6	0.7	-3216	342	0.8	0.02	388	388	062008B25SC 60_72
25SRL1	96	25SRL1-96	9.799	489.9	-0.2	1.7	-89	833	-0.2	0.10	-89	49	071408quant
25SRL1	120	25SRL1-120	9.796	489.8	6.7	1.4	3260	3260	1.5	0.1	736	736	062508recalc
25SRL1	144	25SRL1-144	9.848	492.4	5.0	1.4	2438	2438	1.9	0.1	932	932	062508recalc
25SRL1	168	25SRL1-168	9.816	490.8	8.1	1.4	3987	3987	3.2	0.1	1594	1594	062508recalc
25SRL1	228	25SRL1-228	9.822	491.1	-0.2	1.7	-100	835	0.4	0.1	208	208	071408quant
25SRL2	0	25SRL2-0	9.847	492.3	-1.2	1.65	-585	812	0.4	0.3	190	190	032309cpsrecalcFeMn
25SRL2	12	25SRL2-12	9.861	493.1	-1.1	1.65	-554	814	0.4	0.3	195	195	032309cpsrecalcFeMn
25SRL2	24	25SRL2-24	9.838	491.9	-1.1	1.65	-565	812	0.5	0.3	228	228	032309cpsrecalcFeMn
25SRL2	36	25SRL2-36	9.838	491.9	-1.3	1.65	-621	812	0.4	0.3	185	185	032309cpsrecalcFeMn
25SRL2	48	25SRL2-48	9.842	492.1	1.4	1.65	708	812	0.7	0.3	334	334	032309cpsrecalcFeMn
25SRL2	60	25SRL2-60	9.829	491.4	-3.5	1.0	-1697	491	0.4	0.06	192	192	062008Aquant
25SRL2	72	25SRL-2-72	9.804	490.2	-6.4	0.7	-3129	343	0.3	0.02	160	160	062008B25SC 60_72
25SRL2	96	25SRL2-96	9.814	490.7	-0.3	1.7	-140	834	-0.3	0.10	-140	49	071408quant
25SRL2	120	25SRL2-120	9.784	489.2	6.8	1.4	3328	3328	1.1	0.1	517	517	062508recalc
25SRL2	144	25SRL2-144	9.855	492.7	3.4	1.4	1667	1667	1.4	0.1	702	702	062508recalc
25SRL2	168	25SRL2-168	9.818	490.9	8.1	1.4	3958	3958	2.9	0.1	1435	1435	062508recalc

D1-4.2. SC 25 LIVE IRON/MANGANESE, continued.

Sample Information					IRON				MANGANESE				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Fe, Measured**	**d.l.**	**Fe, µg/L**	**Fe µg/L, Reported**	**Mn, Measured**	**d.l.**	**Mn, µg/L**	**Mn, µg/L, Reported**	**Fe and Mn Source**
25SRL2	228	25SRL2-228	9.831	491.5	-0.2	1.7	-93	836	0.4	0.1	197	197	071408quant
25SRL3	0	25SRL3-0	9.859	492.9	0.1	1.65	44	813	0.6	0.3	303	303	032309cpsrecalcFeMn
25SRL3	12	25SRL3-12	9.841	492.1	0.2	1.65	94	812	0.5	0.3	259	259	032309cpsrecalcFeMn
25SRL3	24	25SRL3-24	9.855	492.8	0.4	1.65	199	813	0.6	0.3	278	278	032309cpsrecalcFeMn
25SRL3	36	25SRL3-36	9.853	492.7	0.7	1.65	325	813	0.5	0.3	265	265	032309cpsrecalcFeMn
25SRL3	48	25SRL3-48	9.843	492.2	2.1	1.65	1025	1025	0.5	0.3	251	251	032309cpsrecalcFeMn
25SRL3	60	25SRL3-60	9.835	491.8	-4.2	1.0	-2088	492	0.3	0.06	158	158	062008Aquant
25SRL3	72	25SRL3-72	9.776	488.8	-6.2	0.7	-3008	342	0.5	0.02	231	231	062008B25SC 60_72
25SRL3	96	25SRL3-96	9.826	491.3	-0.2	1.7	-116	835	-0.2	0.10	-116	49	071408quant
25SRL3	120	25SRL3-120	9.669	483.5	2.0	1.4	957	957	0.9	0.1	431	431	062508recalc
25SRL3	144	25SRL3-144	9.807	490.3	3.3	1.4	1626	1626	0.8	0.1	403	403	062508recalc
25SRL3	168	25SRL3-168	9.818	490.9	7.9	1.4	3864	3864	2.3	0.1	1110	1110	062508recalc
25SRL3	228	25SRL3-228	9.826	491.3	-0.2	1.7	-121	835	0.2	0.1	101	101	071408quant
25SSL1	0	25SSL1-0	9.772	488.6	-1.3	1.65	-619	806	0.3	0.3	158	158	032309cpsrecalcFeMn
25SSL1	12	25SSL1-12	9.830	491.5	-1.1	1.65	-521	811	0.4	0.3	211	211	032309cpsrecalcFeMn
25SSL1	24	25SSL1-24	9.829	491.4	-1.2	1.65	-612	811	0.4	0.3	213	213	032309cpsrecalcFeMn
25SSL1	36	25SSL1-36	9.809	490.5	0.1	1.65	35	809	0.4	0.3	192	192	032309cpsrecalcFeMn
25SSL1	48	25SSL1-48	9.857	492.9	-1.2	1.65	-573	813	0.4	0.3	200	200	032309cpsrecalcFeMn
25SSL1	60	25SSL1-60	9.853	492.6	-5.9	1.0	-2900	493	0.3	0.06	171	171	062008Aquant
25SSL1	72	25SSL-1-72	9.499	475.0	-6.1	0.7	-2914	332	0.3	0.02	162	162	062008B25SC 60_72
25SSL1	96	25SSL1-96	9.815	490.8	-0.1	1.7	-61	834	-0.1	0.10	-61	49	071408quant
25SSL1	120	25SSL1-120	9.820	491.0	3.5	1.4	1722	1722	0.7	0.1	359	359	062508recalc
25SSL1	144	25SSL1-144	10.130	506.5	5.7	1.4	2871	2871	0.9	0.1	432	432	062508recalc
25SSL1	168	25SSL1-168	9.819	491.0	7.8	1.4	3836	3836	2.2	0.1	1095	1095	062508recalc
25SSL1	228	25SSL1-228	9.819	491.0	-0.2	1.7	-122	835	0.0	0.1	23	49	071408quant
25SSL2	0	25SSL2-0	9.888	494.4	-1.1	1.65	-565	816	0.4	0.3	178	178	032309cpsrecalcFeMn
25SSL2	12	25SSL2-12	9.837	491.9	-1.2	1.65	-598	812	0.4	0.3	183	183	032309cpsrecalcFeMn
25SSL2	24	25SSL2-24	9.839	492.0	-1.3	1.65	-630	812	0.4	0.3	204	204	032309cpsrecalcFeMn
25SSL2	36	25SSL2-36	9.848	492.4	-1.2	1.65	-583	812	0.2	0.3	123	148	032309cpsrecalcFeMn
25SSL2	48	25SSL2-48	9.855	492.8	-1.2	1.65	-608	813	0.5	0.3	255	255	032309cpsrecalcFeMn

D1-4.2. SC 25 LIVE IRON/MANGANESE, continued.

Sample Information					IRON				MANGANESE				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Fe, Measured**	**d.l.**	**Fe, µg/L**	**Fe µg/L, Reported**	**Mn, Measured**	**d.l.**	**Mn, µg/L**	**Mn, µg/L, Reported**	**Fe and Mn Source**
25SSL2	60	25SSL2-60	9.835	491.8	-1.9	1.0	-920	492	0.3	0.06	169	169	062008Aquant
25SSL2	72	25SSL-2-72	9.788	489.4	-6.1	0.7	-2995	343	0.3	0.02	130	130	062008B25SC 60_72
25SSL2	96	25SSL2-96	9.820	491.0	-0.2	1.7	-122	835	-0.2	0.10	-122	49	071408quant
25SSL2	120	25SSL2-120	9.763	488.1	13.5	1.4	6582	6582	1.0	0.1	484	484	062508recalc
25SSL2	144	25SSL2-144	9.636	481.8	6.3	1.4	3020	3020	0.8	0.1	387	387	062508recalc
25SSL2	168	25SSL2-168	9.763	488.1	7.8	1.4	3829	3829	2.1	0.1	1038	1038	062508recalc
25SSL2	228	25SSL2-228	9.838	491.9	-0.3	1.7	-157	836	0.0	0.1	13	49	071408quant
25SSL3	0	25SSL3-0	9.894	494.7	0.2	1.65	99	816	0.4	0.3	219	219	032309cpsrecalcFeMn
25SSL3	12	25SSL3-12	9.845	492.3	0.5	1.65	230	812	0.6	0.3	293	293	032309cpsrecalcFeMn
25SSL3	24	25SSL3-24	9.831	491.6	0.3	1.65	129	811	0.6	0.3	284	284	032309cpsrecalcFeMn
25SSL3	36	25SSL3-36	9.857	492.8	0.8	1.65	375	813	0.6	0.3	314	314	032309cpsrecalcFeMn
25SSL3	48	25SSL3-48	9.854	492.7	3.1	1.65	1549	1549	0.3	0.3	168	168	032309cpsrecalcFeMn
25SSL3	60	25SSL3-60	9.844	492.2	1.2	1.0	589	589	0.4	0.06	214	214	062008Aquant
25SSL3	72	25SSL-3-72	9.780	489.0	-4.8	0.7	-2358	342	0.4	0.02	182	182	062008B25SC 60_72
25SSL3	96	25SSL3-96	9.811	490.6	-0.1	1.7	-56	834	-0.1	0.10	-56	49	071408quant
25SSL3	120	25SSL3-120	9.830	491.5	4.1	1.4	2034	2034	0.8	0.1	376	376	062508recalc
25SSL3	144	25SSL3-144	9.776	488.8	6.7	1.4	3285	3285	0.9	0.1	423	423	062508recalc
25SSL3	168	25SSL3-168	9.763	488.1	7.9	1.4	3857	3857	2.1	0.1	1046	1046	062508recalc
25SSL3	228	25SSL3-228	9.807	490.4	5.3	1.7	2587	2587	0.1	0.1	37	49	071408quant

D1-4.3. SC 10 KILLED IRON/MANGANESE.

Sample Information					IRON				MANGANESE				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Fe, Measured**	**d.l.**	**Fe, µg/L**	**Fe µg/L, Reported**	**Mn, Measured**	**d.l.**	**Mn, µg/L**	**Mn, µg/L, Reported**	**Fe and Mn Source**
10SCK1	0	10SCK1-0	9.852	492.6									
10SCK1	48	10SCK1-48	9.8278	491.39									
10SCK1	96	10SCK1-96	9.8638	493.19									
10SCK1	144	10SCK1-144	9.835	491.75	6.63	1.37	3262	3262	0.12	0.09	61.0	61	062508recalc
10SCK2	0	10SCK2-0	8.721	436.05	-1.11	2.41	-484	1050	0.05	0.06	22.8	26	0718quant
10SCK2	48	10SCK2-48	8.27	413.5	-1.19	2.41	-493	995	0.05	0.06	18.7	25	0718quant
10SCK2	96	10SCK2-96	8.145	407.25	-1.31	2.41	-534	980	0.06	0.06	25.1	25	0718quant
10SCK2	144	10SCK2-144	9.8342	491.71	7.20	1.37	3540	3540	0.31	0.09	150.7	151	062508recalc
10SCK3	0	10SCK3-0	8.58	429	-1.34	2.41	-573	1033	0.06	0.06	26.4	26	0718quant
10SCK3	48	10SCK3-48	8.62	431	-1.39	2.41	-597	1037	0.06	0.06	26.7	27	0718quant
10SCK3	96	10SCK3-96	7.441	372.05	-1.30	2.41	-485	896	0.06	0.06	20.7	22	0718quant
10SCK3	144	10SCK3-144	9.8343	491.715	6.14	1.37	3020	3020	0.08	0.09	37.2	44	062508recalc
10SRK1	0	10SRK1-0	9.8471	492.355									
10SRK1	48	10SRK1-48	9.8667	493.335									
10SRK1	96	10SRK1-96	9.8649	493.245									
10SRK1	144	10SRK1-144	9.7213	486.065	7.42	1.37	3604	3604	0.34	0.09	166.3	166	062508recalc
10SRK2	0	10SRK2-0	8.413	420.65	-1.21	2.41	-507	1013	0.11	0.06	45.1	45	0718quant
10SRK2	48	10SRK2-48	8.046	402.3	-1.35	2.41	-543	968	0.11	0.06	45.5	46	0718quant
10SRK2	96	10SRK2-96	7.989	399.45	-0.99	2.41	-396	961	0.11	0.06	44.9	45	0718quant
10SRK2	144	10SRK2-144	9.8498	492.49	6.58	1.37	3241	3241	0.18	0.09	87.9	88	062508recalc
10SRK3	0	10SRK3-0	8.751	437.55	-1.31	2.41	-574	1053	0.12	0.06	50.7	51	0718quant
10SRK3	48	10SRK3-48	7.513	375.65	-1.38	2.41	-518	904	0.13	0.06	48.0	48	0718quant
10SRK3	96	10SRK3-96	8.034	401.7	-1.41	2.41	-567	967	0.12	0.06	46.8	47	0718quant
10SRK3	144	10SRK3-144	9.832	491.6	6.35	1.37	3120	3120	0.22	0.09	107.3	107	062508recalc
10SSK1	0	10SSK1-0	9.8576	492.88									
10SSK1	48	10SSK1-48	9.8451	492.255									
10SSK1	96	10SSK1-96	9.851	492.55									
10SSK1	144	10SSK1-144	9.8572	492.86	6.53	1.37	3218	3218	0.25	0.09	121.0	121	062508recalc
10SSK2	0	10SSK2-0	8.334	416.7	-1.20	2.41	-498	1003	0.12	0.06	51.8	52	0718quant

D1-4.3. SC 10 KILLED IRON/MANGANESE, continued.

Sample Information					IRON				MANGANESE				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Fe, Measured**	**d.l.**	**Fe, µg/L**	**Fe µg/L, Reported**	**Mn, Measured**	**d.l.**	**Mn, µg/L**	**Mn, µg/L, Reported**	**Fe and Mn Source**
10SSK2	48	10SSK2-48	8.664	433.2	-1.25	2. 41	-540	1043	0.13	0.06	58.2	58	0718quant
10SSK2	96	10SSK2-96	7.899	394.95	-0.78	2.41	-310	951	0.17	0.06	65.2	65	0718quant
10SSK2	144	10SSK2-144	9.845	492.25	10.00	1.37	4922	4922	0.44	0.09	218.0	218	062508recalc
10SSK3	0	10SSK3-0	8.62	431	-0.79	2.41	-340	1037	0.15	0.06	65.5	66	0718quant
10SSK3	48	10SSK3-48	9.054	452.7	-0.88	2.41	-400	1090	0.17	0.06	77.0	77	0718quant
10SSK3	96	10SSK3-96	7.876	393.8	-0.86	2.41	-340	948	0.17	0.06	66.2	66	0718quant
10SSK3	144	10SSK3-144	9.8478	492.39	6.36	1.37	3133	3133	0.37	0.09	181.0	181	062508recalc

Shaded fields = data not collected for those samples.

D1-4.4. SC 25 KILLED IRON/MANGANESE.

Sample Information					IRON				MANGANESE				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Fe, Measured**	**d.l.**	**Fe, µg/L**	**Fe µg/L, Reported**	**Mn, Measured**	**d.l.**	**Mn, µg/L**	**Mn, µg/L, Reported**	**Fe and Mn Source**
25SCK1	0	25SCK1-0	9.448	472.4	-0.750	0.57	269.3	269	0.074	0.17	80.31	80	0721quant
25SCK1	48	25SCK1-48	8.272	413.6	-0.726	0.57	235.8	n.d.	0.070	0.17	70.31	n.d.	0721quant
25SCK1	96	25SCK1-96	7.916	395.8	-0.775	0.57	225.6	n.d.	0.071	0.17	67.29	n.d.	0721quant
25SCK1	144	25SCK1-144	9.836	491.8	8.3	1.37	4083	4083	0.098	0.09	48.25	48.25	062508recalc
25SCK1	276	25SCK1-276	9.912	495.6	-0.640	0.57	282.5	n.d.	0.108	0.17	84.25	n.d.	0721quant
25SCK2	0	25SCK2-0	9.817	490.9	-0.818	2.4	1178.0	n.d.	0.129	0.06	63.22	63.22	0718quant
25SCK2	48	25SCK2-48	9.156	457.8	-0.694	2.4	1098.7	n.d.	0.136	0.06	62.31	62.31	0718quant
25SCK2	96	25SCK2-96	8.473	423.7	-0.835	2.4	1016.8	n.d.	0.144	0.06	60.88	60.88	0718quant
25SCK2	144	25SCK2-144	9.839	491.9	6.6	1.37	3256	3256	0.081	0.09	44.27	n.d.	062508recalc
25SCK2	276	25SCK2-276	10.400	520.0	-0.765	0.57	296.4	n.d.	0.115	0.17	88.40	n.d.	0721quant
25SCK3	0	25SCK3-0	9.274	463.7	-0.861	2.4	1112.9	n.d.	0.126	0.06	58.29	58.29	0718quant
25SCK3	48	25SCK3-48	9.272	463.6	-0.799	2.4	1112.6	n.d.	0.126	0.06	58.60	58.60	0718quant
25SCK3	96	25SCK3-96	7.268	363.4	-0.909	2.4	872.2	n.d.	0.131	0.06	47.42	47.42	0718quant
25SCK3	144	25SCK3-144	9.849	492.4	6.0	1.37	2954	2954	0.136	0.09	67.11	67.11	062508recalc
25SCK3	276	25SCK3-276	9.347	467.4	0.194	0.57	266.4	n.d.	0.310	0.17	145.02	145.02	0721quant
25SRK1	0	25SRK1-0	8.951	447.6	-0.720	0.57	255.1	n.d.	0.069	0.17	76.08	n.d.	0721quant
25SRK1	48	25SRK1-48	8.053	402.7	-0.167	0.57	229.5	n.d.	0.103	0.17	68.45	n.d.	0721quant
25SRK1	96	25SRK1-96	8.596	429.8	-0.790	0.57	245.0	n.d.	0.091	0.17	73.07	n.d.	0721quant
25SRK1	144	25SRK1-144	9.836	491.8	3.5	1.37	1729	1729	-0.031	0.09	44.26	n.d.	062508recalc
25SRK1	276	25SRK1-276	9.525	476.3	-0.686	0.57	271.5	n.d.	0.129	0.17	80.96	n.d.	0721quant
25SRK2	0	25SRK2-0	8.668	433.4	-0.747	2.4	1040.2	n.d.	0.166	0.06	72.12	72.12	0718quant
25SRK2	48	25SRK2-48	7.938	396.9	-0.843	2.4	952.6	n.d.	0.167	0.06	66.16	66.16	0718quant
25SRK2	96	25SRK2-96	8.626	431.3	-0.771	2.4	1035.1	n.d.	0.182	0.06	78.45	78.45	0718quant
25SRK2	144	25SRK2-144	9.846	492.3	7.0	1.37	3445	3445	0.236	0.09	116.25	116.25	062508recalc
25SRK2	276	25SRK2-276	9.425	471.3	0.756	0.57	356.4	0.756	0.260	0.17	122.34	122.34	0721quant
25SRK3	0	25SRK3-0	9.128	456.4	-0.857	2.4	1095.4	n.d.	0.182	0.06	82.88	82.88	0718quant
25SRK3	48	25SRK3-48	8.431	421.6	-0.888	2.4	1011.7	n.d.	0.193	0.06	81.36	81.36	0718quant
25SRK3	96	25SRK3-96	8.919	446.0	-0.840	2.4	1070.3	n.d.	0.198	0.06	88.25	88.25	0718quant
25SRK3	144	25SRK3-144	9.859	492.9	27.0	1.37	13293	13293	0.467	0.09	229.99	229.99	062508recalc

D1-4.4. SC 25 KILLED IRON/MANGANESE, continued.

Sample Information					IRON				MANGANESE				
Experiment	**Time**	**Name**	**Weight**	**Dilution**	**Fe, Measured**	**d.l.**	**Fe, µg/L**	**Fe µg/L, Reported**	**Mn, Measured**	**d.l.**	**Mn, µg/L**	**Mn, µg/L, Reported**	**Fe and Mn Source**
25SRK3	276	25SRK3-276	9.859	493.0	0.066	0.57	281.0	n.d.	0.231	0.17	113.97	113.97	0721quant
25SSK1	0	25SSK1-0	7.853	392.7	-0.764	0.57	223.8	n.d.	0.117	0.17	66.75	n.d.	0721quant
25SSK1	48	25SSK1-48	7.819	391.0	-0.815	0.57	222.8	n.d.	0.125	0.17	66.46	n.d.	0721quant
25SSK1	96	25SSK1-96	7.814	390.7	-0.610	0.57	222.7	n.d.	0.156	0.17	66.42	n.d.	0721quant
25SSK1	144	25SSK1-144	9.778	488.9	7.2	1.37	3519	3519	0.372	0.09	181.78	181.78	062508recalc
25SSK1	276	25SSK1-276	9.559	478.0	-0.724	0.57	272.4	n.d.	0.221	0.17	105.53	105.53	0721quant
25SSK2	0	25SSK2-0	7.325	366.3	-0.814	2.4	879.0	n.d.	0.174	0.06	63.65	63.65	0718quant
25SSK2	48	25SSK2-48	7.818	390.9	-0.880	2.4	938.2	n.d.	0.206	0.06	80.33	80.33	0718quant
25SSK2	96	25SSK2-96	8.384	419.2	-0.892	2.4	1006.1	n.d.	0.230	0.06	96.25	96.25	0718quant
25SSK2	144	25SSK2-144	9.842	492.1	3.8	1.37	1864	1864	0.153	0.09	75.53	75.53	062508recalc
25SSK2	276	25SSK2-276	9.453	472.7	-0.708	0.57	269.4	n.d.	0.208	0.17	98.22	98.22	0721quant
25SSK3	0	25SSK3-0	7.675	383.8	-0.583	2.4	921.0	n.d.	0.168	0.06	64.55	64.55	0718quant
25SSK3	48	25SSK3-48	7.987	399.4	-0.788	2.4	958.4	n.d.	0.186	0.06	74.20	74.20	0718quant
25SSK3	96	25SSK3-96	9.226	461.3	-0.858	2.4	1107.1	n.d.	0.202	0.06	93.18	93.18	0718quant
25SSK3	144	25SSK3-144	9.800	490.0	7.3	1.37	3577	3577	1.707	0.09	836.29	836.29	062508recalc
25SSK3	276	25SSK3-276	10.070	503.5	-0.716	0.57	287.0	n.d.	0.224	0.17	112.99	112.99	0721quant

n.d. = no data

Table D2-1. Dry Valley Mine Ion Chromotography Data.

Experiment	Replicate	Time	pH	O_2	PO_4^+	SO_4^{2-}	SeO_4^{2-}	SeO_3^{2-}	NO_3^-	O_2 Ave	NO_3^- Ave	NO_3^- s.d.	Sample ID
10DCL	1	0	7.47	0.7	nd	343	13.6	3.0	4.7				
10DCL	2	0	7.33	0.3	nd	310	13.7	nd	3.0				
10DCL	3	0	7.36	0.22	nd	301	14.0	nd	4.9	0.41	4.2	1.0	10 DCL-1-0
10DCL	1	53	7.32	0.18	nd	339	11.0	nd	2.4	0.18	2.4	na	10 DCL-1-53
10DCL	1	80	nr	0.11	nd	nr	nr	nr	nr				
10DCL	2	80	nr	0.2	nd	nr	nr	nr	nr				
10DCL	3	80	nr	0.99*	nd	340	5.5	nd	2.0	0.20	2.0	na	10 DCL-1-80
10DCL	1	104	nr	0.1	nd	311	3.7	2.9	2.0				
10DCL	1	128	7.30	0.09	nd	320	5.5	nd	2.0				
10DCL	2	128	7.40	0.04	nd	345	nd	nd	2.3				
10DCL	3	128	7.38	0.21	nd	301	3.2	nd	2.0	0.11	2.1	0.2	10DCL-128
10DCL	1	272	nr	nr	5.9	318	nd	nd	2.3				
10DCL	2	272	nr	nr	nd	345	nd	nd	2.0				
10DCL	3	272	nr	nr	nd	320	nd	nd	2.0		2.1	0.2	10DCL-272
10DRL	1	0	6.85	0.31	nd	1512	14.2	nd	4.4				
10DRL	2	0	6.81	0.26	nd	1348	12.2	nd	4.1				
10DRL	3	0	6.86	0.25	nd	1130	13.7	nd	4.2	0.27	4.2	0.2	10DRL-0
10DRL	1	53	6.82	0.15	nd	1391	16.4	nd	2.5				
10DRL	1	80	nr	0.13	nd	1338	11.9	nd	2.0				
10DRL	2	80	nr	0.12	nd	1416	7.0	2.9	2.0	0.13	2.0	0.3	10DRL--80
10DRL	3	80	nr	0.09	nd	1310	nr	nr	nr				
10DRL	1	104	nr	0.1	nd	1338	11.9	nd	2.0				
10DRL	1	128	6.86	0.05	nd	1544	7.0	2.8	2.0				
10DRL	2	128	6.92	0.07	nd	1130	nd	nd	2.0				
10DRL	3	128	6.64	0.05	nd	1416	nd	nd	2.3	0.06	2.1	0.2	10DRL-128
10DRL	1	272	nr	nr	nd	1230	14.2	nd	4.4				
10DRL	2	272	nr	nr	nd	1272	nd	nd	2.0				
10DRL	3	272	nr	nr	nd	1131	nd	nd	2.3		2.9	1.3	10DRL-272
10DSL	1	0	6.75	0.32	5.5	1321	13.5	nd	3.1				
10DSL	2	0	6.66	0.16	nd	1169	11.5	nd	2.7				

Table D2-1. Dry Valley Mine Ion Chromotography Data, continued.

Experiment	Replicate	Time	pH	O_2	PO_4^{+}	SO_4^{2-}	SeO_4^{2-}	SeO_3^{2-}	NO_3^{-}	O_2 Ave	NO_3^{-} Ave	NO_3^{-} s.d.	Sample ID
10DSL	3	0	6.72	0.21	nd	1131	14.8	nd	2.9	0.23	2.9	0.2	10DSL-0
10DSL	1	53	6.7	0.1	*5.4*	1255	14.9	nd	2.5	0.10	2.48	na	10DSL-53
10DSL	1	80	nr	0.08	nd	1264	5.2	nd	2.0				
10DSL	2	80	nr	0.11	*5.5*	1205	6.2	nd	2.0				
10DSL	3	80	nr	0.3	nd	1228	5.8	2.9	2.0	0.16	2.0	0.0	10DSL-80
10DSL	1	104	nr	0.1	*5.4*	1234	3.0	nd	2.4				
10DSL	1	128	6.76	0.07	*5.5*	1536	nd	2.9	2.0				
10DSL	2	128	6.76	0.84	nd	1542	nd	nd	2.0				
10DSL	3	128	6.82	0.06	nd	1205	nd	nd	2.0	0.32	2.0	0.0	10DSL-128
10DSL	1	272	nr	nr	nd	1536	nd	nd	2.0				
10DSL	2	272	nr	nr	nd	1367	nd	nd	2.0				
10DSL	3	272	nr	nr	*5.4*	1036	nd	3.1	2.0	0.06	2.0	0.0	10DSL-272
25DCL	1	0	7.45	0.18	*5.7*	300	14.4	nd	7.1				
25DCL	2	0	7.38	0.16	nd	323	5.3	nd	2.0				
25DCL	3	0	7.4	0.09	nd	392	8.2	nd	2.4	0.14	3.8	2.8	25DCL-0
25DCL	1	20	7.39	0.11	nr	285	14.1	nr	2.6				
25DCL	2	20	7.35	0.12	nr	269	nr	nr	2.0	0.12	2.3	0.5	25DCL-20
25DCL	1	54	nr	nr	nd	323	5.3	nd	2.0				
25DCL	1	66	7.35	0.1	*6.2*	392	nd	nd	2.5				
25DCL	2	66	7.49	0.1	nd	403	nd	nd	2.0				
25DCL	3	66	7.52	0.09	nd	305	nd	nd	2.0	0.10	2.2	0.3	25DCL-66
25DCL	1	90	nr	nr	nd	301	nd	nd	2.0				
25DCL	2	90	nr	nr	nd	403	nd	nd	2.0		2.0	0.0	25DCL-90
25DCL	1	188	nr	nr	nd	299	nd	nd	2.5				
25DCL	2	188	nr	nr	nd	403	nd	nd	2.0		2.2	0.3	25DCL-188
25DRL	1	0	6.88	0.22	nd	991	15.9	nd	5.5				
25DRL	2	0	6.74	0.1	nd	1037	5.8	3.4	2.0	0.16	3.8	2.5	25DRL-0
25DRL	1	20	6.82	0.07	nd	1108	14.7	nd	3.2				
25DRL	2	20	6.8	0.09	nd	1056	1.7	nd	2.0	0.08	2.6	0.9	25DRL-20
25DRL	1	54	6.97	0.18	nd	1029	6.0	3.4	2.0	0.18	2	na	25DRL-54
25DRL	1	66	7	0.07	nd	908	nd	nd	2.0				

Table D2-1. Dry Valley Mine Ion Chromotography Data, continued.

Experiment	Replicate	Time	pH	O_2	PO_4^{+}	SO_4^{2-}	SeO_4^{2-}	SeO_3^{2-}	NO_3^{-}	O_2 Ave	NO_3^{-} Ave	NO_3^{-} s.d.	Sample ID
25DRL	2	66	6.9	0.08	nd	893	nd	nd	2.5				
25DRL	3	66	6.95	0.08	nd	1222	nd	nd	2.0	0.08	2.2	0.3	25DRL-66
25DRL	1	90	6.95	0.1	nd	908	nd	nd	2.0	0.10	2	0	25DRL-90
25DRL	1	188	6.97	0.09	nd	1528	nd	nd	2.0				
25DRL	2	188	6.94	0.1	nd	897	nd	nd	2.0	0.10	2.0	0.0	25DRL-188
25DSL	1	0	6.75	0.17	nd	1128	17.5	nd	3.4				
25DSL	2	0	6.91	0.14	nd	1216	14.4	nd	7.1				
25DSL	3	0	6.87	0.12	nd	1039	15.1	nd	5.8	0.14	5.4	1.8	25DSL-0
25DSL	1	20	6.77	0.011	nd	991	15.0	nd	2.6				
25DSL	2	20	6.83	0.013	nd	1152	13.1	nd	2.0	0.01	2.3	0.4	25DSL-20
25DSL	1	66	nr	nr	nd	1038	5.8	3.4	2.0				
25DSL	2	66	6.75	0.09	nd	1126	4.6	nd	2.0				
25DSL	3	66	6.84	0.07	nd	1039	4.9	nd	3.4	0.08	2.5	0.8	25DSL-66
25DSL	1	90	6.81	0.08	nd	1113	nd	nd	2.0	0.08	2	na	25DSL-90
25DSL	1	120	nr	nr	nd	726	nd	nd	2.0				
25DSL	2	120	nr	nr	nd	nr	nr	nr	nr				
25DSL	1	188	nr	nr	nr	1713	nd	nd	2.4				
25DSL	2	188	nr	nr	nd	1222	nd	nd	2.0		2.2	0.3	25DSL-188
D10CK	1	0	7.05	0.57	nd	328	18.0	nd	7.7				
D10CK	2	0	7.39	0.69	nr	nr	nr	nr	nr				
D10CK	3	0	7.31	0.62	nr	nr	nr	nr	nr				
D10CK	1	456	7.55	0.36	nd	341	18.0	nd	8.1				
D10CK	2	456	7.57	0.47	nr	nr	nr	nr	nr				
D10CK	3	456	6.94	0.07	nr	nr	nr	nr	nr				
D10RK	1	0	6.72	0.35	nd	924	17.8	nd	nr				
D10RK	2	0	6.93	0.39	nr	nr	nr	nr	nr				
D10RK	3	0	nr	nr	nr	nr	nr	nr	nr				
D10RK	1	456	6.94	0.37	nd	1349	18.2	nd	3.7				
D10RK	2	456	7.12	0.59	nr	nr	nr	nr	nr				
D10SK	1	0	6.74	0.45	nd	1238	18.1	nd	7.4				
D10SK	2	0	6.64	0.44	nr	nr	nr	nr	nr				

Table D2-1. Dry Valley Mine Ion Chromotography Data, continued.

Experiment	Replicate	Time	pH	O_2	PO_4^+	SO_4^{2-}	SeO_4^{2-}	SeO_3^{2-}	NO_3^-	O_2 Ave	NO_3^- Ave	NO_3^- s.d.	Sample ID
D10SK	3	0	6.64	0.29	nr	nr	nr	nr	nr				
D10SK	1	456	6.9	0.59	nr	nr	nr	nr	nr				
D10SK	2	456	6.82	0.91	nr	nr	nr	nr	nr				
D10SK	3	456	6.86	0.43	nr	nr	nr	nr	nr				
DV25-CK1	1	0	nr	nr	nd	331	18.2	nd	11.6				
DV25-CK2	2	0	7.39	0.58	nr	nr	nr	nr	nr				
DV25-CK1	1	192	7.25	0.5	nr	nr	nr	nr	nr				
DV25-CK2	2	192	7.5	0.06	nr	nr	nr	nr	nr				
DV25-CK3	3	192	7.51	0.08	nr	nr	nr	nr	nr				
DV25-CK3	3	192	6.94	0.07	nr	nr	nr	nr	nr				
DV25-RK1	1	0	nr	nr	nd	1289	18.5	nd	8.3				
DV25-RK1	1	192	6.96	0.29	nr	nr	nr	nr	nr				
DV25-RK2	2	192	6.97	0.1	nr	nr	nr	nr	nr				
DV25-RK3	3	192	6.92	0.35	nr	nr	nr	nr	nr				
DV25-SK1	1	0	6.78	0.08	nd	1349	18.2	nd	3.7				
DV25-SK1	1	192	6.7	0.15	nr	nr	nr	nr	nr				
DV25-RK2	2	192	6.76	0.45*	*5.55*	2	nd	nd	2.3				
DV25-RK3	3	192	6.96	0.35	*5.33*	nd	nd	nd	nd				

Values are micrograms/liter (µg/L)
nr= not reported
*= degassed
nd= not detected
NO_3^- detection limit= 2 µg/L
na= not applicable
+ PO_4^+ was detected only immediately following analysis of a standard containing PO_4^+

Table D2-2. Smoky Canyon Mine Ion Chromotography Data.

Experiment	Replicate	Time	pH	O_2	PO_4^{+}	SO_4^{2-}	SeO_4^{2-}	SeO_3^{2-}	NO_3^{-}	O_2 Ave	NO_3^{-} Ave	NO_3^{-} s.d.	Sample ID
10SCL	1	0	nr	0.76	nd	419.3	13.2	nd	9.7				
10SCL	2	0	nr	0.71	nd	436.2	15.1	5.4	8.6	0.74	9.150	0.778	10SCCL0
10SCL	1	12	nr	0.26	nd	511.9	16.1	2	5.1				
10SCL	2	12	nr	0.2	nd	528.7	17.6	nd	4.83	0.23	4.965	0.191	10SCCL12
10SCL	1	24	nr	0.64	nr	nr	nr	nr	nr				
10SCL	1	36	nr	0.23	nr	nr	nr	nr	nr				
10SCL	1	48	nr	0.36	nr	nr	nr	nr	nr				
10SCL	1	60	nr	0.37	nd	467.8	11.1	nd	10.37				
10SCL	2	60	nr	0.35	nd	473.9	12.5	nd	12.41	0.36	11.390	1.442	10SCCL60
10SCL	1	84	nr	0.32	nd	446.4	4.7	nd	6.89				
10SCL	2	84	nr	0.29	nd	420.0	3.8	nd	2	0.31	4.445	3.458	10SCCL84
10SCL	1	108	nr	0.2	nr	nr	nr	nr	nr				
10SCL	1	120	7.21	0.61	nr	nr	nr	nr	nr				
10SCL	2	120	7.98	0.61	nr	nr	nr	nr	nr				
10SCL	3	120	7.68	0.76	nr	nr	nr	nr	nr				
10SCL	1	132	nr	0.23	nr	nr	nr	nr	nr				
10SCL	1	246	nr	0.11	nd	655.0	nd	nd	2				
10SCL	2	246	nr	0.09	nd	649.1	nd	nd	2	0.10	2.000	0.000	10SCCL246
10SRL	1	0	nr	0.49	nd	612.1	11.1	nd	11.36				
10SRL	2	0	nr	0.64	nd	605.1	10.5	nd	9.2				
10SRL	3	0	nr	0.61	nd	744.0	6.2	nd	12.92	0.58	11.160	1.868	10SCRL0
10SRL	1	12	nr	0.19	nd	703.3	14.2	nd	8.7				
10SRL	2	12	nr	1.01	nd	712.6	16.6	nd	6.3	0.60	7.500	1.697	10SCRL0
10SRL	3	12	nr	0.38	nr	nr	nr	nr	nr				
10SRL	1	24	nr	0.49	nr	nr	nr	nr	nr				
10SRL	2	24	nr	0.45	nr	nr	nr	nr	nr				
10SRL	3	24	nr	0.36	nr	nr	nr	nr	nr				
10SRL	1	36	nr	0.07	nr	nr	nr	nr	nr				
10SRL	2	36	nr	0.21	nr	nr	nr	nr	nr				
10SRL	3	36	nr	0.12	nr	nr	nr	nr	nr				
10SRL	1	48	nr	0.02	nr	nr	nr	nr	nr				

Table D2-2. Smoky Canyon Mine Ion Chromotography Data, continued.

Experiment	Replicate	Time	pH	O_2	PO_4^{+}	SO_4^{2-}	SeO_4^{2-}	SeO_3^{2-}	NO_3^{-}	O_2 Ave	NO_3^{-} Ave	NO_3^{-} s.d.	Sample ID
10SRL	2	48	nr	0.49	nr	nr	nr	nr	nr				
10SRL	3	48	nr	0.25	nr	nr	nr	nr	nr				
10SRL	1	60	nr	0.27	nd	724.1	4.0	2.31	4.2				
10SRL	2	60	nr	0.29	nd	718.6	5.6	3.5	2.27	0.28	3.235	1.365	10SCRL60
10SRL	1	84	nr	0.29	nd	722.4	nd	nd	3.26				
10SRL	2	84	nr	0.32	nd	709.5	nd	nd	1.6	0.31	2.430	1.174	10SCRL84
10SRL	3	84	nr	0.18	nr	nr	nr	nr	nr				
10SRL	1	108	nr	0.32	nr	nr	nr	nr	nr				
10SRL	2	108	nr	0.16	nr	nr	nr	nr	nr				
10SRL	3	108	nr	0.1	nr	nr	nr	nr	nr				
10SRL	1	120	7.78	1.11	nr	nr	nr	nr	nr				
10SRL	2	120	7.73	0.77	nr	nr	nr	nr	nr				
10SRL	3	120	7.66	0.79	nr	nr	nr	nr	nr				
10SRL	1	132	nr	0.74	nr	nr	nr	nr	nr				
10SRL	2	132	nr	0.17	nr	nr	nr	nr	nr				
10SRL	3	132	nr	0.06	nr	nr	nr	nr	nr				
10SRL	1	246	nr	0.08	nd	708.9	nd	nd	2				
10SRL	2	246	nr	0.05	nd	710.1	nd	nd	2	0.07	2.000	0.000	10SCRL246
10SSL	1	0	nr	0.36	nd	620.1	11.3	nd	8.1				
10SSL	2	0	nr	0.45	nd	631.3	12.6	nd	8.44	0.47	8.270	0.240	10SCSL0
10SSL	3	0	nr	0.61	nr	nr	nr	nr	8.74				
10SSL	1	12	nr	0.46	nd	554.7	13.4	nd	7.19				
10SSL	2	12	nr	0.37	nd	521.9	14.6	nd	7.36	0.42	7.275	0.120	10SCSL12
10SSL	1	24	nr	0.69	nr	nr	nr	nr	nr				
10SSL	2	24	nr	0.17	nr	nr	nr	nr	nr				
10SSL	3	24	nr	0.47	nr	nr	nr	nr	nr				
10SSL	1	36	nr	0.35	nr	nr	nr	nr	nr				
10SSL	2	36	nr	0.3	nr	nr	nr	nr	nr				
10SSL	3	36	nr	0.29	nr	nr	nr	nr	nr				
10SSL	1	48	nr	0.38	nr	nr	nr	nr	nr				
10SSL	2	48	nr	0.26	nr	nr	nr	nr	nr				
10SSL	3	48	nr	0.47	nr	nr	nr	nr	nr				

Table D2-2. Smoky Canyon Mine Ion Chromotography Data, continued.

Experiment	Replicate	Time	pH	O_2	PO_4^{+}	SO_4^{2-}	SeO_4^{2-}	SeO_3^{2-}	NO_3^{-}	O_2 Ave	NO_3^{-} Ave	NO_3^{-} s.d.	Sample ID
10SSL	1	60	nr	0.16	nd	635.2	8.4	4.57	2.27				
10SSL	2	60	nr	0.11	nd	633.1	6.9	2.3	2	0.14	2.135	0.191	10SCSL60
10SSL	3	60	nr	0.03	nr	nr	nr	nr	nr				
10SSL	1	84	nr	0.24	nd	820.1	2.1	nd	2				
10SSL	2	84	nr	0.46	nd	620.1	1.9	nd	2	0.35	2.000	0.000	10SCSL84
10SSL	3	84	nr	0.06	nr	nr	nr	nr	nr				
10SSL	1	108	nr	0.01	nr	nr	nr	nr	nr				
10SSL	2	108	nr	0.2	nr	nr	nr	nr	nr				
10SSL	3	108	nr	0.15	nr	nr	nr	nr	nr				
10SSL	1	120	7.6	0.73	nr	nr	nr	nr	nr				
10SSL	2	120	7.76	0.65	nr	nr	nr	nr	nr				
10SSL	3	120	7.87	0.6	nr	nr	nr	nr	nr				
10SSL	2	132	nr	0.41	nr	nr	nr	nr	nr				
10SSL	3	132	nr	0.14	nr	nr	nr	nr	nr				
10SSL	1	246	nr	0.07	nd	679.5	nd	nd	2				
10SSL	2	246	nr	0.1	nd	668.3	nd	nd	2	0.09	2.000	0.000	10SCSL246
25SCL	1	0	nr	0.81	nd	270.0	11.3	nd	11.2				
25SCL	2	0	nr	0.44	nd	283.98	9.0	nd	8.3				
25SCL	3	0	nr	1.2	nd	284.0	9.0	nd	5	0.82	8.167	3.102	25SCRL0
25SCL	2	12	nr	0.37	nd	649.6	15.7	0	4.45				
25SCL	2	12	nr	0.03	nd	592.7	15.2	nd	7.98				
25SCL	3	12	nr	0.77	nd	nr	15.7	nd	4.45	0.39	5.627	2.038	25SCRL12
25SCL	1	24	nr	0.13	nr	nr	nr	nr	nr				
25SCL	2	24	nr	1	nr	nr	nr	nr	nr				
25SCL	3	24	nr	0.08	nr	nr	nr	nr	nr				
25SCL	1	36	nr	0.42	nr	nr	nr	nr	nr				
25SCL	2	36	nr	0.23	nr	nr	nr	nr	nr				
25SCL	3	36	nr	0.88	nr	nr	nr	nr	nr				
25SCL	1	48	nr	0.56	nd	564.5	2.1	nd	1.1				
25SCL	2	48	nr	0.05	nd	625.7	3.4	nd	2.28				
25SCL	3	48	nr	0.37	nd	495.48	5.7	3.11	2.43	0.33	1.937	0.728	25SCRL48
25SCL	2	53	nr	nr	nr	nr	nr	nr	nr				

Table D2-2. Smoky Canyon Mine Ion Chromotography Data, continued.

Experiment	Replicate	Time	pH	O_2	PO_4^{+}	SO_4^{2-}	SeO_4^{2-}	SeO_3^{2-}	NO_3^{-}	O_2 Ave	NO_3^{-} Ave	NO_3^{-} s.d.	Sample ID
25SCL	1	60	nr	0.51	nd	564.5	nd	nd	2				
25SCL	2	60	nr	0.46	nd	625.7	nd	nd	2				
25SCL	3	60	nr	0.35	nd	698.18	1.7	nd	7.16	0.44	3.720	2.979	25SCRL60
25SCL	1	72	nr	0.46	nd	719	7.6	nr	6.78				
25SCL	2	72	nr	0.31	nd	506.96	6.8	nr	6.74				
25SCL	3	72	nr	0.13	nd	533.26	6.2	nr	6.51	0.30	6.677	0.146	25SCRL72
25SCL	1	96	nr	0.63	nr	nr	nr	nr	nr				
25SCL	2	96	nr	0.84	nr	nr	nr	nr	nr				
25SCL	3	96	nr	0.18	nr	nr	nr	nr	nr				
25SCL	1	120	7.38	0.54	nr	nr	nr	nr	nr				
25SCL	2	120	7.41	1.6	nr	nr	nr	nr	nr				
25SCL	3	120	7.29	0.17	nr	nr	nr	nr	nr				
25SCL	1	144	nr	0.15	nr	nr	nr	nr	nr				
25SCL	2	144	nr	0.27	nr	nr	nr	nr	nr				
25SCL	3	144	nr	0.42	nr	nr	nr	nr	nr				
25SCL	1	168	nr	0.06	nr	nr	nr	nr	nr				
25SCL	2	168	nr	0.01	nr	nr	nr	nr	nr				
25SCL	3	168	nr	0.29	nr	nr	nr	nr	nr				
25SCL	1	228	nr	0.13	nd	506.96	nd	nd	2				
25SCL	2	228	nr	0.07	nd	533.26	nd	nd	2	0.10	2.000	0.000	25SCRL228
25SRL	1	0	nr	1.8	nd	687.2	11.3	nd	8.63				
25SRL	2	0	nr	0.44	nd	683.0	10.8	nd	7.69				
25SRL	3	0	nr	1.2	nd	683.0	10.8	nd	7.69	1.15	8.003	0.543	25SCRL0
25SRL	2	12	nr	0.37	nd	712.6	13.6	nd	4.12				
25SRL	2	12	nr	0.03	nd	649.61	14.9	nd	5.53	0.20	4.825	0.997	25SCRL12
25SRL	3	12	nr	0.77	nr	nr	nr	nr	nr				
25SRL	1	24	nr	0.13	nr	nr	nr	nr	nr				
25SRL	2	24	nr	1	nr	nr	nr	nr	nr				
25SRL	3	24	nr	0.08	nr	nr	nr	nr	nr				
25SRL	1	36	nr	0.42	nr	nr	nr	nr	nr				
25SRL	2	36	nr	0.23	nr	nr	nr	nr	nr				
25SRL	3	36	nr	0.88	nr	nr	nr	nr	nr				

Table D2-2. Smoky Canyon Mine Ion Chromotography Data, continued.

Experiment	Replicate	Time	pH	O_2	PO_4^{+}	SO_4^{2-}	SeO_4^{2-}	SeO_3^{2-}	NO_3^{-}	O_2 Ave	NO_3^{-} Ave	NO_3^{-} s.d.	Sample ID
25SRL	3	48	nr	0.37	nr	nr	nr	nr	nr				
25SRL	2	53	nr	nr	nr	nr	nr	nr	nr				
25SRL	1	60	nr	0.51	nd	799.3	nd	nd	2				
25SRL	2	60	nr	0.46	nd	805.3	nd	nd	2	0.49	2.000	0.000	25SCRL60
25SRL	3	60	nr	0.35	nr	nr	nr	nr	nr				
25SRL	1	72	nr	0.46	nr	nr	nr	nr	nr				
25SRL	2	72	nr	0.31	nr	nr	nr	nr	nr				
25SRL	3	72	nr	0.13	nr	nr	nr	nr	nr				
25SRL	1	96	nr	0.63	nr	nr	nr	nr	nr				
25SRL	2	96	nr	0.84	nr	nr	nr	nr	nr				
25SRL	3	96	nr	0.18	nr	nr	nr	nr	nr				
25SRL	1	120	7.38	0.54	nr	nr	nr	nr	nr				
25SRL	2	120	7.41	1.6	nr	nr	nr	nr	nr				
25SRL	3	120	7.29	0.17	nr	nr	nr	nr	nr				
25SRL	1	144	nr	0.15	nr	nr	nr	nr	nr				
25SRL	2	144	nr	0.27	nr	nr	nr	nr	nr				
25SRL	3	144	nr	0.42	nr	nr	nr	nr	nr				
25SRL	1	168	nr	0.06	nr	nr	nr	nr	nr				
25SRL	2	168	nr	0.01	nr	nr	nr	nr	nr				
25SRL	3	168	nr	0.29	nr	nr	nr	nr	nr				
25SRL	1	228	nr	0.06	nd	637.9	nd	nd	2				
25SRL	2	228	nr	0.13	nd	644.3	nd	nd	2	0.10	2.000	0.000	25SCRL228
25SSL	1	0	nr	1.8	nd	1050.3	5.7	nd	10.56				
25SSL	2	0	nr	0.63	nd	1021.5	7.2	nd	10.43				
25SSL	3	0	nr	0.7	nr	nr	nr	nr	nr	1.04	10.495	0.092	25SCSL0
25SSL	1	12	nr	0.37	nr	nr	nr	nr	nr				
25SSL	1	12	nr	0.33	nd	799.3	2.1	nd	1.1				
25SSL	2	12	nr	0.75	nd	805.3	3.4	nd	2.28				
25SSL	3	12	nr	0.76	nr	nr	nr	nr	nr	0.55	1.690	0.834	25SCSL12
25SSL	1	24	nr	0.62	nr	nr	nr	nr	nr				
25SSL	2	24	nr	0.51	nr	nr	nr	nr	nr				
25SSL	3	24	nr	0.32	nr	nr	nr	nr	nr				

Table D2-2. Smoky Canyon Mine Ion Chromotography Data, continued.

Experiment	Replicate	Time	pH	O_2	PO_4^{+}	SO_4^{2-}	SeO_4^{2-}	SeO_3^{2-}	NO_3^{-}	O_2 Ave	NO_3^{-} Ave	NO_3^{-} s.d.	Sample ID
25SSL	1	36	nr	0.24	nr	nr	nr	nr	nr				
25SSL	1	36	nr	0.15	nr	nr	nr	nr	nr				
25SSL	2	36	nr	0.28	nr	nr	nr	nr	nr				
25SSL	3	36	nr	0.34	nr	nr	nr	nr	nr				
25SSL	3	48	nr	0.3	nr	nr	nr	nr	nr				
25SSL	2	48	nr	0.39	nr	nr	nr	nr	nr				
25SSL	1	48	nr	0.89	nd	1118.9	5.7	3.11	2.43				
25SSL	3	48	nr	1.96	nd	830.9	8.3	nd	2.3	0.89	2.365	0.092	25SCSL48
25SSL	1	60	nr	0.7	nr	nr	nr	nr	nr				
25SSL	1	60	nr	0.35	nd	921.1	3.5	nd	2				
25SSL	2	60	nr	0.24	3.86	730.4	nd	3.92	2				
25SSL	3	60	nr	0.23	nr	nr	nr	nr	nr	0.38	2.000	0.000	25SCSL60
25SSL	1	72	nr	0.52	nr	nr	nr	nr	nr				
25SSL	1	72	nr	0.04	nr	nr	nr	nr	nr				
25SSL	2	72	nr	0.05	nr	nr	nr	nr	nr				
25SSL	3	72	nr	0.42	nr	nr	nr	nr	nr				
25SSL	1	96	nr	0.17	nr	nr	nr	nr	nr				
25SSL	1	96	nr	0.17	nr	nr	nr	nr	nr				
25SSL	2	96	nr	0.01	nr	nr	nr	nr	nr				
25SSL	3	96	nr	0.13	nr	nr	nr	nr	nr				
25SSL	1	120	7.54	1.33	nr	nr	nr	nr	nr				
25SSL	1	120	7.28	0.18	nr	nr	nr	nr	nr				
25SSL	2	120	7.51	0.11	nd	810.3	nd	nd	2				
25SSL	2	120	7.35	0.17	nd	775.9	nd	nd	2				
25SSL	3	120	7.35	0.26	nr	nr	nr	nr	nr	0.35	2.000	0.000	25SCSL120
25SSL	3	120	7.23	0.06	nr	nr	nr	nr	nr				
25SSL	1	144	nr	0.38	nr	nr	nr	nr	nr				
25SSL	1	144	nr	0.23	nr	nr	nr	nr	nr				
25SSL	2	144	nr	0.22	nr	nr	nr	nr	nr				
25SSL	3	144	nr	0.55	nr	nr	nr	nr	nr				
25SSL	1	168	nr	0.23	nr	nr	nr	nr	nr				
25SSL	1	168	nr	0.03	nr	nr	nr	nr	nr				
25SSL	2	168	nr	0.14	nr	nr	nr	nr	nr				

Table D2-2. Smoky Canyon Mine Ion Chromotography Data, continued.

Experiment	Replicate	Time	pH	O_2	PO_4^{+}	SO_4^{2-}	SeO_4^{2-}	SeO_3^{2-}	NO_3^{-}	O_2 Ave	NO_3^{-} Ave	NO_3^{-} s.d.	Sample ID
25SSL	3	168	nr	0.5	nr	nr	nr	nr	nr				
25SSL	1	228	nr	nr	nr	nr	nr	nr	nr				
25SSL	1	228	nr	nr	nd	831.8	1.1	nd	2		2.000	0.000	25SCSL228
SC10-CK1	1	0	nr	1.56	nd	213.3	7.8	nd	nd				
SC10-CK1	1	12	nr	1.09	nd	314.8	8.9	nd	nr				
SC10-CK1	1	24	nr	1.19	nr	nr	nr	nr	nr				
SC10-CK1	1	36	nr	0.87	nr	nr	nr	nr	nr				
SC10-CK1	1	48	nr	1.3	nr	nr	nr	nr	nr				
SC10-CK1	1	72	nr	0.61	nr	nr	nr	nr	nr				
SC10-CK1	1	96	nr	1.54	nr	nr	nr	nr	nr				
SC10-CK1	1	120	nr	1.12	nr	nr	nr	nr	nr				
SC10-CK1	1	144	7.29	0.83	nr	nr	nr	nr	nr				
SC10-CK1	1	168	nr	0.96	nr	nr	nr	nr	nr				
SC10-CK1	1	192	nr	1.84	nr	nr	nr	nr	nr				
SC10-CK2	2	0	nr	1.05	nr	nr	nr	nr	nr				
SC10-CK2	2	12	nr	0.12	nr	nr	nr	nr	nr				
SC10-CK2	2	24	nr	1.44	nr	nr	nr	nr	nr				
SC10-CK2	2	36	nr	0.62	nr	nr	nr	nr	nr				
SC10-CK2	2	48	nr	1.01	nr	nr	nr	nr	nr				
SC10-CK2	2	72	nr	0.34	nr	nr	nr	nr	nr				
SC10-CK2	2	96	nr	1.45	nr	nr	nr	nr	nr				
SC10-CK2	2	120	nr	0.61	nr	nr	nr	nr	nr				
SC10-CK2	2	144	7.66	1.16	nr	nr	nr	nr	nr				
SC10-CK2	2	168	nr	0.71	nr	nr	nr	nr	nr				
SC10-CK2	2	192	nr	0.72	nr	nr	nr	nr	nr				
SC10-CK3	3	0	nr	1.74	nr	nr	nr	nr	nr				
SC10-CK3	3	12	nr	0.81	nr	nr	nr	nr	nr				
SC10-CK3	3	24	nr	1.19	nr	nr	nr	nr	nr				
SC10-CK3	3	36	nr	0.82	nr	nr	nr	nr	nr				
SC10-CK3	3	48	nr	0.85	nr	nr	nr	nr	nr				
SC10-CK3	3	72	nr	0.26	nr	nr	nr	nr	nr				
SC10-CK3	3	96	nr	2.11	nr	nr	nr	nr	nr				

Table D2-2. Smoky Canyon Mine Ion Chromotography Data, continued.

Experiment	Replicate	Time	pH	O_2	PO_4^{+}	SO_4^{2-}	SeO_4^{2-}	SeO_3^{2-}	NO_3^{-}	O_2 Ave	NO_3^{-} Ave	NO_3^{-} s.d.	Sample ID
SC10-CK3	3	120	nr	1.59	nr	nr	nr	nr	nr				
SC10-CK3	3	144	7.8	0.8	nr	nr	nr	nr	nr				
SC10-CK3	3	168	nr	1.69	nr	nr	nr	nr	nr				
SC10-CK3	3	192	nr	1.47	nr	nr	nr	nr	nr				
SC10-RK1	1	0	nr	0.61	nd	426.5	12.58	nd	nd				
SC10-RK1	1	12	nr	0.9	nr	nr	nr	nr	nr				
SC10-RK1	1	24	nr	0.71	nr	nr	nr	nr	nr				
SC10-RK1	1	36	nr	0.31	nr	nr	nr	nr	nr				
SC10-RK1	1	48	nr	1.05	nr	nr	nr	nr	nr				
SC10-RK1	1	72	nr	0.71	nr	nr	nr	nr	nr				
SC10-RK1	1	96	nr	0.79	nr	nr	nr	nr	nr				
SC10-RK1	1	120	nr	0.5	nr	nr	nr	nr	nr				
SC10-RK1	1	144	7.62	0.74	nr	nr	nr	nr	nr				
SC10-RK1	1	168	nr	0.64	nr	nr	nr	nr	nr				
SC10-RK1	1	192	nr	0.71	nr	nr	nr	nr	nr				
SC10-RK2	2	0	nr	0.67	nr	nr	nr	nr	nr				
SC10-RK2	2	12	nr	0.67	nr	nr	nr	nr	nr				
SC10-RK2	2	24	nr	0.87	nr	nr	nr	nr	nr				
SC10-RK2	2	36	nr	0.08	nr	nr	nr	nr	nr				
SC10-RK2	2	48	nr	0.64	nr	nr	nr	nr	nr				
SC10-RK2	2	72	nr	1.09	nr	nr	nr	nr	nr				
SC10-RK2	2	96	nr	0.77	nr	nr	nr	nr	nr				
SC10-RK2	2	120	nr	0.38	nr	nr	nr	nr	nr				
SC10-RK2	2	144	7.27	0.87	nr	nr	nr	nr	nr				
SC10-RK2	2	168	nr	0.36	nr	nr	nr	nr	nr				
SC10-RK2	2	192	nr	0.54	nr	nr	nr	nr	nr				
SC10-RK3	3	0	nr	1.7	nr	nr	nr	nr	nr				
SC10-RK3	3	12	nr	0.54	nr	nr	nr	nr	nr				
SC10-RK3	3	24	nr	1.29	nr	nr	nr	nr	nr				
SC10-RK3	3	36	nr	0.28	nr	nr	nr	nr	nr				
SC10-RK3	3	48	nr	0.22	nr	nr	nr	nr	nr				
SC10-RK3	3	72	nr	0.59	nr	nr	nr	nr	nr				
SC10-RK3	3	96	nr	0.23	nr	nr	nr	nr	nr				

Table D2-2. Smoky Canyon Mine Ion Chromotography Data, continued.

Experiment	Replicate	Time	pH	O_2	PO_4^{+}	SO_4^{2-}	SeO_4^{2-}	SeO_3^{2-}	NO_3^{-}	O_2 Ave	NO_3^{-} Ave	NO_3^{-} s.d.	Sample ID
SC10-RK3	3	120	nr	0.31	nr	nr	nr	nr	nr				
SC10-RK3	3	144	7.46	0.84	nr	nr	nr	nr	nr				
SC10-RK3	3	168	nr	0.99	nr	nr	nr	nr	nr				
SC10-RK3	3	192	nr	0.54	nr	nr	nr	nr	nr				
SC10-SK1	1	0	nr	1.1	nd	719.1	nd	nd	2				
SC10-SK1	1	12	nr	0.2	nr	nr	nr	nr	nr				
SC10-SK1	1	24	nr	0.81	nr	nr	nr	nr	nr				
SC10-SK1	1	36	nr	0.53	nr	nr	nr	nr	nr				
SC10-SK1	1	48	nr	0.69	nr	nr	nr	nr	nr				
SC10-SK1	1	72	nr	0.68	nr	nr	nr	nr	nr				
SC10-SK1	1	96	nr	0.3	nr	nr	nr	nr	nr				
SC10-SK1	1	120	nr	0.55	nr	nr	nr	nr	nr				
SC10-SK1	1	144	7.29	0.48	nr	nr	nr	nr	nr				
SC10-SK1	1	168	nr	0.81	nr	nr	nr	nr	nr				
SC10-SK1	1	192	nr	0.45	nr	nr	nr	nr	nr				
SC10-SK2	2	0	nr	0.92	nr	nr	nr	nr	nr				
SC10-SK2	2	12	nr	0.44	nr	nr	nr	nr	nr				
SC10-SK2	2	24	nr	0.87	nr	nr	nr	nr	nr				
SC10-SK2	2	36	nr	0.36	nr	nr	nr	nr	nr				
SC10-SK2	2	48	nr	0.33	nr	nr	nr	nr	nr				
SC10-SK2	2	72	nr	0.46	nr	nr	nr	nr	nr				
SC10-SK2	2	96	nr	0.73	nr	nr	nr	nr	nr				
SC10-SK2	2	120	nr	0.65	nr	nr	nr	nr	nr				
SC10-SK2	2	144	7.25	0.95	nr	nr	nr	nr	nr				
SC10-SK2	2	168	nr	0.75	nr	nr	nr	nr	nr				
SC10-SK2	2	192	nr	0.49	nr	nr	nr	nr	nr				
SC10-SK3	3	0	nr	0.61	nr	nr	nr	nr	nr				
SC10-SK3	3	12	nr	0.35	nd	318.3	8.9	nd	nd				
SC10-SK3	3	24	nr	0.71	nr	nr	nr	nr	nr				
SC10-SK3	3	36	nr	0.62	nr	nr	nr	nr	nr				
SC10-SK3	3	48	nr	1.21	nr	nr	nr	nr	nr				
SC10-SK3	3	72	nr	0.69	nr	nr	nr	nr	nr				
SC10-SK3	3	96	nr	1.44	nr	nr	nr	nr	nr				

Table D2-2. Smoky Canyon Mine Ion Chromotography Data, continued.

Experiment	Replicate	Time	pH	O_2	PO_4^{+}	SO_4^{2-}	SeO_4^{2-}	SeO_3^{2-}	NO_3^{-}	O_2 Ave	NO_3^{-} Ave	NO_3^{-} s.d.	Sample ID
SC10-SK3	3	120	nr	0.8	nr	nr	nr	nr	nr				
SC10-SK3	3	144	7.57	0.77	nr	nr	nr	nr	nr				
SC10-SK3	3	168	nr	0.67	nr	nr	nr	nr	nr				
SC10-SK3	3	192	nr	0.78	nr	nr	nr	nr	nr				
SC25-CK1	1	0	nr	0.65	nr	nr	nr	nr	nr				
SC25-CK1	1	12	nr	1.28	nr	nr	nr	nr	nr				
SC25-CK1	1	24	nr	0.92	nr	nr	nr	nr	nr				
SC25-CK1	1	36	nr	1.29	nr	nr	nr	nr	nr				
SC25-CK1	1	48	nr	0.27	nr	nr	nr	nr	nr				
SC25-CK1	1	72	nr	1.03	nr	nr	nr	nr	nr				
SC25-CK1	1	96	nr	0.6	nr	nr	nr	nr	nr				
SC25-CK1	1	120	nr	0.42	nr	nr	nr	nr	nr				
SC25-CK1	1	144	7.71	0.89	nr	nr	nr	nr	nr				
SC25-CK1	1	168	nr	1.17	nr	nr	nr	nr	nr				
SC25-CK1	1	192	nr	0.32	nr	nr	nr	nr	nr				
SC25-CK2	2	0	nr	1.33	nr	nr	nr	nr	nr				
SC25-CK2	2	12	nr	1.6	nr	nr	nr	nr	nr				
SC25-CK2	2	24	nr	1.27	nr	nr	nr	nr	nr				
SC25-CK2	2	36	nr	0.66	nr	nr	nr	nr	nr				
SC25-CK2	2	48	nr	0.76	nr	nr	nr	nr	nr				
SC25-CK2	2	72	nr	1.39	nr	nr	nr	nr	nr				
SC25-CK2	2	96	nr	0.58	nr	nr	nr	nr	nr				
SC25-CK2	2	120	nr	0.36	nr	nr	nr	nr	nr				
SC25-CK2	2	144	7.77	1.06	nr	nr	nr	nr	nr				
SC25-CK2	2	168	nr	0.27	nr	nr	nr	nr	nr				
SC25-CK2	2	192	nr	0.36	nr	nr	nr	nr	nr				
SC25-CK3	3	0	nr	1.03	nr	nr	nr	nr	nr				
SC25-CK3	3	12	nr	1.44	nr	nr	nr	nr	nr				
SC25-CK3	3	24	nr	0.73	nr	nr	nr	nr	nr				
SC25-CK3	3	36	nr	0.91	nr	nr	nr	nr	nr				
SC25-CK3	3	48	nr	1.43	nr	nr	nr	nr	nr				
SC25-CK3	3	72	nr	2.32	nr	nr	nr	nr	nr				

Table D2-2. Smoky Canyon Mine Ion Chromotography Data, continued.

Experiment	Replicate	Time	pH	O_2	PO_4^{+}	SO_4^{2-}	SeO_4^{2-}	SeO_3^{2-}	NO_3^{-}	O_2 Ave	NO_3^{-} Ave	NO_3^{-} s.d.	Sample ID
SC25-CK3	3	96	nr	0.45	nr	nr	nr	nr	nr				
SC25-CK3	3	120	nr	0	nr	nr	nr	nr	nr				
SC25-CK3	3	144	7.79	1.05	nr	nr	nr	nr	nr				
SC25-CK3	3	168	nr	0.88	nr	nr	nr	nr	nr				
SC25-CK3	3	192	nr	0.33	nr	nr	nr	nr	nr				
SC25-RK1	1	0	nr	1.35	nd	353.5	8.3	nd	nd				
SC25-RK1	1	12	nr	0.74	nr	nr	nr	nr	nr				
SC25-RK1	1	24	nr	1.05	nr	nr	nr	nr	nr				
SC25-RK1	1	36	nr	0.51	nr	nr	nr	nr	nr				
SC25-RK1	1	48	nr	0.45	nr	nr	nr	nr	nr				
SC25-RK1	1	72	nr	0.95	nr	nr	nr	nr	nr				
SC25-RK1	1	96	nr	0.29	nr	nr	nr	nr	nr				
SC25-RK1	1	120	nr	0.12	nr	nr	nr	nr	nr				
SC25-RK1	1	144	7.76	0.95	nr	nr	nr	nr	nr				
SC25-RK1	1	168	nr	0.04	nr	nr	nr	nr	nr				
SC25-RK1	1	192	nr	0.12	nr	nr	nr	nr	nr				
SC25-RK2	2	0	nr	0.68	nr	nr	nr	nr	nr				
SC25-RK2	2	12	nr	0.85	nr	nr	nr	nr	nr				
SC25-RK2	2	24	nr	0.93	nr	nr	nr	nr	nr				
SC25-RK2	2	36	nr	0.31	nr	nr	nr	nr	nr				
SC25-RK2	2	48	nr	0.56	nr	nr	nr	nr	nr				
SC25-RK2	2	72	nr	1.16	nr	nr	nr	nr	nr				
SC25-RK2	2	96	nr	0.12	nr	nr	nr	nr	nr				
SC25-RK2	2	120	nr	0.12	nr	nr	nr	nr	nr				
SC25-RK2	2	144	7.56	0.12	nr	nr	nr	nr	nr				
SC25-RK2	2	168	nr	-0.17	nr	nr	nr	nr	nr				
SC25-RK2	2	192	nr	0.01	nr	nr	nr	nr	nr				
SC25-RK3	3	0	nr	1.74	nr	nr	nr	nr	nr				
SC25-RK3	3	12	nr	1.07	nr	nr	nr	nr	nr				
SC25-RK3	3	24	nr	1.39	nr	nr	nr	nr	nr				
SC25-RK3	3	36	nr	0.74	nr	nr	nr	nr	nr				
SC25-RK3	3	48	nr	0.91	nr	nr	nr	nr	nr				
SC25-RK3	3	72	nr	0.38	nr	nr	nr	nr	nr				

Table D2-2. Smoky Canyon Mine Ion Chromotography Data, continued.

Experiment	Replicate	Time	pH	O_2	PO_4^{+}	SO_4^{2-}	SeO_4^{2-}	SeO_3^{2-}	NO_3^{-}	O_2 Ave	NO_3^{-} Ave	NO_3^{-} s.d.	Sample ID
SC25-RK3	3	96	nr	0.68	nr	nr	nr	nr	nr				
SC25-RK3	3	120	nr	0.12	nr	nr	nr	nr	nr				
SC25-RK3	3	144	7.57	0.12	nr	nr	nr	nr	nr				
SC25-RK3	3	168	nr	0.55	nr	nr	nr	nr	nr				
SC25-RK3	3	192	nr	0.55	nr	nr	nr	nr	nr				
SC25-SK1	1	0	nr	1	nr	nr	nr	nr	nr				
SC25-SK1	1	12	nr	1.22	nd	540.5	9.17	nd	nd				
SC25-SK1	1	24	nr	0.43	nr	nr	nr	nr	nr				
SC25-SK1	1	36	nr	0.74	nr	nr	nr	nr	nr				
SC25-SK1	1	48	nr	0.74	nr	nr	nr	nr	nr				
SC25-SK1	1	72	nr	0.84	nr	nr	nr	nr	nr				
SC25-SK1	1	96	nr	0.35	nr	nr	nr	nr	nr				
SC25-SK1	1	120	nr	0.41	nr	nr	nr	nr	nr				
SC25-SK1	1	144	7.72	0.65	nr	nr	nr	nr	nr				
SC25-SK1	1	168	nr	0.11	nr	nr	nr	nr	nr				
SC25-SK1	1	192	nr	0.16	nr	nr	nr	nr	nr				
SC25-SK2	2	0	nr	1.14	nr	nr	nr	nr	nr				
SC25-SK2	2	12	nr	1.53	nr	nr	nr	nr	nr				
SC25-SK2	2	24	nr	0.65	nr	nr	nr	nr	nr				
SC25-SK2	2	36	nr	0.42	nr	nr	nr	nr	nr				
SC25-SK2	2	48	nr	0.49	nr	nr	nr	nr	nr				
SC25-SK2	2	72	nr	1.38	nr	nr	nr	nr	nr				
SC25-SK2	2	96	nr	0.39	nr	nr	nr	nr	nr				
SC25-SK2	2	120	nr	0.01	nr	nr	nr	nr	nr				
SC25-SK2	2	144	7.55	0.82	nr	nr	nr	nr	nr				
SC25-SK2	2	168	nr	0.23	nr	nr	nr	nr	nr				
SC25-SK2	2	192	nr	0.05	nr	nr	nr	nr	nr				
SC25-SK3	3	0	nr	0.54	nr	nr	nr	nr	nr				
SC25-SK3	3	12	nr	1.08	nr	nr	nr	nr	nr				
SC25-SK3	3	24	nr	0.39	nr	nr	nr	nr	nr				
SC25-SK3	3	36	nr	0.58	nr	nr	nr	nr	nr				
SC25-SK3	3	48	nr	0.95	nr	nr	nr	nr	nr				
SC25-SK3	3	72	nr	1.38	nr	nr	nr	nr	nr				

Table D2-2. Smoky Canyon Mine Ion Chromotography Data, continued.

Experiment	Replicate	Time	pH	O_2	PO_4^{+}	SO_4^{2-}	SeO_4^{2-}	SeO_3^{2-}	NO_3^{-}	O_2 Ave	NO_3^{-} Ave	NO_3^{-} s.d.	Sample ID
SC25-SK3	3	96	nr	0.72	nr	nr	nr	nr	nr				
SC25-SK3	3	120	nr	0.26	nr	nr	nr	nr	nr				
SC25-SK3	3	144	7.59	1.05	nr	nr	nr	nr	nr				
SC25-SK3	3	168	nr	0.2	nr	nr	nr	nr	nr				
SC25-SK3	3	192	nr	0.36	nr	nr	nr	nr	nr				

Values are micrograms/liter (µg/L)

*= degassed

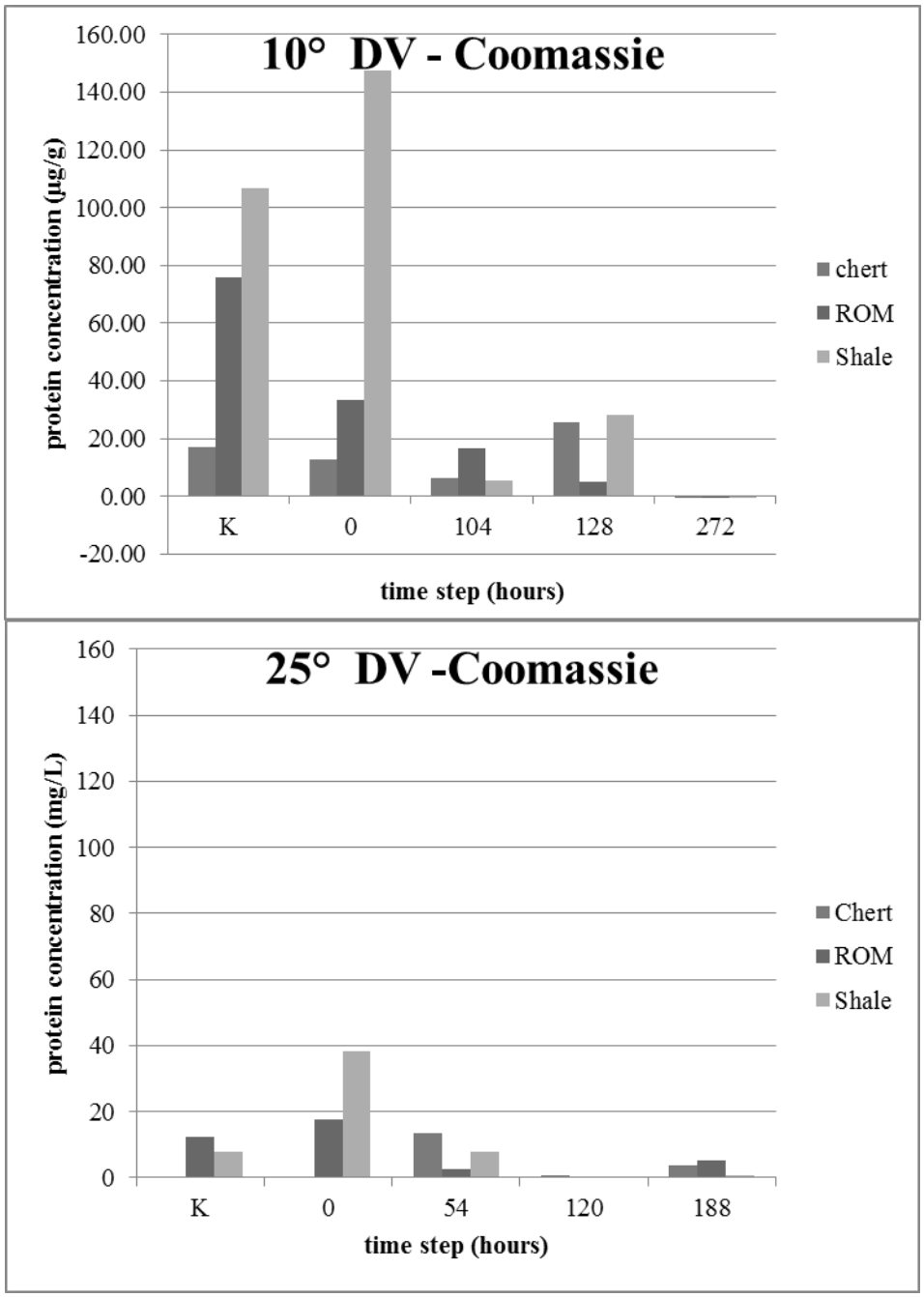
NO_3^{-} detection limit= 2 µg/L

nr= not reported

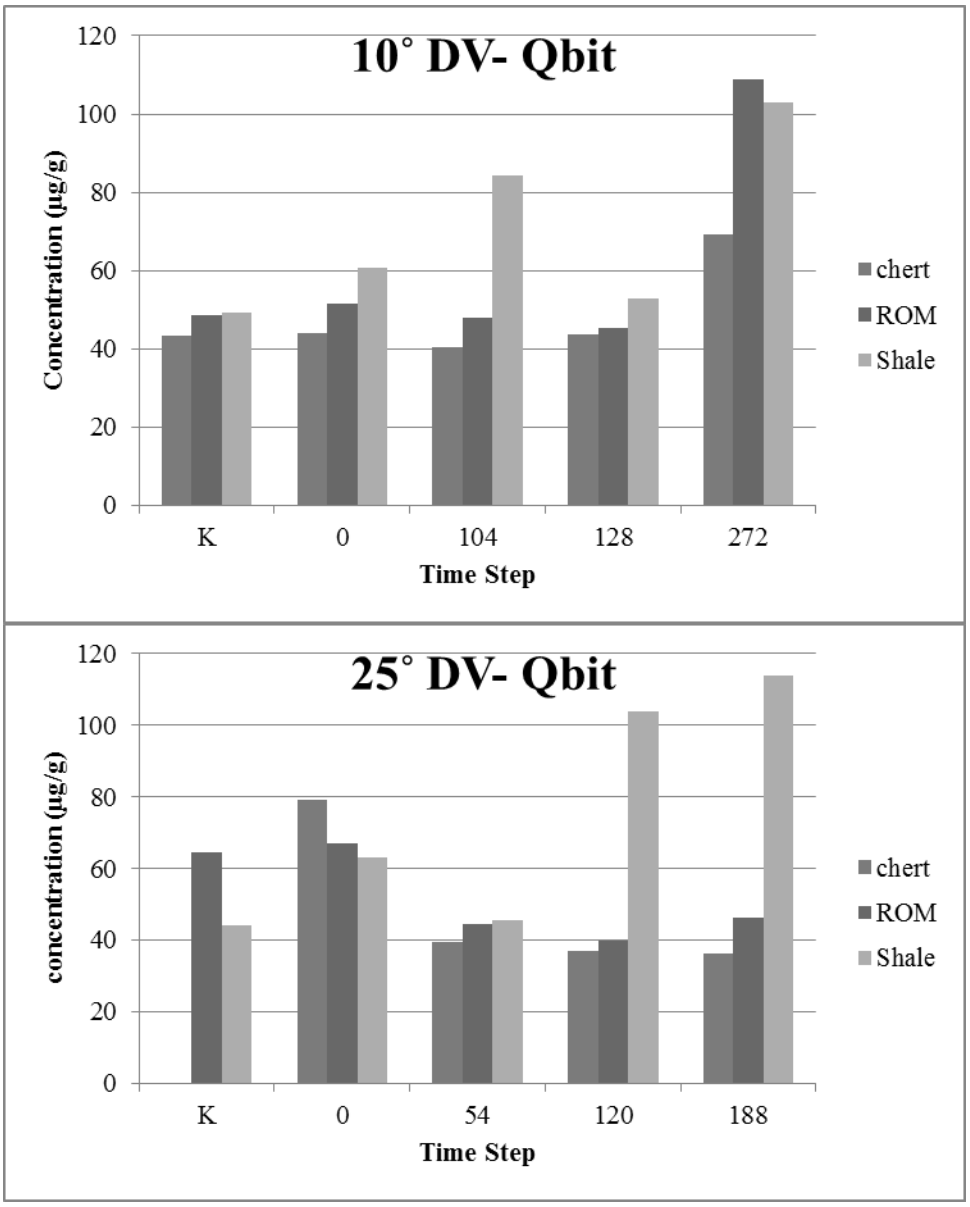
nd= not detected

na= not applicable

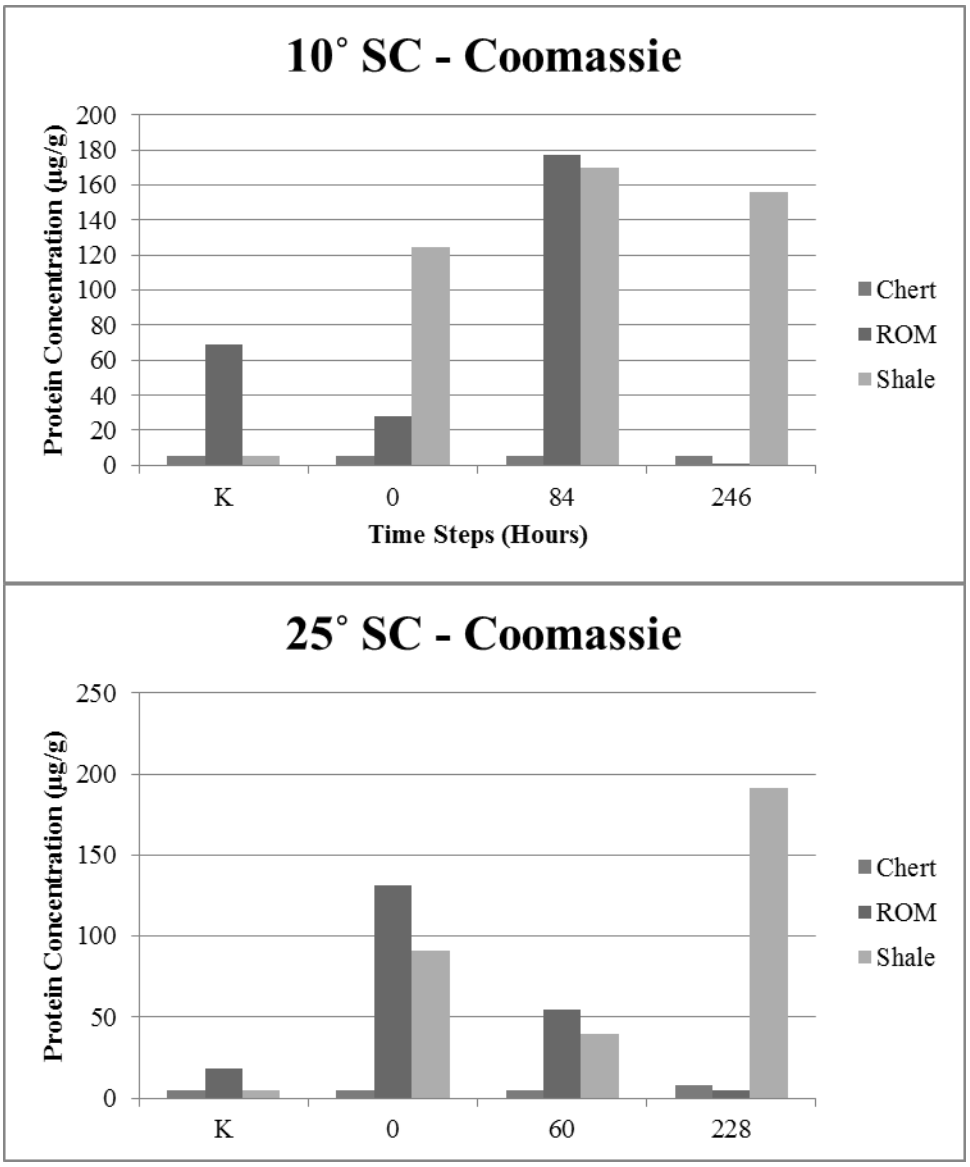
+ PO_4^{+} was detected only immediately following analysis of a standard containing PO_4^{+}



Appendix D3-1. Dry Valley Protein Assey – Coomassie Method



Appendix D3-1. Dry Valley Protein Assey – Qbit Nano-Orange Method



Appendix D3-2. Smoky Canyon Protein Assay – Coomassie Method

APPENDIX E

SPME HYDROCARBON ANALYSIS DATA

APPENDIX E

SPME HYDROCARBON ANALYSIS DATA

E1: Table E1-1. Dissolved Organic Carbon Speciation by HS-SPME-GCMS for Select Samples

Table E1. Dissolved Organic Carbon Speciation by HS-SPME-GCMS for Select Samples.

					GWDV7D2A	ROM mix media	SCD Chert 5	SCD shale 75	10 C con-trol	10 C live end	10 S con-trol	10 S live end
	Example Compound	**# Carbons**	**# Nitrogens**	**Chemical Formula**	**ng in vapor**							
Alkane	Ethanol	C2	0	C_2H_6O				14.20				
Alkane	ethane, 1,1 -oxybis-	C4	0	C_2H_6				40.02				
Alkane	Pentanal	C5	0	$C_5H_{10}O$					36.36	13.31		
Alkane	cyclopentane, methyl-	C6	0	C_6H_{12}	1.27	7.51	14.68	39.62	49.73	12.63	36.53	28.48
Alkane	Pentane, 3-methyl-	6						7.71		11.45		10.60
Alkane	2-pentanone, 4-methyl-	6					2.77	1.75	9.16			
Alkane	Hexane	6					3.60	23.44	17.46		32.00	13.10
Alkane	2-butanone, 3-hydroxy-3-methyl-	6			1.27	1.70			18.17			
Alkane	Acetic acid, butyl ester	6						2.09				
Alkane	Acetic acid, 1,1-dimethylethyl e	6					3.58					
Alkane	2-Pentanone, 3-methyl-	6						2.17				
Alkane	3- hexanone	6							4.94		4.53	4.78
Alkane	Hexane, 3-iodo	6				5.81	2.39	2.46		1.18		
Alkane	Propane, 2-ethoxy-2-methyl-	6					2.34					
Alkane	3-pentanone, 2,4-dimethyl-	C7	0	$C_5H_{10}O$		5.40			31.80			
Alkane	1-pentanol, 2,2-dimethyl-	7	0									
Alkane	2-heptanol, 2-methyl-	C8	0	$C_8H_{18}O$					26.11			
Alkane	2-heptanone, 4-methyl-	8	0						17.98			
Alkane	Nonanal	C9	0	$C_9H_{18}O$		3.60	7.87		21.63	12.28	7.09	
Alkane	heptane, 4,4-dimethyl-	9				1.45			9.74	1.32		
Alkane	Undecane, 2,4, -dimethyl-	9	0	$C_{11}H_{24}$								
Alkane	3-heptanone, 2,4-dimethyl-	9	0	$C_9H_{18}O$								
Alkane	octanal, 7-hydroxy-3,7-	10	0	$C_{10}H_{20}O_2$					17.27			

Table E1. Dissolved Organic Carbon Speciation by HS-SPME-GCMS for Select Samples, continued.

					GWDV7D2A	ROM mix media	SCD Chert 5	SCD shale 75	10 C con-trol	10 C live end	10 S con-trol	10 S live end
	dimethyl-											
Alkane	decanal	C10	0	$C_{10}H_{20}O$		4.61	7.97		27.09	1.38	7.40	7.49
Alkane	Dodecane	C12	0	$C_{12}H_{26}$				2.32	5.71	0.90	24.21	
Alkane	Dodecane, 1-iodo-	12	0								12.29	
Alkane	3-Dodecanol	12	0						5.71			
Alkane	3,6- dimethyldecane	12	0								11.92	
Alkane	Propanic acid, 2-methyl-, 2-methyl	12	0					2.32				
Alkane	9-Undecen-2-one, 6,10-dimethyl-	C13	0	$C_{13}H_{24}O$		3.63				1.05	4.85	
Alkane	Undecane, 4,6-dimethyl-	13	0								4.85	
Alkane	hexane, 1,1-[ehtylidenebis(oxy)	C14	0	C_6H_{14}		6.43		2.14	5.27		20.67	
Alkane	Decane, 2,3,5,8-tetramethyl-	14	0								7.32	
Alkane	Tetradecane	14	0								4.66	
Alkane	Tridecane, 5-methyl-	14	0			6.43						
Alkane	2-nonanone,9-[(tetrahydro-2h-py	14	0						5.27			
Alkane	Dodecane, 4,6-dimethyl-	14	0								8.69	
Alkane	Pentadecane	C15	0	$C_{15}H_{32}$							10.79	
Alkane	hexadecane	C16	0	$C_{16}H_{34}$	1.21			13.39				
Alkane	Tridecane, 6-propyl-	16	0					1.88				
Alkane	propanic acid, 2-methyl-, 1-(1	16	0					11.51				
Alkane	octadecane	C18	0	$C_{18}H_{38}$							4.89	
Alkane	Tricosane	C23	0	$C_{23}H_{48}$							5.09	
Alkane	Octosane	C28	0	$C_{28}H_{48}$							7.97	
Alkane	triacontane	C30	0	$C_{30}H_{62}$							27.31	
Alkane	hexatriacontane	C36	0	$C_{36}H_{74}$							4.64	
Alkane					**2.48**	**31.18**	**30.52**	**111.69**	**203.70**	**41.55**	**161.44**	**35.97**
Alkene	1-Pentene, 2,4,4 trimethyl-	C8	0	C_5H_{10}						0.77		

Table E1. Dissolved Organic Carbon Speciation by HS-SPME-GCMS for Select Samples, continued.

					GWDV7D2A	ROM mix media	SCD Chert 5	SCD shale 75	10 C con-trol	10 C live end	10 S con-trol	10 S live end
Alkene	2-Pentene, 3-ethyl-4,4-dimethyl-	C9	0	C_5H_{10}				1.68				
Alkene	1,2,6 Heptatriene, 2,5,5-trimethyl	C10	0	C9H12				1.89				
Alkene	4,4,7,7 -Tetramethyldeca-1,9-dien	C14	0	C14H24O2					7.47			
Alkene								**3.57**	**7.47**	**0.77**		
Aromatic	Pyrimidine, 5-bromo-	C4	2	C_4H3BrN_2;		1.25						
Aromatic	1-H-Pyrazole, 4,5-dihydro-3,5,5-t	C6	3	C29H22F3N3O2					20.66			
Aromatic	benzene, methyl-	C7		C6H6	0.81			1.77				2.94
Aromatic	Furan, tetrahydro-2,2,5,5-tetram	C8		C4H4O	0.79				17.00		4.36	
Aromatic	Benzenemethanol, 4-hydroxy-.al	C9		C8H10O		1.20	7.27					
Aromatic	Benzenedicarboxylic acid, di	C12		$C_8H_6O_4$				2.54				
Aromatic	Benzenedicarboxylic acid, butyl	C20		$C_7H_6O_2$				2.48				
Aromatic					**1.60**	**2.45**	**7.27**	**6.79**	**37.66**	**0.00**	**4.36**	**2.94**
Cyclic	cyclopentane, methyl-	C6		C_5H_{10}		1.33	6.32	7.26		1.83		9.59
Cyclic	1,2 cyclopentadiol, 1-(1-methyl	C8										7.51
Cyclic	1,8- cineole	C10		$C_{10}H_{18}O$			3.68		22.53			
Cyclic	fenchone	10							8.83			
Cyclic	(+)- isomethol	10							4.87			
Cyclic	Cyclohexane, 1,2-diethyl-3-methy	C11		C_6H_{12}							16.27	
Cyclic	Cyclohexane, 1-ethyl-2-propyl	11									7.29	
Cyclic	Cyclooctane,butyl-	C12		C_6H_{12}							6.98	
Cyclic	cyclohexane, octyl-	C14		$C_{14}H_{28}$					4.90			
Cyclic						**1.33**	**10.00**	**7.26**	**41.13**	**1.83**	**30.54**	**17.10**
Amine	2-Propanamine	C3	1	C_3H_9N			9.38					

Table E1. Dissolved Organic Carbon Speciation by HS-SPME-GCMS for Select Samples, continued.

					GWDV7D2A	ROM mix media	SCD Chert 5	SCD shale 75	10 C con-trol	10 C live end	10 S con-trol	10 S live end
ketone	2-Propanone	3					2.09					
	Plumbane, tetramethyl-	4							6.45			2.04
	4-Nitro-1-methylimidazole	4							6.45			
heterocyclic	2,2,3,3-Tetramethyl-1-d1-aziridine	4							13.40			13.82
	1,2,3- Oxazaborolane, 2-butyl-	6										13.82
ketone	Camphor	C10						2.04	14.54			
	Hydroxylamine, o-decyl-	10						2.04				
terpene	Farnesol	C15									4.58	

These analyses represent GCMS speciation of the aqueous hydrocarbons using SPME methods - volatiles stirred out of aqueous phase, collected on siloxane fiber that is destructively sampled in GCMS.

This table summarizes total concentration by #C compounds within each major class of hydrocarbon (alkane, alkene, aromatic, cyclic, misc)

Samples are groundwater GWDV7D2a and aqueous GWTOC extract (bottle roll);two of the bottle roll extracts used for the MPN work, DMSo and DC5; starting (killed) and ending (live) solutions from the 10 Chert and 10 shale (Dry Valley).

APPENDIX F

SYNCHROTRON MINERALOGY DATA

APPENDIX F

SYNCHROTRON MINERALOGY DATA

Data on CD.
To request DVD copies contact your local public or university library to place an interlibrary loan request to Montana State University. Questions call 406-994-3161.

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TECHNICAL ARTICLE

A Simplified Anaerobic Bioreactor for the Treatment of Selenium-Laden Discharges from Non-acidic, End-Pit Lakes

Andreas Luek · Curtis Brock · David J. Rowan · Joseph B. Rasmussen

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Abstract Selenium (Se) contamination of aquatic resources and its mitigation is of global concern. Anaerobic bioreactors are the most promising method for treating Se-laden water in end-pit lakes resulting from intensive coal mining and waste rock leachate in the Canadian Rockies. This study assessed the suitability of a bioreactor system to treat non-acidic, coal mine effluent containing 85 µg/L of Se, near Grande Cache, AB, Canada, while making the system as cheap as possible using locally available materials. We successfully used a sediment inoculum from the same end-pit lake as the effluent source to obtain sulfur/Se-reducing bacteria and mixed the inoculum with mulch, manure, gravel, limestone, and bone meal to comprise the 'active substrate' for the bioreactors. The anaerobic bioreactors reduced >95 % of the total Se in the inflow water with a flow rate of $\approx$0.2 m^3/h. Se removal was not related to water temperature, which declined from 17 to $\approx$2 °C in November, suggesting water can be treated regardless of temperature. The use of manure as a bacterial carbon/nitrogen source introduced *Escherichia coli* into the downstream environment, but after a short elevated concentration, the abundance of *E. coli* dropped below water quality guidelines. We were able to show that successful Se reduction can be achieved using an anaerobic bioreactor design and locally available material. This design kept the building and maintenance price lower than previous reactors, making the approach promising for larger scale applications and making bioreactors a more cost accessible remediation technology for non-acidic end-pit lakes.

Keywords Bioremediation · Mining effluent · Non-acidic pit lakes · Selenium reduction · Water treatment

A. Luek (✉) · J. B. Rasmussen
Department of Biological Sciences, University of Lethbridge, 4401 University Dr, Lethbridge, AB T1K 3M4, Canada
e-mail: andreas.luek@gmail.com

J. B. Rasmussen
e-mail: joseph.rasmussen@uleth.ca

C. Brock
Alberta Environment, 250 Diamond Ave, Spruce Grove, AB T7X 4C7, Canada
e-mail: curtis.brock@gov.ab.ca

D. J. Rowan
Atomic Energy of Canada Ltd (AECL), Chalk River, ON K0J 1J0, Canada
e-mail: rowand@aecl.ca

Introduction

Selenium (Se) is an important micronutrient for all living organisms (Winkel et al. 2011), yet a slight increase in concentration makes it toxic to many mammals, birds, and fish (Lemly 1993a). In aquatic communities, the most prevalent effects of Se contamination are teratogenic deformities (Conley et al. 2009; Debruyn and Chapman 2007; Hamilton 2004) and a lack of reproductive success (Deforest et al. 2011). These effects are of particular concern in fish, which are sensitive to small increases in Se concentrations (Janz 2011; Lemly 2002). In fish, Se causes severe head, mouth, fin, and spinal deformities (Lemly 1993b) and has been linked to the extirpation of several fish populations (Janz 2011). Se is a contaminant of global concern and discharge of Se into freshwater ecosystems must be controlled.

Common sources of Se contamination are fly ash from coal power plants (Lemly 1997; Ruhl et al. 2012), leachate from irrigated seleniferous soils, including agricultural lands of the western USA (Banuelos et al. 2002; Wu 2004),

and rock drainage from open pit mines, including those in the American and Canadian Rockies, the Appalachian Mountains, and their foothills (Griffith et al. 2012; Kelly and Janz 2009). In Canada, for example, the larger rivers draining the eastern slopes of the Rockies, i.e. the Elk, McLeod, and Athabasca Rivers, are increasingly affected by Se discharged into their tributaries by mining operations in their headwaters (Dessouki and Ryan 2010; Orr et al. 2006). The amount of Se in the Elk River has increased continuously since the 1980s, presently averaging over 5 µg/L (Dessouki and Ryan 2010). At a base flow of approximately 50 m^3/s, this means 21.6 kg of Se/day moving down the Elk River alone (data used from Dessouki and Ryan 2010). On this scale, the amount of Se released downstream is basically untreatable.

Clearly, effective, long-term, cost efficient methods are required to treat large volumes of Se-laden discharge. Thus far, research has focused on three broad approaches to remove Se from wastewater: (1) physical methods including nanofiltration or reverse osmosis (Kharaka et al. 1996), (2) direct chemical treatments using zero-valent iron or ferrous hydroxides (Frankenberger et al. 2004; Zhang et al. 2005), and (3) various biological treatment options. Biological treatments range from Se extraction or precipitation using artificial or constructed wetlands (Thompson et al. 2003; Zhang and Frankenberger 2003), to phytoremediation using bio-engineered plants (Banuelos et al. 2002; Berken et al. 2002; Terry et al. 2003), to bacterial reduction in bioreactors or sludge reactors (Fujita et al. 2002; Lenz et al. 2008; Macy et al. 1993). The anaerobic sulfate-reducing bacteria cultured inside bioreactors are efficient at reducing aquatic selenites and selenates (Se oxyanions) to elemental Se (Cantafio et al. 1996; Hockin and Gadd 2006; Macy et al. 1993). These bacteria preferentially substitute sulfates with Se oxyanions as electron sources due to the chemical similarity of Se to sulfur and the higher energy potential of Se (Steinberg et al. 1992). While several treatment options reduce selenates and selenites to elemental Se using bacteria, this approach using bioreactors has thus far been the most successful at removing Se from wastewater (Lenz and Lens 2009).

While several experimental (small-scale) bioreactors have tested the potential of sulfate-reducing bacterial communities to treat Se-laden effluents (Hockin and Gadd 2006; Lenz et al. 2008; Zhang and Frankenberger 2006), a number of lab-sized approaches tested the performance of specific bacteria (Hunter and Manter 2009; Oremland et al. 1994). Most of these experiments were conducted under very controlled environments with lactate or acetate as the carbon source and were designed for warm to temperate climates. Furthermore, the designed reactors were elaborate constructs with high building and maintenance costs. For one of these test reactors, Cantafio et al. (1996) estimated the price of the acetate feed at US \$0.62/m^3 of water treated. Therefore, to treat one effluent source with a low discharge rate of 0.5 m^3/s, it would cost nearly US \$1 million/year for the acetate feed alone. To treat the Elk River at 50 m^3/s (Dessouki and Ryan 2010), it would cost 10 times that amount (US \$10 million/year) just for the carbon source. Realistically, treatment must be implemented at the discharge source, e.g. mine outflows and small tributaries, to reduce the volume of water requiring treatment. Various large-scale reactors have been built and tested (Gusek et al. 2008; Rutkowski et al. 2013) but challenges remain for efficient treatment and long-term feasibility (Lenz and Lens 2009).

Anaerobic bioreactors were recently deemed the most promising method for the passive treatment of Se-laden effluent from intensive coal mining in the Canadian Rockies in Alberta, Canada (Alberta Environment 2006). Of particular concern for remediation are end-pit lakes, drainage collection pools that remain after open-pit mining has ceased, which have high water concentrations of Se and represent a major Se contamination source for Albertan rivers and their watersheds. The current study assessed the suitability of a bioreactor system to field-treat Se-laden coal mine effluent from a non-acidic end-pit lake, near Grade Cache, in west-central Alberta, while making the reactor as cheap as possible. To reduce the cost, the bioreactor system was of simple design and used, wherever possible, locally available materials, including a sediment inoculum (bacterial source) from the same end-pit mine lake used as the effluent source. We identified three key features needed for successful Se reduction in an anaerobic bioreactor and evaluated the performance of our model reactor along them: first, the required environment within the reactor is anoxic; second, the bacterial community needs to be capable of reducing selenites and selenates to elemental Se and; third, the substrate of the reactor needs to be able to support the growth of the required bacterial community. This study was a proof-of-concept for reclamation of Se-laden, coal mine effluent and provides important considerations for future full-scale treatment designs using end-pit lakes.

Methods

Field Site Description

The bioreactor system was built on the property of Grande Cache Coal Inc., approximately 20 km north of Grande Cache, AB, and about 440 km west of Edmonton, AB, Canada. The section of mine hosting the bioreactor system is currently undergoing reclamation and was chosen due to its consistent discharge of Se-laden water (0.5 m^3/s) as

well as its accessibility. Water for the reactor was diverted from the creek outflow of an end-pit lake (Dyno Lake), which exhibits particularly high levels of waterborne Se due to its position in the lower end of the drainage system of the mine. The average Se content of the water flowing out of Dyno Lake is 92.3 µg/L. Additional water quality and sediment properties of Dyno Lake are shown in Table 1. Water treatment at this site is further complicated by a sub-arctic climate; below-freezing temperatures and winter snow arrives at the beginning of October.

Bioreactor Design

The bioreactor system was a simple flow-return design (Fig. 1a), wherein water was diverted from the outflow of Dyno Lake, treated, and then returned to the creek. Specifically, a 15.2 cm (6″) diameter PVC pipe diverted water from the creek into a 1,022 L (270 gal) plastic sump tank. The creek end of this pipe was placed facing upstream and parallel to the creek flow for maximum collection efficiency. The sump functioned to buffer irregular discharge from the creek and thereby maintained a constant flow into the two bioreactors. The bioreactors were connected to the sump, in parallel, by 2.5 cm (1″) diameter plastic pipes while a T-junction in these pipes connected two 6.4 mm (1/4″) diameter ethylene glycol feeds (clear plastic tubing) from a 341 L (90 gal) storage tank. The storage tank was elevated on a wooden platform, approximately 45.7 cm (18″) off the ground, to ensure flow of the viscous ethylene glycol (Univar, Edmonton, AB, Canada) addition to the creek water before it reached the reactors. Ethylene glycol was added to each reactor for two reasons. Primarily, ethylene glycol was considered to be an additional carbon source for the bacteria, and second, ethylene glycol is a non-toxic antifreeze product, which had the potential to maintain the operations of the reactor in below-freezing temperatures. Ethylene glycol was added as 0.1 % of the creek water volume (vol/vol) and was regulated by a needle valve at the source tank. The use of ethylene glycol, however, was found to be of minimal impact and necessity during the experiment and was discontinued early on. A photo of the bioreactor system in field operation can be seen in Fig. 1b.

Table 1 Selected sediment and water quality metrics of Dyno Lake, the source of the bacterial inoculum and the Se-laden mine water treated in the bioreactor system

	Parameters	Value
Water	Total Se	92.3 µg/L
	Dissolved sulfur	762 mg/L
	Total phosphorus	3 µg/L
	TKN	0.15 mg/L
	DOC	1 mg/L
	pH	7.65
Sediment	Total Se	8.95 µg/g
	Total iron	21.3 mg/g
	TIC	2 %
	TOC	6.5 %
	TC	8.5 %

TIC, TOC, and TC were calculated as percent total of dried sediment

TKN total Kjeldahl nitrogen, *DOC* dissolved organic carbon, *TIC* total inorganic carbon, *TOC* total organic carbon, *TC* total carbon

The bioreactors (Fig. 1c) were wooden boxes measuring 5 m long by 1 m wide by 1 m high (16.4′ × 3.3′ × 3.3′) and containing an active substrate mixture. The bioreactors were placed into the ground so that the top edge of the reactors was at ground level. The bioreactors were lined with waterproof HDPE tarp of 3.2 mm (1/8″) thickness, which was secured to the top edge with nails. This design used the ground to support the contents of the reactors, thereby minimizing material costs. To create a diffuser, a T-junction connected another piece of 2.5 cm (1″) diameter pipe, which was the width of the reactor chamber, to the end of the inflow pipe from the sump. This pipe was placed just above the bottom of the reactor and four 6.4 mm (1/4″) diameter holes (outlets) were drilled equidistant from the T-junction. A gravel anchor covered the diffuser in the first quarter of the reactor and the gravel was held in place by a heavy screen. This screen and gravel baffle assembly served to protect the contents of the main compartment of the reactor from washouts. The main compartment of each reactor was filled with an active substrate composed of a mixture of mulch (carbon source), manure (nitrogen source and a secondary carbon source), washed gravel (bacterial growth surface), limestone (pH buffer), and bone meal (phosphorus source), as well as the bacterial inoculum (Table 2). The active substrate differed slightly in the proportion of mulch and manure between the two reactors (Table 2). The inoculum added to each bioreactor was sediment (soft mud) collected from a shallow wetland at one end of Dyno Lake. The organic, anaerobic nature of the sediment, and the high sulfur content of the water (Table 1) suggested a community of sulfur reducing, anaerobic bacteria was present in Dyno's sediment, later confirmed by microbiological testing (personal communication, A. Sobolewski). The bioreactor's active ingredients were well mixed using a small skid-steer loader prior to filling each reactor. A flap of the tarp liner was used to cover the top of the bioreactors. Water flow through the bioreactors was maintained by gravity at a slope of approximately 2 % (Fig. 1b). A ditch collected discharge from the reactor outflows [two short pieces of 11.4 cm (4.5″) diameter pipe placed near the top of the downstream end of each reactor], and directed the treated water back into the creek. The retention time in the reactor chambers was varied by

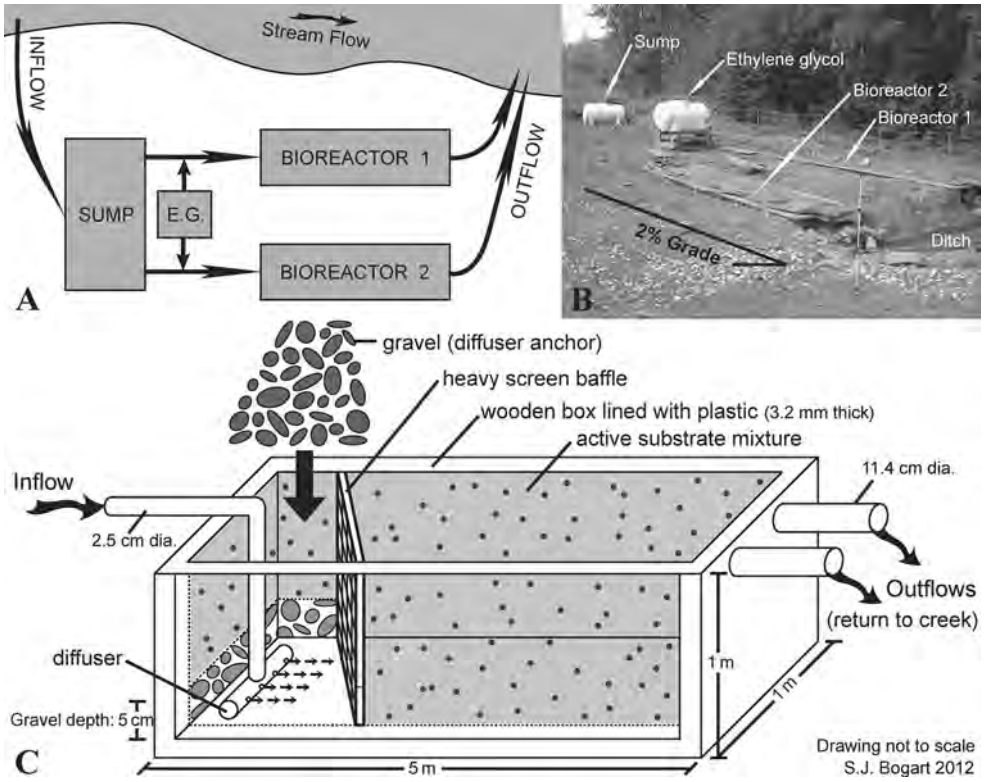

Fig. 1 The bioreactor system and components. **a** Components of the bioreactor system, **b** field photo of the bioreactor system, **c** detailed schematic of one bioreactor and its parts (see "Methods" for measurement equivalents)

Table 2 Amounts of solid ingredients combined to make the active substrate (percent total volume of substrate) and inoculum within each bioreactor

Ingredients	Bioreactor 1	Bioreactor 2
Active substrate		
Mulch	40 %	57 %
Manure	32 %	15 %
Gravel	24 %	24 %
Limestone	2.7 %	2.7 %
Bone meal	1.3 %	1.3 %
Bacterial source		
Inoculum[a]	4.5 L	4.5 L

[a] Sediment from Dyno Lake

manipulating inflow rates through gate valves and was set to $\approx$48 h.

Monitoring and Analysis

The performance of the bioreactor system was monitored weekly from August to November 2008. Water samples were taken from the inflow and from the outflows of each bioreactor on a weekly basis for 10 weeks post start-up. Field measurements were taken for pH, temperature, conductivity, and dissolved oxygen (DO). Water samples were preserved in the field and submitted to a certified laboratory (ALS Environment, Edmonton, AB, Canada) for analysis within 48 h. Water was analyzed for nutrients (i.e. total phosphorus, total Kjeldahl nitrogen (TKN), dissolved nitrate/nitrite (combined), and dissolved sulphate) using ion chromatography. Total Se concentration was analyzed by inductively coupled plasma mass spectroscopy. Biological parameters measured were biological oxygen demand (BOD), dissolved organic carbon (DOC), and abundance of *Escherichia coli* and fecal coliform bacteria.

Data were analyzed using R, an open-source, statistical software (R Core Team 2012) and plotted using the R visualization package, ggplot2 (Wickham 2009). For all tests, statistical significance was accepted at $p \leq 0.05$. Hereon, for simplicity, the outflows of Bioreactors 1 and 2 shall be referred to as Outflows 1 and 2, respectively.

Results

Reactor Performance

Water quality underwent distinct visible changes in the first few days of operation of the bioreactor system. For the first day of operation, the outflow of both bioreactors was a turbid, muddy brown color as a result of fine sediment and organic matter washing out of the active substrate. After this time, the discharged water was a clear, slightly yellow–brown color. With a retention time of 48 h, the mean flow

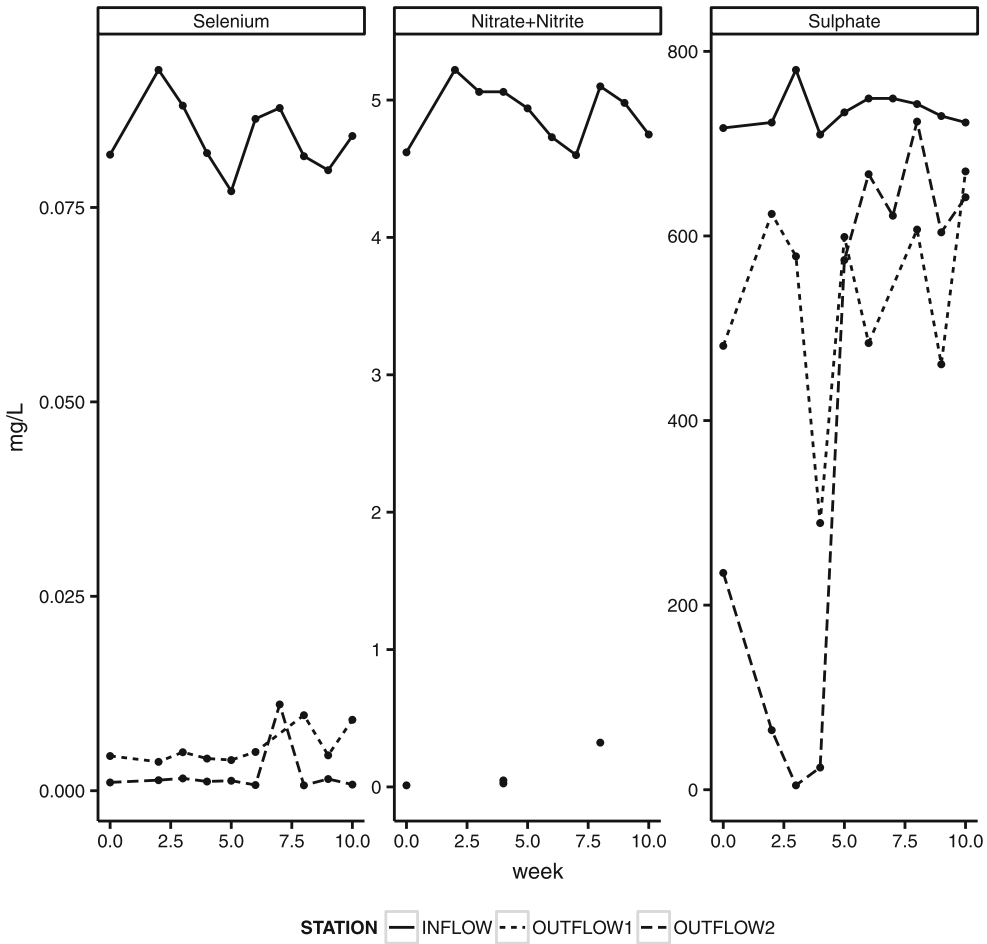

Fig. 2 Change in total Se, dissolved nitrate/nitrite, and dissolved sulphate concentrations of untreated (inflow) and bioreactor treated (Outflow 1 and 2) mine water throughout the 2008 pilot program

per reactor was approximately 94 L/h. This meant that the total volume of water treated was 2,250 L/day or 157,500 L for the duration of the 10 week pilot program and a projected 819,000 L (819 m^3)/year.

Changes in Water Chemistry

The bioreactor system reduced Se, nitrate/nitrite, and some sulfate in the creek water. The average Se concentration in the inflow water was reduced by >95 %. The inflow into the reactor system had an average Se concentration of 84.5 µg/L (SE = 1.46), while the outflows contained an average of 5.52 µg/L (Outflow 1, SE = 0.75) and 2.13 µg/L (Outflow 2, SE = 1.00) of total Se (Fig. 2). A repeated-measures ANOVA was used to compare Se concentrations of the inflow and outflows over time ($F_{2,25} = 1{,}647$; $p < 0.0001$). A Tukey's HSD test revealed that total Se concentrations were significantly different between the inflow and both outflows (Inflow and Outflow 1: $p < 0.001$; Inflow and Outflow 2: $p < 0.001$); however, there was no significant difference between the Se concentrations of the two outflows (Outflow 1 and Outflow 2: $p = 0.112$). As with Se, nitrate/nitrite levels were strongly reduced in the bioreactors. Nitrate/nitrite concentrations in the inflow water was around 5 mg/L but was reduced to close to, and often below, detection limits (<0.01 mg/L) in both outflows (Fig. 2). Dissolved sulfate levels (Fig. 2), however, fluctuated during the experiment but overall, sulfate levels in the inflow were always significantly higher than those of the outflows (repeated-measures ANOVA $F_{2,25} = 9.292$; $p < 0.001$; Tukey HSD: Inflow and Outflow 1: $p = 0.063$; Inflow and Outflow 2: $p = 0.002$). Sulfate was not reduced to the same magnitude as Se or nitrate/nitrite. Although ambient water temperature declined over the 10 week program, from ≈14 °C down to 2 °C (Fig. 3), temperature did not affect Se reduction (regression, Outflow 1: $R^2 = 0.26$, $p = 0.155$; Outflow 2: $R^2 = 0.04$, $p = 0.623$).

Field measurements of pH and conductivity did not show any changes over the course of the experiment. Median pH values of the water at the inflow, Outflow 1, and Outflow 2 were 8.29 (range 8.14–8.39), 6.95 (range 5.89–7.40), and 7.30 (range 6.69–7.57), respectively. Water flowing out of the two bioreactors, was significantly

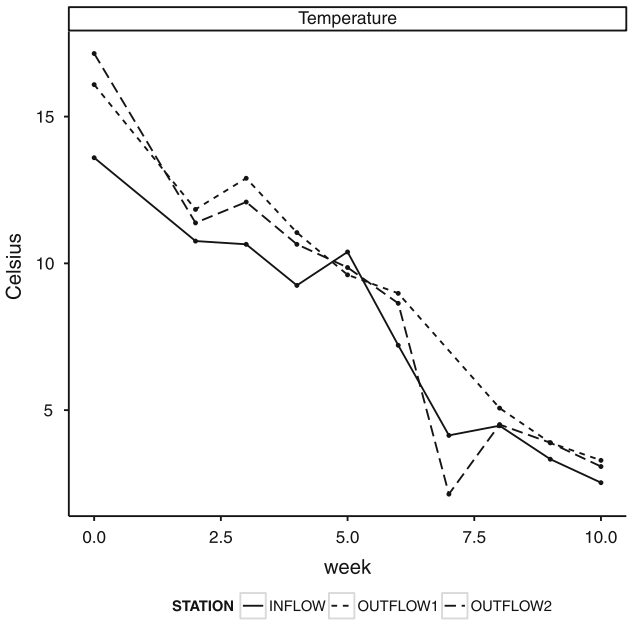

Fig. 3 Water temperature over the course of the monitoring period

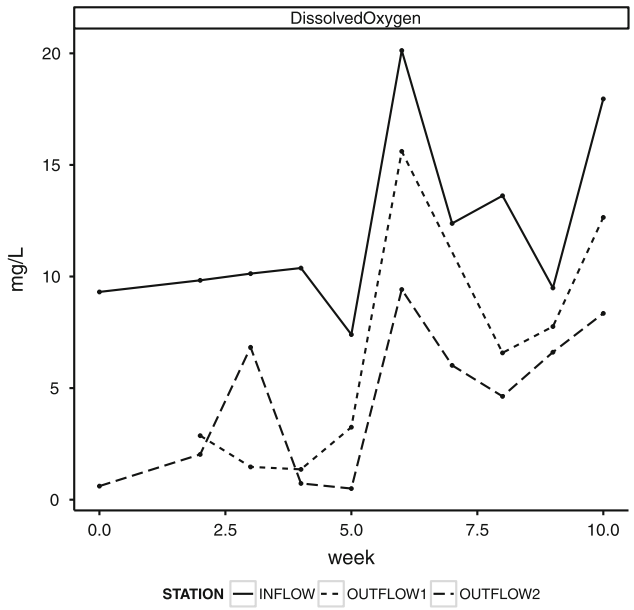

Fig. 4 Dissolved oxygen over the monitoring period

more acidic than inflowing water (repeated-measures ANOVA: $F_{2,25} = 102.2$; $p < 0.0001$; Tukey HSD: Inflow and Outflow 1: $p < 0.0001$; Inflow and Outflow 2: $p < 0.0001$). Conductivity of the inflow water remained constant at 1,997.7 µS/cm (SE = 22.93) throughout the experiment and conductivity of both outflows was the same as the inflow (Outflow 1: 2,393.2 µS/cm, SE = 247.09; Outflow 2: 1,945.0 µS/cm, SE = 61.26).

DO concentrations exhibited some variation in the inflow and outflows (Fig. 4). Generally in the outflows, DO was near 3 mg/L in the first 5 weeks, after which it was around 9 mg/L. DO levels were always lower in the outflows than in the inflow. DO levels at the outflow might be overestimated due to sampling of the outflow water after it surfaces out of the reactor, giving it a chance to mix with atmospheric oxygen again.

Dissolved phosphorus and TKN shared similar trends over time. Phosphorus and TKN levels declined during the course of the experiment but were always higher in both outflows than in the inflow (Fig. 5).

Biological parameters generally decreased over time but showed a similar pattern of being always higher in the outflows compared to the inflow of the bioreactors. BOD was generally below detection limit at the inflow (<1 mg/L), while bacterial growth in the reactor elevated oxygen demand at the outflow considerably (Fig. 6). DOC in both outflows was around three orders of magnitude higher than in the inflow at the beginning of the experiment and declined to around one order of magnitude higher at the end of the experiment (Fig. 6). Bacteria concentrations in the water were highly elevated in the outflows of both bioreactors. While amounts of *E. coli* and fecal coliform bacteria in the inflow were close to detection limits, their concentration was three to four orders of magnitude higher in both outflows (Fig. 7).

Operating Costs

The total cost for constructing and operating the bioreactor system over the 10 week trial period was $45,000. The material cost was $4,500, including hardware to construct the bioreactor system ($1,500), the ingredient mixture ($1,100), and the ethylene glycol, which was discontinued ($1,900 for 341 L or 90 gal). The rest of the costs went to a consulting company to oversee the initial setup of the reactor, a construction company that was hired to build the bioreactor system according to our design, and equipment rental fees (e.g. the skid-steer loader).

Discussion

Bioreactor Efficiency

The bioreactor system was very successful in eliminating Se from Dyno Lake mine effluent. It achieved a 94 % (Outflow 1) and 98 % (Outflow 2) reduction. Se reduction in both bioreactors happened in an environment where sulfate was present in amounts four to five orders of magnitude higher than Se concentrations, showing a strong bacterial preference for Se as an energy source as compared to sulfate (Lenz et al. 2008; Zhang and

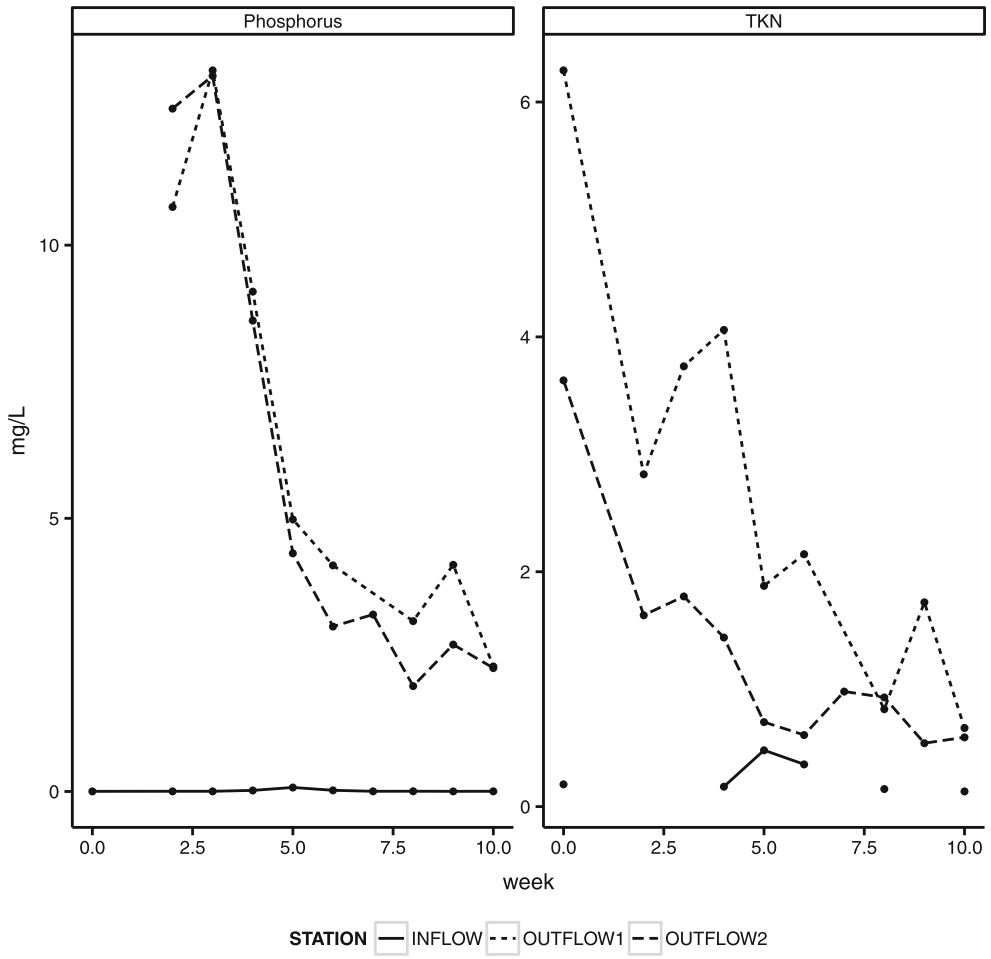

Fig. 5 Total phosphorus concentration and TKN (biologically available nitrogen), in untreated and bioreactor treated water during the experiment. Missing values for the inflow were below detection limits

Frankenberger 2003). The simultaneous reduction of Se oxyanions and nitrate/nitrites suggests potential competition between these substrates during the reduction process, as it was previously determined that nitrate reduction precedes selenite reduction (Steinberg et al. 1992). However, additional evidence (reviewed in Macy et al. 1993), has shown that the terminal reductases used to reduce selenate and nitrate are different. Moreover, nitrite reductase is used by some bacteria, e.g. *Thaurea selenatis*, to catalyze the reduction of selenate to selenite, indicating that the presence of nitrite is required before selenate can be reduced. Oremland and Blum (1999) determined that the reduction of Se oxyanions and nitrate/nitrites in other bacteria is poorly understood but is likely dependent on more processes than is controlled by only one or two enzymes. As we did not identify the bacterial species responsible for Se reduction in our study, we supplied manure as a nitrogen source. However, the reduction of nitrate/nitrites did not affect the reduction of Se in either of the bioreactors (Fig. 2). Moreover, the observed Se removal efficiency of the bioreactors was comparable to previous pilot studies of similar size (Cantafio et al. 1996; Lenz et al. 2008) and a lab-bench study (Fujita et al. 2002), while it performed more efficiently than a large scale field test of a biochemical reactor pit, a related technology (Golder Associates 2010).

Physico-Chemical Changes in the Reactor

While previous studies have used known bacteria grown in controlled laboratory settings as inoculants (Hunter and Kuykendall 2007; Ikram and Faisal 2010), we obtained our bacterial inoculant from the organic sediment of the same water body from which we treated effluent. In doing so, we have shown that the anaerobic portion of the sediment in a water body rich in Se and sulfur can host a bacterial community capable of reducing sulfur and Se oxyanions. The bacteria were very effective at removing Se from the mine water and are likely well adapted to the local environment and water chemistry. Our results support the use

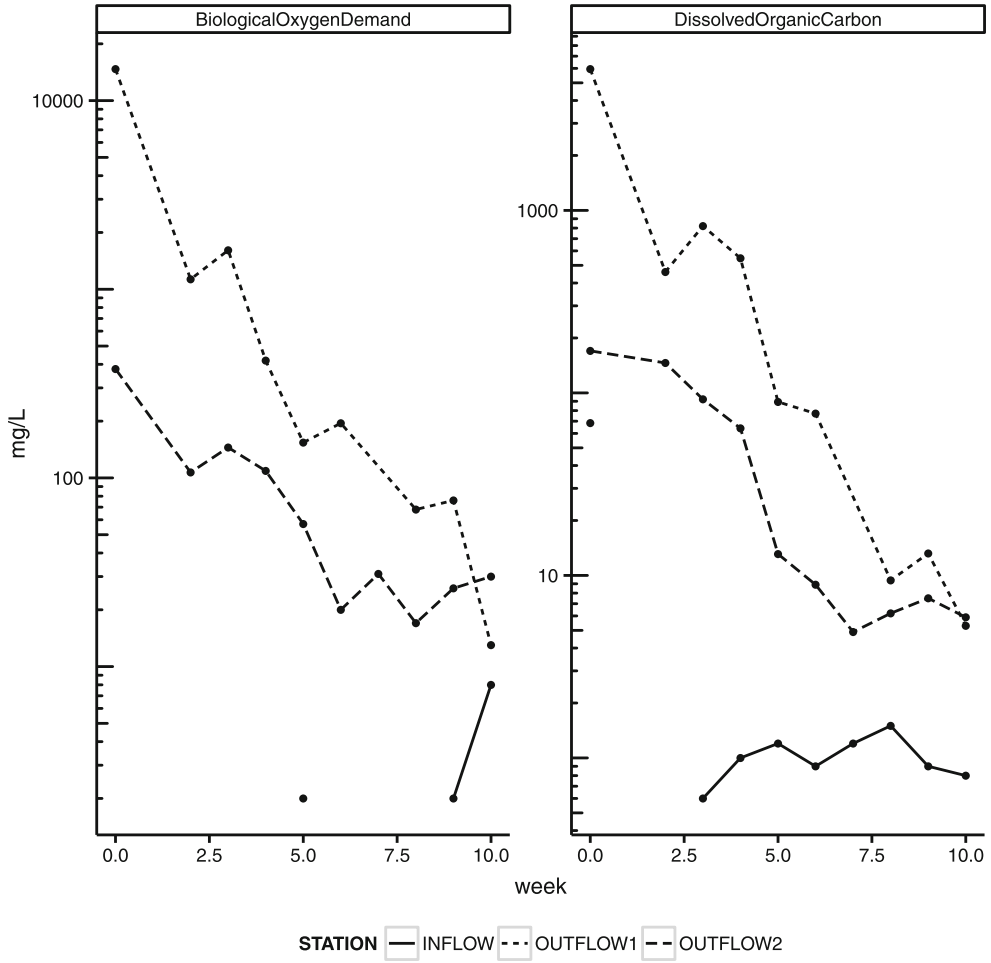

Fig. 6 Biological oxygen demand (BOD) and dissolved organic carbon (DOC) in untreated and bioreactor treated water during the pilot program. Missing values for the inflow were below detection limits

of local bacterial communities present in Se-affected areas for use in treatment.

The observed Se reduction process in our bioreactors was the result of reducing Se oxyanions to elemental Se, a precipitate, which was then deposited within the reactors' active substrate. If the bioreactor system ran longer than in this experiment, an additional stage, such as a flocculation barrier, may have to be added in which elemental Se could be caught after periodically flushing the bioreactors (Cantafio et al. 1996). Long-term operation of the reactor requires replacing the substrate periodically, drying and processing the removed substrate to remove remaining organic matter and concentrate the precipitated Se. The concentrate can then be taken out of the environment for final deposition or the Se could be extracted and recycled for industrial use.

Lenz et al. (2008) showed that bioreactors work under controlled temperature conditions in warmer climates, but our experiment shows that Se-reducing bacteria, present in the local environment, can be used to reduce Se oxyanions under field conditions in a sub-arctic environment. Se removal remained constant even though the inflow water temperature declined from 17 to 2 °C at the end of the experiment. Our results agree with those of a related technology, tested in a different part of the Alberta Rockies which experienced similarly low temperatures (Golder Associates 2010). In general, the temperature within the bioreactors will be slightly warmer than the surrounding environment, due to the in-ground construction. This kept the bioreactors working in sub-freezing ambient temperatures and assures that inflowing water would freeze before the reactor, thereby providing continuous water treatment. We conclude that as long as the mine water is not frozen, it can be treated effectively at near-freezing temperatures with no significant effect on Se removal rates.

DO readings were lower in the reactor effluent than in the inflow; however, outflow measurements never reached anoxic conditions. This is attributed to water turbulence

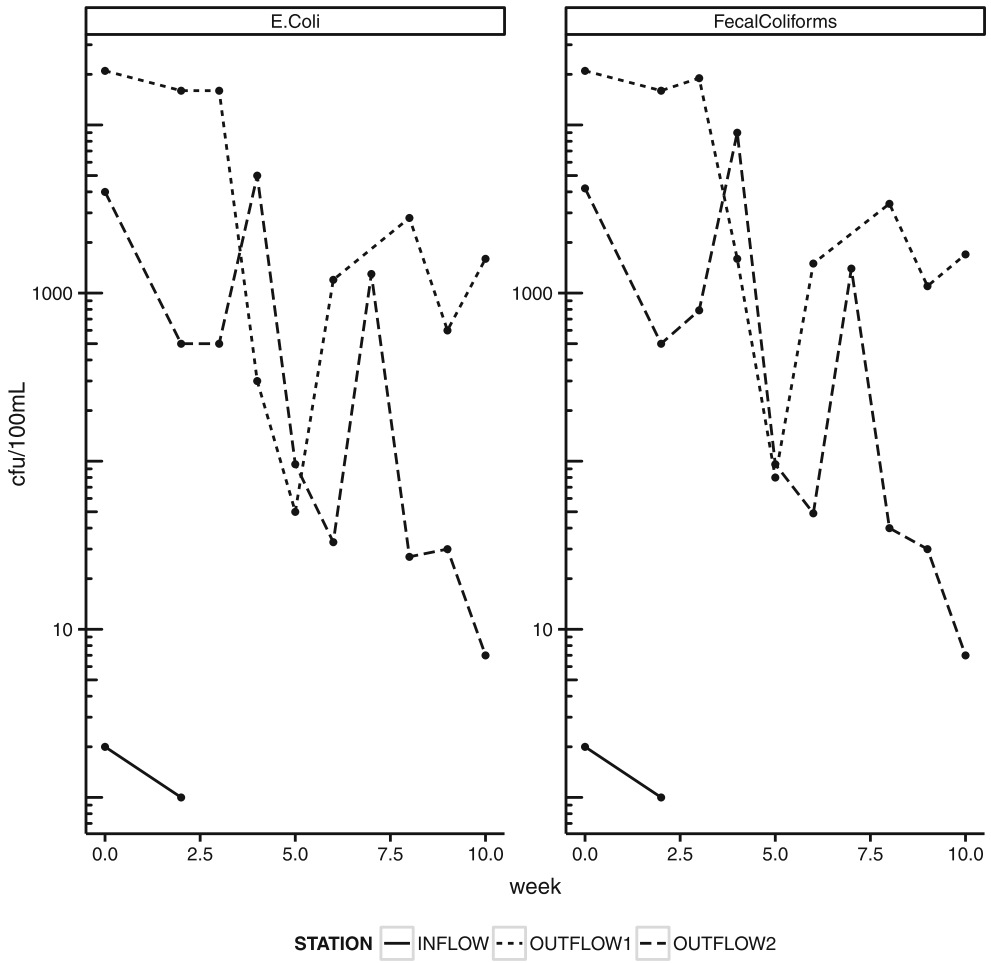

Fig. 7 Concentrations of *E. coli* and fecal coliform bacteria in water for the duration of the experiment. Missing values for the inflow was below detection limits

right after the water exited the reactor, i.e. the point of measurement, where immediate mixing with air enriched DO in the water. Although a confounding point from a research perspective, it is a sign that treated water rejoining the creek will not be oxygen deprived at the point of discharge into the ecosystem.

Conductivity remained fairly unchanged when passing through the reactor, while sulfates and nitrates were removed. The likely reason for the unchanged conductivity is the high calcium carbonate content in the water, which remained in the water after passing through the reactor.

Environmental Challenges of the Design

There were several metrics of potential environmental concern related to the bioreactors, i.e. *E. coli*, fecal coliforms, BOD, DOC, TKN, and total phosphorus, which were at high concentrations in the outflows while not present in the inflow water, or present in very low concentrations. *E. coli* accounted for nearly all of the fecal coliform bacteria (Fig. 7). The source of the *E. coli*, which is restricted to human or animal feces (Health Canada 2006), was the manure used in the bioreactor. The presence of these bacteria in a potential drinking water source is not tolerable (Health Canada 2006). Cell counts declined over time and were mostly under the water quality guidelines [100 cells/100 mL for *E. coli* and 1,000 cells/100 mL for fecal coliforms (Alberta Environment 1999, 2000)] after the first 5 weeks of operation. The increase in bacterial abundance in the outflow resulted in a significantly higher BOD for much of the pilot program. While above guideline values in the beginning of the experiments, BOD fell below the required maximum of 100 mg/L after the first 5 weeks of operation (Alberta Environment 1999, 2000). The outflows also showed increases in DOC, TKN, and total phosphorus compared to the inflow. These changes were all due to the choice of active substrate ingredients for the reactor, i.e. the manure and mulch. Alternative carbon and nitrogen sources need to be found in order to reduce risks of *E. coli* contamination and eutrophication of downstream

systems. In addition to mulch and manure, possible alternative carbon sources are synthetically derived ones such as acetate (Macy et al. 1993), or natural by-products of the food industry including molasses (Cantafio et al. 1996), lactate (Hockin and Gadd 2006; Lenz et al. 2008), or whey (Koschorreck et al. 2011). These carbon sources would allow for more stoichiometric dose control; however, especially in remote settings, these more refined ingredients would increase treatment costs substantially. Less processed, potential carbon sources that are more readily available and are cheaper, include old hay or leaf litter, which could be obtained from local farmers or municipal waste collection, as well as cleared vegetation from overburden on the mine-site (Kumar et al. 2011). The manure, which is a nitrogen source as well as a carbon source, should be replaced by an alternative with adequate nitrogen content. Commercial liquid fertilizers would be an easy way to add a nitrogen source, but again, would have a higher cost than waste products. In our opinion, the best nitrogen source is manure and agricultural waste, but a treatment to limit *E. coli* contamination, i.e. pasteurizing and drying of the manure is necessary prior to use. Finally, it is important to note that although the above biological and nutrient parameters were still higher in the outflows than the inflow, and while some exceeded environmental limits even at the end of the pilot program, the data trends indicate that these parameters would be likely have all been within acceptable limits after a few more weeks of monitoring.

Large-Scale Applications

Our results show that simpler designed reactors work in small field settings, but the treatable volume needs to increase drastically to address rising Se discharge volumes (Dessouki and Ryan 2010). Our pilot-sized bioreactor system treated mine water at a rate of 0.2 m^3/h; however, a full-scale system would need to treat a minimum discharge flow of 0.5 m^3/s, or 1,800 m^3/h, to treat Dyno Lake's average discharge. However, this end-pit lake is only one of many effluent sources at this mine site. While scaling up the size of the bioreactor system appears to be a logical step, we estimate that the size needed to achieve successful treatment of present Se concentrations (Table 1) and discharge volumes between 0.5 and 1 m^3/s, reactors the size of a small end-pit lake would be needed.

Since most discharges, especially from mine sites, flow out of end-pit lakes or settling ponds, we suggest using these water bodies themselves as in situ bioreactors. Organic content in the lake can be increased significantly by adding plant waste products (e.g. woodchips, hay, leaf litter, compost, municipal sewage, agricultural waste), to provide carbon and nitrogen sources for the sulfur/Se reducing bacteria (McCullough and Lund 2011). We have shown that the desired Se reducing bacteria are already present in an end-pit lake laden with Se. Supplementary addition of phosphorus and/or nitrogen through fertilization (dependent on ambient ratios and concentrations) can induce a strong phytoplankton bloom (Schindler 1980), which will reduce DO in the hypolimnion, thereby creating an anoxic environment for the bacterial community. Variation in water levels and discharge volumes, which were addressed through reservoir tanks in the small-scale experiment, require special consideration during the design of a large treatment facility. Fluctuations in the water table would not be too much of a concern, as long as anaerobic conditions within the pit do not get disturbed. Provided the treatment pit is situated at the bottom of the watershed, management of the inflowing water sources upstream can dampen extreme events and ensure continuous successful Se treatment.

We suggest that using end-pit lakes as in situ bioreactors would be the next step in cost efficiency and that this approach would require even less effort than constructing ground-level bioreactors next to lake outflows. While in situ remediation of end-pit lakes has already been tried for acid mine drainage (AMD) lakes (Koschorreck et al. 2011; Lessmann et al. 2003), our results suggest that non-acidic lakes are even more suitable for this approach and should be further investigated.

Conclusions

In our model approach, we applied the general mechanisms of anaerobic bioreactors in the cheapest way possible, together with locally available resources. In our pilot-scale project, we showed effective Se reduction in the field, reducing the concentration of Se in non-acidic mine water by 95 %, even at a water temperature of 2 °C. We highlighted three major factors required for successful Se removal: an aquatic anoxic environment, organic matter providing a carbon and nitrogen source as a bacterial substrate, and sulfur/Se reducing bacteria. Moreover, we showed that those three prerequisites can be met while keeping overall costs low. By assessing the local environment, a field source of Se-reducing bacteria can be collected for use without expensive microbiological testing, laboratory rearing, or purchasing of a commercial inoculant. The overall costs of construction and maintenance of the reactor remained comparatively low by using easily accessible organic substrate manure as well as integrating simple building materials into the landscape. The results are promising for larger-scale applications and the use of existing industrial structures, such as settling ponds or

small end-pit lakes, can make increases in scale feasible and integration into mine remediation processes possible.

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Start-Up of a Passive Remediation Bioreactor for Sulfate and Selenium Removal from Mine Tailings Water

Susan Baldwin[1], Parissa Mirjafari[1], Maryam Rezahdebashi[1], Gaurav Subedi[1], Jon Taylor[1], Luke Moger[2], Katie McMahen[2] and Art Frye[2]

1. *Chemical and Biological Engineering, University of British Columbia, Canada*
2. *Mount Polley Mine, Canada*

ABSTRACT

Before tailings pond water can be discharged to the environment it must meet the very stringent local water quality requirements. In British Columbia, selenium must be below 1µg/L and sulfate, depending on the hardness of the receiving water, must be as low as 100mg/L. To meet this challenge, in anticipation of future mine expansion, Mount Polley Mine commissioned a pilot-scale passive treatment system to remove selenium and sulfate from their tailings pond water. The design was based on laboratory column tests with wood chips and hay that verified removal of selenium and sulfate to the required levels. This paper describes the design and construction of a sub-surface flow wetland and its evolution over several years into a passive remediation system. Regular monitoring and troubleshooting led to upgrades and modifications that improved performance. The subsurface layer of woodchips, hay and manure provides microorganisms with carbon sources. As part of a genomics project, material from this layer was shown to contain many different species of sulfate-reducing bacteria. Additional carbon inputs come from plants and filamentous algae that are beginning to populate the periphery and surface of the wetland. The genomics work also showed that planktonic algae were plentiful in the water column. This pilot-scale process shows that passive remediation can be used to improve the water quality of mine tailings pond water.

Keywords: Biochemical reactors, metals, mining, bioremediation, microbial ecology, selenium, sulfate

INTRODUCTION

The mining industry in British Columbia was valued at C$8.3billion in 2012 (The Mining Association of Canada, 2012) and is therefore a great contributor to employment and prosperity in the Province. Almost every mine has a tailings storage facility into which process effluents consisting of finely ground rock and water are placed. These are very large (squares of kilometers in size). Mount Polley had been investigating several ways of treating their tailings pond water so that they could discharge some of it so as to ease the demand for additional storage capacity. One of the approaches under consideration included a passive treatment process for metal and sulfate removal.

Passive treatment means that natural biological and geochemical processes are harnessed in specially constructed sub-surface and/or surface flow wetlands. The purpose of each cell in the process is to provide the best environmental conditions to encourage the growth of biological organisms that promote metal immobilization and, in cases where needed, sulfate reduction. Since some engineering is usually required they are more accurately referred to as biochemical reactors (BCRs), and a variety of configurations have been used at mine sites to successfully remediate metal-contaminated water (Khoshnoodi et al., 2013; Mattes et al., 2011; Blumenstein and Gusek, 2008; Gusek, 2008).

The main constituents of interest that needed to be reduced in the Mount Polley tailings water in order to meet discharge requirements were sulfate, selenium, copper, molybdenum, phosphorus and nitrate. Sulfate can be reduced by sulfate-reducing bacteria, which are anaerobic organisms that grow in most natural terrestrial and oceanic sediments devoid of oxygen. Sulfate replaces oxygen as an electron acceptor in respiration of these organisms thereby producing the product sulfide. Metal removal occurs concomitantly as metal ions such as Cu^{2+} combine with S^{2-} to make sparingly soluble metal sulfide precipitates (Jalali, 2000). Metalloids such as selenate and selenite can be reduced directly by bacteria to produce elemental forms that precipitate and are immobilized (Stolz et al., 2006;Baldwin and Hodaly, 2003). To achieve metal and sulfate removal the microbes involved are encouraged to grow by being provided with nutrients and anoxic conditions. In BCRs this is achieved through using organic materials obtained from forestry, agricultural and other wastes available nearby the mine site. Within close proximity of the Mount Polley Mine, wood chips, hay and cattle feed lot manure were obtained and shown to support growth of sulfate-reducing bacteria in proof-of-concept laboratory reactors that successfully removed sulfate and selenium to below the required concentrations. Based on these results, a pilot-scale BCR was constructed at the mine site in 2009. This paper describes the configuration of this BCR, the results of water quality and microbial community monitoring carried out over the ensuing years and subsequent modifications that were made to improve performance.

METHODOLOGY

Proof of concept laboratory experiments

Plexiglas columns (I.D.: 11.43 cm, Length: 50.8 cm) with a mixture of 50%dw hay, 20%dw woodchips and 30%dw cow manure were used as up-flow BCRs. These organic materials were pre-soaked in water overnight and adjusted to pH 8.0 before being added to the columns together with laboratory cultures of sulfate-reducing and cellulose-degrading bacteria as inocula as well as

crushed limestone for pH control. For the first few weeks, the columns were fed with a Postgate-B growth medium (Postgate, 1983) to allow a healthy sulfate-reducing bacteria population to build up. Thereafter, simulated tailings water containing 600mg/L sulfate and 15µg/L selenium, plus 52mg/L Iron (Fe) and sources of nitrogen (N), phosphorus (P) and potassium (K) was fed to the BCRs. Iron was required as a source for excess sulfide precipitation. Accumulation of sulfide in the BCR would have inhibited the bacteria from growing, and therefore it had to be removed. The columns were set up so as to prevent any oxygen from getting in (since sulfate-reducers are obligate anaerobes). Over the period of operation, concentrations of sulfate and selenium were measured in the effluent using the turbidimetric barium sulfate American Water Work Association method 4500-SO_4^{2-}, and inductively coupled plasma mass spectroscopy (ICP-MS), respectively. Dissolved oxygen, pH and oxidation-reduction potential were monitored regularly so as to check that optimal conditions were being maintained in the BCRs.

Construction of the field-based pilot-scale BCR

A field-based pilot-scale BCR was constructed at the mine site in December 2009. After experimenting with smaller scale systems, a 100 gallon per minute sub-surface flow BCR with a water cover was constructed using the same organic material mixture composition as was used in the laboratory column experiments. The Figures below show the BCR during construction and immediately after commissioning.

Figure 1 Construction of the field-based BCR showing the perforated feed pipes, organics (brown) and rock (right-hand side) layers.

Figure 2 View of the completed BCR looking down from the top of the tailings storage facility.

Water from the tailings storage facility toe drain flows into the bottom of the BCR through a series of parallel, perforated pipes, percolates upwards through the organic material and then flows out. A layer of rocks on top of the organics keeps them in place. A 3-4m deep water cover acts as an oxygen barrier. The treatment area is approximately 50m by 70m. An island was included in the centre of the pond for aesthetics.

BCR monitoring

Water quality data were collected regularly from the influent and effluent to determine the effectiveness of metal and sulfate removal. The inside of the BCR was sampled once a year by the University of British Columbia team. Since samples from within the organic matrix could not be accessed easily due to the rock layer covering them, water samples from just above the

sediment/water interface were taken. If the BCR was performing as expected then the water percolating out of the sediments into the water column would be anaerobic with evidence of sulfide as an indication of active sulfate-reducing bacteria in the sediments. The microbiology of the water just above the sediments was assessed to see if any sulfate-reducing bacteria were entrained by the water flowing out of the sediments, and to see what other microbes were colonizing the water column. Microbiological analysis was done by extracting DNA and subjecting it to sequencing of the small subunit ribosomal ribonucleic acid (SSU rRNA) gene, which is a barcode that is used to identify microbes. In 2012, the BCR was shut down and drained. At this time, solid samples were taken from within the organic matrix and frozen to preserve the microbial community for later analysis. The BCR was modified based on monitoring results, adding a berm to increase hydraulic retention time and replenishing with fresh organics. Further modifications in 2013 included installation of booms to reduce wind mixing so that anaerobic conditions could be better maintained. One year after reconstruction (August 2013), samples taken from the sediment layer were used for metagenomics, which is a new technique for measuring both the microbes present as well as their function.

RESULTS AND DISCUSSION

Proof of concept laboratory experiments

Even though the pH was adjusted to 8.0 before starting the BCRs, additional NaOH needed to be added to maintain the pH above 6.5. Organic acids leaching from the wood, or produced due to fermentation of organic matter, contributed to pH decrease. Since the desired bacteria require a circum-neutral pH in which to grow, pH adjustment was needed. The pH of the laboratory BCR feed was 8.0, similar to that of the Mount Polley effluent. After 114 days, the pH stabilized above 6.0 and it was only necessary to add NaOH sporadically thereafter. Throughout their operation, conditions remained optimal for sulfate-reducers with dissolved oxygen below 1mg/L except until day 374, when it suddenly increased to 4.7-5.7mg/L. The ORP was below -300mV and the pH was steady between 6.0 and 7.0. Sulfide levels inside the BCR were always below 100mg/L, which is much lower than those known to cause inhibition of sulfate-reduction (Utgikar et al., 2002).

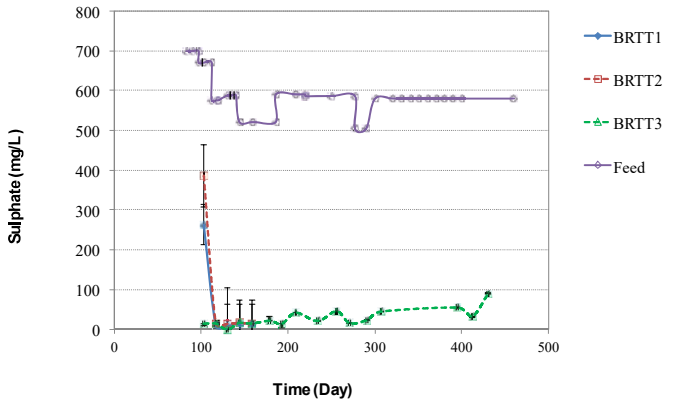

Figure 3 Plot of sulfate concentration versus time for the influent and effluents from all three of the laboratory BCRs. BRTT1, BRTT2 and BRTT3 are triplicate columns run under identical conditions. Sulfate concentration measurements were performed in triplicate with the average values plotted and the whiskers representing the standard deviation.

Two of the BCRs were stopped after approximately 100 days after starting feed of the simulated tailings pond water so as to examine the nature of the microbial population associated with successful performance. The third BCR was run for a total of 430 days to see if and when it would fail. Performance was consistently successful for the entire period (Figure 3). For all BCRs the sulfate concentrations in the effluent were below 100mg/L, the level desired for discharge. The selenium concentrations in the effluent were below the detection limit (< 0.0001mg/L). The proof-of-concept experiment demonstrated that sulfate and selenium can be removed from the Mount Polley tailings water to the required levels using these organic materials in a BCR, provided that the pH is maintained near neutral, no oxygen is allowed to enter the bioreactor and that enough metal ions be present to keep sulfide levels low.

Initial performance of the field-based pilot-scale BCR

Initially, the field-based BCR successfully removed nitrite- plus nitrate-N and selenium to below detection levels (Table 1). Twenty three percent of the sulfate coming in was removed, but the final sulfate concentration was still well above the desired concentration of 100mg/L. Molybdenum concentrations decreased slightly and copper concentrations increased a little. During the 17 June 2010 field trip, 1-3mg/L sulfide was found at the sediment water interface of the BCR at all of the four locations sampled. This indicated that sulfate-reducing bacteria were active in the sediments as expected. Over the course of the following year, performance of the BCR was similar with the exception that sulfate-reduction was less. During the second University field trip in August 2011, no sulfide was detected at three of the sampling locations in the BCR. Some, 4.3mg/L, was measured at only one of the locations, indicating that only parts of the BCR were active for sulfate-reduction. Also, at that time, the sulfate concentrations at the sediment/water interface (464-599mg/L) were not significantly different from those in the influent.

Table 1 Water quality parameters for the field-based pilot-scale BCR

Sampling date	Nitrite + Nitrate-N		Sulfate		Cu (dissolved)		Mo (dissolved)		Se (dissolved)	
	In	Out	In	Out	In	Out	In	Out	In	Out
04/15/2010	3.98	<0.0050	499	384	0.00317	0.00454	0.185	0.121	0.0239	<0.0020
04/15/2010-05/31/2011 *	1.901	0.037	478	416	0.0031	0.0038	0.1650	0.1185	0.0031	0.000917
06/9/2011-07/5/2012 *	1.114	0.123	434	452	0.0030	0.0011	0.1786	0.1237	0.0025	0.0009
09/15/2012-08/8/2013 *	1.613	0.075	498	406	0.0030	<0.0006	0.203	0.081	0.0053	0.00064
09/5/2013-08/8/2014 *	1.975	0.0725	518	475	0.0030	0.0011	0.208	0.109	0.0066	0.0020

* average values

Microbial community analysis from 2010 to 2012

Samples taken during the first two field trips in 2010 and 2011 from the sediment/water interface were analysed for microbial community composition, and in particular the types of sulfate-reducers present was determined (Figure 4). Sulfate-reducers were detected in the BCR in 2010 consistent with presence of sulfide, but they were absent from the sediment/water interface in 2011. Even though sulfate-reducers were not detected just above the sediment surface, they may still have been present inside the organic matrix. Nevertheless, the lack of detection of sulfate reducers coincided with declining performance of the treatment system (Table 1). In 2012, the BCR was drained and it became possible to take samples directly from the organic matrix. When these samples were analysed for microbial community composition, many sulfate reducers were found (Figure 4). The presence of sulfate-reducers suggested that the organic matrix and conditions inside the BCR were suitable for hosting these organisms. But, contrary to expectations, sulfate-reduction rates through the BCR were low. One possible explanation was that sulfate may be reducing to sulfide within the organics, but low metal ion concentrations were not enough to precipitate all soluble sulfide and it was re-oxidized to sulfate upon contact with oxygen diffusing down through the water column. Such a phenomenon was observed in the laboratory bioreactors before Fe^{2+} was added to the column bioreactor feed (Mirjafari et al., 2011).

Performance since 2012 modifications

Recharging of the BCR organics and increasing of the retention time resulted in improved performance (Table 1). The BCR was again visited in August 2013 and sampled for microbial community analysis.

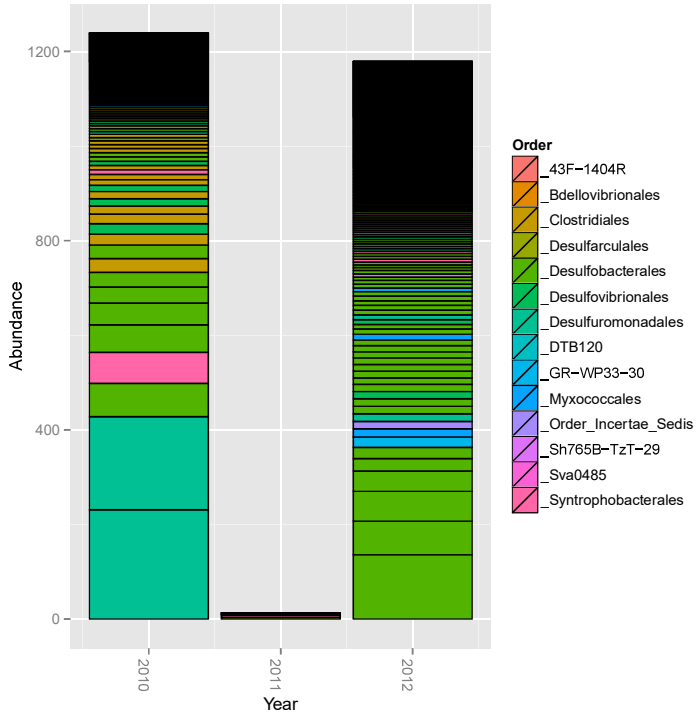

Figure 4 Sulfate-reducing micro-organisms detected in the BCR. Each bar on the plot represents one type of microbe. They are colored according to the Order in which they are classified. Bacteria are classified in taxonomic groups at different levels: Phylum;Class;Order;Family;Genus;Species. Abundance refers to the number of sequences out of a total of 12000, 8000 and 12000 for samples taken in 2010, 2011 and 2012, respectively.

Microbial community composition in 2013

A new technique was used called metagenomics. Instead of amplifying the SSU rRNA gene, which introduces possible biases, whole DNA was sequenced. From this we identified genes involved in sulfate metabolism, such as sulfate-reduction, and the types of bacteria that they came from, thus tying function to taxonomy. The results revealed that a psychrophilic organism, *Desulfotalea psychrophilia*, was the most prevalent sulfate-reducer in the BCR. Interestingly, this type of sulfate-reducer was first found in permanently cold Arctic marine sediments (Rabus et al., 2004), and even can survive at temperatures below 0°C. As before, the *Desulfobacterales*, *Desulfovibrionales* and *Desulfuromonadales* were sulfate-reducing bacteria taxa that were present in the BCR sediments. Presence of a healthy population of sulfate-reducers and detection of sulfide at the sediment/water interface (Table 2) coincided with active sulfate reduction and metal removal; although final sulfate concentrations were not meeting the 100mg/L discharge requirement.

A very interesting phenomenon was noted by the operators during the colder months of 2013, when the BCR was covered with ice and snow. Higher concentrations of sulfide and lower concentrations of BCR effluent sulfate were measured in Spring than in Summer (Table 2). This suggested that sulfate-reduction was active even though temperatures of the BCR water were between 2.1 and 7.7°C. The cover of ice and snow on the surface of the BCR prevented oxygen from getting into the water layer as dissolved oxygen profiles with depth revealed (Figure 5). Improved anaerobic conditions correlated with improved sulfate-reduction. The average BCR influent sulfate

concentration in 2013 was 498mg/L. Sulfate-reduction was highest (35%) in April. Metal removal was also greatly improved in the Spring compared with the rest of the year (percent removal: Se (86%); Cu(56%); Mo(44%)). Presence of cold-adapted sulfate-reducers in the BCR, and active sulfate-reduction and metal removal supports the use of biological treatment in cold climates

Table 2 Sulfate and sulfide concentrations measured in the BCR effluent over 2013

Parameter	14-Mar-13	4-Apr-13	1-May-13	6-Jun-13	10-Jul-13	8-Aug-13	5-Sep-13	3-Oct-13	5-Nov-13	3-Dec-13
Sulphate (SO_4) (mg/L)	383	323	365	434	446	486	488	469	481	493
Sulfides (mg/L) - Preserved with Zn-Acetate	31.6	14.5	0.71	1.23	0.085	0.01			0.106	5.1

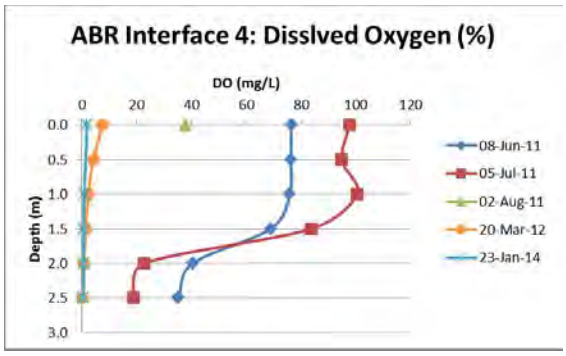

Figure 5 Dissolved oxygen concentrations versus depth below the BCR water surface during winter and summer months.

The BCR in 2014

During the most recent (26 August 2014) sampling of the sediment-water interface in the BCR, sulfide concentrations were higher than were measured in 2013 (August) (Table 2). The locations with higher sulfide concentrations coincided with lower sulfate concentrations. The North East side of the BCR (locations 3 and 4) was more active in terms of sulfate-reduction. Influent sulfate concentrations were 509mg/L. An extimated 15.6% sulfate is being reduced by the system.

Table 2 Concentrations of sulfate and sulfide in the Mount Polley BCR in 2013 and 2014.

	2013		2014	
Location	SO_4^{2-} (mg/L)	S^{2-} (mg/L)	SO_4^{2-} (mg/L)	S^{2-} (mg/L)
1	458	5	471	0
2	458	5	451	60
3	395	9	400	180
4	453	9	426	40-50
Average:	441		437	

Plants (*Typha latifolia*) and filamentus algae successfully colonized the sides and surface of the BCR (Figure 5). At other sites algae have been found to host many microbes, such as sulfate-reducers, and their presence adds organic carbon to the BCR plus they can directly improve water quality (Das et al., 2009;Larratt et al., 2007). Sequencing revealed many types of unicellular algae, such as *Dunaliella*, in the water column. Sub-aqueous plants could be seen growing on the bottom near the edges (Figure 6).

Figure 5 Photograph of the BCR looking South West.

Figure 6 Growth of aquatic plants

CONCLUSION

A laboratory proof-of-concept test demonstrated that removal of sulfate and selenium to below the required levels for discharge was possible. The field-based BCR constructed at Mount Polley Mine using a woodchip, hay and manure organic mixture was found to successfully support an active sulfate-reducing microbial community and some removal of nitrite/nitrate, metals and sulfate was occurring. The system worked best immediately after the addition of fresh organics but thereafter appeared to decline in performance. Rapid depletion of readily available organic material may be a limiting issue for passive treatment and is it recommended that an upstream surge pond be included in future designs into which fresh organics can be added. The BCR was more successful in the colder months when ice and snow covered the water and improved anaerobic conditions inside the BCR. Thus, addition of a more impermeable cover may improve performance throughout the year.

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TECHNICAL ARTICLE

Biotic and Abiotic Sequestration of Selenium in Anoxic Coal Waste Rock

Sean G. Deen[1] · Viorica F. Bondici[2] · Joseph Essilfie-Dughan[3] · M. Jim Hendry[3] · S. Lee Barbour[1]

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Abstract

Mobile selenium oxyanions ($Se^{VI}O_4^{2-}$ and $Se^{IV}O_3^{2-}$) can be sequestered by biotic or abiotic reduction to non-mobile species or by adsorption to mineral surfaces. Microbial analyses and geochemical batch testing with samples collected from a coal waste rock dump in the Elk Valley, British Columbia, Canada were conducted to assess whether Se can be sequestered in anoxic, waste rock by these mechanisms. Bacteria that reduce Se(IV) and Se(VI) to Se(0) were isolated from the waste rock. Isolates that reduce Se(IV) to Se(0) were present in a water sample collected from an underlying rock drain. Three isolates were affiliated with *Pseudomonas* and *Arthrobacter*. One isolate was a putatively novel species. The production of Se(0) was confirmed by X-ray absorption near edge spectroscopy of a red precipitate isolated from a broth media containing rock-drain water. No adsorption or reduction of Se(VI) was observed in anoxic, abiotic (sterile) batch tests conducted with waste rock and a 1.0 mg/L Se(VI) solution, whereas Se(IV) was adsorbed by the waste rock and subsequently reduced to Se(0) in abiotic batch tests with a 0.7 mg/L Se(IV) solution. In non-sterile batch tests using waste rock and rock-drain water (0.39 mg/L Se(VI)), Se(VI) was biologically reduced to Se(IV), which was subsequently removed from solution by a combination of bioreduction, adsorption, and possibly abiotic reduction. This study suggests that, under anoxic conditions, Se sequestration in waste rock may occur via biotic reduction of Se(VI) to Se(IV) followed by adsorption of Se(IV) and abiotic and biotic reduction of Se(IV) to Se(0).

Keywords Abiotic batch tests · Selenate · Selenite · Adsorption · Reduction · Electron microprobe

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✉ Sean G. Deen
sean.deen@usask.ca

Viorica F. Bondici
viorica.bondici@lightsource.ca

Joseph Essilfie-Dughan
joe377@mail.usask.ca

M. Jim Hendry
jim.hendry@usask.ca

S. Lee Barbour
lee.barbour@usask.ca

[1] Department of Civil, Geological, and Environmental Engineering, University of Saskatchewan, 57 Campus Dr, Saskatoon, SK S7N 5A9, Canada

[2] Canadian Light Source, 44 Innovation Blvd, Saskatoon, SK S7N2V3, Canada

[3] Department of Geological Sciences, University of Saskatchewan, 114 Science Place, Saskatoon, SK S7N 5E2, Canada

Introduction

Selenium (Se) is both an essential micronutrient for animal, plant, and human life and a toxic environmental contaminant at elevated concentrations (Lenz and Lens 2009). The toxic effects of Se, as well as its mobility and bioavailability in water (e.g. surface or ground water) are defined by its oxidation state. Selenium is typically present in surface water and shallow groundwater as the soluble, mobile oxyanions $Se^{VI}O_4^{2-}$ and $Se^{IV}O_3^{2-}$ (Dungan and Frankenberger 1999). The mobile nature of the Se oxyanions make aquatic environments, and the fish and wildlife associated with them, particularly susceptible to Se bioaccumulation and its concomitant toxic effects (Lemly 2004; Lenz and Lens 2009). Cases of Se contamination of fish and aquatic wildlife are often associated with irrigation drainage, landfill leachate, and wastes associated with the mining and processing of coal and metals (Lemly 2004).

Mobile species of Se can be removed from water by adsorption onto solids or precipitation when reduced

to insoluble species by abiotic or biotic processes. The Se(IV) oxyanion strongly adsorbs on minerals, such as clays (Bar-Yosef and Meek 1987), Fe(III)-oxyhydroxides (Duc et al. 2003; Rovira et al. 2008; Su and Suarez 2000), pyrite (Kang et al. 2011; Tachi et al. 1998), and siderite (Scheinost et al. 2008). The adsorption of the Se(VI) oxyanion occurs to a much lesser extent than the Se(IV) oxyanion, often via weak electrostatic bonds (Balistrieri and Chao 1987; Hayes et al. 1987). Once adsorbed, Se(IV) and Se(VI) can be reduced to Se(0) in abiotic reactions with Fe(II) or Fe(II)-bearing minerals (Charlet et al. 2007, 2012; Chen et al. 2009; Myneni et al. 1997). Removal of Se(IV) and Se(VI) oxyanions from solution by microorganisms via reduction to insoluble Se(0) and Se(-II), often referred to as bioreduction, occur by three primary mechanisms: (1) incorporation into amino acids or other essential compounds; (2) detoxification; and (3) respiration (Stolz and Oremland 1999). The most environmentally significant form of Se bioreduction is respiration, which occurs in the presence of electron acceptors, such as organic carbon and Fe(II), and the absence of more favourable electron acceptors, such as O_2 and NO_3^-, which can also be removed from solution by microorganisms (Herbel et al. 2000; Knotek-Smith et al. 2006; Maiers et al. 1988; Oremland et al. 1989; Stolz and Oremland 1999). Examples of this process have been observed in the Goddard Marsh and Fording River Oxbow in the Elk Valley, where Se is sequestered in the sediments as Se(0) and Se(-II), while the overlying water column maintains a Se(VI) concentration > 20 µg/L (Martin et al. 2011). Artificial bioreduction systems can also be created to treat Se-contaminated water (Lenz et al. 2008) or enhance abiotic immobilization systems (Knotek-Smith et al. 2006). Previous field studies have reported sequestration of mobilized Se by adsorption of Se(IV) onto Fe(III)-oxyhydroxides (Ziemkiewicz et al. 2011) and bioreduction of Se(VI) to insoluble Se species in a mine pit backfilled with water-saturated waste rock (Bianchin et al. 2013) and in unsaturated coarse coal reject piles (Kennedy et al. 2015). While these studies confirm that Se sequestration can occur within mine waste facilities, the sequestration processes (biotic and/or abiotic) and their possible underlying mechanisms were not investigated.

The Elk Valley, in southeastern British Columbia, Canada has been a major steelmaking coal mining region in Canada since the late 1960s (Goodarzi et al. 2009; Lussier et al. 2003). The Elk River, located in the Elk Valley (Supplemental Fig. S1), contains elevated concentrations of Se. For example, the concentration of Se at a monitoring station at the mouth of the Elk River (Fig. S1) has exceeded the British Columbia Ministry of Environment water quality guideline for aquatic life of 2 µg/L since the late 1990s (Beatty and Russo 2014; Swanson 2010). The dominant source of this Se load can be attributed to waste rock dumps at five coal mining operations in the Elk Valley (Fig. S1; McDonald and Strosher 1998; Wellen et al. 2015).

The primary sources of aqueous-phase Se in the Elk Valley waste rock are pyrite (FeS_2) and sphalerite (ZnS), which contain 21% of the solid-phase Se in the waste rock (Hendry et al. 2015). Oxidation of Se(-II)-containing pyrite and sphalerite by O_2 (Essilfie-Dughan et al. 2017), and possibly NO_3^- introduced to the waste rock during blasting (Mahmood et al. 2017), generates mobile Se(IV) and Se(VI) oxyanions that enter the Elk River (Day et al. 2012; Hendry et al. 2015). Excess carbonate minerals in the waste rock, including siderite ($FeCO_3$) and ankerite ($CaMg_{0.5}Fe_{0.5}(CO_3)_2$), maintain a circumneutral pH in the waste rock dumps (Biswas et al. 2017).

One possible management mechanism to control the discharge of Se-rich waters from the waste rock to receiving waters could be the establishment of anoxic zones. These anoxic zones could include mined-out pits filled with saturated waste rock or constructed water-saturated zones at the base of the oxic waste rock dumps through which the Se-rich drainage must migrate before discharging to receiving waters. The development and assessment of such Se management initiatives require an understanding of the potential Se sequestration mechanisms within the waste rock. As such, the objectives of the current study were to assess the potential for adsorption, abiotic reduction, and bioreduction of Se(IV) and Se(VI) in anoxic coal waste rock from the Elk Valley. These objectives were attained using sterile and non-sterile batch tests and culture-dependent microbial methods on samples of waste rock and associated rock drain water. The presence of bacteria capable of reducing Se(VI) and Se(IV) to Se(0) was confirmed using culture-dependent methods. Adsorption and abiotic reduction of Se(IV) and Se(VI) were quantified in anoxic, sterile batch tests. The minerals associated with sequestered Se were identified using aqueous and solid analytical techniques. In addition to assisting with the development and assessment of Se management initiatives at waste rock dumps in the Elk Valley, the findings of this study may be of value in controlling Se contamination from other sources, including irrigation drainage, landfill leachate, and waste associated with the mining and processing of metals. Furthermore, the methods described in this study are not specific to Se contamination or the mechanisms of Se sequestration. There are many environmental contaminants controlled by both abiotic and biotic controls that can be investigated using experiments designed to simultaneously detect biotic and abiotic reactions.

Materials and Methods

Site Description and Sample Characterization

Samples of waste rock and water from the waste rock drain outlet were collected from the West Line Creek (WLC) waste rock dump in the Elk Valley (Fig. S1). The dump was constructed at the Line Creek Mine between 1981 and 2012 (Mahmood et al. 2017; Villeneuve et al. 2017). As of 2011, it contained 210 M m^3 of waste rock, covered an area of about 2.7 km^2, and had average and maximum heights of 115 and 255 m, respectively (Villeneuve et al. 2017). Data presented by Mahmood et al. (2017) show that WLC has some "transient zones of O_2 depletion" but is mostly oxic, with O_2 concentrations greater than 10% by volume at most sampled intervals. Boulders segregate from the waste rock during end dumping and form a coarse permeable basal drain below the waste rock dump, referred to as a rock drain. The WLC rock drains convey O_2-rich water from upstream of the dump as well as water draining from the dump downstream to Line Creek, a tributary of the Elk River (Villeneuve et al. 2017). Between 2002 and 2012, the annual volume of water discharged from the rock drain was on the order of 1 M m^3. This annual water discharge was estimated to carry about 900 kg/a of dissolved Se out of the dump (Hendry et al. 2015). Currently the discharge water is being treated at the WLC active water treatment facility (Teck Resources Limited 2016).

A rock drain water sample was collected from the rock drain outflow in September 2014 as part of a routine sampling campaign. Key constituents of the drain water sample included (as mg/L): Ca, 302; Mg, 174; Fe, 0.09; Se, 0.39; SO_4^{2-}, 1032; NO_3^-, 21.1; and alkalinity (as $CaCO_3$), 256. The pH of the sample was 7.8. Although the dissolved O_2 content of the water sample was not measured at the time of sampling, the average O_2 content at the rock drain outflow was measured to be 73.3 ± 2.1% of saturation (mean ± standard deviation, n = 21; Sean Carey, McMaster University, personal communication) in June 2012. As such, the rock drain water sample was assumed to be oxic at the time of sampling and allowed to equilibrate under atmospheric conditions at laboratory temperature (22 ± 2 °C) prior to use in the experiments described below.

The solid waste rock sample tested in this study was collected in 2012 as part of a dump sampling program described by Hendry et al. (2015). It was collected from borehole LCO-WLC-12-02a at a depth of 53.7 m below the ground surface from a zone of oxic, unsaturated waste rock placed in the dump between 1990 and 1994 (Mahmood et al. 2017). The gravimetric water content of the sample was 4% (Barbour et al. 2016). Immediately after collection, the sample was vacuum sealed and stored at laboratory temperature prior to geochemical characterization by Hendry et al. (2015). The pyrite and sphalerite concentrations in the sample were determined to be 1265 and 415 mg/kg, respectively, using LECO analysis (Hendry et al. 2015). X-ray diffraction (XRD) analysis showed that siderite and ankerite made up 1 and 5% of the sample, respectively (Supplemental Table S1 in the Online Resource). The remainder of the sample was made up of quartz and clay minerals. As part of the current study, the sample was further characterized using electron microprobe wavelength dispersive spectroscopy analysis (WDS) to confirm the presence of ankerite, which is difficult to distinguish from dolomite using XRD. These measurements showed that the ankerite contained an average Ca:Mg:Fe:Mn cation ratio of 1.10:0.46:0.43:0.01 and the siderites an average Ca:Mg:Fe:Mn cation ratio of 0.03:0.09:0.87:0.01. The XRD and WDS analyses are presented in the Online Resource. Prior to testing and analyses of the solid sample, it was air dried and ground with an agate mortar and pestle. The ground sample had a specific surface area of 3.5 m^2/g as measured by the Brunauer–Emmett–Teller (BET) method.

In addition to batch testing of the waste rock sample, batch tests were also conducted on quartz to represent an inert solid. The quartz sample was prepared by grinding synthetic silica sand (99.7% SiO_2, U.S. Silica, Ottawa, Illinois, USA) with a tungsten carbide swing mill. The specific surface area of the ground quartz was measured to be 0.86 m^2/g using the BET method.

Overview of Methods and Analyses

Three sets of experiments were undertaken to investigate the biotic and abiotic controls on Se, as summarized in Table 1. Biotic and abiotic processes were assessed using standard culture-dependent microbial analyses and sacrificial, sterile batch testing, respectively. The combined effect of biotic and abiotic processes was investigated using non-sterile batch tests. Analyses conducted in each set of the experiments are presented in Table 1. Solution analyses included pH measurements, elemental quantification of Se, Fe, and Mn by inductively coupled plasma mass spectrometry (ICP-MS), NO_3^- quantification by ion chromatography (IC), and Se speciation quantification by high performance liquid chromatography (HPLC) coupled with ICP-MS. The methods' detection limit for Se, Fe, Mn, NO_3^-, Se(VI), and Se(IV) were 0.5, 2, 0.02, 50, 10, and 10 µg/L, respectively. Solid analyses included mineral characterization by XRD, semi-quantitative elemental analysis and collection of backscattered electron (BSE) images by electron microprobe energy dispersive X-ray spectroscopy (EDS), imaging by scanning electron microscopy (SEM), Se redox speciation by X-ray

Table 1 Summary of experiments conducted

Experiment	Technique	Conditions	Analyses
Microbial analyses			
Isolation and identification of Se-reducers	Culturing on agar media	22 ± 2 °C, oxic	16S rRNA gene sequencing
Confirmation of reduced Se	Culturing in broth media	22 ± 2 °C, oxic	XANES, EDS, SEM, XRD, ICP-MS
Sterile geochemical tests			
Control	Abiotic batch tests	33 ± 2 °C, N_2 glove box, sterile	ICP-MS, IC, plating
Se adsorption and reduction	Abiotic batch tests	33 ± 2 °C, N_2 glove box, sterile	ICP-MS, IC, HPLC, plating, XRD, EDS
Non-sterile combined biogeochemical tests			
Se(IV) and Se(VI) sequestration	Batch tests	33 ± 2 °C, N_2 glove box, not sterile	ICP-MS, IC, HPLC, plating, XRD, EDS

absorption near edge spectroscopy (XANES), and elemental quantification of Se by ICP-MS. Prior to ICP-MS analysis, solids were dissolved in hydrofluoric and nitric acids in a procedure modified from Jenner et al. (1990). Details of the XRD, EDS, and XANES analyses are provided in the Online Resource.

Se Bioreduction

The potential for Se bioreduction by the culturable microbial community in the waste rock and rock drain water was assessed using a culture-dependent method. Although not all the bacteria in the samples are culturable, culture-dependent methods make it possible to determine the capabilities of different microbial isolates. Sterile phosphate-buffered saline solution was used for sample suspension and serial dilutions used for culturing. The dilution range, which provided countable bacterial colonies, was pre-determined by plating the samples using eight tenfold serial dilutions. The fourth to eighth dilutions were selected to plate samples in duplicate on both Se(IV)- and Se(VI)-amended basal salt media (BSM). This medium was produced using a recipe modified from that described by Ike et al. (2000) and Maiers et al. (1988) and contained (in g/L): $(NH_4)_2SO_4$, 0.3; $CaCl_2{\cdot}2H_2O$, 0.2; $MgSO_4{\cdot}7H_2O$, 0.143; NaCl, 5.85; KH_2PO_4, 0.05; K_2HPO_4, 0.05; yeast extract, 0.5; 60% sodium lactate syrup, 1.9; agar, 15; and 1 mL trace mineral salt solution. The trace mineral salt solution contained (in g/L): H_3BO_3, 0.6; $Co(NO_3)_2$, 0.15; $CuSO_4$, 0.08; $MnCl_2{\cdot}4H_2O$, 0.99; and $Zn(O_2CCH_3)_2$, 0.35. After the medium was sterilized (single 20 min autoclave wet cycle, 121 °C, 120 kPa), 10 mL of filter-sterilized (0.02 µm, Whatman, Inc.) 100 mM Se(IV) or Se(VI) solution was added to the media to yield 1 mM Se. The Se(IV) and Se(VI) solutions were made with Na_2SeO_3 and Na_2SeO_4 salts (Sigma-Aldrich, St Louis, MO, USA), respectively. Cultured plates were sealed with plastic paraffin film and kept at room temperature for a minimum of 2 weeks prior to enumeration.

A common product of Se bioreduction is red elemental Se nanospheres (Stolz and Oremland 1999). The accumulation of the red nanospheres in Se-reducing colonies grown on solid media causes the colony or centre of the colony to appear red and allows for visual confirmation of Se bioreduction (Oremland et al. 2004). Four red colonies from Se(IV)-enriched BSM plates were subcultured on Se-free BSM plates to confirm the colonies were only red in the presence of Se. These bacterial colonies were subcultured on Se(IV)- and Se(VI)-enriched media to determine if they could reduce Se(IV) and Se(VI). Two bacterial colonies were isolated from each of the waste rock and rock drain water samples. These isolated bacterial colonies were subjected to DNA extraction using an EZ-10 spin column bacterial genomic DNA mini-preps kit (Bio Basic Canada, Markham, ON) following the manufacturer's recommended protocol. Polymerase chain reaction (PCR) amplification of the 16S rRNA gene was performed using a 27F (5′-AGA GTTTGATCMTGGCTCAG) and 1492R (5′-GGWTACCTT GTTACGACTT) primer set, yielding an amplicon approximately 1400 base pairs long. The Econotaq plus master mix (Lucigen Corporation, Middleton, WI, USA) was used for a 50 µL reaction mixture and the final concentration of the primers was 1 µM. The thermal cycling profile was set according to the Econotaq recommended settings. The PCR amplicons were sequenced at Génome Québec (McGill University, Montreal, Canada). Identification and phylogenetic analyses were carried out according to Bondici et al. (2013). For taxonomic identification, the 16S rRNA gene sequences were compared to all the type strains within the Ribosomal Database Project (RDP) database (Cole et al. 2009). A phylogenetic tree was constructed by the neighbour-joining method using MEGA with 1000 bootstrap replicates (Tamura et al. 2011).

An enriched broth media was prepared to isolate red Se(0) particles for subsequent analysis. The media was created by dissolving the BSM ingredients, with the exception of the agar, in the drain water sample in two 500 mL high-density polyethylene bottles. The bottles were sealed

during incubation. To limit the potential toxicity impacts of the elevated Se(IV) concentrations, Na_2SeO_3 salt was added to the broth in two 2 mM increments and two 5 mM increments. After 28 days, a total of 15 mM of Se(IV) was added to each of the bottles. The media was then incubated an additional 14 days, transferred to 50 mL Falcon centrifuge tubes, and centrifuged at 4400 rpm for 20 min.

Abiotic and Non-sterile Batch Tests

All batch test solids, solutions, and bottles were sterilized to eliminate biotic processes from the batch tests. The ground waste rock and quartz samples were sterilized by exposing them to 30 kGy of ^{60}Co gamma radiation (Chemistry Dept., University of Saskatchewan) and autoclaving them in two 30 min dry (gravity, 121 °C, 120 kPa) cycles 24 h apart. Prior to autoclaving, the ground samples were split into 120 mg subsamples, transferred to glass crimp top batch test bottles, allowed to equilibrate with the atmosphere in a nitrogen (N_2) glove box (MBraun, < 100 ppmv O_2) for 2 days, and crimp-sealed with silicon septa. Dry autoclave cycles were used and the solids kept in sealed bottles during autoclaving to minimize oxidation of the minerals during the sterilization process. Concerns that the reduced minerals of interest in the solid waste rock sample may be oxidized during sterilization were addressed by performing the same sterilization procedures on pure-phase mineral samples of pyrite, sphalerite, and siderite. Characterization of these materials before and after sterilization confirmed that no measurable oxidation occurred. Details of the materials tested and analyses conducted are provided in the Online Resource. The autoclaved batch test bottles were reintroduced to the glove box prior to the addition of batch test solutions. The solutions were passed through a 0.02 µm syringe filter during addition to the batch test bottles. The bottles were then resealed with sterile septa. Multiple batch tests with identical solutions were conducted to allow separate bottles to be sacrificially sampled on each sampling day, thus eliminating the risk of contaminating the batch tests during sampling.

Batch tests were conducted in the N_2 glove box. The rock drain water and deionized water (Millipore Milli-Q 18.2 MΩ) used in the experiments were bubbled with N_2 for 1 h prior to being introduced into the glove box. Each abiotic batch test contained 120 mg of ground waste rock or quartz and 16 mL of one of five solutions: Se-free deionized water (control), deionized water with 1.0 mg/L Se(VI), deionized water with 0.7 mg/L Se(IV), deionized water with 86 mg/L Se(IV), or rock drain water. The Se(VI) and Se(IV) solutions were made using Na_2SeO_4 and Na_2SeO_3 salts, respectively. All solutions were adjusted to and buffered at pH 7 with 50 mM PIPES (1,4-Piperazinediethanesulfonic acid), sodium hydroxide pellets, and 1 M hydrochloric acid. The solid to solution ratio in these batch tests was 7.5 g/L, which is three orders of magnitude less than that of the coal waste rock dumps in the Elk Valley (Barbour et al. 2016). While batch tests with low solid to solution ratios do not properly reflect site conditions, they do provide a larger ratio of Se to solid surface while maintaining Se concentrations similar to those expected on site (Day et al. 2012). This results in reactions taking place over a longer period of time and a greater density of sequestered Se on solid surfaces. Similar solid to solution ratios have been used by Bruggeman et al. (2005), Kang et al. (2011), and Scheinost et al. (2008).

All sampling was conducted in the glove box. The days at which samples were collected and details of the sampling program are presented in Table 2. Immediately prior to sampling, each bottle was shaken, opened in the glove box, and, after most of the solid had settled out (generally after 30 min), the supernatant was decanted into a new 10 mL syringe and passed through a 0.2 µm filter. The pH of each sample was measured with an electrode (Thermo Scientific Orion ROSS ultra pH/ATC triode, accuracy: 0.03 pH units, precision: 0.01 pH units) after it was filtered but before it was split into subsamples for ICP-MS, IC, and HPLC analyses. Solution samples were removed from the glove box after

Table 2 Batch test sampling days

Batch test solution	Sample days
Control—no Se	0[a,b], 1[c], 4, 10[a], 22[c,d]
1.0 mg/L Se(VI)	0[a,b], 1[c], 4[a,b], 6, 14, 21[a,b], 30, 42, 60, 82, 100[b,c,d]
0.7 mg/L Se(IV)	0[a,b], 1[c], 3[b], 6, 10[a], 14, 20[b], 29[a], 41, 46, 60, 66, 81[b,c,d]
86 mg/L Se(IV)	0[a,b], 61[a,d]
Drain water (sterile)	0[a,b], 1[c], 4, 7, 14[a], 21[b], 30, 42[a], 47[e], 53, 60, 82, 100[b,c,d]
Drain water (non-sterile)	0[a,b], 1[c], 4[a,b], 7, 14, 21[a,b], 30, 42, 47[b], 53[b], 60[b], 67, 82, 100[b,c,d]

[a]Sampled in triplicate

[b]Sample analyzed by HPLC for Se speciation

[c]Sample plated to assess sterility/CFU enumeration

[d]Four samples combined for composite sample

[e]Sampled in duplicate

they were split into subsamples for analyses. Subsamples requiring preservation were immediately preserved after removal from the glove box while the remainder of the samples were kept sealed until analysis. On the final day (see Table 2), four bottles were combined into composite solution and solid samples. Selected solid samples were rinsed with degassed deionized water three times and air dried in the glove box. Dried solid samples remained in the glove box until analysis.

Plating was conducted on the abiotic batch tests sampled on days 1 and 81 or 100 to confirm their sterility. Approximately 1 mL of the solutions to be cultured was aliquoted into sterile 1.5 mL Eppendorf tubes prior to the solids settling. The samples, as well as two tenfold serial dilutions, were plated in duplicate on Se(IV)-amended BSM, Se(VI)-amended BSM, and Reasoner's 2A (R2A) media (Difco BD, Sparks, MD, USA). Plates were sealed with plastic paraffin film and incubated in the glove box for a minimum of 16 days prior to bacterial colonies counts. The absence of colonies on cultured plates was interpreted as confirmation of batch test sterility.

In addition to the sterile abiotic batch tests, one set of batch tests was conducted using non-sterile waste rock and rock drain water to simulate the potential effects of combined abiotic and biotic processes on Se removal. With the exception of sterilization and plating procedures, the non-sterile batch tests were conducted using the same preparation and sampling procedures as the abiotic batch tests. The ground samples were not irradiated or autoclaved and the rock drain water not filtered. The day 1 and 100 batch tests were plated using the same procedure as the sterile batch tests with the exception of increasing the number of plated dilutions from three to five to account for the higher number of bacteria present in the non-sterile batch tests. These non-sterile batch test results were compared to the abiotic test results to determine the impact of viable bacteria on the concentration of Se in solution.

Results and Discussion

Se Bioreduction

Plating on Se-amended media was conducted to determine whether viable bacteria capable of reducing Se(IV) and Se(VI) to Se(0) were present in the waste rock and drain water. Three days after cultivation, white bacterial colonies with red centres developed on the Se(IV)-amended plates cultured with the waste rock solid and the rock drain water. Bacterial colonies were also present on the Se(VI)-amended plates cultured with waste rock, but not on those cultured with the rock drain water. After 8 days, the colonies on Se(IV)-amended plates were mostly red while the colonies on the Se(VI)-amended plates were red in the centre and yellow on the edges. No colonies were observed on the Se(VI)-amended plates cultured with rock drain water, suggesting the absence of Se(VI)-reducing bacteria or a very small population of Se(VI)-reducing bacteria relative to the Se(IV)-reducing population.

Two colonies from each of the samples cultured on Se(IV)-amended media were isolated. Isolated colonies were sub-cultured on Se-free media, which resulted in the development of yellow colonies within 3 days for colonies originating from waste rock and 10 days for colonies originating from drain water. These results confirm that the colonies only appeared red when Se was available for reduction and that their growth was not dependent on the presence of Se. Isolates grown on Se-free media were sub-cultured on Se(IV)- and Se(VI)-amended media. Colonies grown on the Se(IV)-amended media were similar in size, shape, and colour to those originally selected for isolation. On Se(VI)-amended media, colonies originating from the waste rock sample were yellow with red centres after 8 days while colonies originating from drain water remained yellow, consistent with those that developed on the Se-free plates. The presence of viable Se(IV)- and Se(VI)-reducing bacteria in the waste rock sample and Se(IV)-reducing bacteria in the drain water sample suggest there is potential for Se(IV) and Se(VI) bioreduction to occur within the WLC waste rock dump, given the necessary nutrients and favourable geochemical conditions.

Sequence analyses of almost full-length 16S rRNA gene sequence showed that the isolates originating from the waste rock sample, WR1 and WR2, were closely related to species of *Erwinia* and *Pseudomonas*, respectively (Fig. 1). The isolates obtained from the drain water sample, DW1 and DW2, were closely related to species of *Arthrobacter*. Pairwise comparison of the 16S rRNA gene sequences (≈1400 base pairs) showed that the drain water isolates were 100% identical to each other. Percent identities of the three distinct isolates to the type strains present within the RDP database were as follows: WR1 97% to *Erwinia amylovora*, WR2 99% to *Pseudomonas brenneri*, and DW1 and DW2 99% to *Arthrobacter subterraneus* and *Arthrobacter tumbae*.

Several species of *Pseudomonas* originating from Se-contaminated environments can reduce Se(IV) or Se(VI) to Se(0) under a range of laboratory conditions (Macy et al. 1989; Oremland et al. 1989). *Pseudomonas stutzeri* can reduce Se(VI) to Se(IV) and Se(IV) to Se(0) similarly to the pseudomonad WR2 isolated and cultured in this study (Kuroda et al. 2011; Lortie et al. 1992). Also, *P. aeruginosa* (Macy et al. 1989), *P. fluorescens* (Garbisu et al. 1996; Steinberg et al. 1992), and *P. moraviensis* (Staicu et al. 2015) reduce Se(IV) to Se(0). Reduction of Se(VI) by some *Pseudomonas* species is inhibited by NO_3^-, which was present in the rock drain water sample. *Pseudomonas*

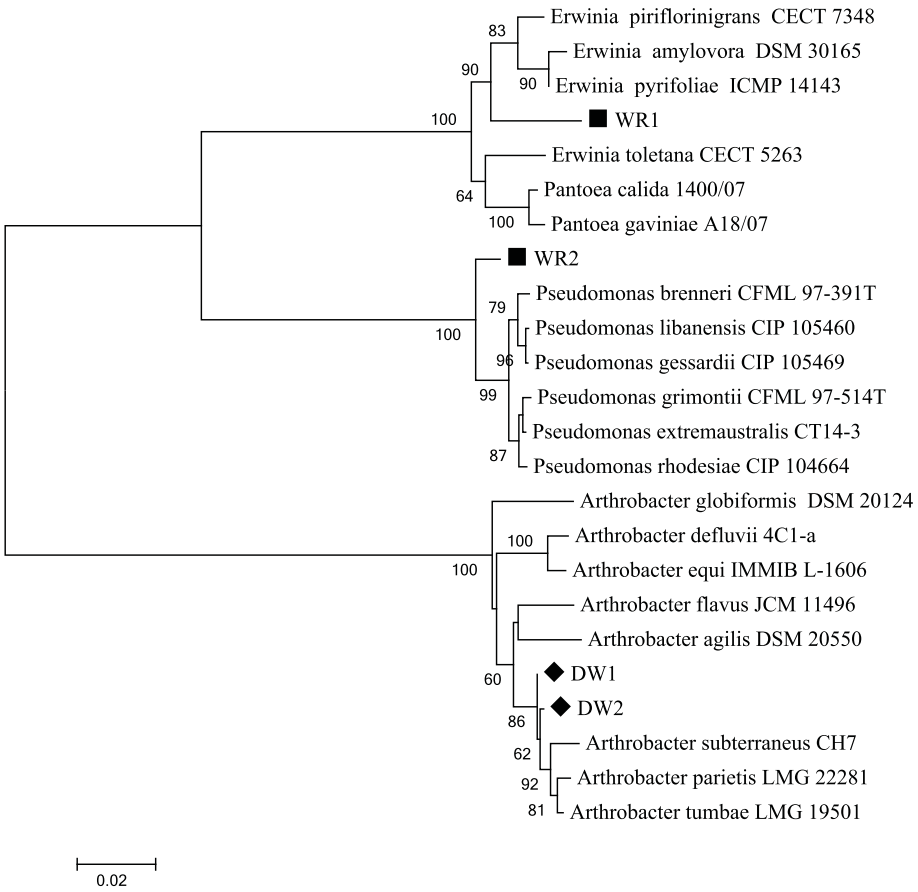

Fig. 1 Neighbour-joining phylogenetic tree of four bacterial isolate sequences and reference 16S ribosomal sequences. Bootstrap values greater than 60 are indicated at the nodes. Isolates were named according to the location of isolation: WR (waste rock), DW (drain water). Bar represents 0.02 substitutions per nucleotide position

fluorescens and some other pseudomonads can remove NO_3^- from solution by denitrification (Hunter and Manter 2009; Lortie et al. 1992; Steinberg et al. 1992).

In contrast to *Pseudomonas*, the ability of *Arthrobacter* to remediate Se-contaminated sites or to treat Se-contaminated waters has not been studied extensively. While several studies identified species of *Arthrobacter* in Se-reducing environments (Maiers et al. 1988; Yang et al. 2016), only two reported Se reduction by an *Arthrobacter* species. One *Arthrobacter* species isolated from a reservoir in California with low Se concentrations reduced Se(IV) to Se(0) but not Se(VI) (Burton et al. 1987). A second species isolated from a coal mine-affected marsh in the Elk Valley reduced both Se(IV) and Se(VI) to Se(0) (Yang et al. 2016). Although the latter species was retrieved from an environment similar to that of DW1 and DW2, it is unlikely to be the same species as DW1 and DW2, given the absence of Se(0) on the Se(VI)-amended media cultured with DW1 and DW2. Finally, we found no information on the Se tolerance or reduction capacity of *Erwinia*; the *Erwinia* genera consists of facultative anaerobic plant pathogens, such as *E. amylovora*, responsible for fire blight in fruit trees (Zhao 2014). Given this difference in capabilities and the marginal sequence homology (97% to known 16S rRNA sequences) for WR1 and *E. amylovora*, WR1 is a putatively novel species.

Broth media was prepared to allow the isolation of reduced Se precipitate from the media for analysis. The broth media appeared pink after 6 days and a red precipitate accumulated at the bottom of the bottles after 17 days. The addition of Se(IV) to the enriched broth resulted in the accumulation of additional red precipitate. The collected XANES spectrum, EDS spectrum, and SEM images corresponding to the red precipitate are presented in Fig. 2. Linear combination fitting analysis of the XANES spectrum (Supplemental Fig. S4 and Table S4) indicates that Se(IV), Se(0), and Se(-II) make up 70.2 ± 3.3, 13.5 ± 1.0, and $16.3 \pm 1.1\%$, respectively of the Se present in the isolated red precipitate. The presence of Se(0) and Se(-II) shows that Se(IV) reduction did occur in the broth media. The Se(IV) content was attributed to the precipitation of $CaSeO_3$, which was supersaturated in the broth (Seby et al. 2001). The sub-micron particles visible in the SEM images (Fig. 2c, d) are of comparable size and shape to other Se(0) nanospheres (Hockin and Gadd 2006; Lenz et al. 2008; Oremland et al. 2004; Yang 2011). Furthermore, the largest peaks of the red precipitate XRD pattern (Supplemental Fig. S3) are consistent with trigonal elemental

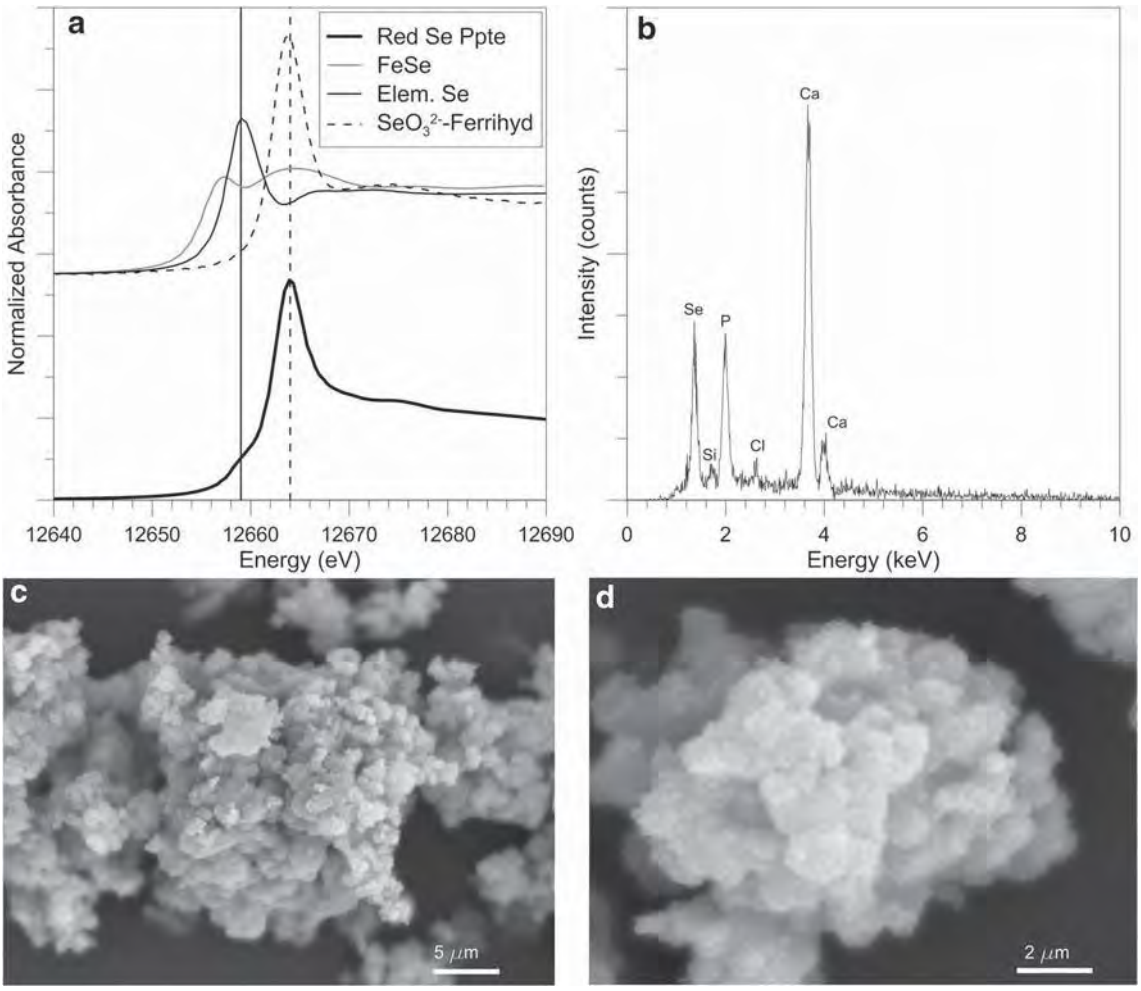

Fig. 2 XANES spectrum (**a**), EDS Spectrum (**b**), and SEM images (**c, d**) of a red precipitate isolated from the broth media

Se measured by Keller et al. (1977). The precipitation of Se(0) nanospheres in the broth confirms the red hue that developed at the centre of the bacterial colonies on Se-amended plate media was solid-phase Se(0) and that both Se(IV) and Se(VI) can be sequestered as solid Se(0) by bacteria present in the WLC waste rock dump.

In addition to being supersaturated with $CaSeO_3$, the broth was also supersaturated with calcite ($CaCO_3$), and hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$; Geochemist's Workbench Spec8, data not presented). The presence of these Ca and phosphate compounds is supported by the EDS spectrum (Fig. 2c) and the ICP-MS results, which determined that the digested precipitate was comprised of 20% Ca, 14.9% Se, and 6.8% P, by weight. There is no indication of these minerals or any other minerals in the XRD pattern (Supplemental Fig. S3). Conversely, XRD analysis of the Se(0)-containing bioreactor sludge by Lenz et al. (2008) suggests the presence of calcite and brushite ($CaHPO_4{\cdot}2H_2O$), but not Se(0). Although the form and importance of P and Ca in the precipitate is unclear, their co-precipitation with Se may act as a marker indicating precipitation of Se(0) when EDS is used to characterize sequestered Se on waste rock.

Abiotic and Non-sterile Batch Tests

The absence of colonies on the plates cultured from the control, 0.7 mg/L Se(IV), and 1.0 mg/L Se(VI) abiotic batch tests confirms that the batch tests were sterile. All but one of the plates cultured from the abiotic rock drain water batch tests were also free of colonies. Eleven colonies (the equivalent of 110 Se-reducing, colony forming units per millimetre; CFU/mL) with red centres grew on one of the Se(IV)-amended BSM plates cultured with the undiluted day 100 abiotic drain water batch test. The presence of Se(IV)-reducing colonies on the one plate has been attributed to contamination of the abiotic rock drain water batch tests during the addition of the filtered solution because the glassware and ground samples for all four sets of abiotic batch tests were sterilized together. Plating of the day 1 non-sterile batch test yielded 1.5×10^7 and 7.5×10^4 CFU/

mL on R2A and Se(IV)-amended plates, respectively. The R2A count decreased to 8.5×10^4 CFU/mL in the day 100 batch test and the Se(IV)-amended media count remained at 7.5×10^4 CFU/mL. These values are much higher than that of the contaminated abiotic batch test and, as such, changes in solution chemistry due to biological activity should be much more evident in the non-sterile batch test results. Furthermore, since not all abiotic drain water batch tests were expected to be contaminated, any biotic processes should yield inconsistent results when compared to the non-contaminated samples. The colonies that developed on the abiotic and non-sterile batch test-cultured plates were not investigated further nor was the cause of the absence of colonies on all Se(VI)-amended plates cultured in the glove box.

Abiotic batch tests conducted using inert quartz yielded no change in solution chemistry. In the quartz batch tests, the standard deviations of measured Se and NO_3^- concentrations were $< 7\%$ of the mean when the batch test concentrations were more than two times the detection limit. The Fe and Mn concentrations were 0.069 ± 0.086 and 0.0078 ± 0.0029 mg/L, respectively. While variation in these values is greater than the sensitivity of ICP-MS, no patterns with time were observed and the mean values are much less than that of the waste rock batch tests (Figs. 3, 4, 5). These data confirm that changes in the solution chemistry of the waste rock batch tests can be attributed to reactions related to the waste rock.

The evolution of pH and the redox elements (i.e. Se, Fe, and Mn) measured in the Se-free (control), 1.0 mg/L Se(VI), and 0.7 mg/L Se(IV) batch tests on waste rock with time are presented in Figs. 3, 4, and 5, respectively.

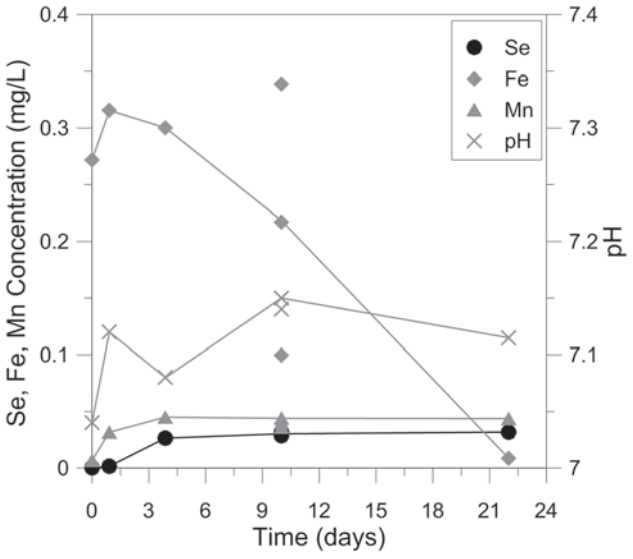

Fig. 3 Measured pH and Se, Fe, and Mn concentrations in sterile, Se-free (control) waste rock batch tests. Points represent single measurements. Lines pass through the average measurement of a given day

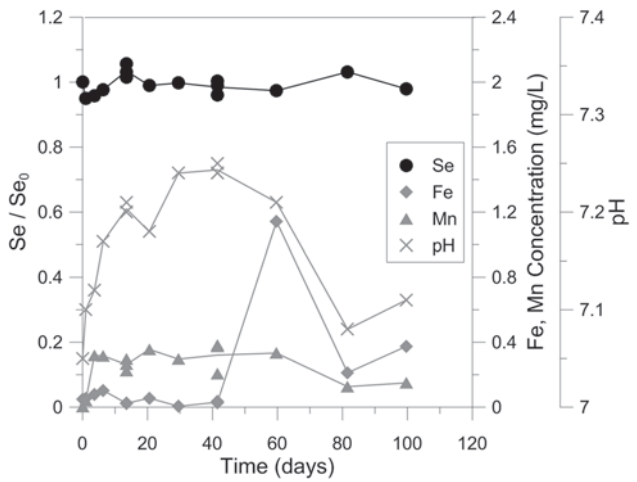

Fig. 4 Measured pH and Se, Fe, and Mn concentrations in sterile, 1.0 mg/L Se(VI) waste rock batch test solutions. Points represent single measurements. Lines pass through the average measurement of a given day

The solutions in each of these batch tests were prepared with deionized water and buffered at pH 7. The Se concentration in the control batch test solutions increased from 0.004 mg/L on day 0 to 0.030 mg/L on day 4. This increase was attributed to the dissolution of Se salts that precipitated in the waste rock pore space during air drying. No measurable change in Se concentration was measured in the 1.0 mg/L Se(VI) batch tests nor in the oxidation state of the aqueous Se. An increase of ≈ 0.03 mg/L relative to the initial 1.0 mg/L is less than the precision of the ICP-MS measurements. In the 0.7 mg/L Se(IV) batch tests, 40% of the Se(IV) was removed from solution on the first

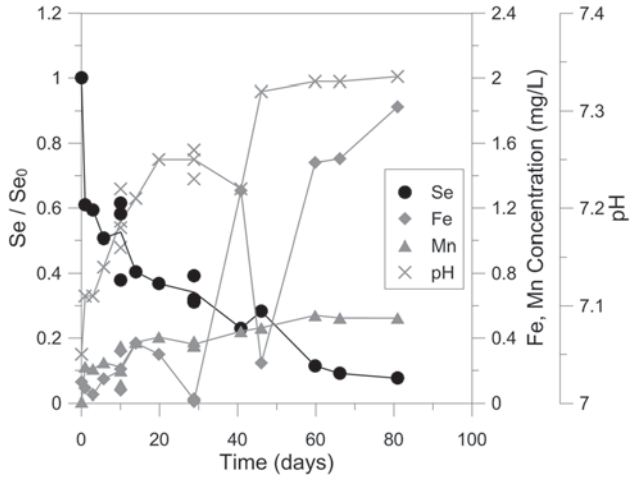

Fig. 5 Measured pH and Se, Fe, and Mn concentrations in sterile, 0.7 mg/L Se(IV) waste rock batch test solutions. Points represent single measurements. Lines pass through the average measurement of a given day

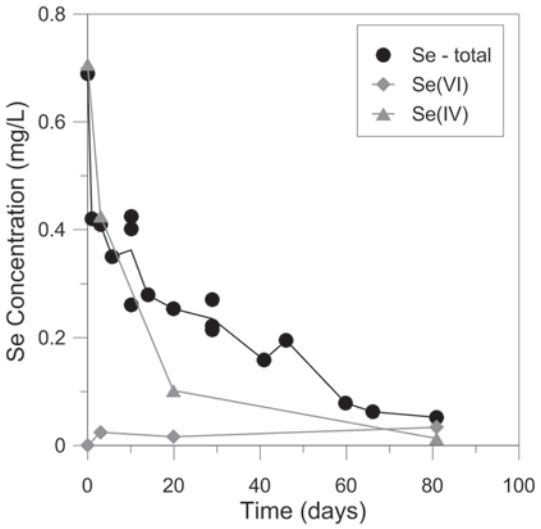

Fig. 6 Measured Se species concentrations in sterile, 0.7 mg/L Se(IV) waste rock batch test solutions. Points represent single measurements. Lines pass through the average measurement of a given day

day and the remainder by day 81 (Fig. 6). The concentration of Se(VI) increased initially and remained around 0.030 mg/L, following the same trend as Se in the control batch tests (Fig. 3). The initial uptake of Se(IV) by the waste rock is attributed to adsorption and the long term uptake is attributed to reduction from Se(IV) to insoluble Se(0). Siderite and pyrite remove Se(IV) from solution by these two mechanisms (Bruggeman et al. 2005; Kang et al. 2011; Scheinost et al. 2008).

In each of the waste rock batch tests, the increases in pH and concentrations of Fe and Mn in the first 2–4 days are attributed to dissolution of the carbonate minerals, siderite and ankerite. The solubility of Fe(III) is very low at neutral pH with the precipitation of goethite or other Fe(III)-oxyhydroxides (Appelo and Postma 2005). The cause of the decreasing Fe concentration with time in the control batch tests is not clear—it may have resulted from the oxidation of Fe(II) to Fe(III) by trace amounts of O_2 (Fig. 3). The increase in Fe concentration in the Se(VI) batch tests after day 42 is attributed to the reduction of insoluble Fe(III) to soluble Fe(II) and, thus, reflects a decreasing redox potential in the batch tests (Fig. 4). As such, the high concentrations of Fe in the Se(IV) batch tests relative to the control and Se(VI) batch tests suggest a lower redox potential and that Se(IV) was reduced to Se(0) (Fig. 5). After day 29, the increased Fe concentration was accompanied by an increase in pH and Mn concentration, confirming the source of Fe(II) and the associated low redox potential was the carbonate minerals in the waste rock. No explanation for the anomalous Fe concentration measurement in the 60 day 1.0 mg/L Se(VI) batch test (Fig. 4) was determined and, because of its anomalous nature, it will not be considered further.

The impact of sample heterogeneity and the precision of analyses on trends in pH and the concentrations of Se, Fe, and Mn are apparent in Figs. 3, 4, and 5, especially on days where batch tests were sampled in triplicate (see Table 2 for list of triplicate sampling days). In most cases where sampling was conducted in triplicate, variations in pH and elemental concentrations were not great enough to obfuscate overall concentration–time trends. One example of this is the day 10 triplicate Se and Mn measurements in the control batch tests (Fig. 3).

The Fe concentrations, however, varied greatly. The variation in Fe on day 10 was likely due to a combination of analytical error and differences in the rate of Fe(II) oxidation to Fe(III) in the three different batch tests. The effects of sample heterogeneity on reaction commencement time and rate are evident during rapid changes in solution chemistry, such as when Se(IV) was reduced to Se(0) and Fe(III) was reduced to Fe(II) (Fig. 5). In this case, the Fe concentration increased between days 29 and 41, decreased between days 41 and 46, and then increased again after day 46. The opposite trend was measured in the Se concentrations. These apparent fluctuations are attributed to differing reaction rates in the batch tests and not to fluctuations in any single batch test. While the use of identical, sacrificial batch tests can make it difficult to differentiate reactions from heterogeneity, it allows us to confirm that the batch test results are repeatable. For example, an equilibrium Se concentration of 0.032 ± 0.005 mg/L was measured in all six of the control batch tests sampled after day 3.

The sequestration of Se by the waste rock as Se(0) precipitate and Se(IV) sorbed to Fe minerals is supported by the EDS spectra (Fig. 7). In preparation for EDS, the waste rock was subjected to sterile, 61 day 86 mg/L Se(IV) batch tests, which resulted in the solid Se concentration increasing from 4.9 to 510 mg/kg. Given that over 99% of the Se on the analyzed waste rock was derived from the batch testing, all Se measured by EDS was assumed to be the result of Se sequestration rather than naturally-occurring Se in the waste rock minerals. In the BSE images corresponding to the EDS spectra (Fig. 7), relatively light elements (e.g., Si, Al, Mg, and Na) appear darker than the heavier elements (e.g. Se, Fe, and Ca). In Fig. 7a, two high-Se locations, C1 and C2, were present on a silicate (grey) mineral. At C1, Se was associated with Ca and P consistent with bioreduced Se(0) (Fig. 2a) indicating that Se(0) was present at C1. At C2, Se(IV) was sorbed to Fe minerals. The ratio of Fe to S at C2 suggests a combination of pyrite and siderite or an Fe(III)-oxyhydroxide. Given that Fe(III)-oxyhydroxides are a common secondary mineral associated with pyrite in the waste rock (Hendry et al. 2015), it is likely that one or more Fe(III)-oxyhydroxides were present at C2; however, we cannot confirm this statement because EDS analyses cannot identify the oxidation state of Fe nor can it detect

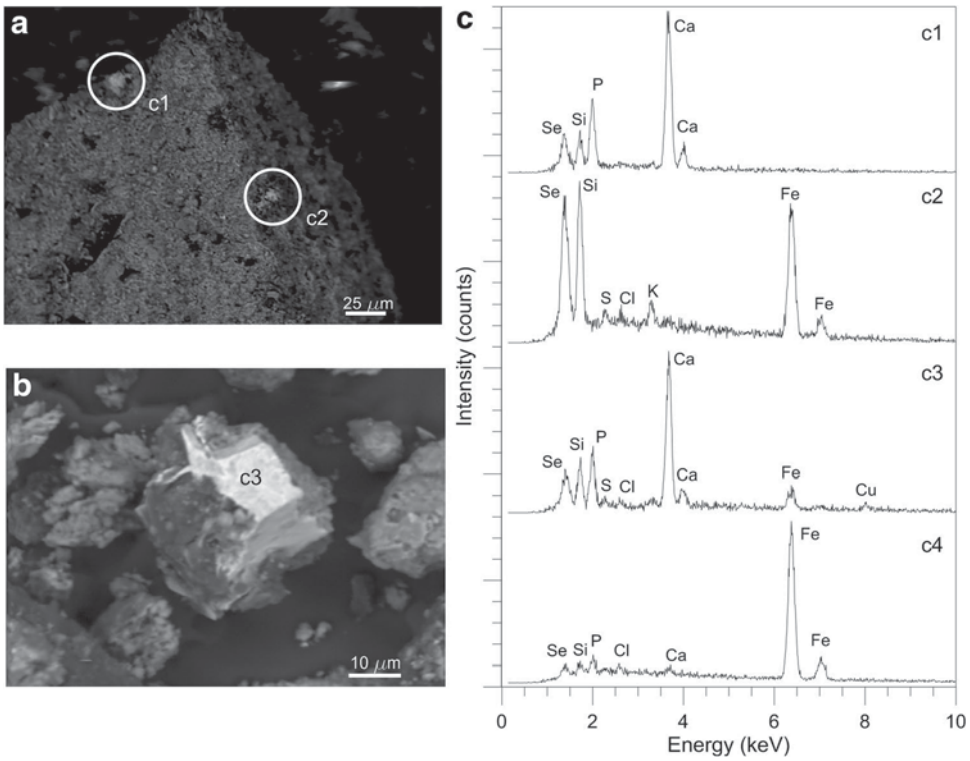

Fig. 7 BSE images (**a, b**) and EDS spectra (**c**) collected from waste rock reacted for 61 days in sterile 86 mg/L Se(IV) batch tests. The corresponding BSE image for EDS spectrum C4 is not presented

the presence of carbonate, hydroxides, or oxides. At C3 and C4, Se was associated with Ca and P, as well as the Fe-minerals chalcopyrite and siderite, respectively. This adds evidence to the hypothesis that reduction of Se(IV) to Se(0) by pyrite "involves an adsorption step" (Bruggeman et al. 2005). Adsorption and reduction of Se(IV) by chalcopyrite (C3) has been found to be very similar to pyrite (Naveau et al. 2007). Sequestration of Se at C4 is attributed to adsorption of Se(IV) and subsequent reduction to Se(0) by siderite, which was observed by Scheinost et al. (2008).

The initial Se(VI) concentration in the abiotic and non-sterile rock drain water batch test solutions was 0.39 mg/L. Consistent with the control and Se(VI) batch tests (Figs. 3, 4), the concentration of Se increased by ≈0.03 mg/L and there was no change in aqueous Se oxidation state (Fig. 8). In the non-sterile batch tests, all Se(VI) was reduced to Se(IV) between days 47 and 53 and 97% of the Se was removed from solution by day 67 (Fig. 9). The reduction of Se(VI) to Se(IV) is attributed to biotic processes given the absence of Se(VI) reduction in the abiotic batch tests. This is supported by the presence of Se(VI)-reducing bacteria in the waste rock sample isolated using culture-dependent methods. Confirmation of reduction of Se(VI) to Se(IV) in the non-sterile batch test solutions highlights the importance of abiotic sequestration of Se(IV) in waste rock dumps where aqueous Se is predominantly present as Se(VI). After the Se was reduced to Se(IV) in the non-sterile drain water batch tests, it was removed from solution much faster than in the

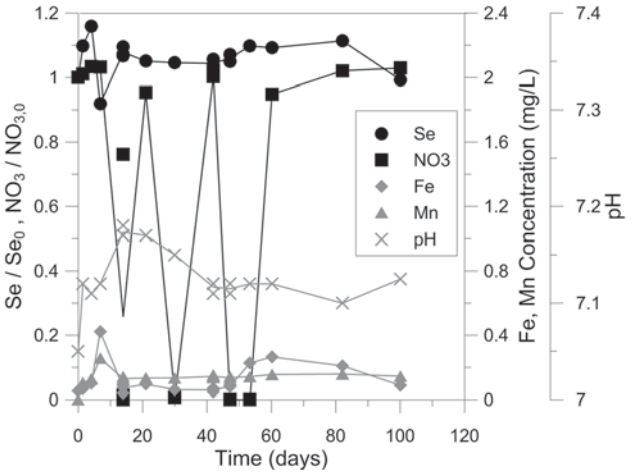

Fig. 8 Measured pH and Se, NO_3^-, Fe, and Mn concentrations in sterile drain water batch test solutions (0.39 mg/L Se(VI), 21.1 mg/L NO_3^-). Points represent single measurements. Lines pass through the average measurement of a given day

sterile 0.7 mg/L Se(IV) batch tests, suggesting that bioreduction of Se(IV) to Se(0) occurred concurrently with adsorption of the Se(IV) to the waste rock and abiotic reduction to Se(0).

A large shift in redox potential prior to Se removal was apparent in the non-sterile rock drain water batch tests (Fig. 9). The initial high NO_3^- concentration is characteristic of oxidizing conditions (Hockin and Gadd 2006;

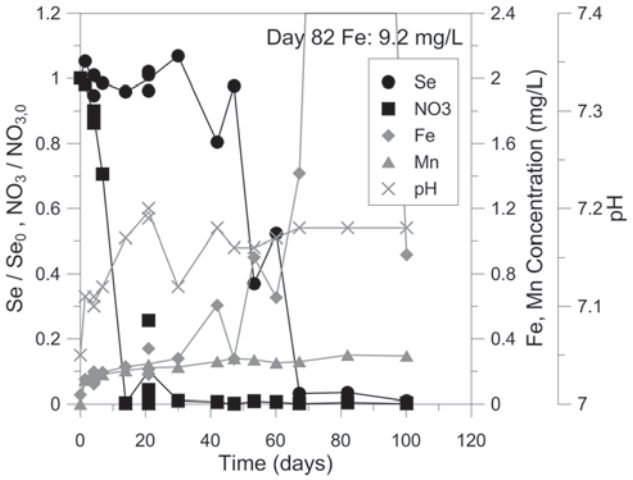

Fig. 9 Measured pH and Se, NO_3^-, Fe, and Mn concentrations in non-sterile drain water batch test solutions (0.39 mg/L Se(VI), 21.1 mg/L NO_3^-). Points represent single measurements. Lines pass through the average measurement of a given day

Masscheleyn et al. 1990) while the high Fe concentration after day 47 is characteristic of reducing conditions (Couture et al. 2015; Kang et al. 2011). The reduction of Se(VI) to Se(IV) only in the absence of NO_3^- is consistent with other studies that have shown that NO_3^- inhibits Se(VI) reduction and is preferentially reduced by several Se(VI)-reducing bacterial species (Oremland et al. 1989; Steinberg et al. 1992). Three of the Se-reducing isolates collected from waste rock and drain water samples are affiliated with NO_3^- reducers in the genera *Pseudomonas* (Steinberg et al. 1992) and *Arthrobacter* (Eschbach et al. 2003). Abiotic NO_3^- reduction by Fe(II) or organic carbon occurs very slowly or not at all unless in the presence of a catalyst (Parmentier et al. 2014; Picardal 2012); however, complete removal of NO_3^- from the drain water did occur in some abiotic batch tests (Fig. 8). Given the inconsistency of NO_3^- removal and the presence of bacterial contamination determined by plating, NO_3^- removal from the abiotic batch tests is attributed to biotic processes.

The delay in Se(VI) reduction in the non-sterile batch tests (47 days) relative to the Se(VI) reduction apparent on the waste rock-cultured Se(VI)-amended BSM plates (3 days) is attributed to the presence of NO_3^- in the drain water, as well as the absence of a carbon amendment, such as lactate. Given the presence of NO_3^-, the non-sterile batch tests should not be used for determining rates of microbial Se(VI) reduction. Further testing using columns that can allow a microbial community to reach equilibrium with anoxic, Se(VI)-laden, NO_3^--depleted water would allow reduction rates representative of anoxic coal waste rock to be determined. Columns packed with waste rock should have a solid to solution ratio representative of the WLC dump rather than the low solid to solution ratio used in this study's batch tests (7.5 g/L). While the non-sterile batch tests were not suitable for determining rates of Se(VI) bioreduction, their use in parallel with abiotic batch tests was very effective in demonstrating the mechanisms of Se sequestration that may take place in anoxic coal waste rock.

Conclusions

Laboratory experiments showed that biotic and abiotic sequestration of Se in coal waste rock from the WLC dump in the Elk Valley, Canada is possible under anoxic, water-saturated conditions. A bacterial isolate affiliated with the genus *Pseudomonas* and a putatively novel species that can reduce Se(IV) and Se(VI) to Se(0) were present in the solid waste rock sample. Further, isolates affiliated with the genera *Arthrobacter* that can reduce Se(IV) to Se(0) were present in water sampled from an associated rock drain. Under anoxic, abiotic conditions, 40% of the initial 0.7 mg/L Se(IV) was removed from solution in 1 day by adsorption to the solid waste rock sample and the remainder was removed by reduction to insoluble Se(0) by day 81. Adsorption of Se(IV) to pyrite, siderite, and/or Fe(III)-oxyhydroxide, and abiotic reduction of Se(IV) to Se(0) by siderite and chalcopyrite were confirmed with EDS. Conversely, under the same environmental conditions, Se(VI) was not removed from solution. Finally, non-sterile batch tests confirm that bacteria in the waste rock reduce Se(VI) to Se(IV) under anoxic conditions without the addition of nutrient amendments, which allowed subsequent bioreduction, adsorption, and abiotic reduction of Se(IV). Based on our findings, the sequestration of Se under anoxic conditions should be considered as a viable method to decrease the concentration of Se in water migrating through coal waste rock dumps in the Elk Valley before it discharges to the Elk River and its tributaries.

Although this study shows Se sequestration within the WLC dump is possible under anoxic, water-saturated conditions, additional research is warranted. This additional research could include characterizing the effects of greater solid to solution ratios on Se sequestration (i.e. the solid to solution ratios under in situ conditions are approximately three orders of magnitude greater than those tested) and the design and management requirements to develop and maintain anoxic zones within the dumps.

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CONUMA COAL RESOURCES LIMITED

2017 ANNUAL RECLAMATION REPORT

BRULE MINE

Prepared for
British Columbia
Ministry of Energy and Mines

Mine's Act **– Permit Number: C-221**

April 30, 2018

Management and parties responsible for environmental monitoring at Brule Mine:

Mark Bartkoski

- President
- 250.242.3764 ext. 2023

Rob Teigen

- Mine Manager
- 250.788.92784 ext. 113

Brenna Fossum

- Environmental Manager
- 250.788.9278 ext. 108

Author of the 2017 Annual Water Quality Report – Brule Mine:

Brenna Fossum, BSc., G.I.T. (AB, BC)

- Environmental Manager
- 250.788.9278 ext. 108

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Executive Summary

In September 2016, Conuma Coal Resources Limited (Conuma) purchased three metallurgical coal mines: Brule, Willow Creek and Wolverine, from Walter Energy Canada (Walter). The mines are located in northeastern British Columbia (B.C.).

In 2017, the Annual Reclamation Program at the Brule Mine was under the direction of *Mines Act* Permit C-221 originally issued on September 8, 2004, and most recently amended on December 12, 2016. Due to the limited number of staff and the significant turn over in Environmental personal some sampling was not conducted in a timely manner or in accordance with the BC Field Sampling Manual.

In 2017, the Metal Leaching (ML)/Acid Rock Drainage (ARD) monitoring included the sampling of pit lakes, dump seeps, ARD Leachate Barrels, and the speciation of selenium from sediment ponds and pit lakes. A summary of the geochemical, water quality chemistry, and selenium speciation results are in Section 4 and the ML/ARD report was compiled by SRK Consulting (SRK). A brief summary of past and future research on ML/ARD, past reclamation and wildlife monitoring are in Section 4.

The Brule Mine adhered to the permitted effluent and air monitoring programs in 2017 (PE-17679 and PA-17680, respectively, issued pursuant to the *Environmental Management Act*). Reports submitted to the Ministry of Environment & Climate Change Strategy (ENV) for the 2017 programs are in Appendix G and H. The 2017 Annual Reclamation Report – Brule Mine has been prepared and submitted by Conuma, and reviewed by Qualified Professionals at Golder Associates Ltd. (Golder), to the Ministry of Energy and Mines and Petroleum Resources (MEMPR) per the Terms and Conditions of Permit C-221.

The Environmental and Reclamation Programs will be continued in 2018 per the Terms and Conditions of C-221.

1.0 Introduction

1.1 *Company Profile*

Conuma Coal Resources Limited (Conuma) is a privately owned Canadian company incorporated in 2016 with headquarters in Tumbler Ridge, British Columbia, and a corporate office in Vancouver.

In September 2016, Conuma purchased the Brule, Willow Creek and Wolverine Mines from Walter Energy, Canada (Walter). Conuma's principal business is the development of metallurgical coal properties in Northeastern BC. In its first 16 months of operation, Conuma successfully shipped more than 3.8 million (M) tonnes of metallurgical coal and has developed the operational capacity to ship in excess of 5.0M tonnes per annum.

The Brule Mine is operated from Tumbler Ridge, B.C.:

Mailing Address .....PO Box 2140, Tumbler Ridge, BC V0C 2W0
Telephone 250.242.3764

The Brule Mine is under the management of Rob Teigen, Mine Manager, and the executive direction related to the Brule Mine is provided by Mark Bartkoski, President.

Implementation and day-to-day direction of the on-site environmental programs are the responsibility of Brenna Fossum, Environmental Manager.

1.1 *Location*

The Brule open-pit coal mine is located in the eastern foothills of the Rocky Mountains in Northeastern British Columbia, approximately 98 kilometers (km) by road northwest of Tumbler Ridge, BC. It is in the Laird Mining District of the Peace River Regional Land District. The mine represents the operating portion of the Brazion Group of properties, which is comprised of the Brule Mine, the Dillon Mine and the Burnt River Exploration Area. Current mining operations occur in the Dillon lease; UTM location Zone 10, 574063, 6139724. Mine access is via Highway 29 northwest of Tumbler Ridge for approximately 70 km, along the Sukunka Forest Service Road (FSR) for 16 km, and then 9 km along the Blind Creek Road. An area map showing the general location of the Mine within the region is in Figure 1.

1.2 *Securing Mine Access*

There are two access points to the Brule Mine. The entrance from the Falling Creek Connector Road (FCCR) allows site access from the Hasler Road. The entrance from the Blind Creek Road is gated at 9 km. Both access points have a gate.

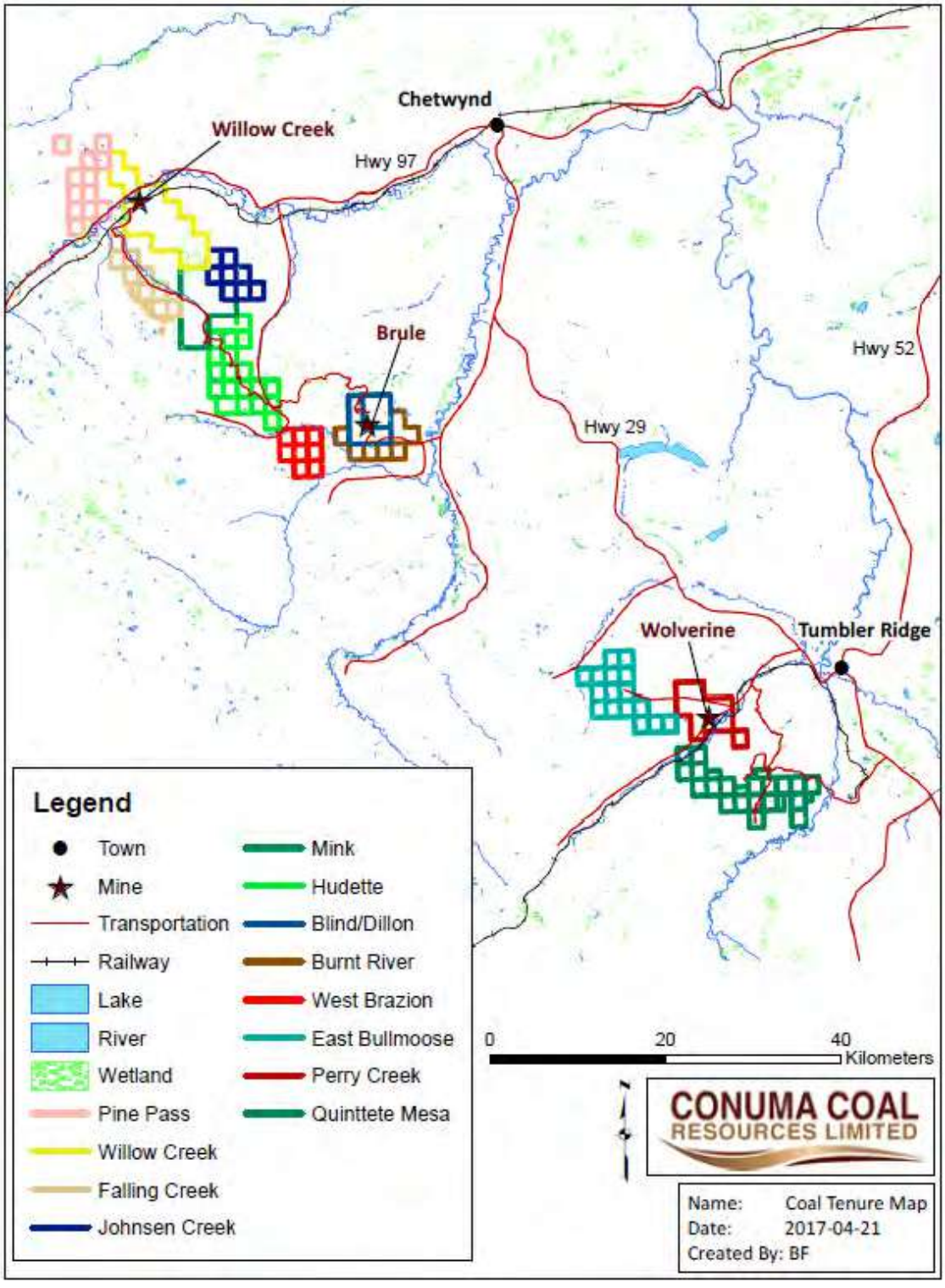

Figure 1: Location of Brule Mine

1.3 *Purpose of Report*

The purpose of the 2017 Annual Reclamation Report – Brule Mine, is to meet the Terms and Conditions under Mine Permit C-221; this report has been prepared and submitted by Conuma to the Ministry of Energy and Mine and Petroleum Resources (MEMPR). The report has been reviewed by qualified professionals at Golder Associates Ltd. (Golder). Included in this report are the results and interpretations of data collected from metal leaching (ML)/acid rock drainage (ARD) barrels, seeps and pit lakes; mine disturbance; and reclamation activities at the Mine during 2017. Additional data are included in Appendix G (Annual Air Quality Report) and Appendix H (Annual Water Quality Report).

1.4 *Permit Amendments*

The following amendments to Mine Permit C-221 have been granted:

- June 18, 1999 Approval of Trial Cargo Project
- September 8, 2004 Permit Issued, Approving Work System and Reclamation Program
- October 15, 2004 Approving Phase I Waste Dump Construction
- November 2, 2004 Approving use of Rip rap for Sediment Pond Construction of Camp Location
- January 25, 2005 Approving Sediment Control Plan
- July 27, 2005 Approving Increase in Annual Production
- January 5, 2007 Approving Phase I Mining from the Brule Pit
- February 5, 2007 Approving Work System and Reclamation Program
- May 30, 2007 Work System and Reclamation Program Correction
- January28, 2010 Approving Name Change
- May 25, 2010 Approving Amendment Request to exempt EMMP Permit Conditions
- November 26, 2012 Approving Change of Name
- September 24, 2013 Approving Coal Reject Backhaul to North East Dump
- July 17, 2014 Approving Biochemical Reactor Water Treatment Facility
- December 12, 2016 Approving Name Change

1.5 *Environmental Staff*

During 2017, the environmental department experienced a significant change in staff, at the end of the year the department consisted of:

- Regional Environmental Manager
- Regional Environmental Sampler

1.6 *Environmental Activities*

In 2017, the environmental staff were responsible for the following:

- Surface and groundwater sampling and reporting
- Air quality monitoring and reporting
- Metal leaching (ML)/acid rock drainage (ARD) monitoring and reporting
- Seep and sump monitoring and reporting
- Sediment monitoring and reporting
- Toxicity monitoring and reporting
- Overseeing Environmental Effects Monitoring (EEM)

- Monitoring the BCR
- Overseeing spill response
- Road and Ditch Inspections
- Selenium Management
- Dustfall Management
- Wildlife Management
- Waste Management

1.7 *Laboratories*

In 2017, Conuma used ALS Environmental (ALS), AGAT Laboratories (AGAT), Nautilus Environmental (Nautilus) and Trent University to conduct chemical analysis of the air, water and sediment samples collected. The dustfall canister analysis was conducted by AGAT in 2017.

2.0 Background

2.1 *Mining Program*

2.1.1 Surface Development to Date

Since the Mine opened in late 2004, the mining activities have resulted in a total surface disturbance of 563.9 hectares (ha) to the end of December 2017. Production at the Mine commenced with the development of the Dillon Pit small mine. The Mine was approved in 2006, including the development of the Blind and Brule pits. Mine operations continued until June 2014, at which time the mine entered Care & Maintenance status, prior to shutdown, mining was occurring primarily in the largest pit (South Brule Pit), with development mainly from south to north. Major components of the Mine site currently include two open pit (South Brule Pit and North Brule Pit), waste rock dumps (North, Northeast and Southeast), crushing plant and two sediment ponds: Main Sediment Pond (MSP) and Sediment Pond 2 (SP2). Small-scale mining efforts recommenced in September 2016, in the northwestern portion of the South Brule Pit; however, full-scale production was conducted in 2017 in the South Brule pit.

Distrubance	Mining		Reclamation								
	Area Distrubed (ha)		Area Re-contoured (ha)		Area Seeded/Planted (ha)		Area Fertilized (ha)		Area Re-vegetated (ha)		Land Use Objective*
	2017	Total	2017	Total	2017	Total	2017	Total	2017	Total	
Waste Dumps	0	82.0	14	0.0	14	0.0	0	0.0	0	0.0	Forestry/ Wildlife
Tailings Ponds	0	19.0	0	0.0	0	0.0	0	0.0	0	0.0	
Plant Site	0	20.0	0	0.0	0	0.0	0	0.0	0	0.0	
Roads	0	21.0	0	0.0	0	0.0	0	0.0	0	0.0	
Administration	0	10.0	0	0.0	0	0.0	0	0.0	0	0.0	
Pit	59.5	393.5	0	0.0	0	0.0	0	0.0	0	0.0	
Stockpiles	2.4	18.4	0	0.0	0	0.0	0	0.0	0	0.0	
Linear	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	
Other	0	0.0	0.5	0.0	0	0.0	0	0.0	0	0.0	
Total	61.9	563.9	0	0.0	0	0.0	0	0.0	0	0.0	

Exempt - pit high walls (6 ha)

* Options include: Forestry, grazing, wildlife habitat, recreation, agricultureal, industrial, residential and other.

Table 1: Summary of Areas Disturbed and Reclaimed

The coal haul across FCCR was active until November 2014, at which time the coal haul proceeded down the Sukunka FSR to Highway 29 to Chetwynd then along Highway 97 to the Willow Creek Mine for processing and rail car transport. This ended in June 2015 once the coal stockpile was depleted. Since the recommencement of mining, coal haul to the Willow Creek rail loadout has been through the FCCR.

A detailed breakdown of surface disturbance is provided in Table 1. Surface soil material has been salvaged from all areas disturbed by mine construction and operations and stored in the various stockpile locations. A more detailed discussion of the previous years' mining and reclamation activities can be found in the 2014 Annual Reclamation Report – Brule Mine.

Table 2 below indicates that 18,250,197 cubic meters of non-acid generating waste consisting of both till and waste rock was mined from the northern part of the South Brule Pit in 2017.

Name of Waste Pile or Pond	Acid Generating Waste (m^3)		Potentially Acid Generating Waste (m^3)		Non-Acid Generating Waste (m^3)	
	2017	Total	2017	Total	2017	Total
Waste Dumps						
South Dump	0	0	0	0	18,250,197	53,476,690
North East Dump	0	0	0	0	0	39,880,000
Total	**0**	**0**	**0**	**0**	**18,250,197**	**93,356,690**
Waste Dumps						
NA	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**
Low Grade Ore/Coarse Rejects/Other Mine Waste						
Till	0	0	0	0	6,219,107	8,236,109
Soil	0	0	0	0	73,390	73,390
Total	**0**	**0**	**0**	**0**	**6,292,497**	**8,309,499**

Table 2: Quantity of Waste Rock, Tailings, Low Grade Ore, Coarse Rejects and other Mine Waste

2.1.2 Future Plans

Future development will occur in the Brule Pit and advance northward towards its final headwall. This expansion would be regulated under the Brule Mine permits and documented in the Brule Annual Reports subject to Ministerial approval of the *Brule Mine 5 Year Mine & Reclamation Program Report (2014 through 2018) & Effluent Permit Amendment Application* submitted in 2013. All associated mining and reclamation of the remaining Brule disturbance will be handled under Permit C-221.

Waste material from the South Brule pit was infill dumped as extraction was completed in the south end of the South Brule Pit. The South dump will remain an infill dump and continue to rise to an elevation of 1,260 meters. The North East Dump will continue to rise above the Blind Creek Road to an elevation of 1,275 meters.

A Water Management Plan has been developed as part of the Environmental Management System. Future updates to the Plan will ensure non-contact water is diverted around the mining areas to reduce dump infiltration and direct sediment laden flow to settling ponds, including the improvement and extension of the South Brule Ditch northward to the Blind Creek FSR. The main ditch, which runs along the spine of the Mine, will also be expanded to include new mining areas. The reduction in contact water will help reduce the chemical loading (selenium, nitrate, sulphate, cadmium, etc.) of sub-surface dump flows. Once ditch designs are finalized, they will be constructed in areas that are permanent for the life of mine and beyond.

The construction of the Biochemical Reactor treatment system (BCR) near the Main Sediment Pond (MSP) for reduction of selenium concentrations in seep water was initiated in the summer of 2014 but halted in December due to adverse weather conditions. Construction was completed in 2015. The BCR is expected to be a low cost alternative to active treatment with proven success in removing excess nitrates and metals in mine-impacted waters in more temperate climates. The effectiveness of this technology will then be used to plan future mitigation strategies aimed at reducing mine related contaminants from entering the natural environment.

2.2 *Baseline Monitoring*

Seasonal field programs were performed prior to and throughout construction to enhance and validate baseline information for the project and to monitor potential environmental effects. The site monitoring program has evolved and expanded with the onset of Mine operations. Ongoing site monitoring programs currently include ML/ARD characterization, water quality, hydrology, climate, and groundwater monitoring. Appendices to the original Mine Permit application provide results of 2004 baseline studies in the areas of wildlife habitat, climate, hydrology, surficial geology and terrain, groundwater, fish habitat, floodplains, wetlands characterization, forest productivity and vegetation metals.

2.3 *Reclamation and Environmental Program*

The objective of the Mine reclamation program is to progressively reclaim areas to establish an ecosystem suitable for wildlife habitat. As the mine has only just started to reach its ultimate extent, there have been few opportunities to date to complete progressive reclamation. Reclamation activities in 2017 are described in following sections in more detail. The Mine has been operating since September 2016.

Environmental protection measures and environmental performance is verified by ongoing water and air quality monitoring, as defined by Mine Permit C-221, Effluent Permit PE-17679, and Air Permit PA-176980, plus regular internal environmental inspections.

ML/ARD leachate barrel water, groundwater and surface water quality sampling was conducted in accordance with the procedures described in the 2013 British Columbia Field Sampling Manual (Province of British Columbia, 2013).

Water samples were collected in laboratory provided sampling bottles by hand or by using an extendable sampling pole. Field measurements of temperature, pH and conductivity were taken downstream of the water sampling to ensure stirred sediment would not cause inaccurate readings within the lab samples. When sampling sites are frozen over during winter conditions, holes are augured or opened using axes; the environmental samplers then waited to allow the water to settle. Staff gauge readings and flow measurements were taken after water sampling for the same reason. Laboratory samples were then packed with ice and sent to the commercial laboratory employed by Conuma - ALS and/or AGAT for lab filtration within 24 hours of sample collection.

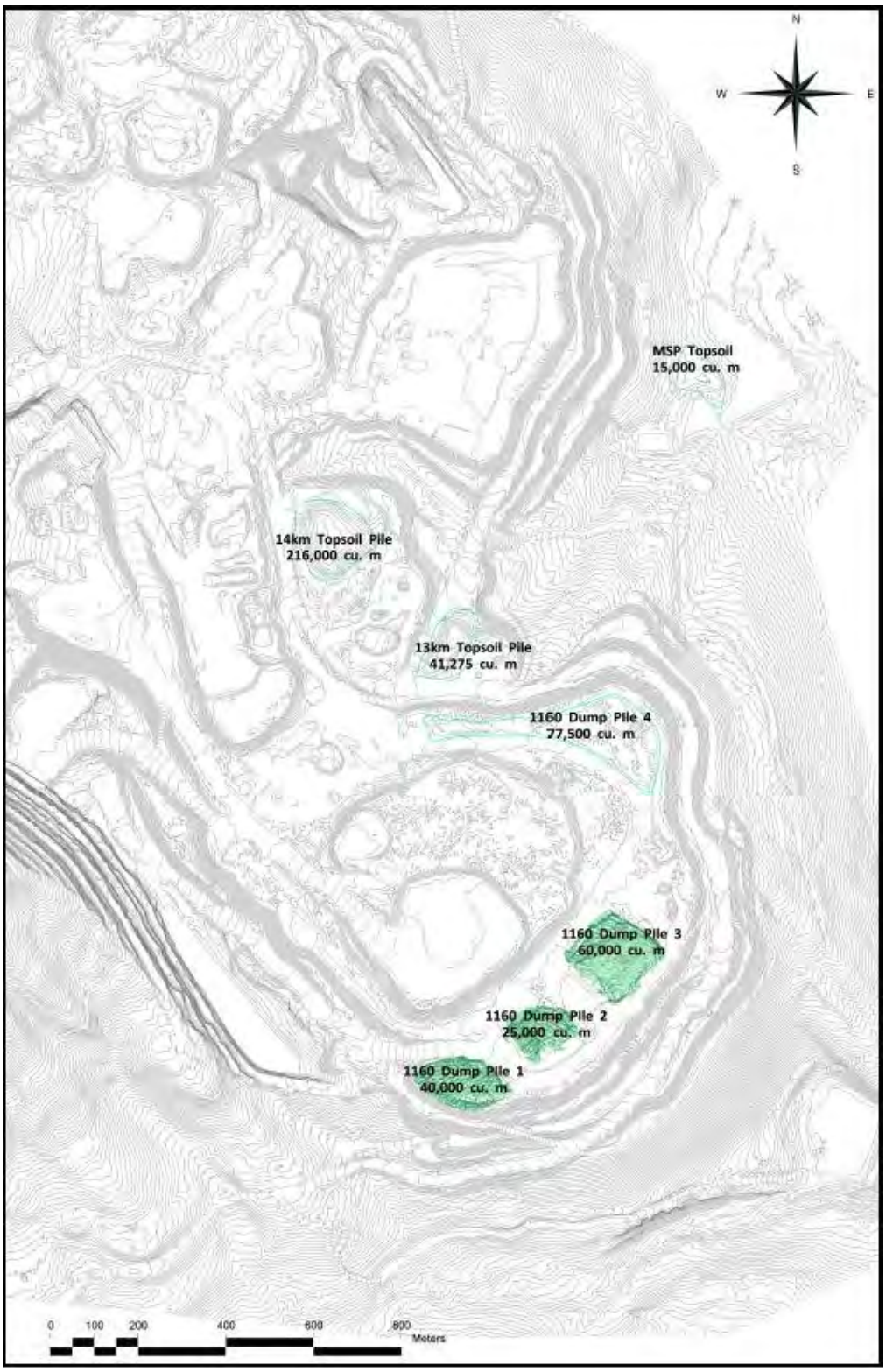

Figure 2: Locations of Soil Stockpiles

Figure 3: Locations of Reclaimed Areas

3.0 Methodology

3.1 *Quality Assurance/Quality Control*

A comprehensive Quality Assurance/Quality Control (QA/QC) program was incorporated into the field and laboratory components of the 2017 Water Quality Monitoring Program and 2017 Air Quality Monitoring Program. QA/QC data are presented in Appendix A of this report and Appendix A of the Water Quality Report (Appendix E) and Air Quality Report (Appendix F). The purpose of a QA/QC program is to verify the reliability of field and laboratory monitoring data through the implementation of procedures for controlling and monitoring the collection and measurement process. The QA/QC program provides information for the evaluation of analytical procedures and for analysis of possible issues pertaining to contamination both in the field and in the analytical laboratory. The QA/QC program is conducted at all stages of the sampling program in both the field and laboratory.

Field quality control QA/QC samples include field duplicates and field blanks. Laboratory quality control samples included duplicates, Certified Reference Materials (CRMs) and Laboratory Control Samples (LCS).

3.1.1 Field Blank

Field blanks, consisting of de-ionized (DI) water, are exposed to the same conditions and treatments as the water samples collected and are intended to monitor contamination that occurs during sample collection and handling (e.g. sample preservation or filtering). Field blanks are prepared as follows: DI water from the laboratory is shipped in 4-Liter bottles and decanted into the appropriate bottles in the Conuma environmental office on the day of sampling and preserved with acids, if needed (immediately before going into the field). The sample bottles are then placed in a cooler with ice packs, and taken into the field by the sampling staff. The blank samples are returned unopened to the office and shipped to the analytical laboratory with the remainder of the samples for analysis.

3.1.2 Field Duplicate

Field duplicates provide a measure of the overall precision of the methods used, including the combined precision of field methods, laboratory methods and the environmental variability over the time-scales (approximately 10 minutes for a full suite of replicate sample collection). A relative percent difference (RPD) of no greater than twice the laboratory precision criteria was defined in the Permit as the Data Quality Objective (DQO) used to identify significant differences between duplicate and sample, where the RPD is defined as:

RPD (%) = (Value 1 – Value 2)/mean x 100

Some degree of environmental variability can be expected in duplicate samples for parameters associated with Total Suspended Solids (TSS), and RPDs are expected to be high at values near the method detection limit (MDL). Duplicate samples that return a large RPD for high concentrations of parameter when compared with MDL are potentially indicative of a problem with sampling methodology and may warrant further investigation and/or training. The converse is true when samples return a large RPD for low concentrations of parameters, close to the MDLs of the analytical procedures employed. In these situations, the large RPD is less indicative of potential methodological problems but does warrant further scrutiny with future sampling efforts. The acceptable level of RPD exceedances is considered problematic is three times the MDL: if a large RPD is observed for sample results below this limit, it is noted, but does not represent a problem in the data collection methods. Slight variations at very low concentrations can also result in high RPD values. For this reason, where the parameter is within two

times the detection limit, RPD was not used as a measure of QA/QC. RPDs greater than 40% when the parameter levels are greater than three times the MDL are highlighted as problems.

The duplicate is intended to evaluate the QA/QC surrounding the sampling methods. Duplicates are prepared by collecting two full sample suites from one location, the first labeled with the correct sampling location name (e.g. WR-2) and the second with an anonymous name (e.g. Melon). When the results are reported back from the analytical laboratory, RPDs are calculated to identify the differences between the replicate and sample. In low flow conditions, or when sampling groundwater, side-by-side sampling is not always possible. When samples are not collected side by side, they are collected sequentially (i.e. WR-2 total metal sample, Melon total metal samples, WR-2 dissolved metal sample, Melon dissolved metal sample, etc.).

3.1.3 Filtration

For surface water, samples for dissolved metal analysis are filtered by the laboratory. For groundwater, samples are filtered in the field using inline filters or syringe filters with 0.45 micrometer (µm) pore spaces. In the event that groundwater samples are unable to be filtered due to extreme turbidity of the water, they are shipped to the laboratory for filtering.

Filtered blanks containing DI water are passed through the filtration apparatus in the same manner as the sample. Analysis of the filtrate provides an indication of the types of contaminants that may have been introduced through contact with contaminated filtration surfaces (filtration apparatus and the filters) or exposure to dust sources.

3.1.4 Field Parameters

Various field meters are used at the Mine to measure in-situ turbidity, conductivity, temperature, pH, dissolved oxygen, oxygen reduction potential (ORP) and flow. All field equipment is regularly calibrated and maintained by the environmental staff. Equipment that can't be calibrated by the environmental staff is sent to the manufacturer or equipment suppliers for calibration. The turbidity and YSI units are sent to third parties for annual calibration. The turbidity, YSI and multi-meter units are calibrated in house per the manufacturer's recommendations. The flow tracker is calibrated in house during each usage.

Field turbidity is obtained using a Hach 2100p turbidity meter that has a range of 0-1000 nephelometric turbidity units (NTU). In weather above freezing a YSI 556 unit is used to measure conductivity, temperature, pH, dissolve oxygen and ORP. For weather below freezing the YSI unit will not function so an Oaklan PCTestr35 Multi-parameter unit is used but it limited to conductivity, temperature and pH only.

The portable flow meter used is a Sontek Flowtracker. This meter utilizes sonar to measure the velocity of water flowing past the sensor and converts that into a flow measurement. Calibration and troubleshooting are performed using "Beamcheck" software, included with the instrument.

3.1.5 Laboratory Quality Assurance/Quality Control

Certified Reference Materials (CRM) verify the accuracy of instrumentation and analytical methods. CRMs are standards with known concentrations, certified by a technically valid procedure and are traceable to a certificate or other documentation issued by a certified distributor. The DQO for CRMs are based on percent recovery, and are set by the laboratory for each parameter and each matrix. The DQO for most metals in water samples is ±20% of the known concentration.

LCS analyses verify the accuracy of instruments with respect to anions, and the DQO is ±10% of the known concentration, with the exception of bromide and ammonia which have DQOs of ±15%. The results of the laboratory analysis of the CRM and LCS tests are provided in Appendix G.

The laboratory reports multiple CRM results for each parameter in each data report. All reported CRM values were within the acceptable level of accuracy, indicating a high level of quality assurance. As CRM target concentrations are developed from a variety of sources and not necessarily from the Mine samples, they are unable to be lowered to meet concentrations closer to those found at site. This has been noted as an issue, especially in the example of cadmium, which has a lab accuracy of 100,000 nanogram per liter (ng/L) and actual site concentrations, which are closer to 50 ng/L.

4.0 Results

The 2017, Reclamation and Environmental Program was based on the required ML/ARD, seep, pit lake, sediment pond, surface water and groundwater sampling programs discussed in Permit C-221. This section outlines sampling locations, frequencies and parameters for the Mine.

- Appendix A – QA/QC
- Appendix B – ML/ARD graphs and tables
- Appendix C – Seeps and Pit Lakes graphs and tables
- Appendix D – Selenium Speciation results
- Appendix E – 2017 ML/ARD Monitoring Report
- Appendix F – 2017 Reclamation Inspection Reports
- Appendix G – 2017 Annual Air Quality Report – Brule Mine
- Appendix H – 2017 Annual Water Quality Report – Brule Mine
- Appendix I – Wildlife Sightings
- Appendix J – Geotechnical Report

4.1 *2017 Mining Production*

Coal was mined from the northern portion of the South Brule Pit in 2017. Table 3 below indicates that 2.3 million tonnes was mined from the South Brule Pit. Most of the mined coal was trucked from the Brule Mine to the Willow Creek Mine for crushing and loading into rail cars. The remainder of the coal has been stockpiled at Brule, to be processed later when the Willow Creek Wash Plan reopens. The coal trucked to Willow Creek did not require milling (washing) as the quality allowed for direct shipping.

Site Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Mining Production (tonnes)											
South Brule Pit	118,221	118,221	161,624	118,890	178,412	280,539	214,709	294,357	242,452	148,235	287,833	211,686
	Mill Production (tonnes)											
South Brule Pit	-	-	-	-	-	-	-	-	-	-	-	-

Table 3: Monthly Mining and Milling Production

Table 4 (Monthly Custom Milling Production), requested on the MEM website was not included as the coal mined from the South Brule Pit did not require milling.

4.2 *Environmental Protection Program*

4.2.1 Environmental Management System

To ensure ongoing environmental protection, an Environmental Management System (EMS) for the Mine was developed. This EMS, which includes Environmental Management Plans (EMPs), Operation, Management and Surveillance (OMS) Manuals and Standard Operating Procedures (SOPs), continues to be revised and expanded upon to encompass changing operations and to ensure it accurately reflects the current practices and standards.
Update Management Plans under the EMS were submitted throughout 2017; however, most of the plans were submitted in Q2 and Q3. Updated Selenium, Flocculant and Dustfall Management Plans were submitted with the 2017 Annual Air and Water Quality Reports (Appendix G and H).

4.2.2 ML/ARD Monitoring

4.2.2.1 Quality Assurance/Quality Control

4.2.2.1.1 Field Blanks – ARD

Five field blanks were collected and sent for analysis in 2017. The results are in Appendix A.1.

- There were no field blank samples that reported parameters over expected levels for 2017.

4.2.2.1.2 Field Duplicates – ARD

There were five duplicate samples collected and sent for analysis in 2017, the following parameters were greater than 40% RPF and greater than three times the MDL. The results are in Appendix A.2.

- May showed Dissolved Titanium (41.27%)
- June showed Total Copper (64.15%)
- September showed Total Suspended Solids (40%), Total Kjeldahl Nitrogen (66.67%)
- October showed Total Manganese (66.67%)

There were six additional parameters that were greater than 40% RPF, but less than 300% of the MDL.

4.2.2.1.3 Field Blanks – Seeps and Pit Lakes

Four field blanks were collected and sent for analysis in 2017. The results are in Appendix A.3.

4.2.2.1.4 Field Duplicates – Seeps and Pit Lakes

For the four duplicate samples taken in 2017, the following parameters were greater than 40% RPD and greater than three times the MDL.

- April showed Total Molybdenum (82.35%)
- June showed Total Copper (40%)
- September showed Total Suspended Solids (41.71%)

Two additional parameters were greater than 40% RPD, but less than three times the MDL. The parameters are shown in Appendix A.4.

4.2.2.1.5 Lab Quality Assurance/Quality Control

Both ALS and AGAT laboratories perform the water analysis for Conuma, and maintain strict guidelines for quality assurance and control. RPDs greater than 40% during winter months can commonly be associated with chopping or auguring through ice and snow. RPD's greater than 40% during summer months can be associated to poor sampling techniques or lab error – these samples are often re-run to confirm the values.

4.2.2.2 ML/ARD monitoring

The Brule Mine has an ongoing monitoring and management program in place to assess the potential for ML/ARD. The monitoring program allows for the prediction of potentially acid generating (PAG) material and helps direct the handling of this PAG material in a manner that ensures neutralization. The ML/ARD monitoring program consists of the following:

- Seep and Pit Lake water chemistry
- Waste rock leachate barrels water chemistry
- Groundwater chemistry
- Selenium Speciation testing
- Active rock dump crests

Locations of the water wells and ARD barrels are shown in Figure 4.

The ML/ARD data analysis was conducted by SRK Consulting Inc. (SRK) and is included in Appendix E. A summary is included below.

Acid rock drainage and metal leaching data for 2017 have shown that:

1) Acid-base accounting samples were non-PAG
2) Samples from SP2 seeps, which monitor the South East Dump, typically record the highest concentrations of nitrate, sulphate and selenium. Likewise, selenium, sulphate and nitrate concentrations were commonly highest in groundwater at sites adjacent to the South East Dump.
3) There is evidence of selenium attenuation in the groundwater system in the Lower Blind Pit/North East Dump area.
4) South Brule Pit Lake is different to the other three pit lakes as its cations are dominated by sodium + potassium rather than magnesium + calcium, and trace element concentrations were more variable and often higher than the other pit lakes. Relatively high nitrate concentrations in the South Brule Pit Lake are likely to be indicative of residual blasting agent as this was the active mining area in 2017.

Waste material, at the Mine, is a mixture of fine/medium grained sandstone, shale, siltstone, carbonaceous shale and minor quantities of mudstone. The waste material is characterized as Non-Acid Generating (NAG) material.

Minor quantities of coal at the contact layers between coal and host rock is deposited into the waste dumps. PAG material is isolated within interior fill, and is end-dumped on the face, inclined at the angle of repose. Mixing occurs at a minimum ratio of 3:1 with other waste rock and till material during the mining and end-dumping process, to ensure that the till and PAG material is not concentrated in any one portion of the dump. PAG material is not placed within 10 meters of the dump platform, nor placed within the lowest 10 meters at the base of the dump. The purpose of this is to limit the amount of PAG material that will be saturated with water and ensure that the PAG material is encapsulated with NAG.

The results for waste rock barrel leachate monitoring are in Appendix B.

4.2.2.2.1 Compliance

Mine Permit C-221 and the Effluent Permit PE-17679 requires quarterly sampling for all known seeps. North Dump 1 and North Dump 2 became the inflow waters to the Biochemical Reactor (BCR) when it was constructed in 2014-2015. This water is sampled monthly as per Permit requirements as BCR-IN.

Six leachate barrels were sampled in 2017. The samples from LSFW, LWSMFW, 1B60U and 1BLU in May, June, July, September and October; samples were collected from 0B60 in May, June, July and September; and samples were

collected from Surface Dirt & Till in May, June, September and October. The results of this ARD monitoring are in Appendix B.

Thirteen seeps were sampled in 2017. The four pit lakes (North Brule, South Brule, Blind and Dillon) were sampled in February, April, June, September and October; and South Brule was also sampled in August. The results of the seep and pit lake monitoring are in Appendix C.

4.2.2.2.2 Location

The ARD leachate barrels are located uphill of MSP, near the BCR. The locations of permitted groundwater sample sites and ARD Barrels are displayed in Figure 4. The seeps are located along the base of the dumps at the Mine. The seeps and pit lakes are displayed in Figure 5.

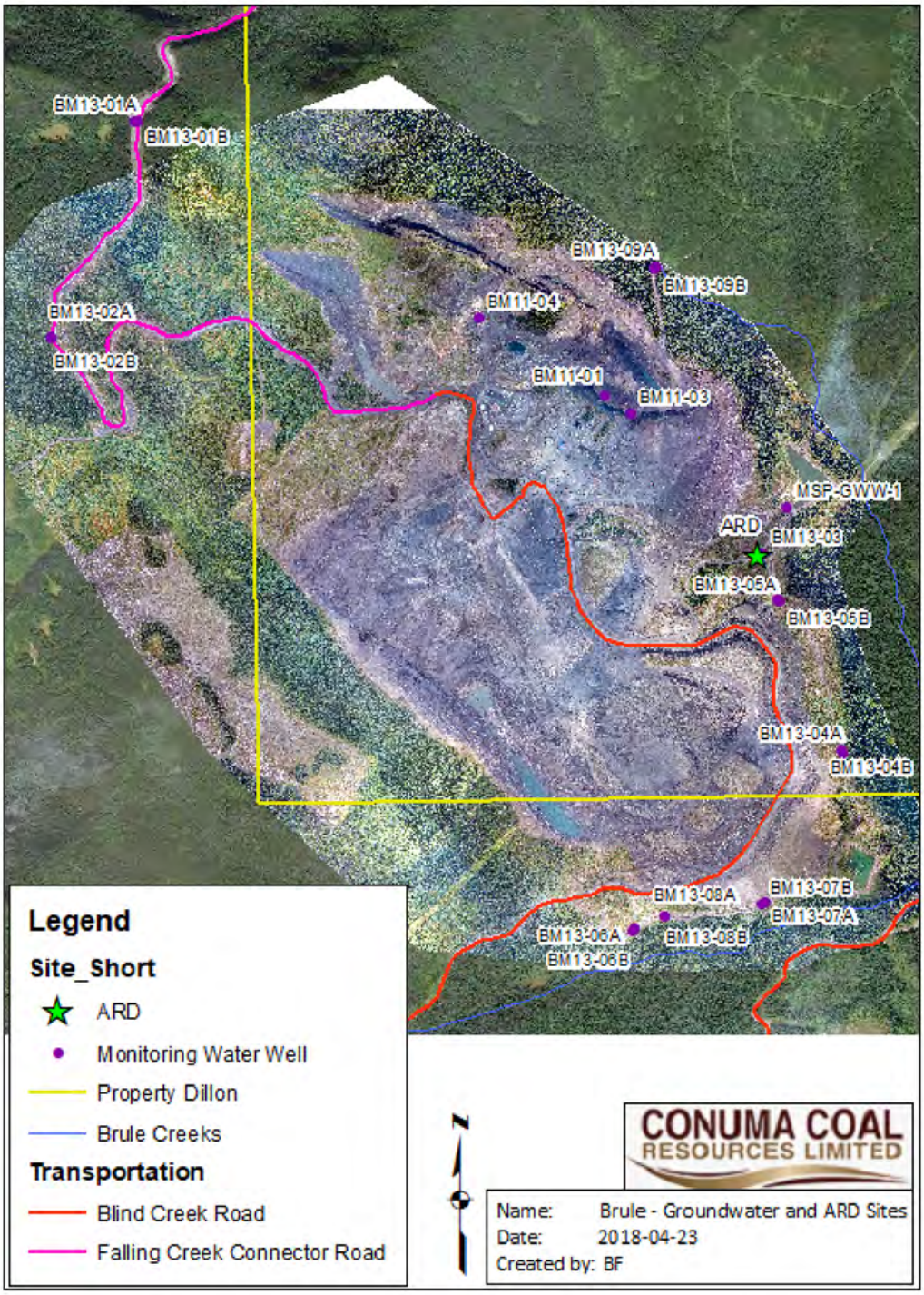

Figure 4: Groundwater and ARD Monitoring Locations at the Mine

4.2.2.2.3 ML/ARD – General Parameters

4.2.2.2.3.1 pH

The pH levels for LSFW continued to decline in 2017 and maintained lower levels than the other sites.

4.2.2.2.3.2 Orthophosphate Dissolved

The concentration of Orthophosphate dissolved in IB60U continued to display decreasing and increasing levels for 2017, a trend since sampling started.

4.2.2.2.3.3 Phosphorous Total Dissolved

The concentration of Phosphorous Total Dissolved in LSFW, IB60U and the Surface Dirt/Till barrels displayed concentrations that were an order of magnitude higher compared to other sites on the same graph.

4.2.2.2.4 ML/ARD – Metals

Due to the lack of analysis of total metals prior to 2016, very little can be discussed regarding trends and concentrations.

4.2.2.2.4.1 Dissolved Aluminum

The annual fluctuation in dissolved aluminum was more subtle in 2017.

4.2.2.2.4.2 Dissolved Arsenic

The concentration of dissolved arsenic for OB60 continued to decline in 2017.

4.2.2.2.4.3 Dissolved Magnesium

The concentration of dissolved magnesium for IBLU and LWSMFW was higher than at other sites.

4.2.2.2.5 Seeps and Pit Lakes – General Parameters

4.2.2.2.5.1 Conductivity

The conductivity values in East Dump displayed a significant decrease in 2017. SP2 East continued to display an increasing trend for 2017.

4.2.2.2.5.2 Chloride

The chloride concentration for East Dump decreased significantly in 2017.

4.2.2.2.5.3 Nitrate

The concentration of nitrate in South Brule Pit Lake maintained higher levels for 2017 compared to other sites. SP2-D displays an significant decrease in concentration for 2017.

4.2.2.2.5.4 Orthophosphate Dissolved

The concentration of orthophosphate dissolved for MSP-D in 2017 displays a similar trend to 2016.

4.2.2.2.5.5 Seeps and Pit Lakes – Metals

4.2.2.2.5.6 Total Antimony

The concentration of total antimony in South Brule Pit Lake maintained a trend of higher concentrations compared to other sites on the same graph.

4.2.2.2.5.7 Total Barium

The concentration of total barium decreased significantly in 2017.

4.2.2.2.5.8 Total Boron

The concentration of total boron displays an increasing trend for 2017.

4.2.2.2.5.9 Total Cobalt

The concentration of total cobalt in South Brule Pit Lake displayed an increasing trend in 2016 & 2017; however, there are no historical samples to compare.

4.2.2.2.5.10 Dissolved Lithium

The concentration of dissolved lithium in South Brule Pit Lake displayed a significant decrease in 2017 followed by an significant increase thus returning to its increasing trend.

4.2.2.2.5.11 Total Molybdenum

The concentration of total molybdenum decreased in 2017 but was still higher compared to other sites.

4.2.2.2.5.12 Dissolved Nickel

The concentration of dissolved nickel for SP2 East maintained a trend of higher concentrations in 2017 compared to other sites in the same graph.

4.2.2.2.5.13 Dissolved Selenium

The concentration of dissolved selenium for MSP-D displays an slightly increasing trend since sampling started; however concentrations of dissolved selenium in East Dump remains higher than other sites on the same graph.

4.2.2.2.5.14 Dissolved Sodium

The concentration of dissolved sodium in South Brule Pit Lake displayed an increasing trend since the initial samples were collected in June 2009. However, the concentrations significantly increased in 2017.

Figure 5: Seep and Pit Lake Monitoring Locations at the Mine

4.2.2.3 Selenium Speciation

Per Permit C-221 one sample from each of the pit lakes and sediment ponds shall be collected annually for determination of selenium species. In 2017, selenium speciation monitoring was conducted on sediment pond effluent, dump seepage water, pit lakes and key water quality sites. Water quality samples were analyzed at Trent University for selenate (Se(VI)) and selenite (Se(IV)). The results are included in Appendix D.

In 2017, water quality samples were collected from MSP-D, SP2-D, BC-01a, North Brule Pit Lake, South Brule Pit Lake, Blind Pit Lake, Dillon Pit Lake, BCR-In Upper (North Dump Seep 2), BCR-In Lower (North Dump Seep 1), BCR-A and SP2 East Seep. Total selenium was analysed along with the selenium species.

The results indicate that Se(VI) was the most prevalent species (90 – 99% of measured concentrations) which had a narrower range than 2016. Cumulative selenium speciation graphs, Se(VI) vs Se(IV) graphs, cumulative tabulated results and 2017 results are in Appendix D. The 2017 results are presented in parts per billion (ppb) in Table 4.

Location	Total Selenium TSe	Selenite Se(IV)	Selenate Se(VI)
BCR-In Upper	126.0	3.1	124.4
BCR-In lower	56.4	0.8	55.2
BCR-A	25.6	0.6	18.4
MSP-D	73.7	2.8	68.4
SP2-D	161.6	1.8	157.2
SP2 East Seep	208.9	1.9	194.5
BC-01A	46.4	1.0	45.1
Sout Brule Pit lake	27.7	4.6	21.6
North Brule Pit lake	4.2	0.4	4.2
Blind Pit lake	17.1	0.4	16.5
Dillon Pit Lake	24.1	0.5	23.7

Table 4: 2017 Selenium Speciation Results

4.2.2.3.1 MSP-D

The concentration of selenium has, in general, been increasing in MSP between 2007 and 2015. However, since 2015 the concentration of Se(VI) has significantly decreased. However, the 2017 concentration of Se(IV) was the highest recorded since 2007.

4.2.2.3.2 SP2-D

The concentration of selenium in SP2-D in 2016 and 2017 was more than five times greater than previous years. The concentrations of total selenium and Se(VI) in SP2-D were the second highest concentrations measured at the Mine in 2017.

4.2.2.3.3 BCR-In Upper (North Dump Seep 2)

Selenium speciation was conducted at the BCR-In Upper for the first time since 2014. The results indicate that Se (VI) is the predominate species by 97%.

4.2.2.3.4 BCR-In Lower (North Dump Seep 1)

Selenium speciation was conducted at the BCR-In Lower for the first time since 2014. The results indicate that Se (VI) is the most predominate species by 98%. Se (VI) has significantly increased since the first sample in 2012; however (Se (IV) has continued to decrease.

4.2.2.3.5 BCR-A

Selenium speciation was conducted for the first time, in 2017, at BCR-A (the outflow of the BCR prior to reaching the aeration pond). The results indicate a significant reduction in Se (IV) and Se (VI) compared to BCR-In Upper and BCR-In Lower.

4.2.2.3.6 Dillon Pit Lake

In 2017 the concentration of Se(IV) was significantly higher than in 2016 but lower than previous years. Se(VI) was the second lowest measured at the Dillon Pit Lake since sampling began in 2010.

4.2.2.3.7 North Brule Pit Lake

Selenium speciation was conducted at the North Brule Pit for the first time in 2016. The concentrations measured were significantly lower than concentrations previously measured at sites at the Mine.

4.2.2.3.8 South Brule Pit Lake

The concentration of selenium in the South Brule Pit Lake in 2017 was less than in 2016 but significantly greater than previous years.

4.2.2.3.9 Lower Blind Pit Lake

The concentration of selenium has, in general, been increasing in the Lower Blind Pit Lake since it was first sampled in 2009. In 2017, the concentration of Se(VI) was the greatest recorded since sampling began in 2009; however, Se(IV) was the lowest measured since 2009.

4.2.2.3.10 BC-01a

The concentration of selenium decreased at BC-01a compared to 2016.

4.2.2.3.11 SP2 Seep East

The concentration of selenium has, in general, been increasing in the SP2 Seep East since it was first sampled in 2009. In 2017, the concentration of Se(VI) and Se(IV) was slightly less than in 2016.

4.2.3 Air Quality Monitoring Program

The 2017 Air Quality Monitoring Program at the Mine was conducted in accordance with Air Permit PA-17680 issued by ENV. The 2017 Annual Air Quality Report – Brule Mine is included in Appendix G and a brief summary is included below:

In 2017, the Air Quality Monitoring Program at the Brule Mine was under the direction of Air Permit PA-17680 originally issued on November 19, 2004 and most recently amended on February 16, 2017. In 2017, Conuma monitored dustfall canisters and the weather monthly, at Brule Mine, per the Terms and Conditions of C-221.

Twenty-six of the 60 compliance sites exceeded the total dustfall Permit Limit of 1.75 milligrams/square decimeter/day (mg/dm^2/day). Ten of the 12 observation sites exceeded 1.75 mg/dm^2/day; however, the observation sites do not have a Permit Limit. Road watering was conducted during the summer months to supress the dust emissions, and a spray station was installed on the crusher during September and became operational in October of 2017.

Due to road building activity by the forest industry, observation site, A6, was moved approximately 100 meters north of the previous location in October.

Weather was downloaded monthly from the weather station located on site. The weather station was calibrated during November 2017.

4.2.4 Water Quality Monitoring Program

The 2017 Water Quality Monitoring Program for surface water, groundwater, sediment, and seeps and pit lakes was conducted per the Terms and Conditions of Effluent Permit PE-17679, issued by ENV. The 2017 Water Quality Monitoring Report – Brule Mine is included in Appendix H and a brief summary is included below:

In 2017, the Water Quality Monitoring Program at the Brule Mine was under the direction of Effluent Permit PE-17679 originally issued on May 30, 2005 and amended on October 14, 2015. Due to the limited number of staff and the significant turn over in Environmental personnel some sampling was not conducted in a timely manner or in accordance with the BC Field Sampling Manual. In 2017, an Environmental Effects Monitoring Program was conducted by Golder Associates. The results indicated that there were some effects from mining on the aquatic environment. Toxicity testing (c.dubia (LC50 and IC25))was also conducted in 2017, the samples at BC-01a did not pass the October testing so the site was resampled in December and the results passed.

Bio-Chemical Reactor (BCR) 1 was cleaned out, refilled and re-started in 2017. Preliminary results indicate that the system is removing nitrate, sulphate and total selenium from the water. A detailed report included up to date results, drawings and re-starting details will be provided to ENV and MEMPR in 2018. Conuma also anticipates designing and constructing a second BCR (BCR2) in 2018, at SP2.

Water quality monitoring identified nitrate, nitrite, and selenium as contaminants of concern. The 2017 annual average nitrate concentration in Blind Creek downstream of the mine (site BC-01a) was above the annual average Site Performance Objective (SPO). Nitrite concentrations at BC-01a were often above the long-term water quality guideline and occasionally above the short-term WQG. Selenium concentration at BC-01a in 2017 was similar to the levels measured in 2016, and the annual average concentration was below the annual average Site Performance Objective. PE-17679 includes an outdated sulphate site performance objective that is less than the current BC water quality guideline. Due to this, the annual average sulphate concentration at BC-01a was above its SPO but below the BC WQG.

4.2.5 Water Quality Prediction, Mitigation and Treatment

Predictions of water quality vs measured water quality are included in the 2017 Water Quality Monitoring Report in Appendix H. The re-start of BCR1 and the design and construction of BCR2 are expected to significantly improve the quality of water on site, along with the development of saturated backfills in the old pits.

4.2.6 Water Management Structures

The Mine employs a variety of systems on site in order to reduce its overall impact on the environment. The North, East and South collection ditches, which collect storm runoff and snowmelt from the outside dump shells, convey water to the sediment ponds. There are two sediment ponds; the MSP and P2. Water collected in the active pit naturally decants to one of the sediment ponds or is pumped to one of the sediment ponds. This water is sampled to ensure that it will not have a detrimental impact on overall water quality in the receiving environment. Maintenance of these waste structures includes the removal of sediment in all sediment ponds and ditches as needed. Reclamation of these structures will follow as described in Permit C-221. Locations of the ditches and other infrastructure are included in the spatial data that was submitted to MEM.

Third party inspections of the sediment ponds are completed on an annual basis. Conuma staff also conduct inspections of all water management structures on an on-going basis.

- Third Party inspections are submitted to the Ministry of Mines and Energy by March 31 annually.
- Any concerns resulting from these inspections are completed as per the recommendations within the reports.

Internal inspections were completed by environmental staff while performing other monitoring duties. Notes were taken of any ditches or culverts that may have sediment build-up; any erosion of berms, banks, ditch or roads around the Mine site or near the ponds; and comments that assess the effectiveness of these structures. Any issues that arose from the inspections were resolved during general maintenance works conducted at the Mine, unless the issues were of higher concern; then a request for immediate maintenance was made to operations and the issues were resolved quickly.

In general, all other ditches were noted to be in good condition through 2017. Culverts were open, and flow was properly maintained within all water management structures. Locations of the ditches are included in the spatial data that was provided to MEM.

4.2.7 Erosion and Sediment Control

Overall, there was little erosion on site; except the dump slop above SP2 which was re-sloped and seeded in August.

This area showed rills that had formed due to poorly controlled water from the haul road (Blind Creek Road, 11-12.5km) above it. This was noted in the May 2015 inspection by MEM. This area was resloped, topsoil was placed and native grass seed was placed in August 2017.

Flocculant was used at MSP and SP2 in 2017.

4.2.8 Soil Salvage

Two additional topsoil stockpiles were created and marked in 2017 and five existing soil stockpiles were identified and marked.

The new soil stockpiles locations are described as the following:

- South East Dump
    - 1160 Topsoil 3 2017
    - 1160 Topsoil 4 2017

The soil was from the pre pit stripping in Phase 2 of the South Brule Pit.

The other topsoil stockpiles are located at the following locations:

- 13km Topsoil
- 14km Topsoil
- MSP Topsoil 2006
- 1160 Topsoil 1 2014
- 1160 Topsoil 2 2014

Figure 2 displays the location of the soil stockpiles at the Mine.

Year	Area Salvaged (Location and Area in ha)	Salvaged Volumes to Stockpile Locations (m^3)							Total Salvaged Volumes (m^3)	No. of Samples for Suitability
		MSP Topsoil 2006	13km Topsoil	14km Topsoil	1160 Topsoil 1 2014	1160 Topsoil 2 2014	1160 Topsoil 3 2017	1160 Topsoil 4 2017		
2006	MSP Pond Area	15,000							15,000	unknown
unknown	unknown		41,275	216,000					257,275	unknown
2014	unknown				40,000	25,000			65,000	unknown
2017	South Brule Phase 2						60,000	25,000	85,000	unknown

Table 5: Quantities of Soil and Overburden Salvaged and stockpiled for Reclamation Use

Conuma is committed to the practice of progressive reclamation where possible. However, in the event that areas are not ready to be reclaimed in conjunction with soil stripping, soils are stockpiled and seeded to minimize erosion losses and are adequately demarcated to ensure that they are not negatively impacted by mining activities. Approximately 85,000 cubic meters of soil was salvaged in 2017. A significant volume of timber was also placed in the soil stockpiles for future use. Future soil stockpile information is included in the spatial data that was submitted to MEM.

4.2.9 Vegetation Management

The Vegetation Management Plan will be revised and submitted to MEM in 2018. It will describe a vegetation monitoring program for evaluating metal uptake in exposed terrestrial and aquatic ecosystems, which specifies sampling requirements and performance criteria. It will have maps of riparian setbacks and vegetative buffers and describe measures that are to be implemented to protect the setbacks and buffers. The Program will be designed to evaluate the success of revegetation, soil development and vegetated erosion control. The monitoring program will include specific sampling parameters and performance criteria.

Conuma will limit disturbance to vegetation to those areas approved by the Mine Permit. Vegetation resources were assessed as a component of terrestrial ecosystem mapping. There were species indigenous to the ecosystems (site series) within the ESSFmv2 and SBSwk2 biogeoclimatic-zone variants.

4.2.9.1 Seeding

Seeding occurred in August on the South East Dump slope above SP2. Tree planting will occur on the slope in 2018.

4.2.9.2 Invasive Plant Management

Invasive plant management will be directed in the EMS by the Vegetation Management Plan. Conuma will manage and control weeds that establish on the site and take reasonable efforts to ensure that weeds do not move from the Mine to adjacent areas. Monitoring for invasive species was done by the Environmental staff throughout the growing period. The Management Plan indicates that Conuma will consider using non-toxic means for weed control when possible. Care will be taken to ensure seed that is used for reclamation is free of weed seed contamination.

No observations of major concern have been noted, though small pockets of scentless camomile was noted above the access road to SP2 and at MSP-D.

4.2.9.3 Metal Update in Vegetation

Walter and Spectrum Resource Group Inc. previously partnered to perform a multi-year study on the concentration of a variety of contaminants in tissues of the various species planted in the waste rock dump reclamation.

Metal uptake in vegetation will now be covered under the Vegetation Management Plan, to be updated and submitted by June 30, 2018.

4.2.10 Wildlife Monitoring and Protection

A logbook for recording wildlife sightings is located at the security office and in the environmental database. Information collected in the logbook includes date, time and location of sighting, species sighted and information related to behaviour, age and number of species observed.

The Wildlife Management Plan (WMP) is an operational document that uses management recommendations for the mitigation of potential project related effects on wildlife and their habitat to provide workers with the necessary tools and information to reduce the chance of a negative wildlife/human interaction.

The WMP provides all workers and contractors a comprehensive list of the general restrictions and mitigation measures to minimize the Mine's residual effect on wildlife and wildlife habitat. The information provided includes the rationale, background and context for these restrictions, requirements and recommendations. Wildlife protection measures in place include:

- General restrictions for wildlife protection,
- Wildlife attractants
- Garbage management
- Preventing problem wildlife
- Dealing with problem wildlife
- Bears (Bear aware program and bear safety)
- Wildlife and vehicles
- Wildlife habitat use
- Wildlife health
- Reporting wildlife observations and incidents

The WMP will be summarized into information sheets and pamphlets and provided to all workers during orientation when they first enter site. Regular inspections of site facilities are completed to ensure compliance with the WMP. Wildlife Report forms are available for operational staff to record wildlife sights. The 2017 Wildlife Sightings Spreadsheet is available in Appendix I.

Previous wildlife assessments focused on species of regional concern (i.e. grizzly bear, elk, moose, mountain caribou, mule and white-tailed deer, marten, fisher, northern goshawk, black-throated green warbler) and species that are blue or red-listed by the ENV and which may occur within the property (i.e. broad-winged hawk, trumpeter swan, Cape May warbler, black-throated green warbler, Connecticut warbler, Philadelphia vireo and Canada warbler).

4.2.11 Archaeological Resources

There have been no archaeological resources identified on site.

4.3 *Reclamation Program*

4.3.1 Geological

Brule's geology is moderately complex, although less-so than the geology of the nearby Willow Creek Mine and Sukunka Colliery. The overall structural style of the Brule coal-measures is dominated by broad to tight concentric, cylindrical to conical folds, associated with folded thrust-faults. This structural style is laterally widespread within the Brule coal property, and furthermore increasingly-intensive at greater stratigraphic depths within the coal-measures. Brule Mine's coal reserves are hosted by the Early Cretaceous coal-bearing rocks of the Gaylard Member of the Gething Formation, lying between the valley's of Sukunka River and Burnt River.

Physical characteristics of the land surface, such as steepness, slope shape, soil moisture and parent material can vary locally over distances of a few meters to several tens of meters, giving rise to related variations in soil classes.

4.3.2 End Land Use

There is no existing agricultural or licensed range land use. The proposed end land use for the project area was wildlife habitat and forestry.

4.3.2.1 Agriculture

There is no existing agricultural or licensed range land use.

4.3.2.2 Forestry/Oil and Gas

The Mine lies entirely within Canfor TFL 48; Canfor harvested timber over significant portions of the Mine and surrounding area in the 1980's. Forestry related activity in the general Brule area is high.

Both oil and gas leases and mining claims are held in the area; there are five leaseholders in the immediate vicinity of the Mine. There are also right-of-way's for pipelines and logging roads.

4.3.2.3 Guiding/Hunting/Trapping

Guide Outfitting Licence 722P999 extents from Highway 97 to the Sukunka River and from the Pine Pass Sukunka headwaters to Chetwynd (i.e. most of Wildlife Management Unit 7022). The licensee is Tracks BC.

Most of the Mine falls within the boundaries of Registered Trap Line 722T003, with a small portion located within the boundary of Registered Trap Line 722T002.

4.3.3 Land Capacity

Land capability was found to be consistent with the land uses described in the 2013 Mine Application. Below are excerpts from that Application. Predicted post-mining land capability was conducted in the 5 Year Mine Plan completed in 2013.

4.3.4 Long-Term Stability

Yearly, a third party engineering firm is contracted to inspect all waste rock dumps and pit slopes, as well as ponds and ditches. These inspections are included as Appendix J.

Throughout the year, mine engineers conduct piezometer monitoring, dump monitoring and pit monitoring as required by the Mine Permit.

One inspection was conducted by Piteau Associates Engineering Ltd. (Piteau) additional information from the Piteau inspections is in Section 4.5.

4.3.5 Re-vegetation Treatments and Fertilizer Applications

The re-establishment of the ecosystems will be supported by the replacement of salvaged soil and coarse woody debris, and the planting of native shrubs and trees. Shrub and tree seeds are collected and shipped to Tipi Mountain Native Plants Ltd. and Twin Sisters Native Plants Nursery for cleaning, stratification, and growth of plugs.

The typical seed application rate is 55 kilogram per hectare (kg/ha), however in areas with harsh site conditions, such as wind-swept slopes, dry sites or for erosion control, the rate may be increased by 10 to 15 kg/ha. A fertilizer formula of 11N:48P:3K is applied at up to 200 kg/ha at time of seeding, as required. Additional remedial fertilizer applications are applied where visually determined to be required. If hand seeding is not appropriate or effective in an area, other remedial activity is employed (e.g. hydroseed, mulching, other). Reclamation at the Mine is conducted in a progressive manner with areas being reclaimed once activities have ceased and no further disturbance is expected; the exception to this would be topsoil stockpiles and regions disturbed from construction activities which are seeded to avoid surface and aeolian erosion.

Reclamation activities will continue to evolve to include the re-sloping of waste dumps and the placement of topsoil on re-contoured waste dumps, decommissioned haul roads, and other inactive disturbed areas, which require a topsoil amendment. Due to the Care and Maintenance state of the mine, no additional vegetation was planted and no fertilizer was used in 2016.

4.3.6 Growth medium

Soil placement occurred on the South East Dump at SP2 in 2017. The soil was place in approximately 50 cm thickness and water divots were created to retard erosion until grass and trees were planted and rooted into the slope.

4.3.7 Landforms

Landscaping was conducted below the office at 15 km on the Blind and on the South East Dump above SP2. Locations and area of this work is included in the spatial data that was submitted to MEM.

4.3.8 Structures and Equipment

The Mine is not at the point of demolishing structures or equipment for closure. This will be carried out according to the Mine Permit and other related regulations and plans, once the Mine enters its Final Closure stage.

Re-sloping of constructed landforms or topsoil replacement occurred at the Mine at 15 km on the Blind and on the South East Dump. As of December 31, 2017, 66.3 ha have been re-sloped and 25.6 ha have been re-vegetated. The 14 ha of dump that was re-sloped above SP2 will be completely re-vegetated in 2018, just native grass seed was applied in 2017. A small area (approximately 0.5 ha) at 15 km on the Blind was also resloped.

4.3.9 Waste Dump Reclamation

Waste dump reclamation has occurred on the Southeast Dump in 2017, this included re-slopping and re-vegetating (grass seed) the area.

Once a dump has reached design or is determined to be no longer active reclamation plans will be activated. In 2018 Conuma will create Dump Plans and a progressive Reclamation Plan.

4.3.10 Open Pit Reclamation

No open pit reclamation has occurred to date; however the Dillon and Blind pits have mostly been infilled with dump material.

4.3.11 Tailings Storage Facility and/or Impoundment Reclamation

There are no tailings storage facilities at Brule.

4.3.12 Road Reclamation

No road reclamation has occurred as all roads are still in use.

4.3.13 Infrastructure Decommissioning/Reclamation

No infrastructure has been decommissioned as mining activities are still in progress.

4.3.14 Secure Openings

All confined space or restricted areas are clearly marked and only authorized personal are to enter the area.

4.3.15 Hazardous Waste Disposal

Brule operates a temporary storage hazardous waste facility onsite, in accordance with the Hazardous Waste Regulations (BCG 77734). Regular inspections of the temporary hazardous waste storage facility ensure proper handling, labeling and storage of hazardous waste and that excess volumes do not accumulate. Used or expired chemicals and reagents are returned to the vendor/manufacturer, where possible. All other hazardous wastes are transported and disposed of in compliance with applicable statutes at a certified facility.

4.3.16 2017 Reclamation Research

To date, ongoing research has been focused on predictive studies for ML/ARD leachate barrels. Research includes the collection of ML/ARD barrel leachate samples. Results for 2017 water quality samples collected from the leachate barrels are in Appendix B.

4.3.16.1 Future Reclamation Programs

Future reclamation activities will adhere to the 5 Year Mine Plan & Effluent Permit Amendment document and the Reclamation Management Plan.

Conuma will approach the reclamation program with the end use land objective in mind of maintaining or improving wildlife habitat. This objective will be met by progressively reclaiming disturbed areas once they are no longer active, minimizing surface erosion and sediment movement, stabilizing slopes, restoring drainage features, creating vegetative cover where practical, and commencing soil rejuvenation and soil building processes.

Conuma commits to minimizing disturbed areas through phased development and progressive reclamation, maximizing backfill opportunities, recovering all soil in upland areas where practical, updating the reclamation plan with a focus on end land use objectives, and implementing a reclamation research program tailored to the Brule Mine environmental conditions.

4.3.16.2 Environmental Effects Monitoring Program

Section 3.3 of PE-17679 requires an EEM Program be conducted every two years. In early 2017 and EEM was conducted. The results are included in the 2017 Annual Water Quality Report – Brule Mine in Appendix H and a summary is included below:

An EEM program was conducted in 2017 by Golder Associates. The purpose of the 2017 EEM program was to provide information regarding the status of benthic biota at established water courses and wetland monitoring stations within the vicinity of the mine site. Monitoring of benthic invertebrate communities at established

monitoring stations on Blind creek, Tributary 3 and the Sukunka River in fall 2017 indicated some evidence of mining-related influences in the receiving environments. Specifically, the benthic invertebrate community sampled downstream of the mine had a lower proportion of mayflies than at upstream reference sites. Mayflies are assumed to be sensitive to contaminants in mine effluent; therefore, a lower proportion of mayflies downstream of the mine may be caused by effluent discharge. Lower proportions of mayflies in downstream Blind Creek and Tributary 3 were also observed in the 2014 EEM study. In the Sukunka River, the mayfly proportion was similar at the upstream and downstream sites, indicating that effluent discharge did not have an effect on the benthic invertebrate community in the Sukunka River.

Other benthic invertebrate community indices did not indicate a difference between upstream and downstream sites. These include total abundance, family level richness, Simpson's diversity index, and the Bray-Curtis Index.

Selenium tissue concentration in periphyton samples was higher at BC-02, downstream of MSP, than at other stations including BC-01a which is downstream of both MSP and SP2 and has a similar Se concentration in water. Se tissue concentration at all other stations was similar to previous surveys, including baseline. It has been suggested that taxonomic differences in the periphyton communities between SP-02 and SP-01a may account for differences in Se bioaccumulation.

Benthic invertebrate Se tissue concentrations were higher at Blind Creek sites downstream of the mine than at upstream sites or in the Sukunka River. The downstream sites showed tissue Se concentrations greater than the interim BC tissue guideline of 4 mg/L. The tissue concentrations were lower than predicted by the bioaccumulation model for Northeast BC.

4.4 *2017 Reclamation Inspection Report*

On May 16, 2017, the Ministry of Energy and Mines conducted a reclamation inspection at the Mine. Two different reports were issued for the inspection: one on May 15 and the other on May 23. The inspection included a review of the following features at the Mine:

- Sediment Pond 2 (SP2)
- Reclaimed East Dump
- Cleared Area Between the South Brule and North Brule Pits
- Bioreactor (BCR) and Main Sediment Pond (MSP)
- South Brule Pit
- ARD Barrels
- North Brule Pit
- Dillon Pit
- Blind Pit

The inspection was completed under the supervision of Conuma's Environmental Manager. The reports compiled by Sonia Meili, Reclamation Inspector, on May 15 and 23, 2017, included four 'Recommendations' for Conuma:

1) *Installation of signage marking soil stockpiles to ensure protection against accidental contamination. In addition, newly established soil stockpiles and soil exposed by recent failure on the Duz Cho Stockpile should be seeded to protect against soil loss. Visual monitoring of all soil stockpiles should occur regularly and actions implemented to prevent soil loss and contamination as soon as possible.*

Soil stock pile signs were placed in Q4 2017. Work will be completed in 2018 to eliminate soil erosion.

2) *Recontouring of dump slopes has created long, smooth surfaces upon which runoff has exploited dozer tracks left from the recountouring work resulting in the formation of rills. MEM recommends Conuma*

consider alternate surface preparation techniques (such as mounting or other techniques or leave the surfaces rough and loose) in future reclamation programs, which will reduce the potential for erosion, increase water-holding, capacity, and create beneficial microclimates for seed germination and seedling establishment.

Divots were placed in the slope, in August, after re-slopping was completed.

3) *In general the ARD field test barrels were in good condition. These tests provide valuable geochemical data and are difficult to replace. MEM recommends that field barrels are regularly inspected and repairs made to maintain the barrels and support structures.*

On September 5, 2017 the ARD stands were moved from above the shop to near the BCR/MSP area. New stands were constructed for greater stability for the barrels.

4) *The monitoring wells located along the SP2 access road were not protected from vehicle collisions or other damage. Some of these wells were located immediately adjacent to, and level with, the access road. MEM recommends protective barriers be installed to prevent loss of these wells due to damage or collisions with vehicles.*

Concrete blocks were placed on either sides of the water wells along the SP2 road in mid-2017.

In addition to the two recommendations, there was one order that was issued to Conuma:

1) *Significant erosion of the resloped Southeast Dump observed during the previous inspection persists. Grass seeding and planting of the surface appears to have been of limited success. Part 10.7.7 of the HSRC requires that all re-vegetated land be re-vegetated to a self-sustaining state using appropriate plant species. In addition, prat 10.7.11 requires that dumps be reclaimed to ensure long-term stability and long-term erosion control. In response to the 2016 Reclamation Inspection, Conuma provided a reclamation plan to address water management issues associated with the Blind creek Road, located above the slope, and to regrade and re-vegetate the area. The work is to be completed in May and June of 2017. Pursuant to the Code references above, MEM requires that the Mine Manager complete the works identified in the Brule Southeast Dump Reclamation Plan submitted April 17, 2017 by September 30, 2017. Following the work, performance of reclaimed slopes shall be inspected and monitored on a regular basis and any required maintenance conducted as soon as possible.*

The re-slopping and grass seeding of the South East Dump was completed in August and September 2017. Additional planting of trees will be completed in 2018.

4.5 *Geotechnical Stability*

Annual safety inspections are conducted on waste rock dumps and sediment ponds. Brule Mine retains Norwest Corporation as well as Piteau Associates to provide geotechnical stability services advising the management of Brule Mine waste dumps and pit slopes and to complete annual inspections. The inspection of the water control structures and high walls was performed by Piteau Associates for 2017.

Piteau conducted one inspection in 2017. The September inspection was for the sediment ponds. The reports received to date outlining the findings of these inspections are included in the Appendix J.

Third party geotechnical inspections of both sediment ponds and ancillary works were completed by Piteau in 2017. At MSP, many of the recommendations and comments made during the inspection were addressed. However, it was also recommended that the datum for pond elevation readings be re-established, so that the pond water level can be determined at the same time as the piezometers are read. At SP2, it was recommended that the accumulation of sediment in the South Ditch and inlet to the pond be removed periodically to maintain flow capacity. With regards to the geotechnical data that are collected by the Engineering Department, it was recommended that the SP-2 piezometric data be reported as elevation heads so that it can be related to pond elevation. It was also recommended that the recent heads in the piezometer next be checked against the assumptions in the original design analyses to confirm that they are within the design thresholds (Piteau 2017).

5.0 Interpretation

5.1 *QA/QC Summary*

The QA/QC protocols were adequate in 2017.

5.2 *Environmental Protection Program*

EMSs are in place at the Mine. In 2018, reclamation will be conducted on the Southeast Dump to finish remediating the erosion rills and re-vegetation the area.

Air Quality and Water Quality Programs were conducted in 2017 at the Mine, per the Terms and Conditions of PA-17680 and PE-17679, respectively. Both reports detailing the programs results are included as Appendices G and H.

5.3 *ML/ARD Monitoring*

In 2017, samples were collected from LSFW, LWSMFW, 1B60U and 1BLU in May, June, July, September and October; samples were collected from 0B60 in May, June, July and September; and samples were collected from Surface Dirt & Till in May, June, September and October. The results of this ARD monitoring are in Appendix B.

In general, the concentration of the metals decreased between 2015 and 2017.

5.4 *Seep and Pit Lake Monitoring*

In 2017, water samples were collected and analyzed from all of the known seeps and pit lakes at the Mine that had water, which resulted in thirteen seeps and four pit lakes. The water samples were collected in February, April, June, September and October; and South Brule was also sampled in August.

SP2-East Sub Seep1.5, SP2-East Sub Seep2.5, SP2-East Sub Seep3 and SP2-East Sub Seep were sampled once; East Dump Seep, SP2-East Sub Seep1,SP2-East Sub Seep 2 and SP2-Middle West Seep were sampled twice; SP2 South Seep, North Dump Seep 1 (BCR-IN Lower), North Dump Seep 2 (BCR-IN Upper) and SP2 Middle Seep were sampled three times. Due to low flow and significant snow and ice cover at the toe of the dumps it was not feasible to collect a water quality sample in the first quarter and fourth quarter of 2017.

The results of the water quality samples indicate that there was a significant change in water quality in SP2 South in 2016, compared to 2015. Due to the lack of historical data, the changes in water quality in the seeps and pit lakes in 2017 is difficult to interpret. Additional monitoring data will be required to develop a baseline for the seeps and pits lakes and to derive annual fluctuations.

5.5 *Selenium Speciation Monitoring*

Selenium speciation monitoring was conducted at 11 sites in 2017. The results indicate that Se(VI) continues to be the prominent form of selenium present at all sample sites. Although, the total selenium (and therefore selenium species) are shown to be higher in the ponds (MSP and SP2) than previously years, except 2016, this can be attributed to the amount of dilution at the time of sampling. The concentration of selenium in the receiving environments (BC-01a) is significantly less than that in the SP2-D and North Dump Seep 2 (BCR-In Upper) but it is about the same concentration as MSP-D and North Dump Seep 1 (BCR-In Lower). The lowest concentration of total selenium measured in 2017 was in the North Brule Pit Lake. The highest concentration of total selenium measured in 2017 was in SP2 East Seep.

5.6 *Reclamation Program*

There have been no changes to the reclamation program since 2015; however, Conuma anticipates completing a comprehensive Reclamation Program, Dump Plan and commencing large scale reclamation projects in summer 2018.

5.7 *Reclamation Inspection Report*

As recommended in the reclamation inspection report from MEM, Conuma will focus on re-vegetation success and remediation of the Southeast Dump.

5.8 *Reclamation Liability Cost Estimate*

The Reclamation Liability Estimate prepared as part of the previous 5-Year Mine Plan (2013), by Stantec, has been included in a separate report. The Reclamation Liability Estimate will be updated in 2018 as part of the upcoming 5-Year Mine Plan.

6.0 Conclusion

The 2017 Annual Reclamation Report presents observations, results and interpretations from the 2017 Reclamation and Environmental Program for the Brule Mine. Conuma Coal Resources Limited was able to compare results obtained during previous years, including baseline monitoring, and observe trends that are present as a result of Mine activities.

Leachate barrels were monitored throughout the frost-free season in 2017. These test barrels will continue to be monitored throughout 2018 to better predict future trends in waste rock dumps.

All known seeps and sumps were monitored quarterly in 2017. These features will continue to be monitored throughout 2018, to better understand the quality of water that has travelled through the dump and into the natural environment.

Approximately 85,000 cubic meters of soil was salvaged and stockpiled on the 1160 dump for future reclamation. Trees harvested for pre pit stripping were also salvaged and stockpile don the 1160 dump. The reclamation on the South East Dump slop will be completed in 2018, along with additional reclamation above the Blind Creek road on the South East Dump.

The 2018 Reclamation and Environmental Program will be conducted per the Terms and Conditions of Mine Permit C-221.

7.0 Recommendations

In order to maintain water protective quality conditions in Blind Creek, active management measures will likely be required in the short term. Specifically, shorter-term contingency measures may be required until such time as other long-term mitigation measures become available, such as saturated fills as bioreactors, or effective use of biochemical reactors (BCRs). Optimizing the existent BCR performance and implementation of additional saturated backfill are among the passive treatment enhancements planned for 2018.

8.0 Signature Page

Written By:

Brenna Fossum, B.Sc., G.I.T. (AB, BC)
Environmental Manager

This document entitled **2017 Annual Reclamation Report – Brule Mine** was review by Golder Associates Ltd. ("Golder") Qualified Professionals, for the account of Conuma Coal Resources Limited (Conuma) (the "Client").

The final version of the Report was reviewed in accordance to permit C-221 requirements

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Alisha Hiyate

Brumadinho failure reverberates across the industry

In fall 2017, a report on mining tailings facilities by the United Nations and sustainability group GRID-Arendal counted 341 people that had been killed since 2008 by tailings dam failures.

On Jan. 25 this year, a tailings dam at Vale's Feijao mine, near Brumadinho, in Minas Gerais state, Brazil, gave way. The one incident nearly doubled the death count from the tailings report, killing more than 300. (Only 206 deaths have been confirmed to date, but another 102 people are still missing.)

Less than a month after the breach, the Brazilian government announced a ban on tailings dams constructed with the "upstream" method. Both the Brumadinho failure and the 2015 Fundao failure in Brazil involved upstream dams, which are considered less stable than other types of dams.

Following the Fundao failure, Vale had committed to decommissioning all 19 of its upstream tailings dams in Brazil – all of which were inactive. Nine had been decommissioned when the Brumadinho failure took place.

Four days after the Brumadinho disaster, Vale announced it would be speeding up the decommissioning of its 10 remaining upstream tailings dams over the next three years at a cost of $1.8 billion. The company will need to temporarily halt production at the operations where the dams are located, affecting up to 40 million tons of iron ore per year.

While there have been reports that Vale had been aware of a greater than acceptable risk of collapse at Brumadinho, the company has denied that there was any warning of an imminent risk of failure.

Beyond Brazil, the global mining industry's reaction to the tragedy has been swift.

Shock at the devastation and loss of life, and the fact that it followed so closely after Fundao (2015) and Mount Polley (2014), has propelled industry associations, professionals and mining companies to come together to formulate a solution.

The International Council on Mining and Metals (ICMM) has convened an independent review aimed at creating a set of international standards by the end of this year (see Page 20).

The standards will include a consequence-based tailings facility classification system with requirements for each level of classification; a system for credible, independent reviews of tailings facilities; and requirements for emergency planning and preparedness.

The idea is to have a consistent system that will be applied by ICMM members wherever they have operations, irrespective of the national requirements.

It is an encouraging first step to addressing an urgent problem that lies at the heart of the industry's ability to earn a social licence, attract younger workers, and of course, its financial viability. **CMJ**

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225 Duncan Mill Rd. Suite 320,
Toronto, Ontario M3B 3K9
Tel. (416) 510-6789 Fax (416) 510-5138
www.canadianminingjournal.com

Editor-in-Chief
Alisha Hiyate
416-510-6742 ahiyate@canadianminingjournal.com
Twitter: @Cdn_Mining_Jrnl

News Editor
Marilyn Scales
mscales@canadianminingjournal.com

Production Manager
Jessica Jubb
jjubb@glacierbizinfo.com

Art Director
Barbara Burrows

Advisory Board
David Brown (Golder Associates)
Michael Fox (Indigenous Community Engagement)
Scott Hayne (Redpath Canada)
Anthony Moreau (Iamgold)
Gary Poxleitner (SRK)

Manager of Product Distribution
Jackie Dupuis
403-209-3507 jdupuis@jwnenergy.com

Publisher & Sales
Robert Seagraves
416-510-6891 rseagraves@canadianminingjournal.com

Sales, Western Canada
George Agelopoulos
416-510-5104 gagelopoulos@northernminer.com

Toll Free Canada & U.S.A.:
1-888-502-3456 ext 2 or 43734

Circulation Toll Free Canada & U.S.A.:
1-800-387-2446 ext 3505

Group Publisher
Anthony Vaccaro

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Tap into the next great resource

By Jeff Swinoga

Mining and metals organizations have taken a reactive approach to managing workforces in the past, hiring when prices rise and shedding excess resources when they fall. Not only is this costly, but it also pushes invaluable knowledge and experience to other sectors, limiting the desired talent available in times of upswing.

Technological advances are also minimizing the pool of available talent. The demand for workers who can master a different set of skills – such as data science, analytics and predictive modelling – is heating up. The challenge is that miners aren't the only ones seeking these skills. People with these capabilities are being sought after worldwide, forcing mining companies to compete with other sectors – not just in Canada, but across the globe.

On top of all this, the mining and metals sector faces ongoing reputational risks. Health and safety issues are of mounting concern both for those considering joining the sector and for those already in it. This was evident at the BMO Global Mining & Metals conference, which highlighted a number of concerns following recent devastating tailing accidents. These events have created an urgent need for improved monitoring capabilities and global safety standards.

The reality is that the majority of the individuals who possess the skills needed for a digital mine are millennials. Younger talent who tend to be more belief-driven consumers who want to buy and work for companies with sophisticated safety and environmental standards, and share a defined moral purpose. Unfortunately, mining companies aren't always perceived to meet these standards.

Miners are stuck. Following low metal prices in 2018, the sector is starting to bounce back and companies will be looking to opportunistically grow their workforce. But companies will struggle to find workers who have the traditional, hands-on experience, with the right skill sets needed to succeed in a rapidly evolving industry. The sector needs an agile, resilient and affordable workforce that can thrive in an environment of both ongoing metal price volatility and digital disruption.

So where do we go from here?

Companies need to stop and think about the future and how to create a workforce strategy that will allow the organization to attract the required capabilities that are needed to grow, while arming the existing workforce with new technological skills. It's time for mining companies to assess the short, medium and long-term requirements for success and invest accordingly. Here are four key considerations:

- **Reskill through education and training.** Don't overlook the talent you have right now. As technology evolves the workforce, companies will need to reskill workers to reduce redundant or changing tasks in the future. This will help balance workforce supply and demand by attracting top talent, while retaining aging employees.

- **Challenge conventional resourcing and development strategies.** Look beyond the mining and metals sector to find new talent. For instance, it may be easier to source planning capabilities from a manufacturing or analytics background.

- **Build a purpose.** Develop a positive narrative by actively communicating your company's values, mission and purpose. This will help build the credibility the sector needs to attract younger, socially-conscious talent.

- **Enhance workplace conditions.** Use technology to build a safer, more flexible workplace for employees. For example, technologies like cloud computing, information sharing and big data are allowing more operations to be performed remotely, so that employees can be removed from hazardous on-site events.

The relationship between people, work and organizations is rapidly evolving in this digital age, and those who want to be prepared to meet future disruption need to realize that talent is their greatest resource. By developing a strategic workforce strategy, mining companies will be better positioned to forecast future supply and demand, and guide how they will attract and grow required capabilities, while reskilling the existing workforce with new skill sets. **CMJ**

JEFF SWINOGA is the EY Canada Mining & Metals Leader. He is based in Toronto. For more information, visit www.ey.com/ca/mining-metals.

A watershed approach means we have to do things differently

By Carolyn Burns & Jane Church

Water is a basic human right. It is central to community wellbeing. Water supports life and good health. It also supports our ecosystems and is often central to a community's livelihood. Water can play an important role in social and spiritual connections for communities. However, the International Council for Mining and Metals (ICMM) highlights that the global demand for water will exceed supply by 40% by 2030. Already as many as 660 million people globally are without access to an improved water source.

Water is also central to the mining process. During the exploration phase water can be diverted to allow for drilling. In construction, an area can be 'dewatered' as the mine is developed. In the operations phase, water is often used in the recovery process, and then treated and discharged into the environment based on legislative and company requirements. Water can also be used in cooling systems and dust suppression.

A recent report by the International Finance Corporation found that almost 70% of the mining operations from six of the largest global mining companies are located in water-stressed countries. When mining activity takes place in water stressed areas it can become a lightening rod for concern, distrust, and in the worst case, conflict. To demonstrate just how big of an issue water is to external stakeholders, water-related issues made up almost 60% of mining cases lodged with the IFC's Compliance Officer Ombudsman between 2000 and 2017. Several international organizations such as the 2030 Water Resource Group have identified improved water stewardship as central to a responsible mining industry and achieving the Sustainable Development Goals (SDGs).

Taking water impacts seriously requires us to take a watershed approach to understanding and mitigating those impacts.

A watershed approach (also referred to as a catchment-based approach) looks at the basic hydrology and biodiversity of a watershed as well as all the activities and impacts in the watershed, including mining, other industries, and social and cultural activities. Taking a watershed approach can have many benefits. It allows for a better understanding of short and long-term impacts, provides clarity on the drivers of water impacts, and can encourage more accountability from all stakeholders. A watershed approach can also highlight opportunities to improve and leverage current water infrastructure to improve water access and quality for all stakeholder groups, including industry. Lastly, a watershed approach can support climate smart mining activities that can contribute to meeting global climate goals.

The challenge with taking a watershed approach is that all water users must be jointly accountable for cumulative water impacts.

The CEO Water Mandate, the Alliance for Water Stewardship, and non-governmental organizations such as the World Wildlife Fund (WWF), are promoting a watershed approach and collective action on water. This is reinforced in a 2018 paper, Water Stewardship: Attributes of Collaborative Partnerships between Mining Companies and Communities, Jocelyn Fraser and Nadja C. Kunz highlight that these groups advocate for context-based water targets that are based on science, the basin's environmental, economic, and social needs and supports collective objectives like the SDGs.

Leaders in the mining industry are also broadly supporting a watershed approach, and this is illustrated in several voluntary standards. The Mining Association of Canada recently added the Water Stewardship Protocol to the Towards Sustainable Mining (TSM) initiative, which will be phased in and reported on by 2021. The ICMM's Water Stewardship Framework, also takes a catchment-based approach of proactive and inclusive engagement between users, transparent reporting, and innovative ways to improve efficiency and multi-stakeholder collaboration.

But, to be effective, a watershed approach requires stakeholders to do things differently.

It requires a diverse understanding about how water is valued and used. We must be open to appreciating and valuing the different meanings and uses for water and the worldviews that shape it. Because communities can be the broadest users of water (for health, livelihoods, and social and spiritual reasons) they must be at the centre of these discussions. Companies should learn about and align with local culture, history, community dynamics, and decision-making processes related to water. Communities should learn about how the industry uses water, how decisions related to water are made, and what the company's priorities and interests are.

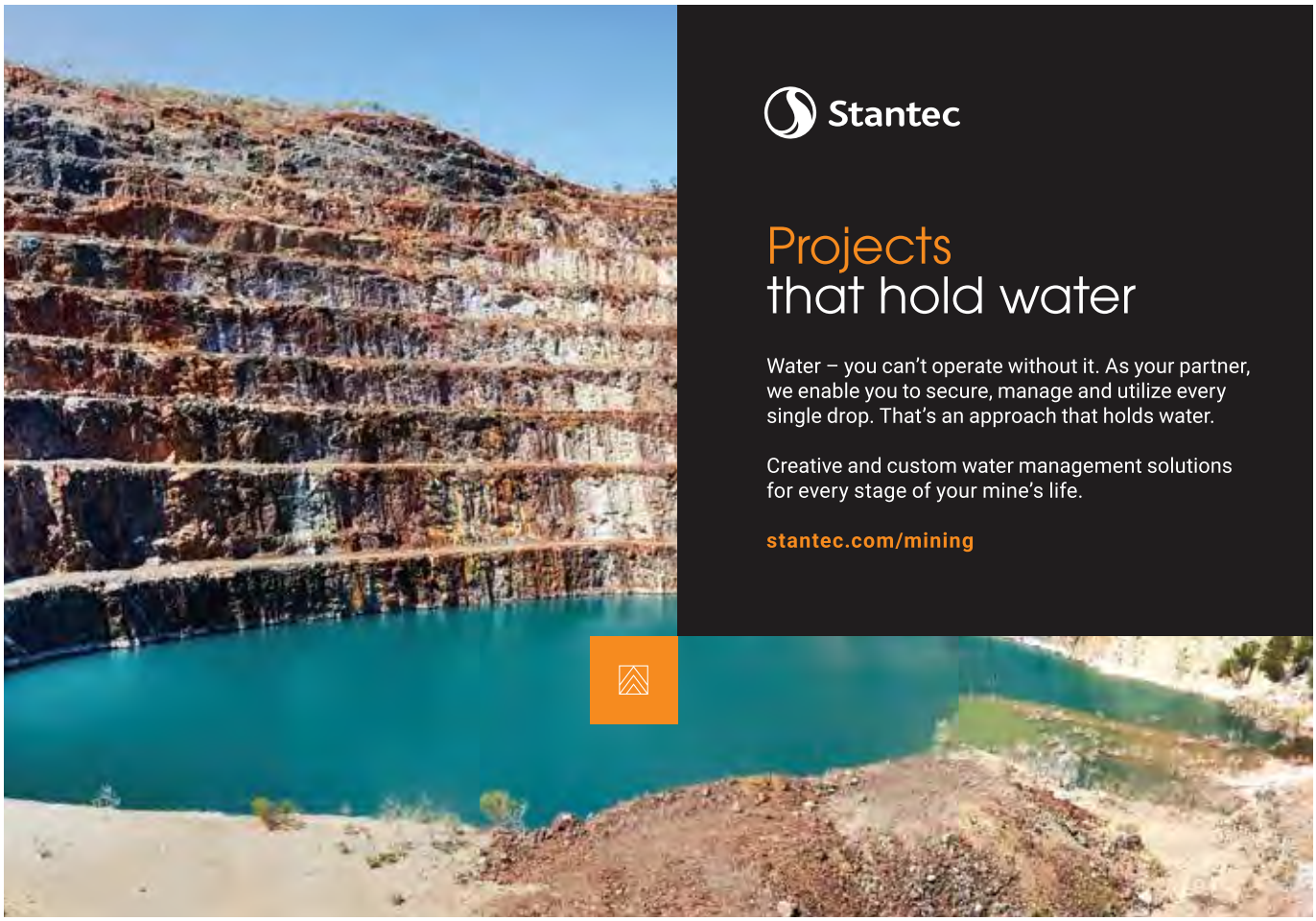
It requires us to share control, to work in partnership. True partnership means that stakeholders must be willing to change their behaviour, to give something up in the pursuit of broader goals, and

to challenge the status quo or current dynamics. It also means that community perspectives and knowledge related to water are included in permitting and approval processes, site design, and environmental and social assessments, and that they can influence decision-making. Governments and government agencies can provide a platform for these discussions and can support specific programming that meets the needs of all stakeholders in a specific watershed. Participatory monitoring programs can be a good example of partnership, if the processes are transparent and information is used to address concerns.

The challenge with taking a watershed approach Is that all water users must be jointly accountable for cumulative water impacts. This has historically been difficult for industry, which has largely focused on site-based impact management which can be largely controlled by one company. There is also often an imbalance of power between water users, which makes accountability and discussion challenging. Building relationships and the trust required to effectively collaborate on water management are important in an effective watershed approach.

It requires us to alter and adapt water management systems based on a shared understanding of the value and uses of water. Companies must also be open to adapting and testing new methods to use and treat water in the mining process. We must collectively share resources and data about water quality and quantity at a watershed level. We must collectively make and monitor commitments about water use, through collective planning Some regions are building this type of partnership watershed approach, such as the Northwest Territories, where regulatory boards, agencies, environmental organizations, the extractive industry, and the public came together to develop a strategy and action plan for addressing water risks from development. **CMJ**

CAROLYN BURNS is director of operations at NetPositive, a non-profit that works with diverse stakeholders to help local communities see sustained positive outcomes from mining. **JANE CHURCH** is a co-founder and director of collaboration with NetPositive.



• TRUCKS | Cat 797F meets Tier 4 Final configuration

Caterpillar's Cat 797F large mining truck is now available in a fuel efficient configuration that meets U.S. EPA Tier 4 Final emissions standards. Through more than 16,000 hours of successful pilot machine operation and 100,000 hours of production truck operation in Tier 4 configuration, the system has proven its ability to deliver strong performance and greater fuel efficiency compared to the Tier 2 797F in most applications.

The 797F Tier 4 Final is equipped with an exhaust after treatment system featuring selective catalytic reduction (SCR), which uses diesel exhaust fluid (DEF) to lower NOx emissions. This Cat emissions platform is proven through more than 20 million operating hours in the field. To maintain superior reliability, the 797F after treatment system uses less than 11% new content. Designed for easy serviceability with readily accessible components, the modular after treatment system is aligned with truck preventive maintenance intervals to maintain high availability.

The new Cat 797F Tier 4 truck. CREDIT: CATERPILLAR

The best-selling truck in the 363-tonne size class, the 797F is powered by the 2,983-kW Cat C175-20 engine, available with optimized fuel maps for customers focused on the lowest fuel burn, Tier 2 equivalent rating, and now Tier 4 Final. Known for delivering class-leading payload and speed-on-grade performance, the 797F delivers the same production performance in Tier 2 and Tier 4 Final configurations.

In addition, the Tier 4 Final 797F reduces total specific fluid consumption costs (fuel plus DEF) in most applications. Lower fuel burn results in longer engine life and lower repair costs.

Field evaluations of the low emissions 797F included a wide range of applications, including oil sands, deep pit copper, iron ore and coal. The trucks exceeded production targets and demonstrated strong engine performance in all applications. **CMJ**

• GRINDING | Eriez releases white paper on trunnion magnets

Eriez has released a new white paper on trunnion magnet technology. According to the paper, performance metrics collected through studies conducted among installations of Eriez Trunnion Magnets worldwide indicate a six-month to one-year payback when compared to trommel screen installations.

Written by Eriez director of mining and minerals processing Jose Marin, the paper explains how trunnion magnets function, highlights their performance advantages, describes retrofitting options, and provides detailed economic justification, including guidelines to assess savings potential.

A graph illustrates how kilowatt usage can be reduced by as much as 750 kW/day or 8%. According to the white paper, cost estimates of a typical 5.5-metre diameter mill indicate savings of up to US$100,000 per year.

There are hundreds of installations of Eriez trunnion magnets worldwide. This system for separating and removing balls, chips or scats in a typical ball/SAG mill operation replaces the dead weight of ball magnets with fresh ore. By effectively removing 80% or more of the worn or broken media, the trunnion magnet reduces power consumption from the mill drive and prevents expensive damage to other equipment, such as pumps and hydrocyclones.

An Eriez trunnion magnet. CREDIT: ERIEZ

To download the paper, Trunnion magnet technology delivers quick payback, visit http://EriezNews.com/nr475. **CMJ**

Inmarsat and Knight Piesold to deliver real-time, tailings dam monitoring

Inmarsat, the world leader in global mobile satellite communications, has joined forces with Knight Piesold UK to deliver highly accurate tailings dam monitoring, analysis and real-time management capabilities for the mining industry.

The collaboration agreement with Knight Piesold UK, a member of the international geotechnical, tailings management and engineering consulting group, will combine its industry leading consultancy with Inmarsat's satellite-enabled IoT solution. This will enable smarter decision making, improved safety standards and support regulatory compliance, offering a new approach to the way tailings dams are currently audited and managed.

Mine tailing audits are typically carried out at infrequent intervals, with employees and third-party consultants making long distance trips to collect data and audit the status of the dam. The solution makes data available between site visits to any accredited users, anywhere in the world. This means that current, on-site auditing practices can now be supplemented with a remote, customizable, daily management cycle, with auditor recommendations and real-time decision making now available to on-site engineers.

Inmarsat's solution collects data from a range of industry standard sensors via edge connectivity such as LoRaWAN (Long Range Wide Area Network), before it is transferred across Inmarsat's L-band satellite network to a single cloud dashboard. This enables mining companies and national regulators to gain a comprehensive view of the status of their dams with granular metrics such as pond elevation, piezometric pressures, inclinometer readings and weather conditions displayed in one place, no matter where the mine is located. The solution is also highly versatile and features sensor-agnostic capabilities.

Working with Inmarsat means mining companies only need one technology partner to manage all of their remote tailings requirements, anywhere in the world. The solution will be available to all of Knight Piesold's clients immediately.

Richard Elmer, regional manager for Knight Piesold UK, said: "Our collaboration with Inmarsat provides our clients access to the latest and best available technology for real-time data collection and analysis. We see this as a game changing improvement in how companies monitor their current tailings storage facilities."

Paul Gudonis, president of Inmarsat Enterprise, said: "We have been working with Knight Piesold's UK practice since 2017 to develop an approach to tailings dam monitoring that supports smarter, safer and more regulated mining practices. Following successful trials, we are pleased to be able to bring what we believe to be a truly disruptive solution to market." **CMJ**

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The mining industry propelled by hydrogen: a clean future is near

By Robert Mason and Alison Babbitt

Climate change and environmental sustainability have increasingly become issues of social concern, and many industries have been looking for opportunities to reduce their carbon footprint.

One such opportunity may be the use of hydrogen technologies, which many believe can play a crucial role in the global energy market's transition to a low-carbon economy.

Current hydrogen technologies could be employed to improve environmental sustainability at a mine site. Here's how:

Energy production and storage

Hydrogen technologies can offer a high percentage of conversion efficiencies, meaning significant savings in electricity costs and decreased CO_2 emissions due to reduced reliance on diesel.

Once aspirational, conversion efficiencies will continue to increase as this industry grows and R&D continues. In addition to improving site efficiency and reliability, the storage system can help to balance seasonal variations, save costs by deploying energy during peak hours and provide a secondary commodity that may be sold, including during a temporary mine closure or at the end of mine life.

Fuel cell electric vehicles

Another opportunity to implement hydrogen at a mining site is by replacing heavy-haul diesel or gasoline trucks with fuel cell electric vehicles that run on hydrogen gas. Recent larger hydrogen applications in heavy machinery by companies such as Alstom and Nikola Corp. demonstrate the industry's progression towards developing FCEVs in heavy-duty trucks that have the potential to yield horsepower. Hydrogen-powered mining equipment and vehicles are currently used by various mines in North America, and their use will increase as the technology is refined. With the global Hydrogen Council recently projecting that hydrogen is expected to contribute to 20% of carbon emissions reduction targets by 2050, using such FCEVs on a large mining site could go a long way in implementing and meeting the sustainability goals of such projects.

Hydrogen implementation challenges

Hydrogen's large-scale implementation faces roadblocks in terms of cost competitiveness and accessibility.

Technologies can only prove to be successful if they are implemented. Mine operators are experienced and comfortable in meeting financial and operational goals with current tools and technologies.

Without a solid and convincing business case for hydrogen, and the knowledge and impetus to consider a change, operators may have serious reservations about changing their working approach. At ground level, and particularly for the more junior operations, implementing hydrogen FCEVs and hydrogen power generation and storage would likely interrupt daily operations and require significant initial investment that might not yield the desired returns in the short term.

The most significant challenge to implementation at present seems to be the lack of cost-competitiveness in hydrogen technologies. However, it may be that with more R&D, hydrogen technologies could become more accessible and affordable.

Sustainable financing

Sustainability-linked loans allow borrowers to reduce their interest rates over time after achieving various environmental milestones. Mine projects are under increasing pressure from equity investors and debt providers to meet robust environmental, social and governance standards.

Could mine developers be incentivized by their lenders to employ hydrogen technologies to help achieve certain specified sustainability standards, which in turn could result in meaningful reductions in the cost of borrowing? Could mining companies employ such sustainable financing to offset the onerous initial investments necessary to implement hydrogen technologies on site? In this respect, sustainable milestones could include target ratios of FCEVs used on site relative to those using diesel or gasoline engines, as well as targets for reductions in the site's overall carbon emissions.

As Canada's interest in hydrogen technologies grows, those involved in the mining industry may benefit through awareness of hydrogen's potential to achieve these sustainability goals. Knowledge of sustainable finance options will likely become progressively relevant to lawyers active in the industry as mines increasingly face pressure to reduce their environmental footprint or risk losing their social licence to operate. Legal professionals should harness this opportunity to suggest innovative solutions to mitigate these challenges of integration, including sustainable financing and lending. **CMJ**

ROBERT MASON is a partner at Norton Rose Fulbright and **ALISON BABBITT** is of counsel.
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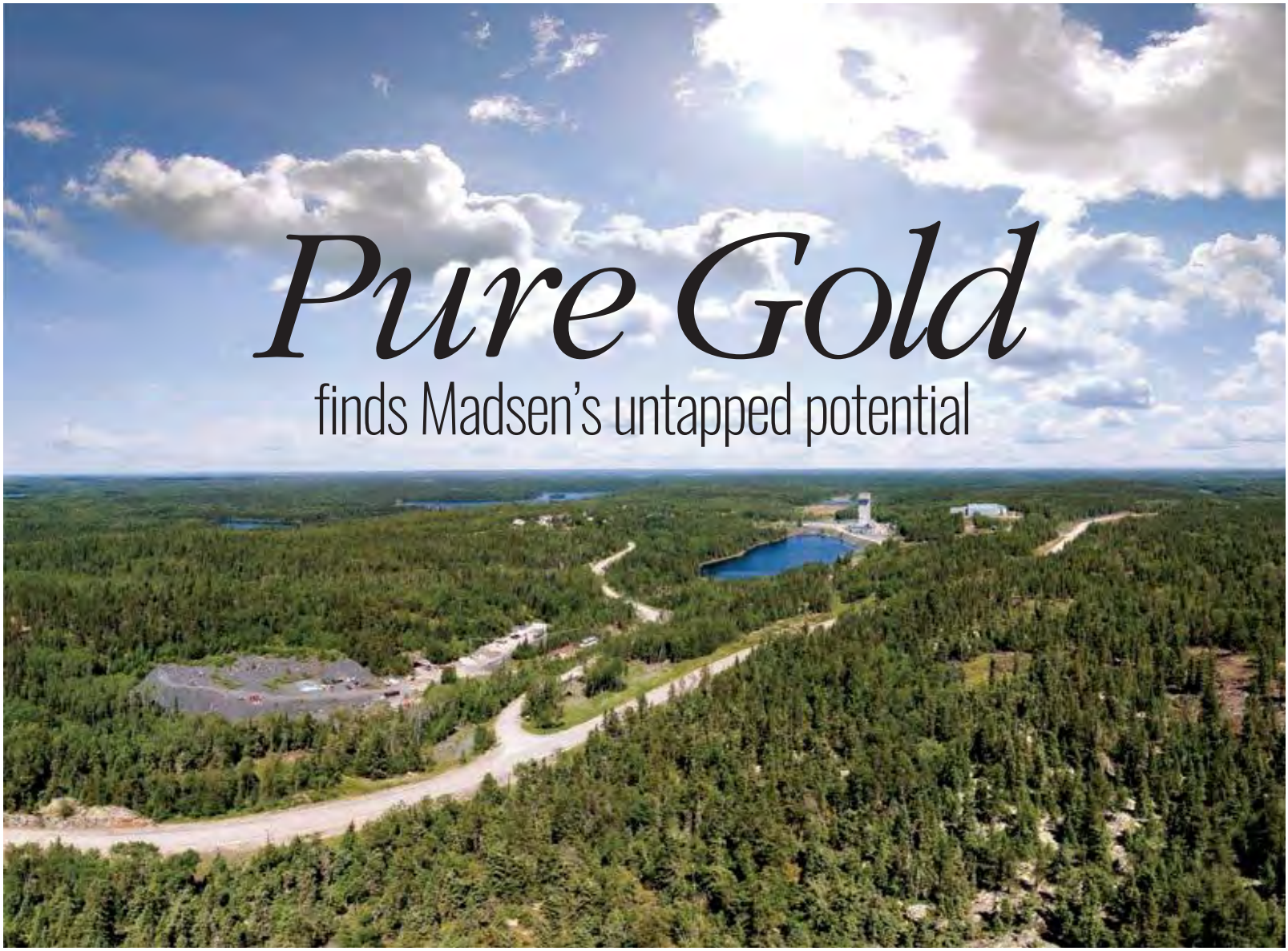

Pure Gold

finds Madsen's untapped potential

Twin studies outline 'starter mine' plus blueprint for expansion

By Alisha Hiyate

It's still lean times for junior miners looking for funding to build the next mine, but since it released its first preliminary economic assessment (PEA) for its Madsen project three years ago, Pure Gold Mining has been putting together a compelling portrait of a low-cost, scalable, and near-term mine.

The latest pieces of the picture come from complementary economic studies released early this year.

Pure Gold Mining's Madsen property in Red Lake, Ont.
CREDIT: PURE GOLD MINING

A February feasibility study outlined a capex of $95-million for the past-producing underground project, in Red Lake, Ont., with a 12-year mine life and average production of 80,000 oz. per year.

"At $95 million it is one of the most capital efficient projects out there," says president and CEO Darin Labrenz. "It's a significant amount of money, but from a mining perspective it's pretty small relative to our peers."

The low capex does seem to be tailored to today's tough mining capital market. But the most compelling aspect of the project is the potential that the feasibility is just the beginning of something bigger.

Shortly after it released the study, Pure Gold also released an initial PEA for several satellite deposits near Madsen that, together, could add 3.7 years of mine life and total production of 210,000 oz. gold.

Labrenz says the studies show the phased development plan that Pure Gold has put together: the feasibility outlines a "starter mine" at Madsen with a robust mine plan and lowest in class capital, and the PEA lays out a blueprint for expansion.

"The PEA is really meant to show the potential for not only a mine life extension, but an opportunity for us to start

CONTINUED ON PAGE 12

Hauling ore to surface during last year's test mining program at Madsen. CREDIT: PURE GOLD MINING

looking at ways to impact the production profile moving forward," he says.

Madsen history

Being located in the prolific and high-grade Red Lake gold camp, it's perhaps not surprising that Madsen was a profitable, operating mine for 36 consecutive years.

Between 1938 and 1976, it produced 2.5 million oz. of gold at an average grade of 9.9 g/t gold. It was mined down to 1,200 metres, but without much systematic exploration, the miners ended up chasing the orebody far from the shaft, with mining of the Austen zone ending up about 2.5 km away from the headframe.

Junior Claude Resources put the mine back into production briefly in the late 1990s. A combination of low gold prices, high mining costs (its contract miners were paid by the tonne), and a lack of exploration led them to put it on care and maintenance in 1999.

Pure Gold's approach, since acquiring the property in 2014, has been more methodical, prioritizing exploration and a solid geological understanding of Madsen above a quick push to production. The first thing the team did was to digitize all existing data for Madsen, including underground mapping, mined stope shape and drill hole data.

"All those records were in paper format so there wasn't a really strong understanding of the deposit itself," Labrenz says.

That data, combined with over 200,000 metres of drilling that Pure Gold has conducted over the past three years, have yielded insights about the geology and Madsen's potential. Previously, Madsen was seen as a stratabound, disseminated replacement style deposit, different from the other Red Lake deposits, which are structurally controlled.

"Our work demonstrated that it is a structurally controlled deposit, exactly the same as every other deposit, and once you recognize that structural control it allowed us to step out and test it," Labrenz says.

That understanding allowed Pure Gold to grow resources at Madsen and led to the discovery of the Wedge deposit, 3 km south of Madsen, in early 2018. In a very short period of time, the company has been able to compile a resource at Wedge and bring it into the recent PEA.

Results from a test mining program at Madsen last year have backed up Pure Gold's geological model. More than 7,000 tonnes of material were collected and stockpiled and 1,555 muck samples were assayed. Two stopes were developed, based on stope shapes from a previous PEA.

"When we reconciled those two stopes back to the resource model we were within 1% on tonne, and our grade was 15% higher so we overachieved by 14%," Labrenz says, adding the grade was 10.9 g/t. "The test mining was done with fantastic ground conditions, very little dilution, and an average mining width of 5.3 metres and so we were quite pleased with the results of the test mining and the reconciliation we saw."

The company plans to use a mixture of conventional cut and fill (59%), mechanized cut and fill (16%), and longhole mining (25%) methods.

High-grade ore from test mining stored underground. CREDIT: PURE GOLD

Study details

The economics of the project are strong. At a base case of US$1,275 per oz., the study projected an after-tax NPV of $247 million (using a 5% discount rate) and an internal rate of return (IRR) of 36%. Total cash costs are expected to be US$607 per oz. gold with an AISC of US$787 per oz.

Probable reserves contained in the Austin, 8 zone, South Austin, McVeigh and A3 zones at Madsen total 3.5 million tonnes grading 9 g/t for 1 million oz. gold.

(Indicated resources at Madsen are 7.2 million tonnes grading 8.9 g/t gold for 2.1 million oz.; inferred resources are1.9 million tonnes grading 7.7 g/t gold for 467,000 oz.)

The feasibility study projects Madsen could be up and running in a short 13 months, once a production decision is made. With the wealth of existing infrastructure, the major costs would be an expansion of the mill to 800 t/d from 550 (including a new ball mill and the installation of a gravity circuit to take advantage of the simple metallurgy of the ore), and a new water treatment plant.

The water treatment plant is needed based on changes in regulations since Madsen was last permitted in the 1990s and on new water quality information collected as part of the feasibility study.

While the capex is significantly higher than the $51 million that was projected in a PEA released in September 2017, the higher capex has to do with an increase in tonnage to 800 t/d from 600 t/d (the current plant can handle more than the

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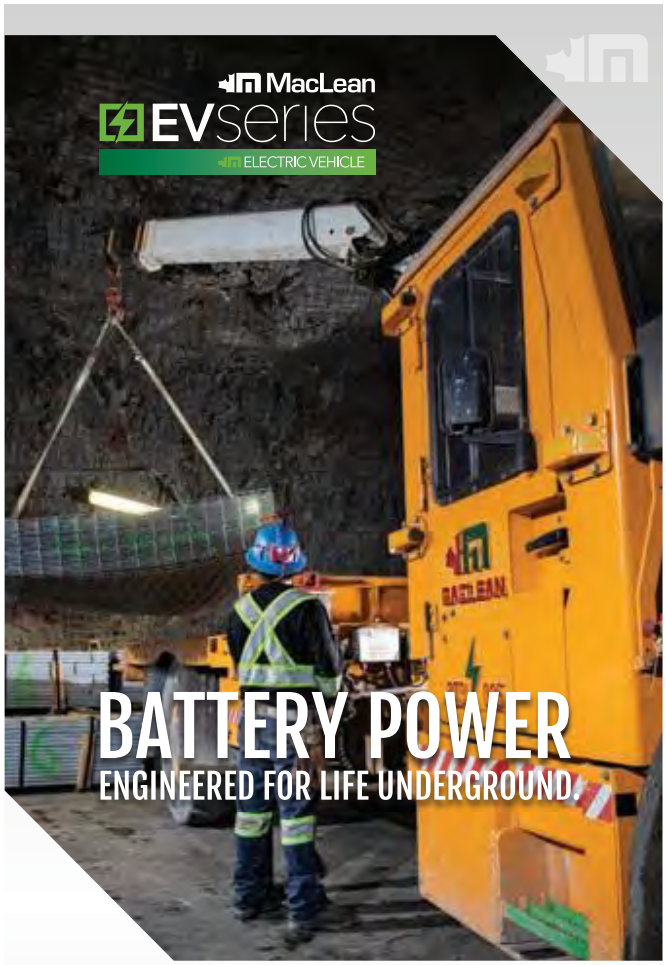

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Scenes from last year's test mining program at Madsen.
CREDIT: PURE GOLD MINING

550 t/d it was designed for), as well as a move to owner operated mining from contract mining (which will make more equipment purchases necessary).

A third change is that the company will now put in a new hoist in order to use the 1,275-metre existing shaft to move ore and waste rather than the ramp starting in the third year of operations.

"Battery technology today wouldn't allow us to move from the deep parts of the mine to surface, so it didn't make sense in the PEA," Labrenz says. "But with the hoist being introduced and the shaft being used, it allows us to use all battery operated equipment and thus reduce that footprint and ventilation requirement."

Madsen is still permitted as a mine, though some permits need to be amended.

"There's no expectation of environmental assessment, it's a brownfield site and it's permitted," Labrenz said. "The feasibility plan uses the same tailings footprint, the plant throughput is lower than the 1,089 tonnes per day in the current (mill) permit, so we don't see any triggers on the EA side. This is strictly a regulatory process."

As for the satellite deposits, Wedge, Russet South and Fork, the recent PEA looked at developing them as a mine life extension to Madsen. The study projected that mining the deposits would cost $57 million and yield an after-tax IRR of 39% using existing infrastructure.

The deposits host combined indicated resources of 7.2 million indicated tonnes grading 8.9 g/t gold for 2 million oz. and 1.9 million inferred tonnes grading 7.7 g/t for 467,000 oz.

Next steps

Now that the feasibility and PEA studies are completed, Pure Gold is focused on two things: getting the cash to build Madsen, and continuing to grow the project through further exploration.

Labrenz points out there are few gold projects out there with the type of grade that Madsen boasts, something that should be a sell on the financing side. The company's largest shareholders include Anglogold Ashanti, which last year increased its holding to 14.9% of Pure Gold's outstanding shares.

On the exploration side, vice-president of exploration Phil Smerchanski has put together an exploration program and budget for 2019, which at press time, was before the board for approval. The Madsen deposit can be traced for over 5 km of strike length, leaving lots of scope for new discoveries in addition to growing existing resources.

"That's one of the keys for our project moving forward is the tremendous exploration upside that we see," Labrenz says.

The company is also targeting Madsen's high-grade 8-Zone, which boasts grades in the range of 20 g/t gold.

"We've relogged all the core in that area, we have a model for how that may be repeated up towards surface, so we have a plan for testing that," Labrenz says.

While it's been "full speed ahead" for the past three years, the bigger picture at Madsen is just emerging.

"We think we're in a really strong position to move forward," Labrenz says. "I would argue that we are the future of Red Lake." **CMJ**

Professor Lesley Warren (left) and her colleagues are mining the genomes of microbes that thrive in wastewater generated by the resource extraction industry. COURTESY: LESLEY WARREN

GENOMICS APPLICATIONS
to wastewater start proving their worth

By Virginia Heffernan

Initiatives to replace chemicals with naturally occurring microbes in mine wastewater treatment are improving as researchers get a handle on how bugs thrive in situ.

"Tailings and wastewater are biologically reactive because they contain a lot of materials and elements that are energy drivers for bugs, so there are lots of bugs that are happy to live in these environments, but we don't really now how they operate – what are the drivers, what are the controls and what are the outcomes?" says Professor Lesley Warren, who holds the Claudette MacKay-Lassonde Chair in Mineral Engineering and is director of the Lassonde Institute of Mining at the University of Toronto.

Acid Mine Drainage (AMD), the acidic metal-rich water formed when air and water react with rock containing sulphur,

CONTINUED ON PAGE 16

is an ongoing risk to streams, rivers, lakes and aquatic life worldwide. As water becomes more acidic, it can leach other metals out of the rock, causing additional toxicity if not properly managed.

Warren and her team are focusing on bacteria that transform those sulphur compounds. Depending on the type of bacteria and the environmental conditions, bugs can either amplify or reduce contamination, so understanding how they operate at various temperatures with different rock types is essential to harnessing their power.

That's where genomics comes in. Microbes that live in wastewater are difficult to grow in the lab, but new technology (metagenomics) has allowed Warren and her team to extract and sequence DNA from microbes to determine their lineage. Some bugs may carry the gene for sulphur oxidation, for instance, while others may prefer to dine on nitrates.

Just over two years after receiving $3.7 million in funding from Genome Canada, her team – co-led by Dr. Jillian Banfield of University of California, Berkeley – is making some breakthroughs. "This technology is profoundly altering our ability to interrogate these bugs in widespread mining environments," Warren says.

Her research is taking place at Canadian mines including Hudbay Mineral's 777 copper-zinc mine and Anderson tailings facility in northern Manitoba, Glencore's Sudbury Integrated Nickel Operations (INO) in northern Ontario and Rambler Metals and Mining's Baie Verte copper mine in Newfoundland. The team has collected more than 300 samples at different points within these wastewater systems during different seasons.

Even though the mines vary widely in terms of their ore types and how long they have been in operation, one genus of bacteria - Halothiobacillus - shows up consistently in the samples from every mine. Just as significantly, the microbes differ from the sulphur-metabolizing bacteria that normally colonize waste rock sites, likely because tailings ponds have much more complex biogeochemistry than is widely recognized.

"This genus appears to be widespread and likely plays a similar role across mine wastewaters," says Warren. "Once we understand the bugs in these systems and what are they are capable of doing, then we can promote or prevent biologically important reactions by knowing which levers we need to press to make that happen."

Lesley Warren (standing, at right) conducting field research. COURTESY: LESLEY WARREN

Having this biological knowledge base also enables predictive modelling of what may occur in the wastewater system and improves monitoring tools.

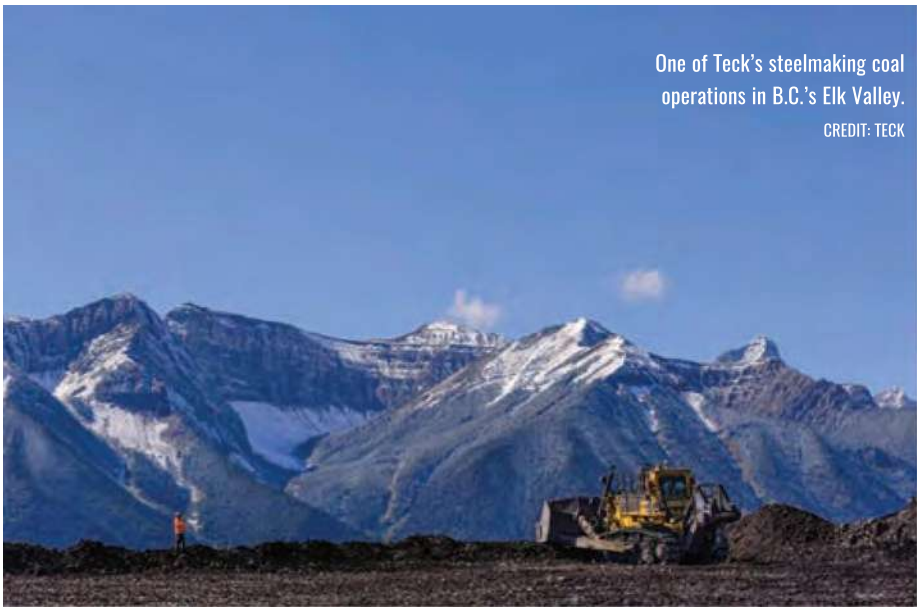
During their research, Warren's team has discovered that conventional analysis of wastewater at commercial labs fails to capture all of the reactive sulphur, so mines may be underestimating their sulphur risk. Labs also use different methods, so there is no consistency in results from mine to mine. Warren is proposing a new methodology that will introduce universality and allow mines to fully constrain the sulphur in their waters.

Teck taps microbes at Elkview

Biological solutions for treating mining wastewater at also being developed by industry and Teck is emerging as a leader this regard. The company has successfully piloted a new method of removing selenium and nitrate from the mine water at its Elkview steelmaking coal mine in British Columbia. The method uses Saturated Rock Fills (SRF), and is currently treating up to 10 million litres of water per day from the mine using naturally occurring biological processes.

Teck commissioned the SRF facility in 2018 on a previously mined pit that had been backfilled with rock and flooded with water, using nutrients such as methanol and phosphoric acid to accelerate microbial activity and contaminant removal.

Capital and operating costs are 20% and 50%, respectively, of conventional techniques with similar capacity because there is no need to build a plant and the fill can be expanded quickly if necessary. The company is currently focusing on using the technology in the Elk Valley where the need is most immediate but has not ruled out using the new treatment method elsewhere in its portfolio of mines.



One of Teck's steelmaking coal operations in B.C.'s Elk Valley.
CREDIT: TECK

"Microbes are widely used to treat mine wastewater but the difference with SRF is that the treatment isn't happening in tanks, it's happening in the natural environment," says Rob Klein, Senior Engineer of Water Quality Management Projects at Teck. "It has a much smaller environmental footprint and that's why I get excited about it. There is much less energy going into it and there are fewer chemicals that we have to add to the process. And there is no waste to manage afterward."

The SRF initiative is one component of Teck's Elk Valley water quality plan approved by the British Columbia government in 2014. The plan is a long-term approach to addressing the management of selenium and other substances released by steelmaking coal mining and affecting the water quality and aquatic life throughout the Elk Valley watershed. Teck owns five large open-pit steelmaking coal mines in the valley and has inherited a legacy of waste rock from more than a century of coal mining there.

The $850-$900 million five-year plan (2018 – 2022) also includes an active water treatment facility at the West Line Creek operation that treats up to 7.5 million litres of water per day, reducing selenium concentrations by about 96% and nitrate concentrations by 99%, and a similar facility being built at the Fording River operation. As for research and development, Teck has several projects underway to better control the release of contaminants at source and to develop new water treatment methods.

Active treatment, where wastewater is collected and then chemically treated, is expensive and labour intensive, so the development of an effective treatment in situ is a leap forward. If Teck can permit more SRF projects to replace the upcoming active water treatment plants in the Elk Valley, the company estimates that total capital spending on water treatment could drop to $600-650 million during the five year period.

"Teck had enough understanding in terms of the linkage between opportunities around using bacteria to treat wastewater and potential outcomes to set up full scale treatment and see what happened," says Warren of Teck's SRF pilot. "That starts to open the door for industry because it's no longer just someone working in a lab with a beaker."

As for Warren and her team, they will be setting up a test pond at Glencore's Sudbury INO this summer to test the their hypotheses about potentially useful biological indicators and to see if they can predict and promote reactions, both good and bad.

"The application of genomics in industry is profoundly important and it will lead to new ideas about how to manage waste and wastewater much more successfully," she predicts. **CMJ**

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BRUMADINHO DISASTER PROVES A TIPPING POINT FOR TAILINGS MANAGEMENT

If there is one good thing to come out of the Brumadinho tragedy in Brazil, it's that it has shocked an entire industry into taking action.

The tailings dam failure, which occurred at a Vale mine in Brazil on Jan. 25, killed more than 300 people – most Vale employees – and released 12 million cubic metres of tailings.

The failure occurred only three years after the Fundao (Vale and BHP Billiton) dam disaster in Brazil, which killed 19 people, and four years after the Mount Polley (Imperial Metals) failure in British Columbia, which thankfully, did not result in any casualties.

The loss of life in the latest incident, combined with the disturbing frequency of tailings dam failures in recent years, has galvanized the industry.

In late February, the UK-based International Council on Mining and Metals (ICMM) announced a process to create an international standard for tailings dams. And in early March, the Global Mineral Professionals Alliance (GMPA), an international group that includes the Canadian Institute of Mining, Metallurgy and Petroleum and the Society for Mining, Metallurgy and Exploration, announced its own Global Action on Tailings initiative.

Tom Butler, ICMM's CEO, says the ICMM initiative, which has the unanimous support of council, was agreed to at an extraordinary meeting of member CEOs in February called in response to the Brumadinho failure.

"Our members recognized it was an incident that requires an extraordinary response and we needed to come up with a response that would result in a step change in how we approach and manage these facilities."

The ICMM standard, which will be defined by an independent panel of experts, is expected to include a consequence-based tailings facility classification system with requirements for each level of classification; a system for credible, independent reviews of tailings facilities; and requirements for emergency planning and preparedness.

This standard, which would provide a baseline for best practice and verification for tailings facilities, would be adopted by ICMM members and then hopefully also by the rest of the global mining industry, Butler said.

> **Our members recognized that (Brumadinho) was an incident that requires an extraordinary response, and we needed to come up with a response that would result in a step change in how we approach and manage these facilities.**
>
> —TOM BUTLER, CEO OF INTERNATIONAL COUNCIL ON MINING AND METALS (ICMM)

Left: Some of the damage done by the Brumadinho tailings dam breach in Minas Gerais, Brazil. CREDIT: TV NBR

Above: Firemen returning following a search at Vale's Corrego do Feijao operation, in Brumadinho after a devastating tailings dam breach this year.

CREDIT: SAMUEL CHAHOUD, ISTOCKIMAGES.COM

"The idea here is to have a system which is also being applied across different countries by ICMM members. And that's with a view to giving confidence to external stakeholder that there is a consistent system being applied irrespective of the national requirements."

Butler says a lot of pressure has been coming from investors.

"From an investor's point of view, it's very difficult for them to understand what's going on because the systems applied by companies vary from company to company and then the systems applied by countries vary from country to country," Butler says. "And we're dealing with global mining companies that have operations all over the world. A lot of pressure has been coming from investors who have realized just how difficult it is to assess what companies are managing and how they're managing them."

Butler says the group is aiming to have the review completed and recommendations laid out by the end of the year, a timeline he says is ambitious but achievable.

"We're not going to start from zero," Butler says. "There is a body of existing good practices and best practice around the world," he said, including from Canada (Mining Association of Canada), and Australia.

"We're certainly not going to try to reinvent the wheel but what we are going to do is try to pick best practice from around the world and put that together into something which would become a standard for implementation by our members."

The collaborative nature of the effort is important, says Charles Dumaresq, vice-president of science and environmental management with the Mining Association of Canada (MAC).

Aside from ICMM and the GMPA, the Canadian Dam Association and the International Commission on Large Dams

CONTINUED ON PAGE 22

(ICOLD) have also been active in working on parts of the tailings construction, management and inspection puzzle.

"A number of people have identified that perhaps the worst possible outcome would be at the international level, to have conflicting sets of guidance from different organizations that are the same in concept but different in detail, or maybe emphasize different areas, and people are left wondering, 'which one do I follow?'" says Dumaresq, who oversaw the recent revisions to MAC's Tailing Guide and its Operation, Maintenance and Surveillance (OMS) Guide.

"If ultimately these various international pieces end up being disjointed it will be potentially quite confusing and that can make it less helpful rather than more so."

Previous review

MAC is an affiliate member of ICMM and was present at recent ICMM meetings to discuss the initiative. Their tailings documents were also circulated to members ahead of the meeting.

ICMM, whose members include many of the world's largest international mining companies, including Vale and BHP, made a similar announcement after the Fundao dam failure in late 2015. The difference between the guidelines that came out of that process and what ICMM intends to do this time is that the first was a high-level governance framework while the new standard will lay out in a lot more detail what is best practice for the management of these facilities.

"One of the things we've realized from this incident in Brazil is that the governance framework that we put in place was very high level," Butler says. "It basically outlines the key components of a tailings management policy and procedure but it didn't go into specifics so it left a lot of flexibility for individual members to implement a system in accordance with the governance framework. I think what we're moving toward is something more specific."

He elaborates: "The governance framework said you've got to have proper accountability, external assurance, a proper change management procedure in place, but it didn't lay out in detail what those different elements might look like if they were being done very well."

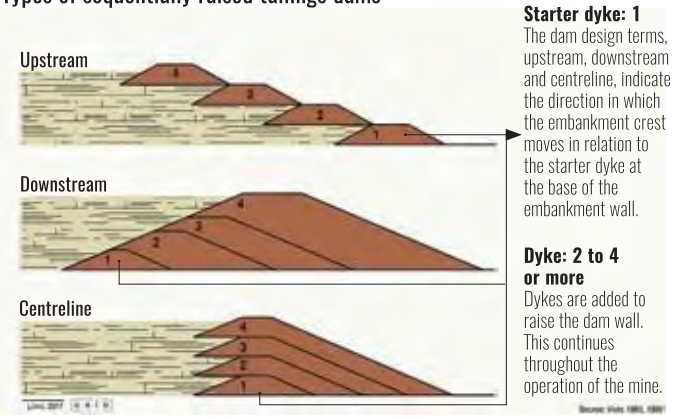
Bryan Ulrich, a vice-president in Stantec's mining practice and an authority on tailings storage and disposal, welcomes the ICMM effort to put together international standards as currently, standards vary from jurisdiction to jurisdiction.

"Many mining companies have developed their own minimum standards for TSF (tailings storage facility) design," Ulrich said in response to emailed questions.

"And of course, there are the very useful documents that were developed by the Mining Association of Canada (MAC) and the Canadian Dams Association (CDA). The MAC and CDA guidance is used in many mine sites, globally, and almost universally when the mine owner is a Canadian company. Having a global standard from ICMM will be a great advancement."

Ulrich points to the Cyanide Code, a similar voluntary program that member companies that produce gold and silver have committed to and that has yielded operational and environmental improvements.

Types of sequentially raised tailings dams



An illustration of the types of tailings dams used in mining. Brazil's government banned upstream dams after the recent Brumadinho failure.

CREDIT:KRISTINA THYGESEN/GRID ARENDAL

> **Tailings is a waste product and it is common for producers to want to reduce the cost of waste storage to the lowest practical limit. I think there is likely to be a shift in focus to spending the right amount of money rather than the least amount.**
>
> – BRYAN ULRICH, MINING VP AT STANTEC

Preventing failures

While the causes of any tailings dam failure are unique and complex, there are some commonalities between incidents.

"One of the recurring themes is around the human factors that are involved," says MAC's Dumaresq. "The decisions that get made – whether they're made with the fullest information, whether they're made at the right level within the organization, the communication breakdowns, assumptions that get made – things like that.

"We're human, we sometimes make mistakes, we all have our own biases," he adds. "You can never eliminate that, but how can you design a system that puts in the kinds of checks and balances to help manage the risk of those human errors?"

Dumaresq notes that this is one of the strengths of MAC's OMS guide and any other systematic approach to tailings management that put checks and balances in place to mitigate the risk of human errors and biases.

In terms of easier, near-term actions the industry can take to prevent catastrophic failures, Ulrich says miners need to shift the focus from the lowest-cost tailings storage options to de-risking their projects.

"Tailings is a waste product, and it is common for many producers to want to reduce the cost of waste storage to the lowest practical limit, which is beneficial to their bottom line and for their shareholders," he notes. "I think that there is likely to be

a shift in focus to spending the right amount of money, rather than the least amount of money. Rather than deferring capital expenditure, the focus should be on de-risking projects."

He adds: "The solution, I believe, will be to have improved, risk-informed designs rather than solutions that centre on net present value-driven economics and factors of safety."

Another way to reduce risk is through the engagement of an engineer of record (EoR), who should be involved in design, construction and operations of the tailings facility.

"Ideally, the EoR should have a long-term engagement, and should be the continuity person, maintaining institutional knowledge when personnel at the mine move," Ulrich says.

Reducing water and waste

A big focus in tailings and processing technology is in reducing the amount of water stored in tailings facilities. For instance, great advances are being made in the volumes of material that filtered tailings (or dry stack) technology can handle from a around 6,500 t/d to tenfold that amount, Ulrich says.

"The equipment manufacturers are making tremendous strides in these technologies by making larger filters, and decreasing the 'squeeze' time for each filter," he explains. "Given the various benefits of using filtered tailings, coupled with decreasing capital and operating costs of the technology, I expect to see filtered tailings operations growing considerably in use."

That said, Ulrich adds that filtered tailings is not a cure-all, and there really is no one-size-fits-all technology for tailings. "Each project should be designed based on its own unique set of requirements, constraints and opportunities."

Filtered tailings can also still pose chemical risks that need to be addressed.

There are also sites that reduce the amount of water not dramatically, but enough that the tailings behave differently and tailings facilities can be designed in a different way, Dumaresq says.

In the longer term, there are many R&D projects under way examining the reduction of waste earlier in the mining process and ultimately, the elimination of waste entirely.

"We begin to produce tailings at the rock face," Dumaresq says. "The first step in producing tailings is breaking rock to extract it – are there different ways that we can break rock, or sort the rock to get better feed going to mill in the first place?"

While some aspects of the tailings issue will take longer to tackle, it's essential to capitalize on the intense focus on the topic because of Brumadinho, says Dumaresq, so the industry can make headway towards making potentially transformational changes before that spotlight fades.

"The positive that comes from these tragedies is that it gets people talking and creates an environment where we can push towards bigger changes that might be harder to get if it wasn't for this level of attention," Dumaresq says. **CMJ**

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NEWMONT DETAILS ITS APPROACH TO WATER STEWARDSHIP

A Q&A with Newmont's director of Environmental Affairs, Briana Gunn

Newmont Mining is one of the world's largest gold miners and one of the companies participating in the first ever Water in Mining conference in Toronto, April 9-10. Ahead of the conference, *CMJ* took the opportunity to find out more about Newmont's commitments to water and sustainability in an email-conducted interview with the company's director of Environmental Affairs, Sustainability and External Relations, Briana Gunn.

CMJ: Can you tell us a little bit about yourself and your history with Newmont Mining, and working in the area of sustainability in mining?

Briana Gunn: I hold a bachelors and a master's degree in civil engineering and have focused my career on the development of strategies for operating and closed mines that support sustainability and manage risk. I joined Newmont Mining in July 2017 following my initial 16 years in environmental consulting industry. At this point in my career, I wanted to work for an organization that has a value underpinned in sustainability which I found in Newmont, whose purpose is to "create value and improve lives through sustainable and responsible mining." Working for Newmont has broadened my exposure to the global sustainability community within mining, in addition to my previous experience in agriculture, manufacturing, beverage, and oil and gas. As part of the Newmont team, I have been able to collaborate across industries, building relationships to promote sustainability and corporate responsibility.

CMJ: What kind of trends are you seeing in the mining industry generally when it comes to water management and water stewardship?

BG: Water is a requirement for sustainable development and is critical to socio-economic growth, energy and food production, ecosystems, and human health. Global concerns around water availability and quality continue to increase, with the World Economic Forum (WEF) classifying the water crisis among the top five global risks for the last seven years.

The increased competition for water resources pose risks to the mining industry related to water access, operational

We believe that having a water stewardship approach is the next step and provides more value than investments in small incremental water management improvements at existing operations.

– BRIANA GUNN, NEWMONT MINING'S DIRECTOR OF ENVIRONMENTAL AFFAIRS

Photo: BlackJack3D, iStockimages.com

disruptions, financial loss, delays in regulatory approval, impacts to reputation and diminished asset value. Making a meaningful contribution to stewardship provides an avenue to manage future risk and secure resources to support longer term operations and growth.

Industry is shifting focus toward having a leadership role in sustainability, setting strategic priorities that address the shared challenges within the watershed in which we operate. Having a shared understanding of the value of water, working in partnership to advance water stewardship, and supporting the objectives of the United Nations Sustainable Development Goals (SDGs) is a growing priority for the industry.

CMJ: Tell us about Newmont's "global water strategy." Why did the company adopt it and what does the strategy consist of?

BG: In 2014, Newmont developed our Global Water Strategy (GWS) with the purpose of maintaining existing and providing future access to water resources. The strategy identifies five pillars that aim to continuously improve how we manage water and respect water's shared use in the catchments and river basins where we operate.

Since implementation, Newmont has improved its approach to manging water through a clear framework with the key accomplishments including:

- ***Water accounting and reporting*** – developing a water accounting framework for each site to consistently record and communicate use of water and volumes returned to the environment.
- ***Governance and site water management*** – developing and implementing site and region-based water strategies covering the life of operations; and identifying a single point of accountabilities.

CONTINUED ON PAGE 26

- ***Water efficiency and targets*** – establishing targets to reduce fresh water consumption; to date the Newmont has exceeded our 2019 target of 5% reduction.
- ***Collaboration and collective action*** – collaborating with local and regional stakeholders to support water management and conservation – educating stakeholders about water use, and developing projects that support shared challenges.

CMJ: What is Newmont doing to increase the sustainability of its own water use?

BG: Newmont views water stewardships as an integral part of sustainability. In 2018, a maturity model was developed that builds on our GWS and its accomplishments to mitigate risk, maintain business operations and strengthen our licence to grow, and our business objectives. Water stewardship is accomplished using a broad range of water partnership and project opportunities. Working collaboratively provides cost-effective and sustainable approaches to water challenges. Superior water stewardship practices build trust and relationships that can also serve as a source of competitive differentiation in securing permits, resources and approvals.

CMJ: Can you describe some of Newmont's out of the box strategies or thinking regarding water management?

BG: Newmont has identified methods to reuse or recycle more efficiently, improve existing infrastructure, improve efficiencies, decrease cost and increase return of water back to the environment. We believe that having a water stewardship approach is the next step and provides more value than investments in small incremental water management improvements at existing operations. We will continue to identify areas for improvement utilizing the learnings of our Global Water Strategy.

CMJ: Newmont uses water risk research tools designed by the World Wildlife Fund and the World Business Council for Sustainable Development. Can you describe some of the benefits of working with or collaborating with partners such as non-profits on sustainability?

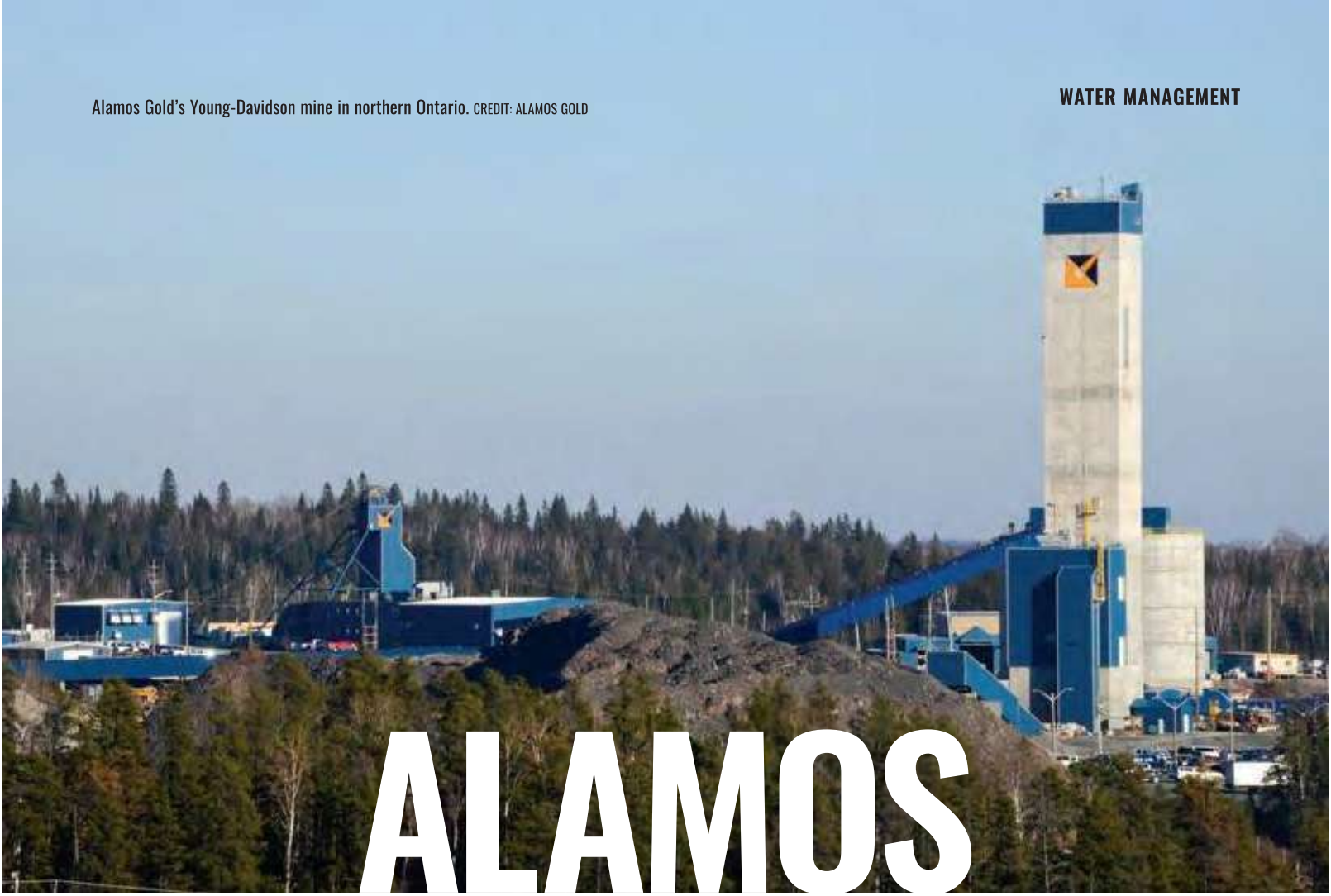
BG: Newmont has looked at water risks in multiple ways, identifying physical, reputational and regulatory risks that exist for ourselves and others within the watersheds in which we operate. In 2018, we formed a partnership with World Resource Institute (WRI) to utilize WRI's Aqueduct Water Risk Atlas and Cost of Water Stewardship database to identify risks at a site level within the watersheds where we are operating. This year, we will develop watershed based targets that are based on prioritized current and future risks and collaboration opportunities.

CMJ: Newmont is involved with the ICMM's Tailings Aspirational Working Group: can you describe the work that's being done there?

BG: Newmont is participating in work with the International Council on Mining and Metals (ICMM) tailings aspirational goal (TAG). An aspirational goal was developed in 2017 by the ICMM Council. Work with ICMM is ongoing; there have been some revisions in the scope of the work based on the recent tragic tailings dam failure in Brazil. The TAG group will be meeting in mid-March to discuss the path forward.

CMJ: Are there any new technologies or trends you're particularly excited about when it comes to water monitoring, water efficiency, tailings or any other area of water management that you would like to highlight?

BG: None to highlight at this time, as stated above we are concentrating on water stewardship as an approach to manage water as a shared resource. **CMJ**



Alamos Gold's Young-Davidson mine in northern Ontario. CREDIT: ALAMOS GOLD

ALAMOS pioneers new water treatment approach

SAGR technology provides new option for ammonia and thiocyanate treatment in cold climates

By Michael Bratty

Ammonia treatment in mining waters is attracting new interest and innovation. Ammonia has a special status for miners, because it is toxic to fish at low concentrations in the unionized form, and because it is not removed in the most popular mine water treatment processes involving lime application.

Furthermore, last year new regulations were published in Canada that introduced an "end-of-pipe" effluent limit for unionized ammonia for new mines, or mines that are closed and reopened (CMJ, April 5, 2018). Formerly, many mines already needed to deal with ammonia to ensure they meet non-acutely toxic criteria, or to meet receiving water targets. Ammonia has commonly been found in mining waters as a residual of blasting compounds or as a by-product of cyanide use, so gold miners pay particular attention to it.

Historically, many mines have relied on natural degradation in ponds for the management of ammonia. However, space limitations and new regulations are motivating innovation.

Historically, many mines have relied on natural degradation in ponds for the management of ammonia, however space limitations and these new regulations are motivating innovation. This article will outline a new approach to handling ammonia in mining effluents, which was pioneered by Alamos Gold at their Young-Davidson mine in northern Ontario. The new approach is a game-changer for the industry in management of ammonia in cold water.

CONTINUED ON PAGE 28

In the Canadian context, the natural degradation processes are essentially focused on the ice-free months of the year, so miners that rely on natural degradation need to provide large storage ponds to hold water through the winter.

Natural degradation can take place through loss of ammonia to the atmosphere at high pH, or through biological oxidation by ubiquitous nitrifying bacteria, or through uptake by aquatic plants including microalgae. Operators in the past have noted that natural degradation of ammonia can be poor in gold mill tailings ponds, where metals and metal complexes can be present that are toxic to algae and other microorganisms, but polishing ponds, where metals are low, are important contributors to ammonia removal. In the Canadian context, the natural degradation processes are essentially focused on the ice-free months of the year, so this means that miners that rely on natural degradation need to provide large storage ponds to hold water through the winter. Gold miners, like Alamos, commonly see ammonia in tailings ponds rising under the ice in the winter and dropping in summer as the algae and bacteria grow more quickly.

Miners that are not able to rely on large ponds to encourage natural degradation of ammonia have either adopted the approach of pH adjustment, which converts unionized ammonia to ammonium (NH_4^+), or they have adopted some kind of water treatment that is able to meet total ammonia nitrogen (TAN) limits. Due to strict effluent limits, the latter approach is used at the Young-Davidson Mine. In other locations, wetlands have been used for TAN reduction, but like natural degradation in ponds, are most useful in summer, and typically requires large land areas. Miners that are contemplating TAN treatment are faced with an array of technologies. If trace metals are also requiring treatment, then a complementary metal removal process is required. Due to the array of options, then an unbiased water treatment assessment is needed to make informed decisions about a variety of treatment and management alternatives. Golder provided such an assessment when Alamos was looking for new ammonia management options at the Young Davidson Mine in 2017. Alamos preferred alternatives that are suitable for winter operation in cold climates, and options that require a minimum of operator attention. Alamos management was willing to consider thinking outside the box, that is, cold water nitrification technologies that had not yet been demonstrated in the mining space but demonstrated promise based on fundamental principles.

The result of the water treatment assessment led to the selection of the Submerged Attached Growth Reactor (SAGR) technology. SAGR is an aerated rock-bed nitrification system provided by Winnipeg-based Nexom. Project experience for the technology came from across the continent, primarily in the municipal treatment sector, such as removing nutrients from the overflow of sewage lagoons. Operations experience with

Construction of the SAGR bioreactor at Alamos Gold's Young-Davidson mine.
CREDIT: GOLDER

SAGR has been that once constructed, the system requires a minimum of supervision, but most importantly, it is capable of efficiently removing ammonia to low limits, in water as cold as 1°C. A key element of cold water operations is the establishment of a nitrifying biomass in the rock bed in warm temperatures, and careful attention to pre-treatment to remove substances which might harm the nitrifying bacteria in the SAGR. An illustration of the SAGR system is provided in Figure 1.

Golder's water treatment assessment

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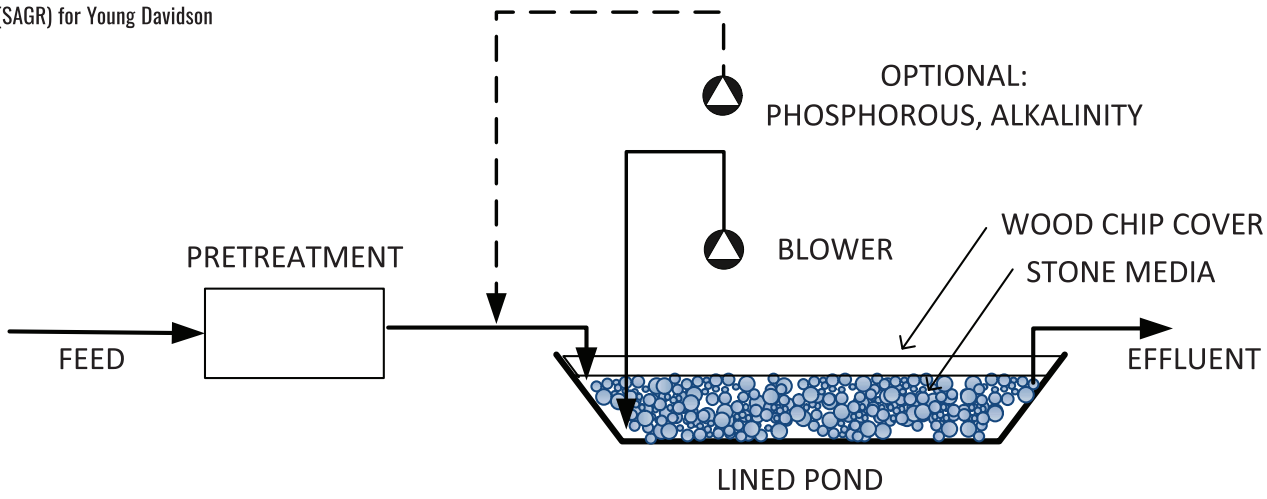
Figure 1: Submerged Attached Growth Reactor (SAGR) for Young Davidson



Construction of the SAGR bioreactor system. CREDIT: GOLDER

considered both established and emerging technologies. The evaluation included the following options: natural degradation, Moving Bed Bioreactor (MBBR), struvite formation through electrocoagulation, breakpoint chlorination, air stripping, ion exchange (with several sub-alternatives for brine handling) and the SAGR. The assessment concluded:

- SAGR was the lowest net present capital and operating costs, compared to any option (apart from natural degradation) considering a treatment campaign of 2 million cubic meters over a two-year period.
- SAGR had relatively low mechanical complexity, and low operational labour input.
- The next best rated option was the MBBR, but such a system is not normally operated at 1°C, and requires a significant cost to heat the feed water.
- The electrocoagulation/struvite process provides another innovative technology in the cold water ammonia space. In the case of the Young-Davidson, an amendment of phosphorous would have been required to match the ammonia removal.

Following a successful pilot testing program for the SAGR in late 2017, conducted at the University of Winnipeg, the SAGR system was constructed in spring 2018, and was started up in late June. The design took advantage of an existing polishing pond at the mine, which was converted to purpose, simplifying the project. The system was designed to handle two different water feed sources, through adjustment of the flow feeding the SAGR:

- A tailings pond feed water with temperatures between 1°C (winter) and 15°C (summer).
- A historic, flooded pit with temperatures consistently 3 - 8°C at depth, and up to 15°C in surface waters in summer.

Within about a month of starting the SAGR, the system was producing effluent that was well below the site's target effluent target for TAN. The system was subsequently ramped up to a flow of 3700 m3/d (700 gpm) through the summer, limited by the capacity of a pretreatment process. Through the fall, as the feed water temperature dropped, then the flow was progressively reduced.

The SAGR was started up and run first using the pit water feed source, which was low in thiocyanate. However, in October, the SAGR received a feed containing an elevated thiocyanate concentration. In spite of the cold feed water temperature, the system adapted to the new feed conditions within weeks, and demonstrated efficient SCN removal, simultaneously with TAN removal. The finding of cold water conversion of thiocyanate at this scale is significant, and would seem to show that the previously established biomass was capable of converting SCN inside the SAGR. This is believed to be the first case of thiocyanate treatment, in a SAGR and in cold water, anywhere in the world. Alamos plans to modify some of the upstream components in the spring of 2019 then put the SAGR through its paces, both for higher strength ammonia feeds, and higher thiocyanate loadings, with the advent of summer in 2019. **CMJ**

Michael Bratty, M.Eng. P.Eng., is a senior mine water treatment engineer with Golder, based in Vancouver. He can be reached at mbratty@golder.com or at +1 (604) 296-7348.

How nature reveals an improved path to mine water management

By Patrick Martel

Have you noticed that the more complex the problems we face in our lives, the more complex strategies we are deploying to solve them?

In the mining industry, the same situation applies. Organizations have now become extremely complex ecosystems. It is sometimes difficult to understand how they really work and interact.

And what if simplicity was the solution to solve complex problems?

Nature has a lot to teach us. Nature can simultaneously and intelligently manage multiple ecosystems of infinite complexity. It manages to evolve constantly in harmony despite the constant integration of new elements that interfere with the entire system. Its flexibility is unbeatable.

Human beings tend to conceive and deploy solutions in "machine" terms, organized in a hierarchical framework. Constantly changing external environments inevitably force these machines to become more complex. Thus, humans in their efforts to adapt are reacting to their changing environment by adding new components instead of responding with flexibility and agility.

Take the example of the relatively complex problem of water management

CONTINUED ON PAGE 32

in a mine, which requires consideration of:

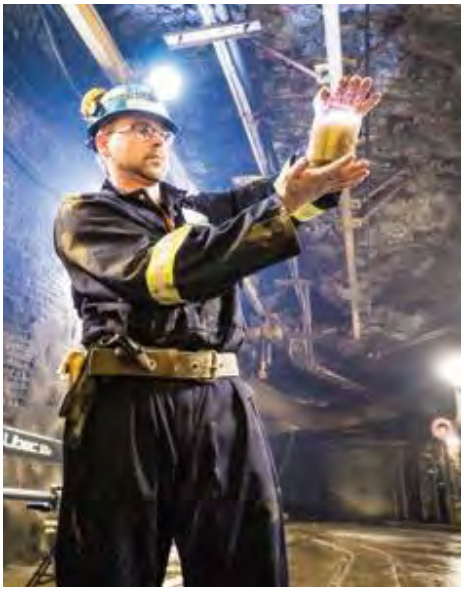
- Where the water is coming from
- Forecasting the quantities of water that must be managed
- Understanding the quality of the water
- Dealing with the seasonal cycles that sometimes saturate the system, and other times deprive it of water
- Determining if contamination of the water can be avoided
- Appropriate treatment strategies
- Worker awareness of issues related to water management
- Adopting adaptive water management strategies that can cope with changing conditions
- How to structure organizations and systems to be more agile
- And don't forget... in winter, water freezes!

And, what if we were inspired by nature in comparing this water to a virus in the human body?

- Just like a virus, this water can come from anywhere (precipitation, process, groundwater, spill, etc.);
- Just like the virus, there's no warning before water begins to affect the system and the level of effect is hardly predictable;
- Just like the virus can affect the body, water can make the mine inoperative or less efficient;
- Just as a virus, water must be neutralized, treated and disposed of;
- Just like the body must work to master this disruptive virus to continue its functions, so must the mine deal with water.

A TED talk by Martin Reeves inspired us with this analogy. In it, Reeves asks what system in nature is best designed to cope with viruses: It is the immune system.

In our daily life at Technosub, we are dealing with dynamic and unpredictable situations, such as managing the water of a mine. In this case, mechanical or "machine" thinking reaches its limits in its ability to deal with the level of complexity, so we must consider and master



this art of "biological thought," inspired by our observations of nature. In other words, we need to think more moderately and subtly about when and how we can influence, rather than to control complex and unpredictable water management situations. Innovation is of the essence and this must be considered in the design of mining water management works and throughout the mining operation.

Remember, we are limited in our capacity to control Mother Nature by force.

The systems in place sometimes are insufficient to protect themselves against changes and have sometimes lost this ability to think and act in a biological manner.

Let's go back to how the immune system defends against viruses to make the analogy to water in a mine. The system is very well organized and has exceptional features. At Technosub, the engineering team uses these six criteria, inspired by the human immune system, when designing water management works.

1 Redundancy

First, it intelligently uses redundancy by having in advance millions of copies of each component (like white blood cells) to create enormous protection against the unexpected. In a mine, redundancy is required for dewatering systems. If a pump shows signs of failure, another pump must be ready to start instantly. Redundancy in piping or valve systems is also required in order to add flexibility in the water management system.

2 Diversity

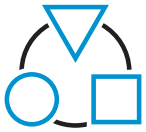
As Mr. Reeves explains, the immune system intelligently exploits diversity, having not only leukocytes but also B and T cells, the natural killer cells and antibodies. Together, the diversity of approaches can manage more or less all kinds of issues. The use of different water management strategies is also required in the mine. This could mean having a good knowledge of the hydrogeology of the site in order to pump the water before it is impacted by the mining operations. Or, understanding the hydrology of the site to prevent a part of the surface water from recharging the groundwater before is causes challenges to operations. Here,

Images courtesy of Technosub.

a global and holistic vision of water is needed in order to develop various strategies adapted to the conditions.

3 Modularity

In the immune system, the design is completely modular. There is, for example the surface barrier of the skin, an immune system that naturally reacts very quickly, and another able to adapt in a very targeted way. If one system fails, another can take control, creating an almost infallible system. In the design of mine water management works, different modules can be arranged to work for a common objective while contributing locally. For example, the installation of a MUDWIZARD sludge management system underground, a module that locally pre-treats the water from the drilling operations to allow recirculation of this water underground. This module contributes to a greater objective, that of reducing the amount of water to be pumped and managed on the surface, thus saving pumps, power and treatment efforts for the final effluent.



4 Adaptation

The immune system has a total ability to adapt. It can develop specific antibodies to threats it has never encountered before. Likewise, the design of the water systems must provide for potential adaptations in the piping. For example, in case of encountering excess water flow, the addition of pumps or the provision for extra power in distribution networks should be planned.

5 Prudence

The immune system operates with incredible prudence, detecting and reacting to the slightest threat and remembering all the previous ones, in case they manifest again. At Technosub, our designers learn from past failures and incorporate the new knowledge acquired to guard against potential future risks. That is why our project managers are always involved in the installation and commissioning of each system, to learn from mistakes and implement improvement on future designs.

6 Integration

The immune system is integrated into the larger system of the human body, and works in complete harmony with the system to create this biological protection. Likewise, the water management system must also adapt to the reality of the mine rather than the mine being at the mercy of the water management system. After all, resources are limited in a mine, and a simple system that is easy to understand and easy to operate is always better than a complex one. This for us is the meaning of success in integration.

These integrated features significantly increase the agility, reliability and resilience of water management strategies. Often, simple modifications to incorporate these six concepts into the initial design will greatly improve ease of use and reduce operational risks and costs.

Finally, we can observe that the typical structure for decision making is not always compatible with the continuously changing challenges encountered in water management. In a mine, everything is changing in real time. Inevitably, in this context, it is easy to be overwhelmed by any decision that requires co-ordination. Therefore, it is necessary to re-examine the design of our systems in order to simplify the decision-making process and to integrate these six elements inspired by the immune system.

In contrast, nature adapts to distribute authority to the billions of individual components that compose it. And from this is another lesson we can follow from nature.

Nature has taken millions of years to optimize complex systems. Why not have the humility to take advantage of this experience to simplify our lives? **CMJ**

Patrick Martel, P.Eng, is vice-president, Innovation Development / Integrated Solutions at Technosub.

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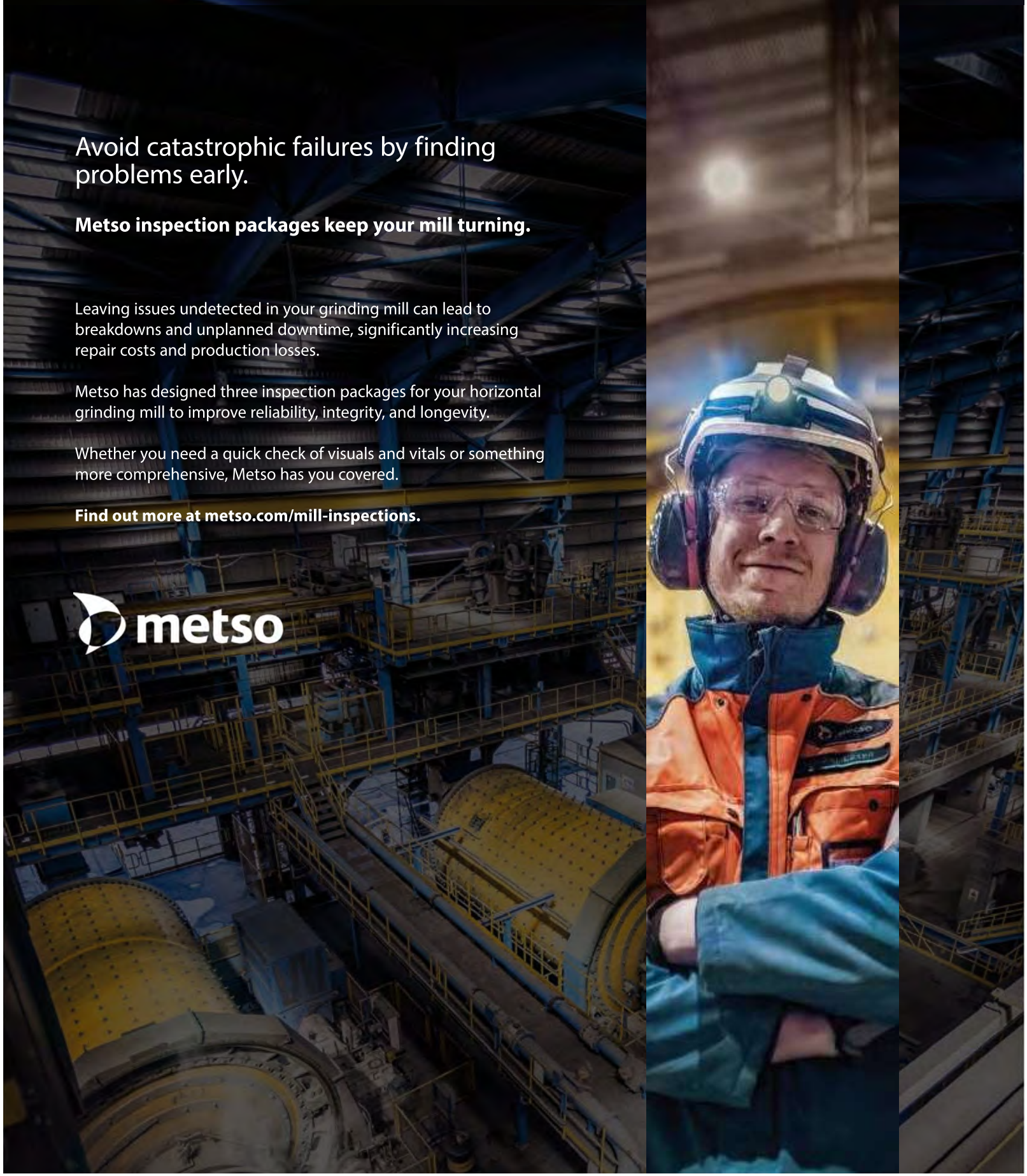

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Gravel Bed Reactors:

A Water Treatment Technology for Industrial & Mining Applications

By Silvia Mancini, Ph.D., P.Geo.; Evan Cox, M.Sc.; Len deVlaming, P.Eng.; Karen Bechard, M.Sc.; Rachel James, M.Sc.; Andrzej Przepiora, M.Sc.; & Florent Risacher, M.Sc., Geosyntec Consultants International Inc.

Construction of the Gravel Bed Reactor in California.

Metal and inorganic impacts to groundwater and surface waters are a critical issue facing many industries in western Canada. A wide range of commercially available treatment solutions exist; however, operational requirements in many industries make most conventional technologies expensive and difficult to comply with discharge criteria.

Geosyntec has designed, constructed, and operated a semi-passive water treatment technology, Gravel Bed Reactors (GBR™), for industrial and mining applications. GBRs™ can treat a variety of water quality issues, including acidity, metals and metalloids, inorganics, and organic chemicals. The treatment of metals and inorganics in GBRs™ has focused on the use of anaerobic biological methods. Using these methods, GBRs™ have demonstrated treatment of metals and inorganics to reduce concentration loading to surface water and / or reduce the requirement for conventional treatment, effectively providing an alternate, cost effective treatment option for these constituents.

Gravel Bed Reactors

A GBR™ consists of an engineered bed of gravel / media through which water containing constituents of concern is passed and treated. For anaerobic biological treatment, required amendments, such as electron donors and nutrients, are added to the water at the inlet of the GBR™ to promote the growth and activity of natural microbes capable of reducing the inorganics, sequentially immobilizing the metals in the gravel bed. GBRs™ are generally constructed within a natural depression or constructed cell near the water requiring treatment. The top and bottom of the treatment zone are lined using synthetic membranes to prevent water loss / influx, creating hydraulic isolation from the surrounding environment.

GBR™ systems combine key positive design elements of existing, conventional bioreactor designs, including:

1. Control of the oxidation / reduction potential within the bioreactor by balancing the addition of simple organic carbon (electron donor) with influent inorganics (electron acceptors) that allows the bioreactor to achieve the target treatment with minimal production of biological solids;
2. Fixed media that supports a stable biofilm of naturally occurring bacteria that allow for robust operation of bioreactors and removal of excess solids with minimal maintenance requirements;
3. Reasonable-sized footprint that can be above or below ground to minimize space requirements; and
4. Simple, inexpensive physical structure and operation and maintenance requirements to allow for treatment at a low cost compared to alternatives.

Treatment of metals and inorganics

While GBRs™ can treat a variety of water quality issues, in western Canada, recent water quality focuses on metals and

inorganics such as selenium and nitrate. Geosyntec has successfully treated selenium and nitrate in GBRs™ to concentrations below target treatment levels using anaerobic biological reduction. Denitrification is the microbially mediated mechanism by which nitrate concentrations in wastewater are reduced to nitrogen gas in GBR™ systems. Selenium can be removed from water by reducing the soluble forms of selenate or selenite to elemental selenium, which can then be sorbed onto solid phases, precipitated, or incorporated into the biomass within the GBR™. Effective removal of selenium requires careful control of the geochemistry and oxidation / reduction potential within the GBR™. This is accomplished through precise regulation of the dose rate of electron donor substrate balanced with the concentration of electron acceptors in the influent water. Treated water quality can be further improved with a variety of simple filtration or polishing processes.

Case studies

Treatment in an Urban Stream, California: Geosyntec developed the design concept, detailed design, and implementation of a subsurface GBR™ system for treating water in an urban stream impacted by selenium. The GBR™ was designed to meet the requirements of the county's nitrogen and selenium management program at a flow rate of approximately 700 m^3/d. Treatability and column studies were conducted by Geosyntec to confirm biological reduction of selenium and provide design parameters for the GBR™.

During start-up operations, Geosyntec evaluated the selenium and nitrate treatment performance of the system, involving the approximation of plug-flow characteristics, sequestration of selenium, treatment of fecal indicator bacteria, and re-oxygenation of water prior to discharge. Testing occurred over extended durations, allowed for the characterization of short and mid-term operational conditions, and used extensive and varied testing protocols that informed the optimal operational conditions. At full operation, the GBR™ treatment system demonstrated the capability to treat influent selenium concentrations of approximately 40 ppb to below the *California Toxic Rule* freshwater chronic water quality criterion of five ppb, allowing for discharge of the effluent to an urban creek.

This GBR™ accomplished treatment in a two-acre footprint compared to what would have been required (20 acres) for the alternative treatment under consideration (constructed wetland). The design of the subsurface GBR™ also allowed for property redevelopment on the land above, including its use as athletic fields for a school.

Treatment at a Coal Mine, West Virginia: Geosyntec designed and operated a GBR™ system for treatment of selenium and nitrate at a coal mine site in West Virginia, where surface water was impacted by selenium in newly exposed rock. The GBR™ was installed beneath an existing parking lot area to minimize the impact on other operations at the site. The excavation was lined with a geo-membrane liner and gravel was added, allowing the parking area to be re-installed above the GBR™ during its operation. Selenium-impacted surface water was amended with electron donor to provide food for the bacteria and added to the inlet of the GBR™. The oxidation / reduction potential within the GBR™ was monitored to allow for adjustments in the dose of electron donor to maintain optimal conditions for removal of selenium. During performance monitoring, the system consistently reduced the influent selenium concentration of approximately 30 ppb to below the target treatment level of five ppb.

Conclusion

GBRs™ offer simpler, less engineered systems compared to other anaerobic biological treatment approaches, like water treatment facilities, packed bed bioreactors, and fluidized bed reactors. This includes using less tankage and equipment, using waste materials (waste rock) as bioreactor packing media, and a smaller treatment facility footprint. Less infrastructure allows easier installation of smaller systems with the potential to treat water at or near the source. This is advantageous to industrial and mining operations in western Canada with challenging locations and montane topography.

Dr. Silvia Mancini, Ph.D., P.Geo., is a principal in the remediation group of Geosyntec Consultants' office focused on managing soil, surface water, and groundwater remediation programs.

APPENDIX 6.19-1: ELK VALLEY WATER QUALITY PLAN – 2019 IMPLEMENTATION PLAN ADJUSTMENT – ANNEX J: ALTERNATIVE TREATMENT MITIGATION PLAN

Elk Valley Water Quality Plan

2019 Implementation Plan Adjustment

Annex J: Alternative Treatment Mitigation Plan

July 2019

Teck

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ACRONYMS AND ABBREVIATIONS

Acronym or Abbreviation	Description
ANFO	Ammonium Nitrate Fuel Oil
AMP	Adaptive Management Plan
AWT	Active Water Treatment
AWTF	Active Water Treatment Facility
BC	British Columbia
BGM	Bituminous Geomembrane
DO	Dissolved Oxygen
EMPR	Ministry of Energy, Mines and Petroleum Resources
ENV	Ministry of Environment and Climate Change Strategy
EVO	Elkview Operations
EVWQP	Elk Valley Water Quality Plan
FRO	Fording River Operations
GBR	Gravel-Bed Bioreactors
GHO	Greenhills Operations
IIP	Initial Implementation Plan
IPA	Implementation Plan Adjustment
KNC	Ktunaxa Nation Council
LCO	Line Creek Operations
N	North
R&D	Research and Development
RWQM	Regional Water Quality Model
S	South
SPO	Site Performance Objectives
SOZ	suboxic zone
SRF	Saturated Rock Fill
Teck	Teck Coal Limited
WLC	West Line Creek

UNITS OF MEASURE

Unit of Measure	Description
%	percent
>	greater than
m^3	cubic metres
m^3/d	cubic metres per day
mg/L	milligrams per litre
µg/L	micrograms per litre

1 Introduction

1.1 Background and Regulatory Context

In April 2013, the British Columbia (BC) Minister of Environment issued Ministerial Order No. M113 (Order), which required Teck to prepare an area-based management plan for the Elk River watershed and the Canadian portion of the Koocanusa Reservoir. In this plan, Teck was required to identify the water quality mitigation, for existing plus planned (to end of 2037) waste rock, that is required to stabilize and reduce concentrations of nitrate, selenium, sulphate, and cadmium and the formation of calcite downstream, its five mines.

From 2013 to 2014, Teck developed an area-based management plan, called the Elk Valley Water Quality Plan (EVWQP). Teck had input from the public, First Nations, provincial and federal governments, technical experts, and other Communities of Interest. Teck submitted the EVWQP to the Minister in July 2014 and it was approved in November that same year. The EVWQP includes an Initial Implementation Plan (IIP) that outlines the mitigation planned to achieve targets for the concentration of selenium, sulphate, nitrate, and cadmium in surface water at specific locations throughout the Elk Valley and in the Koocanusa Reservoir. These targets, both short-term and long-term, are meant to stabilize and reverse increasing concentrations of the four constituents named in the Order. Active Water Treatment Facilities (AWTFs) and clean water diversions were identified in the EVWQP as mitigation tools to achieve this.

In November 2014, the B.C. Ministry of Environment issued Permit 107517 to Teck under the *Environmental Management Act*. Many of the actions and commitments that Teck made in the EVWQP IIP were incorporated into the permit requirements. To maintain compliance, Teck must meet the requirements in the Permit, including the construction and operation of AWTFs on the timelines specified and achievement of water quality targets.

Compliance Limits and Site Performance Objectives under Permit 107517 are collectively referred to as water quality targets in this document. Compliance Limits are set for compliance points. Compliance points are water monitoring stations that are downstream from each of Teck's mine operations in the Elk Valley. These points are intended to be at the point where all or most of the point and non-point discharges from a mine site or portions of a mine site are expected to report. There are eight compliance points that have limits for selenium, sulphate, nitrate, and cadmium.

Site Performance Objectives, or SPOs are set for Order Stations. These stations are also water monitoring stations, but these are further downstream from Teck's mining operations. They are intended to reflect fully mixed conditions, taking into account water from all upstream sources. There are seven Order Stations which have SPOs for selenium, sulphate, nitrate, and cadmium. SPOs are based on the targets from the integrated effects assessment completed for the EVWQP, whereas the Compliance Limits listed in Permit 107517 were based on the 2014 Regional Water Quality Model (RWQM) projected water quality conditions under the IIP.

Mines Act C-Permits require adjustments to the IIP, based on an adaptive management approach, by July 31, 2019 and every three years thereafter. Permit 107517 and Mines Act C-Permits required the RWQM be updated by October 31, 2017. The October 2017 RWQM update showed that the projected concentrations were above limits and SPOs, resulting in the need to update the mitigation plan (IIP).

The 2019 Implementation Plan Adjustment (2019 IPA) is the first adjustment to, and will supersede, the IIP. The 2019 IPA is a revised implementation plan developed to achieve the SPOs and Compliance Limits included in the EVWQP and Permit 107517. Like the IIP, the 2019 IPA is based on the application of biologically-based AWTFs, and clean water diversions where practical to support efficient treatment, to address increasing selenium and nitrate water concentrations within the Elk Valley.

A key component of the EVWQP, Permit 107517, the Adaptive Management Plan (AMP) and the C-Permits is the incorporation of an adaptive management approach which envisions changes in treatment technology over time through Research and Development (R&D) and the advancement of science and technology. The EVWQP indicates that Teck will:

- Advance continuing R&D to identify additional sustainable options to manage water quality now and in the future and that;
- Teck will also adapt the IIP based on advancements from the R&D program, development of mine plans and a review of other relevant management plans. Advancements in technology from the R&D program may lead to incorporation of new technologies and management approaches.

Permit 107517 further conveys this stating:

- The Permittee (Teck) must aggressively pursue all viable approaches for reducing contaminant loadings to the environment and implement in a timely manner. Treatment approaches include passive and active water treatment.
- The Permittee must employ best achievable technology in the development of (these) water treatment facilities.

The AMP Management Question 3 “Are the combinations of methods for controlling selenium, nitrate, sulphate and cadmium included in the implementation plan the most effective for meeting limits and site performance objectives?” includes Key Uncertainty 3.1 “Are there better alternatives to the current active water treatment technologies?” The objective of reducing this uncertainty is to find the most effective and sustainable treatment, and source control, technologies for long-term water quality management with the goal of reducing long term reliance on Active Water Treatment (AWT).

The C-Permits for the Elk Valley Operations dated November 2014 include clauses within section B1c that state:

> Updates to the Initial Implementation Plan
>
> ii. The updated Implementation Plan shall include refinements and changes to management targets, mitigation strategies, timelines for implementing mitigation, monitoring plans and research and technology development programs as necessary to meet the objectives and timelines for water quality constituents in the Elk Valley Water Quality Plan.
>
> iii. Future iterations of the update Implementation Plan shall specifically evaluate the effectiveness of:
>
> - mitigation measures to minimize release of order constituents and reduce reliance on long term active water treatment; and
>
> - progressive reclamation and closure activities.

To meet these requirements and Teck's goal of reducing reliance on AWT over time, Teck currently has more than 20 R&D projects (through an overall R&D program) underway related to water quality in the Elk Valley. These include projects to develop new water treatment methods/technologies and to better control the release of water quality constituents at the source.

The R&D program is advancing in parallel to executing biologically-based AWT (specifically Fluidize Bed Reactor based biological AWT at Line Creek Operations [LCO] and at Fording River Operations [FRO]). Teck has, and continues to, advance R&D to identify alternate sustainable options to manage water quality. These options generally fall into two categories:

1) Source Control: Investigates both constituent sources and control methods and includes studies of alternative technologies such as nitrate management and waste rock covers.

2) Alternative Treatment: Focuses on the investigation of alternative water treatment technologies.

As source control technologies are researched, developed and implemented they will help reduce the load on the environment and reduce the amount of water requiring treatment. A current example of this is Teck's nitrate management program, the objective of which is to reduce the nitrate load on the environment by better managing nitrate-based products used in the blasting process.

As alternative treatment technologies are better understood and implemented they have the potential to augment and/or replace existing biologically-based AWTFs in future adjustments to the implementation plan. A current example of this is the full scale application of Saturated Rock Fill (SRF) technology; a more sustainable water treatment technology which has been successfully tested at a full scale at Teck's Elkview Operations (EVO) through the EVO SRF Full Scale Trial Phase 1 project. Based on this Teck is implementing Phase 2 of the EVO SRF Full Scale Trial which is planned to be operational by the end of 2020.

1.2 Purpose and Content

The purpose of this annex is to present an alternative treatment mitigation plan (based on alternative technologies) developed to achieve the objectives of the EVWQP and the instream water quality performance objectives and limits for selenium and nitrate as defined in Permit 107517. A summary of Teck's current alternatives to biologically-based AWT is provided as well as the planning basis and assumptions used to develop the alternative treatment mitigation plan. Sources (streams) targeted for treatment along with the timing of treatment are consistent with, and in some cases available earlier than, the biologically-based AWT technology strategy upon which the 2019 IPA is based. This annex also outlines the steps Teck is taking to advance alternative treatment technologies which will be integrated into future adjustments of the implementation plan consistent with Teck's AMP.

2 Incorporating Alternative Water Quality Management Technologies through Adaptive Management

Teck's AMP was developed to support implementation of the EVWQP to achieve water quality targets, including calcite targets, ensure that human health and the environment are protected, and where necessary, restored, and to facilitate continuous improvement of water quality in the Elk Valley. Adaptive management provides a structured and flexible process for evaluating and adjusting the EVWQP; inclusive of the implementation plan and the water quality management mitigations included in the implementation plan. This will be done in response to new information and changing conditions, to allow the goals and environmental management objectives of the EVWQP to be achieved as circumstances change.

Teck will adapt (and adjust) the implementation plan in response to monitoring information, advancements from the R&D program and other scientific advancements, development of mine plans and a review of other relevant management plans. Advancements in technology from the R&D program will lead to the incorporation of new technologies and management approaches. The reduction of key uncertainties in the AMP will result in adjustments to incorporate new learning into the implementation plan so that the implementation plan continues to reflect the current understanding.

Following the adaptive management cycle (Figure 2-1), and as discussed in 2019 IPA Report, monitoring and evaluation in 2017 identified the need to adjust the IIP. Teck's R&D program incorporates and follows the adaptive management cycle to advance additional sustainable options to manage water quality.

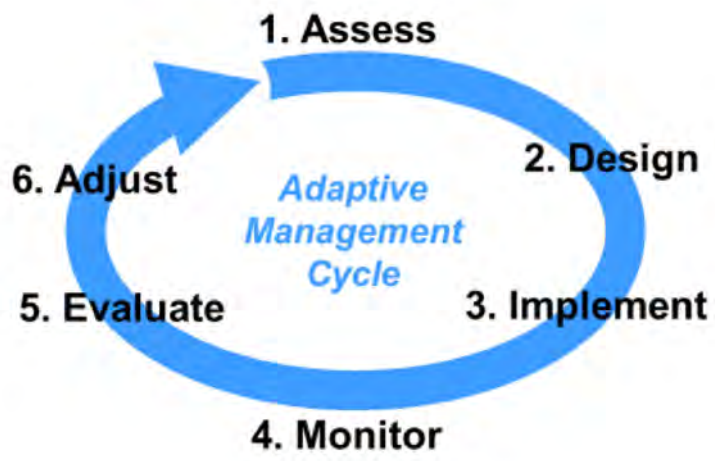


Figure 2-1 Adaptive Management Cycle

The AMP includes Management Questions and associated Key Uncertainties. The primary Management Question relevant to the advancement of additional sustainable water quality management mitigations and the incorporation of new technologies is Management Question 3. Management Question 3 and its associated Key Uncertainties are shown in Table 2-1. The alternative treatment mitigation plan considers, and incorporates, Teck's effort with respect to addressing Key Uncertainties 3.1 and 3.2 which are "are there better alternatives to the current active water treatment technologies?" and "what is the most feasible and effective method (or combination of methods) for source control of nitrate release?",

respectively. Teck's effort understanding Key Uncertainties 3.3, 3.4 and 3.5, and next steps to continue to address these three Key Uncertainties is outlined in the 2018 AMP and in the 2019 IPA Report.

Table 2-1 Adaptive Management Plan: Management Question 3 and Associated Key Uncertainties

Management Question 3	Key Uncertainties
Are the combinations of methods for controlling selenium, nitrate, sulphate and cadmium included in the implementation plan the most effective for meeting limits and site performance objectives?	**3.1. Are there better alternatives to the current active water treatment technologies?**
	3.2. What is the most feasible and effective method (or combination of methods) for source control of nitrate release?
	3.3. Is clean water diversion a feasible and effective water management strategy to support water quality management?
	3.4. What additional flow and groundwater information do we need to support water quality management?
	3.5. Is sulphate treatment required and if so how could we remove sulphate?

MQ = Management Question; KU = Key Uncertainty.

3 Alternative Water Quality Management Technologies

3.1 Introduction

Consistent with the EVWQP, new technologies and water-quality management methods, either now in the R&D phase or expected to emerge in coming years, will help to reduce the long-term reliance on AWT. Although some of these new technologies and methods are not yet advanced enough to be included in the 2019 IPA, they will be considered for future adjustments to the implementation plan.

Teck has, and continues to, advance R&D to identify additional sustainable options to manage water quality. These options generally fall into two categories as previously outlined in Section 1:

1) Source Control: Investigates both constituent sources and control methods and includes studies of alternative technologies such as nitrate management and waste rock covers.
2) Alternative Treatment: Focuses on the investigation of alternative water treatment technologies.

3.2 Source Control

3.2.1 Nitrate Source Control

The source of nitrate in the receiving environment is residuals from blasting activities. Controlling this source is a focus area for Teck. Teck asserts that nitrate source control is a proven and effective mitigation measure to reduce nitrate release from waste rock. In 2016, a nitrate management team was established at Teck in the Elk Valley with the primary objective of identifying and implementing best management practices for blasting to reduce nitrate release. Scoping level estimates of losses were made for each type of blasting product and practice used at Teck operations through a combination of literature review, laboratory testing, and field testing. This information was used to identify and prioritize

best management practices. The following best management practices, listed in order of estimated nitrate reduction potential, were identified:

1. Eliminating the use of all augured emulsion products: This method of loading blast holes causes blasting product to stick to the sides of the upper section of the hole (Figure 3-1), where it remains undetonated.
2. Lining Ammonium Nitrate Fuel Oil (ANFO) holes: ANFO is not water resistant, and liners prevent products from contacting water in the hole to reduce leaching.
3. Maximizing dewatering of wet holes.
4. Limiting sleep time (i.e., the time explosives are in the borehole before detonation) in areas of moving water: The longer explosives are in the ground in areas of moving water the more likely they are to leach.

Figure 3-1 Augured Emulsion Blasting Product Stuck to the Sides of an Upper Section of a Drill Hole for Blasting

Initial calculations have indicated that these practices have the potential to reduce nitrate loss by >50% compared to 2013 baseline practices. Because of this and the large potential benefits to downstream water quality, these best practices have been implemented and continue to be refined with learnings.

To date, the following has been achieved:

- No augured emulsion products have been loaded since 2016.
- ANFO usage has increased across all five sites from an average of 11.9% in 2015 to an average of 50% for 2018.
- All ANFO holes are now being lined to effectively eliminate leaching.

Teck will continue to refine practices to work towards further reduction of nitrogen loss from blasting. Currently, ANFO holes can be lined, and there are trials underway to determine if it is possible to line blast holes filled with emulsion. As expected, with the current understanding of a delay between waste rock placement and the appearance of associated nitrate load in the receiving environment, the benefits of nitrate source control have not yet been observed at downstream monitoring stations.

Teck's R&D team has completed sampling of rock immediately after a blast has occurred to quantify nitrate residuals on rock to work towards quantification and future inclusion of these improvements in the RWQM. This sampling program was done on the three products / product blends that have been used most commonly historically, as well as a new product, not yet used at Teck sites, which is expected to show reduced leaching in wet holes.

Compilation and analysis of information from this field test is currently underway. This study, along with compilation of historical blasting information, will support quantification of the estimated reduction of nitrate loss from improved blasting practices relative to historical practices and will be used to inform refinements to best management practices and further studies to quantify the full range of blasting products, practices and conditions common to Teck's Elk Valley operations.

Nitrate source control will help to reduce nitrate release from waste rock and ultimately improve water quality. These improvements have not yet been quantified nor incorporated into the RWQM (and into the resulting water quality projections included in the 2019 IPA). Once the estimated reduction of nitrate loss from improved blasting practices is quantified the nitrate source terms in the RWQM will be adjusted to reflect. This is expected to be completed prior to, and included in, the 2020 RWQM update. Nitrate source control thus has the potential to have a substantial impact on downstream water quality as well as the sizing, timing and design of water treatment.

3.2.2 Waste Rock Covers and Other Source Control

In order to determine whether reducing net percolation, via a waste rock cover, would improve water chemistry, a study was launched in early 2012 in partnership with the University of Saskatchewan and McMaster University. The geochemistry and hydrogeology of existing waste rock piles was studied between 2012 and 2015, which led to several publications. Over the course of 2017 and 2018, a coupled hydro-geochemical model was developed that attempted to link geochemistry with water movement through a waste rock pile and predict the impact of various covers on water chemistry. The following is a summary of that work, organized by constituent of interest:

Nitrate

The source of nitrate in waste rock is from residual blasting products. It is assumed to be available at initial source concentration during waste rock placement and moves as a conservative species (i.e., transported at the rate of water movement through the waste rock pile with no bio-geochemical alteration). The reservoir of nitrate following waste rock placement is finite; therefore, once flushed from the waste rock, no additional source remains.

The primary impact of cover placement will be a reduction in the rate of water movement through the waste rock pile which will reduce the rate at which the mass of nitrate is flushed from the waste rock pile. Decreasing the net percolation rate may result in relatively small decreases in water content within the waste rock pile, and will affect the time to flush nitrate from the pile. The time to flush nitrate from the waste rock pile can be estimated from the volume of water stored within the pile (waste rock pile height x volumetric water content) and the rate of net percolation. Dividing the stored water by the net percolation rate represents the minimum time to flush nitrate from a waste rock pile. Although denitrification processes have been observed at times within waste rock piles (e.g., suboxic zones), cover placement alone is not anticipated to have an impact on nitrate removal.

Therefore, a cover could be used to slow the rate of nitrate release from a waste rock pile, but not reduce the total mass of nitrate released. If a cover were constructed on a fresh waste rock pile and it reduced infiltration by 50%, the nitrate loading from the pile should decrease by 50%; however, the length of time it takes that pile to completely flush would double. This would not eliminate the need for water treatment, although it may reduce the peak load observed at a treatment facility, and potentially reduce the need for nitrate treatment in a certain locations.

Sulphate and Selenium

Sulphate is produced through the oxidation of sulphide minerals (e.g. pyrite) within waste rock. In a waste rock pile that is oxygenated, the production rate is independent of net percolation rates meaning that sulphate will be produced at a constant rate regardless of how much water passes through the pile. Once the sulphate is present in the pore-water, it will be flushed in a similar manner as nitrate (i.e. behaves conservatively). The difference is that sulphate concentrations will increase with depth in the waste rock pile as the water picks up additional sulphate as it travels through the pile.

Decreasing net percolation rates results in an increase in the concentration of sulphate released, but is not expected to affect the load. If the waste rock pile is thick and the net percolation is low, then the solubility limit for gypsum can be reached and consequently the rate of sulphate loading by flushing will be decreased as a result of gypsum precipitation. Once production rates and the concentrations of sulphate within the waste rock pile decrease, the sequestered gypsum in the pile will rapidly re-dissolve and be released from the pile.

Selenium is released by the same oxidation process as sulphate. As a result, it behaves in a similar manner to sulphate (as described above). Although the precipitation of gypsum is a well-understood process, there is no similar solubility limit for selenium. If selenium behaves in a similar manner to sulphate, but without the benefit of co-precipitation with gypsum as our current research suggests, there is likely no advantage provided by reducing net percolation through the use of covers on selenium loading from the waste rock pile. The total mass of selenium produced through the oxidation process will be removed by whatever volume of water is passing through the waste rock pile. To summarize, based on

research to date, it is believed that unless water is essentially excluded from a waste rock pile, reducing net percolation will not have a positive effect on the amount of selenium being released to the environment.

3.2.2.1 Efficacy of Covers to Reduce Net Percolation

3.2.2.1.1 Soil Covers

Water is the carrier that transports soluble contaminants out of waste rock. The key control offered by covers is the opportunity to reduce the amount of water that flows through a waste rock pile. Rainfall and snowmelt both tend to infiltrate readily into waste rock surfaces, but where the surface is fine-grained or soil-like it can retain the water long enough for some of it to be evaporated or transpired by plants (evapotranspiration).

In 2012, O'Kane Consultants (OKC) was retained by Teck to estimate the effectiveness of soil covers in reducing net percolation by monitoring near surface water balances for twelve instrumented sites in the Elk Valley and at the Cardinal River Operations. Subsurface and meteorological instrumentation were installed at these sites in 2012 and data interpretation and analysis has been completed over five years of monitoring, and continues today. Sites were chosen to represent a range of covered and bare waste rock system in an attempt to quantify net percolation rates and identify the most effective approaches given the cover material available and local climate. These studies have demonstrated that covers with well-established vegetation can limit net percolation to 40% to 70% of precipitation, while sparsely vegetated sites have net percolation rates of 70% to 85% of precipitation. This information, in conjunction with the research completed over the same period of time with respect to the effect of reducing net percolation on water chemistry, suggested that store-and-release covers alone would not be an effective means of reducing selenium loading on the environment.

Net radiation monitoring data was used to calculate the theoretical maximum amount of water that could be removed from waste rock piles through evapotranspiration. These analyses indicated that the practical maximum amount of water that can be evapo-transpired given the climate in the Elk Valley ranges from 30% to 40% of average annual precipitation rates. Based on these calculations, it is not believed that store-and-release covers will be an effective water quality mitigation on their own, but will require additional design elements to further reduce net percolation such as lateral drainage (interflow or runoff) facilitated by the use of synthetics or compact layers. Because natural materials to build compact layers are limited in availability, the focus has been on synthetics.

3.2.2.1.2 Geosynthetic Covers

In order to reduce net percolation through waste rock piles, covers, both synthetic and soil, have been used in other geographies and applications. To evaluate their use at Teck, a desktop review of Bituminous Geomembrane (BGM) cover systems was completed in 2014. A BGM is a type of geosynthetic used in several industries (Municipal landfills, mining, and water storage dams) as an impermeable barrier. BGMs were selected due to their long service life relative to other geosynthetics (300+ years). A typical design consists of an impermeable barrier, a drainage layer, followed by a growth medium to encourage vegetation growth. It is recognized that sourcing the materials required for the drainage layer and growth medium would be a challenge due to the quantity required.

3.2.2.2 Current State of Covers

Over the period of 2012 to 2015 investigations were carried out with respect to the technical feasibility and economics of various covers, including geosynthetic covers. Given the level of uncertainty in the science of covers in the context of the Elk Valley over the period from 2012 to 2015, combined with the high cost to deploy geosynthetic covers, and practical issues associated with that deployment, the implementation of geosynthetic synthetic membranes as part of a cover strategy was not been an area of significant investment for Teck in 2016 to 2017. Studies over this same period of time have also demonstrated that while soil covers in combination with vegetative reclamation may slow the release of nitrate and sulphate under certain conditions, they are unlikely to impact the release of selenium.

In 2018, Teck initiated a second study to understand the state-of-the-art with respect to the use of geosynthetic covers for waste rock on the scale of those located in the Elk Valley. Efforts at the moment are focused on assessing the feasibility of covering a waste rock pile at this scale, with a plan to trial the use of geosynthetic covers at a meaningful scale (multiple hectares) in 2019 if the probability of technical success and economic feasibility are reasonable relative to other potential solutions and given the stage of the research.

Suboxic Zones

A suboxic zone (SOZ) is a zone of low oxygen concentrations (i.e. suboxic zones, less than 5 vol. %) in an unsaturated waste rock. Under the right conditions, SOZs may be utilized for selenate or nitrate removal within an unsaturated waste rock pile. An effective SOZ requires sufficiently low oxygen concentrations with a sufficiently long seepage residence time to support geochemical reduction of selenate or nitrate. The performance of a SOZ for water treatment requires waste rock pile-specific design as geometry and construction methods impact the hydrologic and geochemical performance.

SOZs may be enhanced over large-scale areas of waste rock through control of pore-gas oxygen fluxes. Textual breaks are targeted as a pore-gas control strategy to break up convective gas flows, limit surface fluxes, and slow the flow of water through the zone, increasing residence time.

The study of SOZs is ongoing. Current work is focused on geochemical and microbial process associated with oxygen consumption, which govern the SOZ's performance. Material characterization and additional numerical modelling are also required before a design can be established.

Plans for 2019 and beyond in the area of source control include progressing studies on the effect of alternative dump construction methods, and geomembranes as covers for waste rock, on water quality and the potential role of such technologies in future IPAs.

3.3 Alternative Treatment

3.3.1 Saturated Rock Fills

An SRF is mined-out open pit backfilled with waste rock, with a portion of that rock submerged in water. The water-saturated rock is an environment that is capable of supporting a microbial community that can reduce (denitrify) nitrate to intermediate soluble nitrogen compounds such as dissolved nitrite (NO_2) and ultimately nitrogen gas (N_2), and also reduce soluble selenate to less soluble forms (selenite or elemental selenium) (SRK 2012; Bianchin et al. 2013; Kirk 2014). The zone that supports selenium and nitrogen

conversions is typically the water-saturated rock zone. However, conditions in areas adjacent to and including the capillary fringe could also support reduction.

Denitrification and selenate reduction are forms of anaerobic respiration in which bacteria use nitrate or selenate instead of oxygen to gain energy from consumption of carbon. Carbon provides an electron source for bacteria to “respire” on nitrate and selenate under anaerobic conditions. The bacteria are effectively catalysts shuttling electrons from carbon to nitrate or selenate (i.e., reduction-oxidation, or “redox” reaction). This is a natural process that occurs in nearly all environments where conditions are oxygen free. Iron and sulphate reduction occur by the same process and by many of the same bacteria.

Redox reactions are governed by a “redox ladder” in order of decreasing energy yield for microbial communities. In coal environments, the following order is useful to consider:

Oxygen > Nitrate ≥ Selenate > Elemental Selenium > Iron > Sulphate

Nitrate and selenate are the parameters of interest in terms of reduction, but first free oxygen needs to be removed as it is more energetically favourable than nitrate and selenium. Another consideration for the microbial community is the concentration of nitrate as it is often the control on reduction on mine sites with nitrate concentrations in the tens of mg/L range versus less than 10 mg/L of dissolved oxygen (DO) and the relatively low levels of selenium (typically in the tens to hundreds of µg/L range). However, as waste rock is flushed over time, residual nitrate will decrease and the community will then become more dependent on DO and selenium.

A SRF conceptual model is illustrated in Figure 3-2 and described in Table 3-1.

Figure 3-2 Saturated Rock Fill Conceptual Model

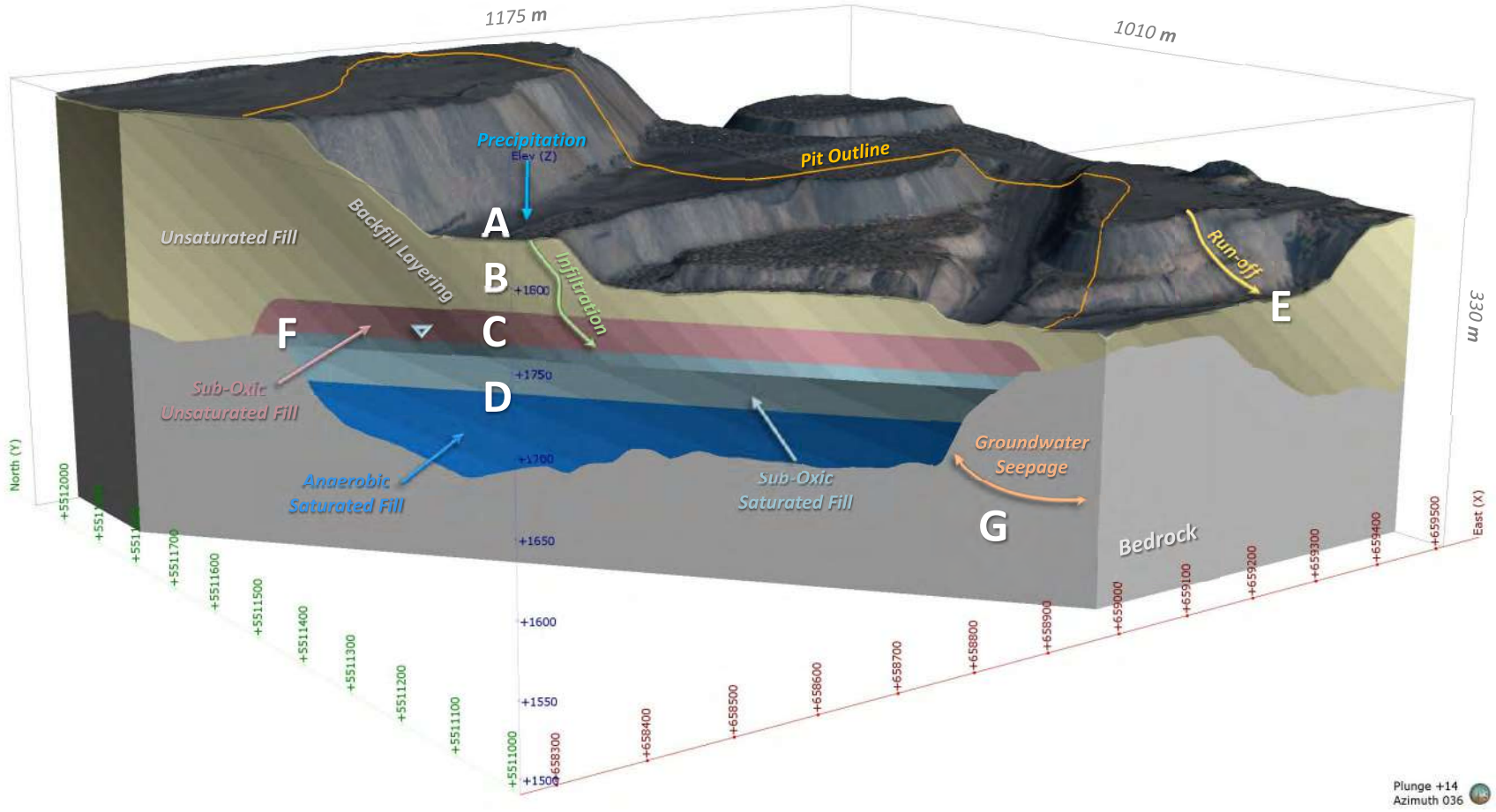


Table 3-1 Process Descriptions for Saturated Rock Fill Conceptual Model

Saturated Rock Fill Conceptual Model Component	Process Description
A. Precipitation and infiltration	Precipitation infiltrates ex-pit rock above saturated zone
	Soluble constituents of interest are transported
B. Weathering processes	Ex-pit rock continues to weather, generating constant source of constituents of interest
	Exception may be ANFO as it has likely flushed from system and nitrogen loading is likely low
C. Constituent of interest migrations to saturated zone	Constituent of interest load continues to increase as infiltration migrates towards saturated zone
	Dump layering from construction may result in tortuous path towards saturated zone
	Degree of water saturation increases towards saturated zone
	Lower rates of oxygen diffusion towards the saturated zone may lead to lower oxidation rates
	Suboxic microbial communities begin to reduce nitrate and selenium moving towards saturated zone
D. Saturated zones	Naturally occurring microbial communities remove dissolved selenium and nitrate in the presence of DOC
	The form of sequestered selenium is likely a mixture of selenite and elemental selenium
	Based on available DOC, up to 1 mg/L oxygen, 2 mg/L nitrate and 1 mg/L selenium can be passively treated
	The low amounts of nitrate being reduced may favour microbial ammonia production as opposed to nitrogen gas
	The saturated zone becomes more reducing with depth to at least ferric iron reduction
	Release of constituents of interest such as arsenic and nickel is not apparent with ferric iron reduction
	The potential to produce hydrogen sulphide throughout a passive system is low
E. Run-off	A small portion of precipitation will run off dump
	Run-off may partially infiltrate dump at gravity low, or continue on as surface water
F. Overflow and run-off	The water table appears to be below spill point
	If pit were to spill, overflow may contain less selenium than unsaturated mine rock contact water
G. Groundwater seepage or infiltration	A portion of ex-pit seepage will report to groundwater
	Groundwater could infiltrate SRF
	Infiltration groundwater could either dilute selenium and nitrate or be a source
	Seepage from saturated zone will report to groundwater
	Seepage to groundwater low in dissolved selenium and nitrate
	Overall contributions to groundwater likely greatest from saturated zone, but not the only source

ANFO = Ammonium Nitrate Fuel Oil; As = arsenic; DOC = dissolved organic carbon; SRF = Saturated Rock Fill.

SRFs can be passive or actively managed. Passive implies processes that occur with no active efforts made to encourage nitrate and selenium conversions (reduction) with dissolved nitrate and selenium from the overlying unsaturated waste rock leaching into the saturated rock zone and then being removed from solution.

An actively managed SRF uses the same biogeochemical processes as a passive SRF, except mine water is injected into the SRF at one location and extracted at another location. An example of an actively managed SRF is the full-scale trial SRF at EVO's F2 Pit (Figure 3-3). A carbon source is likely required (such as methanol, which is being used at EVO's F2 Pit), proportional to nitrate and DO concentrations because natural dissolved organic carbon (DOC) release rates in the SRFs do not appear sufficient to support a microbial community that can treat high nitrate concentrations (i.e., there is a stoichiometric carbon requirement, meaning the more nitrate present, the more carbon that is needed). Further, DO (up to 10 mg/L in surface water) needs to be depleted by the microbial community to create the anaerobic conditions required for denitrification, and a carbon source is needed to support this process. Selenium concentrations (~0.200 mg/L) are typically two to three orders of magnitude lower than nitrate concentrations (~30 mg/L). Thus, denitrification requirements primarily control the microbial community.

Figure 3-3 Saturated Rock Fill Full Scale Trial at Elkview Operations

The current Applied R&D Program at Teck was initiated approximately seven years ago (in 2011). Teck established a specific SRF R&D team in 2012, with specialists from various organizations contributing to the development of SRF technology. In that time, Teck's has advanced its understanding of SRF technology.

From 2016 to 2018 the primary focus of the Applied R&D Program has been the evaluation of the ability of SRFs to remove selenium and nitrate from mine-affected water at increasing scales of operation. Because of this focus, Teck's understanding of longevity, reversibility, risk and cost has advanced considerably over the last two years. A Failure Modes and Effects Analysis process was used to identify risks associated with the SRF technology in early 2016, which was then used to guide laboratory and field studies to evaluate those risks. In 2016, a pilot SRF trial was executed at EVO and run at 500 m^3/d, and included several lab tests (which occurred in parallel to support the pilot). These results were documented and used to support the development of a full-scale SRF trial at EVO. The trial was constructed through 2016 and 2017. The full-scale trial SRF at EVO has successfully operated since January of 2018 with near complete removal of selenium and nitrate in flows up to 10,000 m^3/d. The performance report for the full-scale SRF, which includes the detailed results and conclusions, was submitted to ENV, EMPR and KNC on January 31, 2019.

Given the successful results from the full-scale trial SRF at EVO Teck is progressing three work fronts for SRFs as outlined below:

1) **Planning to transition EVO SRF Full-scale Trial Phase 1 to Phase 2 Operations**: With the current water source (Natal Pit) to the EVO SRF partially depleted, a project has commenced to design, permit, construct and commission Phase 2 of the Full-scale Trial. Phase 2 will increase the treatment capacity of the EVO SRF Full-scale Trial to 20,000 m^3/d to treat water from Erickson Creek in addition to water from Natal Pit.

   The intention to transition to Phase 2 of the Full-Scale Trial was identified to ENV, EMPR and KNC in July 2018. A review of data from the full-scale trial with ENV, EMPR and KNC was completed at the beginning of August 2018. A risk summary was submitted to this group and a workshop to discuss uncertainties and risks held in October 2018. A project description was issued (by Teck) in early February 2019 to start the Mine Review Committee (MRC) process for the pending permit application submission. A workshop was completed in mid-February 2019 to review results from the performance report, to further review the remaining uncertainties and risk, and sample approaches to managing / mitigating these risks.

   Subsequent discussions have occurred since February 2019 and approval for early site works was issued by EMPR in June 2019. Early site works is scheduled to commence in August 2019 with construction of Phase 2 planned to be completed in 2020 along with ramping-up the SRF to the 20,000 m^3/d treatment capacity.

2) **FRO Eagle 4 SRF Field Trial:** The Eagle 4 SRF has been identified as an SRF that is currently available and in a relevant location. Because each SRF in the Elk Valley has unique characteristics, additional R&D is planned to predict how this SRF will function at a full-scale and to understand what will be required to scale up and ultimately transition to operation. Section 3.2.2 outlines the plan, and associated forecasted timeline, for an SRF field trial at

Eagle 4 followed by design, permitting and construction of the full-scale SRF and ultimately transition to full operations.

3) **LCO South Pit characterization**: South Pit at LCO has been identified as an SRF that will be available for use in 2019 and is in a relevant (i.e. a location near sources of selenium and nitrate that are targeted for mitigation) location. To evaluate the capacity of an SRF to improve water quality, the first step required is to characterize (e.g. understand the water table, existing water quality, etc.) the SRF before a pilot- or full-scale trial. This characterization will commence in 2019.

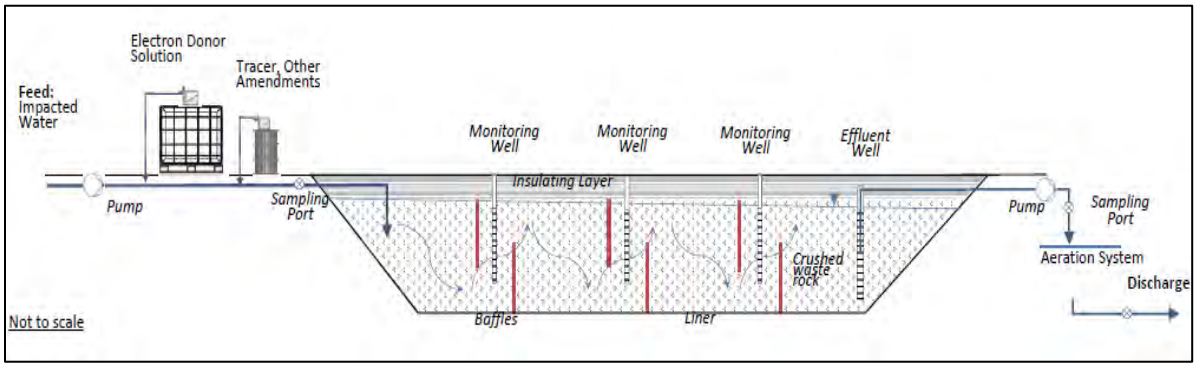
While the fundamental mechanisms are the same, there are site specific considerations for each SRF. The identification of, and planning for, other potential SRFs remains ongoing and will continue in parallel to the three work fronts outlined above. Research, to varying degrees, is expected to be required to characterize each SRF depending on (a) how different site specific considerations are from other SRFs and (b) the level of understanding developed through other SRFs and the overall SRF R&D program.

3.3.2 Gravel Bed Bioreactors

Gravel Bed Bioreactors (GBRs) are purpose-built in situ treatment facilities that function in a similar fashion, relying on the same biogeochemical processes to reduce nitrate and selenium, as SRFs. They have the advantage of providing the optionality to locate and size the reactors to suit specific site requirements. This technology has been used to treat selenium and nitrate in other contexts / environments (and at lower influent concentrations), and needs to be verified for conditions in the Elk Valley.

The GBR allows for the establishment of a stable anaerobic biofilm in a packed bed bioreactor that provides the reducing conditions required to remove selenium and nitrate. The GBR systems combine the key design elements of conventional bioreactors and engineered treatment wetlands in a relatively simple treatment process. Under the stable reducing conditions in the anaerobic GBR, selenium is reduced and immobilized within the biofilm on the gravel matrix in the bioreactor. Figure 3-4 is a schematic of a typical GBR.

Figure 3-4 Gravel Bed Bioreactor Schematic



Teck is progressing work on two fronts as outlined below to verify this technology in the Elk Valley and support advancing to full scale implementation:

1) **Advancing a GBR Full Scale Verification Project at FRO**: The FRO GBR Verification Project aims to demonstrate the GBR technology. A permit application for a GBR designed with a treatment capacity of 2,500 m^3/day is planned to be submitted in 2019. The GBR is planned to be constructed in 2020 and operated in 2021 to generate data to verify the technology's applicability in the Elk Valley. Based on the results of the verification project, GBRs may be assessed as an alternative treatment technology for full scale implementation at FRO and potentially at other locations in the Elk Valley.

2) **Evaluating the potential of GBRs at other locations (including at LCO)**: Several opportunities for implementing GBR technology exist, including at LCO, identified during a scan of potential locations in the Elk Valley. Locations and plans for future GBR projects are under development and ongoing in parallel to the verification project at FRO.

3.3.3 Other Alternative Treatment Technologies

In addition to SRFs and GBRs, research on alternative treatment technologies is ongoing. One area of research is the assessment of passive and semi passive treatment options. A focus of this research is on the use of zero valent iron as a semi passive, non-biological treatment option. Lab results to date have been promising and show reduction of selenium, nitrate and other metals from mine water. Teck completed five small scale studies at three operations in the Elk Valley in 2018. Results from this trial are currently being summarized and will be used to guide further evaluation of zero valent iron technology in the future.

4 Modelling and Planning Basis

4.1 Overview

The 2019 IPA Report identifies that mitigation measures included in the 2019 IPA need to meet the following three criteria:

- Have quantified effectiveness.
- Are required to meet Compliance Limits and/or SPOs.
- Are permitted (or can be permitted) and can be relied on to be effective.

As a result the 2019 IPA is based on the application of biologically-based AWT and diversions (where practical that support efficient treatment) to manage selenium and nitration concentrations in the Elk Valley.

The alternative treatment mitigation plan, on the other hand, incorporates alternative mitigation technologies to manage selenium and nitration concentrations. The assessment quantified effectiveness and ability to permit continues to evolve for individual mitigation alternatives with each alternative at different stages of development. This alternative treatment mitigation plan incorporates SRFs with the planning basis and model inputs for SRFs outlined in this section.

Like the development of individual alternative mitigation technologies, the alternative treatment mitigation plan will continue to evolve and be adapted based on the development stage of available alternative mitigations. The following are not integrated into the alternative treatment mitigation plan (nor the RWQM) at this time but may be in at a later date:

- Nitrate Source Control, as described in Section 3.2.1, will help to reduce nitrate release from waste rock and ultimately improve water quality. Once the estimated reduction of nitrate loss from improved blasting practices is quantified the nitrate source terms in the RWQM will be adjusted to reflect the change. Nitrate source control thus has the potential to have a substantial impact on downstream water quality as well as the sizing, timing and design of water treatment.

- GBRs, as described in Section 3.3.2, are currently being advanced through a verification scale GBR at FRO. At this time estimated GBR treatment capacity has not been incorporated into the alternative treatment mitigation plan nor into the RWQM. It is envisioned that following the verification scale GBR at FRO, and further assessment of GBR locations in the Elk Valley, that these may be incorporated into the alternative treatment mitigation plan to augment / replace AWTF and / or SRFs.

4.2 Planning Basis and Inputs

4.2.1 Planning Basis

The 2019 IPA was developed based on refinements and additions to both the management decisions (i.e., the sources to target for treatment and how quickly treatment could be constructed) and inputs (i.e., the effluent quality from treatment, release rates, and water availability for treatment) used to set the EVWQP IIP. These collectively constitute the planning basis on which the 2019 IPA was formed. The 2019 IPA planning basis is described in Section 2.3 of the 2019 IPA Report. The alternative mitigation plan described in this annex has same planning basis, with the exception of the SRF inputs described below.

4.2.2 Saturated Rock Fill Inputs

The planning basis inputs related to SRFs is based current understanding of the technology and of the mine and water management plans. The specific input decisions are put forward for the purposes of illustrating the potential for the technology to influence the IPA in the future, and would be refined with updated technical and mine planning information as part of a future IPA. The main SRF inputs are the backfilled pit volumes and dates available.

Backfilled pit/potential SRF water volumes and dates available to be used for water treatment (not accounting for treatment project durations to bring an SRF into operations) at Teck's operations in the Elk Valley are shown in Table 4-1. Backfilled pit volumes and timing were estimated with mine planning / operations input in 2019. The date pit available to incorporate water treatment infrastructure is the estimated date when backfilling of the identified SRF is at a point that water treatment infrastructure for an SRF could start to be installed. An estimated two year construction and commissioning period (based on the EVO SRF Full-Scale Trial Phase 2 preliminary schedule) would need to be added to these dates to account for the time required to bring the SRFs into operation. This duration would be further evaluated on a project specific basis and is dependant on the size of the SRF and the distance of the SRF from

intended water source (to be treated). Backfilled pit water volumes were determined using an estimated void space of 29% within the backfilled pits which is supported by field data from drilling programs at FRO's Eagle 4 backfilled pit and at EVO's F2 backfilled pit (EVO SRF).

Table 4-1 Identified Backfilled Pit/Saturated Rock Fill Volumes at Teck's Elk Valley Operations

Backfilled Pit / Saturated Rock Fill	Backfilled Pit Volume (m^3)	Backfilled Pit Water Volume (m^3)	Date Pit Available to Incorporate Water Treatment Infrastructure
EVO - F2 Pit	24,000,000	7,000,000	Now
EVO - Baldy Ridge 3	5,600,000	1,620,000	2028
LCO - South Pit	5,800,000	1,680,000	2019
LCO - NLX Pit	17,900,000	5,190,000	2023
FRO - Eagle 4	5,500,000	1,600,000	2019
FRO - Lake Mountain (Swift) Pit	52,800,000	15,310,000	2025
FRO - Eagle 6	3,500,000	1,020,000	To be Determined
TOTAL	**115,100,000**	**33,420,000**	

EVO = Elkview Operations; FRO = Fording River Operations; LCO = Line Creek Operations; NLX = North Line Creek Expansion.

Estimated SRF treatment capacity was calculated based on results from the EVO SRF Full Scale Trial . The following logic was used:

1) Treatment Zone – In the EVO SRF full scale trial a vertical density gradient was observed within the backfilled pit where water density increased with pit depth (density stratification). The current understanding is that this can occur because as water resides in a backfilled pit, it has the opportunity to dissolve elements within the backfill creating higher total dissolved solids. When the water intended for treatment was injected into the F2 SRF it was observed to flow across the top of the existing water in the pit. For the EVO SRF the depth from the water table to the level at which water being injected for treatment remains above the more dense water existing within the pit is ~15m. This was identified as the effective treatment vertical thickness.

   The effective treatment vertical thickness was compared to the vertical thickness of the saturated zone (i.e. from the water table to pit bottom) which, for the EVO SRF, is ~70m. Taking the ratio of the effective treatment vertical thickness to the vertical thickness of the saturated zone, 15:70 (or 0.21), provides an estimate that ~21% of the saturated zone thickness is effective for treatment. This was used to calculate a lower limit of the saturated zone effective for treatment and does not consider steps that could be taken to further expand this treatment zone (such as dewatering a portion of existing water in a backfilled pit to minimize density differences) and increase the effective treatment thickness. Applying a ~21% saturated zone thickness for treatment (based on EVO SRF) to the estimated water volumes of individual backfilled pits (Table 4-1) results in the estimated treatment volume of each SRF shown in Table 4-2.

2) Treatment Capacity – Zero-order and first-order reaction rates (for de-nitrification and selenium reduction), based on the EVO SRF Full Scale Trial, were used to determine potential treatment capacity of individual SRFs. The more conservative of these reaction rates (i.e. zero-order reaction rates) were used to estimate SRF treatment capacity. Furthermore, estimated treatment capacity also considers estimated influent nitrate concentrations. An influent nitrate concentration of 150mg/L was used which, in general, is on the high end of projected future instream nitrate

concentrations (in streams requiring treatment). To calculate the residence time for selenium and nitrate removal, zero-order reaction rates and future influent nitrate concentrations of 150mg/L result in an estimated hydraulic residence time of 27 days. This was used to estimate the treatment capacities of individual SRFs shown in Table 4-2.

Table 4-2 Potential Saturated Rock Fill Treatment Capacities at Teck's Elk Valley Operations

Saturated Rock Fill	Backfilled Pit Water Volume (m^3)	Treatment Volume (m^3)	Estimated Treatment Capacity (m^3/d)	Date Pit Available to Incorporate Water Treatment Infrastructure
EVO - F2 Pit	7,000,000	1,491,000	82,000	Now
EVO - Baldy Ridge 3	1,620,000	348,000	19,000	2028
LCO - South Pit	1,680,000	360,000	20,000	2019
LCO - NLX Pit	5,190,000	1,112,000	61,000	2023
FRO - Eagle 4	1,600,000	342,000	18,000	2019
FRO - Lake Mountain (Swift) Pit	15,310,000	3,281,000	182,000	2025
FRO - Eagle 6	1,020,000	218,000	12,000	To Be Determined
TOTAL	**33,420,000**	**7,152,000**	**394,000**	

Using the estimated treatment capacities shown in Table 4-2, SRFs are modelled using the same nitrate and selenium effluent concentrations as AWTF. This is described in the planning basis section (Section 2.3) of the 2019 IPA Report (Table 2-2).

5 Alternative Mitigation Plan and Projected Water Quality Concentrations

5.1 Alternative Mitigation Plan

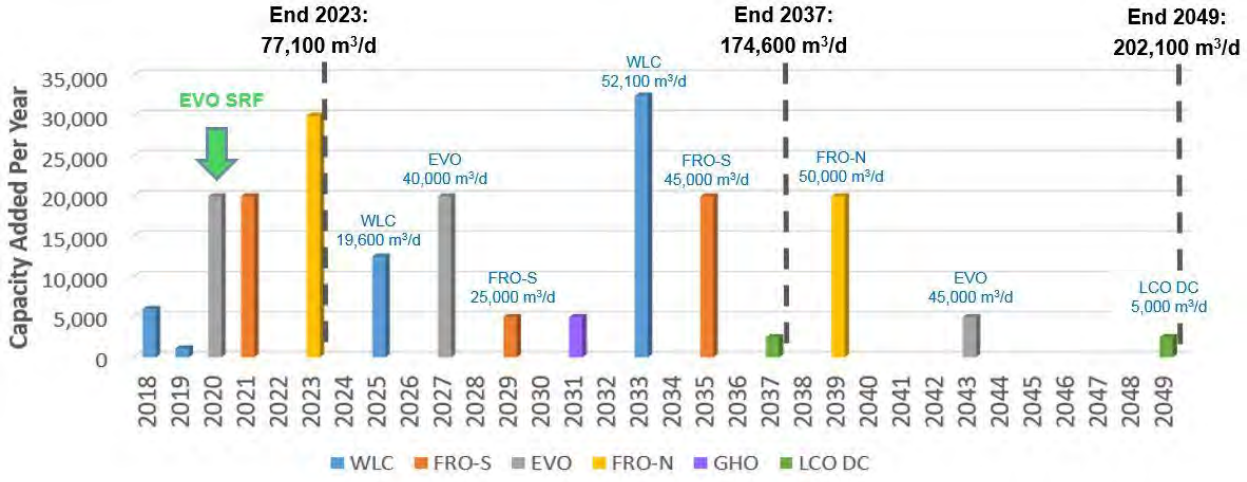
The summary of water quality mitigation, in chronological order, for the alternative treatment mitigation plan is shown in Figure 5-1 The alternative treatment mitigation plan has the same total treatment volume as the 2019 IPA (204,600 m^3/d). The differences between the alternative treatment mitigation plan and the 2019 IPA are:

- The EVO SRF (treatment capacity of 20,000 m^3/d) is planned to be in place and fully effective by the end of 2020. This is ~21 months sooner than the EVO AWTF 1 in the 2019 IPA. In this alternative mitigation plan, the EVO SRF replaces the EVO AWTF and improves water quality concentrations sooner.
- For mitigation after the FRO AWTF-S Phase I, AWT capacity is augmented or replaced with SRF capacity based on the estimated available capacities, and dates available for use for water treatment, for different SRFs shown in Table 4-2. Table 5-1 provides an extension of Table 4-2 to show which AWTFs identified in the 2019 IPA would be augmented and/or replaced by SRFs. Including the replacement of EVO AWTF 1 with the EVO SRF, ~153,000 m^3/d of the 204,600 m^3/d total treatment required could be achieved via SRF water treatment facilities. SRF fully effective dates are consistent with AWTF fully effective dates with some key exceptions:
    - The Eagle 4 SRF is shown as fully effective by June 30, 2023, 6 months earlier than FRO AWTF-N Phase I to take advantage of moving from a field trial (planned to be

constructed in 2019 and into 2020, and trial operations starting in late 2020) directly into full operation following design, permitting and construction of the full Eagle 4 SRF in 2021 and 2022.

- EVO SRF Phase II is shown as fully effective by December 31, 2025, two years earlier then EVO AWTF Phase II is planned in the 2019 IPA. With Phase I of the EVO SRF planned to be fully effective by December 31, 2020 this provides five years of operation of Phase I and adequate time to expand for Phase II. This also helps to manage and eliminate potential exceedances to selenium limits at the Michel Creek Compliance point that are projected to occur in the 2019 IPA in 2026 and 2027.

Figure 5-1 Projected Water Quality Mitigation Dates for the Alternative Treatment Mitigation Plan between 2018 and 2050



Notes: Treatment assumed to be fully effective by the end of December in the year indicated.
Values in blue font are the cumulative treatment capacities

Table 5-1 Saturated Rock Fill Treatment Capacity to Augment / Replace Active Water Treatment Capacity in the Alternative Treatment Mitigation Plan

Saturated Rock Fill	Estimated Treatment Capacity (m^3/d)	Date Pit Available to Incorporate Water Treatment Infrastructure	AWT Treatment Capacity Replaced (m^3/d)	Notes
EVO - F2 Pit	82,000	Now	45,000	Replaces all AWT capacity at EVO
EVO - Baldy Ridge 3	19,000	2028	0	
LCO - South Pit	20,000	2019	12,500	Replaces WLC AWTF Phase III
LCO - NLX Pit	61,000	2023	32,500	Replaces WLC AWTF Phase IV
FRO - Eagle 4	18,000	2019	18,000	Replaces 18,000 m^3/d of FRO AWTF-N Phase I
FRO - Lake Mountain (Swift) Pit	182,000	2025	45,000	Replaces FRO AWTF-S Phase II and Phase III. Replaces FRO AWTF-N Phase II.
FRO - Eagle 6	12,000	To be Determined	0	
TOTAL	**394,000**		**153,000**	

AWT = Active Water Treatment; AWTF = Active Water Treatment Facility; EVO = Elkview Operations; FRO = Fording River Operations; LCO = Line Creek Operations; NLX = North Line Creek Expansion; SRF = Saturated Rock Fill; WLC = West Line Creek.

The alternative treatment mitigation plan is further detailed in Table 5-2. For comparison, the IIP treatment sequence (with updates to the timing of the first three AWTFs [WLC AWTF, FRO AWTF-S and EVO AWTF Phase I]) since the development of the EVWQP, is shown in Table 5-3. Both Table 5-2 and Table 5-3 are organized by site. A summary of the comparison between the alternative treatment mitigation plan, the 2019 IPA and the IIP treatment sequence is shown in Table 5-4.

Table 5-2 Alternative Treatment Mitigation Plan

Site	Sources Targeted for Mitigation	Treatment	Hydraulic Capacity (m^3/d)	Associated Diversions and Conveyance of Mine-Influenced Water	Fully Effective Date [(a)]
FRO	Swift, Cataract and Kilmarnock creeks	FRO AWTF-S Phase I	20,000	• Diversion of Upper Kilmarnock watershed • Convey mine-influenced water to treatment • Discharge to the Fording River	December 31, 2021
		FRO - Lake Mountain (Swift) Pit Saturated Rock Fill (SRF)	45,000		December 31, 2029
	Clode Creek, North Spoil and Swift Pit	FRO Eagle 4 SRF	18,000	• Convey mine-influenced water to treatment • Discharge to the Fording River	June 30, 2023
		FRO AWTF-N Phase I	12,000	• Convey mine-influenced water to treatment • Discharge to the Fording River	December 31, 2023
LCO	West Line Creek and Line Creek	WLC Phase I	6,000	• Diversion of Upper Line Creek, Horseshoe Creek and No Name Creek • Convey mine-influenced water to treatment • Discharge to Line Creek	December 31, 2018
		WLC Phase II	1,100		December 31, 2019
		LCO South Pit SRF	12,500		December 31, 2025
		LCO NLX Pit SRF	32,500		December 31, 2033
	LCO Dry Creek	LCO Dry Creek Phase I	2,500	• Convey mine-influenced water to treatment • Discharge to the Fording River	December 31, 2037
		LCO Dry Creek Phase II	2,500		December 31, 2049
EVO	Bodie, Gate and Erickson creeks	EVO SRF Phase I	20,000	• Convey mine-influenced water to treatment • Discharge to Erickson Creek	December 31, 2020
		EVO SRF Phase II	20,000		December 31, 2025
		EVO SRF Phase III	5,000		December 31, 2043
GHO	Leask, Wolfram, Thompson and Greenhills creeks	GHO Phase I	5,000	• Convey mine-influenced water to treatment • Discharge to Thompson Creek	December 31, 2031
		GHO Phase II	2,500		Post-2100
Total			**204,600**		

[(a)] In the 2017 RWQM, the fully effective date is the date when the treatment facility has been built, seeded, commissioned and is effective at the hydraulic capacity listed above.

AWTF = Active Water Treatment Facility; EVO = Elkview Operations; EVWQP = Elk Valley Water Quality Plan; FRO = Fording River Operations; GHO = Greenhills Operations; LCO = Line Creek Operations; RWQM = Regional Water Quality Model; WLC = West Line Creek.

Table 5-3 Initial Implementation Plan Developed as Part of the Elk Valley Water Quality Plan (2014)

Site	Sources Targeted for Treatment	Treatment Facility	Hydraulic Capacity (m^3/d)	Associated Diversions	Associated Conveyance of Mine-Influenced Water	Fully Effective Date in 2017 RWQM
FRO	Swift, Cataract and Kilmarnock creeks	Fording River South	20,000	Diversion of Upper Kilmarnock watershed and Upper Brownie watershed	• Convey mine-influenced water to treatment • Discharge to the Fording River	Q4 2021
	Clode Creek, North Spoil and Swift Pit	Fording River North Phase I	15,000	–	• Convey mine-influenced water to treatment • Discharge to the Fording River	Q4 2023
		Fording River North Phase II	15,000	–		Q4 2030
LCO	West Line Creek and Line Creek	WLC Phase I	7,500	–	• Convey mine-influenced water to treatment • Discharge to Line Creek	5,500 m^3/d in Q1 2018 1,600 m^3/d in Q1 2019
		WLC Phase II	7,500	Diversion of Upper Line Creek		Q4 2033
	LCO Dry Creek	LCO Dry Creek	7,500	–	• Convey mine-influenced water to treatment • Discharge to the Fording River	Q4 2029
EVO	Bodie, Gate and Erickson creeks	EVO Phase I	30,000	Diversion of Upper Erickson watershed and South Gate Creek	• Convey mine-influenced water to treatment • Discharge to Erickson Creek	Q2 2022
		EVO Phase II	20,000			Q4 2025
GHO	Leask, Wolfram, Thompson and Greenhills creeks	GHO	7,500	–	• Convey mine-influenced water to treatment • Discharge to Thompson Creek	Q4 2027
Total			**130,000**			

EVO = Elkview Operations; FRO = Fording River Operations; GHO = Greenhills Operations; LCO = Line Creek Operations; RWQM = Regional Water Quality Model; WLC = West Line Creek.

Table 5-4 Treatment Capacity and Timing Comparison between the Alternative Treatment Mitigation Plan, the 2019 Implementation Plan Adjustment and the Initial Implementation Plan

Modelled Treatment	Alternative Treatment Mitigation Plan		2019 Implementation Plan Adjustment		Initial Implementation Plan	
	Date Fully Effective	Hydraulic Capacity (m^3/d)	Date Fully Effective	Hydraulic Capacity (m^3/d)	Date Fully Effective	Hydraulic Capacity (m^3/d)
West Line Creek (WLC) Phase I	December 31, 2018	6,000	December 31, 2018	6,000	June 30, 2014	7,500
WLC Phase II	December 31, 2019	1,100	December 31, 2019	1,100	-	-
Fording River Operation (FRO) AWTF-S Phase I	December 31, 2021	20,000	December 31, 2021	20,000	December 31, 2019	20,000
Elkview Operation (EVO) Saturated Rock Fill (SRF)	December 31, 2020	20,000				
Elkview Operation (EVO) AWTF Phase I			September 30, 2022	20,000	December 31, 2021	30,000
FRO Eagle 4 SRF	June 30, 2023	18,000				
FRO-N Phase I	December 31, 2023	12,000	December 31, 2023	30,000	December 31, 2023	15,000
Line Creek Operations (LCO) South Pit SRF	December 31, 2025	12,500			-	-
WLC Phase III			December 31, 2025	12,500	-	-
EVO SRF Phase II	December 31, 2025	20,000				
EVO Phase II			December 31, 2027	20,000	December 31, 2025	20,000
FRO Lake Mountain Pit SRF	December 31, 2029	45,000				
FRO-S Phase II			December 31, 2029	5,000	-	-
Greenhills Operation (GHO) Phase I	December 31, 2031	5,000	December 31, 2031	5,000	December 31, 2027	7,500
Line Creek Operations (LCO) NLX Pit SRF	December 31, 2033	32,500			-	-
WLC Phase IV			December 31, 2033	32,500	January 1, 2032	7,500
FRO-S Phase III			December 31, 2035	20,000	-	-
Line Creek Operation (LCO) Dry Creek Phase I	December 31, 2037	2,500	December 31, 2037	2,500	January 1, 2028	7,500
FRO-N Phase II			December 31, 2039	20,000	December 31, 2031	15,000
EVO SRF Phase III	December 31, 2043	5,000			-	-
EVO Phase III			December 31, 2043	5,000	-	-
LCO Dry Creek Phase II	December 31, 2049	2,500	December 31, 2049	2,500	-	-
GHO Phase II	2100+	2,500	2100+	2,500	-	-
Total Hydraulic Capacity (m^3/d)		**204,600**		**204,600**		**130,000**

The alternative treatment mitigation plan, like the 2019 IPA, has a larger total treatment volume than the IIP (e.g., total treatment on the order of 200,000 m^3/d compared to 130,000 m^3/d) and applies to both the Permitted and Planned Development Scenarios (this is further described in the 2019 IPA Report).

5.2 Projected Water Quality Concentrations

Water quality concentrations were projected for the alternative treatment mitigation plan using the RWQM and the planning basis described in Section 2.3 of the 2019 IPA Report. This is provided for illustrative purposes. The total capacity was the same as for the 2019 IPA, with the same effluent concentrations assume for SRFs. As a result, the projected water quality concentrations for the alternative treatment mitigation plan are similar to those in the 2019 IPA. The differences in the projections were a result of timing.

In the case of the EVO SRF, and the ability to have it available earlier than the EVO AWTF 1 (i.e. EVO SRF fully effective end of 2020 compared to EVO AWTF 1 fully effective September 2022) could result in in lower projected concentrations for the near term. For this reason the plots of most interest comparing the 2019 IPA (inclusive of EVO AWTF 1) and the alternative treatment mitigation plan (inclusive of EVO SRF in place of EVO AWTF 1) for selenium at both the EVO Michel Creek Compliance location (Figure 5-2 and Figure 5-3) and Koocanusa Reservoir (Figure 5-4 and Figure 5-5) are shown below. As shown following the alternative treatment mitigation plan could result in:

- Meeting selenium compliance limits ~21 months sooner at the EVO Michel Creek Compliance location and;
- Meeting limits at Lake Koocanusa earlier compared to the 2019 IPA (i.e. after FRO AWTF-S is fully effective (end of 2021) or sooner depending on actual instream concentrations compared to after EVO AWTF 1 is fully effective in September 2022 under the 2019 IPA).

Although not shown on the figures below, but shown in Table 5-4, under the alternative treatment mitigation plan EVO SRF Phase II could be in place and fully effective by December 31, 2025. This would help to manage and eliminate potential exceedances to selenium limits at the Michel Creek Compliance point that are projected to occur in the 2019 IPA in 2026 and 2027 (Figure 5-2 and Figure 5-3).

Figure 5-2 Projected Selenium Concentrations at the Michel Creek Compliance Point Under the 2019 Implementation Plan Adjustment (i.e. including EVO AWTF 1)

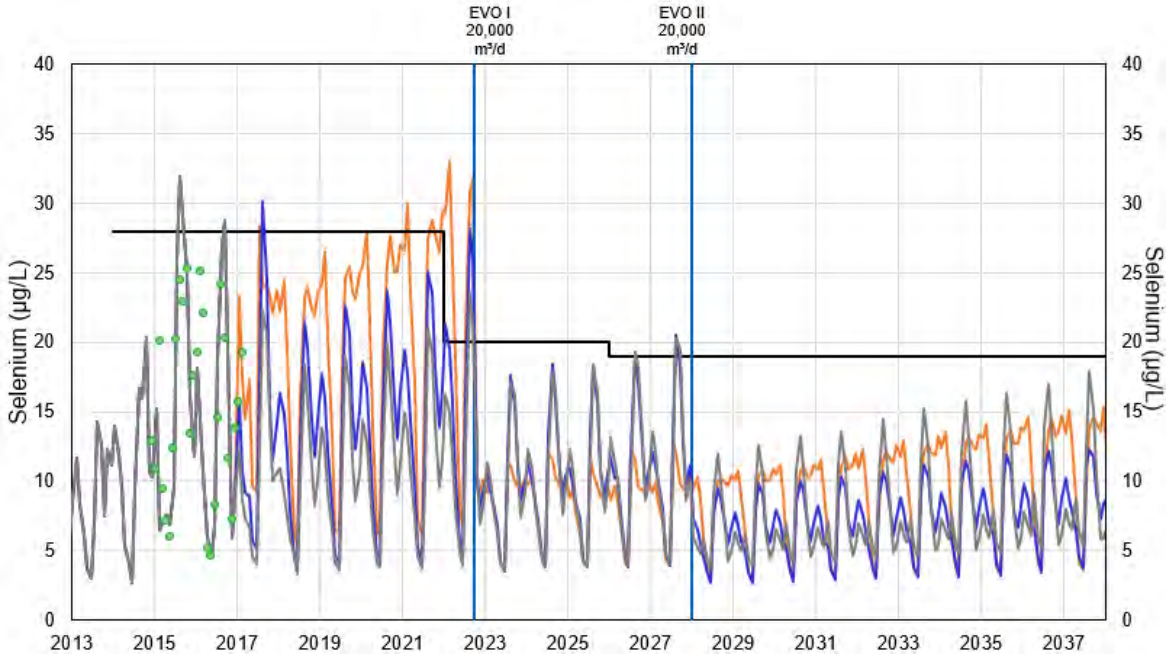


Figure 5-3 Projected Selenium Concentrations at the Michel Creek Compliance Point Under the Alternative Treatment Mitigation Plan (i.e. including EVO SRF in place of EVO AWTF 1)

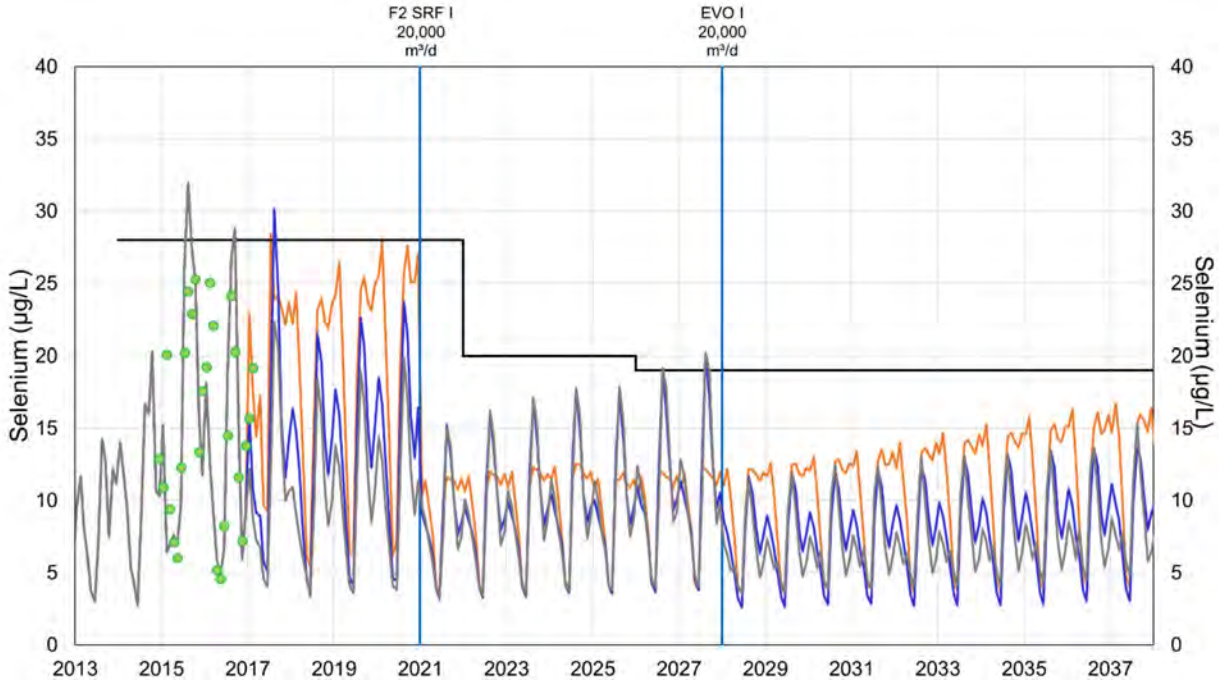


Figure 5-4 Projected Selenium Concentrations at Koocanusa Reservoir Under the 2019 Implementation Plan Adjustment (i.e. including EVO AWTF 1)

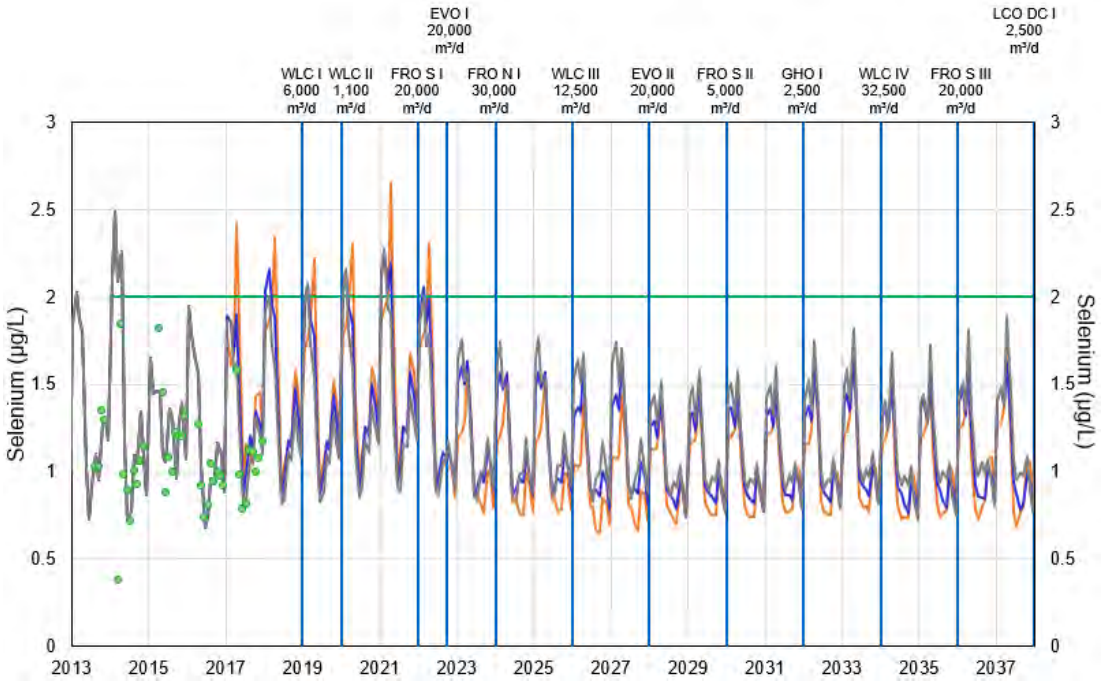
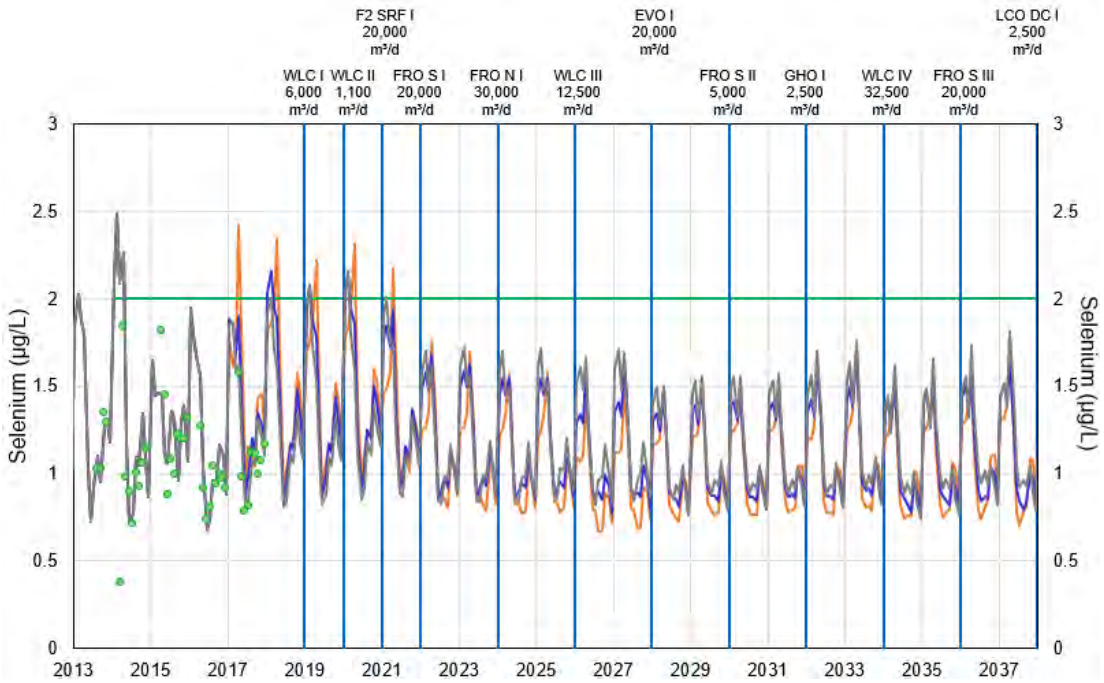


Figure 5-5 Projected Selenium Concentrations at Koocanusa Reservoir Under the Alternative Treatment Mitigation Plan (i.e. including EVO SRF in place of EVO AWTF 1)



6 Next Steps and Future Adjustments of the Implementation Plan

As R&D continues to advance, alternative options to manage water quality will continue to be identified, better understood, and developed for implementation to help meet the objectives of the EVWQP. This includes both source control technologies (that will help reduce the load on the environment and the amount of water requiring treatment) and alternative treatment technologies (to augment and/or replace existing biologically-based AWTFs).

In parallel, Teck will continue to work with EMPR, ENV and KNC to incorporate alternative options to manage water quality into future adjustment of the implementation plan, following an adaptive management approach. This alternative treatment mitigation plan, as presented in this document, is intended to help continue the discussion with respect to integrating alternative technologies into the implementation plan. The alternative treatment mitigation plan will continue to evolve to reflect updated understanding and new information (from ongoing research, monitoring, supporting studies, etc.).

7 References

Bianchin M, A Martin, and J Adams, 2013. In-Situ Immobilization of Selenium within the Saturated Zones of Backfilled Pits at Coal-Mine Operations: BC Mine Reclamation Symposium, September.

Kirk LB. 2014. In Situ Microbial Reduction of Selenate in Backfilled Phosphate Mine Waste, S.E. Idaho. Montana State University Doctoral Dissertation.

APPENDIX 6.19-2: ELK VALLEY WATER QUALITY PLAN – FIVE YEAR UPDATE

Elk Valley Water Quality Plan

Five Year Update

Teck

September 2019

Elk Valley Water Quality Plan: Five Year Update

More than 4,000 Teck employees live and work in the Elk Valley and are committed to protecting the environment. That's why we are taking action to ensure that water quality is protected in the valley now and for generations to come.

Over the five years since it was launched, significant progress has been made towards achieving the objectives of the Elk Valley Water Quality Plan, a long-term approach to address the management of substances released by mining activities in the Elk Valley.

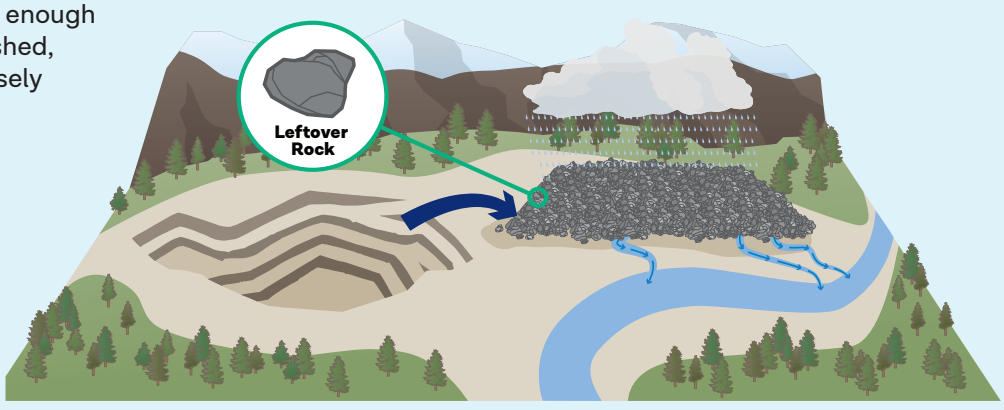
Our goal is to stabilize and reverse the trend of selenium and other substances to ensure the ongoing health of the watershed, while at the same time allowing for continued sustainable mining in the region.

The first water treatment facility was built and is now successfully operating at our Line Creek Operations. We are applying what we've learned to build a larger tank-based plant which is under construction now at our Fording River Operations. As a result, we are seeing reductions in selenium and nitrate concentrations downstream of the Line Creek facility and we expect further significant reductions in other areas as future facilities come on line.

One of the most exciting advancements has come from our Research and Development program, which has developed a new form of water treatment using Saturated Rock Fills (SRF). Our first SRF has been commissioned at Elkview Operations and is achieving near complete removal of selenium and nitrate. SRF water treatment technology can help to achieve water quality objectives more quickly and efficiently than other forms of treatment. The SRF at Elkview is treating up to 10 million litres of water each day and we have plans to expand the Elkview SRF to treat 20 million litres per day.

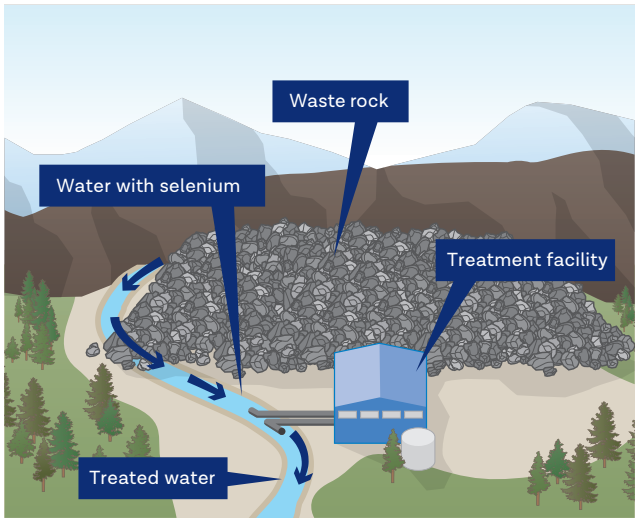
The Challenge

Water quality challenges in the Elk Valley are connected to the long history of mining in the region. The mining process generates large quantities of leftover rock that contains naturally-occurring substances such as selenium, an element that is essential for human and animal health in small amounts. Water from both precipitation and runoff flows through these rock piles and carries selenium and other substances, such as nitrate, into the local watershed. If present in high enough concentrations in the watershed, these substances can adversely affect aquatic health.



We are building water treatment facilities at our Elk Valley operations to ensure the health of the watershed.

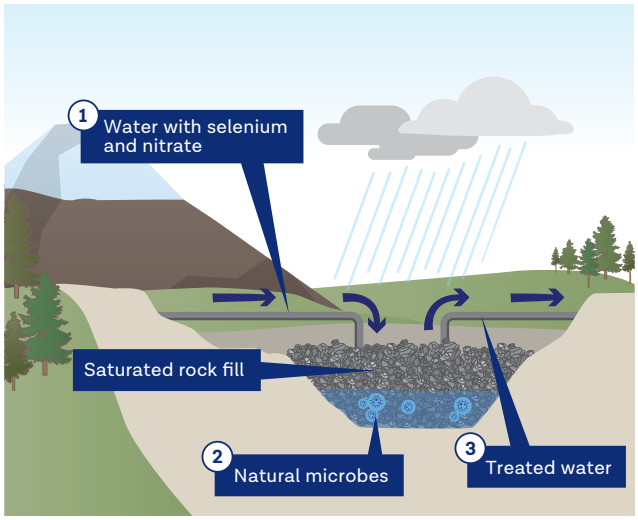
We are using innovative water treatment technologies to achieve the objectives of the Elk Valley Water Quality Plan.



Tank-Based Plants

This biological treatment process removes nitrate and transforms selenium into a solid form through a process that includes the following steps:

1. Biological treatment to convert dissolved forms of selenium to solid form
2. Nitrate is converted into inert nitrogen gas and safely released
3. Solid selenium is extracted and safely disposed of in a secure onsite facility
4. Safely treated water is discharged



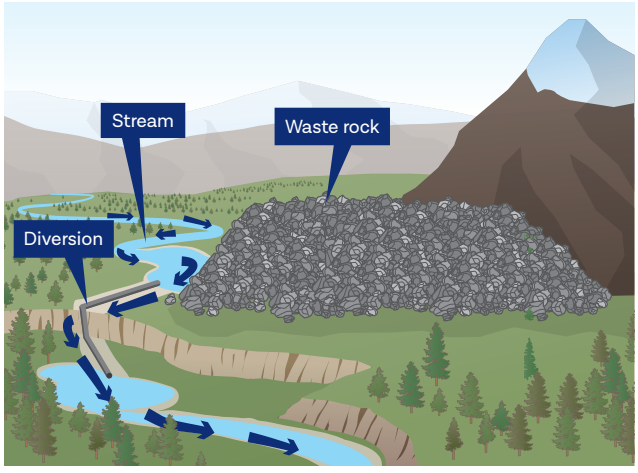
Saturated Rock Fill

Saturated Rock Fills use naturally-occurring biological processes in former mining areas that have been backfilled with rock and saturated with water to remove selenium and nitrate:

1. Water for treatment is injected into the SRF
2. Natural bacteria convert dissolved forms of selenium into a solid form which remains securely stored in the SRF and nitrate to inert nitrogen gas which is safely released
3. Safely treated water is pumped out of the SRF and discharged

The benefits of SRF over other forms of water treatment:

- Quicker to build and less complex to operate
- Lower cost and more sustainable
- Treat larger volumes of water
- Use less energy
- Smaller environmental footprint



Water Diversions

Clean water diversions involve the construction of earthen dikes, channels or other physical barriers and/or pipes to direct clean water around mining activities.

Monitoring

We are conducting extensive studies and monitoring of water quality and aquatic health which includes regular water quality sampling at approximately 100 stations in the Elk Valley. To date, regional monitoring indicates that current levels of selenium and other substances are not impacting populations of fish or birds.

Monitoring shows that selenium concentrations have been reduced downstream of our operational water treatment plant at Line Creek as a result of water treatment and we expect further significant reductions as the Fording and Elkview facilities come on line.

Sharing Monitoring Results

Teck is committed to being transparent with stakeholders as we implement the Elk Valley Water Quality Plan. We make data and results from ongoing water quality, aquatic and animal health research and monitoring undertaken as part of the Plan available, and we will continue to share those results going forward. This includes Annual Reports completed by an Environmental Monitoring Committee comprised of an independent scientist and representatives from the B.C. Government, Ktunaxa Nation Council, Interior Health Authority, and Teck.

Monitoring reports related to the Elk Valley Water Quality Plan can be found at: **teck.com/elkvalley**

Research and Development

Teck is investing $30 million this year in over 20 research and development projects. These include projects to continue to improve our understanding of water quality, source control and treatment options.

Three examples of this work are:

- **Alternative treatment technologies**
  We are exploring the use of smaller water treatment facilities that can be built much closer to where the treatment is needed.
- **Nitrate prevention**
  This includes using liners that prevent explosives that contain nitrate – used in the mining process – from coming in contact with water.
- **Waste Rock Covers**
  We are continuing to evaluate different forms of physical covers for waste rock piles ranging from vegetative to geosynthetic covers.

Community Engagement

Throughout 2019, we'll be providing opportunities for you to learn more about the Elk Valley Water Quality Plan, our progress and our challenges, and to provide input into the ongoing implementation of the plan.

The Elk Valley Water Quality Plan is an adaptive plan that will continue to be updated based on new technology and learnings as well as feedback we receive along the way.

We will be holding public information sessions in the region in Fall 2019. More details will be provided.

To learn more and provide feedback please visit **teck.com/elkvalley** or contact us at

- 1.855.806.6854
- **feedbackteckcoal@teck.com**

If you leave your contact details, we will respond directly to you.

Teck

APPENDIX 6.19-3: ENVIRONMENTAL MONITORING COMMITTEE – 2019 PUBLIC REPORT

PERMIT 107517

ENVIRONMENTAL MONITORING COMMITTEE

2019 Public Report

About this Report

This report is prepared by the members of the Environmental Monitoring Committee, and produced and distributed with the support of Teck. For information about the Environmental Committee and what it does, please see page 9.

This report summarizes the 2018 results presented in the technical reports that Teck submitted to the Ministry of Environment and Climate Change Strategy. These technical reports are available to the public and you can find them at https://www.teck.com/responsibility/sustainability-topics/water/water-quality-in-the-elk-valley/research-and-monitoring-reports/

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Message from the Environmental Monitoring Committee

Dear readers,

This is our fifth annual summary of the environmental reports we have reviewed. You can find our previous reports at www.teck.com/ElkValley.

Teck's environmental monitoring programs in the Elk Valley produce a lot of complex information. We've done our best to highlight what we feel are the important findings in Teck's results and analyses from 2018. The technical reports that form the basis of our summary are available to the public, and you can access them if you wish. We've provided a list of these reports, and directions on where to find them, at the end of this report.

This was another busy and productive year for our committee. We met five times in person for a week each time and had 15 conference calls. We reviewed 65 reports, study designs, and data packages, and provided 1,442 pieces of technical advice to Teck and the Director, Regional Operations Branch, Ministry of Environment and Climate Change Strategy. We are proud to be members of this committee and we are committed to providing scientific recommendations to improve, broaden, and support environmental monitoring in the Elk Valley.

In conjunction with the release of this report, we hold an annual public meeting. This meeting is intended to give you an opportunity to ask us questions about the information we have reviewed.

We hope that you are able to find and understand information about water quality in the Elk Valley that is important to you. We want to keep improving how we share this information, so please let us know what we can do better. You can chat with us directly at the public meeting, fill out our feedback form, or email us anytime through our facilitator, Lynne Betts at emcpermit107517@gmail.com.

Sincerely,

Patrick Williston
on behalf of the British Columbia Ministry of Environment and Climate Change Strategy

Heather McMahon
on behalf of the Ktunaxa Nation Council

Alison Neufeld
on behalf of the British Columbia Ministry of Environment and Climate Change Strategy

Jesse Sinclair
on behalf of the Ktunaxa Nation Council

Bruce Kilgour
Independent Aquatic Scientist

Carla Fraser
on behalf of Teck

Jennifer Jacobsen
on behalf of the Interior Health Authority

Mark Digel
on behalf of Teck

How Teck Manages Water Quality in the Elk Valley

The Elk Valley Water Quality Plan

Extracting coal from underground layers, or seams, causes certain substances to be released into nearby creeks and streams that then flow into rivers and lakes. Monitoring results indicate that the concentrations of these substances are increasing in areas impacted by mining in the Elk Valley.

In April 2013, the British Columbia Minister of Environment issued Ministerial Order No. M113 that required Teck to develop an area-based management plan and to identify the actions it will take to manage water quality downstream of its five steelmaking coal mines. The mine-related substances of concern in that order are selenium, nitrate, sulphate, cadmium, and calcite.

Between 2013 and 2014 Teck developed the Elk Valley Water Quality Plan with feedback from the public, First Nations, provincial and federal governments, technical experts, and other stakeholders. Teck submitted the Elk Valley Water Quality Plan to the Minister in July 2014 and it was approved in November that same year. The Elk Valley Water Quality Plan guides water quality management in the Elk Valley and has these four environmental objectives:

- protect aquatic ecosystem health
- manage bioaccumulation of mine-related substances in the environment
- protect human health
- protect groundwater

The Elk Valley Water Quality Plan, or EVWQP, has targets (limits) for the concentration of selenium, sulphate, nitrate, and cadmium in surface water at seven specific locations—called order stations[1]—in the Elk Valley and in the Koocanusa Reservoir. The EVWQP also has targets for the amount of calcite in streams influenced by mining. These water quality targets—both short-term (2014 to 2019), medium-term (2020 to 2025), and long-term—are meant to first stabilize and then decrease concentrations over time to protect the most sensitive aquatic life and human health from mining-related effects on water quality.

You can learn more about the Elk Valley Water Quality Plan here:

https://www.teck.com/media/2015-Water-elk_valley_water_quality_plan_T3.2.3.2.pdf

[1]These seven locations were specified in Ministerial Order No. 113, which is why they are referred to as "order stations".

The Elk Valley Permit

Following the approval of the Elk Valley Water Quality Plan, the Ministry of Environment issued Permit 107517—often called the Elk Valley Permit. Many of the actions and commitments described in the Elk Valley Water Quality Plan were made legal requirements by this permit, including the target concentrations for water quality. Teck must meet all the requirements in this permit.

Permit 107517 does not replace any of the permits previously issued to each of the mine operations. It is regionally focused and adds another layer of legal requirements for Teck.

You can can find more information about Permit 107517 on the BC government website:

https://www2.gov.bc.ca/gov/content/environment/waste-management/waste-discharge-authorization/search-status-and-documents

Water Quality Targets

Water quality targets are limits for the amount of selenium, sulphate, nitrate, and cadmium in the water. These targets are meant to protect aquatic life based on available data during the development of the Elk Valley Water Quality Plan. There are two types of water quality targets in Permit 107517: compliance limits and site performance objectives. We refer to both of these as permit limits in this report.

Compliance limits are set for compliance points. Compliance points are water monitoring stations that are downstream from each of Teck's mine operations in the Elk Valley. These points correspond to stream locations where all or most of the mine-influenced water accumulates from an operation. There are eight compliance points.

Site performance objectives are set for order stations. Order stations are water monitoring stations that are further downstream from Teck's mining operations where water that is mine-influenced is mixed with water that is not. Because of this mixing, concentrations at order stations are expected to be lower than at compliance points. There are seven order stations.

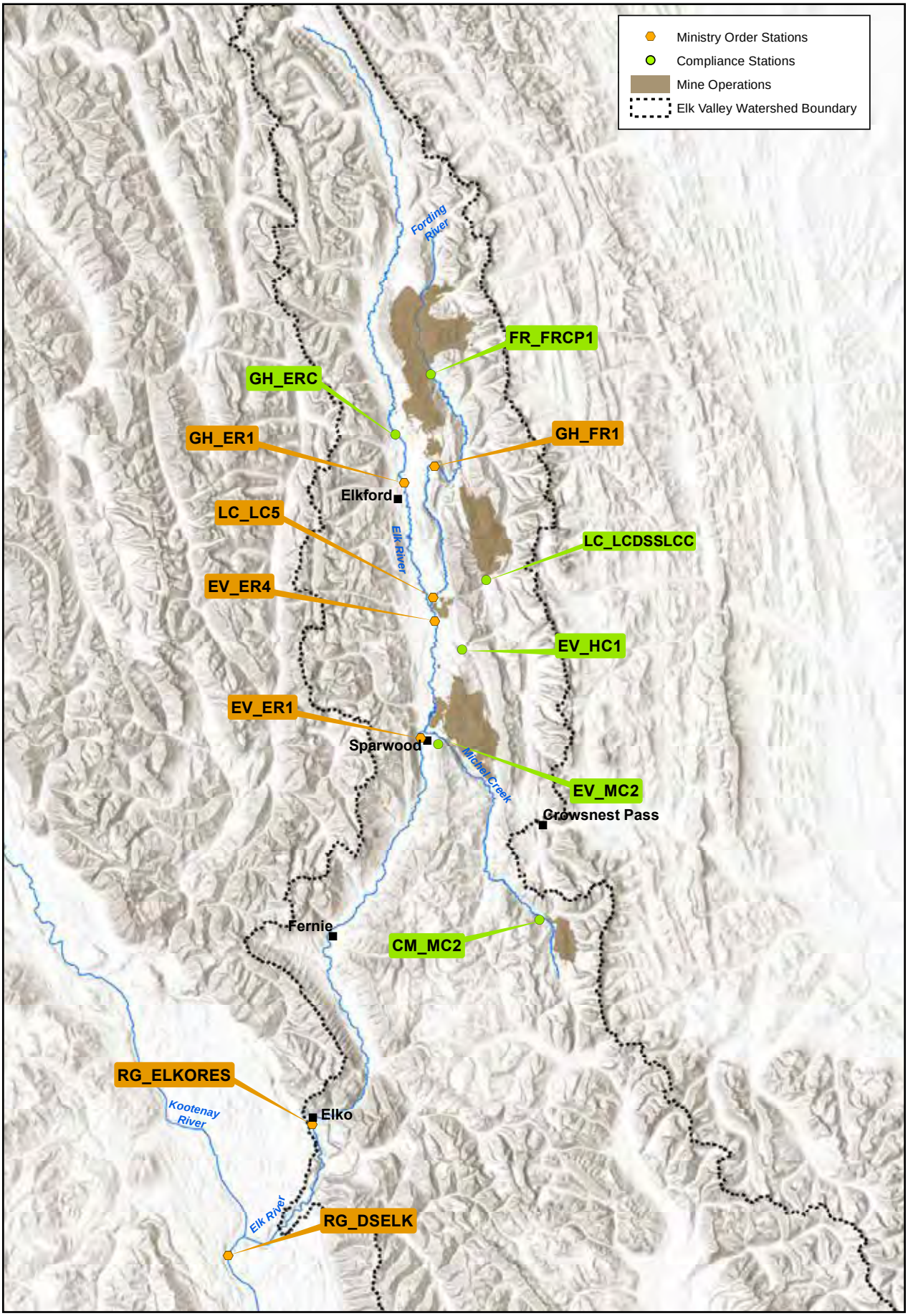


Figure 1. Compliance points, order stations, and boundaries of Permit 107517 in the Elk Valley.

The Environmental Monitoring Committee

Permit 107517 requires Teck to form an Environmental Monitoring Committee (EMC). In 2018, the members of this committee included:

- an independent aquatic scientist
- two representatives from the British Columbia Ministry of Environment and Climate Change Strategy (ENV)
- one representative from the British Columbia Ministry of Energy, Mines, and Petroleum Resources (EMPR)
- one representative from the Interior Health Authority (IHA)
- two representatives from the Ktunaxa Nation Council (KNC)
- two representatives from Teck

The federal government (Environment and Climate Change Canada) has been invited to participate on the committee, but has declined active participation. Federal representatives have, however, agreed to consider requests from the EMC to provide specific input on a case-by-case basis.

Permit 107517 also states that the Environmental Monitoring Committee must review these monitoring and management programs:

Monitoring Programs

- Surface Water Monitoring
- Groundwater Monitoring
- Calcite Monitoring
- Local Aquatic Effects Monitoring
- Regional Aquatic Effects Monitoring
- Toxicity Testing
- Human Health Risk Assessment

Management Programs

- Adaptive Management
- Tributary Management

All of these programs are required under Permit 107517 and are focused on the Elk River watershed and the Canadian portion of the Koocanusa Reservoir. The Environmental Monitoring Committee reviews all the information associated with these programs and provides advice to Teck. It is up to Teck to respond to or adopt the committee's advice. These programs are strengthened by the advice the committee provides.

The Environmental Monitoring Committee cannot approve Teck's programs. And it does not replace or affect the consultation process between the BC provincial government and First Nations.

The members on the Environmental Monitoring Committee have different areas of expertise and bring different perspectives to the committee's discussions about Teck's monitoring and management programs. The committee provides technical advice and the KNC representatives also provide advice relating to the Ktunaxa's stewardship principles and worldview.

Ktunaxa Stewardship

Archaeological evidence indicates that for more than 10,000 years the Ktunaxa (pronounced 'k-too-nah-ha') people have occupied the lands along the Kootenay and Columbia Rivers, and the Arrow Lakes of British Columbia. The Ktunaxa Territory is divided into Land Districts, and the Elk Valley falls within one of these districts, called Qukin ?amak?is, or Raven's Land. The Ktunaxa people have continuously used and occupied the Elk Valley area within Qukin ?amak?is, and the formation of the geography of the Elk Valley is described in the final events of the Ktunaxa Creation story.

Because of the Ktunaxa's deep connection to the Elk Valley, the Ktunaxa Nation Council (KNC) has been invited to have three representatives on the EMC to provide both science-based advice and advice relating to the Ktunaxa's stewardship principles and worldview.

Information about the Ktunaxa Nation, the Ktunaxa creation story, and Ktunaxa law has been provided by KNC and can be found in Appendix A.

Projecting Future Water Quality

To examine and understand how activities at its five coal mines affect water quality, Teck has developed a regional water quality model. This model simulates how historical, current, and future mining activities affect the concentrations of selenium, sulphate, nitrate, and cadmium in the Elk Valley and the Koocanusa Reservoir. It also simulates how the various mitigation measures Teck has planned (water treatment and clean-water diversions for example) will affect water quality. The model uses historical and current information to project future concentrations.

Teck developed the first regional water quality model in 2014 to inform the EVWQP. Teck is required to update the model every three years, and the first update was submitted to the Director in October 2017. The water quality projections mentioned later in this report are taken from the 2017 model. Work on the next update is underway and is due to the Director in October 2020.

The EMC does not provide advice on the water quality model or its development, but it does review the model's outputs. This information is helpful to the EMC when members are reviewing and providing advice on Teck's monitoring and management programs.

The initial implementation plan in the EVWQP was based on the 2014 regional water quality model. The updated projections and schedules for active water treatment in the 2017 model required Teck to subsequently update the EVWQP implementation plan. Teck has now finalized the 2019 Implementation Plan Adjustment and it can be found at https://www.teck.com/responsibility/sustainability-topics/water/water-quality-in-the-elk-valley/news-and-publications/.

Who is the Director?

The Director is the representative from the regional government office within the British Columbia Ministry of Environment and Climate Change Strategy that is responsible for issuing permits under the Environmental Management Act and for determining compliance with permit requirements. All the study designs, plans, and reports required under Permit 107517 are submitted to the Director, many of which require written acceptance or approval.

Adaptive Management

Adaptive management is an approach to environmental management that helps environmental managers make progress towards environmental goals, while at the same time allowing them to incorporate learnings along the way. Adaptive management combines research with management actions to help managers systematically test assumptions, learn, and adapt.

Teck is required to develop and implement an adaptive management plan. Teck began developing the plan in early 2015 and submitted it to the Director in August 2016. The KNC and Teck requested an extension to make sure the document was acceptable to KNC. Following several rounds of discussions with the EMC, Teck submitted the most recent version of the plan to the Director in December 2018. It was formally accepted by the Director in May 2019.

The adaptive management plan was developed to support the implementation of the EVWQP to achieve water quality and calcite targets; to ensure that human health and the environment are protected (and where necessary, restored); and to facilitate the continuous improvement of water quality in the Elk Valley.

Following the six stage adaptive management cycle (see text box), Teck's adaptive management plan is guided by six management questions that will be evaluated through the implementation of the EVWQP. The six management questions identified in Teck's 2018 Adaptive Management Plan are:

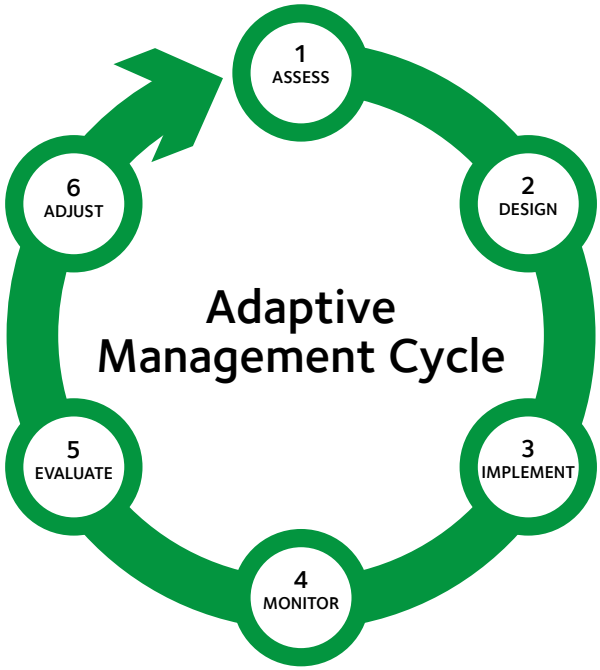
Management Question 1:
Will water quality limits and site performance objectives be met for selenium, nitrate, sulphate, and cadmium?

Management Question 2:
Will the aquatic ecosystem be protected by meeting the long-term site performance objectives?

Management Question 3:
Are the combinations of methods for controlling selenium, nitrate, sulphate, and cadmium included in the implementation plan the most effective for meeting limits and site performance objectives?

What is Adaptive Management?

It is a systematic, rigorous approach to environmental management structured around a six stage management cycle (a form of the plan-do-check-act management loop). It focuses on learning about important uncertainties, while at the same time implementing management actions based on the current understanding. It provides a framework in which management actions are adapted based on what is learned.



Management Question 4:
Is calcite being managed effectively to meet site performance objectives and protect the aquatic ecosystem?

Management Question 5:
Does monitoring indicate that mine-related changes in aquatic ecosystem conditions are consistent with expectations?

Management Question 6:
Is water quality being managed to be protective of human health?

The 2018 plan also identifies continuous improvement goals for each management question and a response framework for determining when additional mitigation actions or other adjustments may be needed to protect the aquatic ecosystem and human health.

Teck is required to submit an annual report that describes the activities undertaken during the previous year in each stage of the adaptive management cycle. Following the Director's acceptance of Teck's 2018 Adaptive Management Plan, Teck submitted its first annual report in July 2019. In addition to a description of activities undertaken, the annual report summarized the results and learnings from 2018 and described Teck's next steps.

Teck is also required to update its adaptive management plan every three years. The next update is due in December 2021. Teck continues to work with the EMC to develop a means of tracking progress towards continuous improvement goals; to develop and implement additional triggers to the response framework (groundwater and calcite, for example); and to develop definitions of unacceptable conditions for integration in the response framework.

The EMC will continue to review and provide advice on the three-year plan update and the annual reports.

What We Learned From the Monitoring Programs in 2018

Surface Water Quality

In addition to the eight compliance points and the seven order stations, Teck routinely monitors water quality at 88 other locations in the Elk Valley. All monitoring results are used to evaluate Teck's compliance with its permit requirements and its progress towards achieving the objectives set in the Elk Valley Water Quality Plan.

For compliance points and order stations:

- results for selenium, nitrate, sulphate, and cadmium are compared to permit limits
- results for other mine-related substances are compared to BC water quality guidelines

For the 88 other monitoring locations:

- results for selenium, nitrate, sulphate, and cadmium are compared to BC water quality guidelines
- results for other mine-related substances are compared to BC water quality guidelines

Monitoring results are presented in an annual report that Teck submits to the Director and the EMC in March every year.[2]

[2]Permit 107517 Annual Water Quality Monitoring Report, 2018 (March 2019)

Compliance

Permit 107517 has specific targets (limits) for the concentration of selenium, nitrate, sulphate, and cadmium at the compliance points and order stations, and Teck is required to meet these limits to be in compliance. Water quality in the Elk Valley is affected by several factors including background conditions, the placement of waste rock, annual and seasonal rain and snow (and the resulting surface flows, or hydrology), water treatment, and how the operations manage water. Changes to these factors influence whether or not a location is in compliance with the limits set in Permit 107517.

In 2018, Teck maintained compliance at the compliance points and order stations for 88.5% of water samples tested. There were recurring exceedances of permit limits at two compliance points: FRCP1, a site on the upper Fording River; and LCDSSLCC, a site on Line Creek. One order station, DSELK in the Koocanusa Reservoir near the confluence of the Elk River, reported a non-compliance for the average concentration of selenium in the month of April.

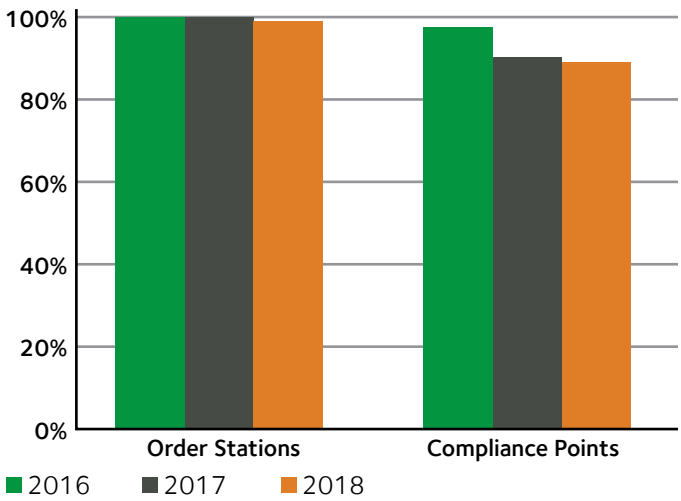


Figure 2. Teck's compliance with permit limits at order stations and compliance points from 2016 to 2018.

Fording River (FRCP1)

The FRCP1 location is a compliance point on the upper Fording River, approximately 525 m downstream of Cataract Creek. It is intended to capture the mixed water of the Fording River and all tributaries (both mine-influenced and not mine-influenced) that flow into it. One of those tributaries, Cataract Creek, is influenced by waste rock at the Fording River Operations. From October to December 2018, mixed water in the Fording River flowed underground leaving only water from Cataract Creek flowing past the compliance point. Water samples collected at this compliance point during this time were representative of Cataract Creek, not mixed waters in the Fording River. Changes in hydrology and undiluted waste rock runoff were important drivers of the selenium, nitrate, and sulphate exceedances at FRCP1 in 2018 (Figures 3 to 5).

Teck has been monitoring the aquatic biota downstream of this location to evaluate whether the biota is being affected by these higher concentrations through the winter months. Teck and the EMC continue to review these results. To reduce the concentrations of mine-related substances in the Fording River, Teck is currently constructing an active water treatment facility just south of the Fording River Operations. The facility start up will commence late 2020 with a ramp up to full operation in 2021. This facility will treat water from Cataract Creek, Swift Creek, and Kilmarnock Creek.

Selenium, Nitrate, and Sulphate Concentrations at FRCP1 in 2018

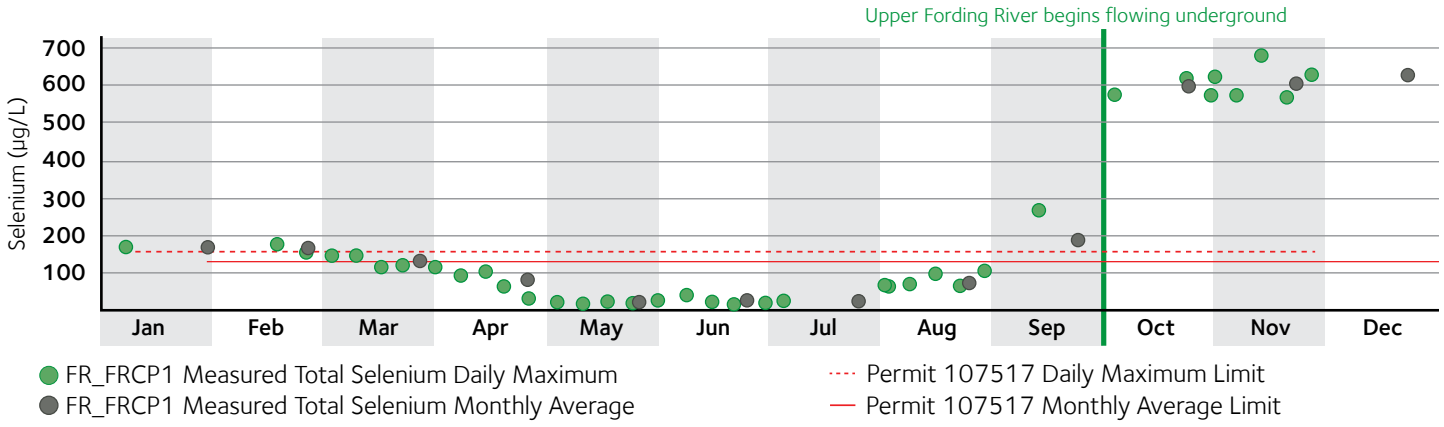


Figure 3. Selenium concentrations (in µg/L) at the Fording River compliance point, 525 m downstream of Cataract Creek, in 2018.

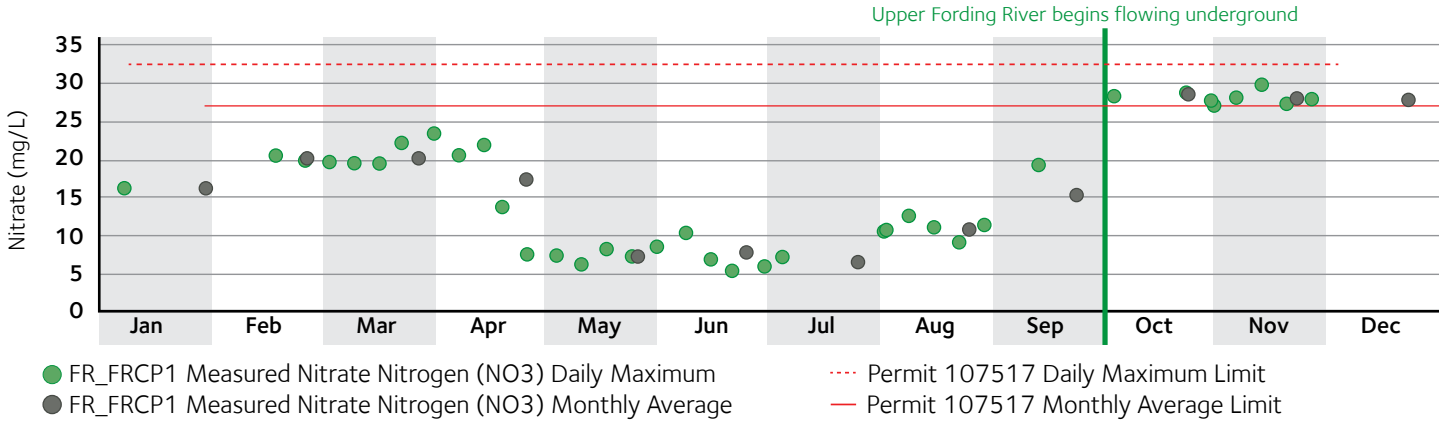


Figure 4. Nitrate concentrations (in mg/L) at the Fording River compliance point, 525 m downstream of Cataract Creek, in 2018.

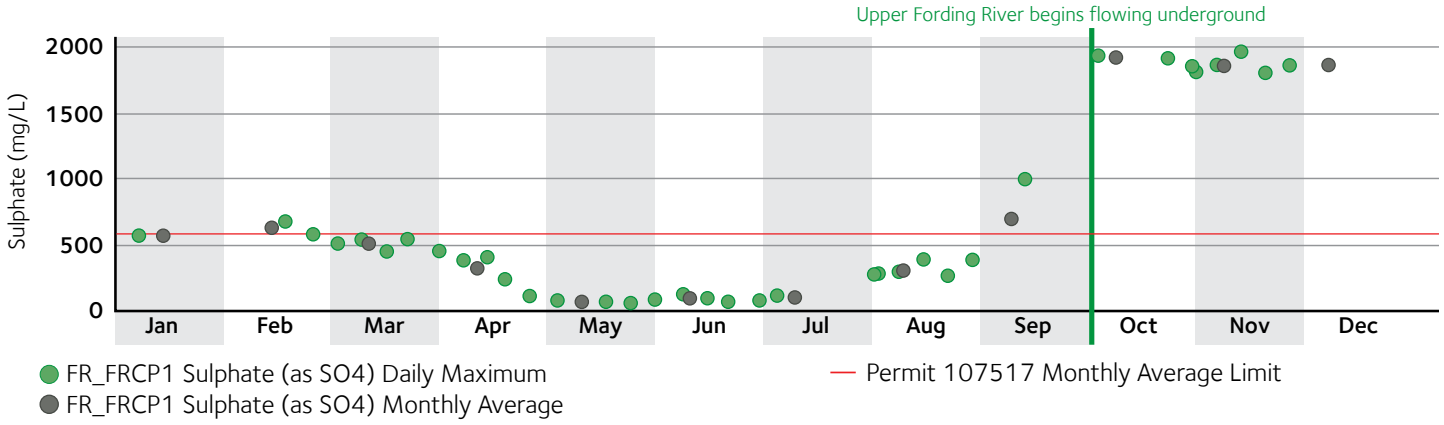


Figure 5. Sulphate concentrations (in mg/L) at the Fording River compliance point, 525 m downstream of Cataract Creek, in 2018.

Line Creek (LCDSSLCC)

The LCDSSLCC location is a compliance point in Line Creek approximately 1500 m downstream from the West Line Creek Active Water Treatment Facility. In February 2018, the facility was temporarily shut down to add an advanced oxidation process (see page 39 for more information). In the three months that followed, selenium concentrations in Line Creek were above permit limits. The treatment facility was restarted in October 2018 and selenium concentrations at the Line Creek compliance point returned to below permit limits (Figure 6).

Nitrate concentrations also exceeded permit limits at this location in 2018 (Figure 7). The treatment facility removes 90% of the nitrate, but concentrations in Line Creek remained close to, or slightly above the permit limits. Teck continues to monitor and assess the potential effects of these nitrate levels to the aquatic biota in Line Creek. See page 39 for more information on these monitoring results.

Teck's updated modelling projects to meet compliance limits with its nitrate concentrations by 2026 when the active water treatment facility at West Line Creek is expanded.

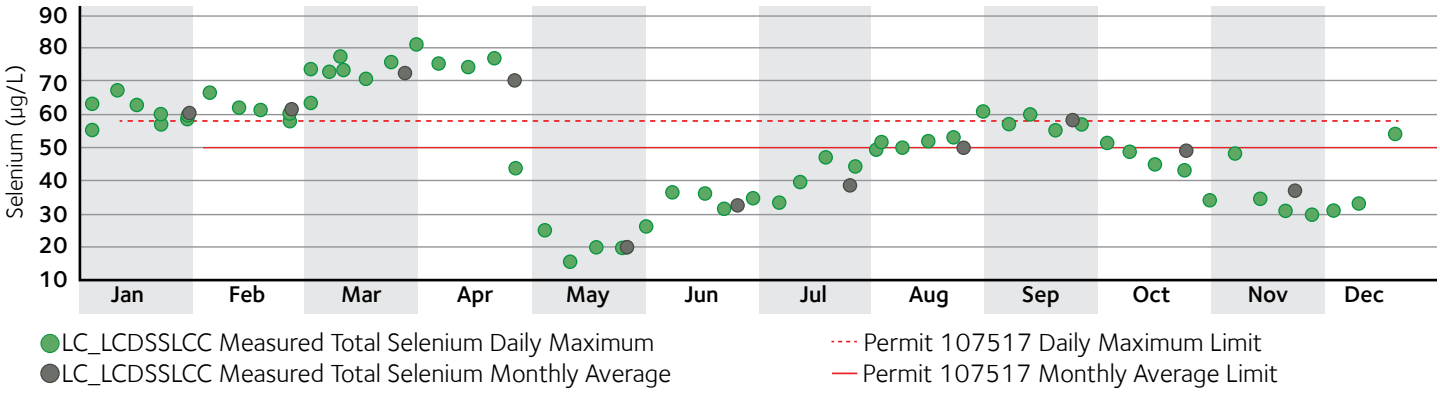


Figure 6. Selenium concentrations (in µg/L) at the Line Creek compliance point in 2018.

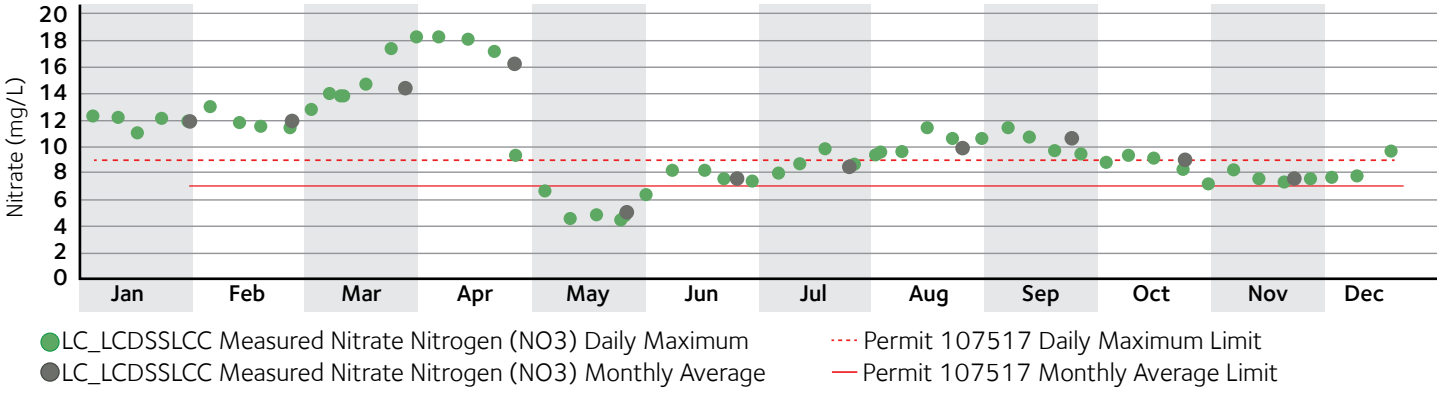


Figure 7. Nitrate concentrations (in mg/L) at the Line Creek compliance point in 2018.

Koocanusa Reservoir (DSELK)

The DSELK location is an order station in the Koocanusa Reservoir just downstream of the confluence of the Elk River. It is intended to capture the mixed water of the Kootenay River and the Elk River. In April 2018, the reservoir at this location was a river channel running through the bottom of the reservoir. The April water samples were collected from the eastern river bank and the average selenium concentration in April was 2.7 µg/L; the monthly average limit is 2 µg/L (Figure 8).

Upon receiving this result, Teck investigated and found that the riverine condition in April did not allow mixing between the Elk River and the Kootenay River at this location. Teck discovered that the eastern shoreline primarily represented water from the Elk River and the western shoreline represented water from the Kootenay River. See page 43 for more information.

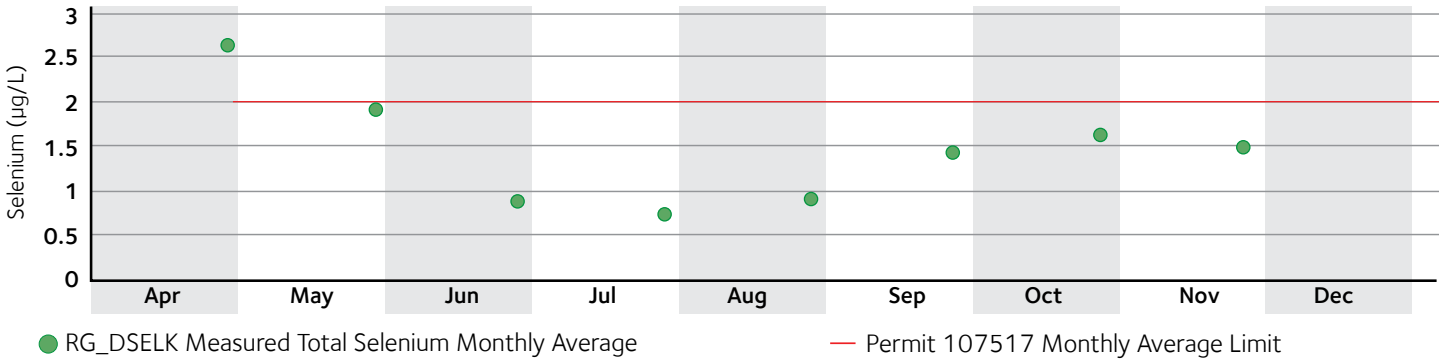


Figure 8. Monthly average selenium concentrations (in µg/L) at the Koocanusa Reservoir order station in 2018.

Results Above BC Water Quality Guidelines

BC water quality guidelines are science-based benchmarks intended to protect the most sensitive life stages of the most sensitive aquatic species occurring in the province. These guidelines are policy; they are not enforceable standards. The guidelines are developed by the Ministry of Environment and Climate Change Strategy for consideration in decision making. Results above a BC water quality guideline may or may not result in changes to aquatic biota, depending on site-specific conditions and the sensitivities of the local aquatic biota.

Teck collected approximately 1400 water samples in 2018 and compared the laboratory results to the BC water quality guidelines:

- 24 of 1400 samples taken (1.7%) measured above the aluminum guideline
  - no spatial or temporal patterns
  - has not increased over time
  - not related to mining operations
- 79 of 1400 samples taken (5.6%) measured above the iron guideline
  - occurred at the peak of spring melt
  - no spatial pattern
  - has not increased over time
- 160 of 1400 samples taken (11.4%) measured above the mercury guideline
  - occurred at the peak of spring melt
  - no spatial pattern
  - has not increased over time
  - not related to mining operations
- 51 of 1400 samples taken (3.6%) measured above the cobalt guideline
  - occurred in Corbin Creek and Michel Creek
  - has increased over time
  - related to mining operations
- 15 of 1400 samples taken (1.1%) measured above the nitrite guideline
  - occurred mainly in Corbin Creek (11) and Michel Creek (2)
  - has increased over time
  - related to mining operations
- 66 of 1400 samples taken (4.7%) measured above the uranium guideline
  - occurred mainly in West Line Creek (54) upstream of the active water treatment facility
  - also found in Fording River (9), Corbin Creek (2), and Greenhills Creek (1)
  - related to mining operations

Trends in Water Quality

Teck continually evaluates its monitoring results to look for trends. Teck then compares those trends to what was projected in the Regional Water Quality Model. If a trend is unexpected, Teck investigates the cause. If the cause is determined to be mining-related, Teck will evaluate options and take appropriate management actions. Teck reports water quality trends in the annual report it submits to the Director and the EMC in March every year.[3] The four mine-related substances identified in the EVWQP—selenium, nitrate, sulphate, cadmium—are the main substances of concern, but nickel and cobalt have recently emerged as additional substances of concern in localized areas.

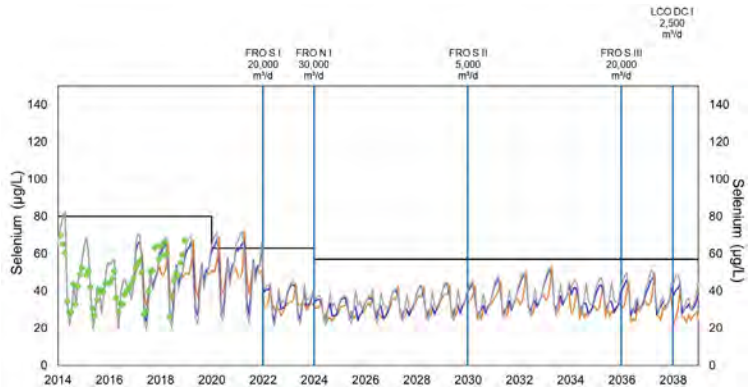
Selenium

Selenium is a common element found naturally in rock, and it is an essential nutrient for all living things at low concentrations. In water, selenium is taken up by algae and other microorganisms and transferred through the food web where it accumulates in the body tissues of aquatic invertebrates, fish, birds, and other vertebrates—this is called bioaccumulation. When selenium accumulates at high concentrations in the tissues of animals, it can interfere with their reproduction, especially in animals that lay eggs such as fish, birds, amphibians, and reptiles. In humans, long-term exposure to elevated selenium can result in fever, nausea, and selenosis. Selenosis is characterized by multiple organ damage, especially the liver and skin.

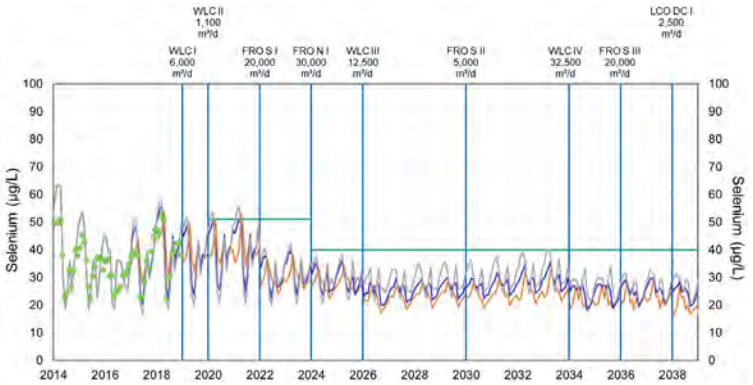
Selenium concentrations in the Elk Valley have increased over time and have exceeded permit limits at three locations (see the *Compliance* section on page 15). The Regional Water Quality model projected selenium concentrations would exceed permit limits at certain locations until the commissioning of the Fording River South Active Water Treatment Facility (Figure 9). Teck expects the commissioning of the Elkview Saturated Rockfill Facility (start-up will commence late 2020 with a ramp up to full operation in 2021) will further improve water quality by decreasing selenium (and nitrate) concentrations in Erickson Creek, Michel Creek, and the Elk River.

[3]Permit 107517 Annual Water Quality Monitoring Report, 2018 (March 2019)

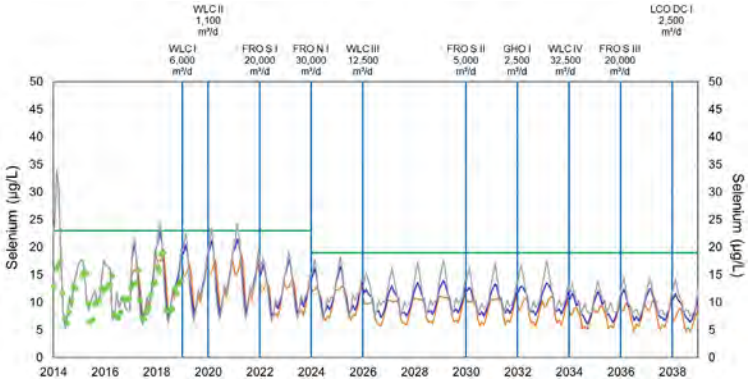
Projected Concentrations of Selenium at Four Order Stations (based on the 2019 Implementation Plan Adjustment)



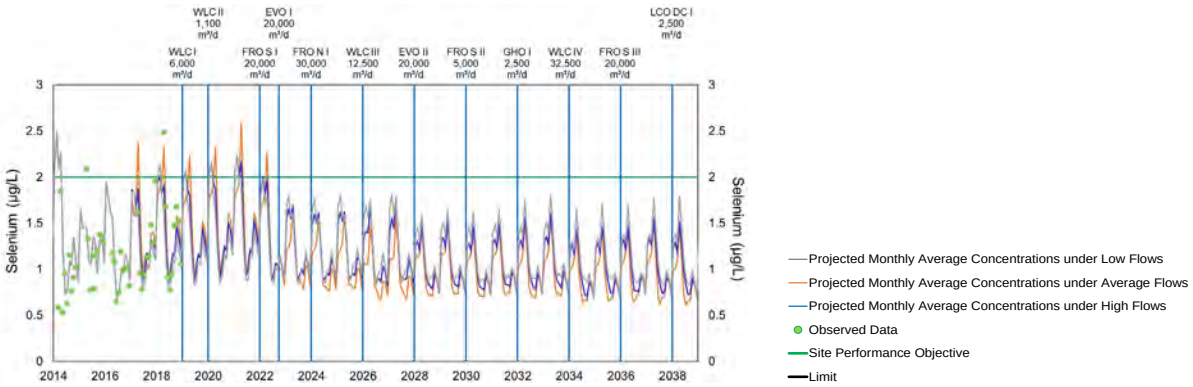
a) Fording River downstream of Greenhills Creek (GH_FR1)



b) Fording River downstream of Line Creek (LC_LC5)



c) Elk River upstream of Grave Creek (EV_ER4)



d) Koocanusa Reservoir (RG_DSELK)

Figure 9. Projected concentrations of selenium at four order stations (based on the 2019 Implementation Plan Adjustment).

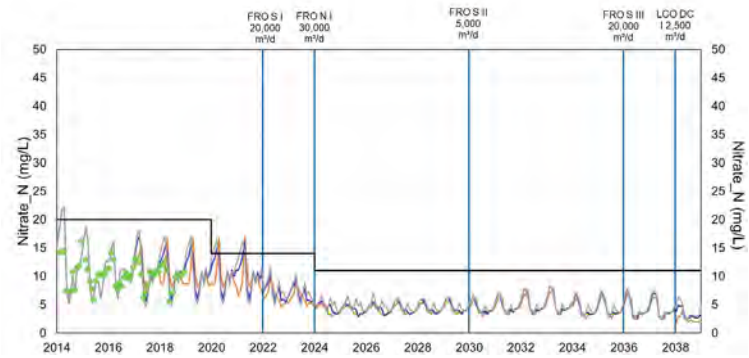
Nitrate

Nitrate is an organic compound made of nitrogen and oxygen. Nitrate is a key component of the explosives used in mining. It is carried by water from waste rock piles into streams and rivers. High concentrations of nitrate in the water may be harmful to fish and other aquatic organisms by disrupting their ability to use oxygen. This harms their growth and development, particularly during the early life stages (as larvae or eggs, for example). In humans, nitrates are a particular concern for babies and pregnant women. Exposure to high levels of nitrates reduces the amount of oxygen in the blood resulting in a condition called methemoglobinemia. High concentrations of nitrate in the water can also contribute to excessive plant growth (eutrophication).

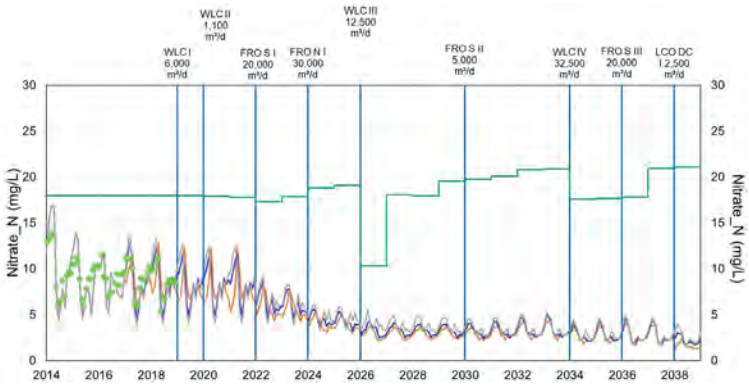
Concentrations of nitrate in the Elk Valley have been increasing over time, but levels are currently below permit limits—except for two locations: the Fording River compliance point and the Line Creek compliance point (see page 15 in the *Compliance* section for more information). The Regional Water Quality Model projects that once the Fording River South Active Water Treatment Facility is operational (facility start up will commence late 2020 with a ramp up to full operation in 2021), nitrate concentrations in the Fording River will be below permit limits, with some seasonal variability (during some months the concentrations will not meet the limits). The Regional Water Quality Model projects that Teck will reach compliance with its nitrate limits in Line Creek by 2025 when the West Line Creek Active Water Treatment Facility is expanded (Figure 10).

Teck has made a significant effort over the past year across all operations to reduce nitrate loading in the receiving environment by increasing the use of plastic liners during blasting. Liners help to reduce the loss of explosive emulsion to fissures in the rock and improve combustion. This means less residual nitrate ends up in the waste rock. Because nitrate takes years to move through spoils, it will take time to measure the benefits of these improvements in Elk Valley waters. The EMC does not review or provide advice related to Teck's nitrate management activities.

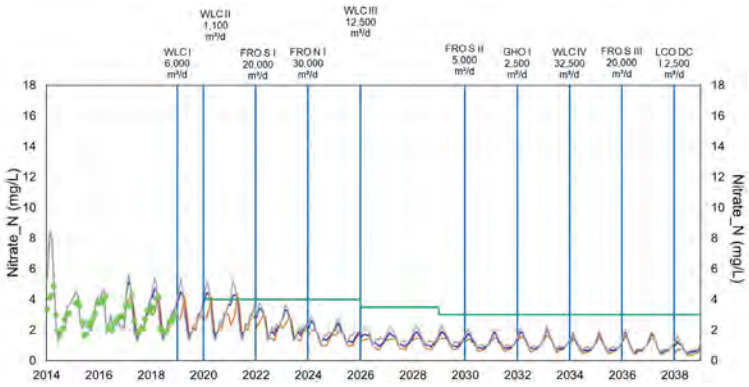
Projected Concentrations of Nitrate at Four Order Stations (based on the 2019 Implementation Plan Adjustment)



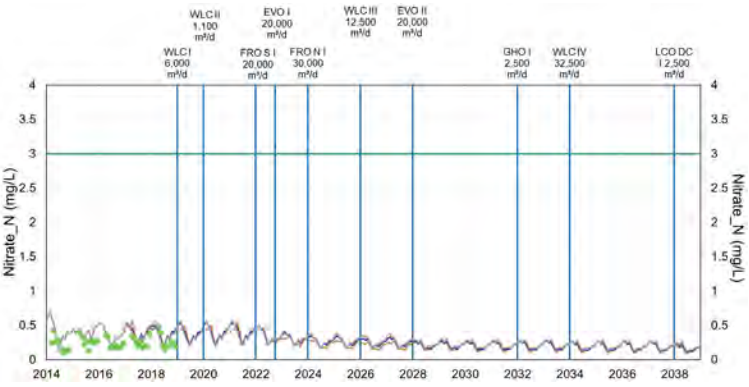
a) Fording River downstream of Greenhills Creek (GH_FR1)



b) Fording River downstream of Line Creek (LC_LC5)



c) Elk River upstream of Grave Creek (EV_ER4)



d) Koocanusa Reservoir (RG_DSELK)

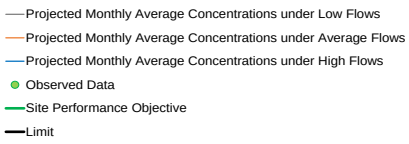
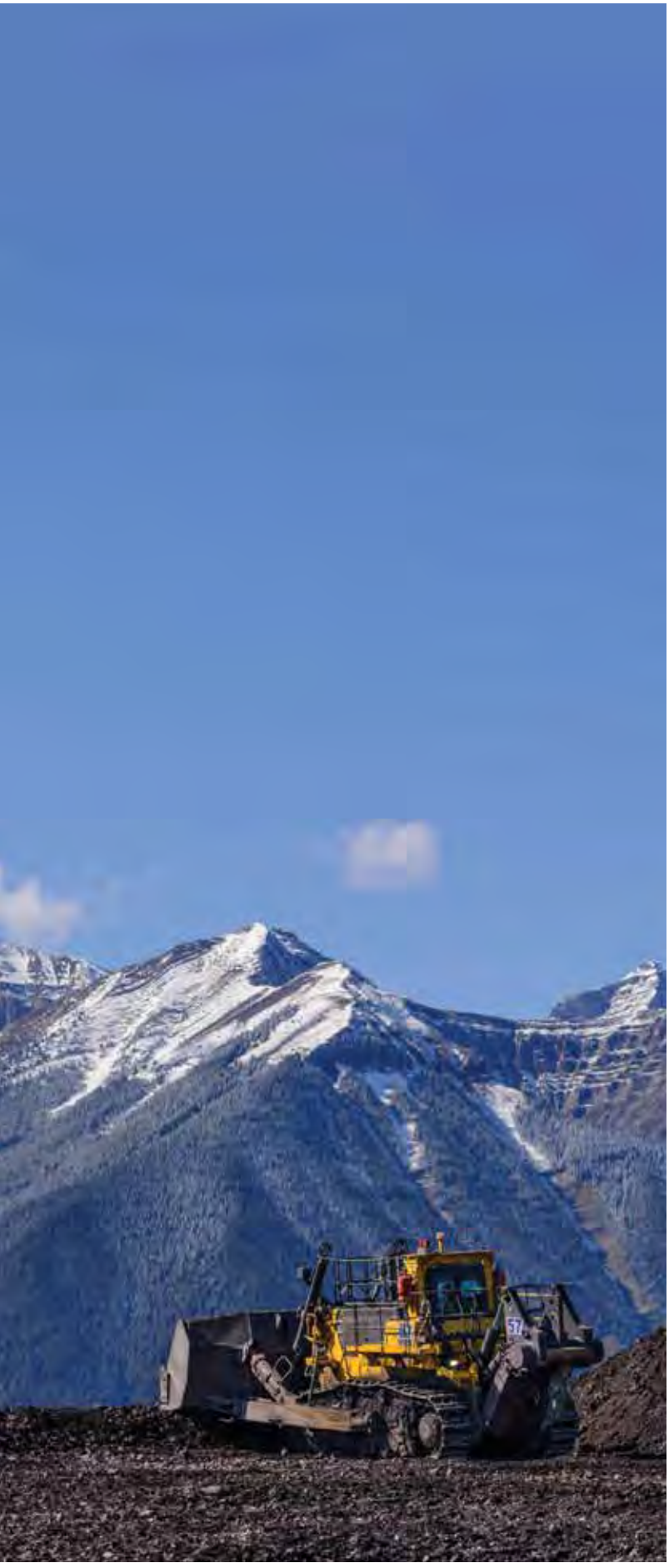


Figure 10. Projected concentrations of nitrate at four order stations (based on the 2019 Implementation Plan Adjustment).



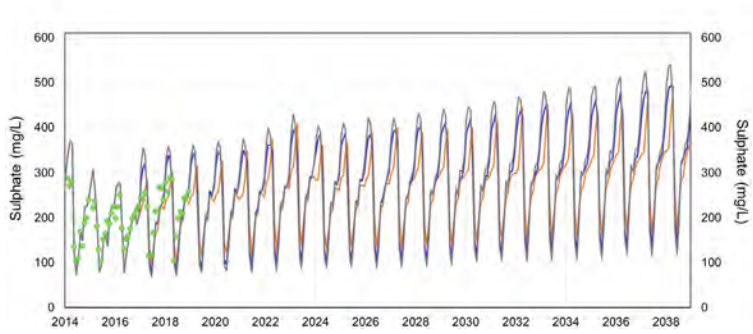
Sulphate

Sulphate is released from waste rock through the oxidation (exposure to oxygen) of minerals containing sulphide. When exposed to high sulphate in water, aquatic invertebrates experience impaired regulation of bodily fluids, and high sulphate levels can be harmful to fish and other aquatic organisms. Sulphates in humans may have a laxative effect (cause diarrhea) that can lead to dehydration; this is of particular concern for infants.

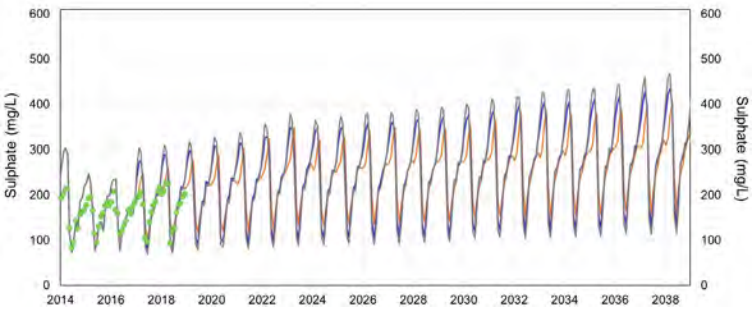
Concentrations of sulphate in the Elk Valley have been increasing over time, but have been below permit limits—with the exception of the Fording River compliance point (see page 15 in the *Compliance* section for more information). The concentrations of sulphate are projected to continue increasing, but they are projected to remain below permit limits—except at the Fording River compliance point and the Line Creek compliance point. Sulphate concentrations at the Fording River compliance point are projected to be above the permit limit by 2027 and at the Line Creek compliance point by 2026 (Figure 11).

There is uncertainty about the breadth of potential risks that projected sulphate concentrations may cause for aquatic life, so Teck was required to study the toxicity of sulphate to better understand this. The EMC provided input and review of this study (see page 41).

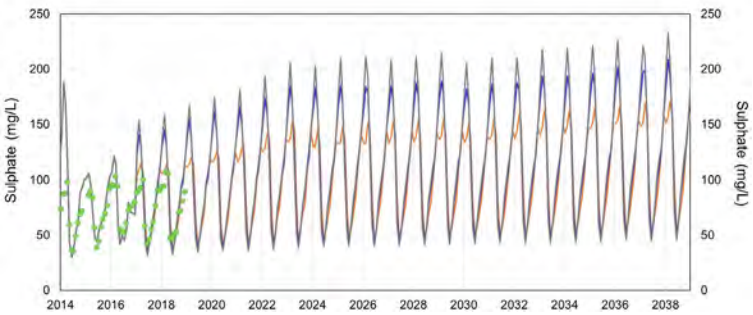
Projected Concentrations of Sulphate at Four Order Stations (based on the 2019 Implementation Plan Adjustment)



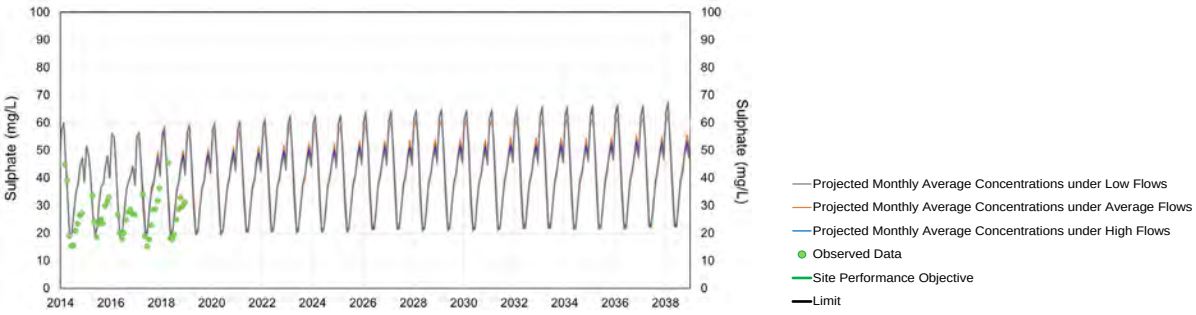
a) Fording River downstream of Greenhills Creek (GH_FR1)



b) Fording River downstream of Line Creek (LC_LC5)



c) Elk River upstream of Grave Creek (EV_ER4)



d) Koocanusa Reservoir (RG_DSELK)

Figure 11. Projected concentrations of sulphate at four order stations (based on the 2019 Implementation Plan Adjustment).

Cadmium

Cadmium is a rare, naturally occurring metal formed from the mineral sphalerite. It is released during mining and it is found in the waste rock at certain locations in the Elk Valley. Cadmium can be harmful in aquatic environments at very low concentrations. At this time there is inadequate evidence to state whether or not cadmium has the potential to cause cancer from lifetime exposures through drinking water.

The permit limit for cadmium is the BC water quality guideline and this varies with water hardness. The guideline is approximately 0.6 µg/L when water hardness is 400 mg/L (upper Fording River) and approximately 0.35 µg/L when water hardness is 200 mg/L (in the lower Elk River). Concentrations of cadmium throughout the Elk Valley are below permit limits and do not appear to be increasing over time. There are some seasonal trends, but these appear to be driven by background conditions. There are elevated concentrations in some tributaries influenced by mining activities, but these concentrations are still below the permit limits. The concentration of cadmium at the order stations has been below 0.1 mg/L.

Nickel

Nickel is a common, naturally-occurring metallic element. Although it does not accumulate in fish, plants, or animals, nickel does accumulate in soils and sediments and may have an adverse effect on aquatic life when concentrations are high in the water.

In the Elk Valley, nickel concentrations are below the BC guideline. The concentrations are higher at localized areas in Corbin Creek downstream of Coal Mountain Operations and in Michel Creek, but still remain below the guideline (Figure 12).

The BC guideline for nickel is 150 µg/L, but Teck—through additional monitoring programs—has measured adverse responses to sensitive benthic invertebrates at concentrations ranging from 5 to 22 µg/L. Teck notified ENV, EMC, EC, and KNC of this finding and continues to monitor and review the results with the EMC. Teck is currently working on developing an updated site-specific nickel screening value that will protect sensitive invertebrates. The EMC will be asked for input as this progresses. Teck is also evaluating water treatment options for nickel.

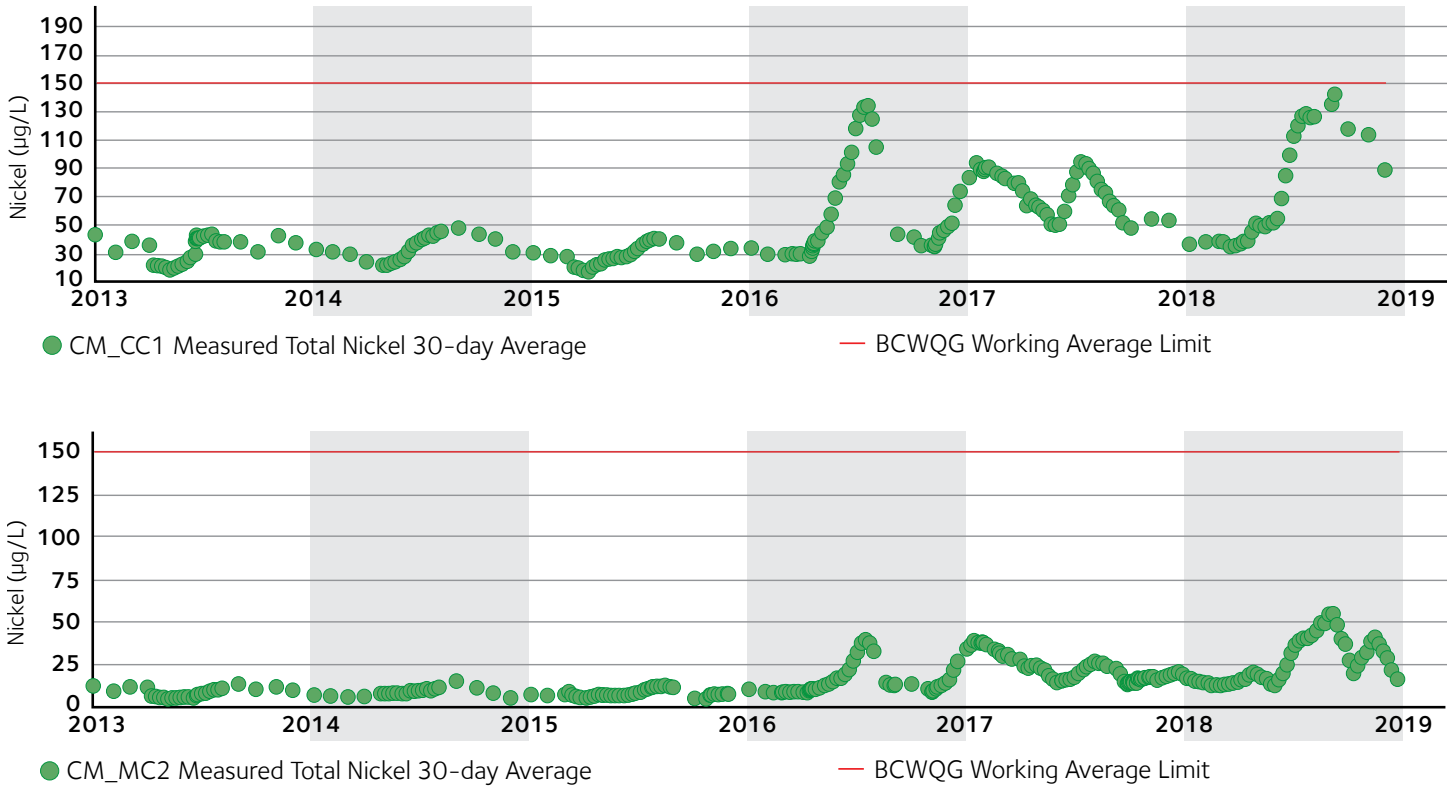


Figure 12. Concentration of nickel (in µg/L) in Corbin Creek downstream of Coal Mountain Operations (top) and in Michel Creek (bottom) since 2013.
See map on page 8.

Cobalt

Cobalt is a naturally-occurring element that is found in small amounts in rocks, soil, water, plants, and animals, often combined with other elements. It is an essential nutrient for humans at low concentrations and is an important component of the vitamin B12. But like selenium, too much cobalt can have adverse health effects for humans, including serious impacts on the heart and thyroid.

The maximum concentrations of cobalt observed at a localized level in Corbin Creek downstream of the Coal Mountain Operations and in Michel Creek were below the BC guideline of 110 µg/L. But the long-term average was above the BC guideline of 4 µg/L, and concentrations have been increasing over time (Figure 13). Along with nickel, Teck is looking into water treatment options for cobalt.

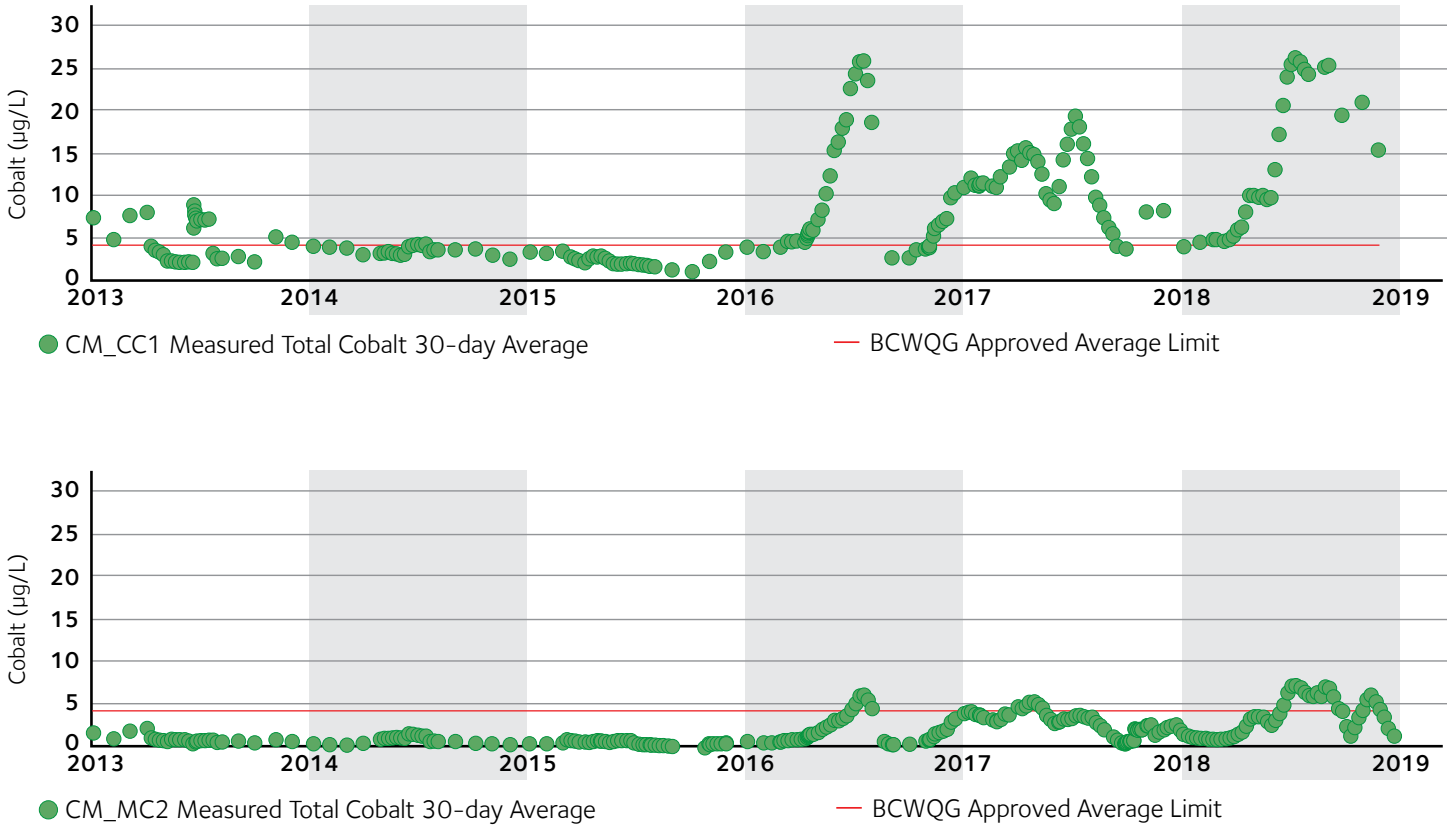


Figure 13. Concentration of cobalt (in µg/L) in Corbin Creek downstream of Coal Mountain Operations (top) and in Michel Creek (bottom) since 2013. See map on page 8.

Calcite

Calcite is a common component of sedimentary rock, particularly limestone, and is made up of calcium carbonate – a calcium salt. Calcium carbonate is very common; it is the main building block of animal shells and is the white crust that builds up on the bottom of your tea kettle.

As water travels through rock (both underground and on the surface), calcite in the rock dissolves and the calcium carbonate is carried into streams and rivers. Here the calcium carbonate can recrystallize and form a thin layer of calcite on the streambed. This process does occur naturally in streams, but mining operations have the potential to increase the rate, extent, and depth of the formation of calcite when water passes through waste rock piles.

When that thin layer of calcite on the streambed builds up over time, it starts to form a calcite crust that can cement gravel and rocks together, degrading habitat for fish and aquatic insects. The degree of degradation can vary as shown in Figures 14 to 16.

Figure 15. A fully concreted streambed in Porter Creek. This reach has a calcite index of 3.

Annual Calcite Monitoring

Teck has been monitoring calcite levels in the Elk Valley annually since 2014. In 2018, 100 rocks at each of 312 sites on 117 stream reaches were surveyed, and 354 km of stream were assessed and mapped. The surveys measure the presence of calcite and the level of concretion (how cemented the rocks are to the streambed) to generate a calcite index between 0 and 3.

Calcite Index Value

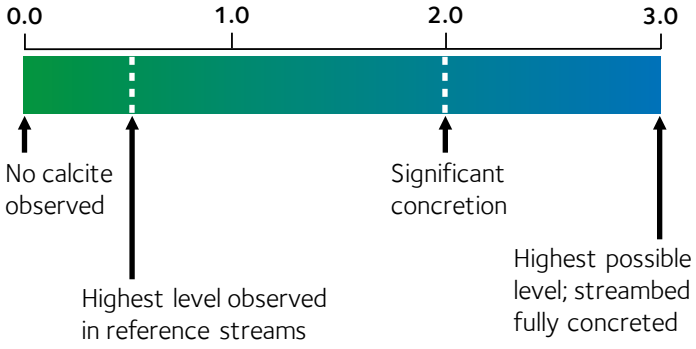


Figure 14. Range of values for the calcite index.

Permit 107517 describes the site performance objectives for calcite in streams that are fish-bearing, provide fish habitat, or flow directly into fish-bearing streams:

- By December 2024, Teck must achieve calcite concretion of less than 0.50. This means at least 50% of rocks sampled within the reach have no concretion (are not stuck to the stream bed).
- By December 2029, Teck must achieve a total calcite index of less than 0.5. This is the level of calcite that is found naturally in streams unaffected by mining.

There has been an increase in calcite over time in the Elk Valley. The results show that the percent of kilometers with a calcite index between 0 and 0.5 is decreasing over time in both streams and creeks (tributaries) and in the Fording and Elk rivers (main stems), while the percent of kilometres in the main stems with a calcite index between 0.51 and 1.00 is increasing (Figure 16). The majority of mine-affected areas that Teck has sampled had low levels of calcite (calcite index values ranging between 0 and 0.5) and this is consistent with streams that have not been influenced by mining (reference streams). Of the 288 kilometres of mine-exposed rivers and tributaries surveyed in 2018, 85.8 kilometres (30%) of these are impacted by calcite at levels higher than background.[4]

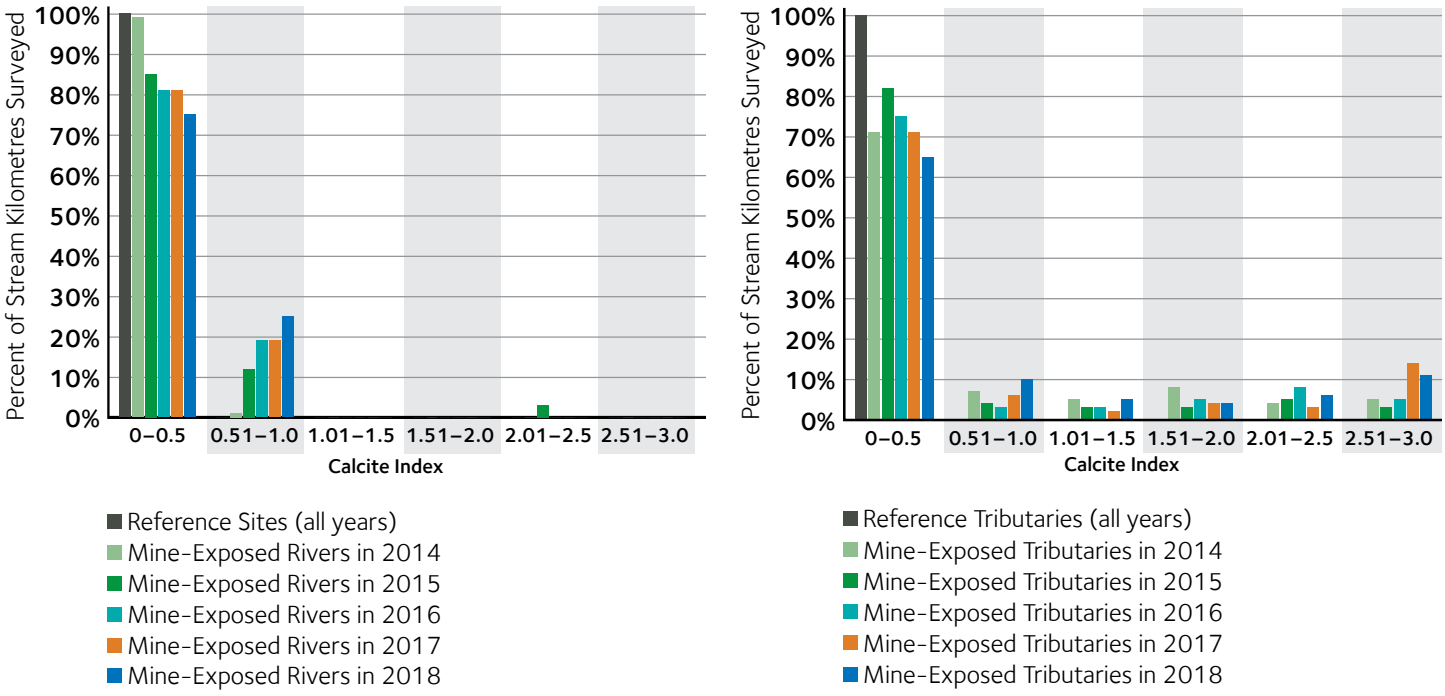


Figure 16. Calcite distribution (by percent of stream kilometres surveyed) in the Elk and Fording Rivers (left) and tributaries (right) from 2014 to 2018.

[4]Calcite Monitoring Program 2018 Annual Report

Biological Effects of Calcite

Teck has been conducting studies since 2015 to learn about the potential effects of calcite on the aquatic environment. The first study focused on the effects of calcite in streams on aquatic insects (mayflies, stoneflies, and caddisflies) and algae. The results showed that the average percent of mayfly larvae in the insect community tended to decrease to below the regional reference normal range when calcite index values were above 1. However, areas having a calcite index greater than 1 also tended to have elevated concentrations of selenium, nitrate, and/or sulphate above benchmarks. Therefore, the effects of calcite could not be distinguished from those associated with water quality (that is, in areas where effects are observed, the effects may be due to calcite or water quality, or both, depending on the area).

The second phase (2016 and 2017) of the study focused on the relationship between calcite index and incubation conditions for fish eggs laid in the gravel on the bottom of the streams. While calcite was found to have some effect on the amount of oxygen available in the gravels, the effects on incubation conditions are predicted at depths deeper than the typical depths of the eggs and at sites with calcite concretion that may prevent fish from being able to dig their nests (redds). The third phase of the study (2018) focused on finding a link between calcite formation on the streambed and the suitability of spawning habitat for Westslope Cutthroat Trout (measured by the presence of redds and the density of redds within a stream). In five streams sampled within the upper Fording River watershed, redds were found across the full range of calcite index values up to 1.7. However, the current data suggests there may be an influence of calcite on redd density. These results are preliminary and are based on a small sample size, so more study is needed to better understand the effect of higher calcite index values on redd presence (are they there?) and density (how many are there?).

What is a redd?

A redd is a fish nest. Certain species of fish—like trout and salmon—use their tails to scoop out a hollow in the gravel of a streambed. The female lays her eggs in this hollow, the male fertilizes them, and the female covers the eggs with gravel.

Managing Calcite

Teck is required to manage the formation of calcite and reduce calcite levels in mine-affected streams in the Elk Valley. Since October 2017, Teck has been applying antiscalant (a chemical compound that prevents calcite particles from forming) in Lower Greenhills Creek to prevent new calcite from forming on the streambed. The calcite index value in 2018 for Lower Greenhills Creek has not changed from 2017 suggesting that the antiscalant is successful in preventing new calcite from forming. However, based on recent research, antiscalant does not remove existing calcite from the streambed. Teck will continue to pursue other technologies for removing calcite.

Teck is also required to monitor water quality and aquatic effects downstream of any calcite treatments. Monitoring results from 2018 showed no negative effects on water quality in, or downstream, of Lower Greenhills Creek, and showed no toxicity effects related to the antiscalant. Teck will continue monitoring this calcite treatment system to better understand its effectiveness and to determine what the results might mean for calcite treatment in other creeks.

The EMC doesn't review studies or plans related to calcite management, but it does review the results of the water quality and aquatic monitoring that Teck conducts downstream of calcite treatments.

Groundwater Quality

In the Elk Valley, groundwater generally flows below the surface in shallow sand and gravel aquifers, parallel to streams and rivers (surface water). Mining influences on groundwater can occur through two main pathways (Figure 17):

- **Groundwater pathway:** Mine-related substances infiltrate the ground from mine sources (such as waste rock, process plants, and settling ponds) and influence aquifers close to mining operations. In areas where this is the main pathway, concentrations of mine-related substances in groundwater are expected to be higher than in nearby surface water.
- **Surface water pathway:** Mine-influenced surface water interacts with aquifers in the valley bottoms. In areas where this is the main pathway, concentrations of mine-related substances in groundwater are expected to be equal to or less than nearby surface water because of mixing with freshwater sources.

The surface water pathway is believed to be the main pathway for transporting mine-related substances to groundwater on a regional scale. The majority of groundwater receptors (drinking water, livestock, and wildlife) are influenced by this pathway in the valley-bottoms. As surface water quality improves through treatment, groundwater quality is also expected to improve.

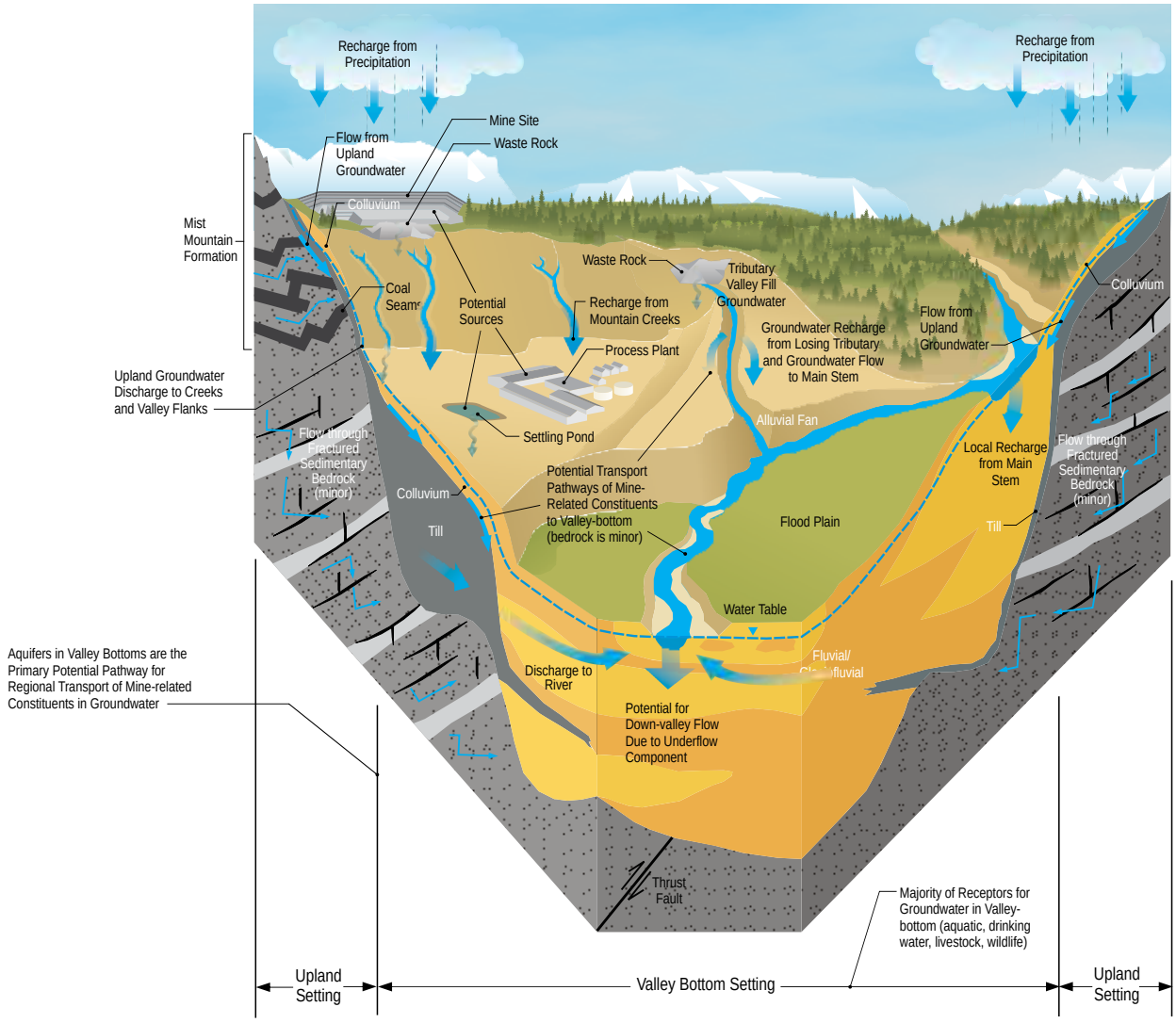


Figure 17. Pathways for mining influences on groundwater.

What is an aquifer?

An aquifer is a geological formation where groundwater can flow and be stored. Aquifers can be located right below the ground surface or very deep underground. They can be very large or quite small. They consist of layers of sand, gravel, or bedrock that is saturated with water.

To better understand the potential effects of mining operations on groundwater and the interactions between surface water and groundwater, Teck carries out six monitoring programs in the Elk Valley. There are five site-specific groundwater monitoring programs (one at each mine operation) and a regional groundwater monitoring program. The site-specific programs focus on the potential sources of mine-related substances and identify the transport pathways to the valley bottoms of the Elk River, the Fording River, and Michel Creek. The regional program focuses on the groundwater flow paths within the valley bottom and how they relate to the receptors. The EMC reviews and provides advice on the regional program. There is a groundwater working group that is linked to the EMC, which provides particular expertise on this topic.

The regional groundwater monitoring program identified twelve study areas in the Elk Valley where there may be transport of mine-related substances to groundwater in the valley bottom. Every three months Teck collects water samples and groundwater elevations from 37 wells in the study areas. The water samples are analyzed in a laboratory and the results are compared against BC guidelines for drinking water, aquatic life, livestock, and irrigation (primary screening criteria) and site performance objectives and compliance point concentrations for selenium (secondary screening criteria). Groundwater chemistry is compared to chemistry at nearby surface water stations to increase understanding of surface water and groundwater interactions. Measuring groundwater levels helps to understand groundwater flow direction and seasonal changes in aquifer storage.

Teck now has four years of regional groundwater results. In general, results from 2018 (Figure 18 and 19) were relatively similar to previous years.

Sparwood Area Groundwater Study

Teck's monitoring program identified elevated concentrations of mine-related substances, primarily selenium, in groundwater in the Sparwood Area. Teck has been conducting a special groundwater study in the Sparwood area to identify the potential sources and pathways of mine-related substances in drinking water.

In 2018, Teck reviewed all the domestic wells in the Sparwood Area and analyzed how groundwater could be affected by mining activities. The analysis confirmed that mine-influenced groundwater exists in some aquifers and suggested that the source of mine-related substances was likely from groundwater flowing through the Michel Creek valley bottom rather than directly from Baldy or Sparwood Ridge. Seven new wells were drilled in the Sparwood Area to address these gaps in our understanding of the groundwater flow paths.

Teck's Drinking Water Monitoring Program

Teck offers private well owners in the Elk Valley the opportunity to have their water tested for mining-related substances. Well owners along Michel Creek, the Fording River, and the Elk River should be aware that concentrations of some mine-related substances may be elevated, especially when creeks and rivers have low flow. Teck shares the laboratory results with well owners and regulatory agencies, but they are otherwise confidential. The laboratory results are compared to the BC drinking water quality guidelines. If the results are above background levels but below the BC water quality guidelines, Teck will continue to sample the well annually or every three months, depending on the results. If the results are above guidelines for mine-related substances, Teck provides alternate drinking water and continues routine monitoring.

In 2018, four of the thirteen wells that were sampled routinely as part of this program had concentrations of selenium temporarily above the BC drinking water guideline of 10 µg/L.

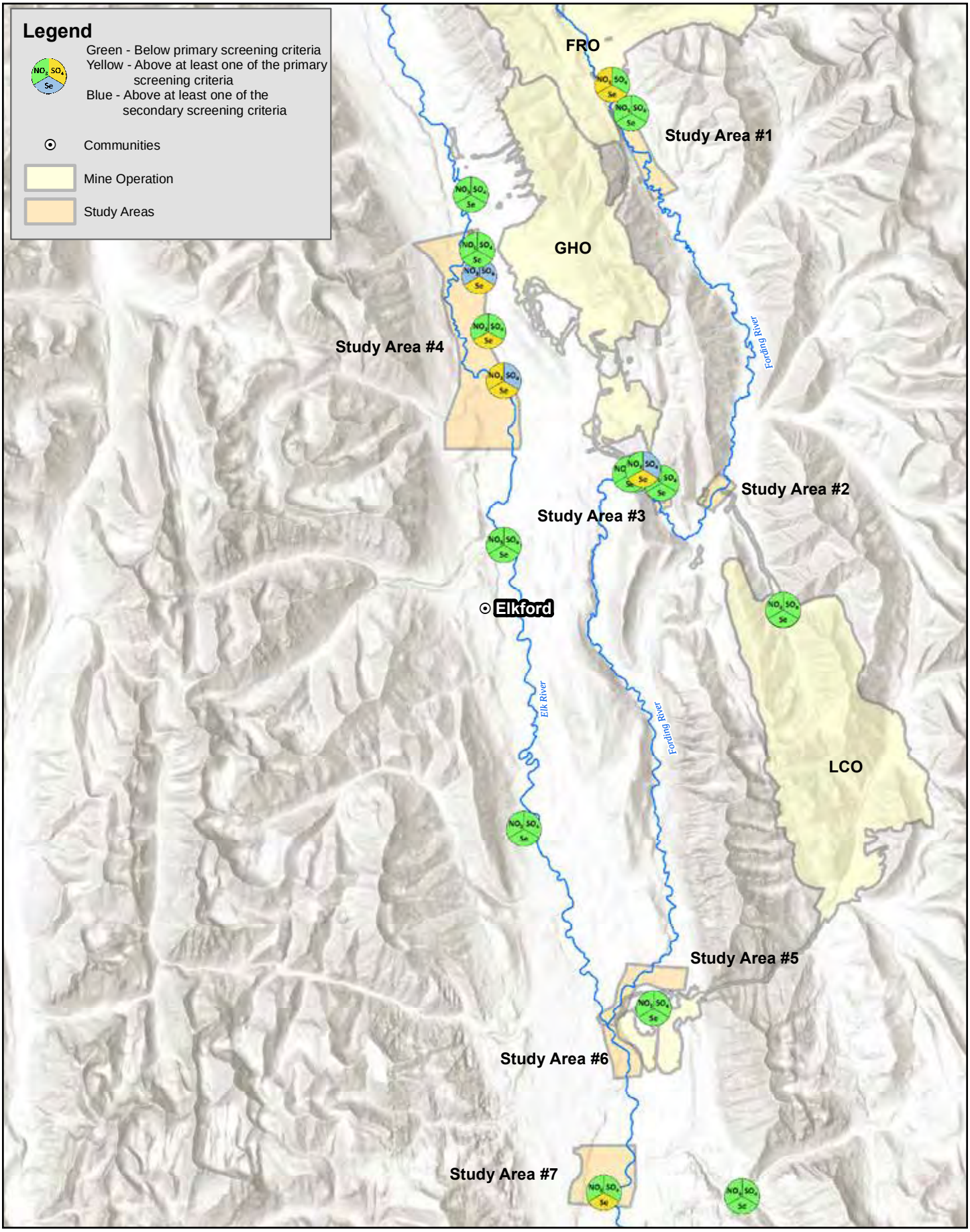


Figure 18. Results from the 2018 groundwater monitoring program (north valley).

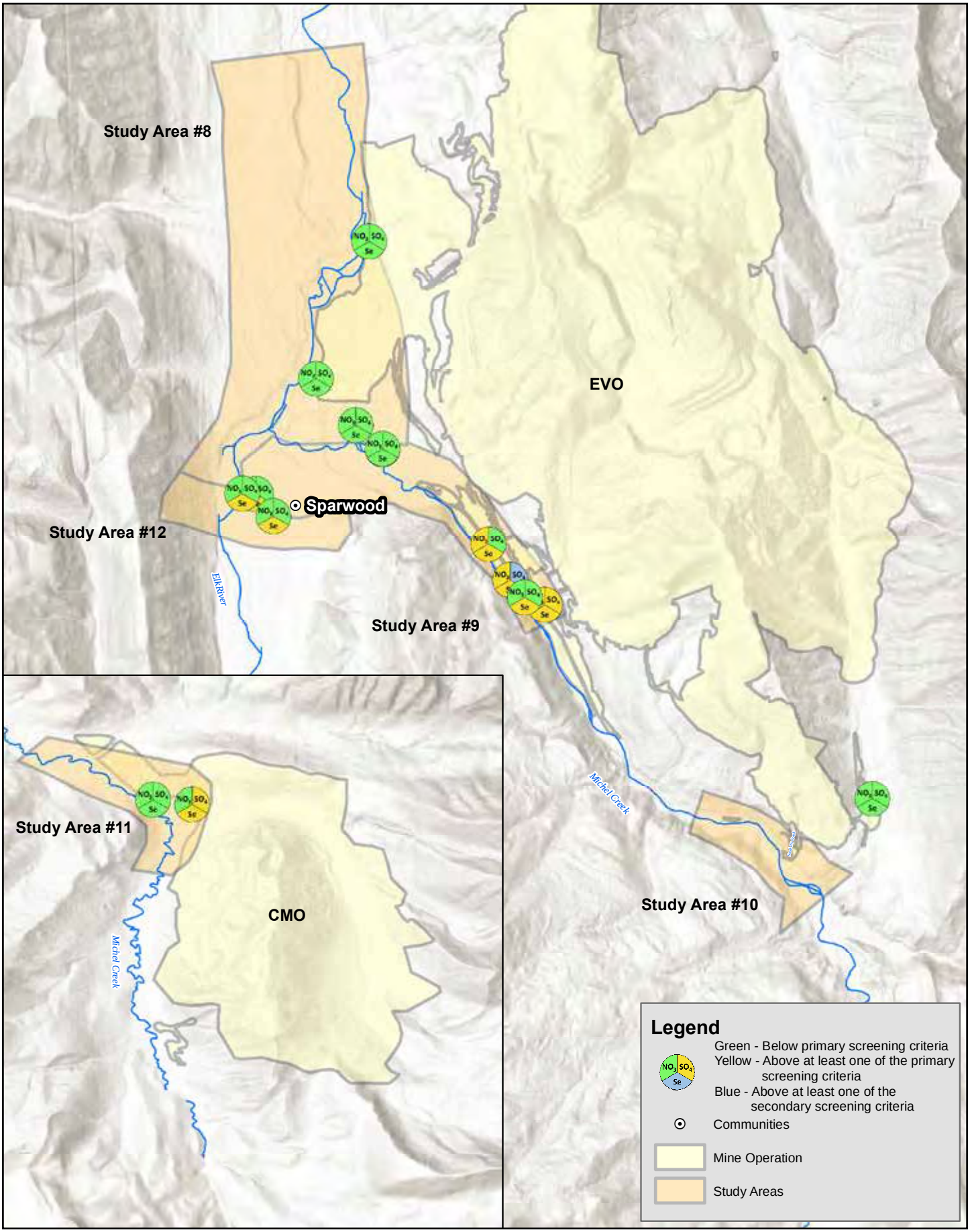


Figure 19. Results from the 2018 groundwater monitoring program (south valley).

Effects on Aquatic Life

Regional Monitoring

Teck's Regional Aquatic Effects Monitoring Program (RAEMP) is a valley-wide program that looks at the biological effects of water quality on aquatic organisms, specifically benthic invertebrates and fish. Routine field sampling occurs every year, and the results are analyzed and shared with the EMC as they are generated. A RAEMP report is developed every three years. The purpose of this program is to:

- assess the effects of mine operations, individually and together, on aquatic ecosystems within the Elk River watershed
- monitor changes over time
- help understand whether Teck's management and mitigation actions are working as intended by the Elk Valley Water Quality Plan and Permit 107517

Teck completed the first comprehensive cycle of field sampling in 2015 and a subset of sampling in 2016 and 2017 in target areas. The first RAEMP report was submitted to the Director in September 2017.[5]

In March 2018, Teck developed a new study plan for the 2018 to 2020 RAEMP cycle. Based on advice from the EMC, Teck added five new studies to better understand:

- lentic areas (locations with slower moving water)
- reproductive effects of selenium on the Columbia Spotted Frog
- reproductive effects of selenium on the fish, Redside Shiner
- toxicity in sediment
- nutrient loading from mine-related sources and active water treatment facilities

Teck completed the second comprehensive cycle of sampling in 2018. This included benthic invertebrate sampling at 69 locations and fish sampling at 18 locations: 11 for Westslope Cutthroat Trout and 7 for Mountain Whitefish.

The results from the routine sampling and the additional studies will be included in the RAEMP report submitted to the Director and the EMC in September 2020.

[5]Regional Aquatic Effects Monitoring Program 2015-2016 Report

Benthic Invertebrates

Benthic invertebrate communities in the flowing portions of the Elk River and its tributaries are dominated by mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera). These three aquatic invertebrates are collectively called EPT. EPT are considered highly sensitive to changes in water quality and habitat disturbance. When EPT are abundant, it indicates good quality habitat for aquatic organisms.

Of the 46 mine-exposed areas sampled in 2018, five had EPT abundances less than the normal range observed in reference (not mine-exposed) tributaries. Results from 2018 again showed a reduction in the proportion of three types of mayflies in the upper part of the Fording River. The extent and cause of this reduction cannot be explained by water quality or calcite effects alone and may be due to both mine-related and natural factors. Teck is continuing to investigate this under the Fording River Operations Local Aquatics Effects Monitoring Program (page 39).

The selenium concentrations in the tissues of benthic invertebrates collected in fast-moving waters have typically been less than what is considered to have a 10% effect on benthic invertebrate reproduction (this is called the Level 1 benchmark). The preliminary results from 2017 and 2018 indicate that 8 out of 76 areas sampled (9.2%) had one sample or more with a selenium concentration greater than the Level 1 benchmark for benthic invertebrates. Accumulation in these areas was expected given the projected selenium concentrations for these areas in the EVWQP. The concentrations of selenium in benthic invertebrates from slow-moving water have frequently been greater than the Level 1 benchmark. You can find more information about the benchmarks, and how they were derived, in the Elk Valley Water Quality Plan (EVWQP).

The tissue results were compared to normal ranges in reference tributaries and to water quality and bioaccumulation models that were developed for the EVWQP. In 2017 and 2018, tissue selenium concentrations measured in benthic invertebrates from 72.3% of the mine-exposed areas (47 of the 65 areas sampled) were above the upper end of the normal range of reference tributaries.

The tissue selenium concentrations in benthic invertebrates were generally within the range predicted by the bioaccumulation model presented in the EVWQP in all study areas, except for Bodie Creek and Dry Creek near Line Creek Operations. Bodie Creek was receiving water pumped from mining pits that had forms of selenium more easily accumulated, which led to higher selenium concentrations in benthic invertebrates. In Dry Creek, tissue concentrations are uncharacteristically high and Teck is evaluating the different forms of selenium. The EMC will continue to review this information and provide input through the Dry Creek Local Aquatic Effects Monitoring Program.

Figure 20. Mayfly (Ephemeroptera)

Figure 21. Stonefly (Plecoptera)

Figure 22. Caddisfly (Trichoptera)

Fish

In the first cycle of the RAEMP (2015 to 2016), Teck studied three species of fish that are common in the Elk Valley: Westslope Cutthroat Trout, Mountain Whitefish, and Longnose Sucker.

Westslope Cutthroat Trout are widely distributed throughout the Elk River watershed and are the only fish present in the Fording River upstream of Josephine Falls. Teck sampled fish from the Elk and Fording Rivers in 2015 and again in 2018. Samples were obtained by taking a very small amount of muscle, called a plug. Fish are then released.

Preliminary results from the September 2018 sampling events indicate that nearly all of the fish sampled had selenium concentrations near or above the upper limit of the normal range observed in reference-area fish. These results are similar to those from 2015. However, these tissue concentrations were within the ranges projected by the bioaccumulation models developed for the EVWQP. All the fish collected from fast-moving water had selenium concentrations less than the Level 1 benchmark for reproductive effects, except for the fish from Line Creek. You can find more information on this topic on page 39).

Teck also conducts an annual population study on Westslope Cutthroat Trout in the Fording River. This study is not a permit requirement, but the results are shared with the EMC. The 2017 results indicated that the population was stable and potentially increasing[6]; however, preliminary results from September and October 2019 showed a very concerning decrease in juvenile and adult Westslope Cutthroat Trout density estimates compared to 2017. These findings are being evaluated under the adaptive management framework and Teck is involving all regulatory agencies. The EMC will be provided information on the evaluation.

Mountain Whitefish are found mainly in the Elk River and in the lower reaches of the Fording River, Line Creek, Alexander Creek, and Michel Creek. Samples were collected in 2015 and 2018 and analyzed for selenium concentrations.

Fifty-six mountain whitefish were euthanized in 2018 to obtain both muscle and ovary tissue samples. Eight locations were sampled, including two reference locations and six mine-influenced locations. The concentration of selenium in muscle tissue was higher than the BC water quality guideline for aquatic life for fish collected from the six mine-influenced locations. The concentration of selenium was below the guideline for fish collected from the reference locations. The concentration of selenium in the ovary tissue was higher than the guideline at both the reference and the mine-influenced locations. For fish collected at four of the six mine-influenced locations, the concentration of selenium in ovary tissue was above the interim screening value proposed by Teck (29.3 mg/kg dw). Teck and the EMC are discussing redoing the study to better understand the potential consequences of elevated selenium levels to Mountain Whitefish.

What is mg/kg dw?

The abbreviation *mg* stands for milligrams, *kg* stands for kilogram, and *dw* stands for dry weight. So a selenium concentration of 11 mg/kg dw means there is 11 milligrams of selenium per kilogram of dry fish tissue.

Dwarf Longnose Suckers are found in slow-moving waters throughout the Elk Valley. Teck collected tissue samples from fish in 2015 (from six locations) and 2018 (from Goddard Marsh only) and analyzed them for selenium concentrations. More intensive sampling will be carried out in fall 2019.

In the six mine-exposed areas sampled in 2015, the concentration of selenium was greater than for those fish collected from reference areas. The concentrations of selenium in ovary and muscle tissues were above the Level 1 benchmarks for reproductive effects for all individuals from Goddard Marsh, some of the fish from the Elk River wetland (downstream from Grave Creek), and some of the fish in Stanford Pond (near Fernie). The results from 2018 indicate that concentrations are increasing and Teck is discussing a selenium effects study on this species in the next few years. The results from 2019 will be shared with the EMC for their review and advice, and will be reported in the RAEMP 2020 report.

Figure 23. Westslope Cutthroat Trout

[6]Upper Fording RIver Westslope Cutthroat Trout Population Monitoring Project 2012 to 2017

Local Monitoring

Local aquatic effects monitoring programs are designed to answer specific questions about aquatic effects that arise because of the unique circumstances of a particular mine operation and that cannot be answered using only the regional aquatic effects monitoring program. Teck currently has five local aquatic effects monitoring programs underway.

Fording River Operations

The local aquatic effects monitoring program at the Fording River Operations began in 2016. The intent of this program is to document current conditions and evaluate the aquatic effects of mine development and the planned active water treatment facilities (two active water treatment facilities are required by Permit 107517). The first three years of monitoring results are required to understand aquatic conditions before treatment so changes could be measured as the treatment facilities come online. The Fording River South Active Water Treatment Facility is currently under construction; commissioning is planned for late 2020. This facility will treat water from Cataract Creek, Swift Creek, and Kilmarnock Creek.

Results from the past three years showed a decrease in the abundance of mayflies in the upper Fording River at specific locations. The results from Teck's investigations do not point to a single direct cause. The decrease in abundance is likely due to a combination of both mine-related and natural factors (such as mine-related water quality concentrations of selenium, nitrate, and nickel; water temperature variability; annual flow variability; and predation by other organisms). Because sections of the upper Fording River flow underground at certain times of the year, the 2019 monitoring program will assess how benthic invertebrate communities re-establish after a drying event.

The program will continue to address the key questions related to the effects from Fording River Operations and the active water treatment facilities as they are commissioned.

Greenhills Operations

The local aquatic effects monitoring program at Greenhills Operations began in 2017 to gain a better understanding of the side channel that lies between Greenhills Operations and the Elk River. This side channel receives flow from Thompson Creek, Wolfram Creek, Leask Creek, and Mickelson Creek.

Results from 2017 and 2018 indicated that the side channel is used by a variety of fish and birds, from spring through fall when the side channel has flowing water. Seasonal drying of the side channel makes it poor habitat for amphibian breeding. Water quality in the side channel is influenced by Wolfram Creek and Thompson Creek, resulting in concentrations above the EVWQP Level 1 benchmarks (>10% effect size) for fish. Selenium concentrations in benthic invertebrates were higher in the side channel than in the mainstem of the Elk River, but the community endpoints did not differ greatly. In Thompson Creek and the downstream wetland, selenium concentrations in benthic invertebrates were above the EVWQP Level 2 benchmarks (> 20% effect size) for fish and birds.

The study design for 2019 takes a more focused look at water quality in the west-side tributaries, the side channel, and the mainstem of the Elk River. It will also look at groundwater-surface water interactions in the side channel and will continue monitoring the benthic invertebrate community and tissue chemistry to support answering the outstanding key questions of the program.

Line Creek Operations

There are two local aquatic effects monitoring programs at Line Creek Operations. The first began in 2014 to understand the potential effects of the West Line Creek Active Water Treatment Facility on water quality and aquatic organisms. Teck built the facility to reduce the concentration of selenium and nitrate in Line Creek. This facility is required by Permit 107517 and is the first of its type in the Elk Valley.

The facility was operational from July to October 2014. It was shut down because of performance issues until late 2015. Water quality monitoring results from 2016 and 2017 indicated that the facility was removing 95% of the total selenium and 90% of the nitrate from the water. However, biological monitoring results showed elevated concentrations of selenium in the tissues of aquatic organisms collected in Line Creek immediately downstream of the facility. An investigation determined that the treatment process was converting the remaining selenium in water to a form that is more easily accumulated by aquatic organisms. The facility was again shut down from March to August 2018 while Teck added an advanced oxidation process to the facility to address the selenium conversion.

The temporary shutdown of the treatment facility in 2018 did not result in changes to the kinds, proportions, or numbers of benthic invertebrates in Line Creek. As predicted, results from 2018 indicate that selenium concentrations in aquatic biota decreased when the active water treatment facility was recommissioned with the advanced oxidation process. Monitoring in 2019 will confirm these results. This program continues to monitor water quality and aquatic organisms downstream of the facility to monitor the effectiveness of the treatment facility.

A second local aquatic effects monitoring program at the Line Creek Operations also began in 2014. This program was designed to determine the effects of the Line Creek Phase II project on the Dry Creek drainage by evaluating the potential effects of mine-related substances on aquatic biota. This program is required under a different permit (Permit 106970), but it was brought to the EMC for their review and advice early in 2019 through the adaptive management framework.

The first three years of annual monitoring results (2014 to 2017) showed little change in the conditions of the three creeks within the Dry Creek drainage: Dry Creek, Grace Creek, and Unnamed Creek. In May 2017, the concentrations of nitrate, selenium, and sulphate increased. Nitrate concentrations were above the Level 1 benchmark for potential effects to aquatic biota, while the concentrations of selenium, sulphate, and cadmium were below this benchmark. Selenium concentrations in benthic invertebrates were similar in upper and lower Dry Creek and benthic invertebrate communities were not adversely affected. In 2018, results showed another increase in the concentrations of mine-related substances in Dry Creek and both the rate and magnitude of change was faster than what was projected by the Regional Water Quality Model. Another unexpected finding in 2018 was elevated concentrations of selenium in benthic invertebrate tissue samples collected in Dry Creek. These concentrations were 5 to 10 times greater than what was measured in 2017. Teck has been investigating these unexpected observations and has added four monitoring locations in the latter part of 2018 and increased monitoring frequency. Toxicity test results conducted in 2018 showed a low potential for direct effects to aquatic life. Despite the changes in water quality in Dry Creek, and the unexpected selenium concentrations in the benthic invertebrates, benthic invertebrate communities were similar between upper and lower Dry Creek in 2018.

Elkview Operations

There are currently no site-specific issues or questions at Elkview Operations that require a local aquatic effects monitoring program. If a specific issue or question arises that cannot be addressed by the regional program monitoring, Teck will work with the EMC to develop a local program.

Coal Mountain Operations

The first year of local aquatic effects monitoring at the Coal Mountain Operations was 2019. This monitoring program was required by Permit 107517 because of results coming out of the regional monitoring program, Coal Mountain Operations management plans, and the routine laboratory tests for toxicity (bioassays). This program also supports the closure plans for Coal Mountain Operations. Results from the regional monitoring program, Coal Mountain Operations management plans, indicated that the benthic invertebrate community in Corbin Creek downstream of the Coal Mountain Operations and in Michel Creek displayed reduced numbers of certain species when compared to the reference sites. Results from the routine bioassays showed that water from Michel Creek was having a negative effect on certain test species. Teck launched an investigation into these results and found that nickel may be the cause, even though concentrations were below the BC water quality guideline. See the *Nickel* section on page 27 for more information.

The 2019 program will focus on water and sediment quality, calcite index, and benthic invertebrate tissue and community metrics. These results will help answer key questions about the magnitude and spatial extent of effects from the closure activities, such as pit pumping.

Bioassay Studies

Bioassays are laboratory tests that involve exposing certain organisms (such as very young fish, water fleas, amphibians) to water or sediment collected from a monitoring location, and observing growth, reproduction, and survival of individuals. Teck routinely tests waters from various creeks in the Elk Valley and from the Fording and Elk rivers. In 2018, Teck also undertook detailed laboratory tests to understand the sensitivities of invertebrates, amphibians, and fish to mine-related substances.

Routine Laboratory Tests

Short-term laboratory tests are conducted on water samples collected from a number of monitoring stations throughout the Elk Valley. These tests are part of Teck's routine water quality monitoring, which is conducted monthly (weekly during spring). The short-term laboratory tests use water fleas (a small 1 to 5 mm crustacean called *Daphnia magna*) and very young Rainbow Trout. The water sample passes the test if 50% or more of the organisms survive exposure (tests last 96 hours for trout and 48 hours for the water flea). Failing the test triggers follow-up investigations that may include re-testing the water sample or additional studies to determine the cause of the failure.

In 2018, 294 short-term tests with Rainbow Trout were conducted and all samples passed. A total of 305 water flea short-term tests were completed and four samples from Cataract Creek failed. Teck completed various follow-up studies and the results suggested that mineral precipitates (including calcite) were responsible for the failures.

Long-term laboratory tests are conducted every three months on water samples collected from the eight compliance points. These tests use algae, amphipods, water fleas, Fathead Minnows, and very young Rainbow Trout. Long-term tests range in duration from 72 hours (for algae) to 30 days (for Fathead Minnow and Rainbow Trout). About one third of the 115 long-term tests conducted with mine-influenced waters showed inhibited growth or reproduction in one or more of these organisms compared to the growth and reproduction of organisms held in reference (non mine-influenced) river water (Figure 24). Long-term test results help Teck and the EMC understand the health of the Elk River and its tributaries.

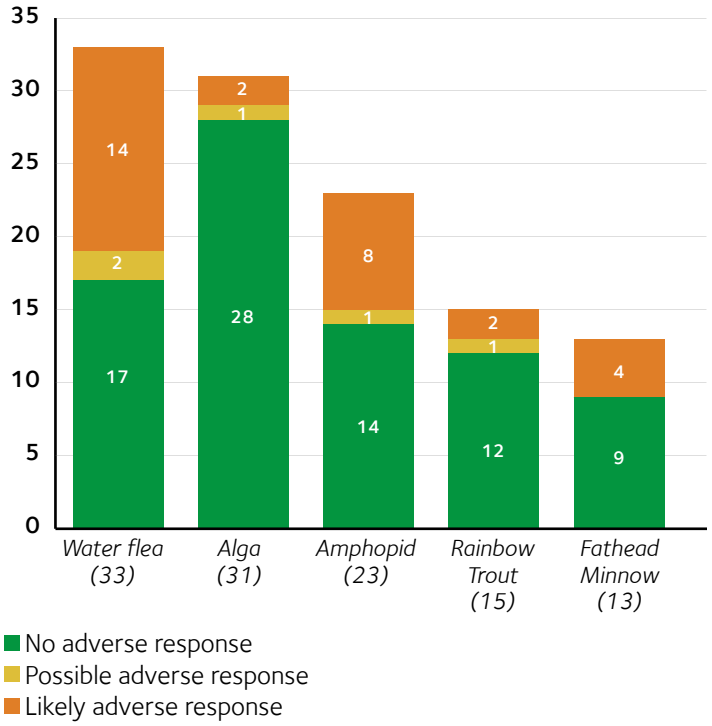


Figure 24. Number of long-term laboratory tests by species in 2018.

Nitrate and Sulphate Laboratory Tests

When the EVWQP was developed, the limits for nitrate and sulphate in the water were set based on the available science, as well as provincial and federal benchmarks. There was some uncertainty at the time whether these limits were low enough to protect the most sensitive aquatic organisms. Teck began conducting laboratory tests to investigate the tolerances of aquatic invertebrates, fish, and amphibians to nitrate and sulphate (at the same time) under conditions similar to what is found in the Elk Valley. The results from those tests have confirmed that the benchmarks used to develop the limits are in fact protective of sensitive aquatic invertebrates and fish, with a margin of safety potentially greater than prescribed in the EVWQP.

The sensitivity of amphibians to nitrate and sulphate has not been well studied, and so their tolerances were unknown during the development of the EVWQP. Teck, therefore, started laboratory tests with frogs (Northern Leopard frogs) in 2016. Testing with frogs has been challenging. The tests require that the tadpoles be reared in the laboratory; a process that takes months. Studies in 2016 and 2017 produced unreliable results because of unexplainable mortalities in the control samples (lab water). The laboratory tests were repeated in 2018, this time with success. The 2018 results will be reported in 2019, but they generally support that the limits for nitrate and sulphate are low enough to protect amphibians as well as aquatic invertebrates and fish.

Amphibian Egg-Viability Laboratory Tests

Several species of amphibians live in the side channels of the Elk River and in its smaller tributaries. The sensitivities of amphibians to selenium has not been well studied. Teck conducted a preliminary study of selenium toxicity to Columbia Spotted Frog in 2012, but the EMC felt there remained a gap in understanding the risks of selenium exposure to the survival of larval Columbia Spotted Frog (and other amphibians) in the Elk Valley. In 2018, Teck collected fertilized egg masses of Columbia Spotted Frog from side-channels of the Elk River and reared them in the laboratory to evaluate the survival and deformity rates of eggs and tadpoles. The results showed no evidence of selenium effects on egg survival, or tadpole development, at egg selenium concentrations of up to 11 mg/kg dw. This work was repeated in 2019 to capture sites with a broader range of aqueous selenium concentrations as previous studies have observed concentrations upwards of 38 mg/kg dw.

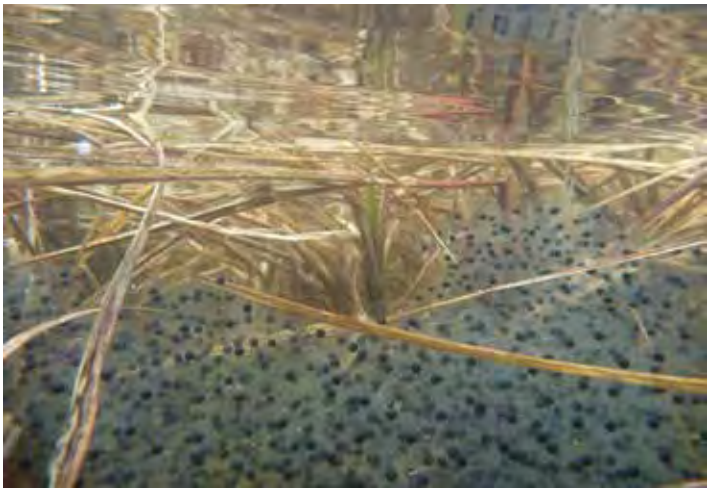


Figure 25. Columbia Spotted Frog egg mass within vegetation.

Figure 26. Columbia Spotted Frog tadpoles in the laboratory.

Fish Egg-Viability Laboratory Tests

The limits for selenium in the EVWQP were based on previous studies in the Elk Valley and elsewhere. To provide more confidence in the benchmark for concentrations of selenium in ovaries, egg-viability studies became a requirement in Permit 107517. Teck completed an egg-viability study in 2015 using eggs collected from Westslope Cutthroat Trout. That study measured the concentration of selenium in eggs and evaluated their survival and development in the laboratory. The EMC considered the results and determined they were sufficient to confirm the critical selenium level in Westslope Cutthroat Trout ovaries.

The EMC recommended the next egg-viability study should focus on Redside Shiners. Redside Shiners are small-bodied fish that are abundant in the Elk River watershed. Monitoring results from 2015 and 2016 show that this species accumulates greater amounts of selenium in its tissues compared to most other fish species and relative to tissue-based water quality guidelines in the Koocanusa Reservoir. The EMC recommended Redside Shiners for this study because little is known about the accumulation and toxicity of selenium in that species.

Teck designed and implemented an egg-viability study on Redside Shiners in 2018. Redside shiners were successfully maintained in the laboratory, but the fish would not spawn. The study continued in 2019, where Teck collected eggs of Redside Shiner, fertilized them in the field, and brought them back to the lab. Results showed no effect of selenium, at the tested concentrations, on survival, growth, or deformities for this species.

Koocanusa Reservoir

The Koocanusa Reservoir straddles the border between Canada and the United States, and lies within the traditional territory of the Ktunaxa people. Three Canadian rivers supply most of the inflow to the reservoir: the Kootenay River (62%), the Elk River (26%), and the Bull River (11%).

Since 2014 Teck has conducted studies to understand the physical, chemical, and biological conditions in the Canadian portion of Koocanusa Reservoir. This program is designed to determine if conditions in the reservoir are changing and if those changes can be attributed to influences from the Elk River and upstream mining activities. Teck collects samples upstream and downstream of the Elk River confluence, and compares the results to identify potential mining-related effects. The results of this monitoring program are summarized in reports that Teck submitted to the Director:

- the 2014 to 2016 monitoring cycle[7] (submitted in June 2017)
- 2017 water quality conditions[8] (submitted in June 2018)
- year one of the 2018 to 2020 monitoring cycle[9] (submitted in June 2019)

Currently, Teck is continuing year two of the 2018 to 2020 monitoring cycle, collecting information on water (physical and chemical), sediment (physical and chemical), phytoplankton, zooplankton, benthic invertebrates, and fish.

Water Quality

Based on the results from 2014 to 2018, water quality in the Koocanusa Reservoir is generally good with minor exceptions. Concentrations of nitrate and selenium tended to be higher in areas downstream from where the Elk River flows into the reservoir (the confluence) compared to areas upstream of the confluence (when considering the annual average surface water quality). However, permit limits and BC water quality guidelines for nitrate, selenium, sulphate, and cadmium were met consistently at the order station in the Koocanusa Reservoir, except for selenium in April 2018.

In April and May 2018, the riverine condition of the reservoir prevented field samplers from accessing the usual permitted sampling location safely. The April samples were therefore collected along the eastern shoreline. In May 2018, water samples were collected from both the eastern and western shorelines. The differences in the concentration of water quality parameters (selenium, for example) between the shorelines suggested that the water at this sampling location was not fully mixed. Follow-up studies by Teck (from April to August 2018) have offered insight into how water from the Elk River and the Kootenay Rivers behave in the reservoir. When water levels in the reservoir are low and the reservoir is river-like, the Elk River does not substantially mix with water from the Kootenay River until 4 or 5 kilometres downstream of the permitted sample location. At higher water levels (June through August and beyond), substantial mixing did not occur until 15 kilometres downstream of the permitted sample location.

Figure 27. Riverine condition of the Koocanusa Reservoir in April and May 2018.

[7] Koocanusa Reservoir Monitoring Report, 2014 to 2016 (June 2017; updated June 2019)

[8] Permit 107517 2017 Summary Report of Monitoring Results in the Koocanusa Reservoir (June 2018)

[9] Koocanusa Reservoir Monitoring Program Annual Report, 2018 (June 2019)

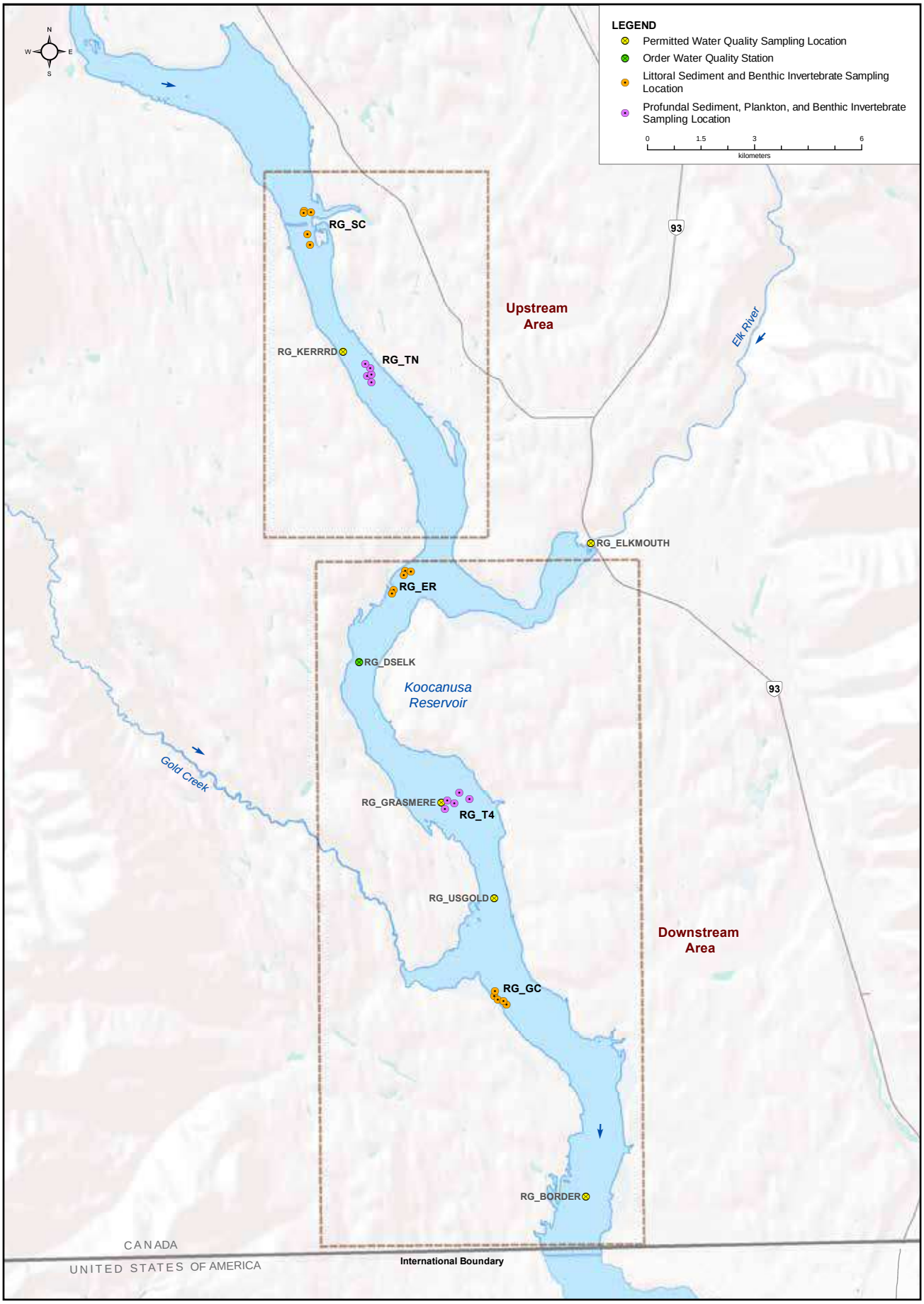


Figure 28. Teck's sampling locations in the Koocanusa Reservoir.

Sediment Quality

Sediment results from 2014 to 2018 showed that concentrations of most metals and polycyclic aromatic hydrocarbons[10] were higher in sediments collected downstream of the Elk River confluence, but these concentrations were all below the BC sediment severe-effects guidelines. Certain metals, including arsenic, nickel, iron, and manganese were above the BC sediment low-effects guidelines both upstream and downstream of the Elk River.

Aquatic Algae and Invertebrates

Samples of phytoplankton (tiny suspended algae) and zooplankton (tiny suspended invertebrates) were collected in Koocanusa Reservoir upstream and downstream of the Elk River confluence in 2015, 2016, and 2018. The numbers and kinds of organisms present (community structure) were evaluated, as well as the concentration of selenium in zooplankton. The results showed no significant differences between the upstream and downstream locations.

Clams, insect larvae, worms, seed shrimp, and mites were among the organisms found in reservoir sediments. These types of organisms are typical of reservoir habitat (deep and slow moving). There were minor differences in the kinds of organisms found in sediments downstream of the Elk River confluence compared to upstream, with natural variations in sediment texture likely to be the cause of those biological variations.

Fish

Teck collected samples of several different fish species in Koocanusa Reservoir from 2014 to 2018, including Peamouth Chub, Northern Pikeminnow, Largescale Sucker, Redside Shiner, and Yellow Perch. These samples provided important information on fish age, condition (weight in relation to length), liver size, gonad size, and growth. In addition to these fish health and population measurements, the concentration of selenium was measured in the muscle tissue, whole body tissues, and ovaries (Figure 30 and 31).

Figure 29. Redside Shiner

[10]Polycyclic aromatic hydrocarbons are organic compounds containing only carbon and hydrogen. They occur naturally and are released from burning fossil fuels, trash, tobacco, and wood.

Teck conducted fish health surveys of Peamouth Chub and Redside Shiner in Koocanusa Reservoir that focused on fish survival (mean age), growth (body size-at-age), reproduction (relative gonad weight) and energy storage (relative liver weight and overall condition). The results from these surveys showed no consistent patterns among fish species, sexes, or sampling years that would indicate an influence from the Elk River (Table 1).

Selenium concentrations measured in fish tissues from Koocanusa Reservoir were compared to guidelines published by the USEPA[11] and the British Columbia Ministry of Environment. They were also compared to the benchmarks established in the EVWQP. Selenium guidelines for fish tissues are estimates above which there is a potential risk of reproductive impairment. Guidelines vary between agencies because each agency employs different methods for defining a protective threshold and the critical burden of selenium in fish tissue (causing reproductive effects) is an evolving field of study. It is agreed, however, that the concentration of selenium in ovaries is the most relevant measure for evaluating ecological effects because it is selenium in eggs that poses risk of reproductive effects in fish.

The average concentrations of selenium in the ovaries of fish collected from the reservoir were frequently above the BC guideline of 11 mg/kg dw, particularly in Peamouth Chub, Northern Pikeminnow, and Redside Shiner. For all species except Redside Shiner and Northern Pikeminnow, the average selenium concentrations in the ovaries were below both the EVWQP Level 1 benchmark (18 mg/kg dw) and the USEPA guideline (15.1 mg/kg dw). Redside Shiner samples were above the Level 1 benchmark at both downstream and upstream locations (above mine-influenced waters) in the three years it was sampled (2015, 2016, and 2018).

Table 1. Summary of statistical results for fish health endpoints for 2014, 2015, 2016, and 2018.

Sex	Response	Endpoint	Peamouth Chub				Redside Shiner	
			2014	2015	2016	2018	2016	2018
Female	Survival	Mean age	↑ O	O O	O ↓	O O	O O	O O
	Energy Use - Growth	Adjusted body weight-at-age	↑ O	O ↓	↓ ↓	O O	O O	O ↑
	Energy Use - Reproduction	Gonad weight-at-adjusted body weight	↓ O	O O	↑ ↑	O O	O O	O O
	Energy Storage	Condition (Adjusted body weight-at-fork length)	O ↓	O O	O O	↓ ↓	O O	O O
		Liver weight-at-adjusted body weight	O ↑	↓ ↓	↑ ↑	O ↑	↑ ↑	↑ O
Male	Survival	Mean age	↑ O	O O	O ↓	↓ O	O O	O O
	Energy Use - Growth	Adjusted body weight-at-age	O ↑	O O	O ↓	O O	O O	O O
	Energy Use - Reproduction	Gonad weight-at-adjusted body weight	O O	O -	↑ O	O O	O O	O O
	Energy Storage	Condition (Adjusted body weight-at-fork length)	↑ O	O O	O O	O O	↓ O	O O
		Liver weight-at-adjusted body weight	O ↑	O O	O O	↓ O	O ↑	O ↑

O no significant difference
↓ downstream fish significantly lower
↑ downstream fish significantly higher

Blue symbols: Fish collected in Koocanusa Reservoir near the Elk River relative to Sand Creek
Red symbols: Fish collected in Koocanusa Reservoir near Gold Creek relative to Sand Creek

[11]The acronym USEPA stands for the United States Environmental Protection Agency. The guidelines were published in 2016.

Redside Shiners appear to have a greater body burden (greater accumulation) of selenium than most other species. The implications of these higher concentrations are currently unknown because no studies have been done to determine the toxicity of selenium on this species. Redside Shiners are highly abundant in the Elk Valley watershed, so the EMC has recommended a study to evaluate the effects of selenium on the early life stages of Redside Shiners (see page 42).

Individual fish, including Peamouth Chub, Northern Pikeminnow, Longnose Sucker, and Rainbow Trout collected downstream of the Elk River confluence had selenium concentrations above the Level 1 EVWQP benchmark for ovaries; however, only Northern Pikeminnow showed average selenium concentrations in their ovaries above the Level 1 benchmark. When a selenium guideline or benchmark is exceeded, it does not necessarily mean that there will be an effect to the organism. Fish species have a range of sensitivities to selenium in their ovaries, and critical levels have not been established for all the species that have been reported in the Koocanusa Reservoir. Ongoing and future studies will be evaluating the sensitivity of species that exhibit elevated selenium in their tissues to better understand whether effects are expected.

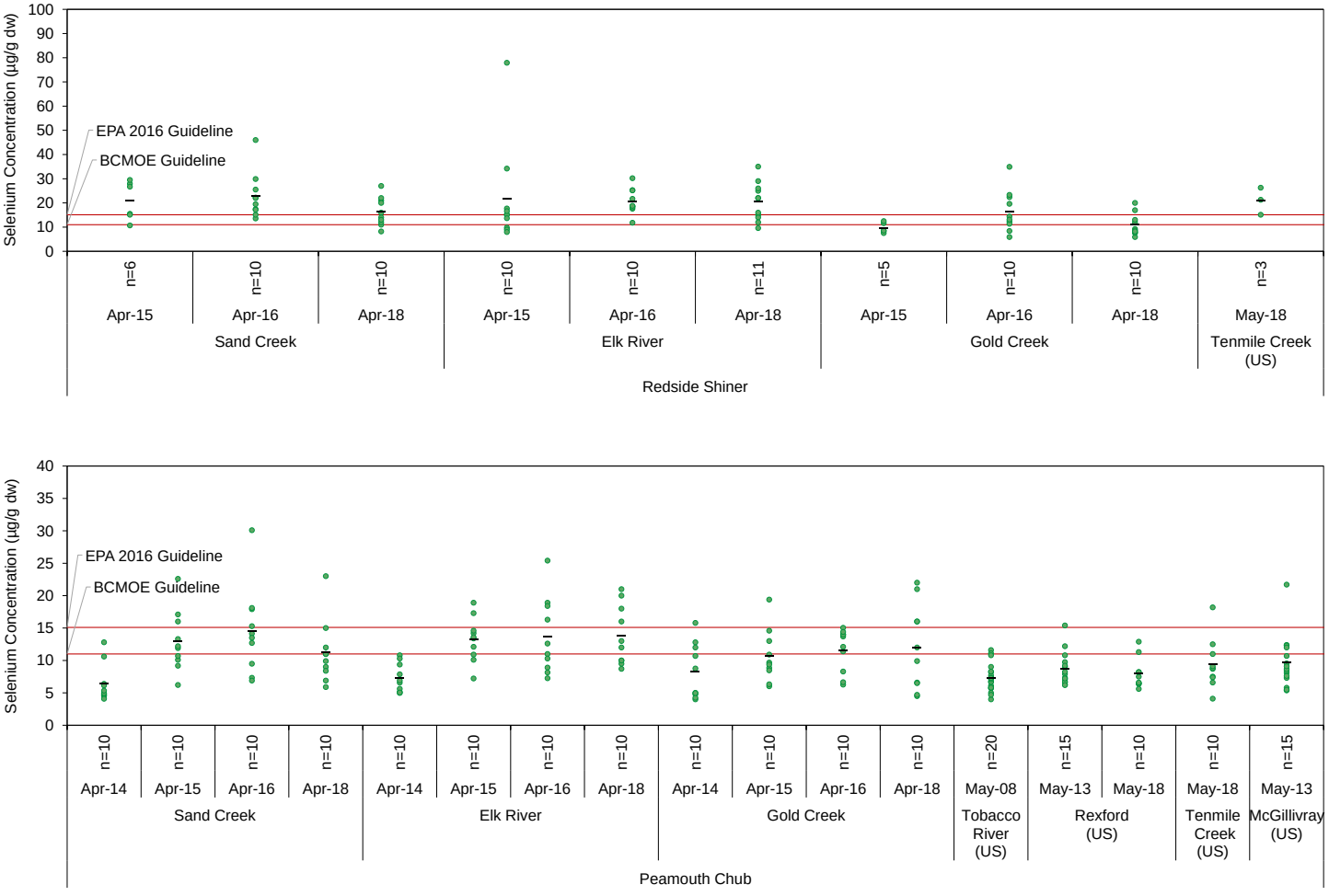


Figure 30. Concentrations of selenium (mg/kg dw) in the gonads and ovaries of Redside Shiner and Peamouth Chub in the Koocanusa Reservoir from 2008 to 2018.

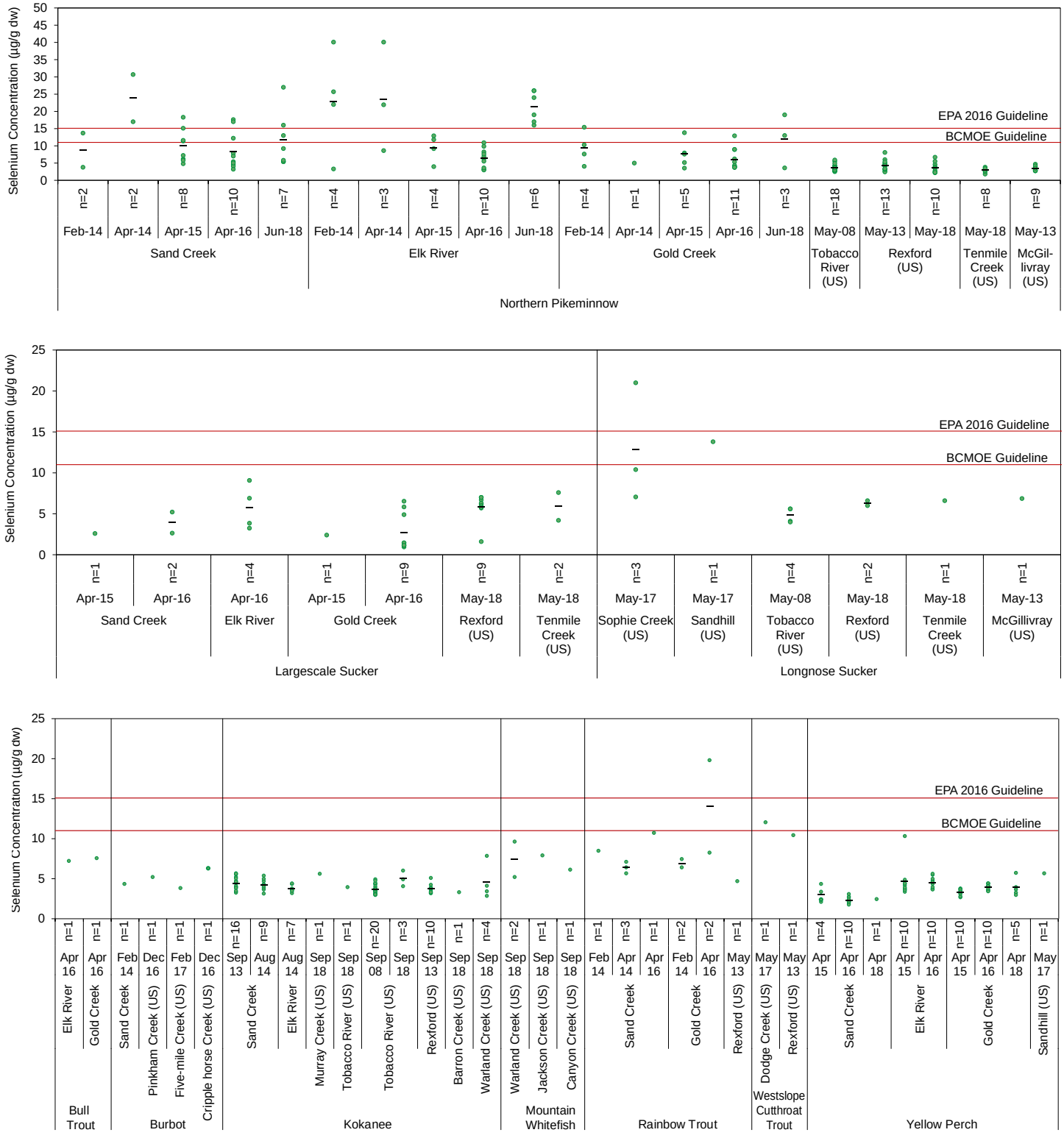


Figure 31. Concentrations of selenium (mg/kg dw) in the gonads and ovaries of various fish species in the Koocanusa Reservoir from 2008 to 2018.

Other Programs

Human Health

Teck is required to conduct a human health risk assessment for the Elk Valley. A human health risk assessment determines the potential risks to human health posed by the presence of certain substances within a defined area. It considers the toxicity of the substances, how much of the substances humans are exposed to, and how often. A human health risk assessment is not a monitoring program, but rather a snapshot in time that relies on the most recent monitoring results from other programs.

Teck submitted a Human Health Risk Assessment (HHRA) report to the EMC and the Director in March 2016. After reviewing that report, two EMC member organizations (IHA and KNC) felt the potential health risks to Ktunaxa citizens—based on their preferred consumption rates of wild foods—were not addressed. To address these concerns, Teck evaluated the risks associated with consuming wild foods at the preferred rates defined in the Ktunaxa First Nation Diet Study (Firelight 2015). Teck described the results of their evaluations in a technical memo and submitted it to the EMC and the Director in September 2016. Following the review of that technical memo, the EMC acknowledged that there were information gaps in what was known about current and preferred consumption rates. In addition, IHA and KNC felt that two separate documents would be a source of confusion and misunderstanding among community members, decision-makers, and other readers, and felt the 2016 HHRA should be reissued. KNC also had outstanding concerns with the portrayal of the preferred consumption rates in the follow up evaluation.

IHA and the KNC, with support from the First Nation Health Authority, reached out to the Director and the Ministry of Health to express their concerns and to resolve the stalemate over the 2016 HHRA. The Director has formally acknowledged that Teck submitted the HHRA report by the permit deadline, but the report has not yet been approved or rejected. The Director is expecting that Teck work with KNC and IHA to resolve the information gaps and submit an updated HHRA that includes a complete analysis of both current and preferred consumption rates in one report due later in 2020.

The KNC is working on an updated preferred consumption rate study which will inform the 2020 HHRA. And Teck, KNC, and IHA are working together to define the objectives and scope for an updated human health risk assessment, meeting every month for targeted discussions to ensure progress on this important file. Teck and the KNC are continuing with the wild foods sampling program to provide additional information for the assessment.

What are wild foods and what is the Wild Foods Sampling Program?

Wild foods are plants or animals harvested from the land and water that humans eat or use for teas and medicine. Some examples are rose hips, huckleberries, fish, elk, and deer.

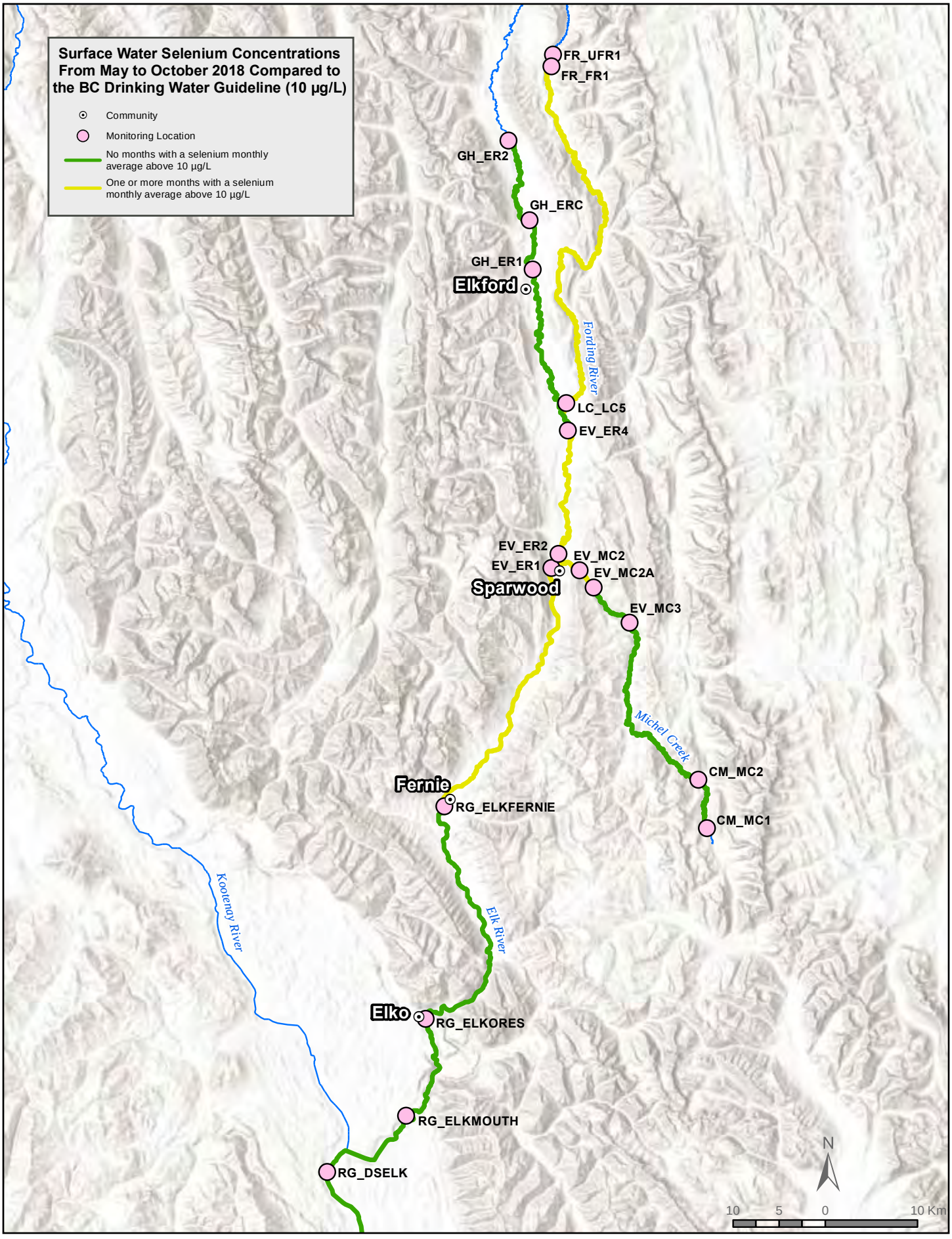
Teck accepts donations of small samples (about ½ cup) of wild foods harvested from the Elk Valley. Teck sends the samples to a laboratory to measure the concentration of mine-related substances. The results from the wild foods sampling program are used in all human health risk assessments in the Elk Valley. If you are interested in learning more about the program and possibly donating a sample or two, you can email samples.teckcoal@teck.com.

Is the water safe to drink?

The Interior Health Authority recommends that people do not drink surface water (from rivers, streams, or lakes) anywhere in the province. Surface water can contain microbiological contaminants (bacteria, viruses, and parasites) and industry-related substances. In the Elk Valley, industry-related substances are largely mine-related. Untreated surface water should be boiled to address microbiological contaminants, but this will not address risks associated with mine-related substances.

In the Elk Valley, the surface water at many locations has selenium concentrations above the BC drinking water guideline of 10 µg/L (see map on page 51). Some of these locations see these levels only during winter months, but some locations (such as tributaries close to mine operations) see these levels year round. Short-term exposure (skin contact or ingestion) from time to time is not a health risk; however, long-term frequent exposure increases the health risk. See page 20.

Drinking water systems in the Elk Valley depend on groundwater wells, not surface water. The selenium levels in tested drinking water wells are generally below 10 µg/L, with the exception of four private wells. We encourage private well owners in the Elk Valley to contact Teck to have their water tested.


Surface Water Selenium Concentrations From May to October 2018 Compared to the BC Drinking Water Guideline (10 µg/L)
Community
Monitoring Location
No months with a selenium monthly average above 10 µg/L
One or more months with a selenium monthly average above 10 µg/L
FR_UFR1
FR_FR1
GH_ER2
GH_ERC
GH_ER1
Elkford
Fording River
LC_LC5
EV_ER4
EV_ER2
EV_ER1
EV_MC2
EV_MC2A
Sparwood
EV_MC3
Michel Creek
CM_MC2
CM_MC1
Fernie
RG_ELKFERNIE
Kootenay River
Elk River
Elko
RG_ELKORES
RG_ELKMOUTH
RG_DSELK
N
10 5 0 10 Km

Tributary Management

Tributaries are smaller streams that flow into a larger stream or river (which are sometimes referred to as a mainstem) or a lake. Tributaries provide vital habitat for a variety of aquatic life and are important for the overall health of an aquatic ecosystem.

Mining activities have the potential to affect the quality of water and habitat in tributaries, and in some cases the removal of tributary habitat was permitted to allow for mining of coal resources. Permit 107517 requires Teck to complete a tributary evaluation and to develop a tributary management plan with advice from the EMC. Permit 107517 states:

> *The Tributary Management Plan is intended to incorporate protection and rehabilitation goals for tributaries that will support achieving the area-base objectives of the EVWQP. In development of the Tributary Management Plan, those tributaries that are not impacted by mining activities, that provide relatively high habitat value, and/or support ongoing habitat use by fish and sensitive aquatic-dependent wildlife (i.e., directly or indirectly through food production) shall be identified as the highest priority tributaries for permanent protection. Those tributaries that have been impacted by mining, provide or have the potential to provide relatively high habitat values, and/or support or could support habitat use by fish and sensitive aquatic dependent wildlife shall be identified as the highest priority tributaries for restoration or rehabilitation.*

The tributary management plan must be updated each year. Teck has been developing the Tributary Management Plan with the EMC since 2016, and submitted the first plan in 2017. This plan was accepted by the Director in February 2018 with conditions for the 2018 plan. EMC discussion and advice on the 2018 plan reflects differing perspectives on this plan.

What is an aquatic ecosystem?

An aquatic ecosystem is all living things that depend on each other and their environment for food and shelter. This includes bacteria, fungi, insects, snails, and tiny free-floating plants and animals called plankton. There are also large plants—like cattails and reeds—plus fish, amphibians, reptiles, and birds.

This plan will guide Teck's environmental management of tributaries and Teck will refer to this plan during mine planning. The overall goal of the Tributary Management Plan is to

> *Protect and rehabilitate tributaries of the Elk River watershed on a priority and feasibility basis to benefit fish, aquatic-dependent wildlife, and vegetation, recognizing biological, social, and economic values, and Ktunaxa worldview.*

All the tributaries upstream of Sparwood that flow into the Fording River, Michel Creek, and the Elk River—and that are currently mine-influenced[12] or could be influenced by Teck's future development plans—are included in the management plan[13]. The mainstem of the Fording River, Michel Creek, and the Elk River are not considered to be tributaries and are managed according to the EVWQP and Permit 107517. Tributaries that have been permanently removed or severely altered by mining activities are also not included, consistent with Permit 107517 which states these are out of scope.

In developing the Tributary Management Plan, Teck and the EMC undertook two important activities: tributary evaluation and tributary prioritization.

[12] Mine-influenced means that the mine footprint extends into a tributary's catchment, so the tributary receives water that has been changed from being in contact with mine works.

[13] The plan also includes two tributaries that flow from the area of Coal Mountain Phase 2 into the Elk River near Hosmer.

Tributary Evaluation

Teck assessed the ecological value of the tributaries of the Elk River and the Fording River and identified those tributaries that play a significant role in supporting the Elk Valley watershed as a whole. Teck worked with the EMC and the Elk Valley Fish and Fish Habitat Committee throughout this activity to make sure the evaluation results were supported by local knowledge. Teck submitted the results of this evaluation to the Director in June 2016.[14]

Tributary Prioritization

Once the tributaries were evaluated, the next step for Teck was to determine which tributaries were a priority for protection, rehabilitation, or both. Teck developed a tool (with EMC advice) which generated prioritized lists of tributaries. The EMC participated in an exercise to consider the biological values of all the tributaries and brought forward considerations for interpreting the lists. Teck considered all the input from the tool and the EMC when it determined the final prioritized list. The EMC does not have consensus on all tributary priorities.

Teck must update its Tributary Management Plan each year to include changes to its current and future mine development plans. The EMC reviews and discusses the draft versions of each annual update and all the supporting materials and information. Teck considers all the input the EMC provides before submitting the final version to the Director. The Director is currently reviewing and considering the 2018 Tributary Management Plan, which was submitted in February 2019. The EMC continues to discuss implementation and future refinements of the plan.

[14]Data Report for the Tributary Evaluation Program

Glossary and Appendices

Glossary

active water treatment
a method of removing substances from water that requires regular human intervention and management. For example, the active water treatment facility at Line Creek Operations uses a system of tanks that use bacteria and other micro-organisms to remove mine-related substances from the water.

acute toxicity
the adverse effects of a substance on an organism that result from either a single exposure or from multiple exposures in a short period of time.

adaptive management
a systematic, rigorous approach to environmental management that focuses on learning about important uncertainties, while at the same time implementing management actions based on the current understanding.

aquatic organisms/aquatic life
animals (invertebrates, amphibians, fish, birds, etc.) that live in or depend on an aquatic environment.

area-based management plan
an environmental management plan for a designated area under the Environmental Management Act.

baseline
current or existing conditions that serve as a reference point for comparing future conditions.

benchmark
a standard or point of reference against which things may be compared or evaluated. See also effect benchmark and Level 1 benchmark.

benthic invertebrates
small organisms that lack backbones and live in or on the bottom of sediments of rivers, streams, and lakes; these include the larvae of aquatic insects, as well as clams, snails, mussels, crayfish, and various other kinds of aquatic worms.

bioaccumulation
the buildup of substances, both toxic and benign, within the body tissues of an organism.

calcite
a mineral made up of calcium, carbon, and oxygen.

calcite index
a numeric expression of the extent and degree of calcite formation; typically given as a range from 0 to 3.

chronic toxicity
the adverse effects of a substance on an organism that result from long-term exposure.

compliance point
a water monitoring station that is immediately downstream from one Teck's mine operations in the Elk Valley.

constituent
an element, substance, or ionic compound

control sample
a sample containing water that has not been modified or impacted by mining, that is subjected to the same analyses as the mine-water being tested; this helps to confirm the quality and reliability of the results. See also lab water.

crustacean
a large, diverse group of invertebrates with an external skeleton.

daily maximum limit
the maximum allowable concentration of a substance in a 24-hour period.

Director
the governmental office within the British Columbia Ministry of Environment and Climate Change that is responsible for issuing permits under the Environmental Management Act and for determining compliance with permit requirements.

discharge, v
flowing from one source into another.

effect benchmark
the concentration of a substance shown to produce a specific level of effect on an organism.

effluent
outflow or waste from human activities that is introduced into water or onto land.

Elk River watershed
the area that includes the Elk River and all of its tributaries.

Environmental Management Act
a British Columbia legislation that regulates release of effluent to water, land, and air.

exposed site/area/stream
sites, areas, or streams that are downstream of mining activities.

groundwater
water that flows beneath the water table, in soils and geologic formations.

hardness, hard water
water with a high content of calcium and magnesium or other dissolved metals.

human health risk assessment
an assessment to determine the potential risks to human health posed by the presence of contaminants within a defined area.

lab water
distilled or city water sometimes used in control samples in laboratory tests.

Level 1 benchmark
the concentration above which there is a potential for a 10% effect on the growth or reproduction of an organism.

local aquatic effects monitoring program
programs designed to answer specific questions about aquatic effects that arise because of the unique circumstances of a particular mine operation.

larval stage, larvae
the newly hatched, juvenile form of an animal before metamorphosis into an adult.

monthly average
the average of all samples collected in a calendar month at a sample location.

order station
a location specified by Ministerial Order No. 113 to monitor water quality.

periphyton
freshwater organisms such as algae and bacteria that attach to rocks, plants, suspended particles, and other objects in the water.

phytoplankton
microscopic algae that live in the water column and are food for zooplankton and fish.

pit dewatering
the movement of water from pits to support mine operations

reach
a section of a stream that is typically 100 metres long or more.

reference (stream, area, tributary)
a watercourse that has not been affected by mining activity; typically located upstream of mine operations.

regional aquatic effects monitoring program
a long-term monitoring program to assess potential regional-scale effects in the aquatic environment downstream of mining operations within the Elk River watershed.

site performance objective
an authorized limit or standard set by the Director for specific location.

tributary
a river, stream, or creek flowing into a larger river or lake.

water quality guideline
the recommended limit for the concentration of a substance in the water to protect ecological or human health; may be federal or provincial.

water quality limit
an authorized limit for the concentration of a substance in the water set by the Director for specific location.

wild foods
food that is harvested through hunting, gathering, and fishing.

zooplankton
tiny invertebrates that live in the water column and are food for many fish species.

Appendix A - The Ktunaxa Nation and the Elk Valley

The Ktunaxa Nation is made up of all Ktunaxa citizens residing both within and outside of **Ktunaxa ʔamakʔis**, including the member communities and their citizens. The northern portion of **Ktunaxa ʔamakʔis** has historically been claimed by Canada, while the southern half is claimed by the United States. In Canada, the member communities of the Ktunaxa Nation include, **ʔakink'umɬasnuqɬiʔit** (Tobacco Plains Band), **ʔaq̓am** (formerly known as St. Mary's Band), **yaqan nuʔkiy** (Lower Kootenay Band), and **ʔakisq'nuk** (Columbia Lake Band). The Ktunaxa Nation maintains unceded Aboriginal title in much of what is now considered the East and West Kootenays. Ktunaxa communities south of the Canada-USA border are located in what is now Idaho and Montana. The Elk Valley, which is wholly within the unceded and unsurrendered territory of the Ktunaxa has been occupied continuously by the Ktunaxa Nation since time immemorial, and is maintained as Aboriginal title by the Ktunaxa Nation. The British Columbia (BC) portion of the traditional territory is subject to ongoing treaty negotiations with the Province of BC and the Government of Canada.

The Elk Valley was traditionally used and occupied by the Ktunaxa Nation. Important Ktunaxa settlements were maintained in the Elk Valley well into the 20th century, and Ktunaxa citizens continue to reside throughout the lower Elk Valley, including in Sparwood, Fernie, and elsewhere. Ktunaxa oral histories, supported by historic archival and ethnographic data, suggest that Ktunaxa presence in the Elk Valley has long been centred on an important habitation area named **ḵ aqawakanmituk**, a Ktunaxa settlement at the confluence of Michel Creek and the Elk River near present-day Sparwood. This is a very important cultural area in the Elk Valley. It was occupied annually, and likely for a long period of time up to the late 1800's, by the Michel Prairie people, also referred to as the Fernie Band, or **ḵ aqawakanmitukniḵ**. This was a historic Ktunaxa community with close ties to the current Ktunaxa community of Tobacco Plains whose annual round included hunting bison on the eastern slopes of the Rocky Mountains. As described further below, many Michel Prairie people died as a result of early smallpox epidemics, likely in the late 1700s.The settlement of **ḵ aqawakanmituk** at Michel Prairie included important tobacco cultivation areas, as well as habitation areas, processing areas, and other features including trails that connected the valley to mountain passes to the east. While there are no reserve lands in the Elk Valley, the Ktunaxa understand that reserve areas were promised in the area of Michel Flats and present day Sparwood, but were never formally allotted.

The Elk Valley itself falls within the Ktunaxa traditional land district of **qukinʔamakʔis**. **Qukin ʔamakʔis** is translated as Raven's Territory, Raven's Land or the Land of Raven. It is also sometimes used as a synonym for the Elk Valley because the valley and its surrounding mountains make up the majority of the lands associated with Raven. Today, the Elk Valley is known to Ktunaxa peoples not only for the richness of its fish and game but also for the presence of coal and extensive coal mining, and the associated restrictions on access to mining lands, many of which are private. For the Ktunaxa Nation, the history of coal mining in the Elk Valley, including recent history, has been a story of exclusion with more than a century of efforts by non-Ktunaxa individuals and companies to extract **qukin nuʔkiy** (Raven's Rock, or Coal) from **qukinʔamakʔis** (Raven's Land). Available information (archival and ethnographic), as well as oral histories and archaeology, supports an understanding that the Elk Valley in general, and specifically the upper Elk River, including areas around Michel Creek, Line Creek, Grave Creek, Round Prairie, and the Fording River, has been continuously used and occupied by Ktunaxa peoples, and specifically Upper Ktunaxa peoples, for hundreds of years prior to 1846.

Water is fundamental to the Ktunaxa creation story, and is understood by Ktunaxa knowledge holders to be the basis for all living things within **Ktunaxa ʔamakʔis**. Rivers, streams, lakes, and riparian areas provide essential habitat for the fish, and many of the animals and plants that Ktunaxa harvesters rely on, and responsible stewardship of water is a critical component of Ktunaxa responsibility. The Ktunaxa principle **ofʔa'kxam̓ is q̓** apiqapsin is translated to mean a responsibility for stewardship of all living things. Within the borders claimed by Canada and British Columbia, the **ʔamakʔis** of the Ktunaxa Nation covers approximately 70,000 km2 (27,000 square miles) of mountains, valleys, rivers and lakes in the Kootenay region. The region's landscape is alive with Ktunaxa culture and history. The Ktunaxa creation story relates the origins of the Ktunaxa people and describes the events and relationships that helped shape—and continue to shape—**Ktunaxa ʔamakʔis**. The geography of the Elk Valley is formed in the final events of the story, when the animal chief and creation hero, **Naɬmuqɛ̓in**, collapses, forming the Rocky Mountains with his body.

Ktunaxa Law

Ktunaxa law (**ʔaknumuɬtiťiť**) and oral history (**ʔaqaťq'anuxwatiť**) are both sacred and legal in nature. Ktunaxa land use rights are based on a sacred covenant with the Creator, whereby, in exchange for the land providing the Ktunaxa with the necessities of life, the Ktunaxa are responsible as stewards of the lands and resources in **Ktunaxa ʔamakʔis**. The Ktunaxa have terms that address the natural world and how people are a part of it. **ʔakuk'pukam** speaks to anything that gets life from the earth through roots. **ʔakuk'pukamnam** adds the human dimension, whereby the earth's life is translated into human life. That is, the Ktunaxa have roots that tie them to **Ktunaxa ʔamakʔis**, and they are of the earth. In other words, they believe that what they do to the earth, they do to themselves and to future generations. The Ktunaxa phrase that captures interconnectedness and the stewardship concepts applicable to land management is **YaqaťHankatiťiťkinaʔamak**. This phrase translates to "our people care for the land, the land cares for our people."

More information on the Ktunaxa laws and principles can be found in Section C for the Baldy Ridge Expansion project found on the Environmental Assessment Office website (https://projects.eao.gov.bc.ca/p/baldy-ridge-extension/docs).

Ktunaxa Creation Story

In ancestral times referred to by the Ktunaxa as the animal world, there were references made many times by the Creator to when there will be ʔaqɬmakniƛ̓ (people).

At that time, there was some disturbance caused by a huge sea monster known as Yawuʔniƛ̓, who killed many of the animals. A council was called by the Chief animal, Naɬmuqɛ̓in. Naɬmuqɛ̓in was huge. He was so tall that he had to crawl on his hands and knees, for if he stood up his head would hit the ceiling of the sky.

It was decided that Yawuʔniƛ̓ had to be destroyed. A war party was formed. Yawuʔniƛ̓ plied the Kootenay and Columbia River System including Columbia Lake and Arrow Lakes.

Yawuʔniƛ̓ was sighted in the Columbia Lake near Yaqaʷn Nuʔkiy and the chase was on. At that time, the Kootenay River and the Columbia Lake were joined. As the chase proceeded, Naɬmuqɛ̓in gave names to many locations along the Kootenay River, Kootenay Lake, Arrow Lakes and the Columbia River.

Yawuʔniƛ̓ was pursued down the Kootenay River past the Wasa sloughs, now called Wasa, BC. Skinkuɛ̓ got into trouble here when he fell into the river and had to be rescued by Wasa, (horse-tail).

The chase went by where the St. Maryʸs River empties into the Kootenay River. ʔaq̓am, where the St. Maryʸs Reserve is now located, then on down river to Kanƛ̓ak (spring) where Mayuk (weasel) joined the war party. There were animals on both sides of the river as the chase continued, and among the party was a parasite, ʔaʷkukɬakuwum, who had to be carried on the backs of other animals. His name was Ƈumtus and he was mean and bossy. The other animals grew tired of his nagging and dumped him into the river at a place now known as Yaqakiɬ waẗmitquɬiɬki Ƈumtus.

Leaving the land of the Eagle, ʔaʷknuqɬuɬaṁʔamaƛ̓is and into the land of the woodtick, Ƈaṁna ʔAmakis, past Wasaʔki (Waldo) then on past the now 49th Parrallel and then past Kaxax (Turtle), now underwater, near Rexford, Montana. The chase went on by ʔaʷkiʔyi (jennings) and on by ʔaqswaq (libby) then into Skinkuɛ̓ ʔAmakis (the land of Coyote), past ʔaq̓anqmi (Bonners Ferry, Idaho) then northerly past the now international boundary into ʔaɛ̓pu ʔamakis, the land of the Wolverine, past Yaqaʷn Nuʔkiy (Creston, BC) then up the Kootenay Lake past ʔaq̓asqnuk, (Kuskannok, BC). The chase went on by ʔAkuqɬi (Akokli Creek), past Ksanka Creek. The Yawuʔniƛ̓ chose to follow the Kootenay River past ʔaqyamɬup (Nelson, BC). The chase was now in Miɛ̓qaqas ʔamakis (the land of Chickadee).

At Kiƛ̓siɬuk, (Castlegar, BC) Yawuʔniƛ̓ went north into the Arrow Lakes, past ʔakinƛ̓aʔnuk (Arrow Rock) where arrows were shot into a crevice in the rock. If the arrow was true, the journey continued, if the mark was missed, beware, danger ahead. The arrow was true and the journey continued past Ƈaɬnuʔniƛ̓ (Nakusp) then up past Ktunwakanmituk Miɛ̓qaqas (Revelstoke, BC) where the Columbia River flows into the Arrow Lakes, then up and around The Big Bend then down past ʔaknuqɬuk (Golden, BC) past Yaknusuʔki (Briscoe, BC) then on past Yakyuɛ̓ki. The chase carries on through Kwataq̓nuk (Athalmere) then past Kananuk (Windermere, BC) past ʔakiskq̓nuk (Windermere Lakes), then back into the Columbia Lake, Yaqaʷn Nukiy, (Canal Flats, BC). This completed the cycle of the chase.

Yawuʔniƛ̓ would once again escape into the Kootenay River and the chase would go on. The chase would go on and on. Every time the war party thought they had Yawuʔniƛ̓ cornered, Yawuʔniƛ̓ would escape again.

One day sitting on the river bank observing the chase was a wise old one named Kiƛ̓um. Kiƛ̓um told Naɬmuqɛ̓in, You are wasting your time and energy chasing the monster. Why not use your size and strength and with one sweep of your arm, block the river from flowing into the lake and the next time the monster enters the lake you will have him trapped. Naɬmuqɛ̓in took the advice of Kiƛ̓um and did as he was told. The next time Yawuniƛ̓ entered the lake, he was trapped.

Having successfully corralled Yawuʔniƛ̓, a decision had to be made as to whom the honor of killing Yawuʔniƛ̓ would be bestowed upon. The honor was awarded to Yamakpaɬ (Red-headed Woodpecker).

When Yawuʔnik̓ was killed, he was taken ashore and butchered and distributed among the animals. There remained only the innards and bones. The ribs were scattered throughout the region and now form the Hoo Doos seen throughout the area.

Na+lmuqƛin then took the white balloon-like organ, known as the swim bladder, and crumbled it into small pieces and scattered it in all directions saying, 'These will be the white race of people'. He then took the black ingredient from the inner side of the backbone, the kidney, and broke it into small pieces and scattered them in all directions declaring,'These will be the black race'. He then took the orange roe and threw the pieces in all directions saying,'These will be the yellow race of people'.

Na+muqƛin looked at his bloody hands and reached down for some grass to wipe his hands. He then let the blood fall to the ground saying, 'This will be the red people, they will remain here forever'.

Na+muqƛin, in all the excitement, rose to his feet and stood upright hitting his head on the ceiling of the sky. He knocked himself dead. His feet went northward and is today know as Ya·+iki, in the Yellowhead Pass vicinity. His head is near Yellowstone Park in the State of Montana. His body forms the Rocky Mountains.

The people were now keepers of the land. The spirit animals ascended above and are the guiding spirits of the people.

Ktunaxa Nation website: Ktunaxa.org

Appendix B - New Technical Reports Available Online

A number of Teck's technical reports are now available online. Most of these reports are those that have been reviewed by the Environmental Monitoring Committee and submitted to the Director under Permit 107517. Some reports are provided as additional information, but are not formally reviewed by the EMC. The following reports will be added in 2019.

- Surface Water Quality Monitoring 2018 Report
- Chronic Toxicity Testing Program 2018 Report
- Fording River Operations Local Aquatic Effects Monitoring Program 2018 Report
- Greenhills Operations Local Aquatic Effects Monitoring Program 2018 Report
- Line Creek Operations Local Aquatic Effects Monitoring Program 2018 Report
- Calcite Monitoring Program 2018 Report
- Calcite Effects on Fish Spawning and Incubation 2018 Report
- Regional Groundwater Monitoring Program 2018 Report
- Koocanusa Reservoir Monitoring 2018 Report

You can find the technical reports at: https://www.teck.com/responsibility/sustainability-topics/water/water-quality-in-the-elk-valley/research-and-monitoring-reports/

Appendix C - Feedback Form

Please contact the independent facilitator for the Environmental Monitoring Committee if you have questions about this report, the Committee, or the science-based advice it provides.

Contact Information:
Environmental Monitoring Committee
Lynne Betts, Independent Facilitator
emcpermit107517@gmail.com

☐ Notify me about the EMC's annual public meetings and reports.

I would like to request the EMC's advice or input, plus feedback from Teck on the following:

☐ Surface Water Quality

☐ Groundwater Quality

☐ Effects on Aquatic Life

☐ Koocanusa Reservoir

☐ Tributary Management

☐ Adaptive Management

☐ Human Health

Name: _____

Affiliation (if any): _____

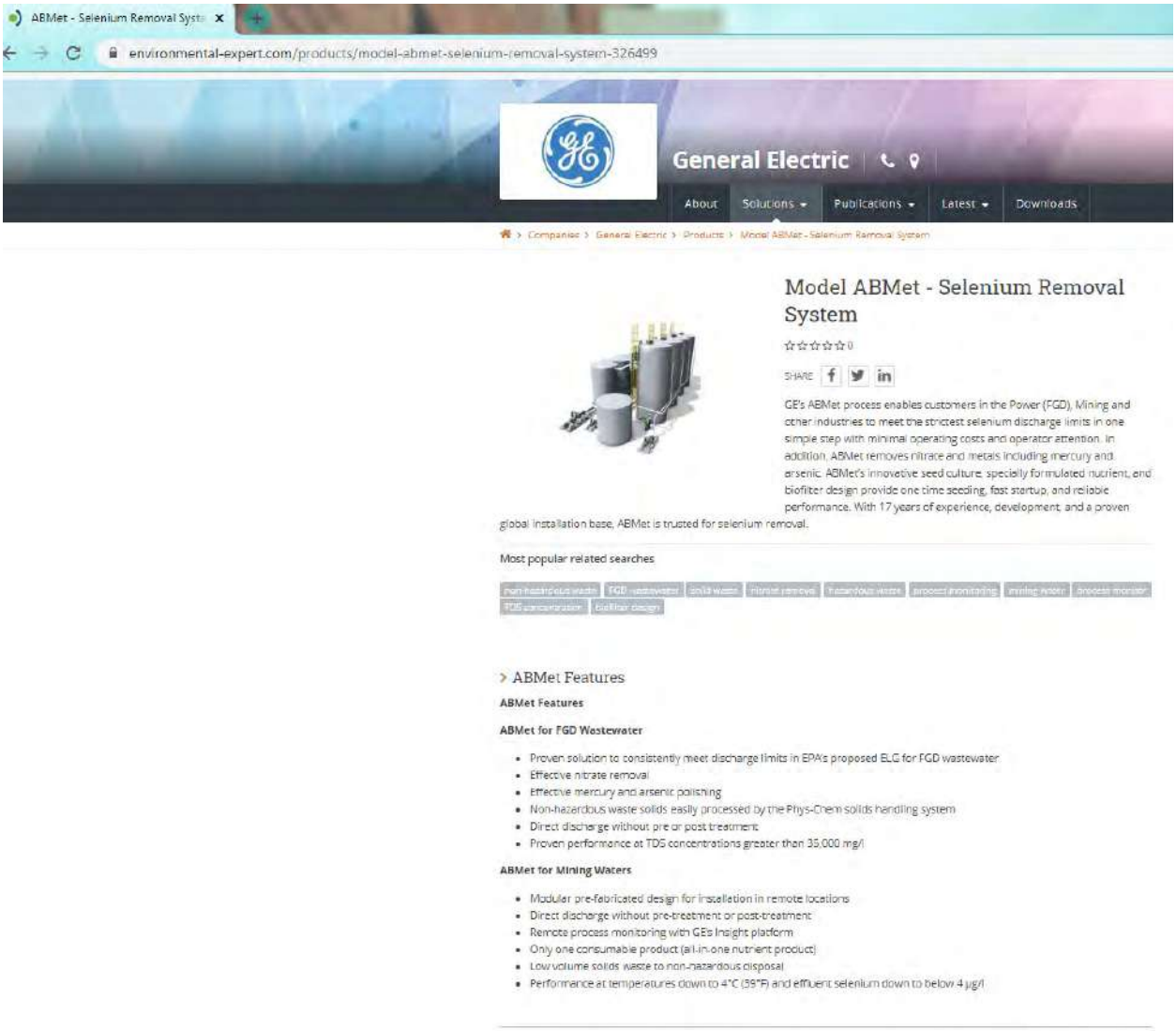
Email: _____ Phone: _____

Notes

Notes

Notes

APPENDIX 6.21-1: ABMET REFERENCE



Source: https://www.environmental-expert.com

APPENDIX 6.23-1 AQUATIC MONITORING PLAN - DRAFT

Aquatic Monitoring Plan
Draft

Benga Mining Limited
Grassy Mountain Coal Project

February 2020

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1.0 INTRODUCTION

1.1 Background

The following draft Aquatics Monitoring Plan (AMP) has been developed for the Grassy Mountain Coal Project (the Project) with the objective of verifying predicted potential effects to the downstream aquatic environment and to westslope cutthroat trout (WSCT) as identified in the surface water quality assessment (Consultant Report [CR] #5, CIAR #42) and the fisheries and aquatic environment assessment (Addendum 1, CR #6, CIAR #44). The various aspects of the monitoring plan are developed to verify the predictions of environmental effects made during the EIA and to confirm whether mitigation measures have achieved the desired outcomes. This AMP is essential for identifying whether the proposed mitigations or monitoring methodologies need to be modified or adapted as the Project proceeds in order to continue to be effective and to address previously unanticipated adverse environmental effects.

1.2 Purpose

The EIA process identified water quality and WSCT as important aquatic ecology valued components (VC). Residual effects were predicted, which require monitoring to confirm the performance of mitigation applied to remove or counterbalance any predicted effects on these valued aquatic ecology VCs. The effectiveness of the mitigation measures and determination of significance will be confirmed though the AMP.

The AMP was developed based on regulatory requirements associated with federal and provincial legislation including the federal *Species at Risk Act* (*SARA*) and *Fisheries Act* as well as the provincial *Wildlife Act*. The various programs within the AMP, such as groundwater monitoring, hydrology monitoring, or calcite monitoring, were also based on best management practices and the current scientific literature.

The purpose of the AMP is to test predictions of the EIA regarding potential Project effects on stream flows, water quality, sediment quality, and fish and fish habitat during operations, closure and early post-closure phases. The AMP integrates the monitoring of various aquatic resource components into a single document, thereby providing a single instrument for regulatory review of aquatic effects and reducing costs of sampling, administration and reporting.

1.3 Context

This preliminary draft AMP has been prepared using the most current information available regarding mitigation, monitoring, and potential adaptive management options related to the Project. Finalization of the AMP will occur shortly after Project approval; however, Benga recognizes for the purposes of the regulatory approval process regulators require a sufficient amount of information regarding the AMP to reduce uncertainty as part of a final decision process. The intent of this preliminary draft is to provide the foundations of the Project's AMP, with recognition that an agreement on sampling locations, parameters, and reporting frequency with provincial and federal regulators will be required,

as well as additional logistics, which will be developed in the detailed design phase such as standard operating procedures, and alignment with pending construction and operations schedules.

2.0 REGULATORY STATUES, APPROVALS AND GUIDELINES

The following Acts, guidelines, and recovery strategies were used to shape this AMP:

- *Fisheries Act*, including the anticipated Coal Mining Effluent Regulation;
- *Species at Risk Act* (SARA);
- WSCT Recovery Strategy (DFO 2014), including population distribution objectives;
- Draft WSCT Recovery Strategy (DFO 2019);
- *Precautionary Principles*; and
- *Environmental Protection and Enhancement Act* (EPEA).

The final version of the AMP will list all the pertinent provincial and federal approval conditions relevant to AMP and will provide a concordance of how they are addressed in the Plan.

3.0 INDIGENOUS CONSULTATION

Indigenous consultation to date has focused on identifying traditional knowledge and VCs related to fisheries, aquatic environment and water itself. This has been used as input into the EIS and the development of the Project.

Going forward, Benga has committed to developing an Indigenous monitoring program in cooperation with Indigenous groups to work in parallel with other western science-based monitoring programs. In addition, Benga will consult with Indigenous groups in developing the final AMP through a series of workshops. Benga has committed to providing Annual Reporting documents to Indigenous groups highlighting the results from the AMP and seeking any input that would help Benga improve monitoring and the effectiveness of mitigation measures.

4.0 POTENTIAL EFFECTS OF THE PROJECT THAT REQUIRE MITIGATION

The EIA (Addendum 1, Aquatic Ecology Effects Assessment, CR #6, CIAR #44) identified that WSCT population trends could be potentially influenced by the Project through Project footprint interactions, changes in water resources (groundwater and surface water), fluvial geomorphology (fish habitat), food supply (drift invertebrates), and water quality. After the application of mitigation, the aquatic effects assessment predicted two Project residual effects, which will be counterbalanced through the Fisheries Offsetting Plan. They consisted of changes to tributary and mainstem aquatic and/or riparian habitat resulting from the Project footprint, and changes to hydrology in Gold and Blairmore creeks potentially affecting WSCT habitat.

An overview of the potential Project effects to WSCT and their linkages to the components of this AMP is provided in Figure 4.0-1.

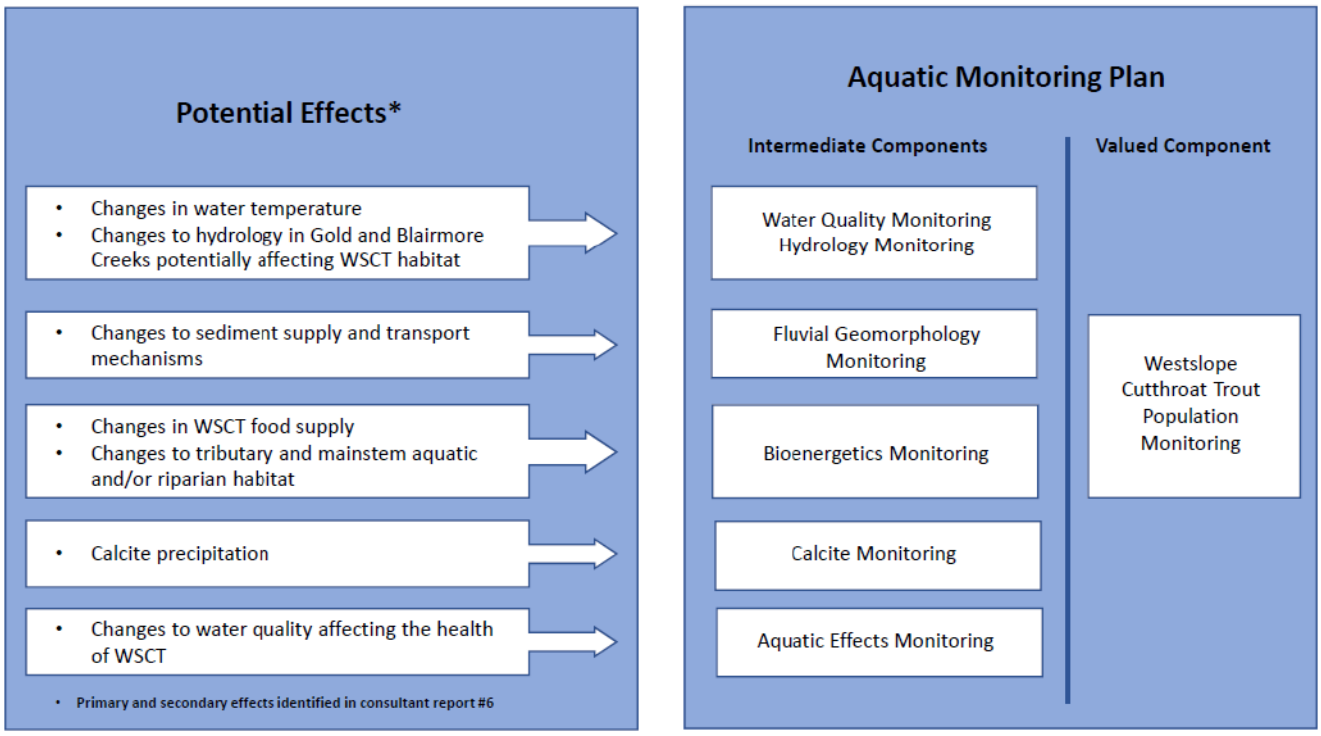

Figure 4.0-1 Linkage between potential effects to the Aquatic Monitoring Plan

5.0 MITIGATION PROGRAM

A mitigation program has been developed to minimize or eliminate potential effects of the Project to the downstream receiving aquatic environments of Blairmore Creek, Gold Creek, and the Crowsnest River, as outlined in Table 5.0-1. Benga has already committed to these mitigation measures and expects that they will become part of the anticipated EPEA approval for the Project. Table 5.0-1 summarizes the potential effects of the Project that require mitigation, the mitigation objectives, the proposed mitigations measures, how the Project will implement the proposed technical or economically feasible mitigation measures, and how Benga will ensure effectiveness of the mitigations.

Table 5.0-1 Potential Project Effects, Mitigation, Project Implementation, and Effectiveness

Potential Project Effects	Mitigation Objectives	Mitigation	Technical or Economically Feasible Project Mitigation Implementation	Mitigation Effectiveness
Changes to surface water quality, from surface water runoff, surface and groundwater interactions and discharge of mine-influenced water.	Minimize or eliminate changes to surface water quality, which can affect aquatic resources and WSCT habitat quantity and suitability and/or survival and reproduction of WSCT.	• Ensure clean-water (*i.e.*, runoff collected from natural non-disturbed areas or non-mine-influenced water) is directed towards sedimentation ponds. • Ensure water quality is managed to comply with water quality criteria that are protective of aquatic health. • Identify mine planning techniques and options in the mine plan and water management plan to avoid the potential for water quality effects that can affect fish and fish habitat.	• Clean water ditch lines will be implemented into the Project's mine plan. • By design waste rock will be piled in areas that facilitate collection of contact water for treatment. • Actively managed saturated backfill zones will be designed and operated to remove nitrate and selenium from contact water. • The Project will adhere to provincial and federal water quality guidelines and site-specific water quality objectives.	• Engineering designs will be developed by certified engineers following industry approved standards. • Construction and Operations Monitoring will be conducted by qualified specialists and/or certified engineers to ensure mitigations have been installed and functioning properly. • Water quality guidelines and site-specific water quality objectives will be regulatory approved.
Changes to aquatic and/or riparian habitat for WSCT associated with the Project footprint.	Minimize or eliminate changes to aquatic and/or riparian habitat for WSCT.	• Minimize the Project's physical disturbance footprint. • Utilize existing infrastructure, rather than adding new infrastructure disturbance, should be used or upgraded where feasible and sustainable. • Maintain a 100 m setback from the mainstems of Gold and Blairmore creeks. • Ensure offsetting measures to counterbalance any permanent loss of riparian or fish habitat that cannot be avoided are developed.	• Through proactive and strategic mine planning, the Project's footprint has been minimized to the extent possible through storing of waste rock in existing disturbed locations and making best use of existing facilities and disturbance. • Through proactive and strategic Mine Planning, avoidance of dumping waste rock into valley bottoms has been implemented (which requires hauling waste rock up slopes which is not a common mining practice). • The Project has developed and, pending final consultation with Indigenous groups and DFO, will implement an approved Fisheries Offsetting Plan.	• Liaison with mine planners during the environmental impact assessment phase helps identify environmental constraints that the engineering teams can be aware of so that technical and economic measures can be implemented into mine plans. This approach of 'mitigation through design' is proactive *vs* reactive to potential environmental impacts. • The Project's Fisheries Offsetting Plan was developed to adhere with the goals and objectives of the DFO Fisheries Protection Provisions (FPP) of the *Fisheries Act*, the *Species at Risk Act Permitting Policy*) and the WSCT Recovery Strategy, and will be revisited accordingly based on any pertinent regulatory updates.

Table 5.0-1 Potential Project Effects, Mitigation, Project Implementation, and Effectiveness

Potential Project Effects	Mitigation Objectives	Mitigation	Technical or Economically Feasible Project Mitigation Implementation	Mitigation Effectiveness
Changes in water temperature, which may cause changes to the thermal regime, affecting WSCT habitat quantity and suitability.	Minimize or eliminate changes in water temperature.	• Minimize the removal of riparian vegetation. • Maintain appropriate riparian reserves and management zones from watercourses. • Ensure the construction of sedimentation ponds for surface water run-off and non-impacted mine pit minimize disturbance to associated tributaries to the best extent possible. • Although changes in stream temperatures are not predicted to occur, the due diligence measurements of discharge temperatures in receiving environments should occur to ensure that water temperatures are within tolerances for WSCT. • Progressive reclamation should occur to accelerate revegetation, reforestation and end land uses to provide overhanging cover and shade for watercourses.	• The Project's footprint will remain 100 m away from Blairmore Creek and Gold Creek as far as possible. • Where a 100 m setback is not possible (limited to small portion of the coal handling plant, due to steep topography), vegetation clearing will be minimized, and erosion and sedimentation control measures will be installed. • Stream temperature measurements at discharge points will be implemented as part of this Plan. • A Conservation and Reclamation Plan has been developed for the Project, which is based on a progressive reclamation approach to re-establish vegetation as soon as possible.	• Temperature mitigation is highly effective with low uncertainty. • Engineering designs will be developed by certified engineers following industry approved standards. • Proposed mitigation measures are proven industry standards and best practices. • Proposed C&R Plans are based on proven industry standards and monitoring of C&R mitigation effectiveness will be conducted early in the mine, which will confirm whether the measures are successful or unsuccessful. This approach will allow for timely consultation with Indigenous groups to discuss findings and make appropriate adjustments to ensure the lessons learned are applied to subsequent reclamation years.

Table 5.0-1 Potential Project Effects, Mitigation, Project Implementation, and Effectiveness

Potential Project Effects	Mitigation Objectives	Mitigation	Technical or Economically Feasible Project Mitigation Implementation	Mitigation Effectiveness
Changes in WSCT food supply in Gold and Blairmore creeks, which can affect WSCT and suitable aquatic habitat quantity or suitability.	Minimize or eliminate changes in WSCT food supply.	• Minimize the removal of riparian vegetation. • Maintain appropriate riparian reserves and management zones from watercourses. • Construction of sedimentation ponds for surface water run-off and non-impacted mine pit water should minimize disturbance to associated tributaries to the best extent possible. • Although significant changes in stream temperatures are not predicted to occur, measurement of discharge temperatures in receiving environments will ensure that water temperatures are within tolerances for WSCT. • Progressive reclamation will accelerate revegetation, reforestation and end land uses to provide overhanging cover and shade for watercourses.	• The Project has developed and, pending final consultation with Indigenous groups and DFO, will implement an approved Fisheries Offsetting Plan that accounts for riparian habitat loss. • The Project's footprint will remain 100 m away from Blairmore Creek and Gold Creek as far as possible. • A Conservation and Reclamation Plan has been developed for the Project, which is based around a progressive reclamation approach.	• Development, construction, and monitoring of DFO and AER approved Fisheries Offsetting Plans would be implemented by qualified environmental specialists.

Table 5.0-1 Potential Project Effects, Mitigation, Project Implementation, and Effectiveness

Potential Project Effects	Mitigation Objectives	Mitigation	Technical or Economically Feasible Project Mitigation Implementation	Mitigation Effectiveness
Changes to sediment supply, transport mechanisms and sediment yield, which can affect WSCT habitat quantity and suitability.	Minimize or eliminate changes to sediment supply, transport mechanisms and sediment yield.	• Develop erosion and sediment control measures that are based on industry standards. • Design access and mine haul roads to a stable angle to reduce erosion. • Store salvaged topsoil away from watercourses and surface waterbodies. • Apply erosion and sediment control practices to salvaged soil to reduce potential erosion and sediment transport off-site. • Direct surface water runoff and pit water to sedimentation ponds. • Discharge water to watercourses in a manner that does not cause erosion or other damage to downstream areas. • Develop a progressive reclamation plan to accelerate revegetation, reforestation and end land uses to provide overhanging cover and shade for watercourses.	• A Water Management Plan has been developed to capture, collect, and appropriately treat water associated with the Project's footprint. • Site drainage and surface runoff will be managed through the incorporation of erosion control methods so that overland flow does not direct sediment-laden water into any natural watercourses. • Each discharge point on Gold Creek and Blairmore Creek will be engineered to avoid erosion or other damage to adjacent areas. • A Conservation and Reclamation Plan has been developed for the Project, which is based on a progressive reclamation approach.	• Engineering designs will be developed by certified engineers following industry approved standards. • Flow discharge protocols are highly effective and part of industry standards and best practices. • Effectiveness of the mitigation measures will be monitored by qualified specialists to ensure mitigations are installed and functioning properly. • Proposed erosion and sediment controls are. • Erosion and sediment measures are based on proven industry standards and best management practices and are highly effective with low uncertainty.

Table 5.0-1 Potential Project Effects, Mitigation, Project Implementation, and Effectiveness

Potential Project Effects	Mitigation Objectives	Mitigation	Technical or Economically Feasible Project Mitigation Implementation	Mitigation Effectiveness
Calcite precipitation, which can affect WSCT habitat quantity or suitability.	Minimize or eliminate calcite precipitation.	• Minimize the volume of waste rock that may come into contact with surface water systems. • Measure calcite formation in watercourses to identify if it is within each watercourse's range of natural variability.	• Through proactive and strategic Mine Planning, the Project's footprint has been minimized to the extent possible through storing of waste rock in existing disturbed locations and making best use of existing facilities, including through backfilling mined-out pits to limit the volume of waste rock that may come into contact with surface watercourse. • Through proactive and strategic Mine Planning, avoidance of dumping waste rock into valley bottoms has been implemented. • A cascade will be constructed from the discharge point of the SBZ, which will promote CO_2 off-gassing and atmospheric equilibration and thereby reduce the volume of calcite precipitates. • The water would then pass through a coarse gravel ditch line, before entering into the SBZ holding pond where water would be allowed to further equilibrate and be monitored for specific water quality parameters. • The Project has developed a calcite monitoring program presented in this AMP.	• The proposed calcite monitoring program was based on other regulatory approved industry calcite monitoring plans.

6.0 MONITORING PLANS

The purpose of the AMP is to test predictions of the EIA regarding potential Project effects on stream flows, water quality, sediment quality (*i.e.,* calcite precipitation), and fish and fish habitat during operations, closure and early post-closure phases. The AMP integrates the monitoring of various aquatic resource components into a single program, thereby providing a single instrument for regulatory review of aquatic effects and reducing costs of sampling, administration and reporting.

The AMP involves the monitoring of aquatic components including:

- Water Quality;
- Aquatic Effects;
- Calcite;
- Groundwater – Surface Water Interaction;
- Hydrology;
- Fluvial Geomorphology,
- Bioenergetics; and
- WSCT Population.

The monitoring approach for each of these components is provided in the following sections.

6.1 Water Quality Monitoring

6.1.1 Goals and Objectives

The overall goal of this component is to characterize and evaluate effluent that will be released from the mine into the aquatic receiving environment of Blairmore Creek, Gold Creek, and the Crowsnest River.

6.1.2 Study Design

6.1.2.1 Baseline Characterization

Establishment of a baseline will incorporate the previously collected EIA related information and the AMP specific sampling period of record, which will start at the regulatory approval phase (approximately one year). Additional baseline data will continue to be collected after start of construction at upstream location and at reference locations.

The purpose of the baseline data collection will be to further characterize the existing water quality environment in order to have a defensible data set to compare monitoring results for their effectiveness, and to support in the identification and analysis of stressor indicators and effects indicators.

6.1.2.2 Water Quality Sampling Locations

Samples will be collected from one or more reference areas and appropriately located exposure areas. For effluent characterization, samples would be collected at each final discharge point (FDP). From a long-term trend analysis perspective, samples would be collected from identified distinct effluent plumes, which will be determined during mine operations. In general, the potential sampling sites could include the following:

Blairmore Creek:

Reference Area: water frequented by fish that are not exposed to effluent and that has fish habitat that as far as practicable is most similar to that of the exposure areas.

- One or more sampling sites upstream of the proposed mine footprint.

Exposure Area: aquatic receiving environment that is exposed to FDPs from the following water management infrastructure:

- West Sedimentation Pond;
- three discharge points associated with the Saturated Backfill Zone Polishing Pond; and
- Plant Site Sedimentation Pond.

Crowsnest River:

Reference Area:

- Upstream of the confluence with Blairmore Creek.

Exposure Area:

- Downstream of the confluence with Blairmore Creek; and
- Downstream of the confluence with Gold Creek.

Gold Creek:

Reference Area: water frequented by fish that are not exposed to effluent and that has fish habitat that as far as practicable is most similar to that of the exposure area.

- One or more sites upstream of the proposed mine footprint on Gold Creek; and
- A location on Caudron Creek, a tributary to Gold Creek.

Exposure Area: aquatic receiving environment that is exposed to FDPs from the following water management infrastructure:

- North East Sedimentation Pond; and
- East Sedimentation Pond.

6.1.2.3 Sampling Frequency

Water samples will be collected from each FDP once per calendar quarter.

Once distinct effluent plumes are identified, water samples will be collected once per calendar quarter.

6.1.2.4 Water Quality Parameters

Collected (grab) water quality samples will be analyzed for the following parameters provided in Table 6.1-1.

Table 6.1-1 Core List of Water Quality Analytes to be Analyzed

Physical Parameters • Alkalinity • Electrical conductivity • Hardness • pH • Temperature • Total Dissolved Solids • Total Suspended Solids **Nutrients** • Ammonia • Nitrite • Phosphorus • Sulphate • Total nitrate **Organics** • Total organic carbon • Dissolved organic carbon	**Total and Dissolved Metals** • Aluminum • Arsenic • Calcium • Cadmium • Chromium • Cobalt • Copper • Lead • Iron • Mercury • Manganese • Nickel • Uranium • Zinc • Total selenium

Collection of water quality data will help provide the necessary information to understand toxicity testing results, as well as help interpret the results from the biological monitoring studies, which is described further in the Aquatic Effects Monitoring section below (Section 6.2).

6.1.2.5 Water Quality Guidelines and Site-Specific Objectives

The Project will adhere to the pertinent provincial and federal water quality guidelines (WQG) for both Blairmore Creek and Gold Creek. Exceptions to these guidelines are the Project's proposed sulphate and selenium site-specific water quality objectives (SSWQO) established for Blairmore Creek.

6.1.2.6 Approach Triggers

Approach triggers are used to assess monitoring data, to provide an early alert to potentially decreasing water quality conditions. As an example, these approach triggers (Figure 6.1-1) could be set below the values of final Project approval limits, as a proportion of the WQGs and SSWQOs (*e.g.,* 75%). This is based on the rationale that above this level, any upward trend or variability in water quality could lead to an exceedance. Specific trigger values will be finalized for each analyte as part of the final, approved version of the AMP.

6.1.2.7 Water Quality Guideline Exceedance

WQG or SSWQO exceedance results in specified actions and identified adaptive management responses. The protection goal and level of scientific rigor inherent in the WQGs and SSWQO informs the specific actions or adaptive management in the event that they are exceeded; briefly the basis for WQGs and SSWQOs includes:

- WQGs are established by governments for various water protection purposes. Exceeding WQGs triggers investigation and implementation of solutions (where warranted) on an expedited timeline. Where a WQG is exceeded, the AMP's response would be to conduct a re-evaluation of the WQG and if appropriate, develop a science, and aquatic risk based SSWQO on an accelerated timeline (Figure 6.1-2).
- SSWQOs represent guidelines that have undergone considerable refinement through site-specific analysis and testing or other rigorous scientific review, such as the site-specific objectives for selenium and sulphate proposed for Blairmore Creek. Exceeding SSWQOs triggers specific actions, and SSWQOs are not normally subject to a re-evaluation step (Figure 6.1-3).

Although the Project focuses primarily on maintaining water quality conditions in watercourses potentially influenced by the mine and specifically involves water quality assessment, biological indicators are also used as verification to ensure that the WQGs (or SSWQO) are adequately protective. The assessment of biological indicators would be reported as part of the AMP, or more immediately if required by regulators following previous notification of a water quality trigger exceedance or meaningful change in a biological indicator.

6.2 Aquatic Effects Monitoring

6.2.1 Goals and Objectives

The overall goal of this component is to evaluate the effects of effluent released from the mine on the aquatic receiving environment of Blairmore Creek/Crowsnest River and verify that contact water from the mine does not adversely influence Gold Creek.

6.2.2 Study Design

6.2.2.1 Sampling Locations and Activities

For Aquatic Effects, the components required to be monitored, frequency of sampling, and sample locations are outlined in Table 6.2-1.

Table 6.2-1 Aquatic Effects Monitoring Locations and Activities

Station Location(s)	Monitoring Parameters	Monitoring Frequency	Description of Monitoring Activities
Effluent from each discharge point	Water Quality (effluent subset)	Quarterly	Effluent from each discharge point will be analyzed for the parameters listed in Table 6.1-1.
	Sublethal Toxicity	2x a year	Effluent from each discharge point will be analyzed for sublethal toxicity responses from rainbow trout, *Ceriodaphnia dubia* and *Lemna minor*. Test organisms/sampling frequency will change based on results from the first three years of testing.
	Acute Toxicity	Monthly	Effluent from each discharge point will be analyzed for acute toxicity to rainbow trout and D*aphnia magna*. Sampling frequency may be decreased based on testing results.
Aquatic Effects monitoring at established water quality sample locations	Water Quality	Quarterly	A larger set of water quality variables than is monitored from liquid effluent will be monitored at the established AMP sample locations four times annually.
	Sediment Quality	Once every three years	Sediment will be monitored for total organic carbon as well as particle size at all benthic invertebrate community monitoring stations.
	Benthic Algae	Once every three years	Benthic algae will be monitored for biomass and tissue chemistry.
	Benthic Invertebrate Community	Once every three years	Benthic invertebrate communities will be sampled and evaluated by investigating various endpoints (density, evenness, richness, and Bray-Curtis index) as well as tissue chemistry.
	Fish Health	Once every three years	Fish health will be sampled and evaluated by investigating various effect indicators (growth, reproduction, condition and survival).

6.2.2.2 Toxicity Testing of Effluent

6.2.2.2.1.1 Acute Toxicity Testing

Effluent will be required to be non-acutely lethal to fish and invertebrates. In order to monitor compliance, acute toxicity testing will occur. Effluent from each discharge point will be analyzed monthly for two different test species (rainbow trout and Daphnia magna). Any sample resulting in an

acutely lethal response will trigger increase sampling frequency, with potential remedial measures to be taken.

6.2.2.2.1.1.2 Sublethal Toxicity Testing

In addition to acute toxicity testing, effluent will also be tested for sublethal toxicity. Sublethal toxicity will be sampled for twice annually once the mine is discharging. Samples will be tested for effects on fish early life stage development, invertebrate reproduction as well as plant and algae toxicity.

6.2.2.3 Benthic Algae

Benthic algae are an important component of benthic invertebrate habitat because they provide food and shelter for invertebrates. The biomass of benthic algae on hard substrates tends to increase with increasing levels of nutrients. As a result, benthic algae growing on rock (called epilithic algae) can be used as indicators of nutrient enrichment. Primary producers also present an opportunity to measure selenium in the food web. A benthic algae survey will be included as part of this aquatic effects sampling, which will be to determine whether there is enhanced algal growth in response to effluent exposure, as well as monitor selenium uptake in exposed areas.

6.2.2.4 Benthic Invertebrates

Benthic invertebrate communities will be monitored in both the reference and exposure areas. The communities will be quantified as various endpoints. Endpoints include total benthic invertebrate density, Simpson's evenness, taxa richness, and the Bray-Curtis index. Each endpoint will be examined, and differences between the reference and exposure communities evaluated. Results of this evaluation will determine if benthic invertebrate communities significantly differ between the reference and exposure areas. Additionally, benthic invertebrates will be analyzed for tissue chemistry. Doing so will allow for additional monitoring of selenium uptake in exposed areas.

6.2.2.5 Fish Health

A fish health study will monitor fish populations in receiving environments for signs that exposure to effluent may negatively impact fish health. This will include monitoring growth, reproduction, condition factor, and survival in both the reference and exposure areas.

A key consideration when selecting a sentinel species is the mobility and residency time of that species relative to effluent exposure. Fish species that are resident in the aquatic system under investigation for most or all of their life cycle and exhibit territorial behavior or limited mobility/movement relative to the size of a study area are preferred because of the observed responses of these species are reflective of their localized environment. Species that are migratory or spend only a small proportion of their life cycle in the area under investigation are not suitable as sentinel species because exposure to effluent is minimal or transient.

It is also best practice that preference be given to species of relatively small adult size since age-at-first maturity and adult natural mortality vary in proportion to adult size. This is because the adult abundance of small species should respond more rapidly to stressors that affect fecundity and/or larval survival. In the case of the Project, the immediate study area of Blairmore and Gold creeks do not contain any fish that would traditionally be considered appropriate as a sentinel species. Based on this, Benga will consult with both DFO and ECCC to develop the final approach to monitor fish health in the receiving environment.

6.3 Calcite Monitoring

The following calcite monitoring approach is largely based on the calcite monitoring plan developed as part of the Elk Valley Water Quality Plan (Teck 2014). The ideas and methodology from the Teck (2014) plan were followed as it was developed by a team of experts with extensive collaboration from regulators. Teck has successfully implemented this calcite monitoring plan for five years, demonstrating the effectiveness of the study design. The stratified approach taken also allows the methodology to be scaled to the size of system that requires monitoring.

The intent of calcite monitoring is to document the extent of calcite deposition, the degree to which deposition has occurred, as well as to characterize the calcite depositions. The following sections outline the general concepts for capturing this information. Detailed field methodology and procedures will be provided prior to the implementation of the calcite monitoring for the Project.

6.3.1 Goals and Objectives

The goals of this program are to provide baseline information regarding naturally occurring calcite formations in the local study area (LSA) and to monitor calcite deposition in defined watercourses in the LSA. The implementation of the calcite monitoring will help the Project better understand effects to the receiving environment caused by upstream mine disturbance. The objectives of this program will be to:

- characterize naturally occurring calcite formations in the LSA;
- monitor calcite formations in streams directly receiving mine waters as well as reference stream(s);
- document changes to the calcite formations (temporally and spatially);
- determine trends (*i.e.*, rates) of calcite deposition;
- present a standard methodology for data collection and interpretation for calcite monitoring efforts; and
- inform any plans for calcite mitigation.

6.3.2 Study Design

6.3.2.1 Stream Selection

Site selection is an important factor when monitoring calcite in an aquatic system. It will be important to capture sites/streams that will be directly impacted by receiving mine waters, as well as appropriate reference locations. This section describes the selection process for the AMP.

Project-Affected Streams

Mine exposure is a key part of the stream selection process as mine influenced streams have increased potential for calcite deposition. As such, all reaches downstream of proposed mine discharges are included in the monitoring plan. All treated contact water will be discharged to Blairmore Creek, however, given the status of Gold Creek as designated critical habitat under the *Species at Risk Act*, the reaches of Gold Creek downstream of the mine are included in the study design. By monitoring Gold Creek for potential increased calcite deposition, uncertainty associated with surface water/groundwater interactions will be reduced.

The mine influenced streams have been further differentiated into reaches. A complete breakdown of reaches will occur prior to any field sampling activities.

Reference Streams

Inclusion of reference streams allows the AMP to provide context for the extent, degree and trends of calcite formation occurring in mine-affected streams. Monitoring reference streams will be of particular importance when examining long-term and large-scale spatial monitoring as they will provide information pertaining to natural environmental variability.

Reference streams were selected from areas in the LSA that were consistent over the long term (*i.e.,* not impacted by major development or anthropogenic disturbance) while also preferentially being located a sufficient distance from further mine development. As the reference streams need to mimic conditions in the mine-affected streams as closely as possible, parameters such as elevation, stream order, geology and channel morphology were also considered during the selection process.

Reference streams were selected using the following process:

- characterization of exposure reaches by stream order, bedrock geology, spatial distribution and channel morphology;
- review of reference sites from past studies in the area such as the baseline assessment (Addendum 1, CR #6, Appendix A1, CIAR #44), and selection of appropriate locations using reach characteristics; and
- review additional locations to obtain reference streams that will adequately represent the spectrum of stream characteristics expected in the mine-affected streams.

The above criteria revealed several possible locations for reference streams. Those most relevant to the monitoring objectives are upper Blairmore Creek and Caudron Creek (a tributary to Gold Creek).

6.3.2.2 Sample Timing and Frequency

As the rate of change in calcite deposition is unknown for this system, annual sampling is recommended for the first three years of the plan. If after three years it is determined that sampling frequency is not adequate, it will be changed accordingly.

Annual sampling for calcite will be undertaken in the fall. This will ensure any eggs deposited in redds/spawning gravels will have had an appropriate amount of time to incubate, emerge, and allow fry to migrate to lower energy lateral habitats before spawning gravels are disturbed. Sampling will be completed while field crews are stationed at site sampling for other monitoring plans. This will ensure data captured is correlated with other sampling data while ensuring efficiencies in the Project are maximized.

6.3.2.3 Sampling Stratification

Calcite is best assessed using a stratified approach. This approach is based on the hierarchy of spatial scales in stream networks. Using a spatial stratification approach allows for observations to be extrapolated over larger areas (Bisson *et al*. 2006). The three scales at which sampling could occur and that have been considered are: catchment, reach, and habitat unit.

Monitoring at the catchment scale for this study would not provide the spatial resolution required to inform and adequately trigger a mitigation response. Likewise, while monitoring at the habitat-unit scale would provide finer resolution, mitigation actions are not likely to be implemented at this scale. As such, monitoring at this scale would exceed the level of detail required for this monitoring plan. Consequently, stream reach is the recommended spatial scale to be adopted as the sampling unit for the calcite monitoring plan. A stream reach is a portion of a stream that is smaller than a catchment, but larger than a habitat unit.

6.3.2.4 Baseline Characterization

Reach Identification – Sampling Unit

Reaches for streams to be monitored will be delineated using a desktop approach. Macrohabitat reach breaks will be delineated in Gold Creek and Blairmore Creek mainstems based on the criteria described in Lewis *et al*. (2004) classifying reaches as "a homogeneous section of stream channel, characterized by uniform discharge, gradient, channel morphology, channel confinement, and streambed and bank materials." Detailed baseline habitat assessments completed in May and October of 2016 identified reach breaks as:

- changes in stream gradient;
- changes in discharge, often where a significant tributary enters the mainstem; or
- identified barriers to fish movement.

This approach for reach delineation aligns the AMPs calcite monitoring with all other Project disciplines allowing for a more coherent, thoughtful analysis of data collected.

If during field studies, reach break observations differ from those defined during the desktop exercise, data collected in the field will be used to better refine the reach length. As such, reaches may evolve over the length of the monitoring plan.

Within-Reach Replication – Sampling Sites

Sampling sites will focus on locations within each reach that contain spawning gravels. As this habitat is most sensitive to degradation resulting from calcite deposition, it will be important to monitor this specific type of habitat to better understand its susceptibility to calcite deposition in this system.

In order to understand variability within the sampling unit (stream reach), replication is required. Following methodology from other calcite monitoring plans, triplicate sampling will be performed within each reach (Teck 2014). Locations containing appropriately sized spawning gravels nearest 25%, 50% and 75% of the total reach length will be sampled.

All sampling units are anticipated to be over 300 m which will allow for triplicate sampling. As the plan evolves, reach lengths may change based on field observations. In the event changes to reach breaks occur, the following guidelines will dictate the number of samples collected per reach:

- Reaches <200 m – One sample collected over the entire length of the reach.
- Reaches <300 m –One sample collected at the downstream end of the reach and a second sample collected beginning at 100 m. Care will be taken to ensure sampling sites do not overlap.
- Reaches ≥300 m – Samples will be collected at 25%, 50% and 75% of the total reach length.

6.3.2.5 Data Collection

Capturing the Extent of Calcite Deposition

The extent of calcite deposition will be measured in the field at each sampling site. These data will be used to extrapolate the linear coverage of calcite deposition over a reach.

Site-Level Extent

Calcite presence will be estimated by employing a modified pebble count (Wolman 1954 and CABIN 2009). The pebble count procedure typically has a participant systematically moving through the stream while periodically stopping and randomly selecting a particle to measure. This methodology is traditionally used to garner information pertaining to substrate size and embeddedness but can easily be adapted to also capture information regarding calcite presence.

The participant will randomly select a particle to be measured. All particles randomly selected will be included as datapoints, although only those larger than 2 mm will be measured. Particles smaller than 2 mm will be noted as fines but will not be measured. All measured particles will have their intermediate axis measured in mm, as well as a recording the presence (score = 1) or absence (score = 0) of calcite.

Linear Extent/Gradient

Desktop analysis will occur to estimate the extent of calcite deposition. The mean extent of calcite as a total percentage of spawning gravels available will be calculated. This will be done by the following formula:

$$Spawning\ gravels\ calcite\ coverage = mean\ site\ level\ extent * 100$$

Linear gradients of calcite extent will also be presented over the multiple sites and reaches sampled.

Capturing the Degree of Calcite Deposition

Degree is used to describe the level of stream bed concretion. This will be estimated by level of effort required to remove the particle from the stream bed. Levels of concretion will be scored as follows:

0 – Not concreted (negligible resistance to remove particle)

1 – Partially concreted (resistance, but removable)

2 – Fully concreted (immovable)

If the particle retrieved was too fine to visibly discern calcite presence/absence it will be assigned a concretion score of 0. This will be reported for each particle removed but will be specific to resistance created by calcite.

Type of Calcite Depositions

The type of calcite deposition will be recorded in addition to extent and degree. Types of calcite formations that can be visibly discerned in the field will include calcified algae, calcareous laminate, calcified moss/tufa, barrage tufa, calcite scale, and insect tufa.

Rate of Change

After multiple years of data have been collected, it will be possible to examine the rate of change in extent and degree of calcite deposition.

6.3.2.6 Plan Assessment and Refinement

The Calcite Biological monitoring approach will be refined as it progresses through the years. As more detailed field data is captured, the plan can become more refined and tailored to ensure site selection, field methodology and data analysis is functioning as intended.

6.4 Groundwater-Surface Water Monitoring

6.4.1 Goals and Objectives

The overall goal of this program is to evaluate the effects of Project activities on the survival and persistence of WSCT in Blairmore and Gold creeks, through fulfilling the following objectives:

- confirm surface water to groundwater fluxes;
- monitor and further evaluate groundwater-surface water (GW/SW) interaction; and
- support the Project's fisheries offsetting approach.

This monitoring component includes installation and monitoring of several well pairs adjacent to key reaches on Gold and Blairmore creeks to verify the GW/SW interaction.

It is important to note that the groundwater monitoring included within the AMP is linked to the Project's overall groundwater monitoring program, which forms part of the Project's Water Management Plan (WMP). The intent of the WMP is to implement measures to capture, collect and treat surface and groundwater at the source, and the WMPs groundwater monitoring program will have the primary objective to confirm the efficiency of the capture of contact water and the secondary objective to ensure that the receptors are not negatively impacted by the Project activities. The information presented in the AMP is the linkage to the secondary objective.

6.4.2 Study Design

6.4.2.1 Baseline Characterization

The AMPs GW/SW monitoring network will comprise the installation of 12 well pairs, each comprising one shallow and one deeper monitoring well, adjacent to reaches of Blairmore and Gold creeks. The well locations were chosen to allow for assessment and monitoring of vertical gradients and fluxes within key reaches of both creeks, potential groundwater effects associated with key water management infrastructure features, and more detailed characterization within an ephemeral reach of Gold Creek. Monitoring well locations, rationale, monitoring parameters and frequency are summarized below.

6.4.2.2 Sampling Locations

Several existing hydrometric monitoring stations are located along Blairmore and Gold creeks to monitor total streamflow. Data from these stations indicates anomalous or inconsistent variations in the average annual unit runoff, losing reaches in both creeks where streamflows decline between downstream stations, and areas with subsurface flow. This suggests that the stations are located in areas with differing relationships between surface water and groundwater.

Groundwater monitoring well pairs are proposed within multiple reaches of both creeks to characterize local hydrogeologic properties, quantify vertical hydraulic gradients and inform fish habitat planning.

Five monitoring well pairs (A1 – A5) are proposed in four reaches of Blairmore Creek, and seven monitoring well pairs (B1 – B4, C1 – C3) are proposed in four reaches of Gold Creek.

Sections of Gold Creek (most notably in Reach 6 as classified in Addendum 1, CR #6, Appendix A3, CIAR #44) have also been found to be ephemeral, with surface water flows becoming subsurface or hyporheic throughout certain times of the year. Surface water flows within this reach also appear to be split between side channels and the coarse valley fill. Because Gold Creek sustains a population of WSCT there is an interest in maintaining surface flows within this mainstem stretch of the stream.

Three monitoring well pairs (C1 – C3) are proposed in this reach at locations with different proportions of surface flow and hyporheic or subsurface flow based on field observations or flow measurements upstream and along this particular reach. An upstream well pair is proposed around the GC-3 transect, where surface flow losses are common in all but freshet conditions. A downstream well pair is proposed around the Lille legacy coal pile area, where the Gold Creek channel has been observed to be dry multiple times. An intermediate well pair is proposed between these locations, where surface channel conditions are less known but may support greater channel flow given there are less braids in this area. The distance between these locations is approximately 1 km. The location of these proposed wells is tabulated in Table 6.4-1.

To support planning of potential stream modification the depth to groundwater, vertical hydraulic gradient, and thickness of unconsolidated deposits should be further explored. The thickness of unconsolidated deposits here should be determined to provide estimates of the groundwater flux (*i.e.,* verification of subsurface flow) in those deposits.

Table 6.4-1 Overview of Proposed Monitoring Locations and Rationale

Monitoring Well Location	UTM Coordinates		Description	Rationale
	Easting	Northing		
A1	684066	5508565	Upper Blairmore Creek (Reach 5)	Assess vertical flux, monitor conditions downgradient of northwest surge pond
A2	684670	5507250	Upper Blairmore Creek (Reach 4)	Assess vertical flux, monitor conditions downgradient of western sedimentation pond
A3	685000	5504700	Mid Blairmore Creek (Reach 3)	Assess vertical flux, monitor conditions downgradient of southwest surge pond
A4	684900	5503500	Mid Blairmore Creek (Reach 2)	Assess vertical flux, monitor conditions downgradient of plant-site sedimentation pond
A5	683500	5500825	Lower Blairmore Creek (Reach 2)	Assess vertical flux in losing reach overlapping inferred fault zone
B1	687430	5510725	Upper Gold Creek (Reach 9)	Assess vertical flux, characterize background conditions upgradient of mine

Table 6.4-1 Overview of Proposed Monitoring Locations and Rationale

Monitoring Well Location	UTM Coordinates		Description	Rationale
	Easting	Northing		
B2	687800	5508300	Mid Gold Creek (Reach 8)	Assess vertical flux, monitor conditions downgradient of northeast sedimentation pond
B3	687800	5506400	Mid Gold Creek (Reach 7)	Assess vertical flux, monitor conditions downgradient of eastern sedimentation pond
B4	687400	5504600	Lower Gold Creek (Reach 6)	Assess vertical flux, monitor conditions downgradient of southeast surge pond
C1	687500	5503750	Lower Gold Creek (Downstream Reach 6)	Assess vertical flux, monitor conditions in longitudinal profile along ephemeral / subsurface flow portion of Reach 6
C2	687560	5503370		
C3	687650	5503050		

6.4.2.3 Monitoring Parameters and Frequency

Following well installation, all wells will be developed, and slug tested to determine hydraulic conductivity. Top of well casing will also be surveyed to local hydrometric benchmarks and a regional datum.

Subsequent monitoring will be undertaken at every well pair and include:

- Continuous groundwater levels and temperatures, using dataloggers. Temperature monitoring in the monitoring wells will supplement planned monitoring of stream temperature at adjacent hydrometric stations. Differences in groundwater temperature fluctuations and stream temperature variations can be used to quantify groundwater contributions to streamflow at each location using analytical solutions.
- Quarterly monitoring of groundwater quality.

6.4.2.4 Continuous Level Monitoring

Monitoring wells should be outfitted with pressure transducers to continually monitor changes in water level, monitoring for changes in the vertical hydraulic gradient, and comparing pressure and temperature readings to the streams at adjacent hydrology stations. Continuous level monitoring combined with hydraulic conductivity testing results will allow for point estimates of groundwater discharge/recharge.

6.5 Hydrology Monitoring

Hydrology monitoring includes the continuous tracking and analysis of several hydrometric stations along key reaches of Gold and Blairmore creeks to confirm spatial and temporal variability of runoff across the Project, assist in evaluating groundwater-surface water interaction and support mitigation or

fisheries offset planning needs. The data may support monitoring and assessment of potential Project effects related to the Project water management infrastructure features. Additional monitoring of flows and water levels at each feature is also likely to be required as part of EPEA or other permitting requirements, but these are outside the scope of the current document.

6.5.1 Goals and Objectives

This monitoring program will assess predicted Project effects on surface flows and support in the tracking of fish and/or aquatic metrics dependent on flows and/or water levels such as water quality, fluvial geomorphology, and fish habitat. The plan will monitor the effectiveness of mitigation measures and inform adaptations of these measures as necessary based on monitoring results. The goals and objectives of the hydrology monitoring are to:

- Measure changes to surface flows (and flow-dependent variables) resulting from the Project.
- Monitor hydrology, channel geomorphology and fish habitat related to the Project.
- As appropriate, consider and incorporate adaptations to mitigation measures should measurement indicate that Project targets are not being met.

6.5.2 Study Design

6.5.2.1 Baseline Characterization

During the Project's baseline phase, the hydrological sampling was comprised of 10 streamflow stations on Gold and Blairmore creeks, one of which is operated by Water Survey of Canada (WSC). The monitoring station ID's, locations, and rationale are summarized in Table 6.5-1. Except for one new proposed station, the locations of all nine stations will remain installed as during the Project's baseline data collection. By maintaining this consistency, measured data can be directly compared to the assessments performed during the EIA to verify effect predictions. The assessment nodes were selected to integrate potential Project effects on downstream watercourses and waterbodies, and comparison of these data with the upstream reference sites. Using the same assessment nodes during baseline data gathering and as the Project effects come online enables a Before-After-Control-Impact approach to be applied.

6.5.2.2 Sampling Frequency and Locations

The monitoring frequency of surface water level, surface flow, and groundwater level (water quantity) will be continuous, using pressure transducers and dataloggers at stations:

- Along Blairmore Creek, from background station BC-H03 to the station adjacent to the mine site, BC-H02, and downstream stations BC-H01/b.
- Along Gold Creek, from background station GC-H03 to the stations adjacent to the mine site, GC-H04, GC-02, GC-01, and GC-HLLL, and downstream station WSC 05AA030.

The Crowsnest River represents the receiving watercourse for both Gold and Blairmore creeks and is monitored year-round by WSC at station WSC 05AA008.

Table 6.5-1 Proposed Hydrology Monitoring Locations

Creek	Station ID	Easting	Northing	Period of Record	Rationale
Blairmore	BC-H01	683541	5500649	Sep 2013-Dec 2014 Mar 2016-present	Gauge towards the watershed mouth, designed to monitor watershed-scale flows and all changes due to Project developments (all upstream of here). Gauge is designed to be superseded by BC-H01b, less impacted by losses to underlying fault, once a robust concurrent flow relationship has been established between these gauges.
	BC-H01b	684111	5502731	Not yet started	Unit area runoff at BC-H01 lower than upstream, likely due to losses in thrust fault. This gauge will monitor runoff upstream of fault intersection, but downstream of Project impacts.
	BC-H02	684976	5505089	Oct 2013-Aug 2014	Mid-reach gauge monitoring impacts of more southerly (downstream) Project developments.
	BC-H03	684065	5508565	Oct 2013-Aug 2014 May 2015-present	Upper watershed gauge, monitoring 'reference' streamflows not impacted by any Project developments.
Gold	05AA030 (Gold Creek near Frank)	688123	5498070	Sep 1975-present	Long-term Water Survey of Canada gauge monitoring flows near the mouth of Gold Creek, operated seasonally by WSC from mid-March to November. Discussions with WSC should be held to potentially annualize the flow gauging here, using potential solutions such as winter (December to mid-March) data collection by Benga.
	GC-HLLL	687480	5503760	April 2019-present	Downstream gauge in a flow-loss reach near Lille, monitoring relatively small channel flows (relative to GC-H01) where connectivity and habitat quality is typically degraded, and is the focus for potential future offsetting and stream restoration.
	GC-H01	687478	5504579	Sep 2013-Dec 2014 Mar 2016-present	Mid-reach gauge designed to monitor flows and all changes due to Project developments (all upstream of here).
	GC-H02	687874	5506467	May 2016-present	Mid-reach gauge established in 2016 to support monitoring of higher flows near the confluence of Gold and Caudron creeks.
	GC-H04	687776	5508102	June 2017-present	Upper watershed gauge established in a relatively low-runoff reach with elevated predicted Project flow impacts.
	GC-H03	687594	5510958	May 2016-present	Upper watershed gauge established in 2016, monitoring 'reference' streamflows not impacted by any Project developments.

The proposed approach to surface hydrology monitoring has been subdivided into the main phases planned for the Project. During all periods, monitoring methods will be the same as those applied and described in the EIA (Addendum 1, CR #6, Appendix A2, and Appendix A3, CIAR #44). As the Project progresses, monitoring methods may be updated to reflect evolving technologies and best practices. An overview of the main differences expected between mine periods are as follows:

- **Pre-Construction**: Prior to mine construction occurring, the monitoring will remain unaltered from the 10 stations in Table 6.5-1 in order to:
  - continue to improve knowledge of current and baseline water quantity conditions; and
  - obtain data to refine the inputs and assumptions for flow-dependent modelling and predictions, such as chemical or constituent loading, instream flows, and mine water balances.
- **Construction and Operations**: The construction and operation monitoring system will be the most intensive phase of the monitoring program, given that EPEA monitoring is expected at all locations where water is discharged from mine site water management features. The *Fisheries Act* monitoring will remain unaltered from Table 6.5-1, although by this stage it is expected that the BC-H01b station will have collected enough information to remove the need for existing BC-H01 station impacted by fault-line flow losses.
- **Closure Phase**: A number of EPEA monitoring sites will likely be removed given the reduction of active water management processes during this phase; however, the monitoring for *Fisheries Act* requirements will remain unaltered from the previous stage (9 stations) given the landscape changes that will have occurred relative to baseline.

6.5.2.3 Instream Flow Assessment Verification

This component of the AMP includes the detection of changes in WSCT Area Weighted Suitability (AWS) at established microhabitat transects (within mesohabitat units) during the Instream Flow Assessment (IFA) in key reaches of Gold and Blairmore creeks. The purpose of this component is to verify predictions made during the IFA, evaluate whether adaptive mitigation is required, and implement and monitor mitigation effectiveness, if necessary.

Baseline Characterization

Monitoring will continue into the Project operations phase, at all 44 transects established for ongoing baseline monitoring within the IFA program, and nine additional pool tail-out sites established for baseline spawning surveys introduced in the next section. Several of the transects will also serve as hydrometric monitoring stations.

The IFA transects were focused on riffle, pool and run/glide mesohabitats, which dominate the mesohabitat distributions along each creek. Five of these transects (BC-10, BC-11, BC-12 on Blairmore Creek, GC-9 and GC-13 on Gold Creek) were characterized with wetted-area substrate dominated by spawning gravels, which are essential to the spawning process and survival of WSCT in

these creeks. Additional monitoring of spawning gravels, in addition to the above transects, was established at an additional nine sites, primarily pool tail-outs, with spawning gravels and high WSCT abundance. Here, additional sampling was conducted including Wolman pebble counts, from which worst-case shear stress differences during the life of mine were calculated. By maintaining this consistency between baseline and future monitoring locations, measured data can be directly compared to the predictions and effects assessment to verify effects are consistent with predictions in the EIA.

Sampling schedule

Project-area AWS estimates could theoretically be updated using the existing flow-hydraulic-habitat relationships developed using baseline, with Project-phase streamflow data as it becomes available through time. Ongoing monitoring of the flow-hydraulic-habitat relationships with transect data remain critical to capture changes in these relationships that may occur primarily due to channel geomorphology and substrate changes during high-flow events, and extreme low flow events yet to be adequately captured within the existing flow-hydraulic-habitat relationships.

A three-times annual schedule of IFA-related monitoring, at all transects, is proposed including sampling during higher-flow period (May to June), lower-flow period (August to September) and intermediate-flow period around spawning time (late-June to July). The monitoring for intermediate-flow period also forms the primary data collection for the fluvial geomorphology component.

6.5.2.4 Fluvial Geomorphology Monitoring

In concert with monitoring of discharge hydrology, WSCT population trends, and instream flows (IFA), the fluvial geomorphology monitoring will validate the predictions of the effects assessment of the mine development and determine the effectiveness of mitigating flow on channel morphology and sediment to inform adaptation of the mitigations as necessary based on monitoring results.

The main purpose of monitoring will be to confirm that predictions made during the effects assessment remain valid, and to trigger adaptive mitigation if necessary. Monitoring may also identify unforeseen effects that were not predicted.

Study Design

The fluvial geomorphology monitoring has been designed for all phases of the Project including baseline, construction, operations, and closure phases. The fluvial geomorphology monitoring program was developed in conjunction with the baseline hydrology and instream flow monitoring components and the WSCT population monitoring.

Monitoring locations will include 33 sites on Gold Creek and 20 sites on Blairmore Creek that will be monitored through the mine lifecycle. Twenty-eight sites on Gold Creek and 16 sites cross-sections on Blairmore Creek were used in the IFA study (Addendum 1, CR #6, Appendix A3, CIAR #44). Four additional sites on Blairmore Creek and five sites on Gold Creek were identified as preferred WSCT spawning locations.

Monumented cross-sections will be surveyed annually following the freshet to document fluctuations in channel cross-sectional morphology in Gold and Blairmore creeks. Photographs of the bed and banks will be taken twice annually to document the condition of the bed and banks. Monitoring will document fluctuations in grain size of spawning substrate in both creeks. Grain size will be measured in the field annually following freshet. Wolman pebble counts will be completed with (N > 100) at the monitoring sites. The D_{84}, D_{50}, and D_{16} for each site will be compared annually to identify changes in bed sediment. The percent of sediment that is within the spawning grain size will be determined.

Monitoring will target defined locations of spawning substrate in Gold and Blairmore creeks. Spawning surveys are conducted annually and will identify the locations of WSCT spawning habitat. The location of spawning habitat will be compared annually to determine systematic changes in the location of spawning habitat through the lifecycle of the Project.

6.6 Westslope Cutthroat Trout Population Monitoring

6.6.1 Goals and Objectives

The goal of this program is to monitor the long-term persistence and sustainability of WSCT in Gold and Blairmore creeks. The objectives of this plan will be to:

- build on snorkel surveys and extend the current population trend monitoring data (2016, 2017, 2018, 2019) over a 10-year period;
- investigate with regulators the feasibility to continue with fry and juvenile density monitoring that was executed in 2016 and develop a trend monitoring dataset; and
- collect detailed fish distribution, habitat utilization and trend monitoring data to support the Fisheries Offsetting Plan.

These data will aim to establish information specific to WSCT population dynamics (population size, population demographics, WSCT distribution) over time to reduce uncertainty regarding the population trend and the long-term viability, persistence and sustainability of the WSCT populations inhabiting Gold Creek and upper Blairmore Creek.

6.6.2 Study Design

6.6.2.1 Baseline Characterization

Baseline characterization began in 2016, and included spring spawning surveys, genetic sampling, condition factor (K), summer population assessments, employing a blended approach with both electro-fishing (fry/juvenile recruitment) and snorkel surveys (adult/subadult population estimates) and over-wintering surveys. Subsequently, to reduce the handling of WSCT, snorkel surveys were employed during 2017, 2018 and 2019 during spring spawning, summer rearing and overwintering. To characterize fry/juvenile recruitment without the use of electrofishing, visual counts of fry (young of the year) and juveniles (<10 cm fork length [FL]) were completed during the snorkel surveys. Fork-

length informs population size and demographic structure. These surveys will continue on an annual basis until Project construction and operations commence.

During baseline characterization, representative survey index sites were established, and annual data were collected for each site. Snorkel surveys were generally conducted in the spring (spawning), summer (rearing) and early winter (overwinter) seasons, focusing on abundance, fork length (FL) by class, and habitat use. The AMP is designed to continue building a robust dataset characterizing the WSCT populations in Gold and Blairmore creeks by collecting repeatable data collected using consistent methodology over time.

6.6.2.2 Sampling Locations

The location of the monitoring sites has been chosen to ensure all habitat types are ecologically represented including sites upstream and downstream of potential Project effects. The WSCT populations in Gold and Blairmore creeks will be monitored using adult/sub-adult population estimates and annual recruitment of fry/juvenile (0+, 1+) density estimates using the following metrics:

- population size;
- population demographics; and
- fish distribution.

6.6.2.3 Thresholds and Targets

The threshold or target of this monitoring is to ensure the persistence and recovery of WSCT populations during Project operations, decommissioning and closure within natural variation. The data collected as part of this monitoring will be used with data collected from other monitoring programs (including the proposed Fisheries Offsetting Plan) to generate a better understanding of WSCT population status.

Construction and Operations

The construction and operations monitoring phase will continue to follow the annual baseline monitoring through the life of the Project. The frequency of monitoring may be required to address specific potential Projects effects on WSCT populations within the LSA and may require an adaptive approach to both monitoring and mitigation strategies to ensure defined population targets are maintained.

Closure

This monitoring phase will address potential effects the closure of the mining site may have on the WSCT populations.

6.7 Bioenergetics Monitoring

6.7.1 Goals and Objectives

The overall goal of this program is to monitor potential changes in aquatic habitat required for the survival and persistence of WSCT in Blairmore and Gold creeks. This program will provide baseline information regarding food availability and fish condition, as well as a comprehensive methodology for monitoring fish condition in the LSA. The implementation of the bioenergetics monitoring will help the Project better understand potential effects to WSCT caused by up-land mine disturbance. The objectives of this plan will be to:

- quantify the food energy provided to WSCT by their primary food supply, drifting invertebrates;
- quantify individual fish condition, based on relative weight (Wr);
- integrate food energy, fish condition, and hydrological monitoring data into a species-specific bioenergetics model;
- quantify any changes in food supply, individual fish condition, and fish population condition;
- determine the causes of any observed changes in food supply, individual condition, and/or population condition, to facilitate adaptive management and offsetting/mitigation programs; and
- present a standard methodology for data collection and interpretation for bioenergetics monitoring.

6.7.2 Study Design

6.7.2.1 Baseline Characterization

A full site characterization study will occur prior to as well as during the first implementation cycle of the plan. This will include riparian vegetation loss delineation and quantification, and dilution zone delineation downstream of each effluent discharge point on Blairmore Creek. These data will help identify suitable sampling areas as well as identify potential confounding factors that may affect data interpretation.

6.7.2.2 Sample Area Selection

Site selection is an important factor when developing effective bioenergetics monitoring. It will be important to capture sites that will be directly impacted by receiving mine waters, as well as appropriate reference locations. Samples will be required to be taken from two types of exposure areas, and reference areas.

Exposure Areas

Mine exposure is a key part of the site selection process as mine influenced streams have increased potential for deleterious effects on fish condition. All treated contact water will be discharged to

Blairmore Creek, however given that Gold Creek is designated critical habitat under the *Species at Risk Act*, the reaches of Gold Creek downstream of the mine are included in the study design. By monitoring Gold Creek for potential changes in fish condition, uncertainty associated with other influences not related to mine activity will be reduced.

Areas exposed to mine influences will be separated into two categories. These are defined as follows:

- Treated Contact Water Exposure Area: all fish habitat and waters that are exposed to treated contact water and frequented by fish; and
- Riparian Exposure Area: all fish habitat and waters frequented by fish at and downstream of areas where riparian vegetation has been removed.

It is foreseeable that some exposure areas will see effects from both treated contact water and riparian vegetation removal. However, all efforts will be made to delineate sample locations that will adequately distinguish between the two potential impact sources.

Reference Areas

Inclusion of reference streams allows the plan to provide context for the extent, degree, and trends of deleterious effects on fish condition occurring in mine-affected streams. Monitoring reference streams will be of particular importance with respect to evaluating potential long-term and large-scale spatial effects as they will provide information pertaining to natural environmental variability.

Reference streams were selected from areas in the LSA that were consistent over the long term, while also preferentially being located a sufficient distance from potential future mine development. As the reference streams need to mimic conditions in the mine-affected streams as closely as possible, parameters such as elevation, stream order, geology and channel morphology were also considered during the selection process.

Reference streams were selected using the following criteria:

- Characterization of exposure reaches by stream order, bedrock geology, spatial distribution and channel morphology.
- Review of reference sites from past studies in the area such as the baseline assessment (Addendum 1, CR #6 Appendix A1, CIAR #44), and select appropriate locations using reach characteristics.
- Review additional locations to obtain reference streams that will adequately represent the spectrum of stream characteristics expected in the mine-affected streams.

The above criteria revealed several possible locations for reference streams. Those most relevant to the monitoring objectives are upper Blairmore Creek (above the proposed mine footprint) and Caudron Creek.

6.7.2.3 Sample Timing and Frequency

Sampling will occur twice annually, during summer and fall. Terrestrial inputs to drift invertebrate assemblage are generally highest during summer, and fall should allow measurement of young-of-year fish. Two annual measurements for both food supply and fish condition will also help evaluate and calibrate the bioenergetics model.

6.7.2.4 Data Collection

6.7.2.4.1.1.1 Temperature Monitoring

Stream temperature is an important component of bioenergetics modeling, as it can influence energy output, consumption, and growth rates, and has been linked to the spatial distribution of WSCT (Deslauriers *et al*. 2017). Stream temperature will be monitored using continuous *in-situ* dataloggers placed at each established sample station and will be supplemented with long-term stream temperature data that is being collected at multiple hydrometric stations in Blairmore and Gold creeks. Dataloggers will be visited and read on a quarterly basis to mitigate potential data loss due to battery drain or loss of the units.

Temperature and light dataloggers will be installed in 30 cm long PVC enclosures, and secured to the stream bed. Loggers will be set to record temperature and light intensity every 30 minutes. Additionally, stream temperature data collected at multiple long-term hydrometric stations (installed in both Blairmore and Gold creeks) will supplement sample station data.

6.7.2.4.1.1.2 Drift Invertebrates

Drift invertebrates are the primary source of food for WSCT and encompass both aquatic invertebrates drifting in the water column, and terrestrial or aerial invertebrates, drifting on the surface. By collecting drift invertebrate samples and determining the biomass of the respective aquatic and terrestrial components, the available food energy can be estimated for a given area.

Drift invertebrate assemblage data in the form of total abundance, diversity, and biomass is generally expressed per unit volume (m^3), where:

$$per\ unit\ volume\ (m^3) = submerged\ area\ (m^2) \times mean\ set\ velocity\ (^m/_s) \times total\ set\ duration\ (s)$$

- biomass and flow will be the primary data used for interpretation; and
- characterizing the taxonomic composition of the drift using metrics such as richness, diversity, or presence/absence of certain taxa (depending on their propensity to drift) may prove useful for interpretation for specific projects.

Collection of drift samples requires flowing water and is, therefore, only suitable for erosional zones in freshwater habitats; moderate-flowing riffle areas in rivers and streams. Approximate site locations will be identified prior to commencement of the monitoring plan. However, exact site locations within

the reach should be selected in the field to ensure that an appropriate environment is sampled. Detailed procedures will be outlined prior to the implementation of this plan and adapted from Cavanagh *et al*. (1997), Lewis *et al*. (2004), Hatfield *et al*. (2007).

6.7.2.4.1.1.3 Fish Condition

The condition of an individual fish can be easily estimated by using a ratio between length and weight. When combined, the condition of each individual fish in a sample can then be used to estimate overall population health. These two parameters (length and weight) will be collected during all fish capture. The method of determining fish condition will be Relative Weight (Wege and Anderson 1978).

Fish will be collected using a combination of backpack electrofishing and minnow trapping. The procedures will be adapted from federal and provincial guidance (*e.g.*, AFMB 2013a, 2013b; ECCC 2012) with an emphasis on minimizing or eliminating potential harm and handling time. Federal guidance for non-lethal sampling recommends a minimum of 100 age 1+ fish from each sampling area (ECCC 2012). However, given the potential impact that such sampling effort would have on WSCT in the study watercourses, the objective for this program will be collection and measurement of 50 age 1+ fish per site. Power analyses indicate that a total sample (*n)* of 250-500 fish should be sufficient to detect small-to-medium effects at a statistical significance threshold (*p*) less than 0.1.

Relative Weight (Wr)

Relative weight is a measure that compares the actual weight of an individual to its expected weight (standard weight) based on a standard weight equation (Blackwell *et al*. 2000). The equation was first proposed 40 years ago for Largemouth Bass (Wege and Anderson 1978) and has been regularly used as a fish condition metric since (Blackwell *et al*. 2000). It can be used to infer whether a population of fish is well-fed and growing as would be expected (Blackwell *et al*. 2000). Relative weight is often expressed as an average and will be used in this study to examine the growth efficiency of WSCT within the study area at various size classes.

$$W_r = \left({}^{W}/_{W_s}\right) \times 100 \qquad [1]$$

Where W = actual fish weight (g)

W_s = standard weight (g)

Standard weight equations are created based on regressions of the length-weight relationships of many fish populations across the species' range. The goal is to represent the weight of a fish in "good condition" by estimating the weight of a fish at the 75th percentile based on its length (Midas

et al. 2013). For this plan, the standard weight equation used was proposed for North American lotic rainbow trout by Kruse and Hubert (1997):

$$\log_{10} W_s = 3.099 \log_{10} TL - 5.189 \qquad [2]$$

where:

TL = total length (mm)

WSCT captured during field surveys will be measured for both fork length (FL) and total length (TL), thus avoiding any confounding factors due to requiring a conversion equation.

Relative weight can be highly variable, but generally a well-fed fish in good condition will have a W_r around 100 (Midas *et al*. 2013). Fish with $W_r > 100$ are above average and in very good condition, and fish with $W_r < 100$ are below average (Midas *et al*. 2013). Generally, fish with W_r between 80 and 100 are within the range of healthy populations (Anderson and Neumann 1996).

6.7.2.5 Data Integration

Data collected as part of the bioenergetics monitoring field plans will be integrated using Fish Bioenergetics 4.0 (Deslauriers *et al*. 2017). This program integrates multiple environmental and physiological inputs, including stream temperature, energy density and type of prey, the energy lost through movement and respiration, spawning/reproduction, and mortality. These variables will be input into existing bioenergetics models for WSCT (or generating a new model if species-specific models are not available) to generate curves and parameters such as growth rate, consumption, net production, and population dynamics, over the course of a year for a given cohort (life stage).

6.7.2.6 Quantifying Potential Changes in Response to Project Activities

Potential changes due to Project activities will be quantified by comparing the model outputs from reference areas to mine-affected areas. Coarse, visual comparisons will accompany more robust statistical comparisons. The refinement of study areas conducted during preliminary site selection should also facilitate comparison between both predicted effect sources (effluent and riparian loss).

7.0 MITIGATION EFFECTIVENESS EVALUATION AND ADAPTIVE MANAGEMENT

7.1 Overview

The AMP's mitigation effectiveness evaluation and adaptive management approach will involve establishing indicators and thresholds according to baseline characterization, improved practices based on research and monitoring results, and input from the public engagement and Indigenous consultation programs. As the Project proceeds, monitoring throughout all Project phases will allow water quality targets to be reviewed and, if necessary, modifications can be made to site expectations.

Mitigation effectiveness evaluation and adaptive management is a planned and systematic process for continuously improving environmental management practices by learning about their outcomes. Mitigation effectiveness evaluation and adaptive management provides flexibility to identify and implement new mitigation measures or to modify existing ones during the life of a project. As per Figure 7.1-1, Benga's program is organized into four main components, which are reevaluated and reassessed in a feedback loop.

Figure 7.1-1 – Adaptive Management Feedback Loop

Adaptive management itself, is intended to respond to changes and advances in technology or to react to measured outcomes that are different from those predicted during the EIA. Benga understands that outcomes that are different from modelled predictions may result from areas of uncertainty including:

- **Representativeness of input data** – the EIA analysis is based on information about the Project from sampling that may not be representative of Project conditions. For example, the amount of selenium present in the waste rock is from a limited number of rock samples. If these sample turn out to be not representative, the total amount of selenium loading could be greater or smaller.
- **Other assumptions used for modelling the Project** – Some parts of the EIA analysis are based on assumptions using professional judgement and where possible, conservative bias. There is a possibility that these assumptions may be incorrect and lead to unexpected impacts.

- **Errors and omissions** – Although the EIA analysis has been conducted with care and using quality control procedures to minimize errors, there is always a possibility that errors and omissions could lead to outcomes that are not currently foreseen.
- **Unforeseen external factors** – During the Project life, it is possible that currently unforeseen external or environmental changes could work to create a cumulative effect with the Project that is not included in the EIA analysis.

With respect to Project mitigation effectiveness evaluation and adaptive management, Benga is committed to achieving continual improvement in environmental performance. The development and implementation of all monitoring and mitigation identified for the Project and housed in the monitoring and follow-up programs will be tracked in relevant management plans. As site conditions and monitoring dictate, or as new technology emerges, Benga will adaptively manage its site practices and monitoring program to meet the defined objectives. For some programs this would involve regular evaluation of predictive models; which would be clearly defined in each applicable management plan.

In summary, if a monitoring and mitigation effectiveness evaluation identify that adverse environmental effects are greater than predicted, Benga will evaluate whether they result in changes to the conclusions presented in the effects assessment. If changes are confirmed, Benga will evaluate the need for revised mitigation actions and management practices to manage effects. Where the need for revised or additional mitigation is identified, these will be further developed and implemented.

7.2 Assess the Problem

Assessing the problem includes an assessment of the uncertainty associated with the mitigation effectiveness, the likelihood that the uncertainty can be reduced and, the opportunities to refine, modify or augment the mitigation measures.

7.3 Adaptive Management Process Design

Once the problem has been identified and assessed, the design of the adaptive management program can commence, beginning with determining the best approach to adaptive management. The following are design considerations for the adaptive management program:

- data analysis methods and frequency;
- predicted trajectories for indicators; and
- triggers for action and potential adaptations.

Benga is confident in the mitigation measures selected but acknowledges that a formal process may be warranted to optimize the measures, as opportunities to refine aspects of the management strategies are available. This formal process includes the following points:

- predicted trajectories through time for the indicators as described in the EIA;
- an AMP designed to allow observed trends to be compared to predicted trajectories; and
- triggers for action, should predicted trajectories and observed trends not align, and a plan of action if and when triggers are pulled.

7.4 Implement, Monitor and Evaluate

The mitigation described throughout the EIA will be incorporated into monitoring plans for the Project. Final monitoring protocols will be established and baseline data will be collected soon after the Project is approved so that trends and progress can be evaluated. If indicators meet targets or align with desired trends, no adaptive management is required although continuing assessment of new technology and best practices may reveal an opportunity for improvement. Should indicators not meet targets or trends diverge from the desired trajectory, a sequence of Project-specific actions will be triggered. Prior to adjusting any mitigation, steps will be taken to investigate the observations, as necessary. If required, the following sequence will be followed:

- Monitoring results will be verified and investigated.
- Possible adaptations to mitigation will be identified and evaluated based on monitoring results.
- A work plan will be developed to adapt mitigation or monitoring, if required.

7.5 Adjust the Mitigation as Required

If mitigation adjustments are determined to be required, then they will be implemented with careful consideration to proper planning, approvals, notifications and consultation. In this step of the adaptive management process, the work plan will be implemented. Any required notifications or approvals will be obtained before acting to confirm that all interested or affected parties are properly informed. If adjustments to mitigation measures are required, Section 5.0 of this Plan will be updated to reflect the adapted mitigation for the Project.

Table 7.5-1 outlines adaptive management adjustments that could be implemented if monitoring indicates that aquatic parameters are not meeting targets. Since the monitoring plan has not been implemented, nor monitoring conducted, these are options for consideration.

Table 7.5-1 Potential Project Effects, Adaptive Management Options and Effectiveness

Potential Project Effects	Mitigation Objectives	Economic or Technically Feasible Adaptive Management Option(s)	Adaptive Management Effectiveness
Changes to surface water quality, from surface water runoff, surface and groundwater interactions and discharge of treated contact water.	Minimize or eliminate changes to surface water quality, which can affect aquatic resources and WSCT habitat quantity and suitability and/or survival and reproduction of WSCT.	• Operational adjustments to the SBZ and other water management infrastructure to achieve better results. • Implementation of Gravel Bed Reactor (GBR) contingency measure. • Implementation of an active water treatment facility (AWTF) contingency measure. • Addition of a metals treatment plant.	• A GBR consists of an engineered bed of gravel/media through which water containing constituents of concern (*e.g.*, nitrate and selenium) is passed for treatment. Examples of an effective application of the GBR technology for the treatment of selenium include a full scale GBR implemented to effectively reduce selenium concentrations in surface water from approximately 40 µg/L to less than 5 µg/L over an operating period of nearly eight years, to meet the requirements of Irvine Ranch Water District's (IRWD's) Nitrogen and Selenium Management Program (Mancini *et al.* 2019). • AWTFs that implement fluidized bed reactor technology is an effective process for removal of selenium. This is the same technology that was chosen and installed by Teck at its Line Creek Operations, which has been shown to efficiently reduce selenium concentrations to below 20 ug/L based on a capacity of 7,500 m^3/day. • Water treatment plants to remove metals like zinc and cobalt are proven technology.
Changes to aquatic and/or riparian habitat for WSCT associated with the Project footprint.	Minimize or eliminate changes to aquatic and/or riparian habitat for WSCT.	• Implementation of additional fish offsetting measures (*e.g.*, development of additional pool habitat, additional riparian vegetation). • Implementation of additional riparian vegetation as part of the Conservation and Reclamation Plan.	• The Project's Fisheries Offsetting Plan was developed to adhere with the goals and objectives of the DFO Fisheries Protection Provisions (FPP) of the *Fisheries Act*, the *Species at Risk Act Permitting Policy* and the WSCT Recovery Strategy, and would be revisited accordingly based on any pertinent regulatory updates (*i.e.*, updates to recovery strategies). • Proposed C&R Plans are proven industry standards and monitoring of C&R mitigation effectiveness will be conducted early in the mine life (via progressive reclamation), which will confirm whether the measures are successful or unsuccessful. This approach will allow for timely consultation with Indigenous groups to discuss findings and make appropriate adjustments to ensure the lessons learned are applied to subsequent reclamation years.

Table 7.5-1 Potential Project Effects, Adaptive Management Options and Effectiveness

Potential Project Effects	Mitigation Objectives	Economic or Technically Feasible Adaptive Management Option(s)	Adaptive Management Effectiveness
Changes in water temperature, which may cause changes to the thermal regime, affecting WSCT habitat quantity and suitability.	Minimize or eliminate changes in water temperature.	• Implementation of additional fish offsetting measures (*e.g.*, development of additional pool habitat, additional riparian vegetation). • Implementation of additional riparian vegetation as part of the Conservation and Reclamation Plan.	• Similar to above.
Changes in WSCT food supply in Gold and Blairmore creeks, which can affect WSCT and suitable aquatic habitat quantity or suitability.	Minimize or eliminate changes in WSCT food supply.	• Implementation of additional fish offsetting measures (*e.g.*, development of additional pool habitat, additional riparian vegetation). • Implementation of additional riparian vegetation as part of the Conservation and Reclamation Plan.	• Similar to above.
Changes to sediment supply, transport mechanisms and sediment yield, which can affect WSCT habitat quantity and suitability.	Minimize or eliminate changes to sediment supply, transport mechanisms and sediment yield.	• There is a low probability that the proposed industry practices would not be suitable for this Project; consequently, additional adaptive management techniques are not directly applicable aside from a commitment to implement additional construction and engineering measures to address a specific problem should it arise.	• Proposed mitigation measures are proven industry standards and best practices.
Calcite precipitation, which can affect WSCT habitat quantity or suitability.	Minimize or eliminate calcite precipitation.	• Implementation of an active treatment process (*e.g.*, high-density sludge [HDS] lime treatment).	• Active treatment processes for the minimization or elimination of calcite precipitation are proven industry standards or best practices.

8.0 AQUATIC MONITORING PLAN IMPLEMENTATION

8.1 Roles and Responsibilities

This section will be included in the final version of the Program and will outline specific roles and responsibilities for employees and contractors related to the implementation of the Aquatic Monitoring Program.

8.2 Information Management and Reporting

This section will outline how the monitoring results and adaptive management actions will be recorded, stored, tracked and made available to interested stakeholders. Accurate record keeping will be necessary to assess the implementation of the Program, to measure the effectiveness of management and to develop and implement any necessary improvements.

8.3 Change Management

This section will outline the process for altering any part of this Program, which may be required due to changes resulting from ongoing adaptive management.

8.4 Communication Management

This section will outline the process that will be used for communicating the results of the program to interested stakeholders.

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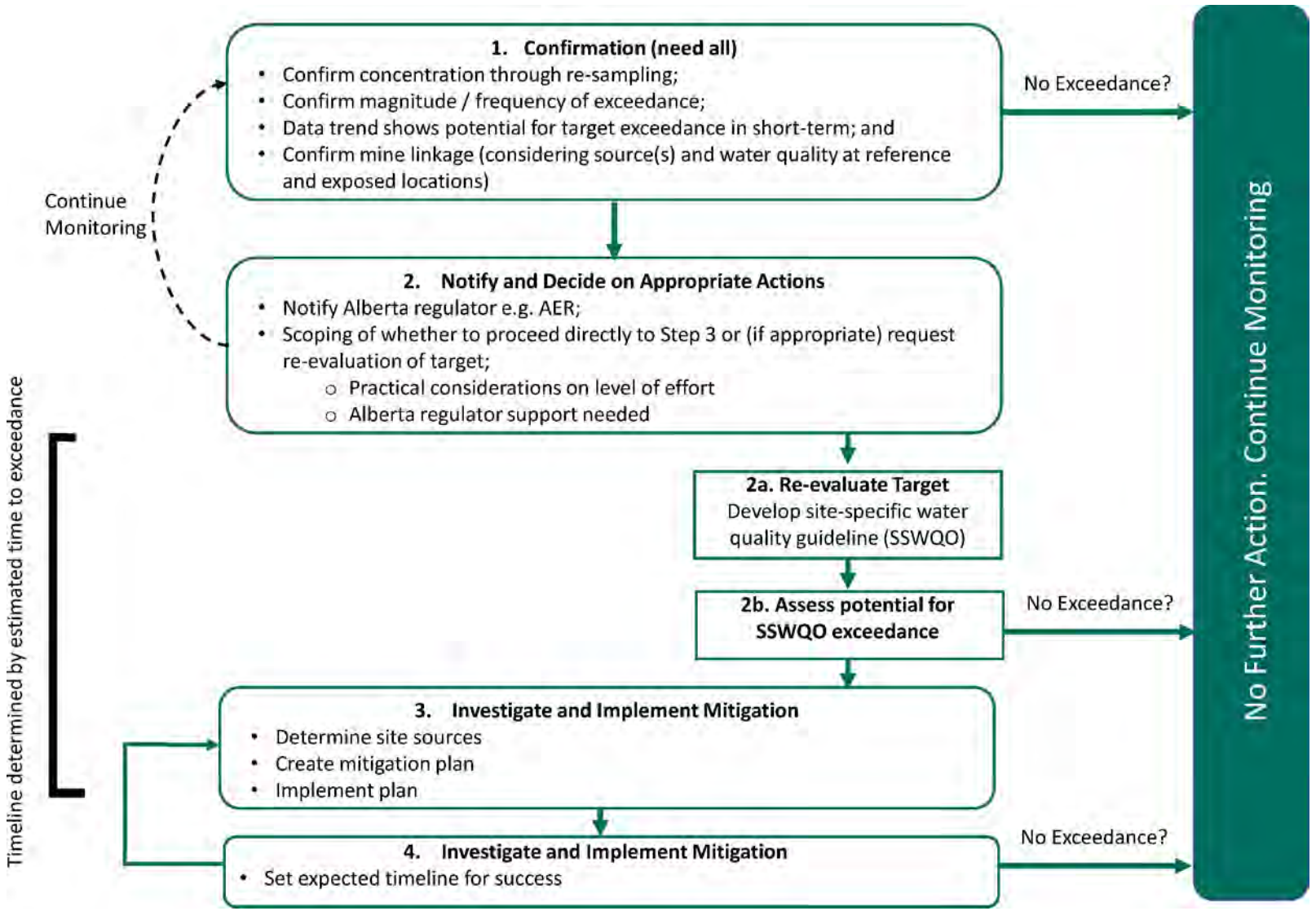

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

TRIGGER EVENT 1 - MONITORED EXCEEDANCE OF APPROACH TRIGGERS FOR WATER QUALITY

PROJECT:	14-00201
DRAWN BY:	JLAMBERTS
CHECKED BY:	MB
DATE:	FEBRUARY 24, 2020

FIGURE

6.1-1

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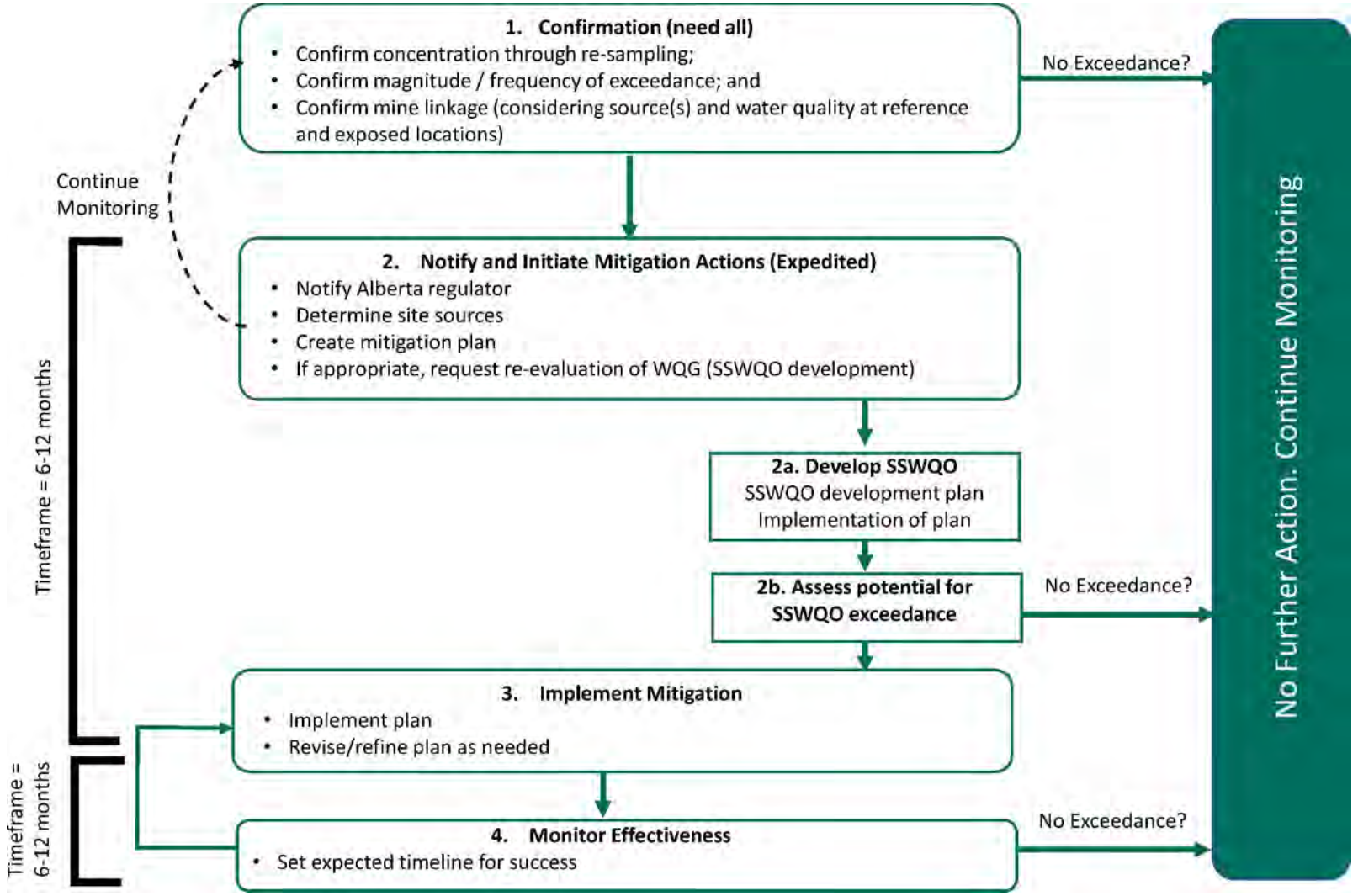

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

TRIGGER EVENT 1 - MONITORED EXCEEDANCE OF ALBERTA WQG IN BLAIRMORE AND GOLD CREEKS

PROJECT:	14-00201
DRAWN BY:	JLAMBERTS
CHECKED BY:	MB
DATE:	FEBRUARY 24, 2020

FIGURE

6.1-2

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\Resubmission\Information Request 3\Fig 6-1-2 Trigger Event 2 - Monitored Exceedance 14-00201.mxd

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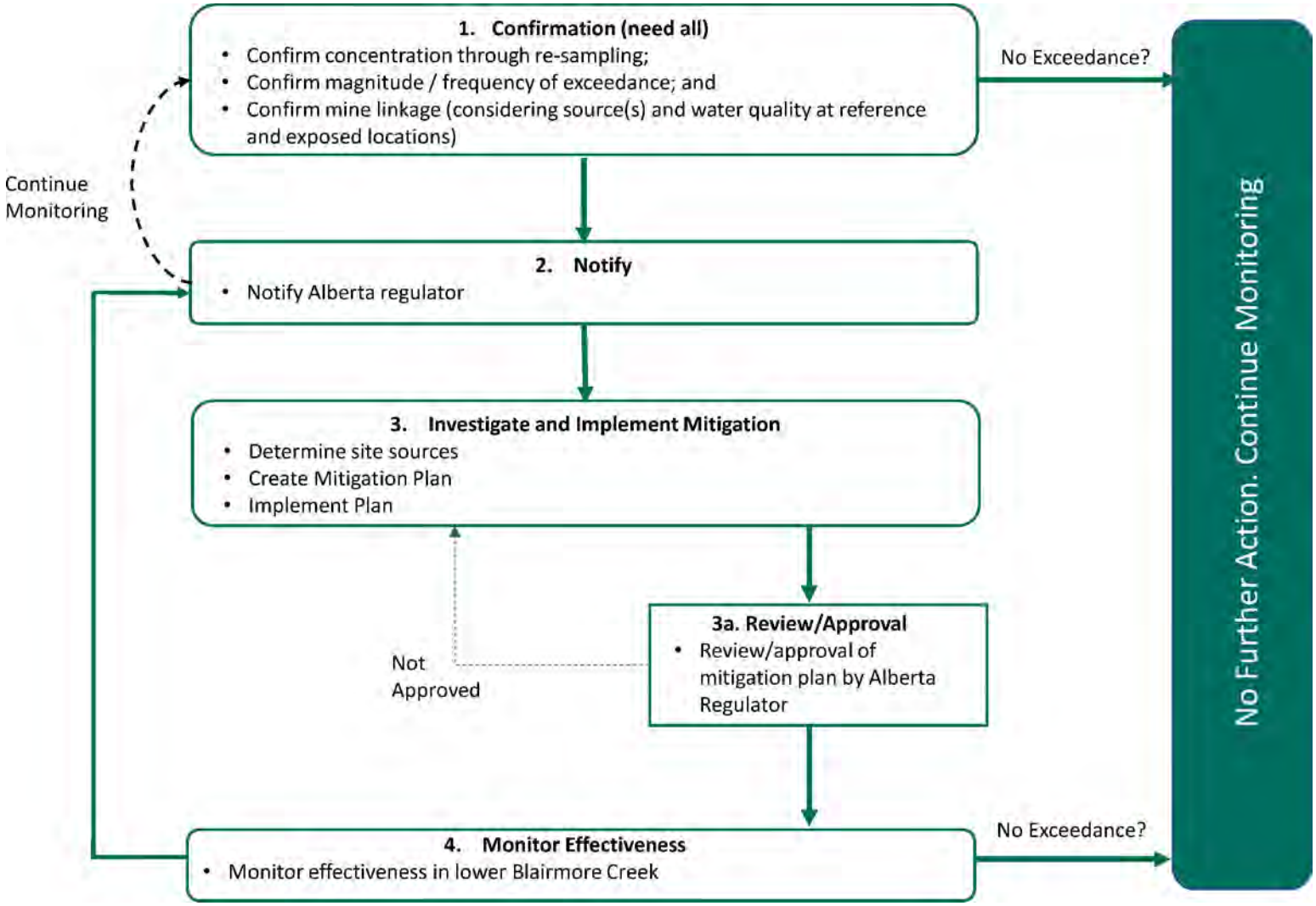

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

TRIGGER EVENT 1 - MONITORED EXCEEDANCE OF SSWQO IN LOWER BLAIRMORE CREEK

PROJECT: 14-00201
DRAWN BY: JLAMBERTS
CHECKED BY: MB
DATE: FEBRUARY 24, 2020

FIGURE
6.1-3

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APPENDIX 6.25-1: WATER QUALITY MODEL RESULTS: MEAN MONTHLY HYDROLOGY MODEL RESULTS

Appendix 6.25-1 Water Quality Model Results

Mean Monthly Hydrology

Blairmore Creek Water Quality Model Results

Mean Monthly Hydrology

Figure 1 - Mean Monthly Hydrology Model Results

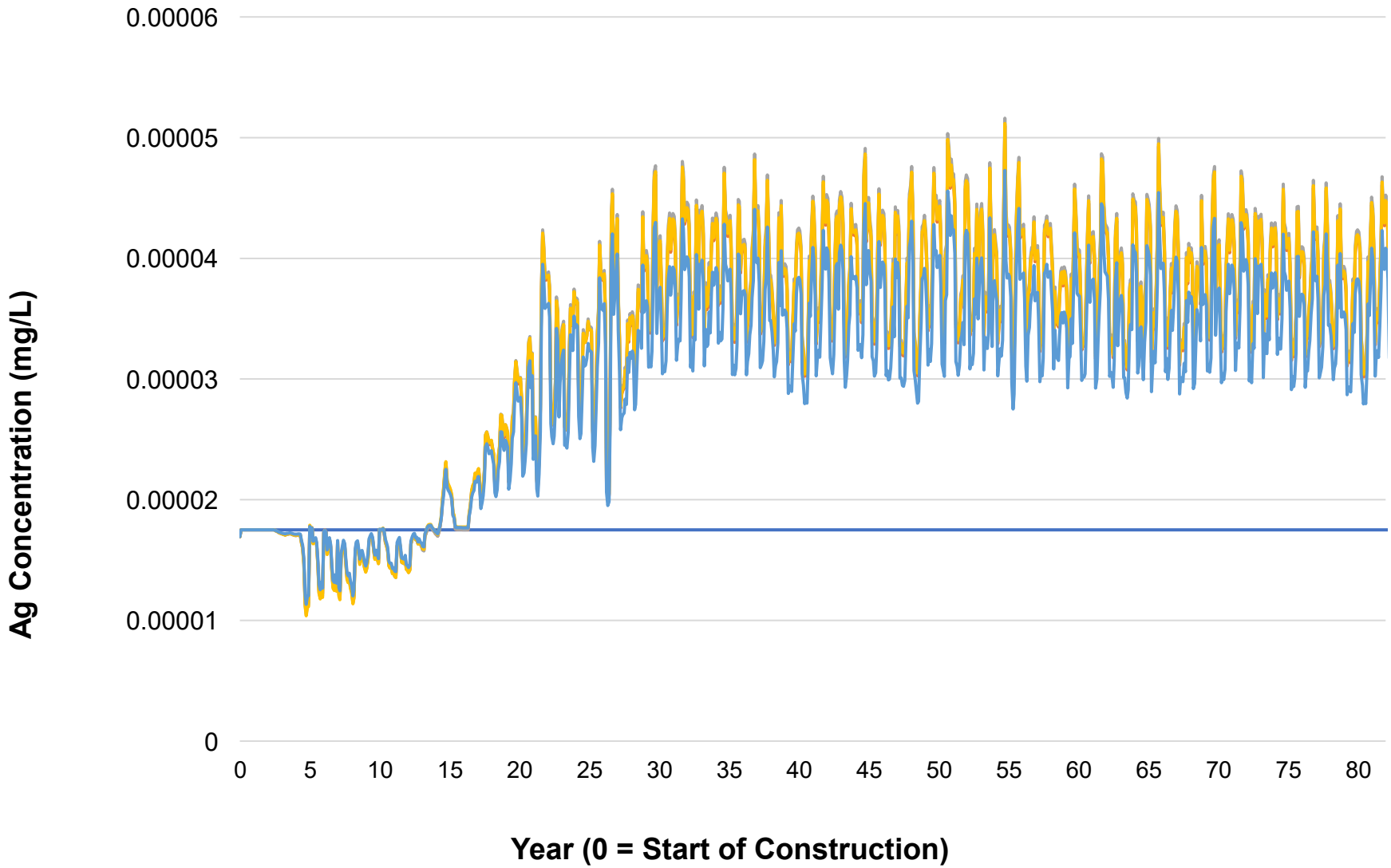

Figure 2 - Mean Monthly Hydrology Model Results

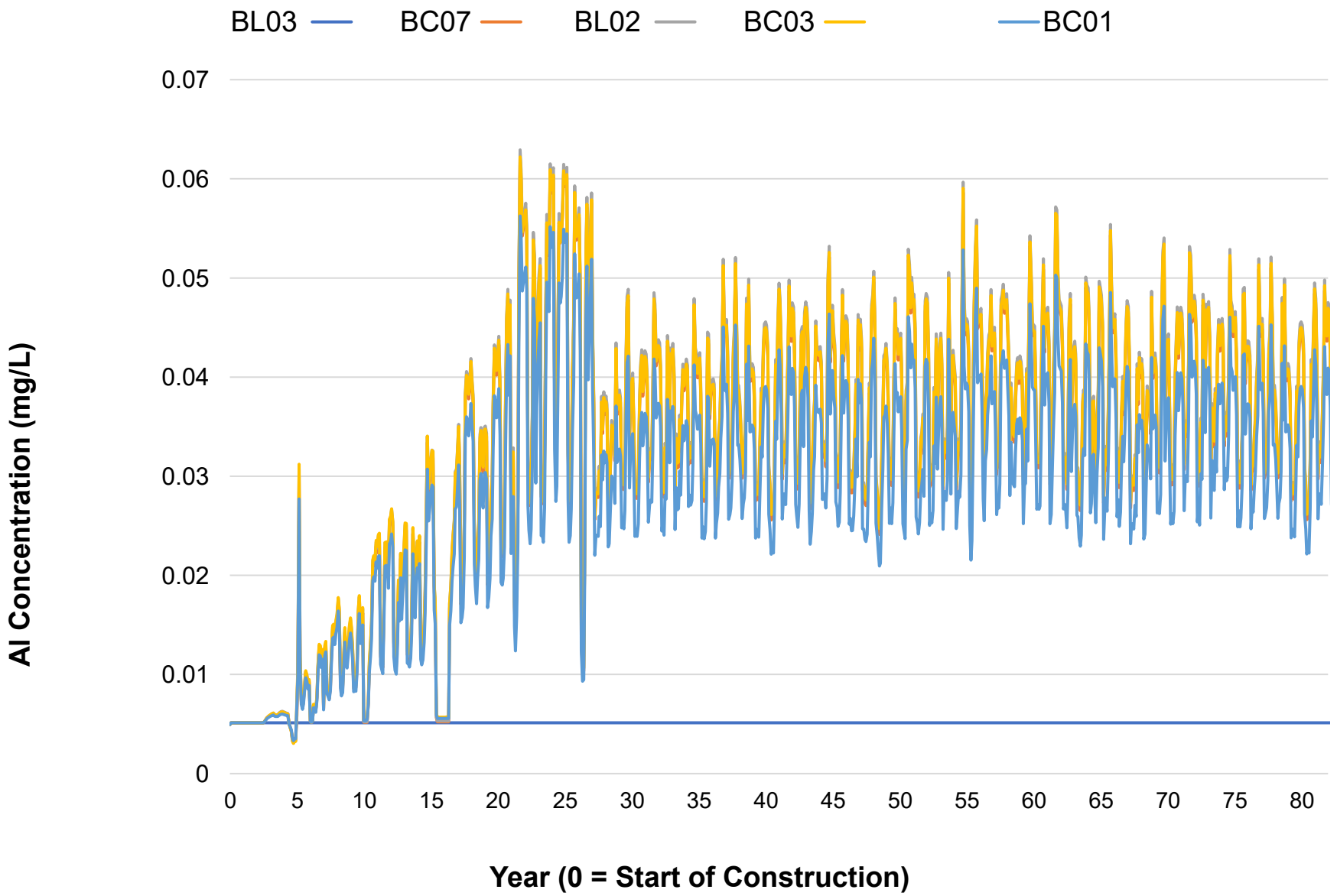

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Figure 3 - Mean Monthly Hydrology Model Results

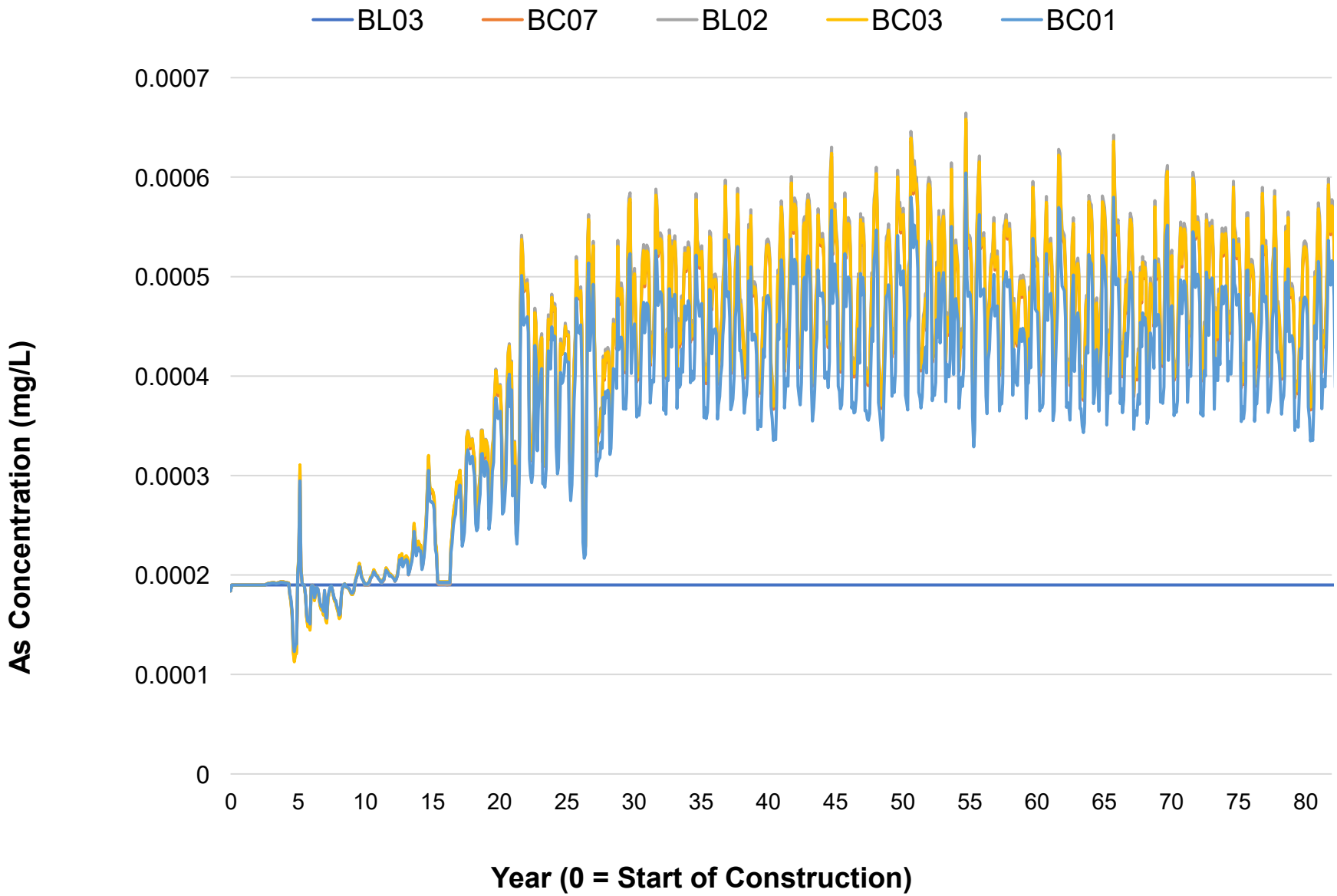

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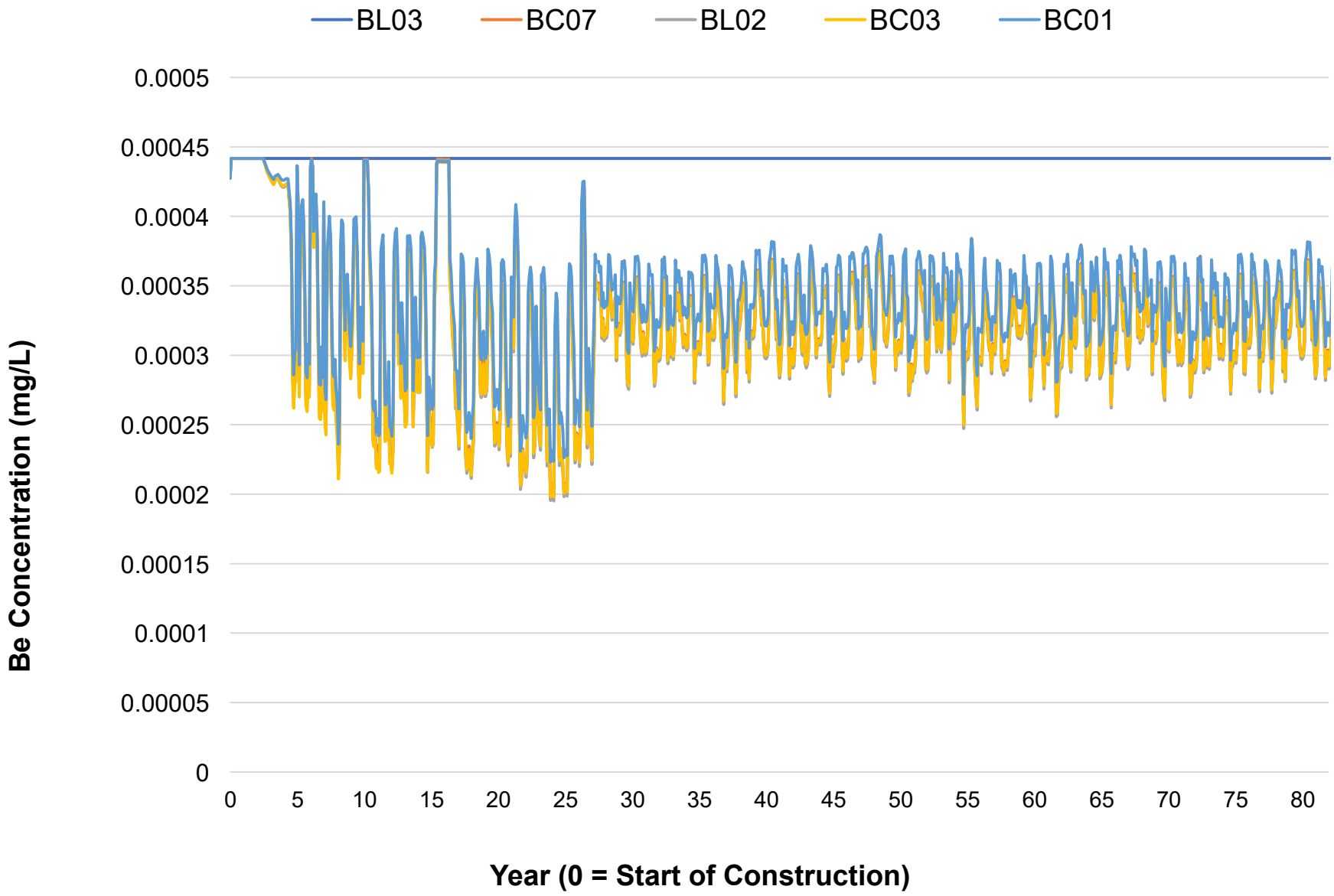
Figure 4 - Mean Monthly Hydrology Model Results



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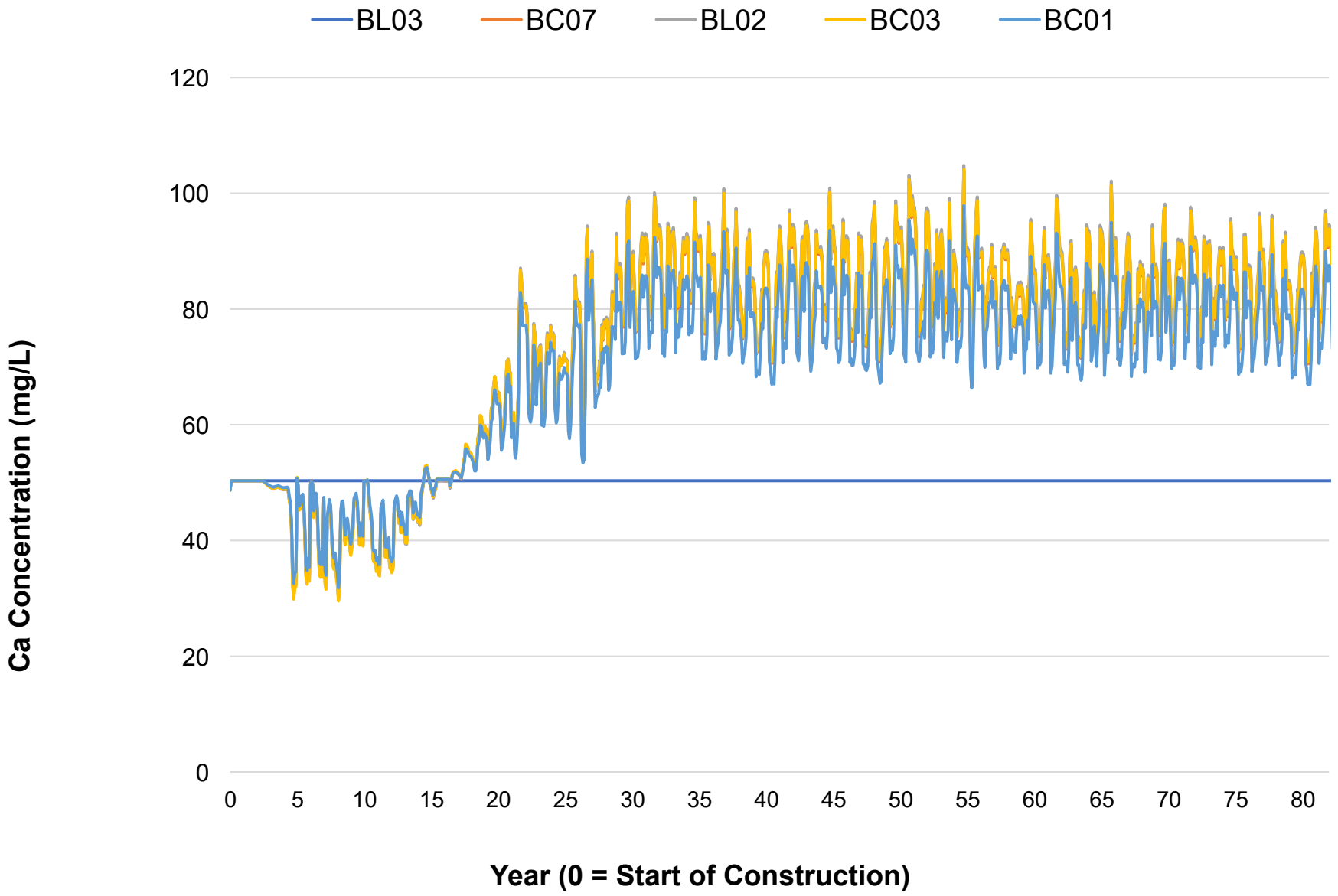

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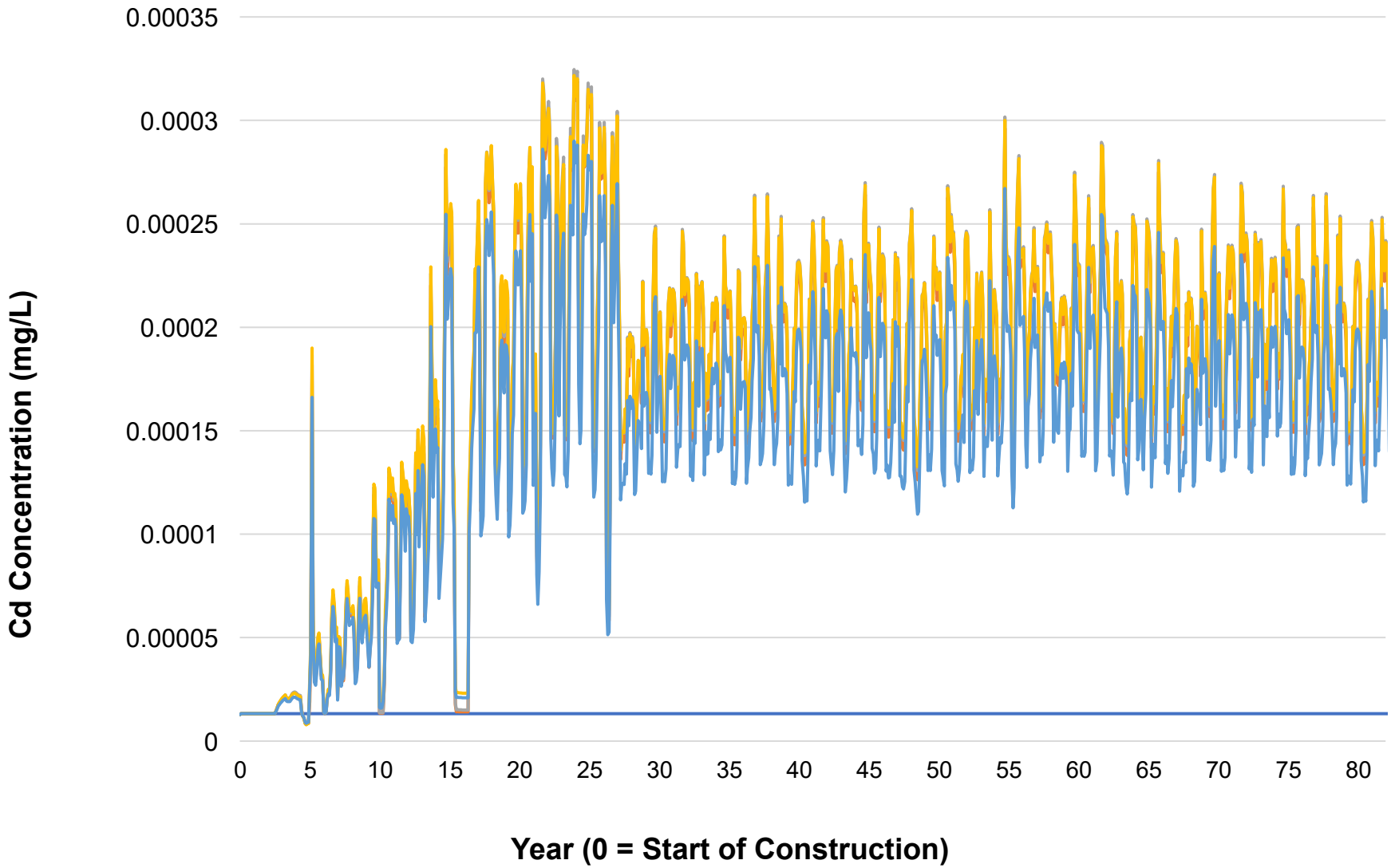


Figure 7 - Mean Monthly Hydrology Model Results

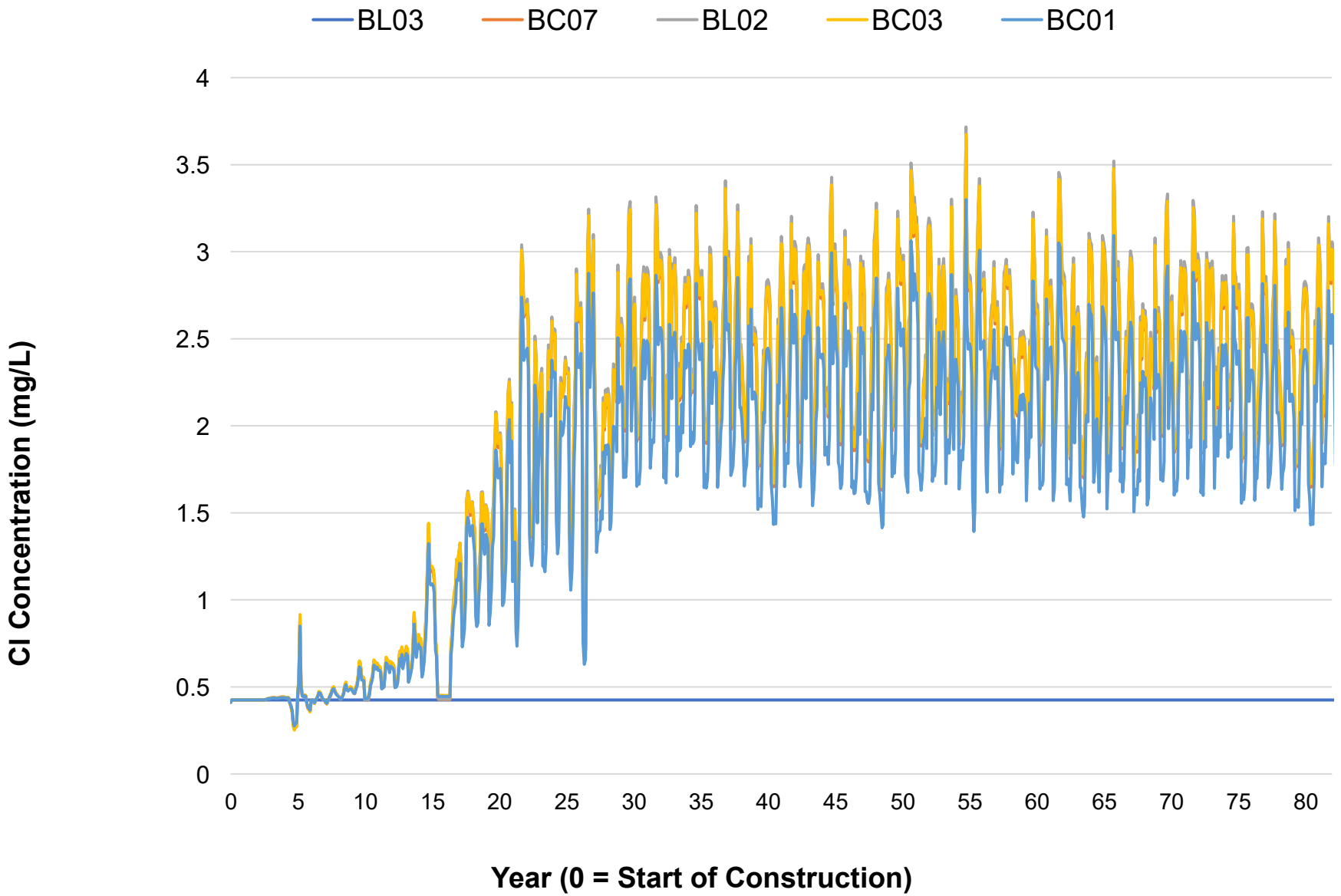
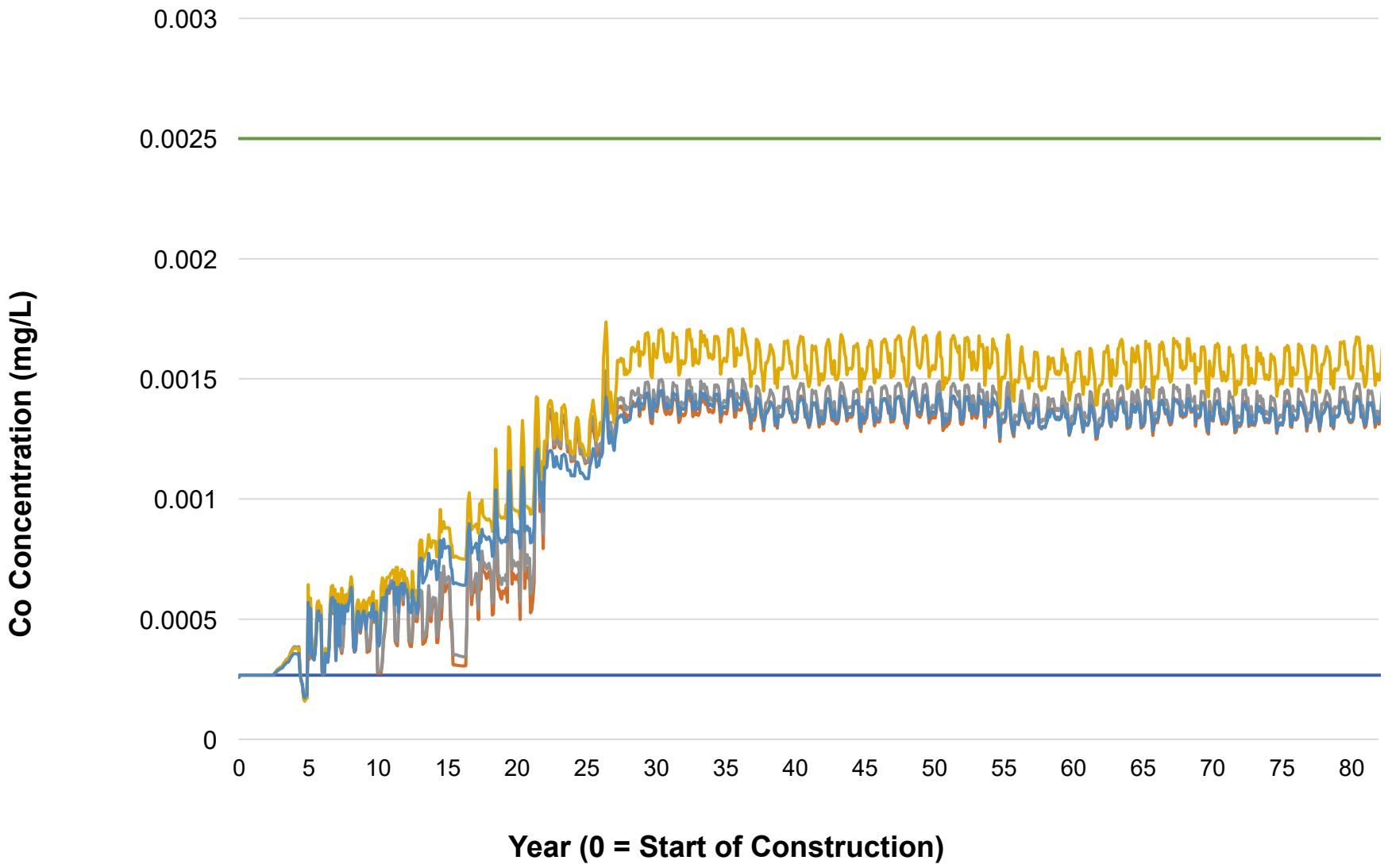


Figure 8 - Mean Monthly Hydrology Model Results



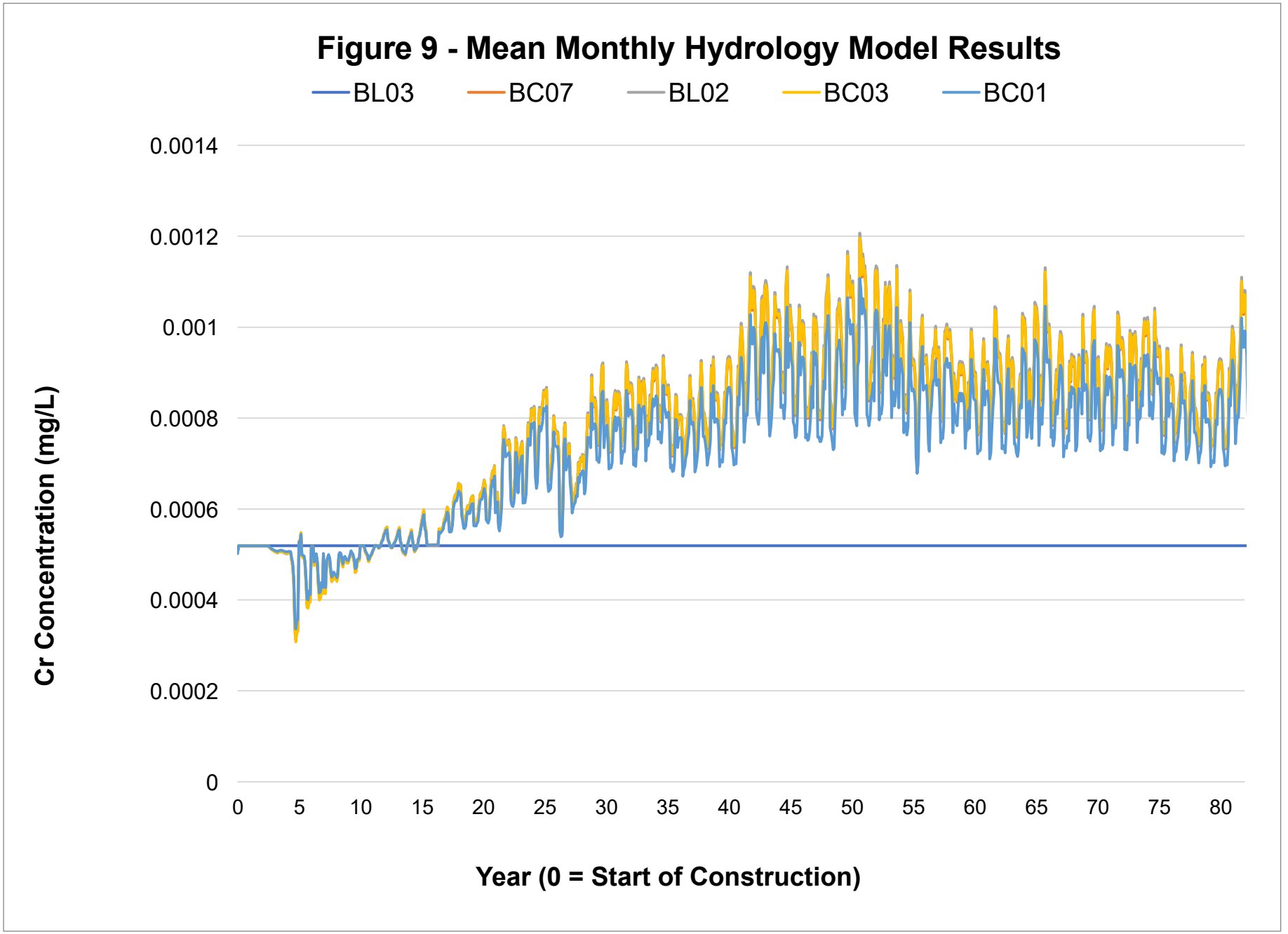


Figure 9 - Mean Monthly Hydrology Model Results
BL03
BC07
BL02
BC03
BC01
0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
Cr Concentration (mg/L)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
Year (0 = Start of Construction)

Figure 10 - Mean Monthly Hydrology Model Results

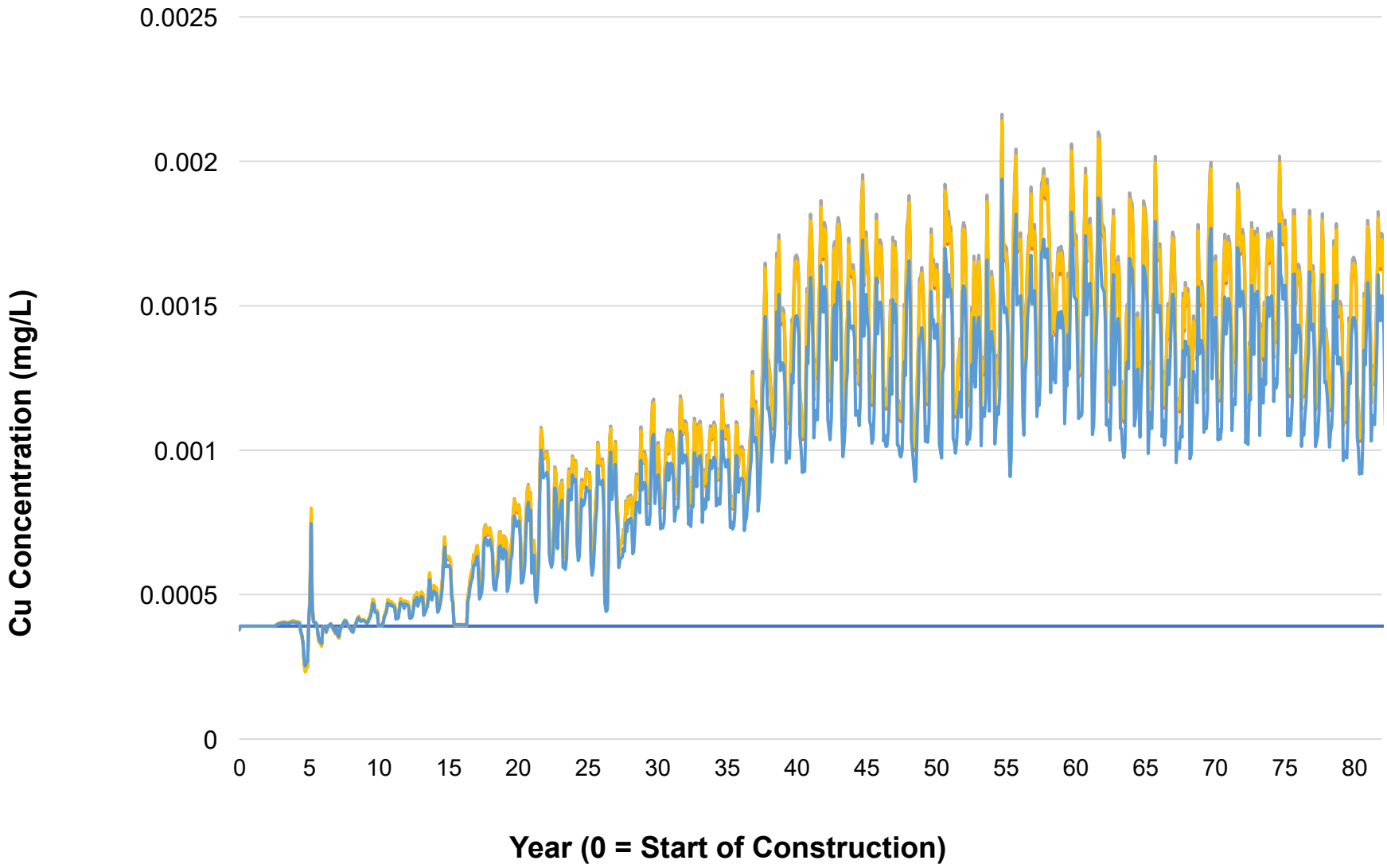


Figure 11 - Mean Monthly Hydrology Model Results

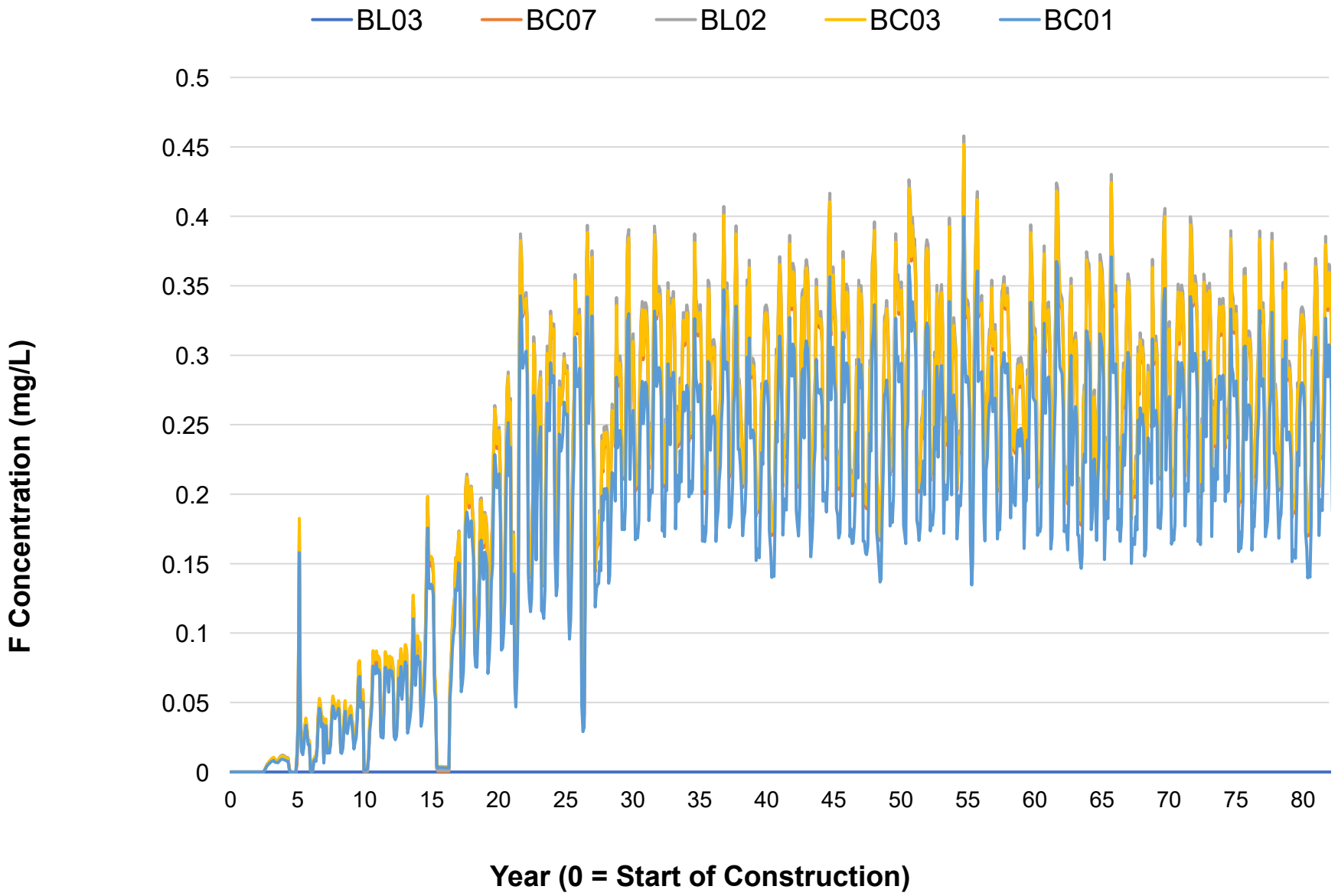


Figure 12 - Mean Monthly Hydrology Model Results

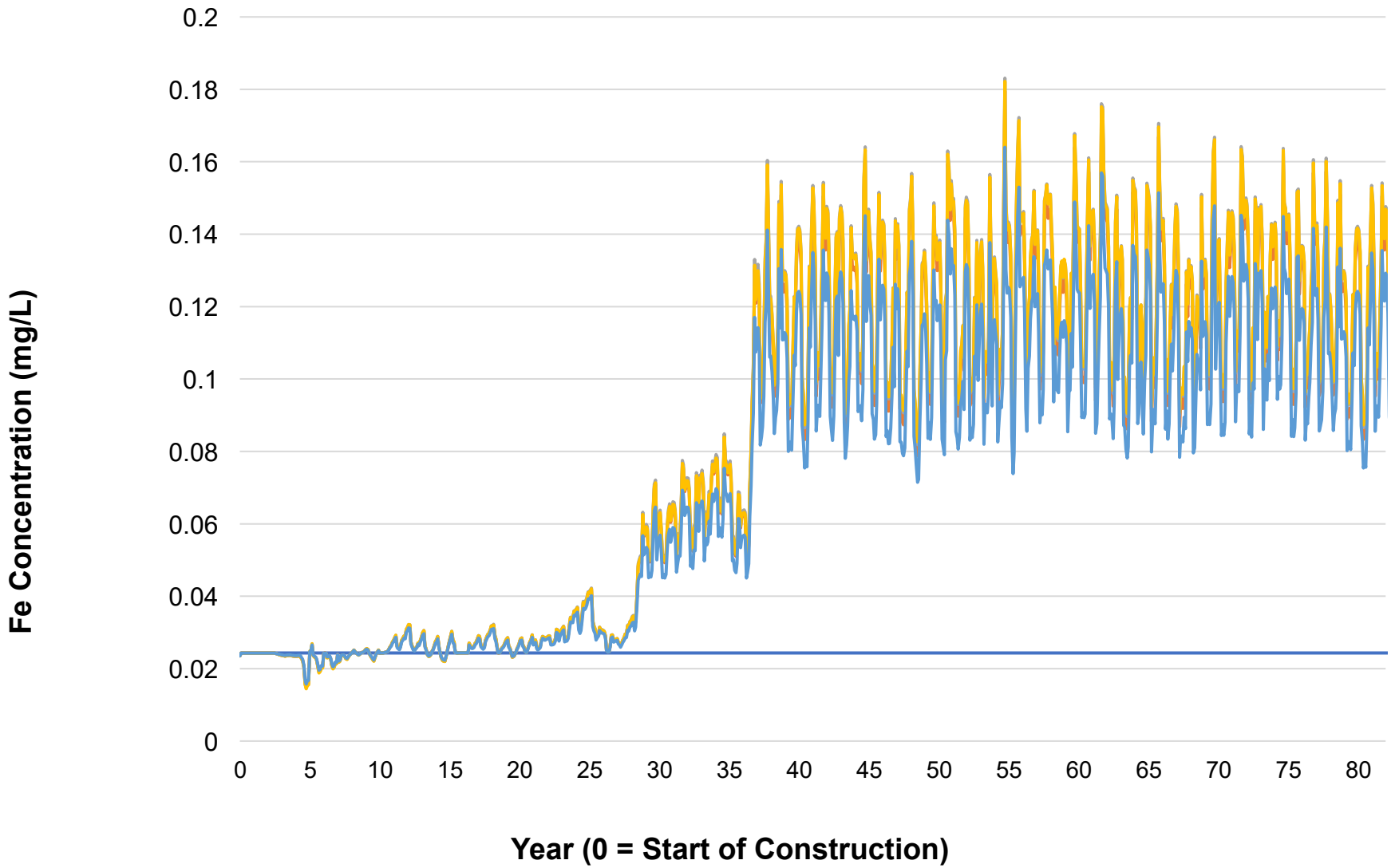


Figure 13 - Mean Monthly Hydrology Model Results

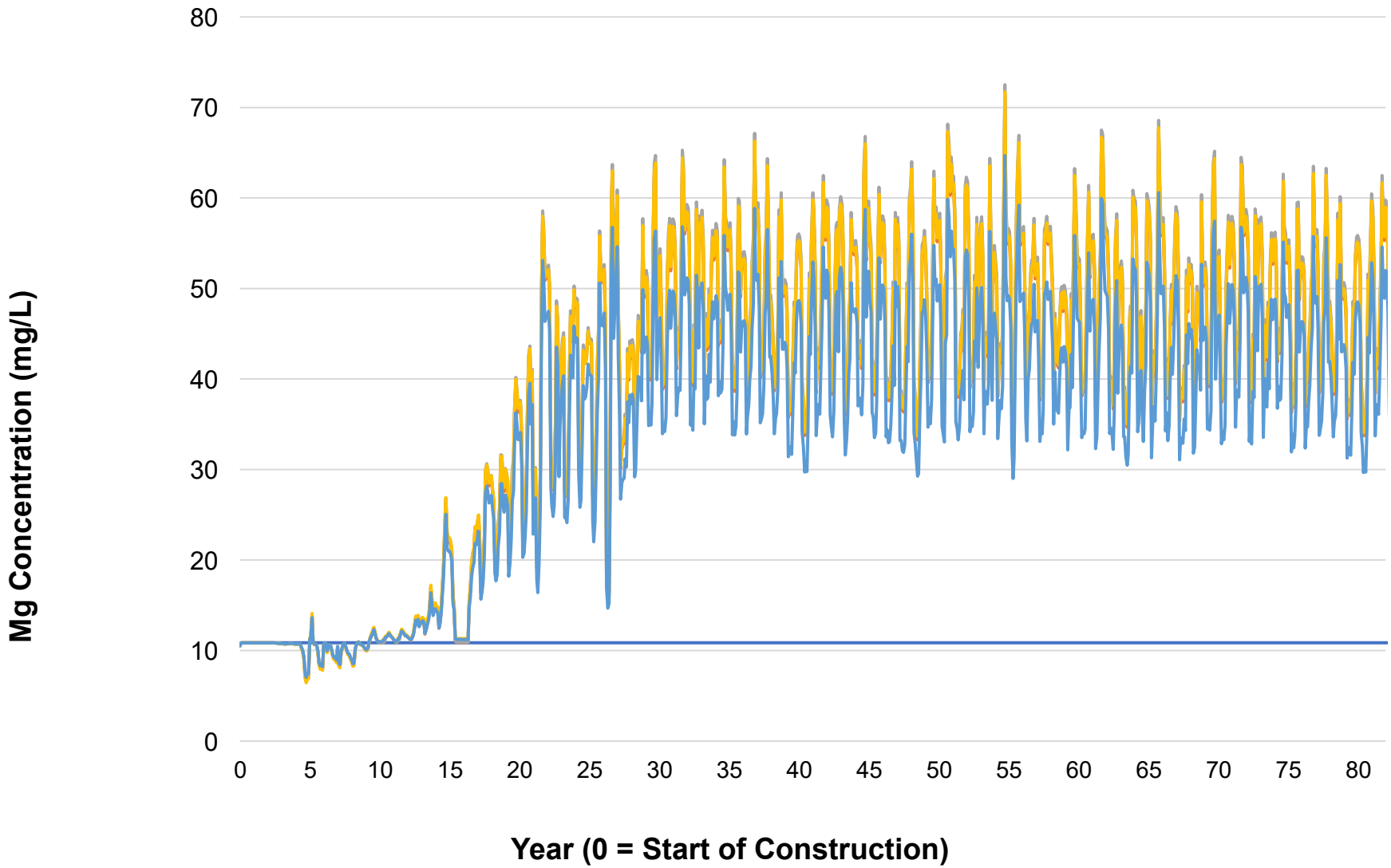


Figure 14 - Mean Monthly Hydrology Model Results

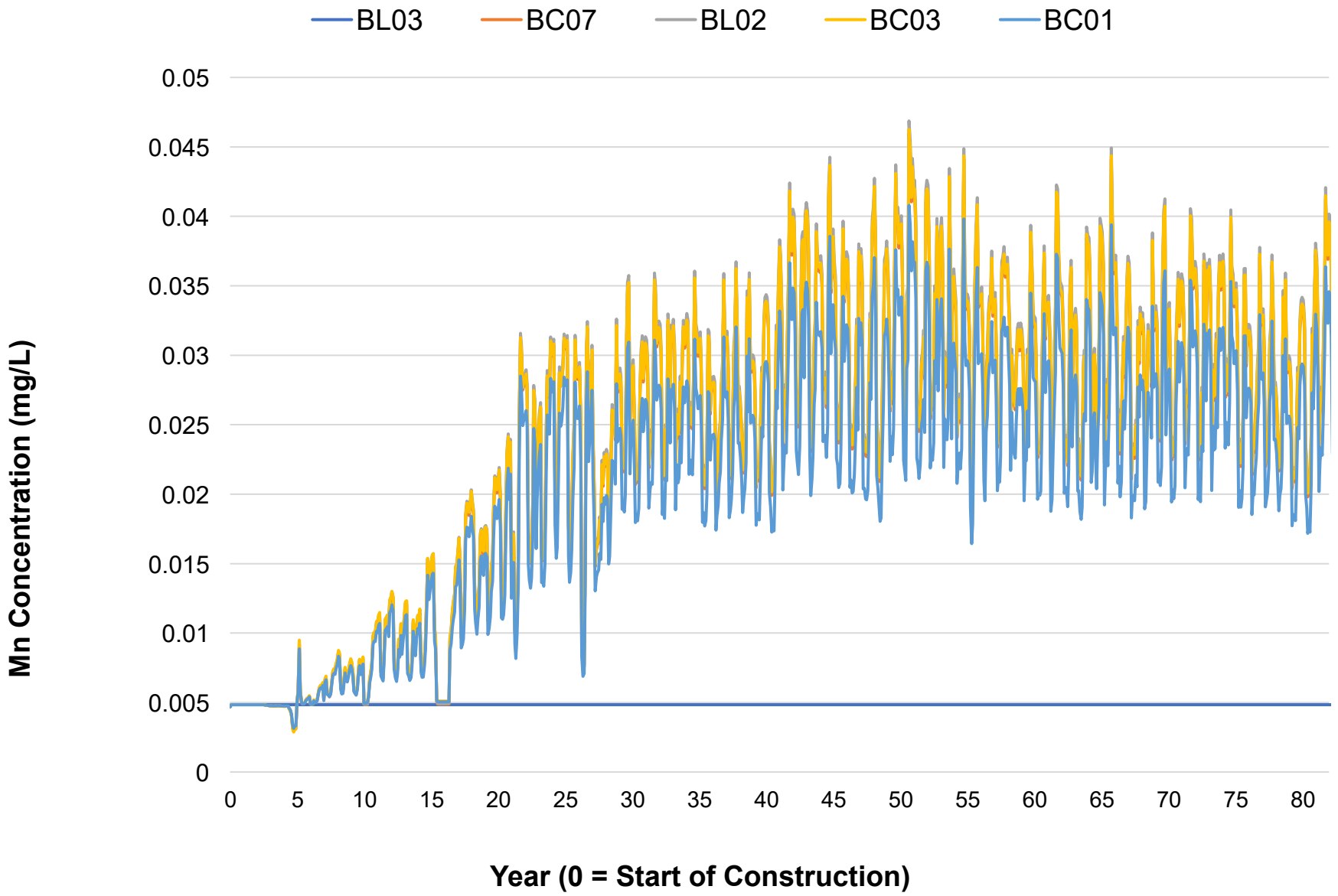


Figure 15 - Mean Monthly Hydrology Model Results

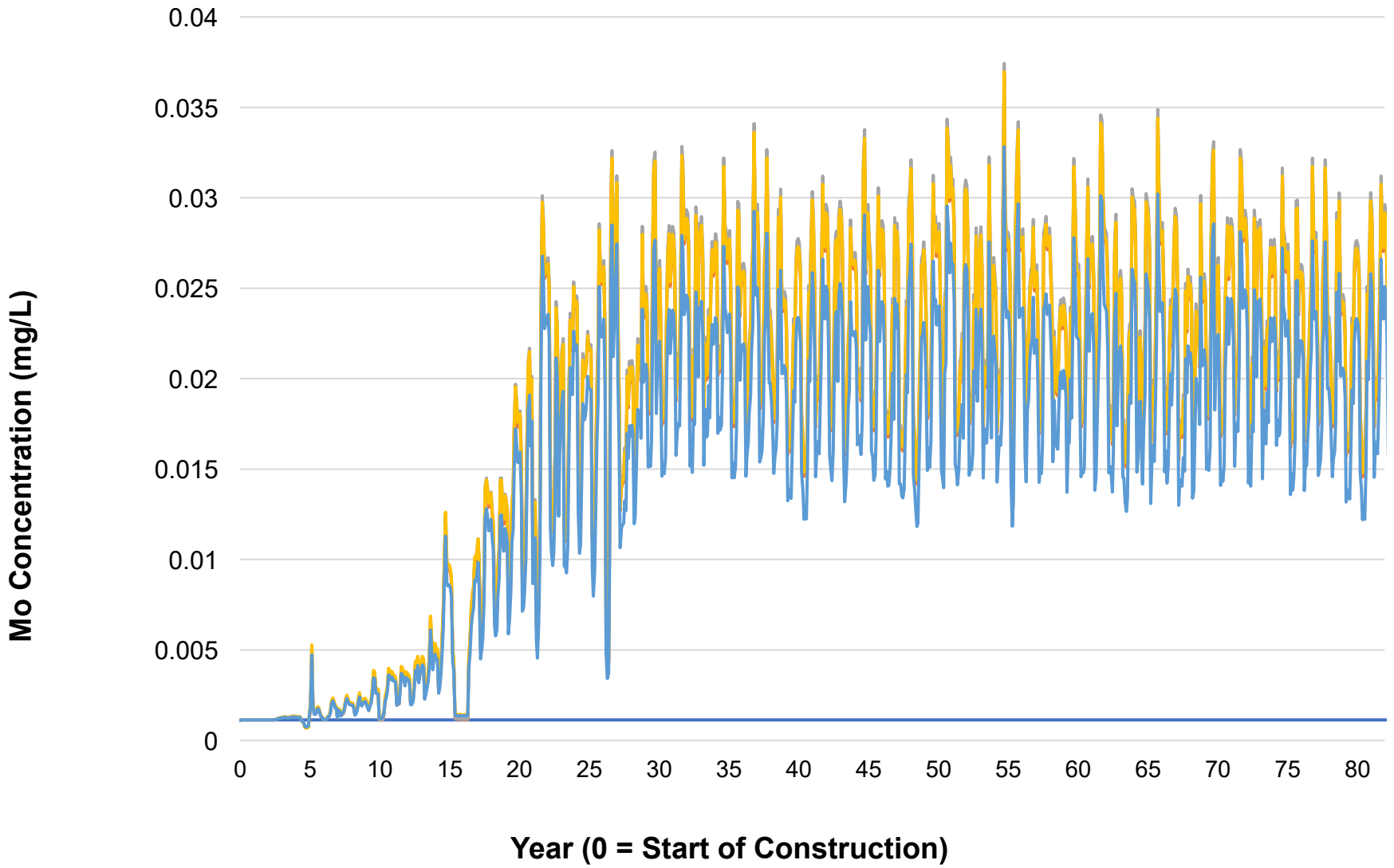


Figure 16 - Mean Monthly Hydrology Model Results

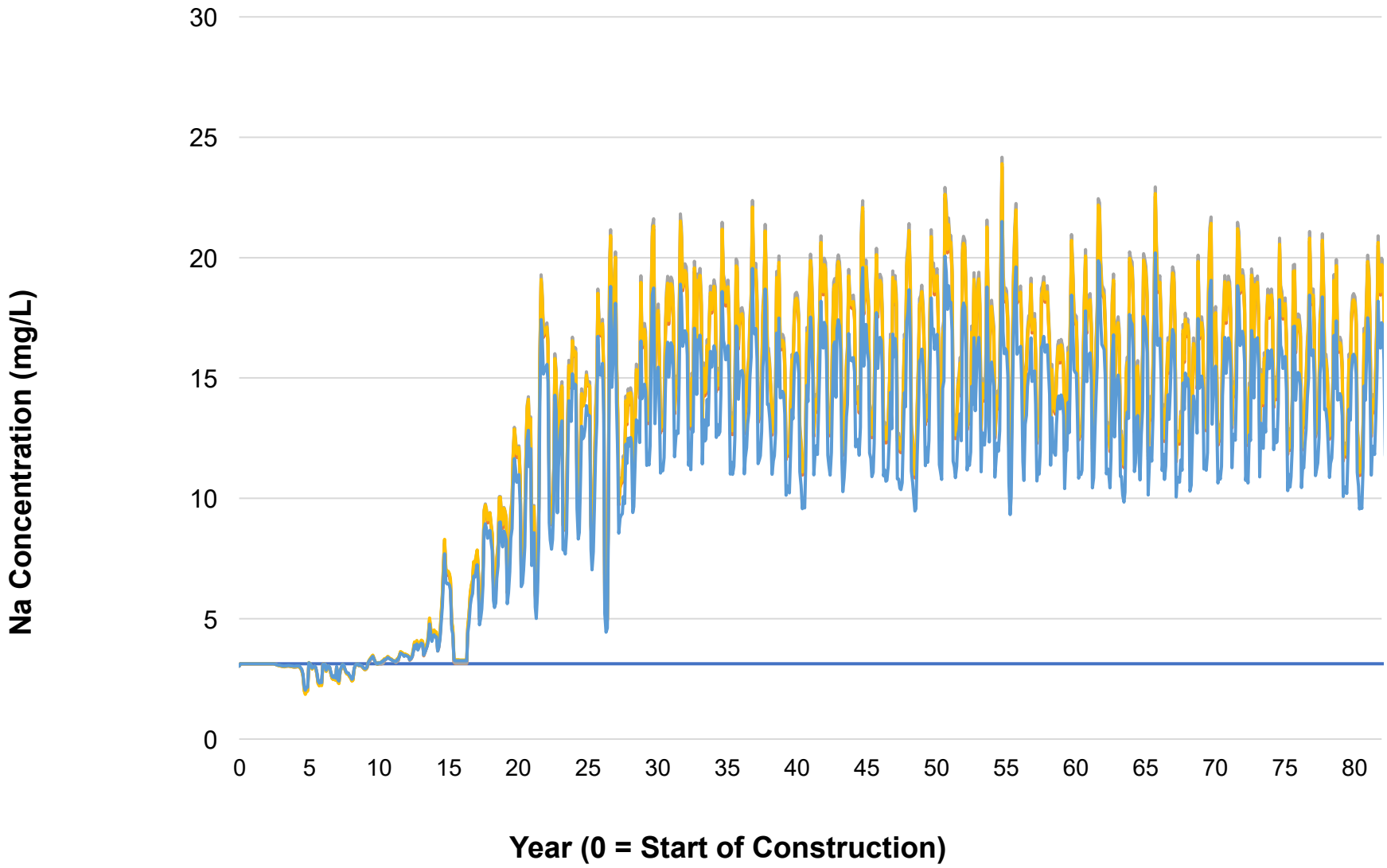


Figure 17 - Mean Monthly Hydrology Model Results

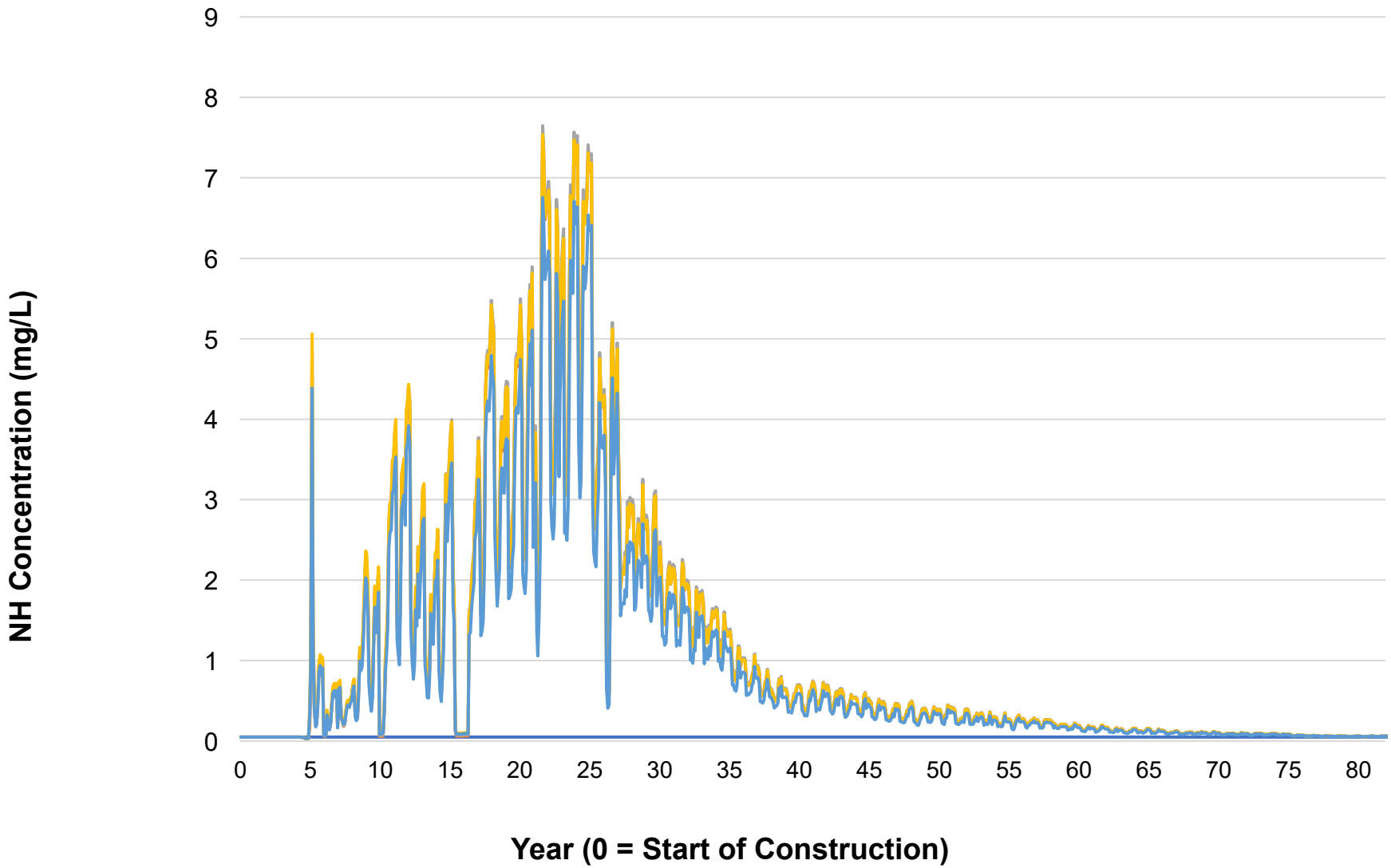


Figure 18 - Mean Monthly Hydrology Model Results

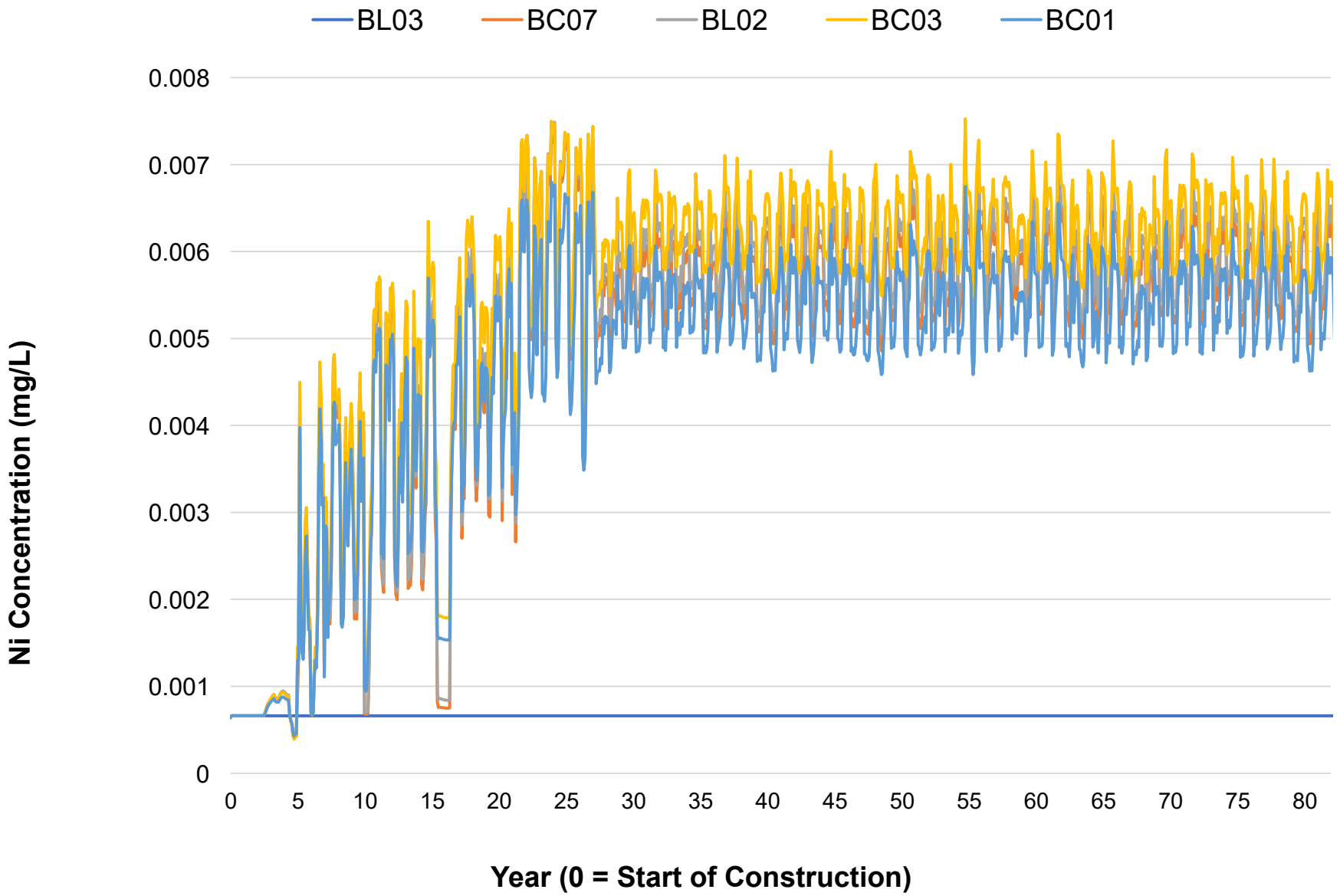


Figure 19 - Mean Monthly Hydrology Model Results

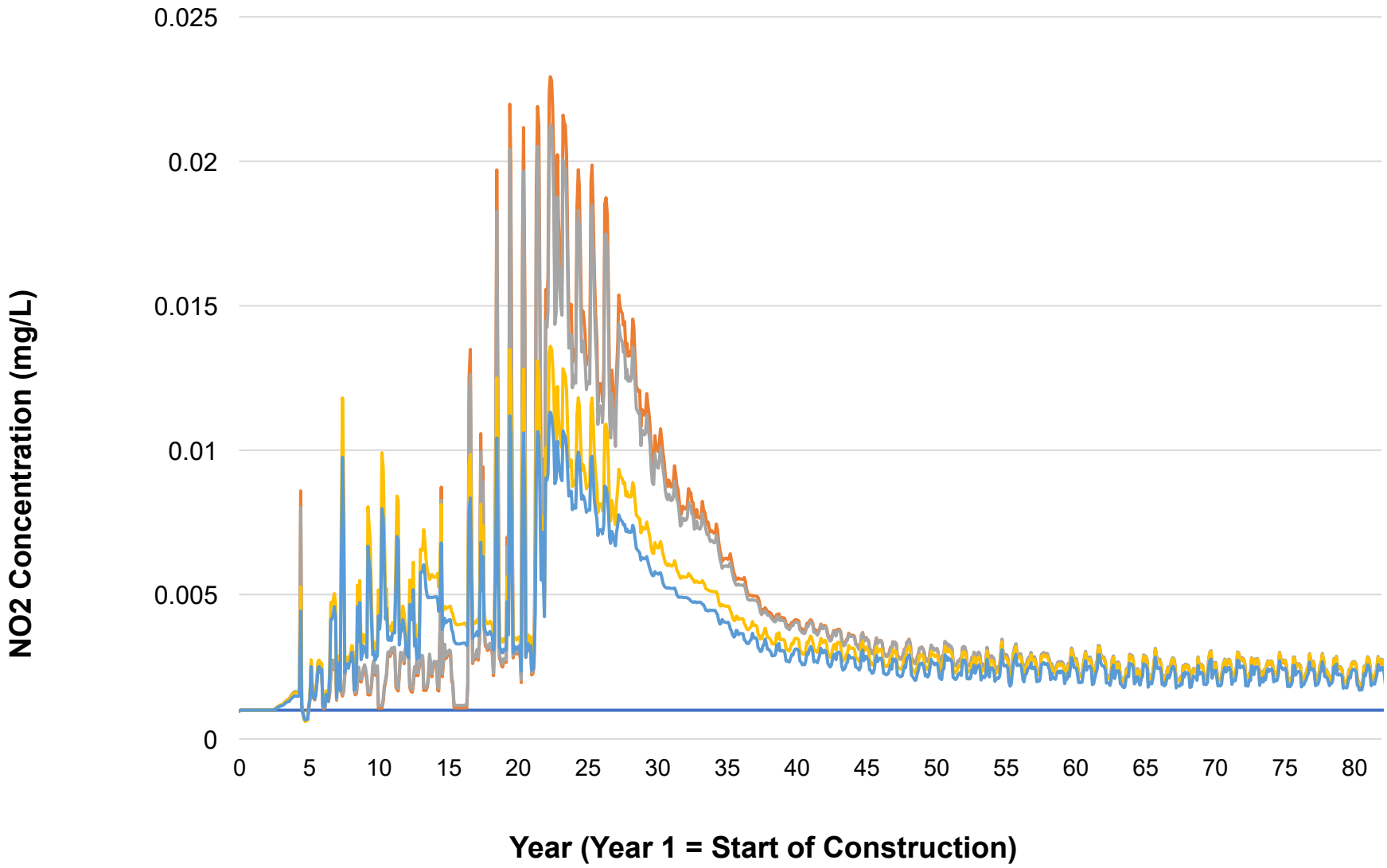


Figure 20 - Mean Monthly Hydrology Model Results

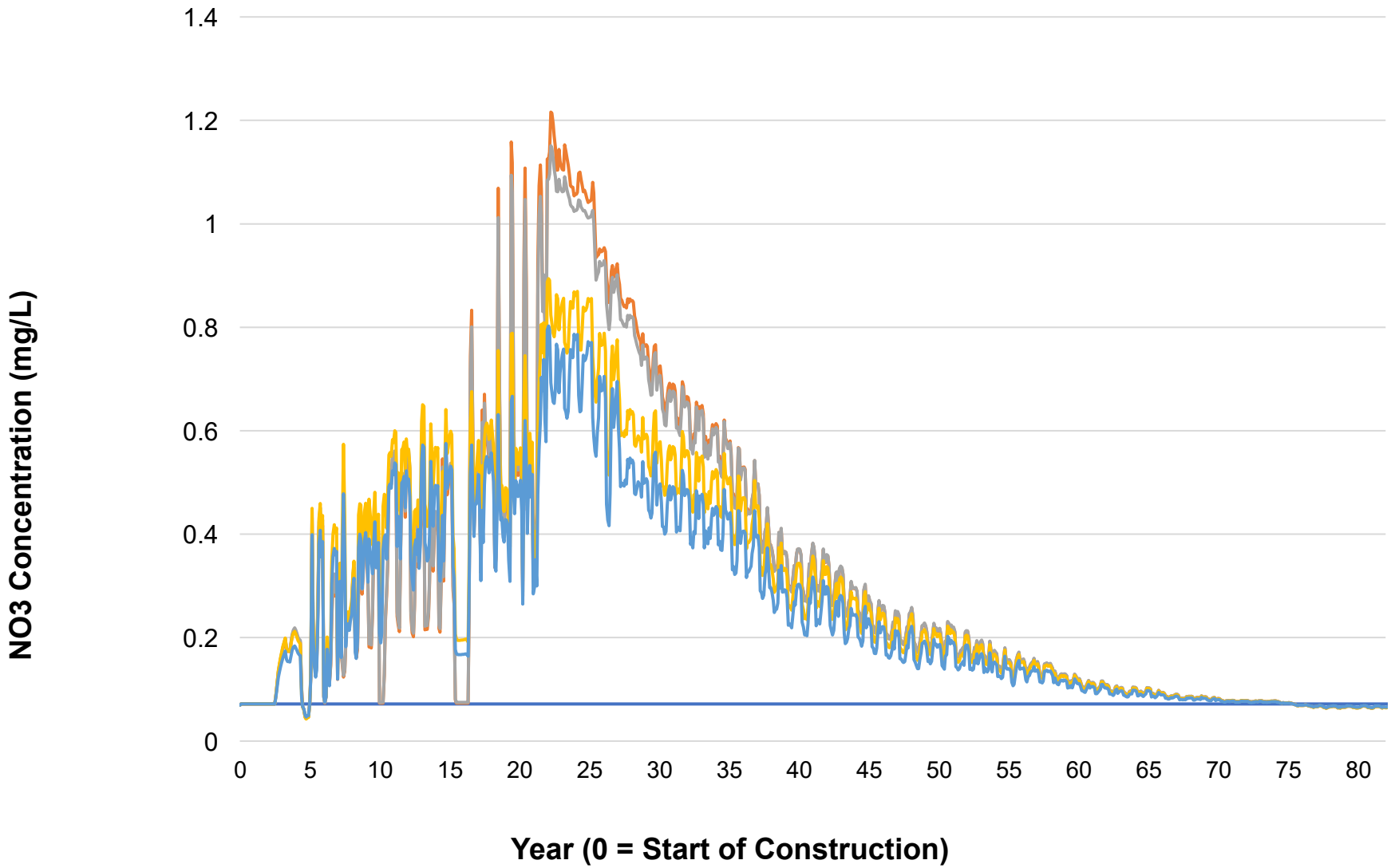


Figure 21 - Mean Monthly Hydrology Model Results

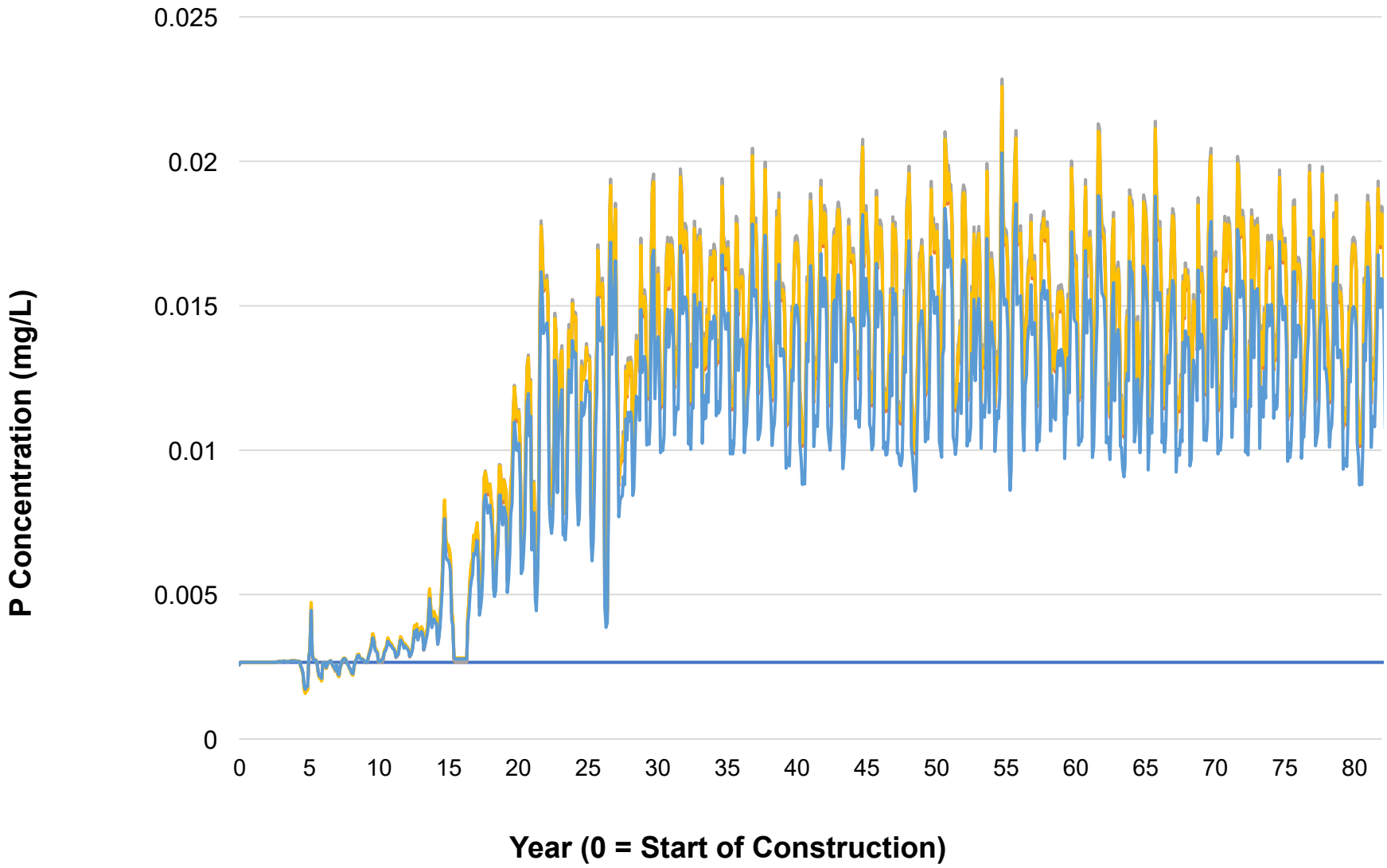


Figure 22 - Mean Monthly Hydrology Model Results

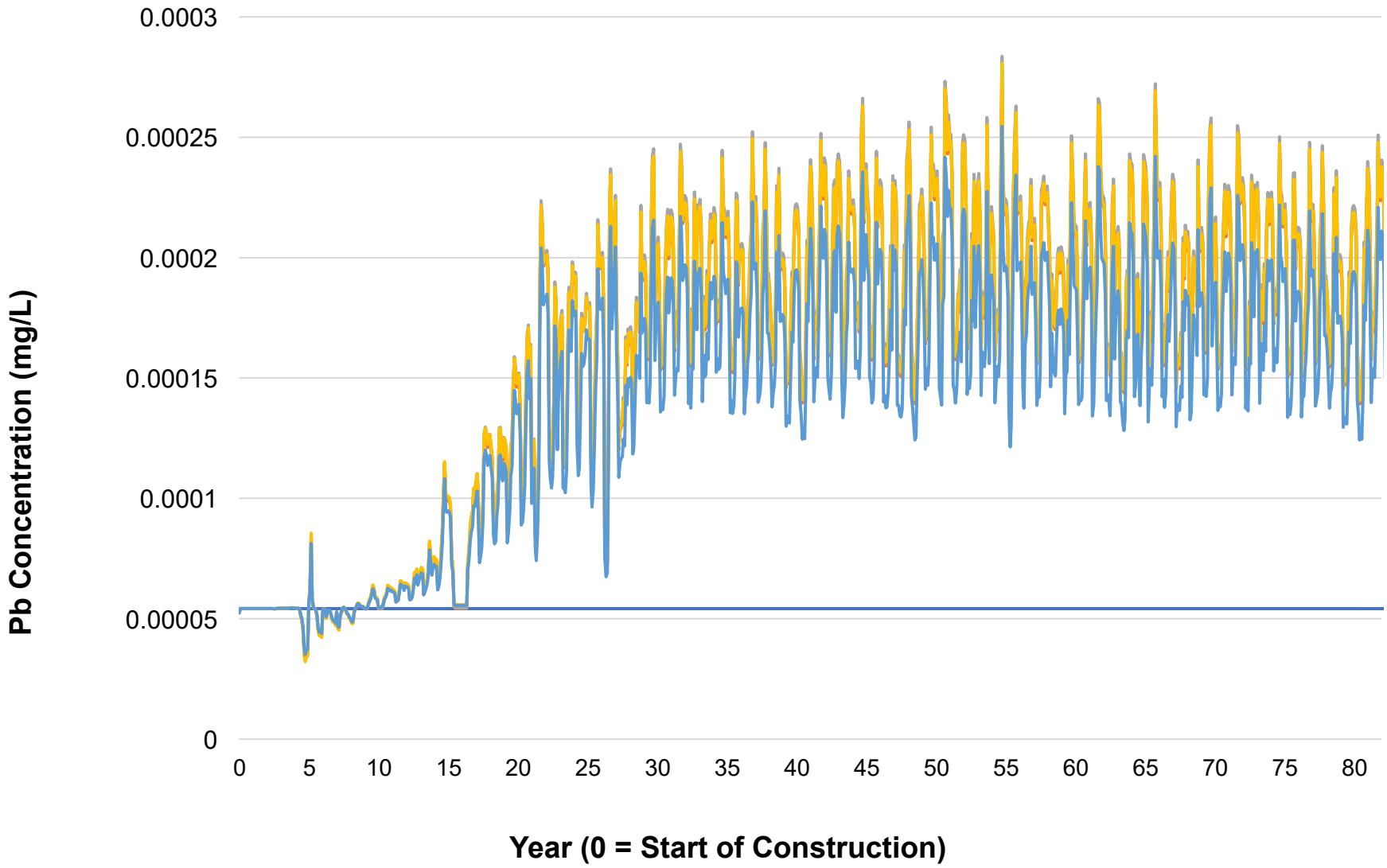


Figure 23 - Mean Monthly Hydrology Model Results

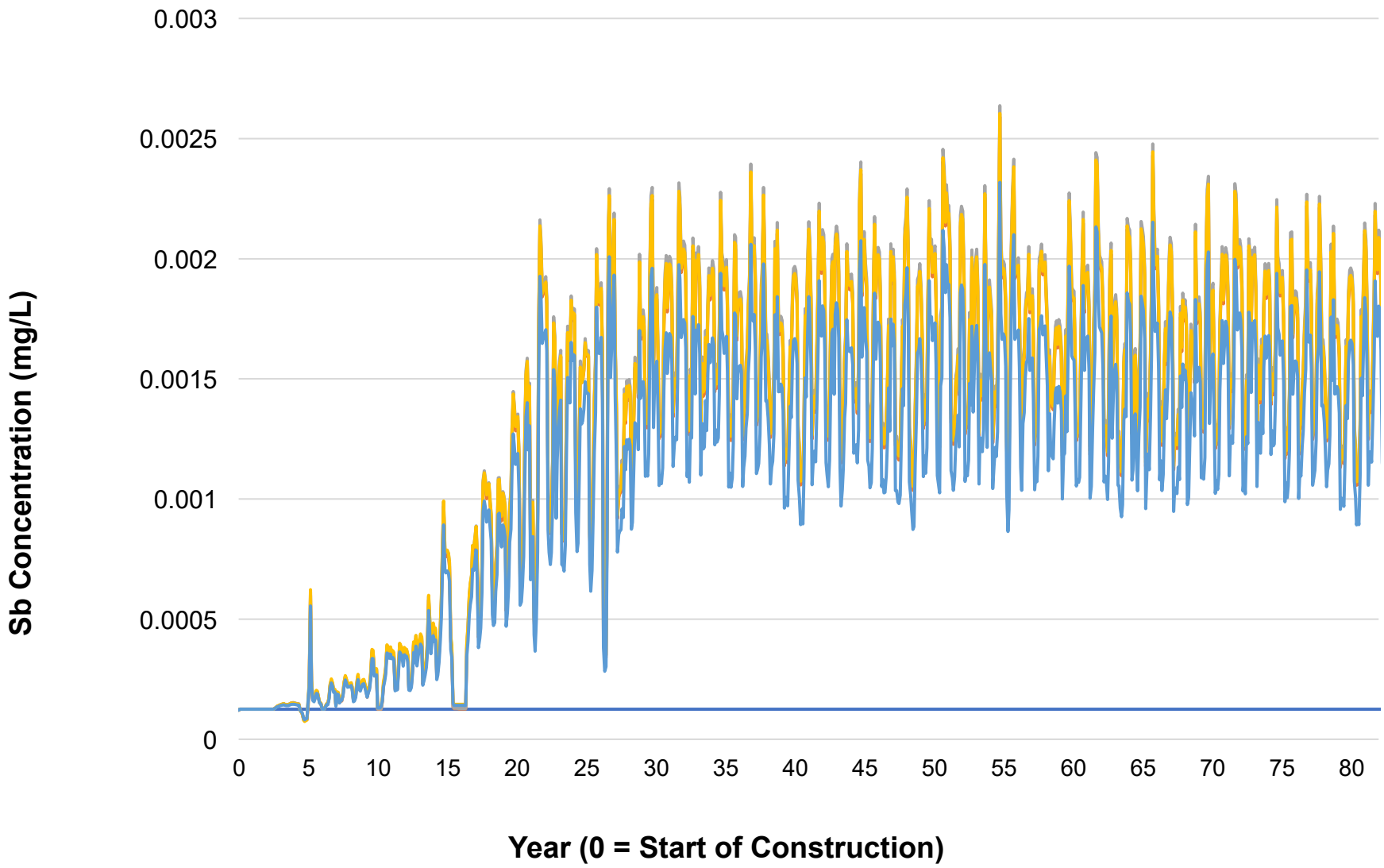


Figure 24 - Mean Monthly Hydrology Model Results

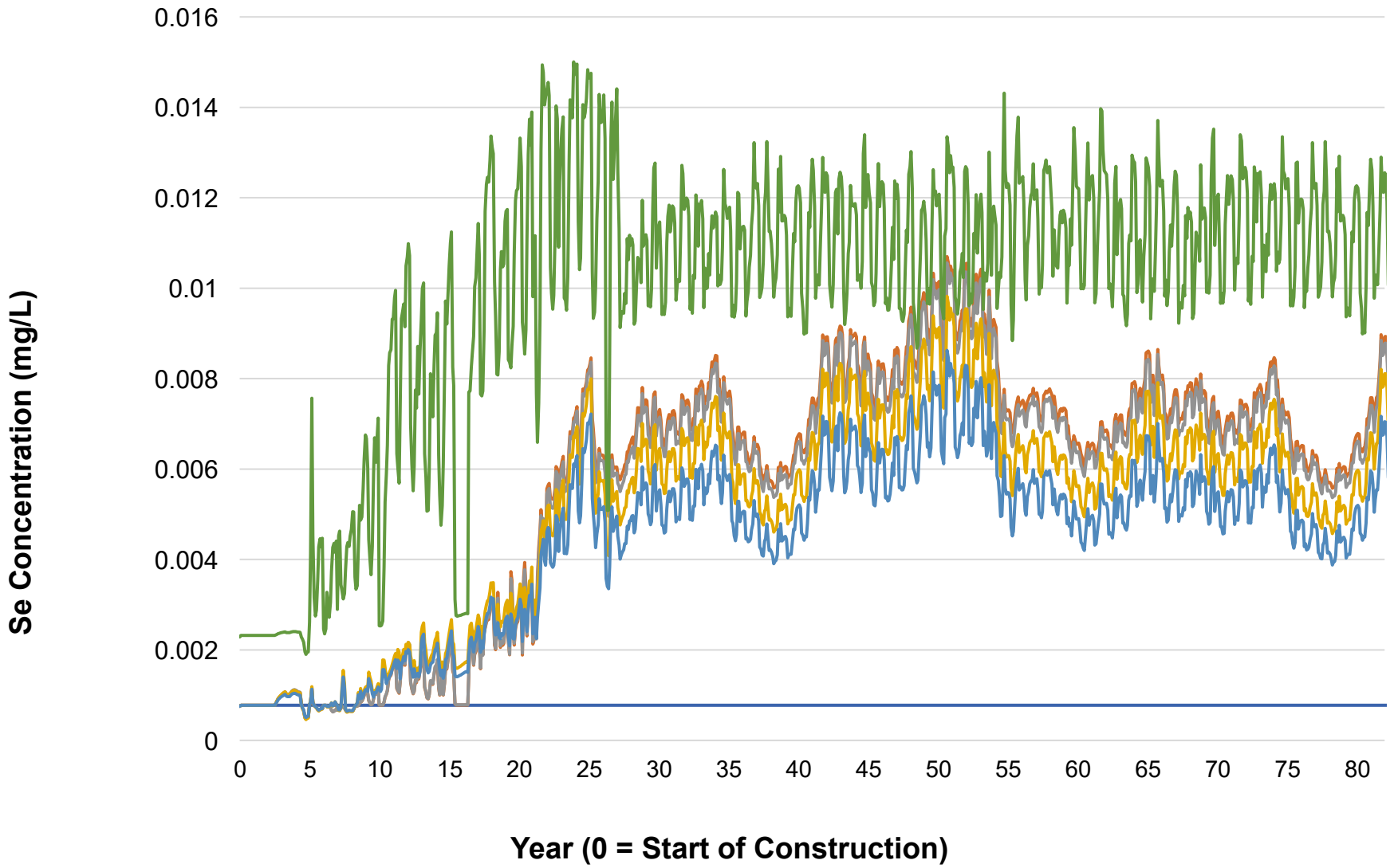


Figure 25 - Mean Monthly Hydrology Model Results

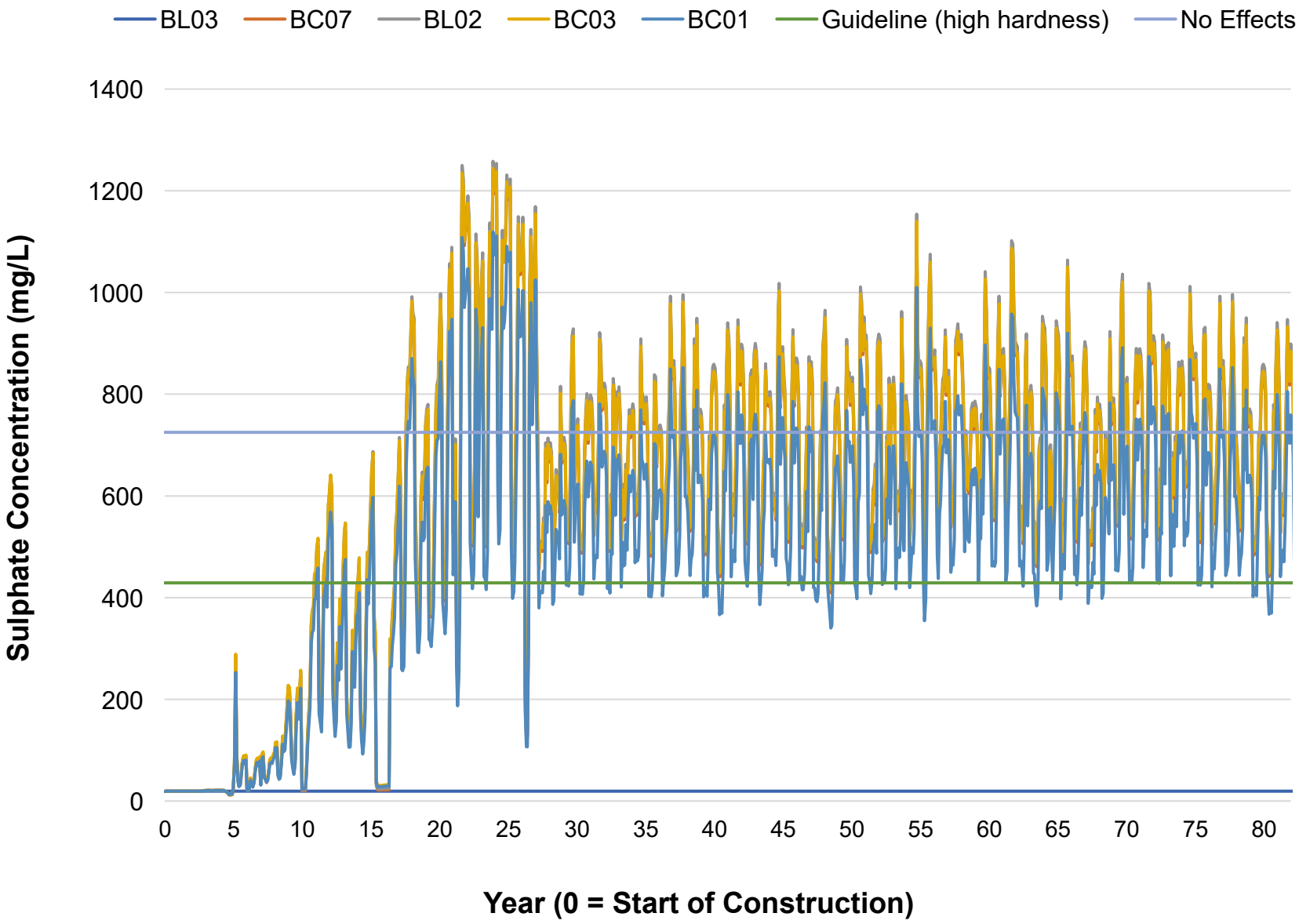


Figure 26 - Mean Monthly Hydrology Model Results

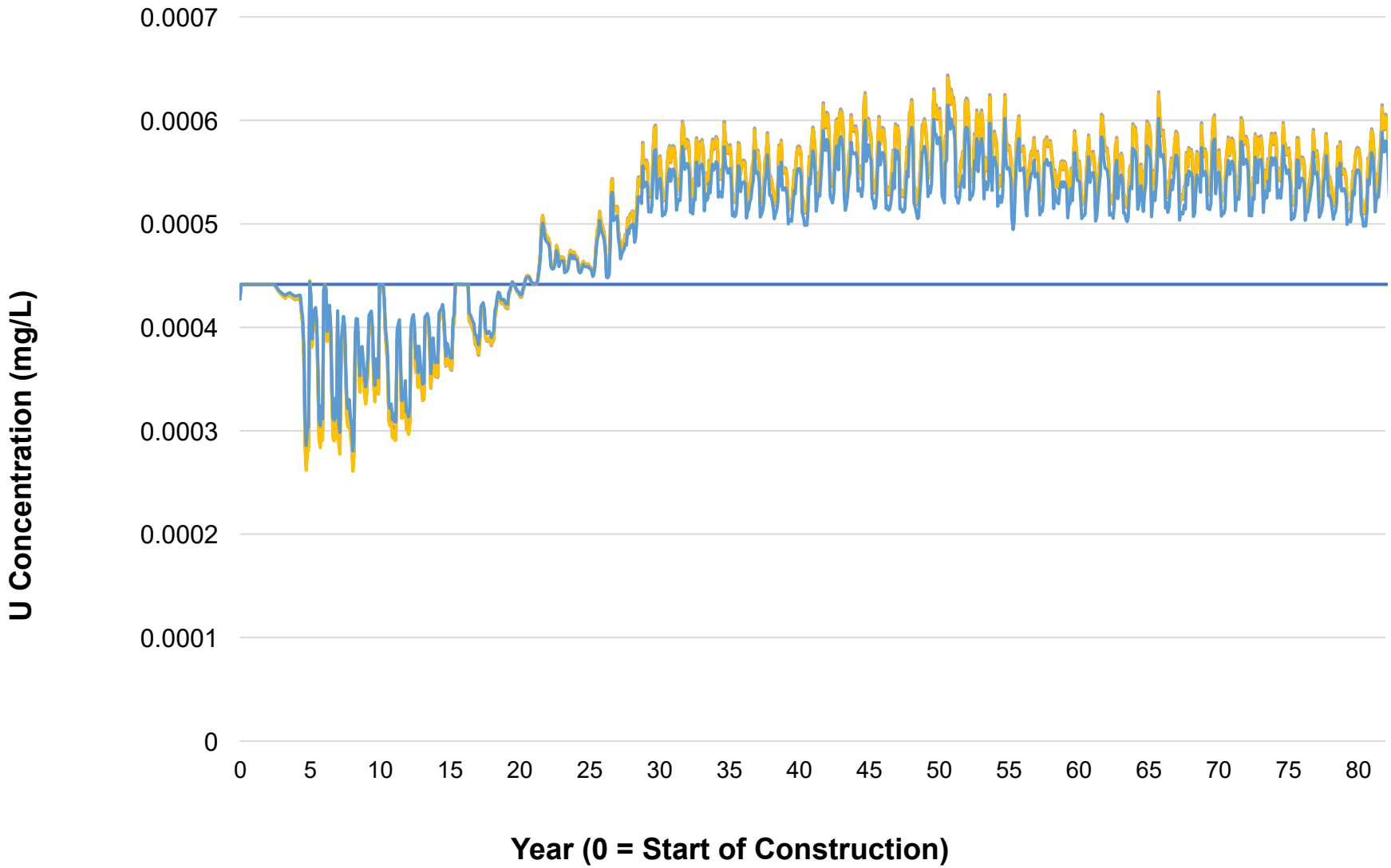
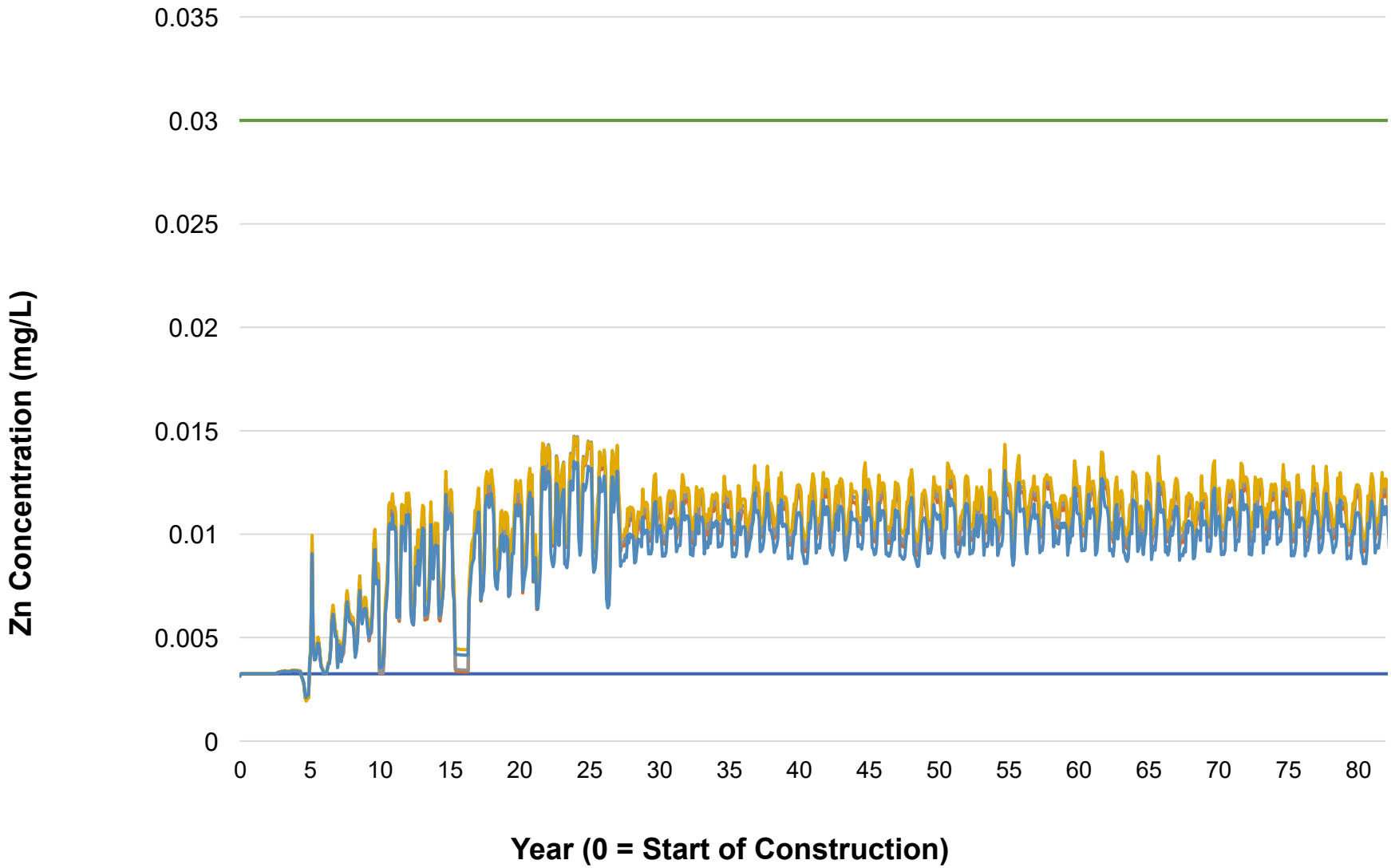


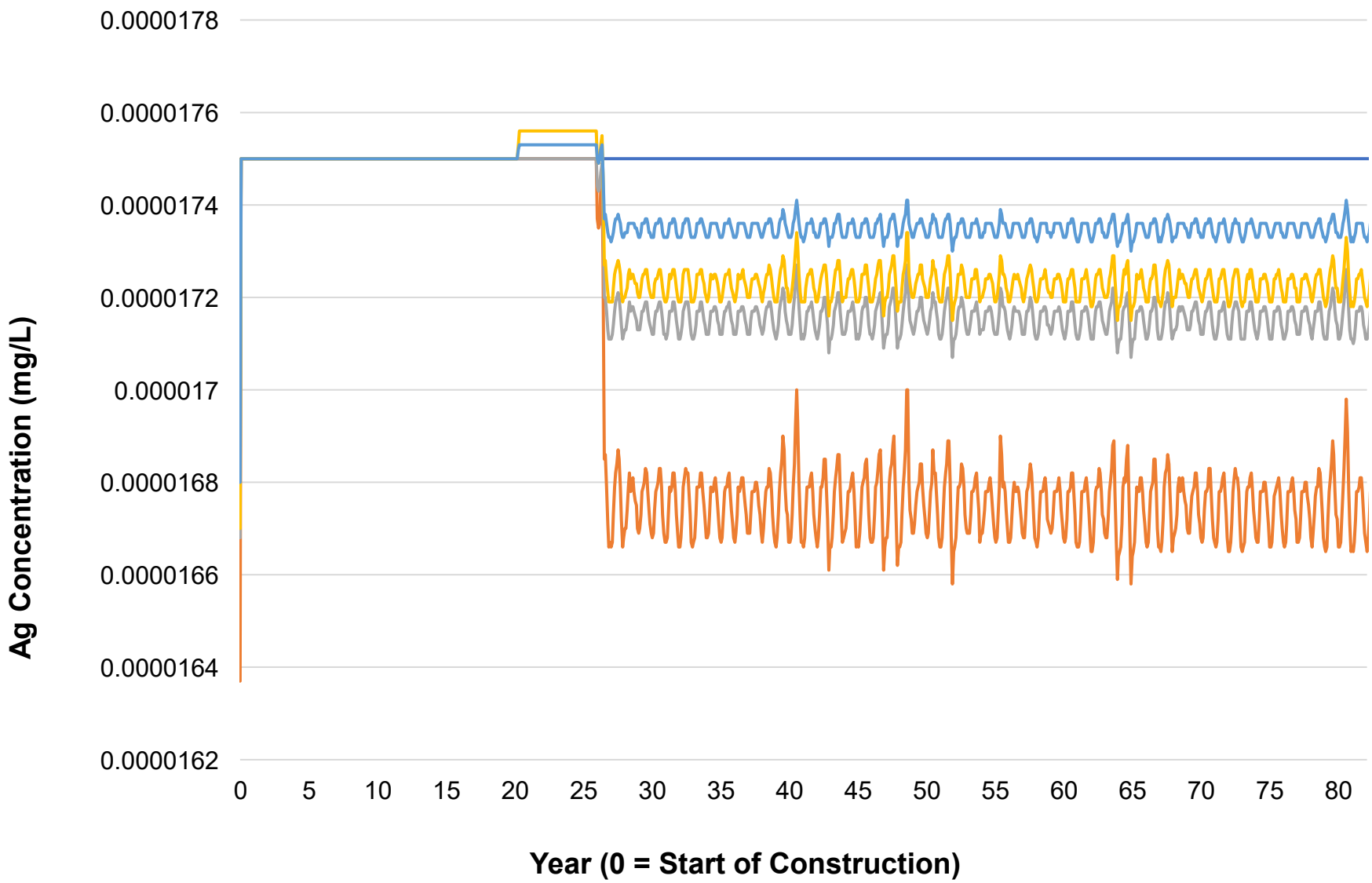
Figure 27 - Mean Monthly Hydrology Model Results



Gold Creek Water Quality Model Results

Mean Monthly Hydrology Model Results

Figure 28 - Mean Monthly Hydrology Model Results



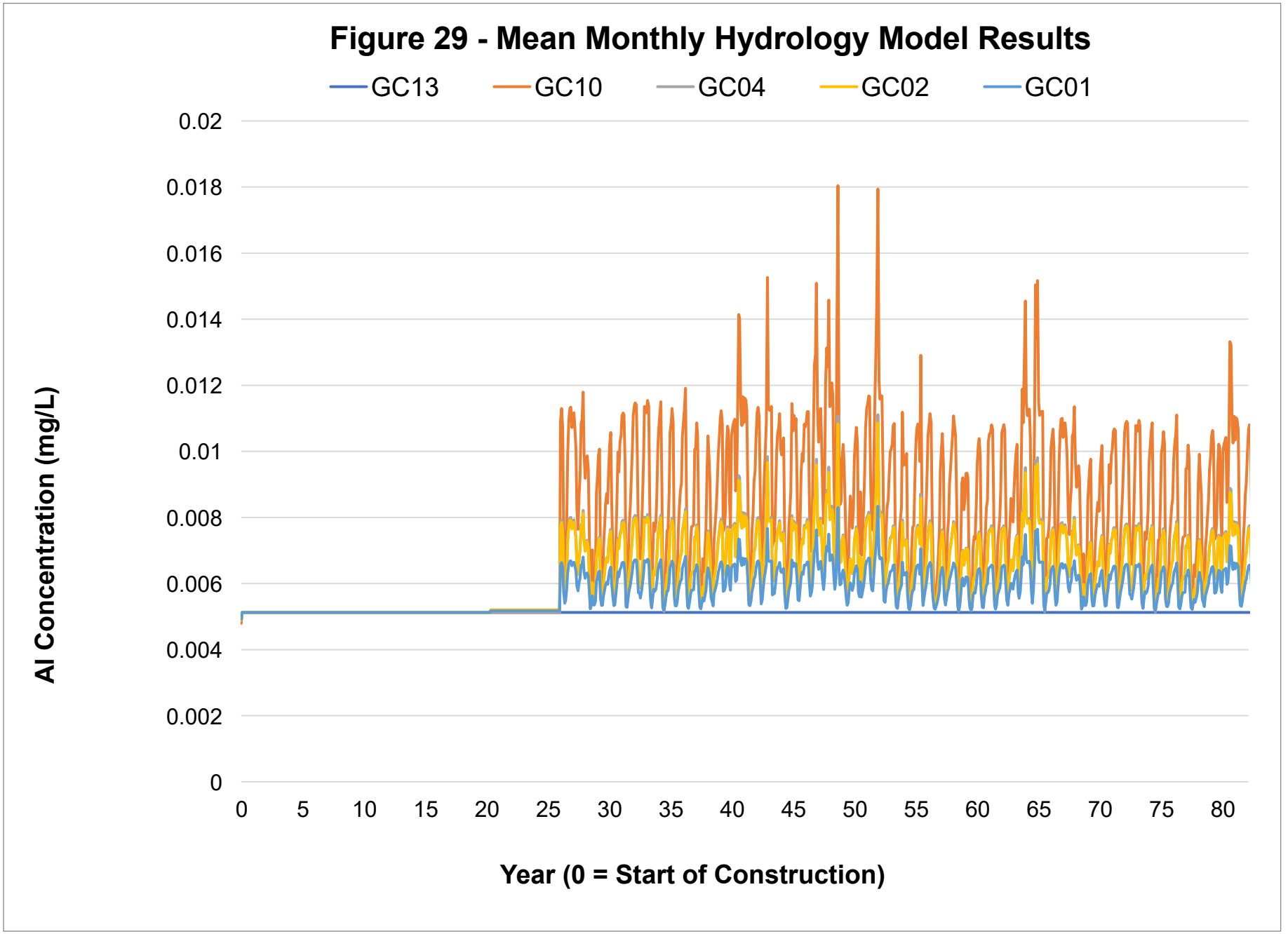


Figure 29 - Mean Monthly Hydrology Model Results
GC13
GC10
GC04
GC02
GC01
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
Al Concentration (mg/L)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
Year (0 = Start of Construction)

Figure 30 - Mean Monthly Hydrology Model Results

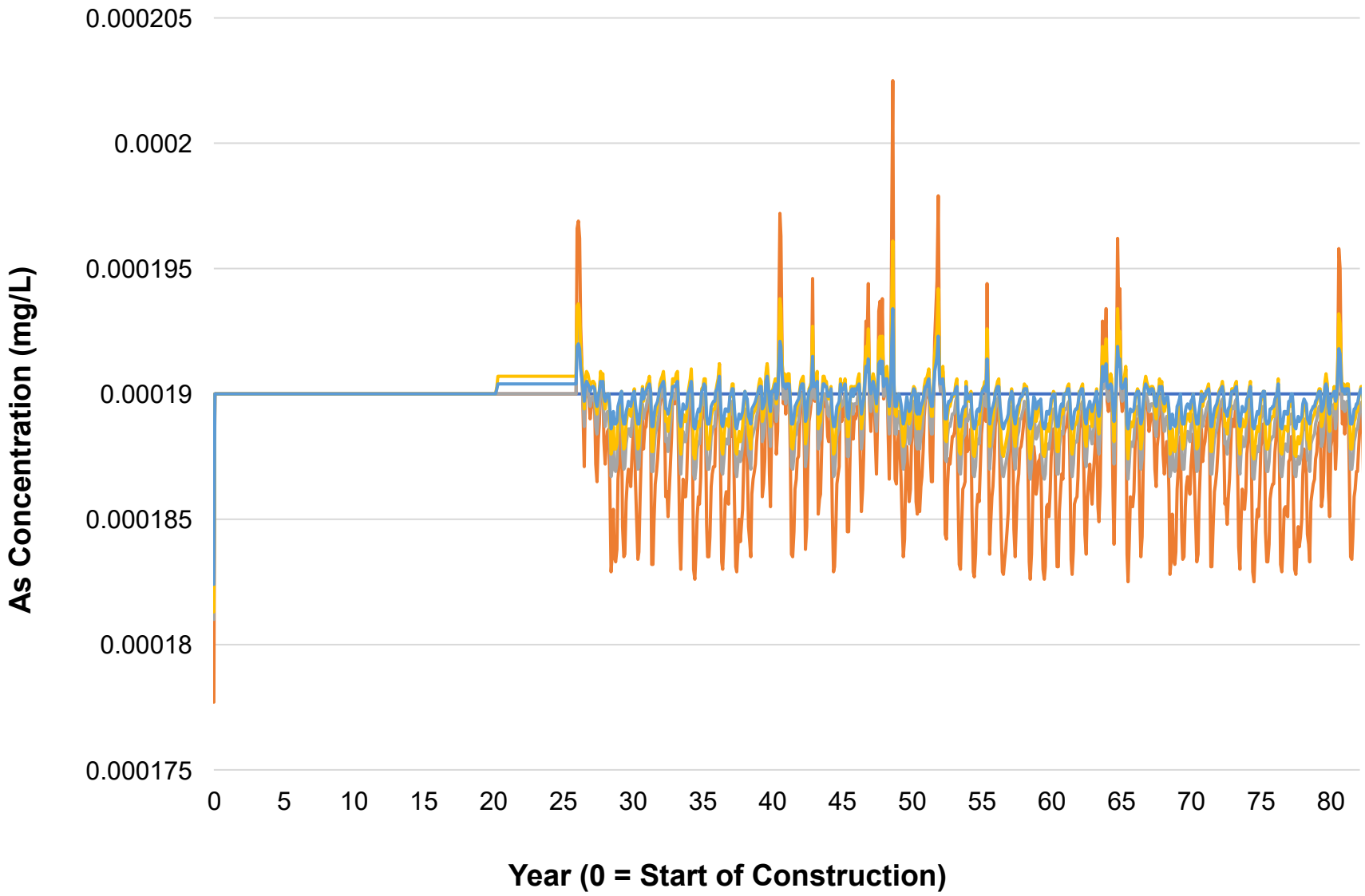


Figure 31 - Mean Monthly Hydrology Model Results

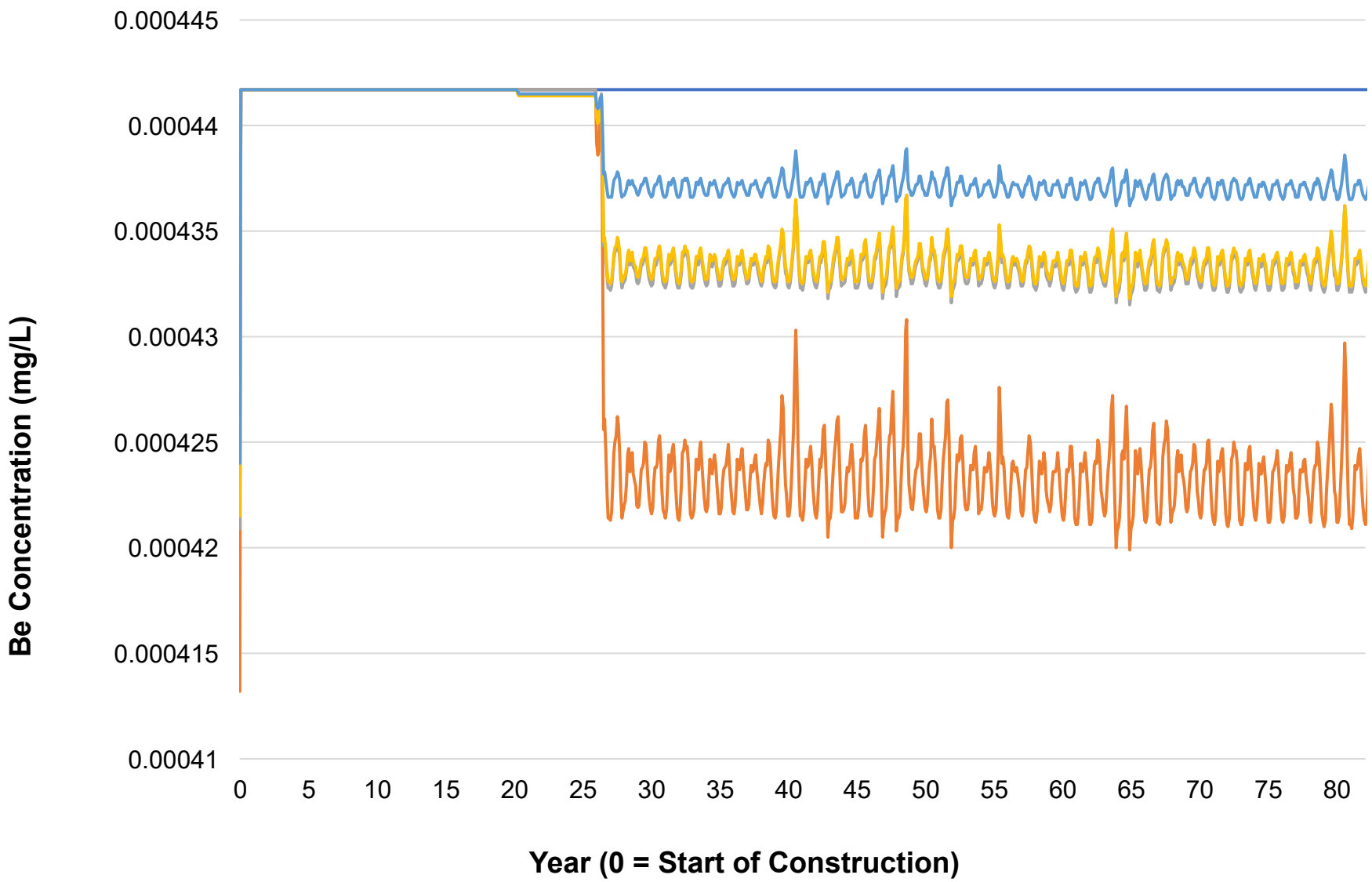


Figure 32 - Mean Monthly Hydrology Model Results

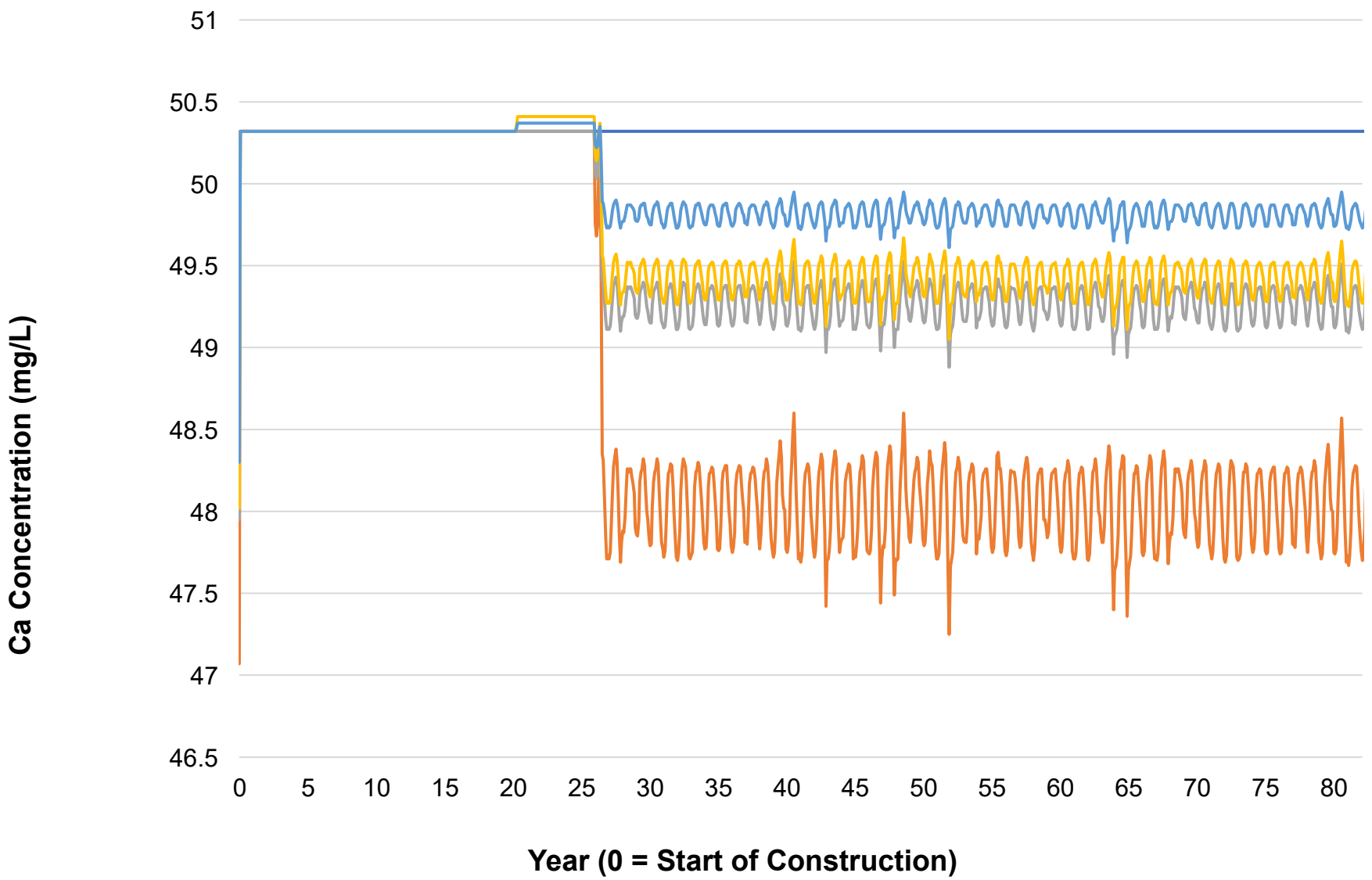
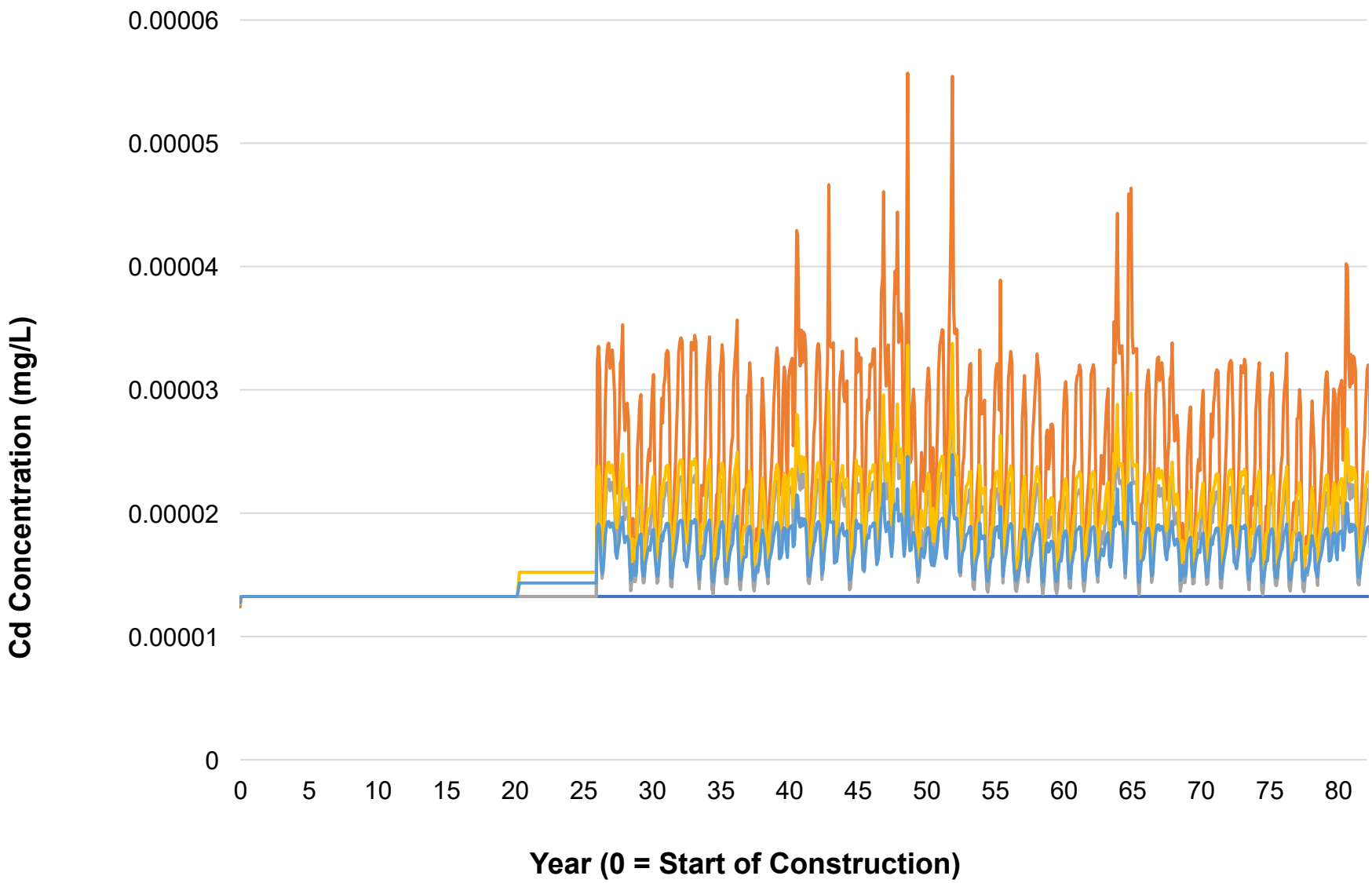


Figure 33 - Mean Monthly Hydrology Model Results



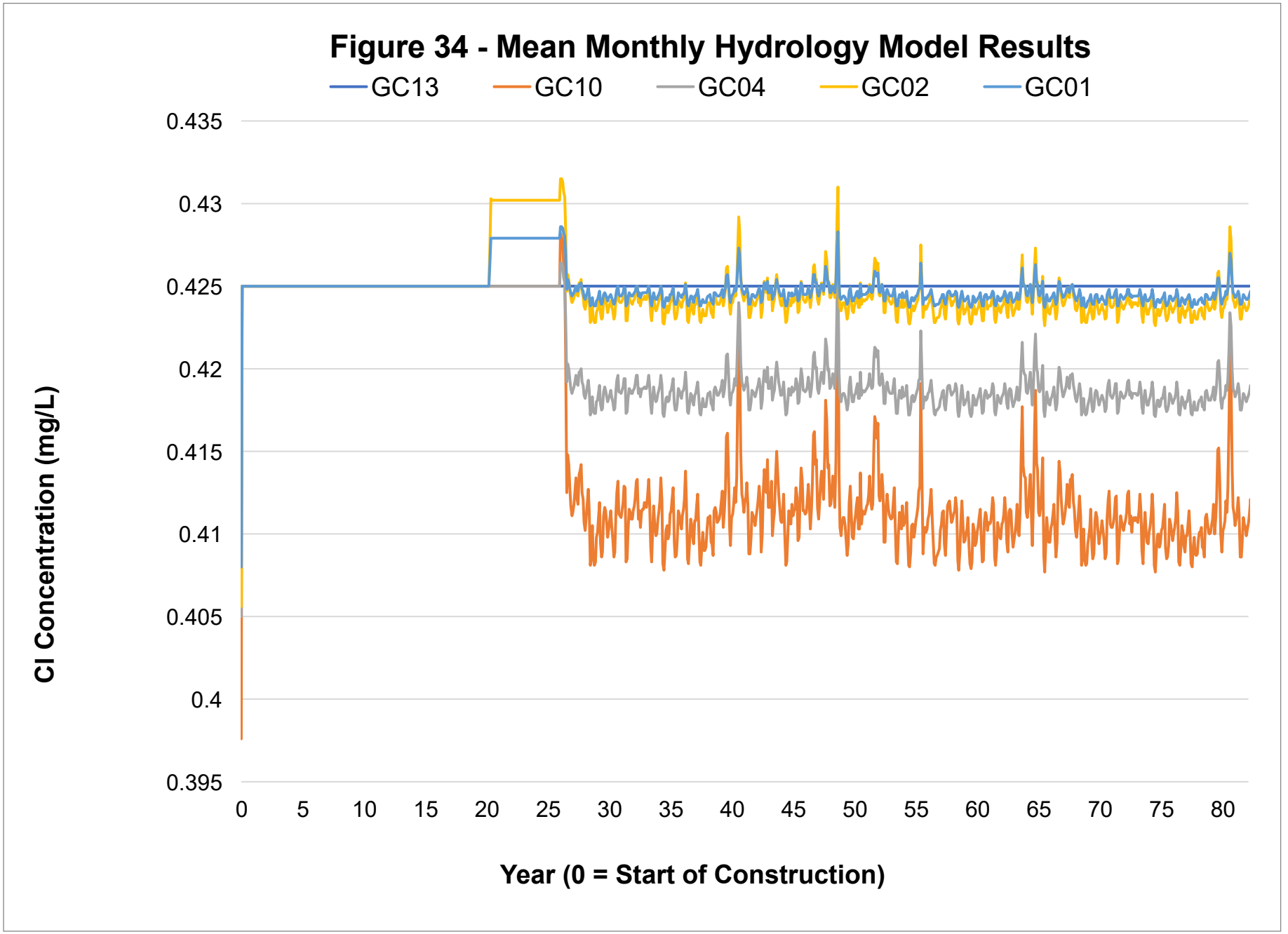


Figure 34 - Mean Monthly Hydrology Model Results
GC13
GC10
GC04
GC02
GC01
0.435
0.43
0.425
0.42
0.415
0.41
0.405
0.4
0.395
Cl Concentration (mg/L)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
Year (0 = Start of Construction)

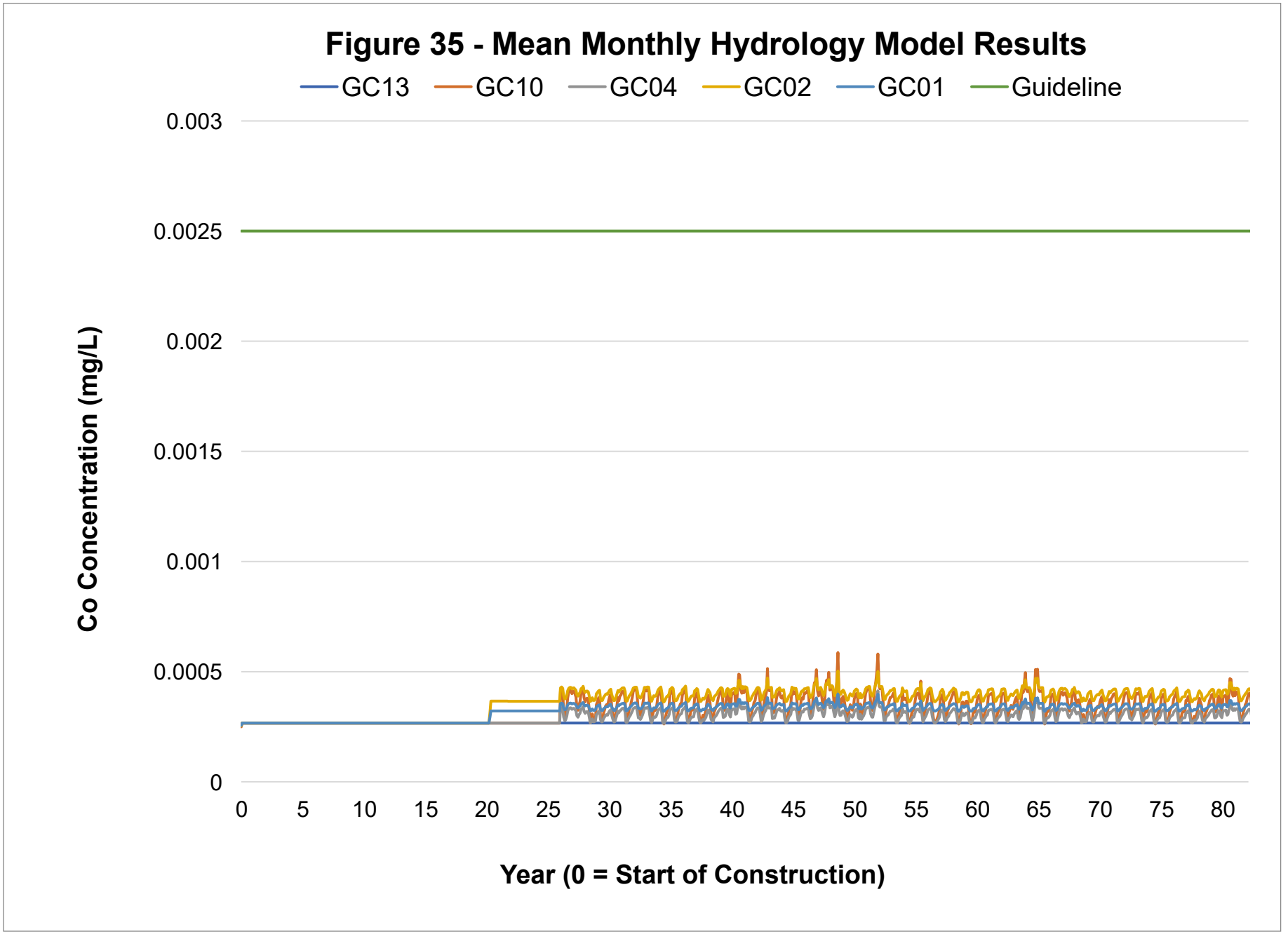


Figure 35 - Mean Monthly Hydrology Model Results
GC13
GC10
GC04
GC02
GC01
Guideline
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Co Concentration (mg/L)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
Year (0 = Start of Construction)

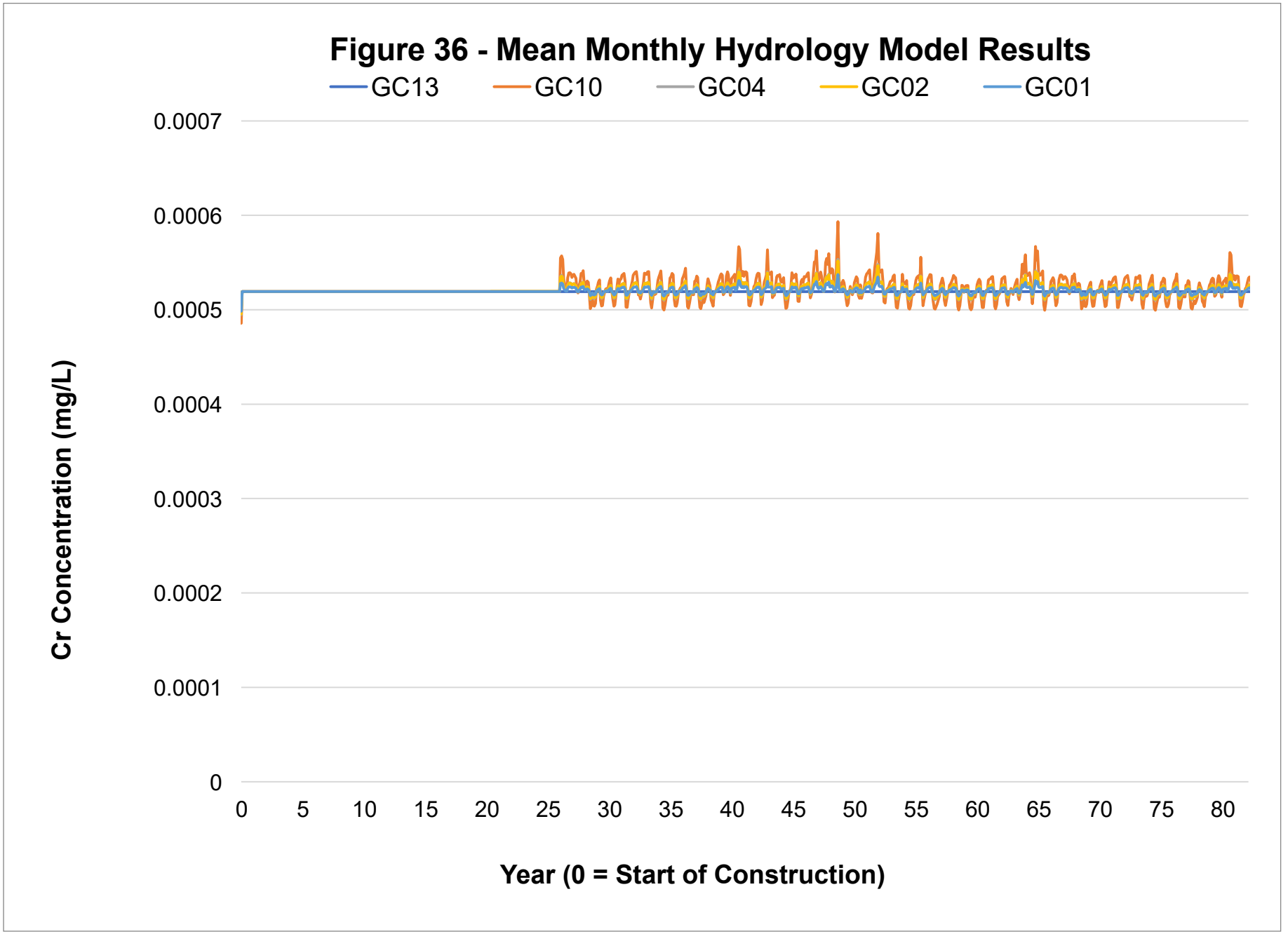


Figure 36 - Mean Monthly Hydrology Model Results
GC13
GC10
GC04
GC02
GC01
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
Cr Concentration (mg/L)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
Year (0 = Start of Construction)

Figure 37 - Mean Monthly Hydrology Model Results

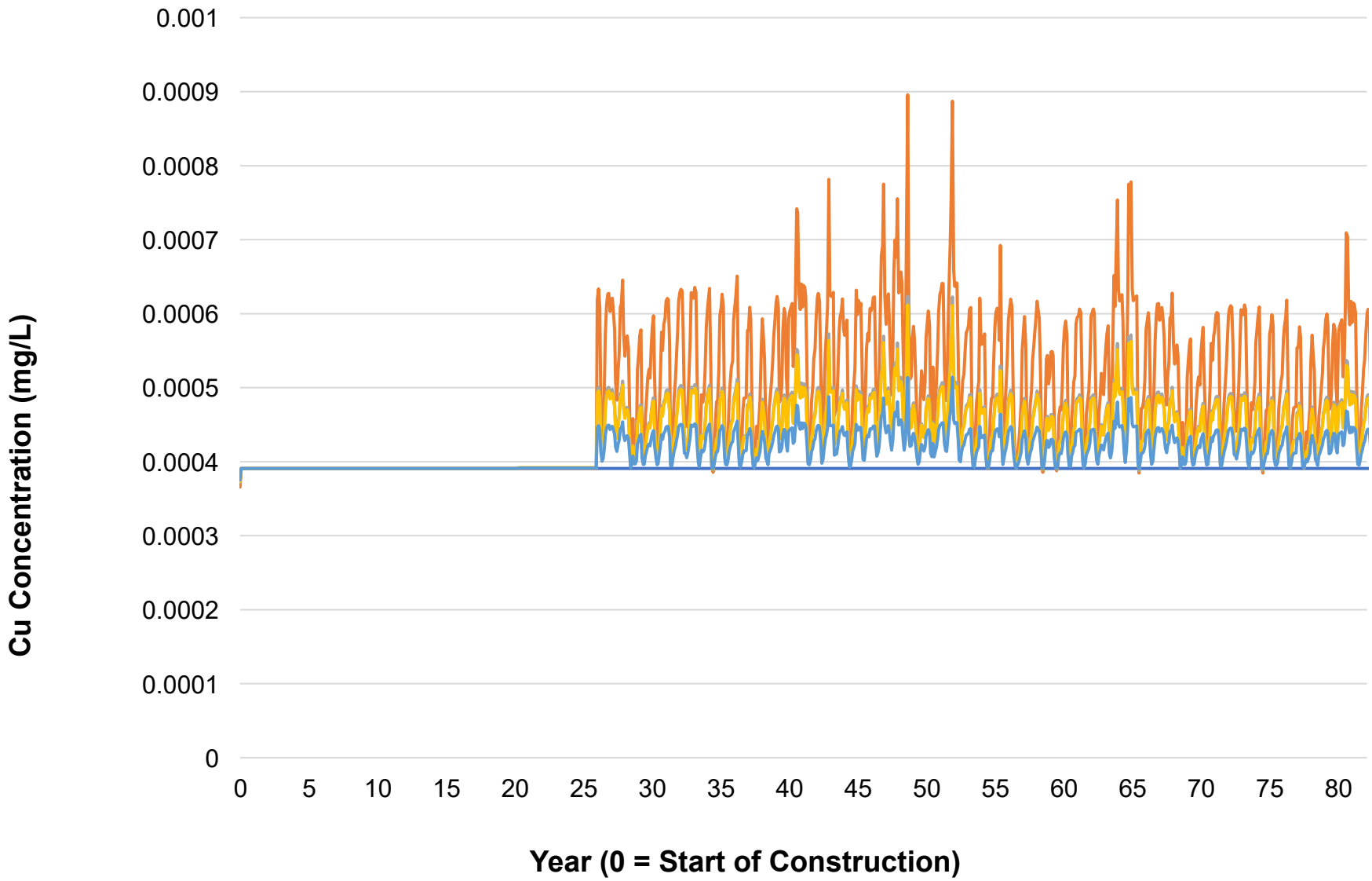
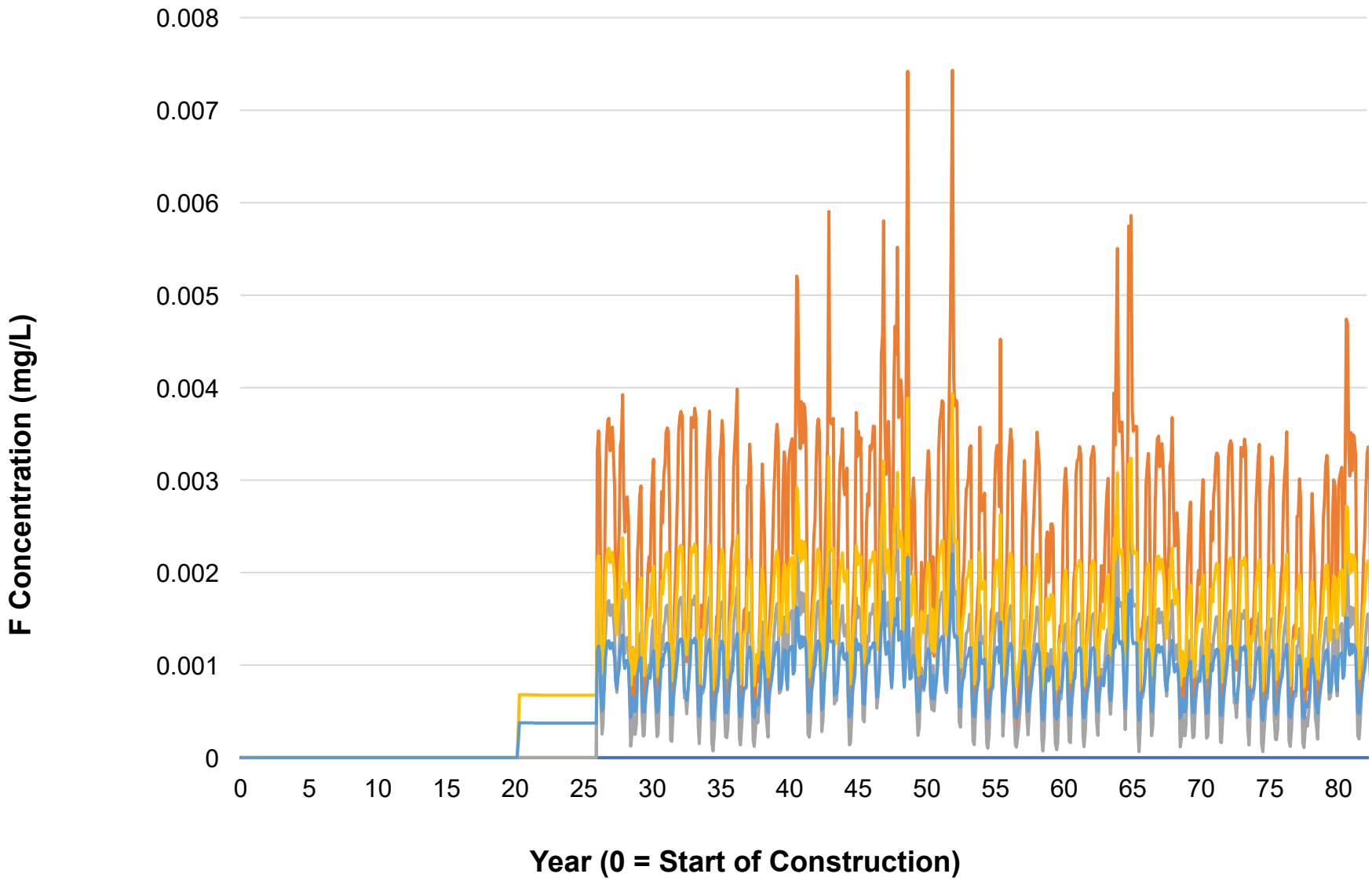


Figure 38 - Mean Monthly Hydrology Model Results



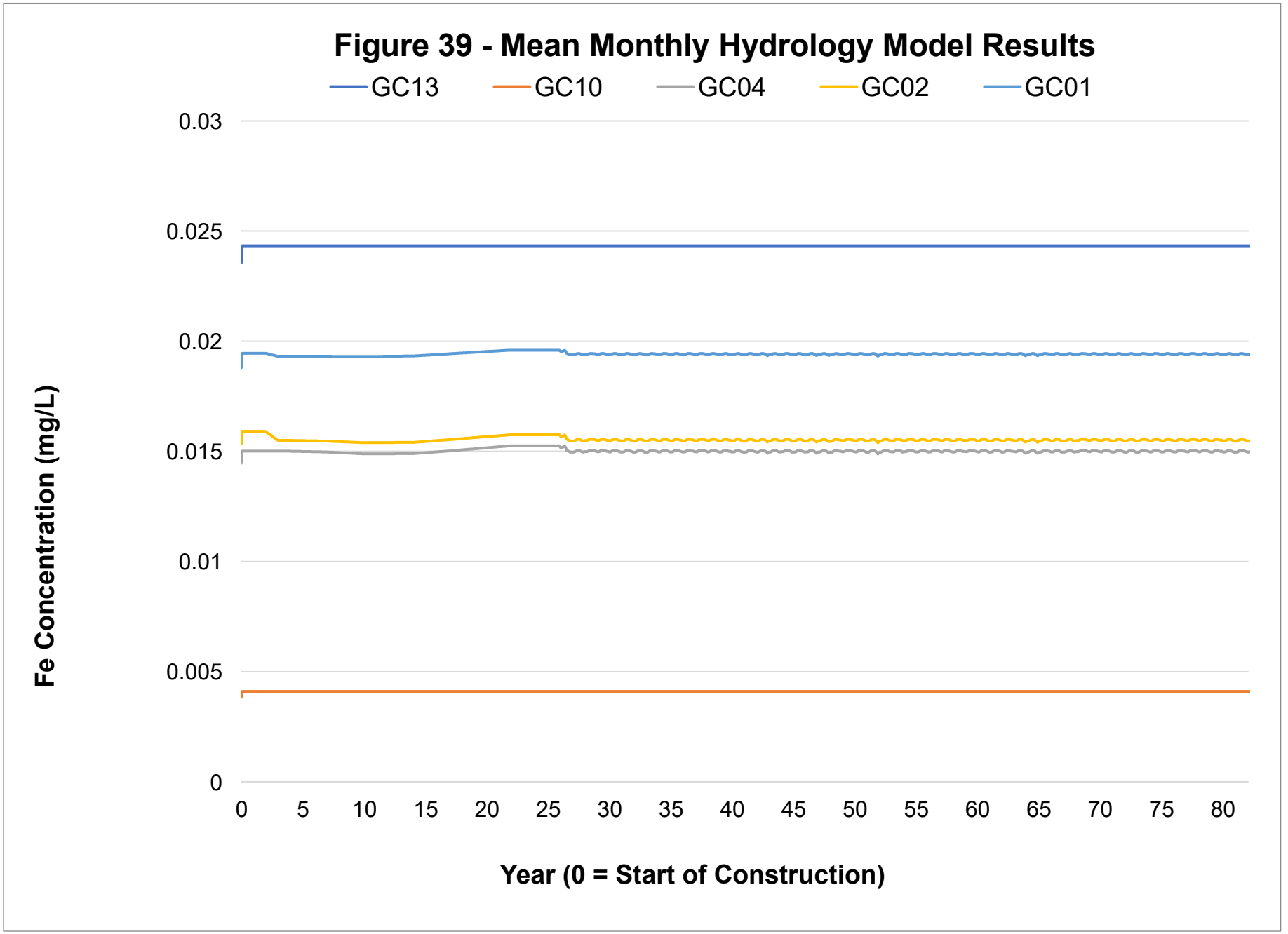


Figure 39 - Mean Monthly Hydrology Model Results
GC13
GC10
GC04
GC02
GC01
0.03
0.025
0.02
0.015
0.01
0.005
0
Fe Concentration (mg/L)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
Year (0 = Start of Construction)

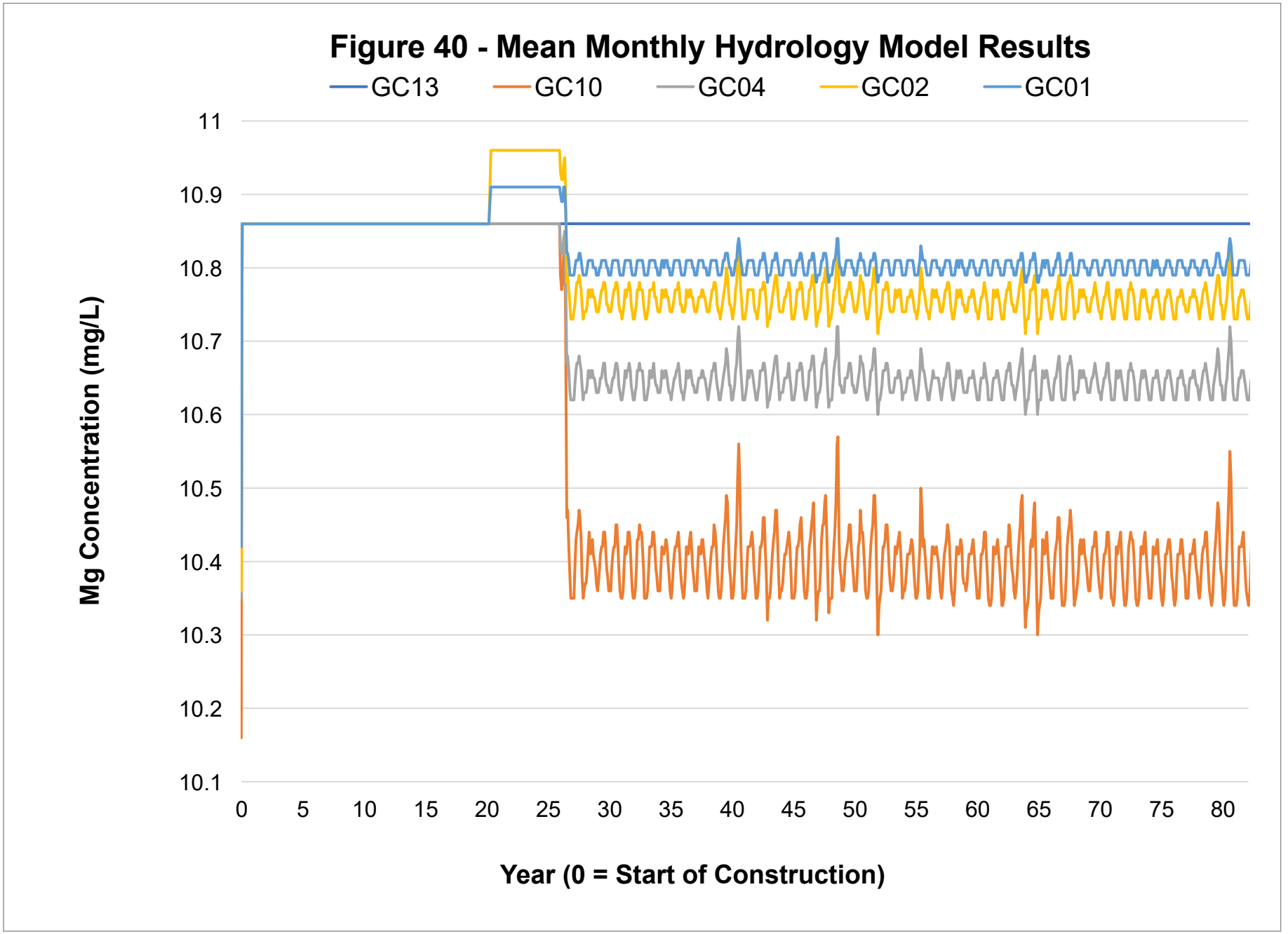


Figure 40 - Mean Monthly Hydrology Model Results
GC13
GC10
GC04
GC02
GC01
11
10.9
10.8
10.7
10.6
10.5
10.4
10.3
10.2
10.1
Mg Concentration (mg/L)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
Year (0 = Start of Construction)

Figure 41 - Mean Monthly Hydrology Model Results

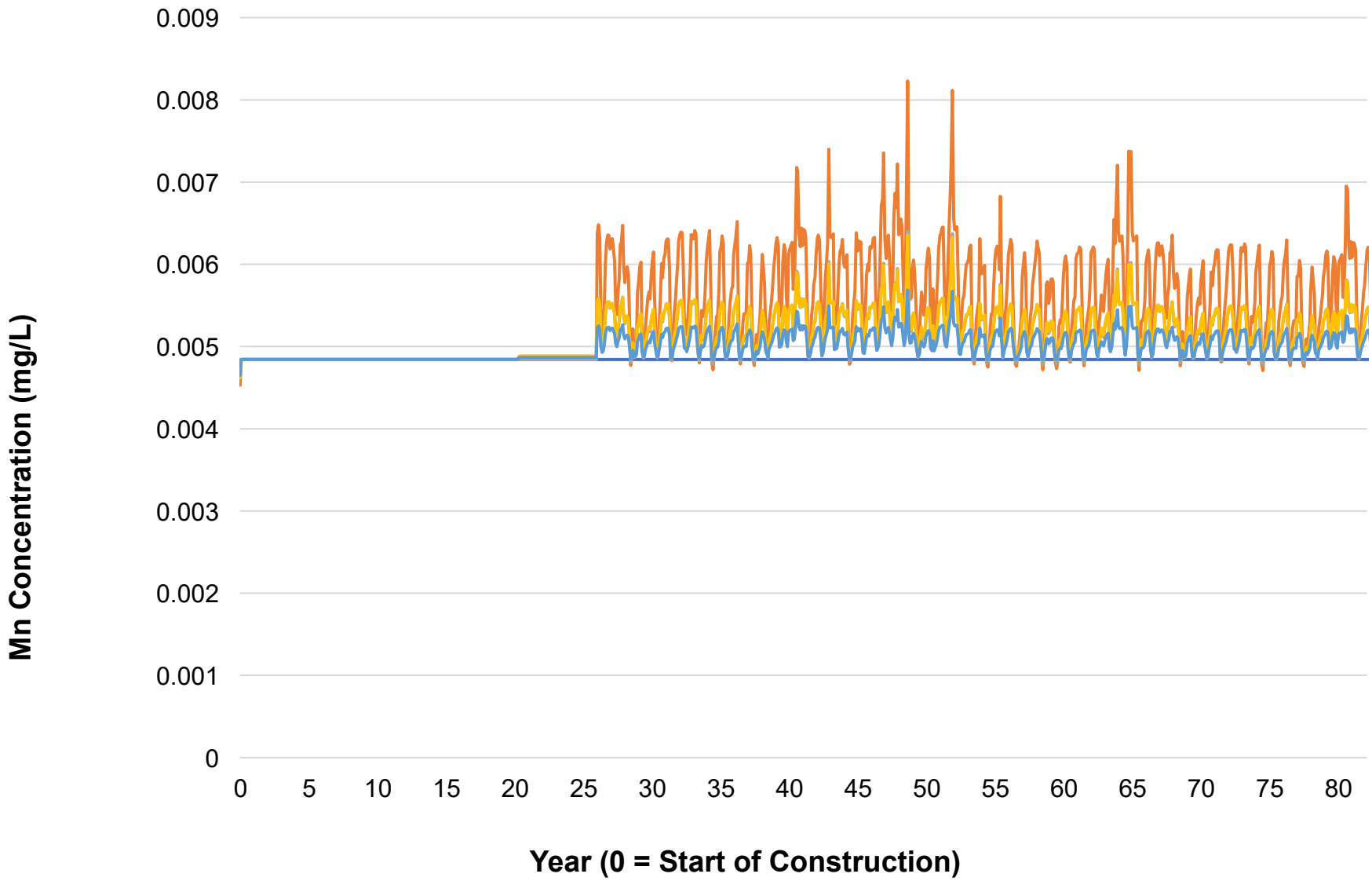


Figure 42 - Mean Monthly Hydrology Model Results

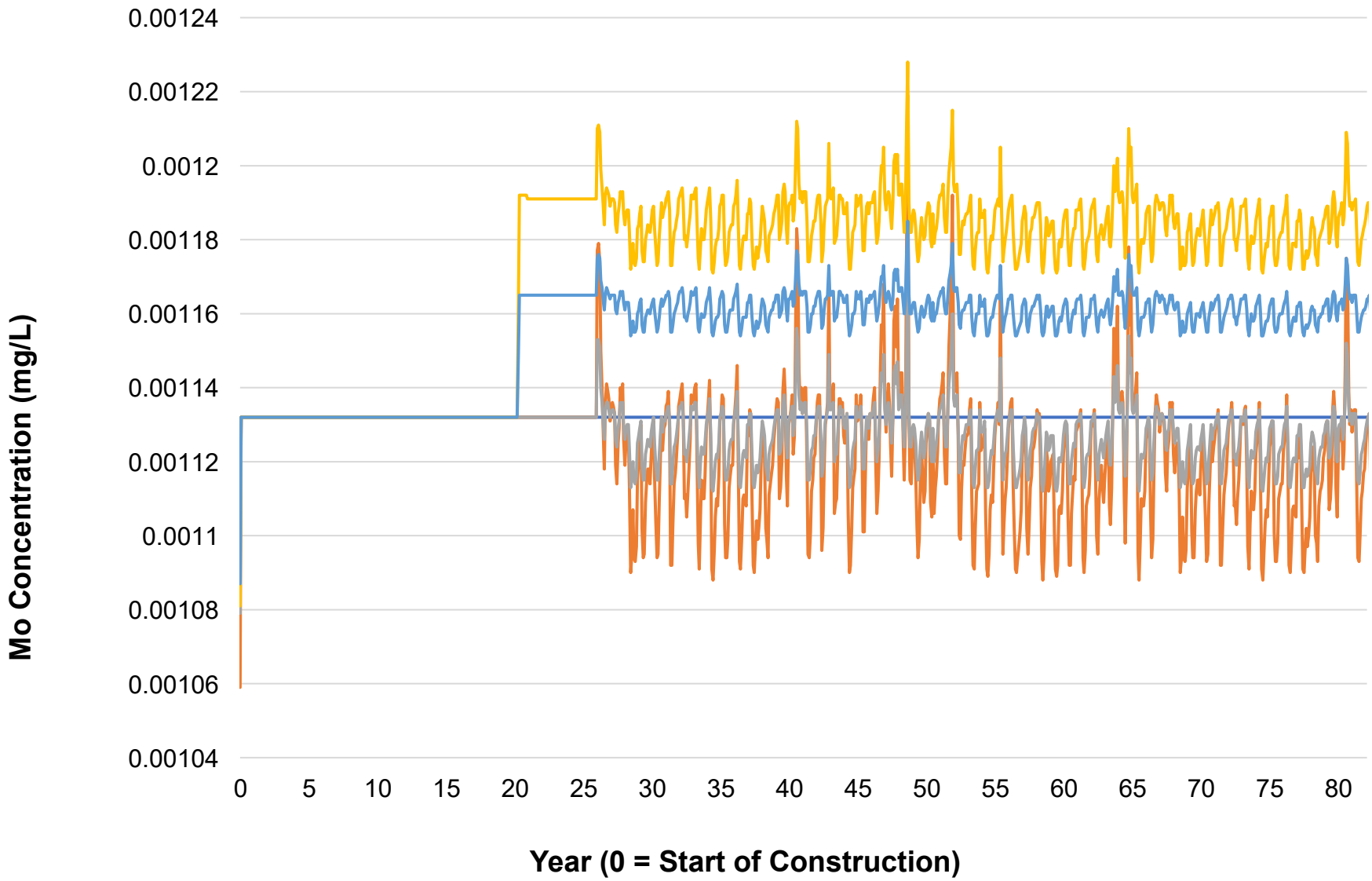


Figure 43 - Mean Monthly Hydrology Model Results

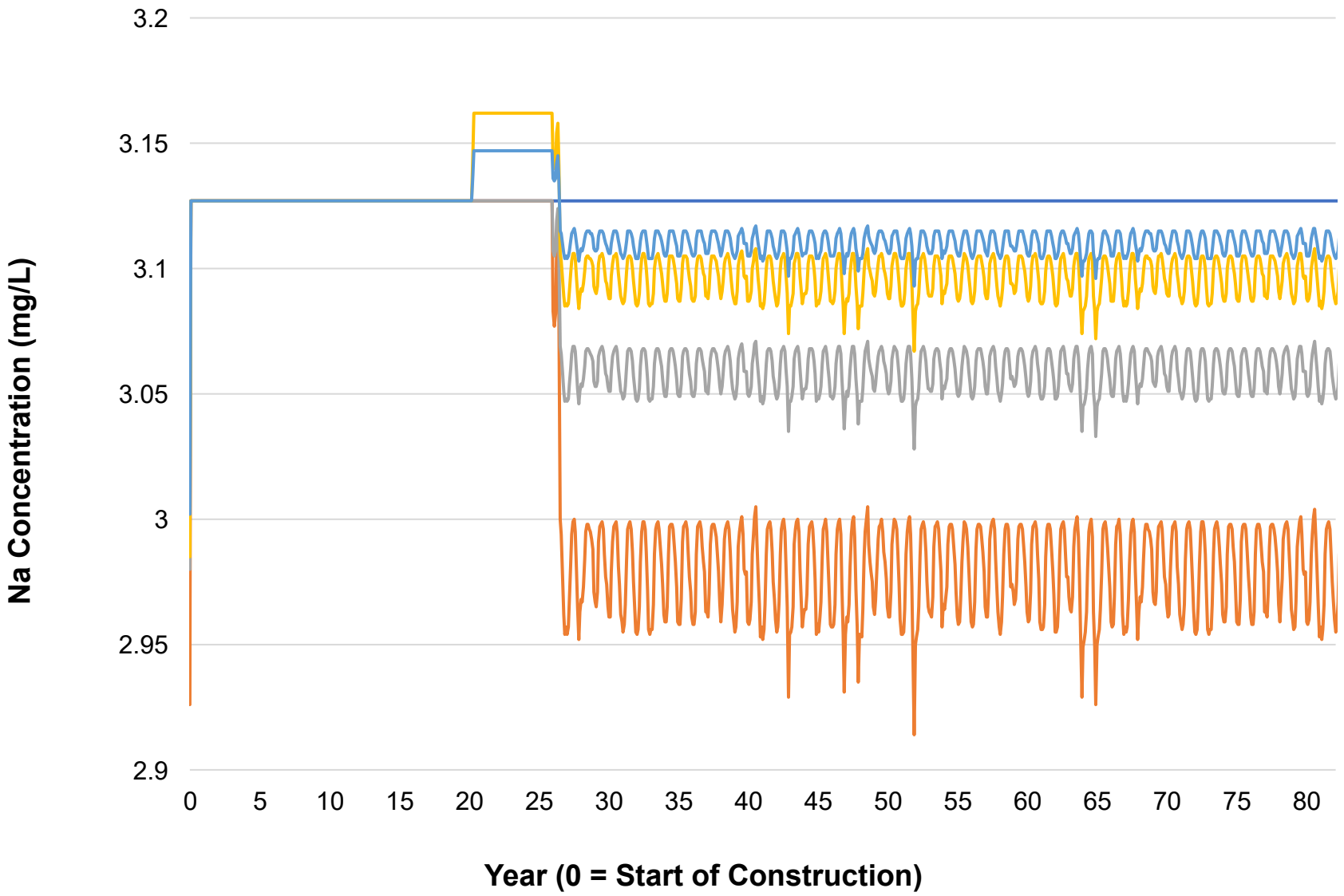


Figure 44 - Mean Monthly Hydrology Model Results

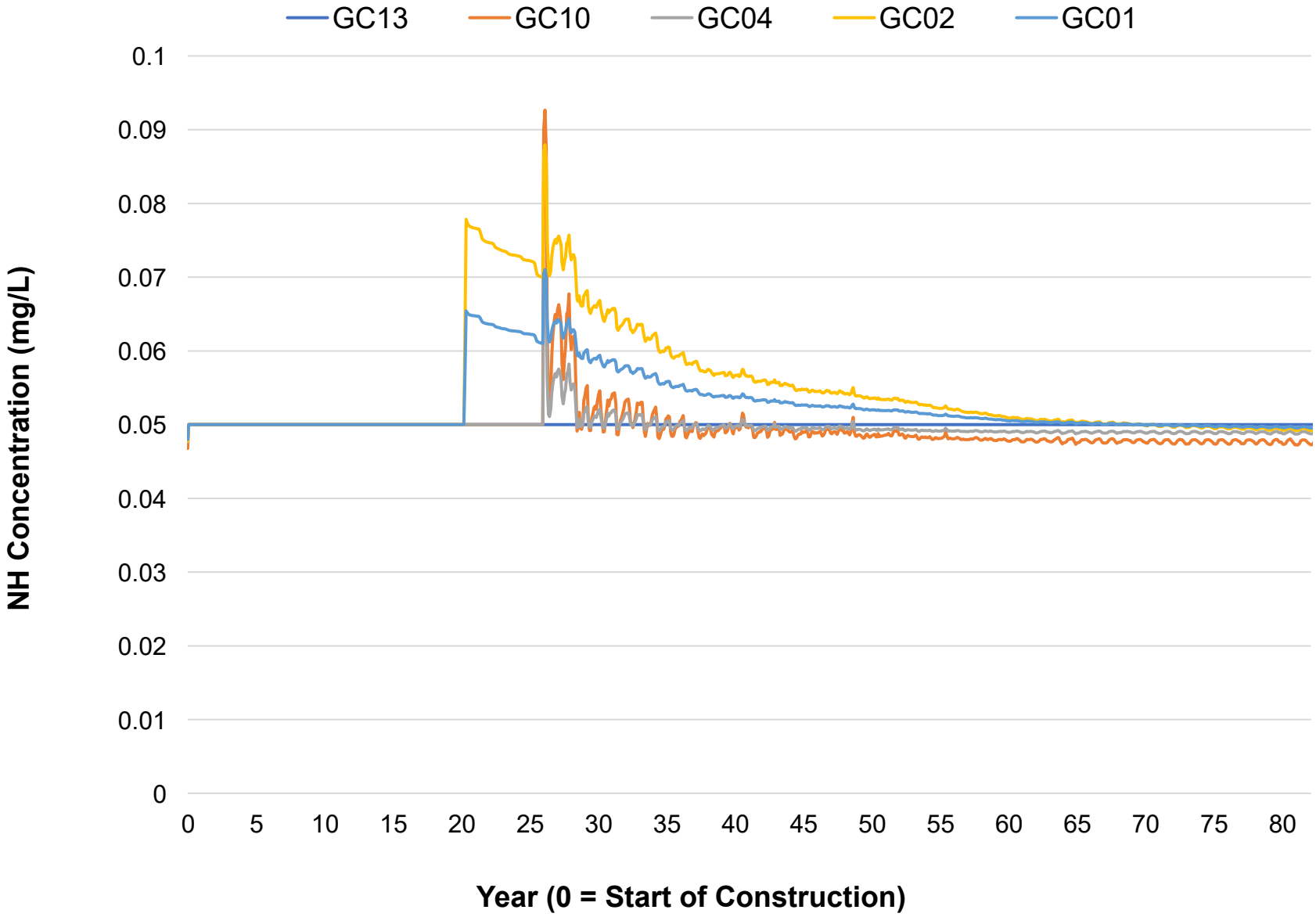
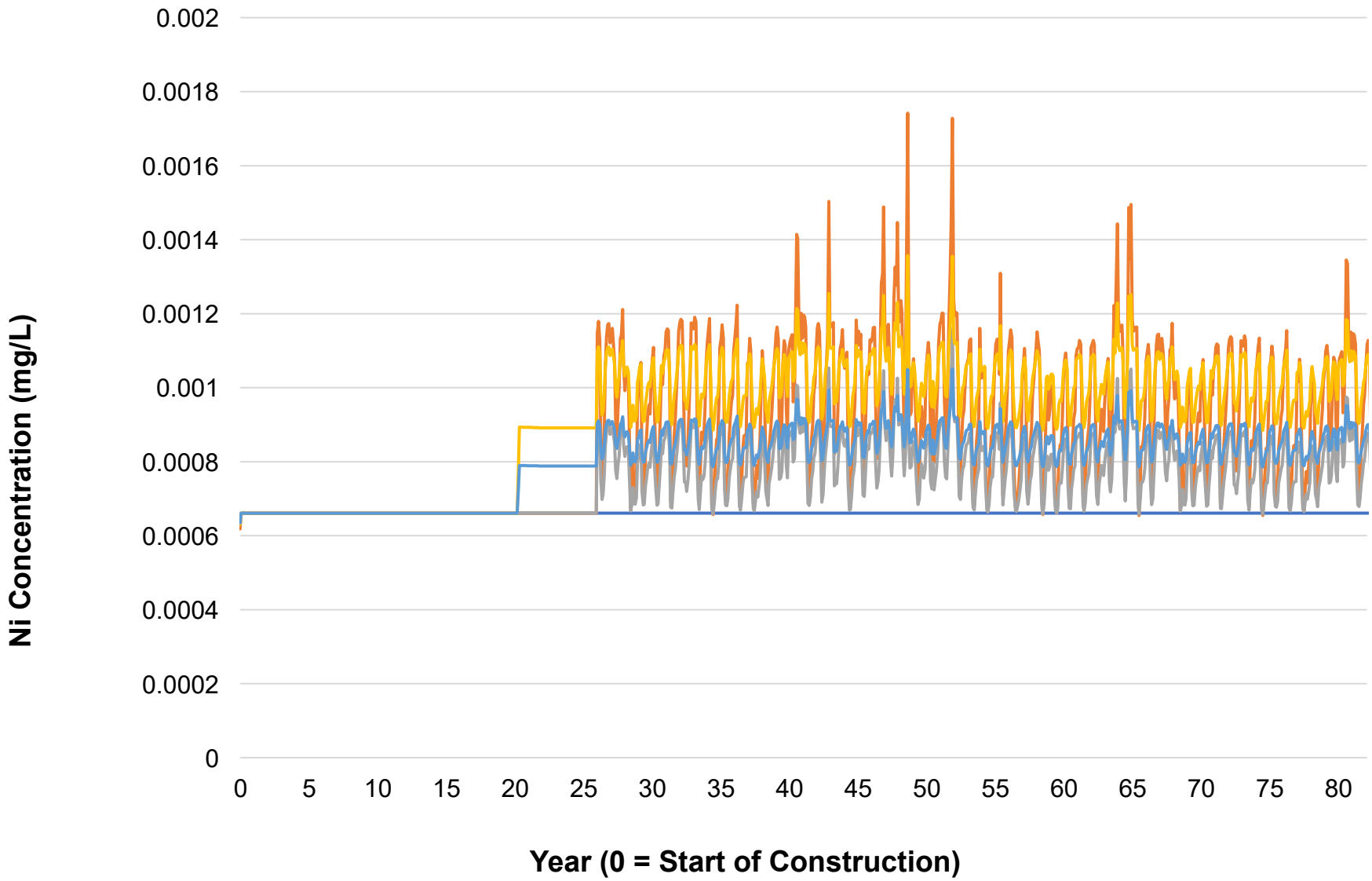


Figure 45 - Mean Monthly Hydrology Model Results



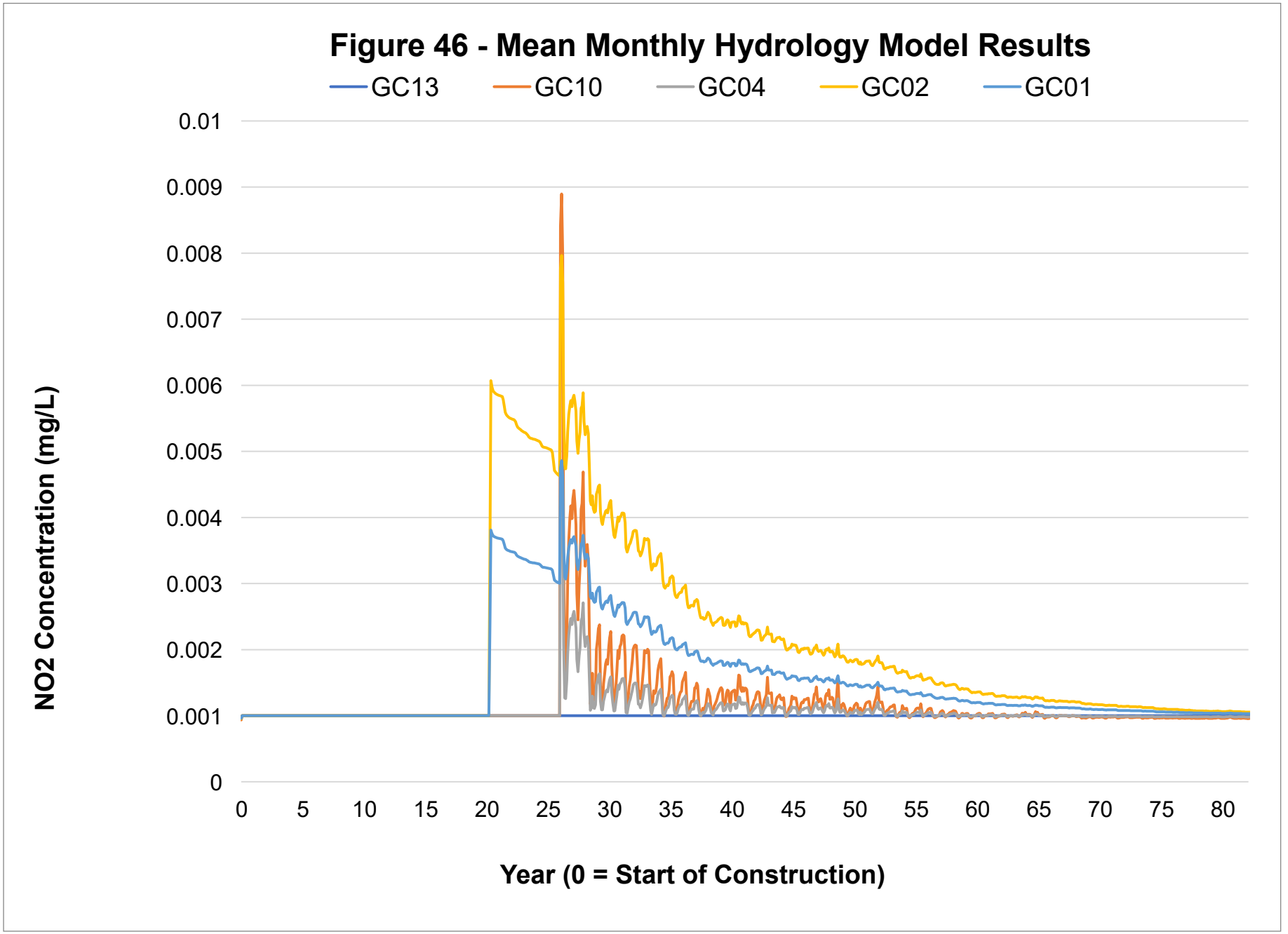


Figure 46 - Mean Monthly Hydrology Model Results
GC13
GC10
GC04
GC02
GC01
NO2 Concentration (mg/L)
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
Year (0 = Start of Construction)

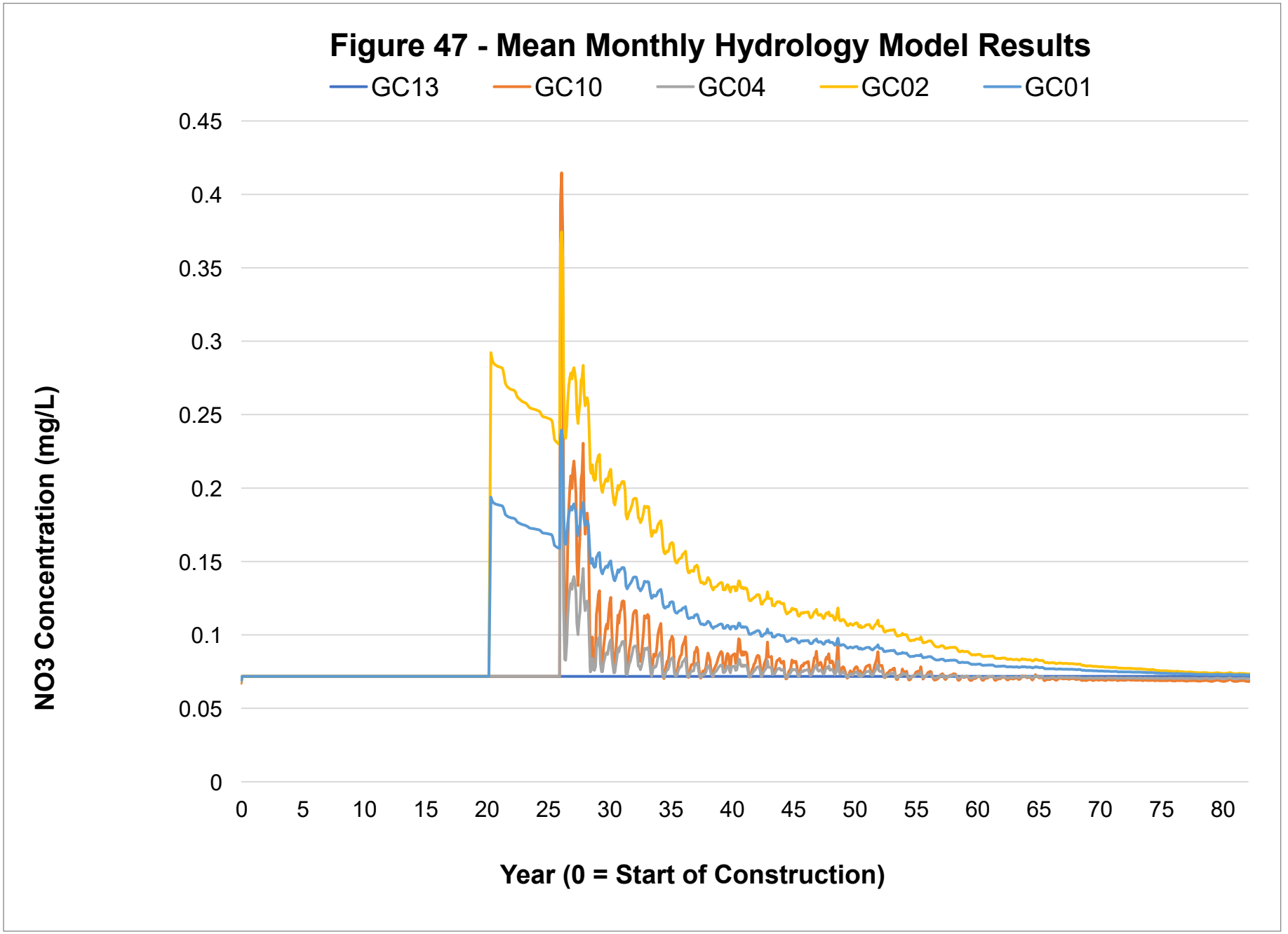


Figure 47 - Mean Monthly Hydrology Model Results
GC13
GC10
GC04
GC02
GC01
NO3 Concentration (mg/L)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
Year (0 = Start of Construction)

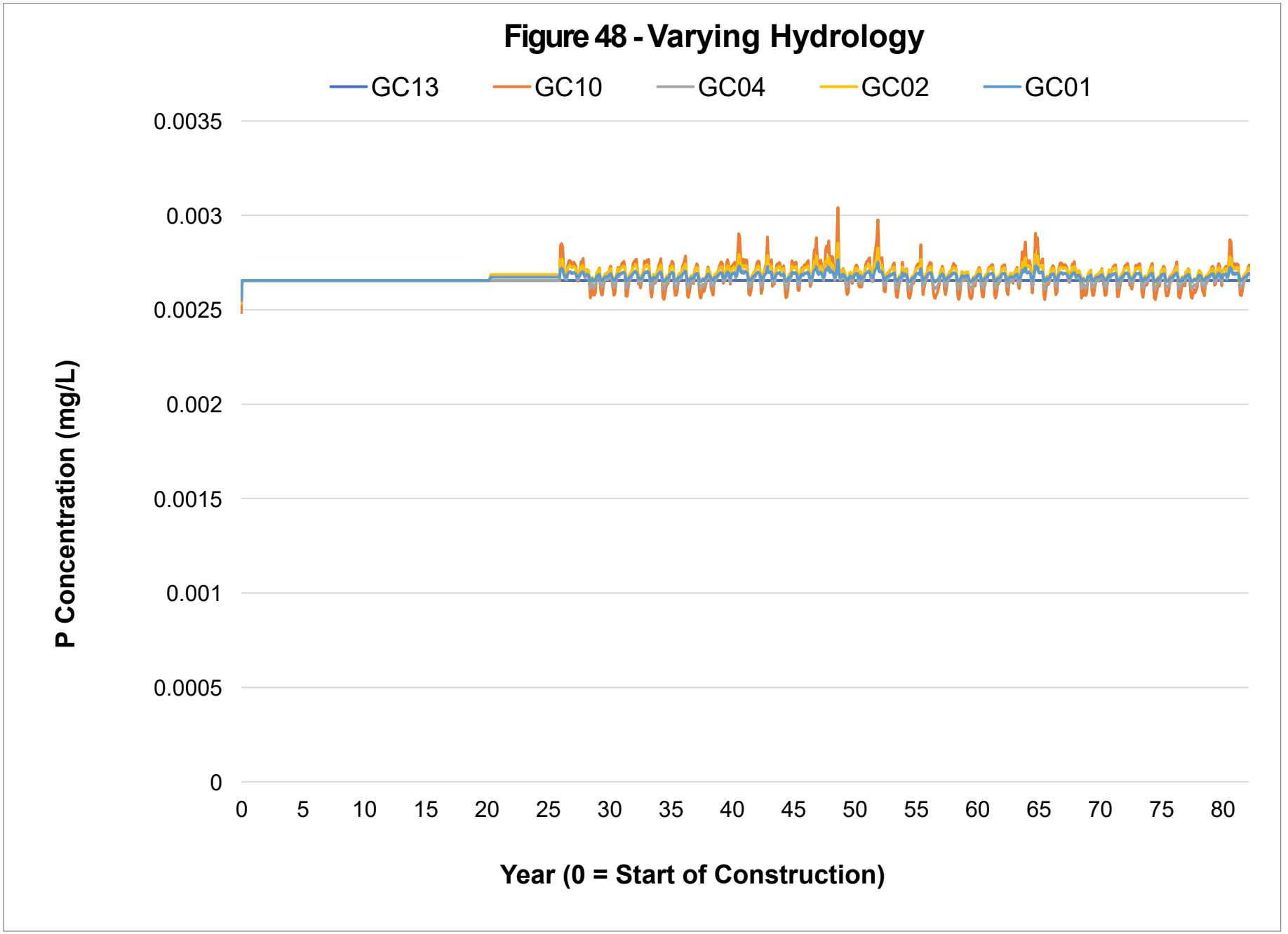
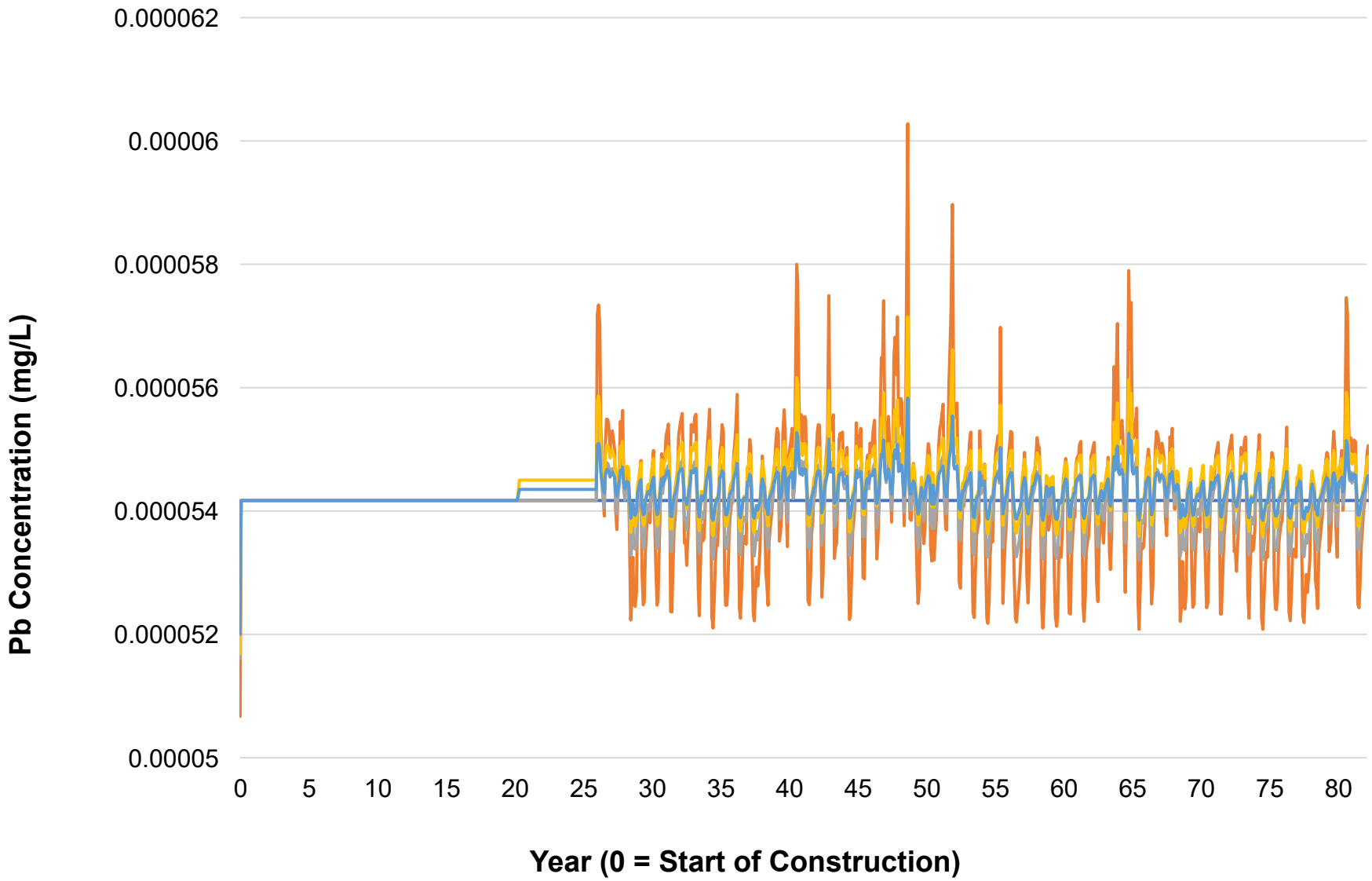


Figure 48 - Varying Hydrology
GC13
GC10
GC04
GC02
GC01
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
P Concentration (mg/L)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
Year (0 = Start of Construction)

Figure 49 - Mean Monthly Hydrology Model Results



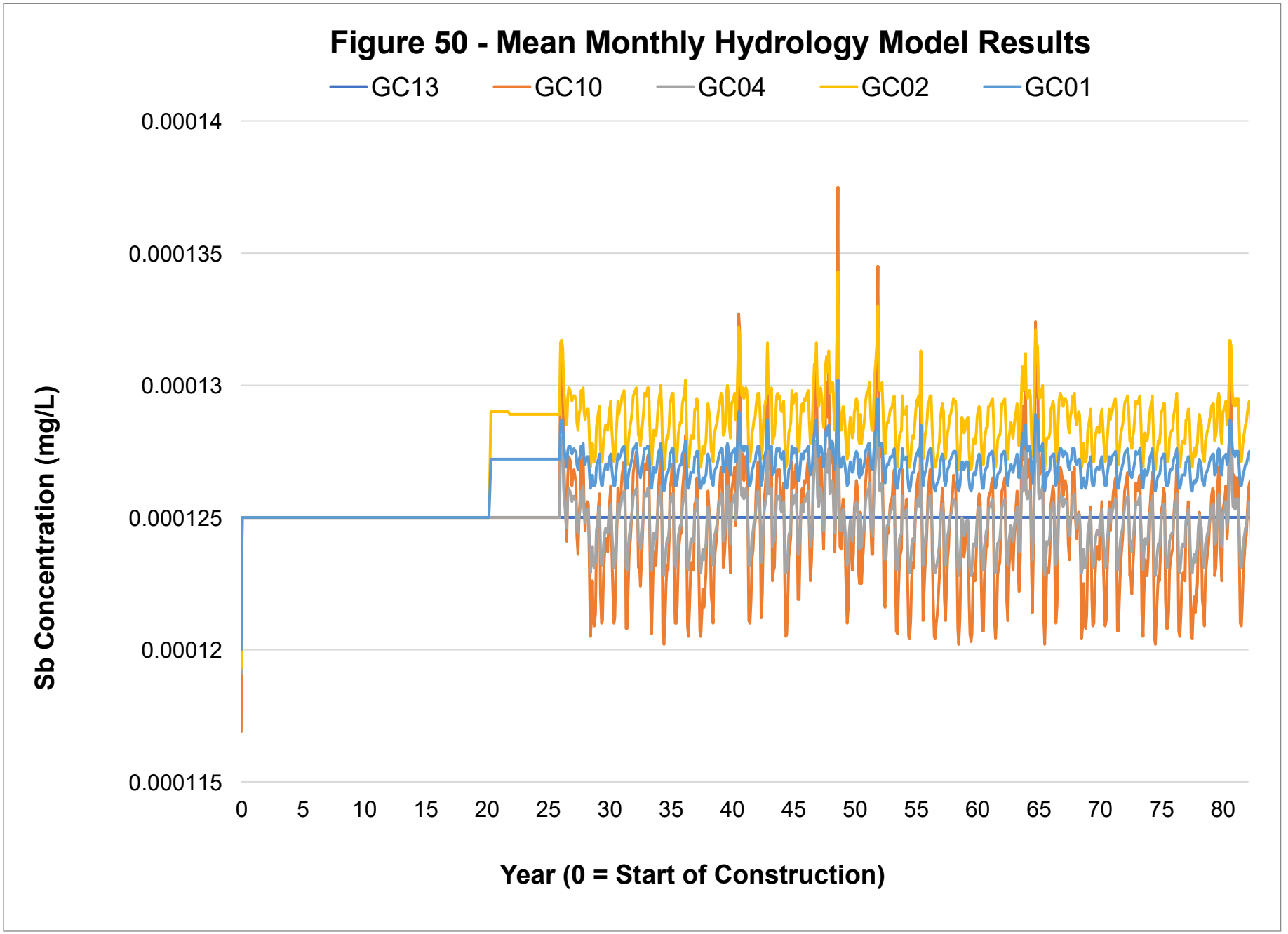


Figure 50 - Mean Monthly Hydrology Model Results
GC13
GC10
GC04
GC02
GC01
0.00014
0.000135
0.00013
0.000125
0.00012
0.000115
Sb Concentration (mg/L)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
Year (0 = Start of Construction)

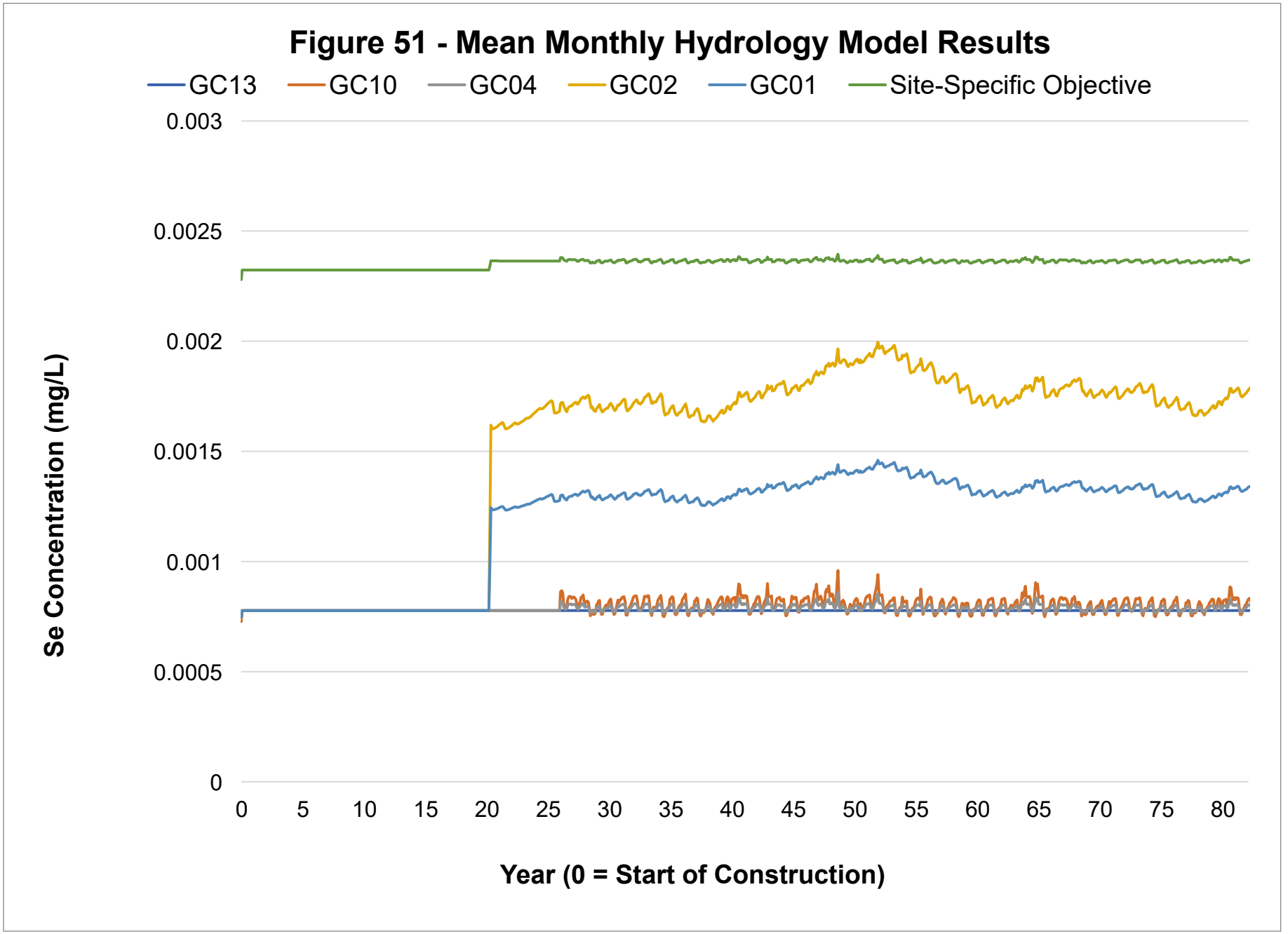


Figure 51 - Mean Monthly Hydrology Model Results
GC13
GC10
GC04
GC02
GC01
Site-Specific Objective
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Se Concentration (mg/L)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
Year (0 = Start of Construction)

Figure 52 - Mean Monthly Hydrology Model Results

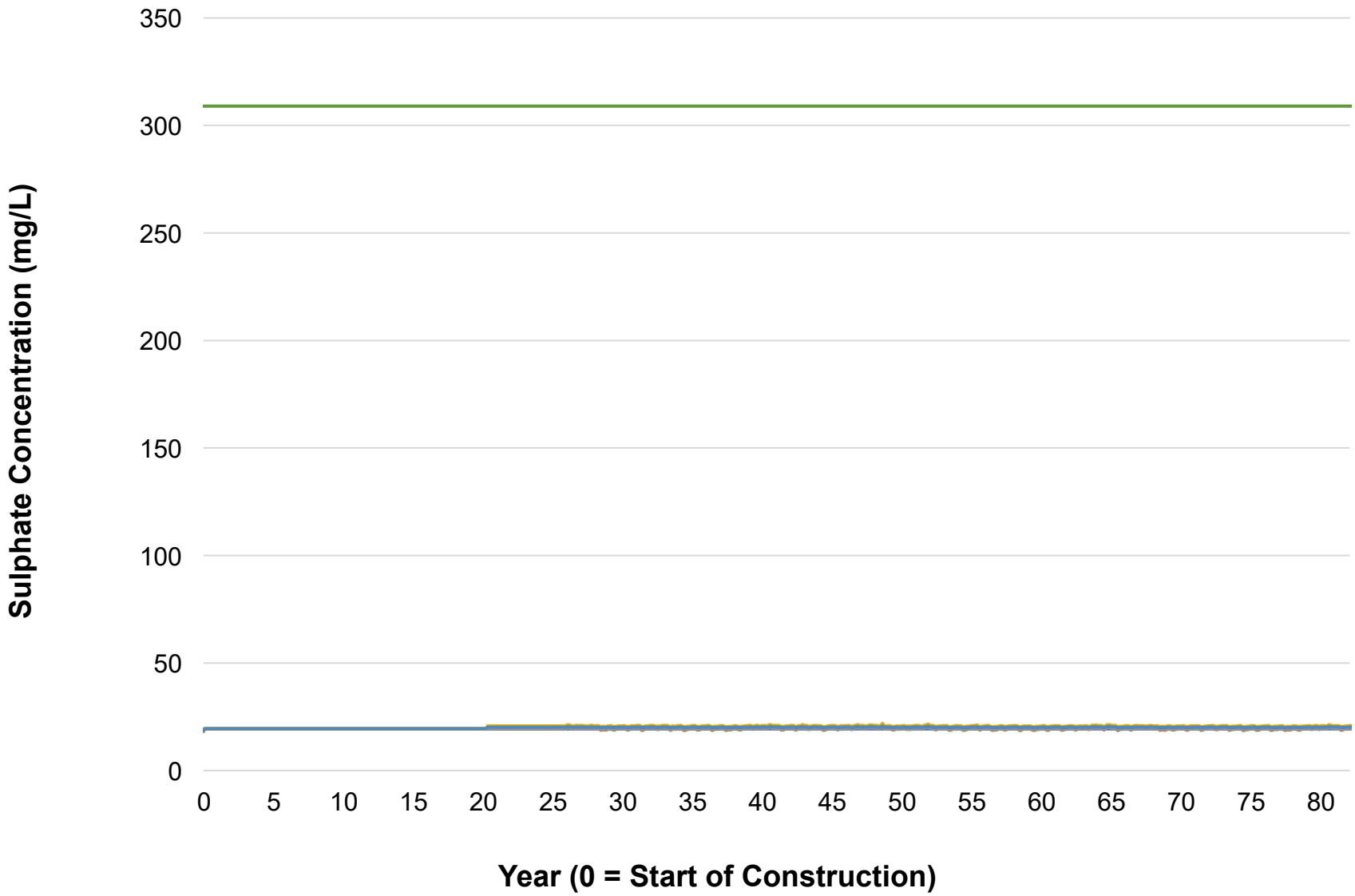


Figure 53 - Mean Monthly Hydrology Model Results

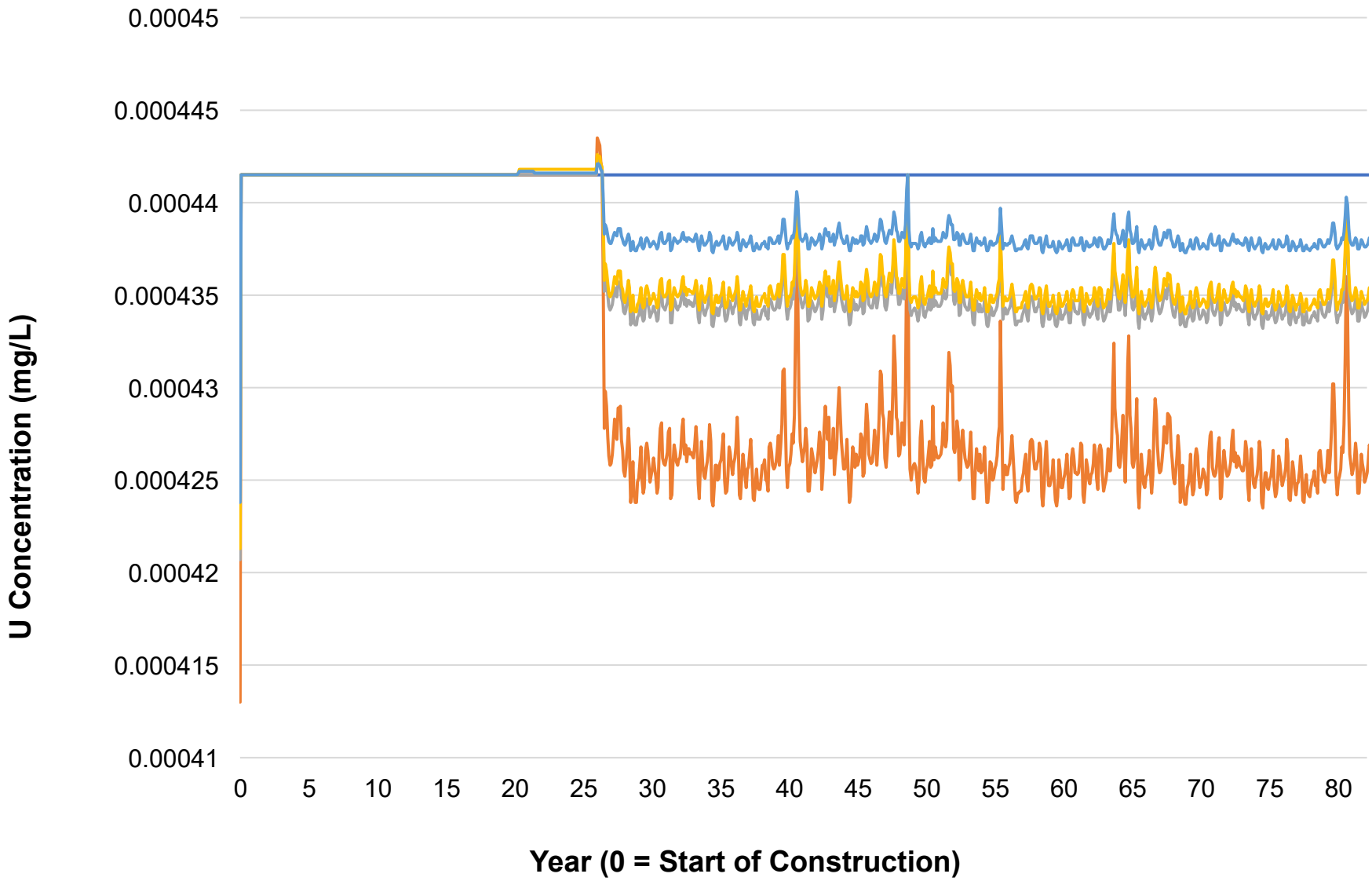
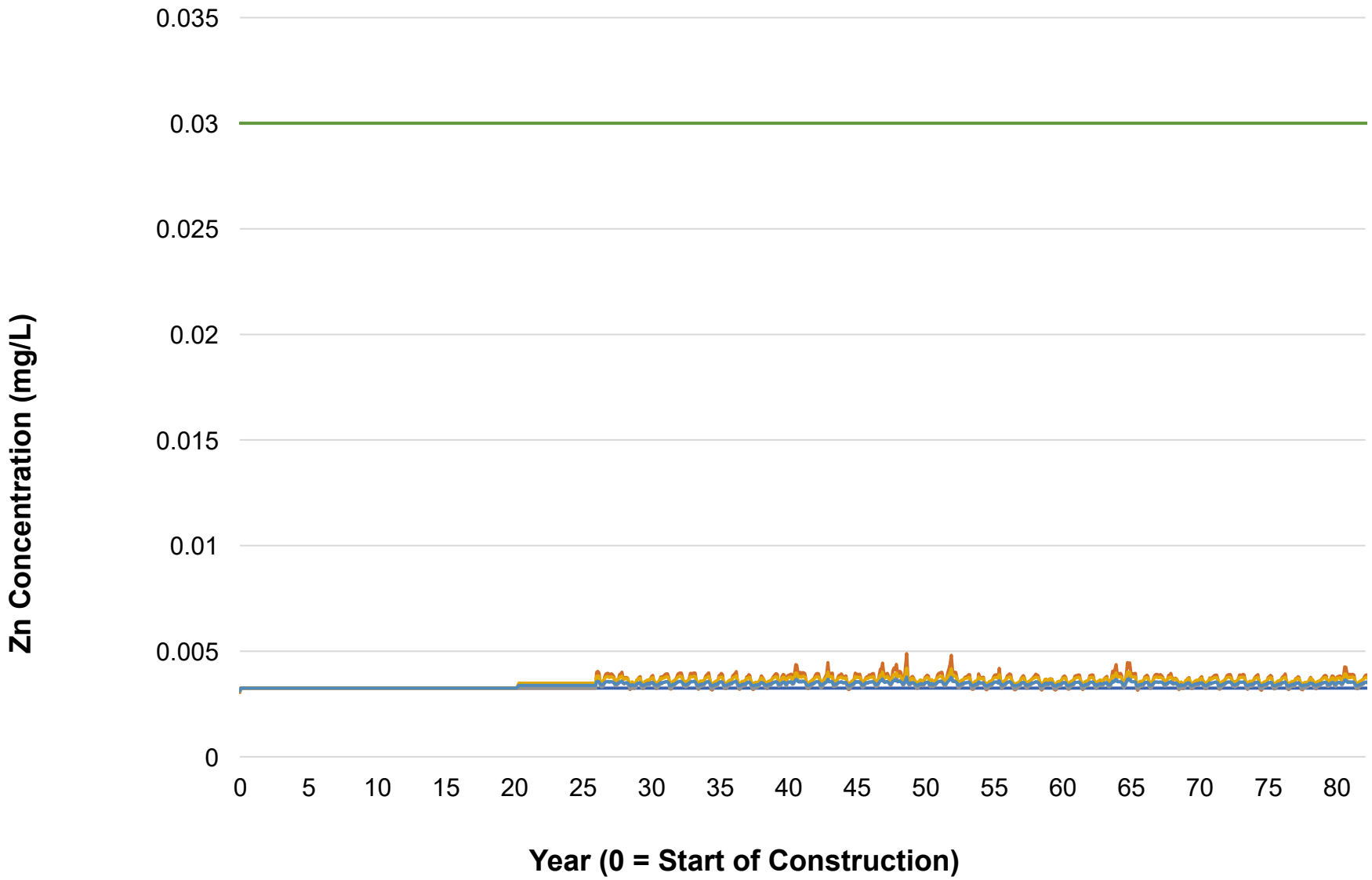


Figure 54 - Mean Monthly Hydrology Model Results



APPENDIX 6.25-2: WATER QUALITY MODEL RESULTS: ACIDIC PIT WALLS

Appendix 6.25-2 Water Quality Model Results

Concentration of Co, Se, SO4 and Z for 100% Acidic Pit Wall Sensitivity

Figure 1 - 100% Acidic Pit Walls

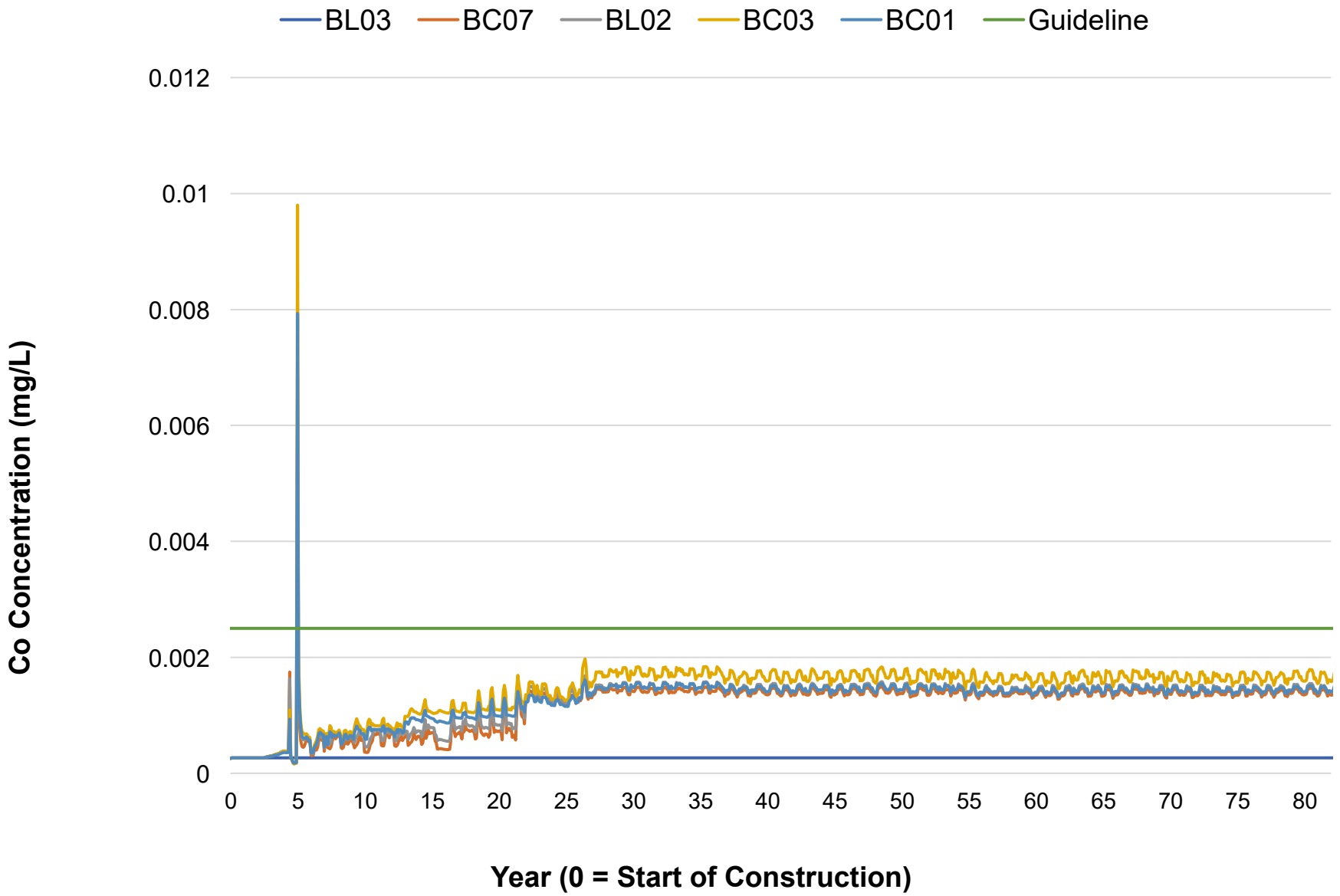


Figure 2 - 100% Acidic Pit Walls

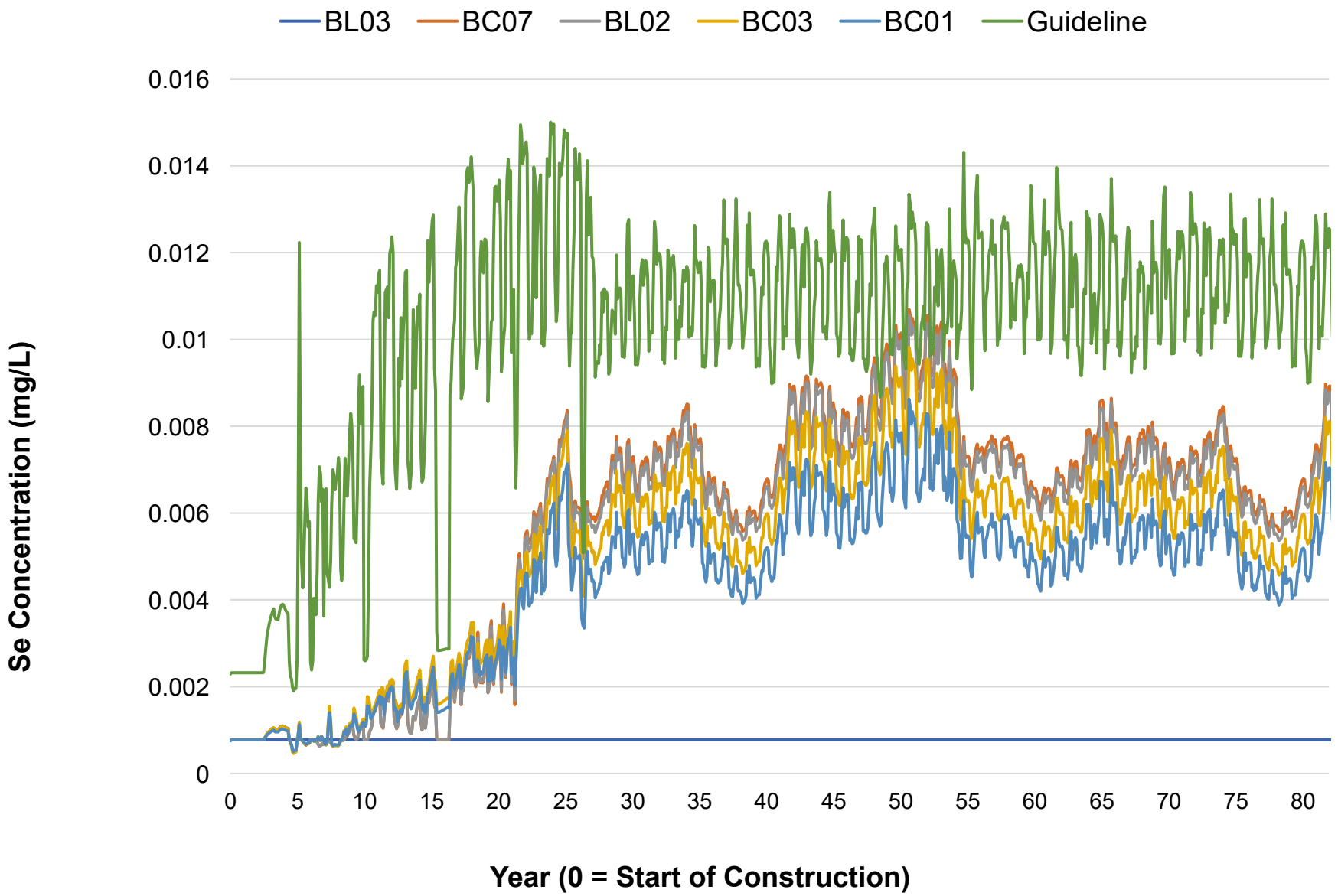


Figure 3 - 100% Acidic Pit Walls

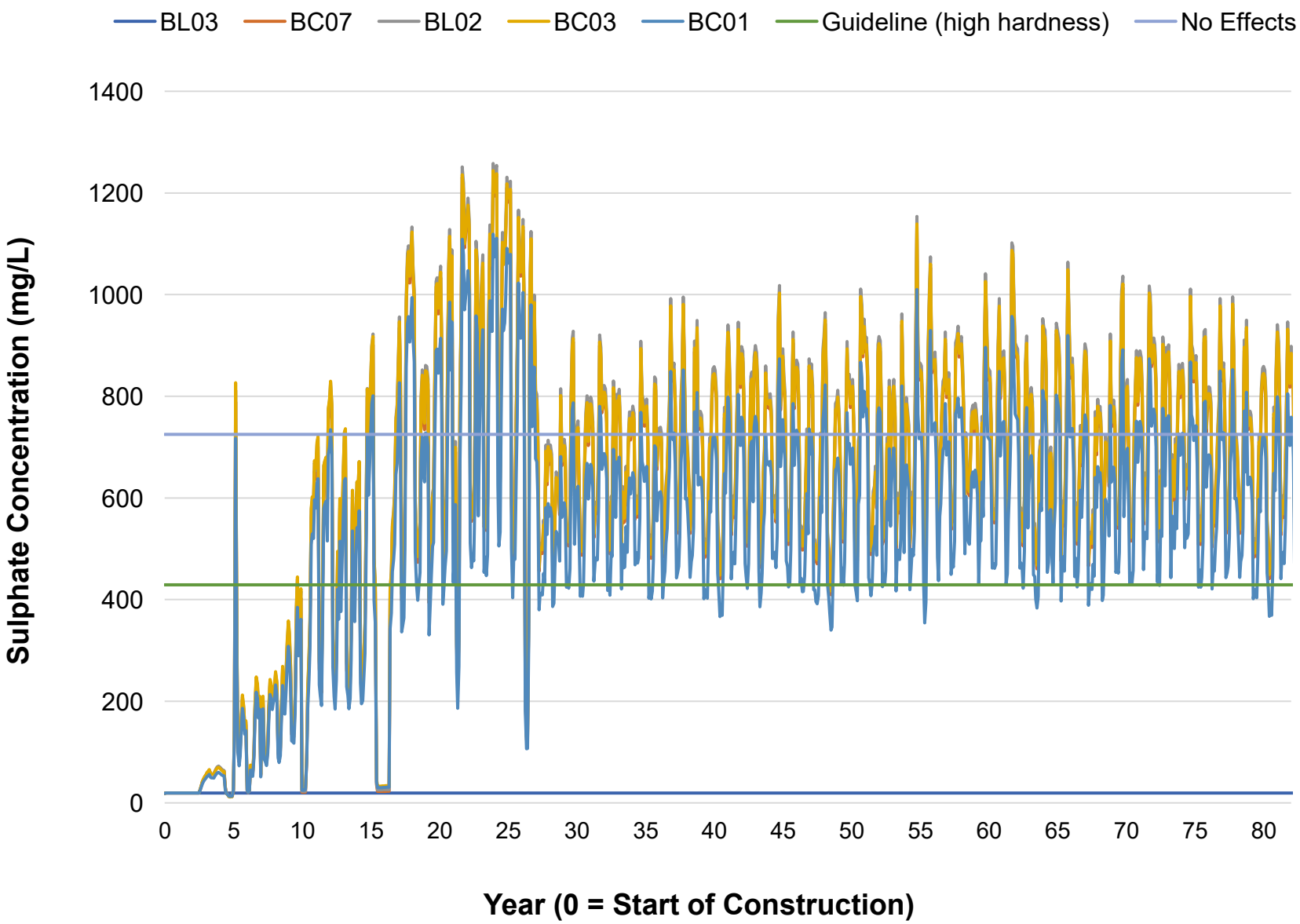


Figure 4 - 100% Acidic Pit Walls

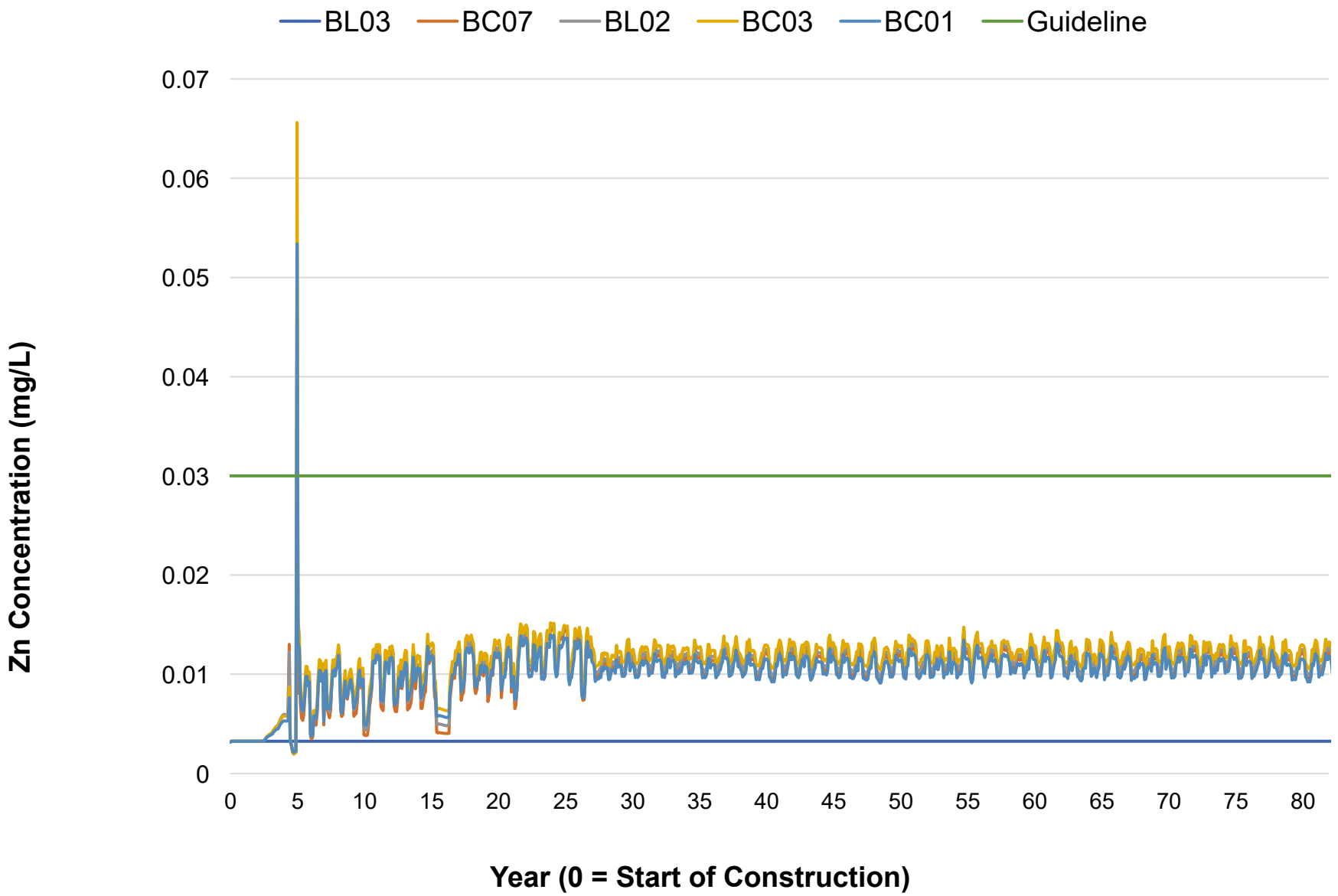


Figure 5 - 100% Acidic Pit Walls

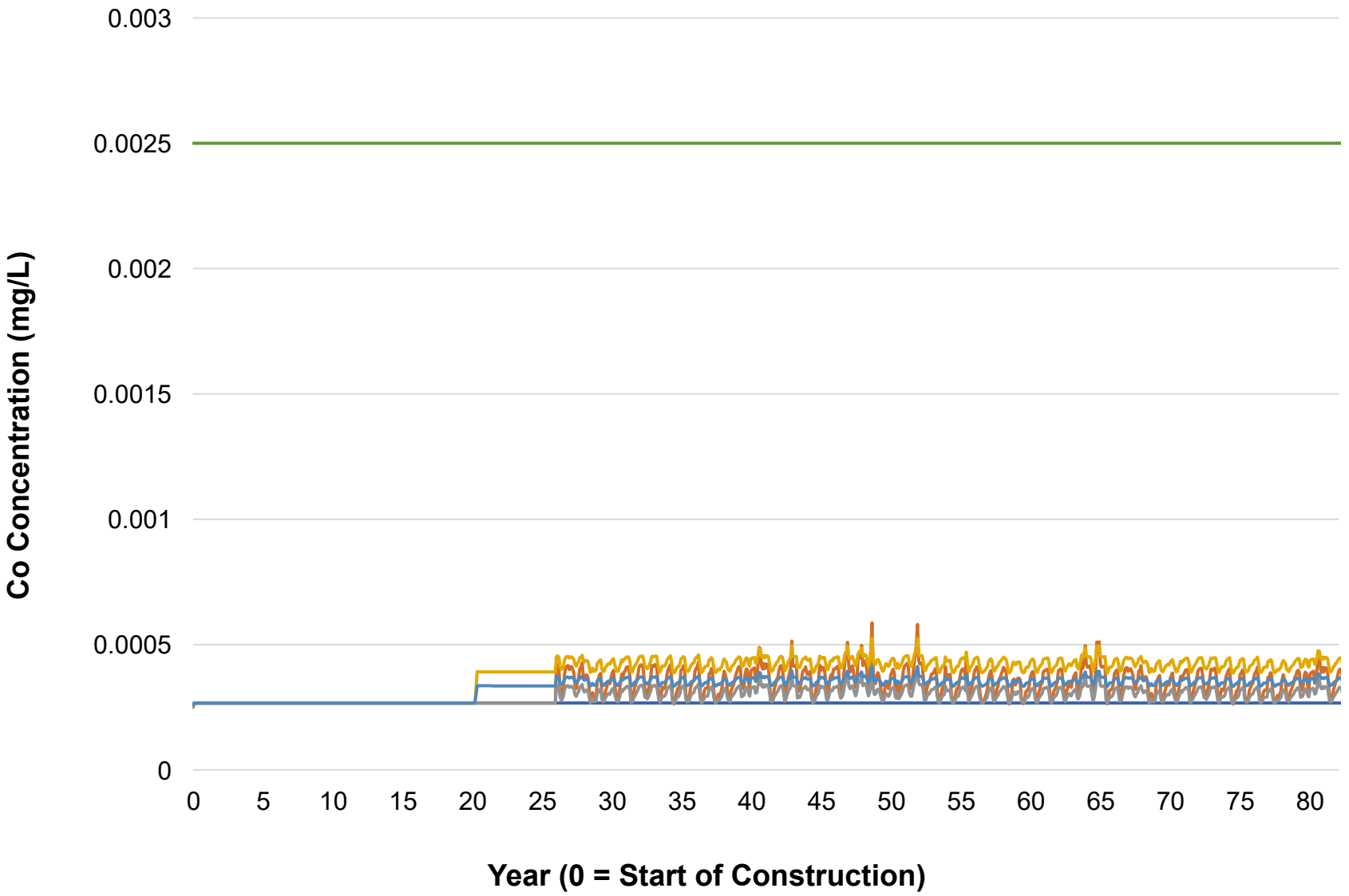
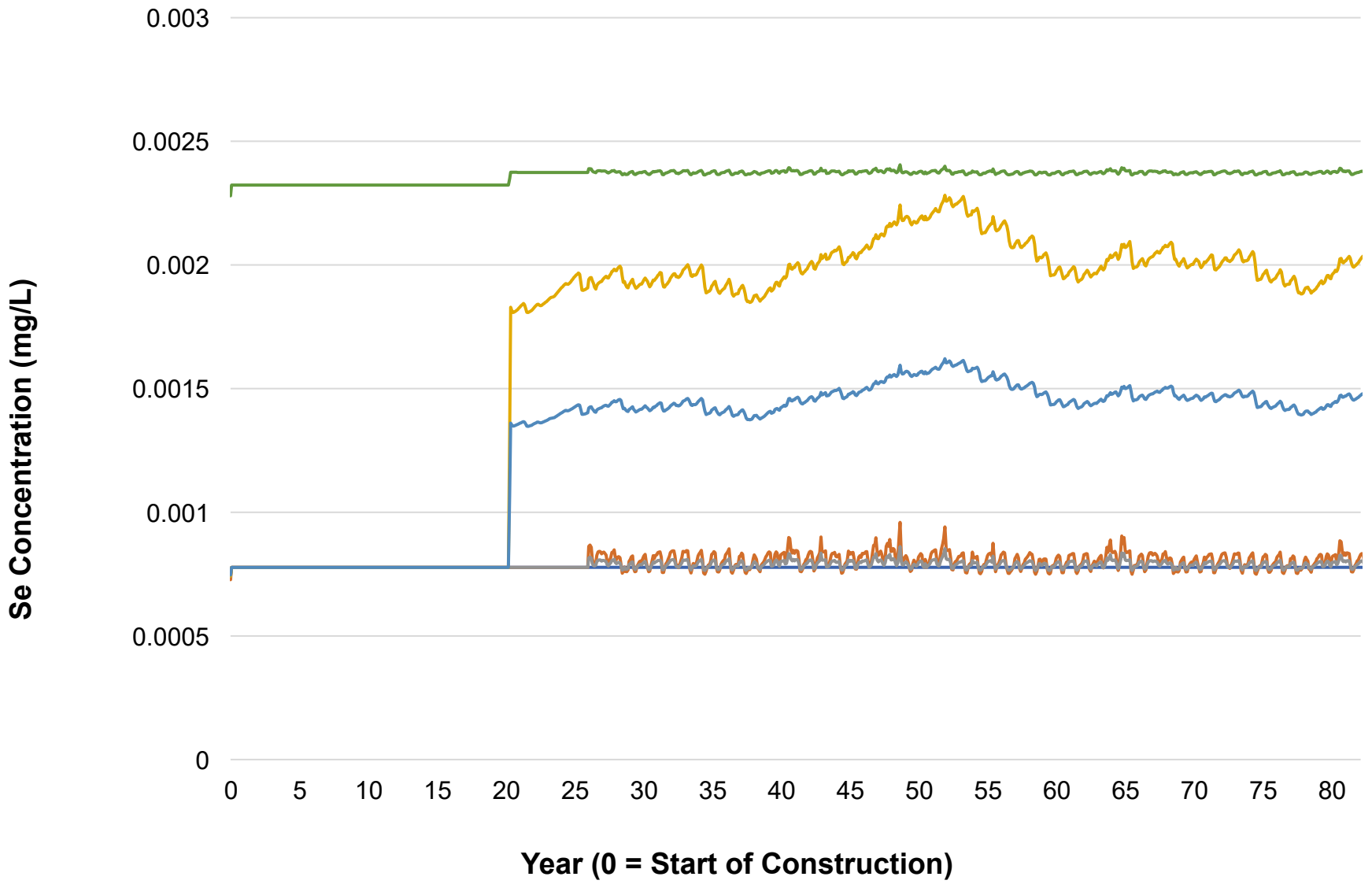


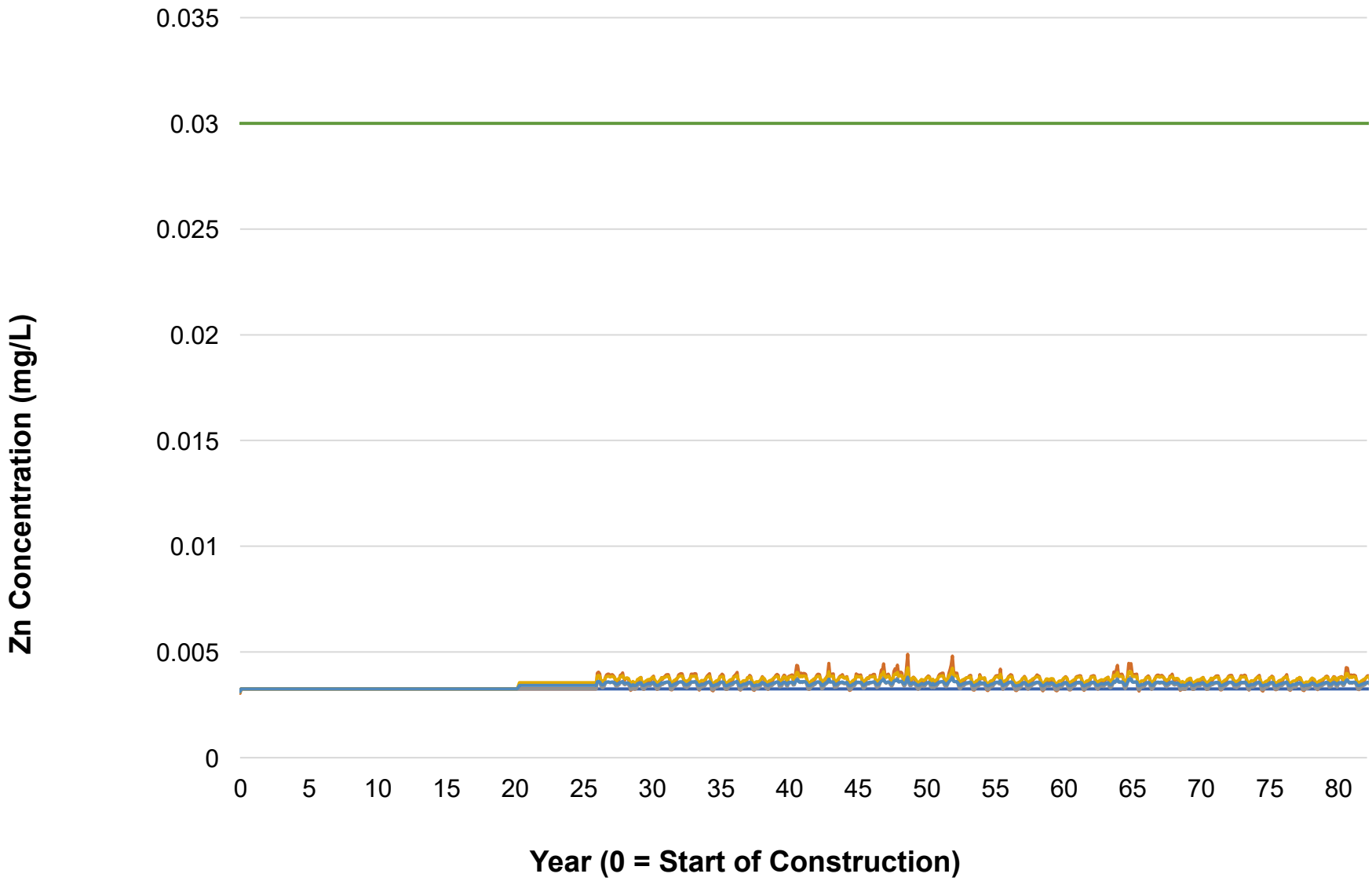
Figure 6 - 100% Acidic Pit Walls



C:\Users\sjensen\Desktop\Grassy 2020\20200211 Results\IR Model Run WQ Results 20200211 ACID.xlsm

Figure 7 - 100% Acidic Pit Walls

Figure 8 - 100% Acidic Pit Walls

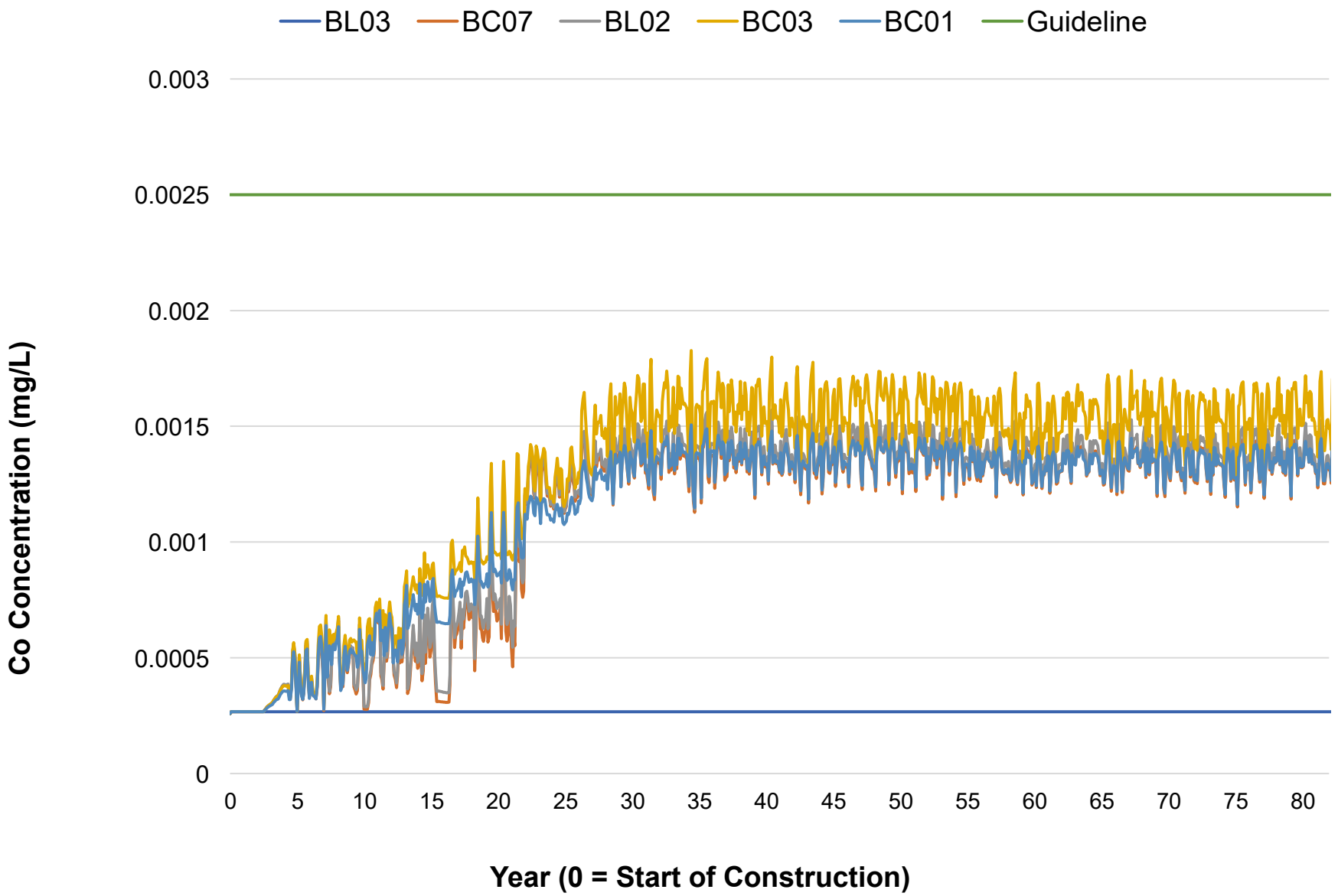


APPENDIX 6.25-3: WATER QUALITY MODEL RESULTS: IRREGULAR DISCHARGE RATES

Appendix 6.25-3 Water Quality Model Results

Concentration of Co, Se, SO4 and Z for Irregular Discharge Rates

Figure 1 - Irregular Discharge



C:\Users\sjensen\Desktop\Grassy 2020\20200211 Results\IR Model Run WQ Results 20200211 Irregular disch.xlsm

Figure 2 - Irregular Discharge

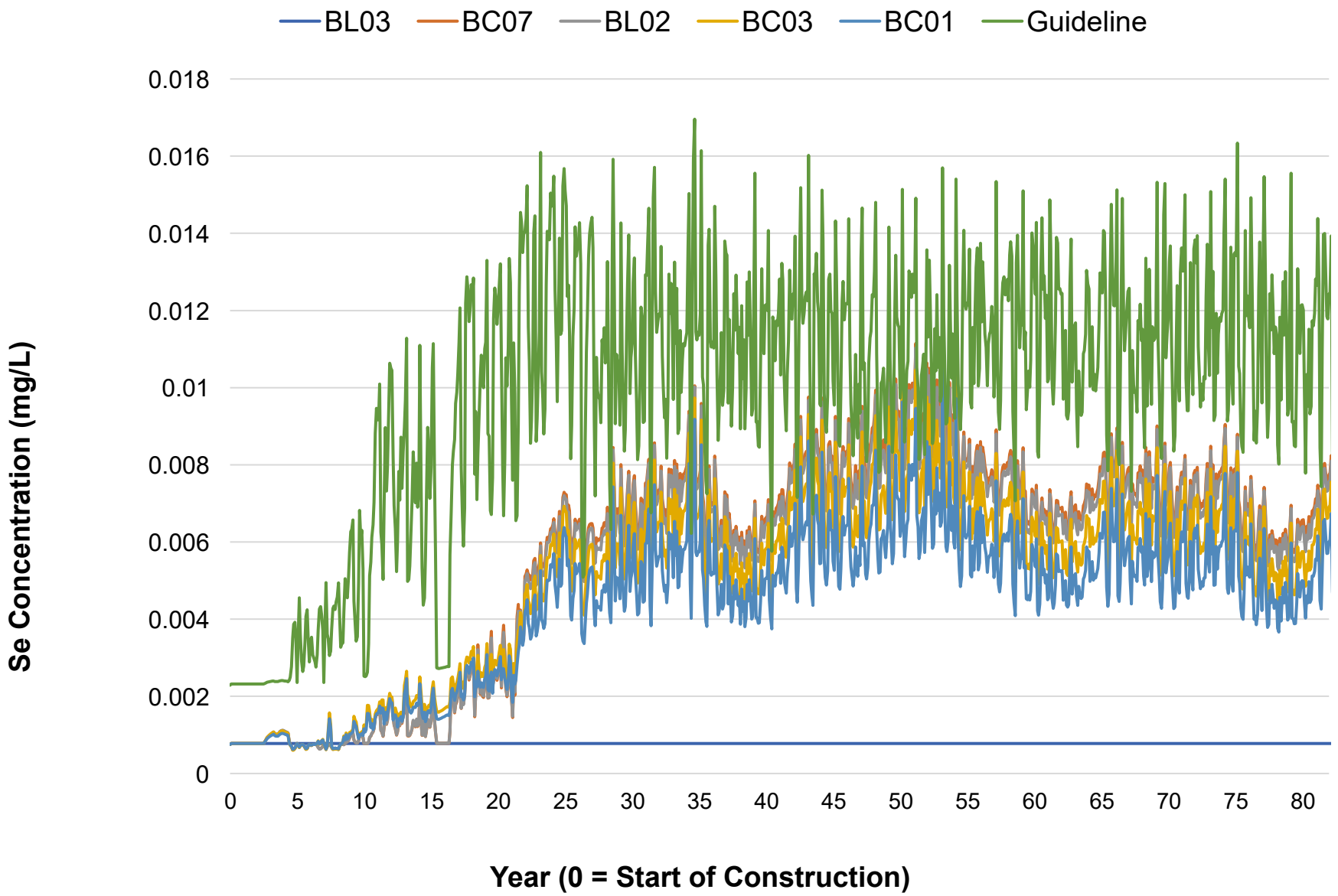
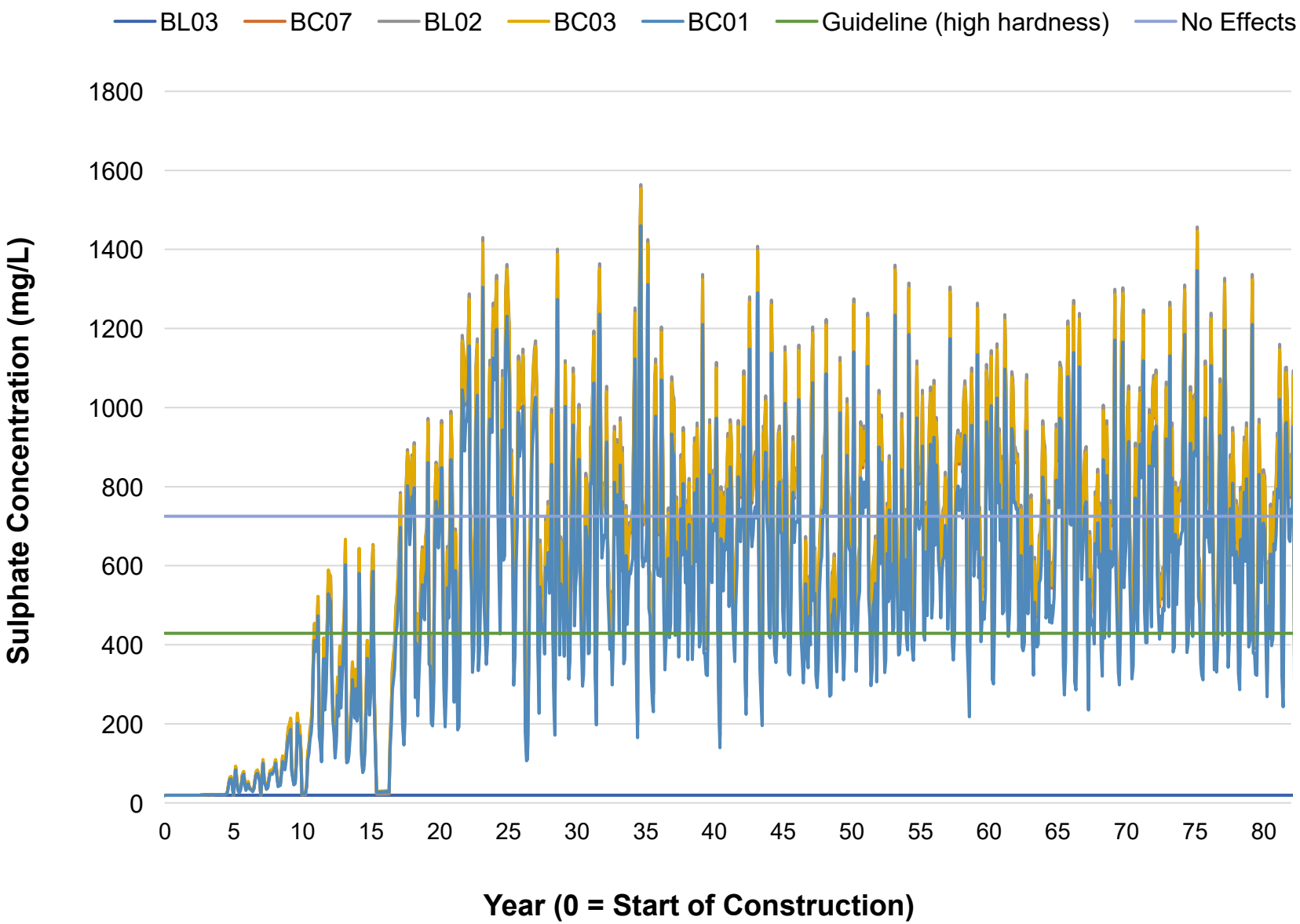
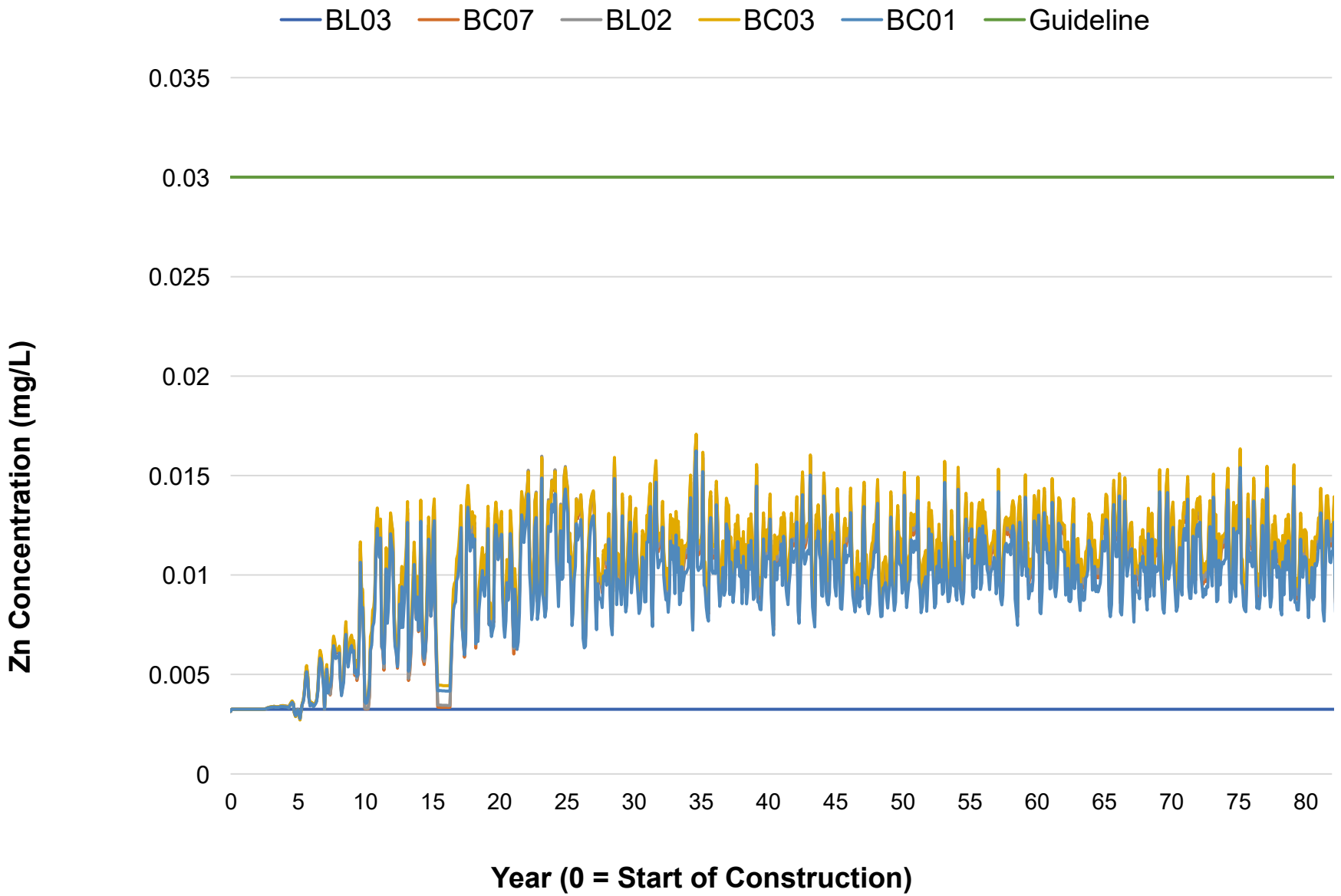


Figure 3 - Irregular Discharge



C:\Users\sjensen\Desktop\Grassy 2020\20200211 Results\IR Model Run WQ Results 20200211 Irregular disch.xlsm

Figure 4 - Irregular Discharge



APPENDIX 6.27-1: HUMAN HEALTH RISK ASSESSMENT (HHRA) – ADDENDUM 1

MILLENNIUM
EMS Solutions Ltd.

#148, 2257 Premier Way
Sherwood Park, AB T8H 2M8
tel: 780.496.9048
fax: 780.496.9049

Suite 202, 701 64 Avenue SE
Calgary, AB T2H 2C3
tel: 403.592.6180
fax: 403.283.2647

#102, 11312 98 Avenue
Grande Prairie, AB T8V 8H4
tel: 780.357.5500
fax: 780.357.5501

toll free: 888.722.2563
www.mems.ca

Grassy Mountain Coal Project
Human Health Risk Assessment (HHRA): Addendum 1

Prepared for:
Benga Mining Ltd.

Prepared by:
Millennium EMS Solutions Ltd.
Suite 202, 701 64 Avenue SE
Calgary, Alberta
T2H 2C3

February 2020
File #14-00201-00

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1.0 INTRODUCTION

On November 28, 2019 Benga Mining Ltd. (Benga) received the "*Joint Review Panel Information Request Package #6*" (CIAR #295) which included a request to include water-based exposure pathways as a part of the Human Health Risk Assessment (HHRA) (JRP Information Request [IR] 6.27). In response to this request, this addendum to the HHRA took into consideration water-based exposure pathways (both groundwater and surface water) within the Local Study Area (LSA) (including the end pit lake [EPL], Blairmore Creek and Gold Creek), as well as the Regional Study Area (RSA), including the Crowsnest River and the Oldman Reservoir.

Of note, while not independently assessed, consideration of the Crowsnest River was addressed as surface water concentrations would be lower than those predicted at Blairmore Creek. Therefore, consideration of the potential for human health risk within Blairmore Creek is inherently protective of the Crowsnest River.

2.0 OBJECTIVES AND SCOPE OF WORK

The scope of this human health risk assessment (HHRA) update was consistent with the final Terms of Reference (TOR) for the Project issued by the Alberta Energy Regulator (AER 2015) and the *Guidelines for the Preparation of an Environmental Impact Statement* issued by the Canadian Environmental Assessment Agency (CIAR #11).

In specific response to JRP IR-6.27 (a) and (b) the following revisions were incorporated into the HHRA update:

- Assessment of water-based exposure pathways (both groundwater and surface water) within the EPL (at Closure), and the downstream receiving aquatic environments, with the inclusion of the Oldman Reservoir using predicted concentrations of contaminants of potential concern (COPC) as well as predicted concentrations within the Oldman Reservoir;
- Specific consideration of an Indigenous group conceptual site model (CSM) indicating linkages between the Project and indigenous specific routes of exposure; and
- Revision of the risk characterization including both a contaminant-by-contaminant assessment as well as a cumulative risk analysis (sum of all HQs) addressing the cumulative exposure to all COPCs from all pathways.

3.0 PROBLEM FORMULATION

The Project related chemical source contribution requiring detailed exposure risk modelling and assessment, as part of the HHRA update, was expanded to include water-based exposure(s). Human health risk was evaluated based on exposure to water, soil, air and food (both plant and animal

based) within the LSA, EPL, RSA, Blairmore Creek, Gold Creek, Crowsnest River and the Oldman Reservoir.

The problem formulation presented herein is an update (as applicable) to the *Grassy Mountain Coal Project Environmental Impact Assessment Updated Human Health and Wildlife Screening Risk Assessment* (Addendum 10, Appendix 4.9-1, CIAR #251) and is the basis by which applicable chemicals, receptors, exposure scenarios and exposure pathways are defined within the risk assessment.

3.1 Identification and Characterization of Receptors

3.1.1 Receptor Exposure Locations and Groups

The HHRA-update considered the LSA, (EPL [at Closure], Blairmore Creek, Gold Creek), and the RSA (Crowsnest River and the Oldman Reservoir) and assessed the maximum chemical concentrations predicted by the air quality assessment within these locations. It should be noted that aerial deposition caused by operational activities were not included in assessment of the EPL which does not exist during operations nor at the Oldman Reservoir as the Project was deemed to have negligible aerial contaminant contribution at this receptor location.

Finally, provided that the assessment considered maximum depositional loading at Blairmore Creek and that all potential chemical loading accumulates within the Oldman Reservoir, an independent evaluation of Crowsnest River was not required (a prediction of health risk within Blairmore Creek or within the Oldman Reservoir act as a conservative approximation of the potential for human health risk elsewhere).

3.1.2 Receptor Characteristics

Human receptors were identified as those people potentially impacted by the Project and included consideration for Indigenous residents, agricultural residents, other area residents, workers and visitors to the area. The HHRA assessed Indigenous resident receptor for the quantitative exposure and risk modeling as that receptor was expected to have the propensity of contaminant exposure. Receptors were further defined by age groups (infant, toddler, child, teen, and adult) consistent with Health Canada (2010a). Indigenous receptor characteristics are summarized in Table 3-1.

Table 3-1 Human Receptor Characteristics[1]

Parameter	Infant	Toddler	Child	Teen	Adult	Worker
Age	0 - 6 mo.	7 mo. - 4 y	5 - 11 y	12 - 19 y	≥ 20 y	≥ 20 y
Body weight (kg)	8.2	16.5	32.9	59.7	70.7	70.7
Soil ingestion rate (g/d)	0.02	0.08	0.02	0.02	0.02	0.1
Water ingestion rate (L/d)	0.3	0.6	0.8	1	1.5	1.5
Air inhalation rate (m^3/d)	2.2	8.3	14.5	15.6	16.6	33.6
Ingestion of Plants						
Plant ingestion rate (g/d)	0	67	98	120	137	0
Root vegetable ingestion rate (g/d)	0	105	161	227	188	0
Berry ingestion rate (g/d)[2]	0	12	20	25	33	0
Labrador tea ingestion rate (g/d)[2]	0	1	1	3	3	0
Cattail ingestion rate (g/d)[2]	0	1	1	3	3	0
Ingestion of Wild Game and Fish[3]						
Moose ingestion rate (g/d)	0	27	39	55	84	0
Grouse ingestion rate (g/d)	0	14	21	29	45	0
Hare ingestion rate (g/d)	0	12	18	25	39	0
Caribou ingestion rate (g/d)	0	16	24	33	51	0
Deer ingestion rate (g/d)	0	16	24	33	51	0
Fish ingestion rate (g/d)	0	23	42	49	54	0
Dermal Exposures						
Surface area – hands (cm^2)	320	430	590	800	890	890
Soil loading to hands (g/cm^2-event)	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04
Surface area – other (cm^2)	1460	2580	4550	7200	8220	2500
Soil loading to other surfaces (g/cm^2-event)	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05
Ingestion of Breast Milk by Infants						
Breast milk ingestion rate (g/d)	664	0	0	0	0	0

[1] Values from Health Canada (2010a) unless otherwise stated

[2] Derivation of the berry, Labrador tea, and cattail ingestion rates was described in HC-9 (Addendum 6, CIAR #70).

[3] For Indigenous receptors; overall wild game ingestion rate based on Health Canada (2010b), proportion by wild game species estimated for region based on Wein *et al.*, 1990. Calculated wildlife ingestion rates for the adult scenario were provided in HC-9 (Addendum 6, CIAR #70). Calculated fish ingestion rates for all scenarios based on the work of Chan *et al.*, 2016.

3.2 Chemical Inventory

The chemical inventory was expanded to include all groundwater and surface water associated COPCs, as well as those parameters previously identified through an inventory of expected Project air emissions, as described in the Air Quality Assessment (EIA, CR #1a, CIAR #42) and in the *Grassy Mountain Coal Project Environmental Impact Assessment Updated Human Health and Wildlife Screening Risk Assessment* (Addendum 10, Appendix 4.9-1, CIAR #251).

The COPCs identified for the project included:

- criteria air contaminants (CACs) (air only);
- metals (air and water);
- polycyclic aromatic hydrocarbons (PAHs) (air only); and
- volatile organic compounds (VOCs) (air only).

The HHRA (Addendum 10, Appendix 4.9-1, CIAR #251) evaluated the potential health risks for all identified COPCs for which adequate toxicological data was available. A list of the chemicals included in the HHRA update is presented in Table 3-2.

Table 3-2 Chemicals of Potential Concern (COPCs)

Chemical Group	Chemicals		
Criteria Air Contaminants	• Carbon Monoxide (CO) • Nitrogen Dioxide (NO_2)	• Sulphur Dioxide (SO_2)	• Particulate Matter <2.5 µm ($PM_{2.5}$) and <10 µm (PM_{10})
Metals	• Aluminum • Antimony • Arsenic • Barium • Beryllium • Bismuth • Cadmium • Chromium II, III • Chromium VI • Cobalt • Copper	• Fluoride • Iron • Lead • Lithium • Magnesium • Manganese • Mercury • Molybdenum • Nickel • Potassium • Phosphorus	• Selenium • Silver • Strontium • Thallium • Tin • Titanium • Uranium • Vanadium • Zinc • Zirconium

Table 3-2 Chemicals of Potential Concern (COPCs)

Chemical Group	Chemicals		
Polycyclic Aromatic Hydrocarbons (PAH)	• Acenaphthene • Acenaphthylene • Anthracene • Benz[a]anthracene • Benzo[a]pyrene • Benzo[b]fluoranthene	• Benzo[g,h,i]perylene • Benzo[k]fluoranthene • Chrysene • Dibenzo[a,h]anthracene • Fluoranthene • Fluorene	• Indeno[1,2,3-cd]pyrene • Naphthalene • Phenanthrene • Pyrene
Volatile Organic Compounds (VOCs)	• Acetaldehyde • Acrolein • Benzene	• Formaldehyde • Propylene	• Toluene • Xylenes
Other	• Ammonium • Calcium • Chloride	• Coal Dust[1]Diesel • Particulate Matter (DPM)[1] • Sodium	• Silica (and silicates)[1] • Sulphate

[1]Coal Dust, Silica (and silicates) and DPM were included as COPCs in response to Alberta Energy Regulator (AER), Health Canada (HC) and the Joint Review Panel (JRP) Information Requests (IRs), including: AER-154 (Addendum 5, CIAR #69), HC-1 (Addendum 6, CIAR #70), JRP IR-4.10 (CIAR #251).

Assessment of acute and chronic inhalation was completed for all COPCs with relevant TRVs. A multimedia exposure assessment, which included exposure through secondary oral and dermal contact pathways, was completed for a subset of the identified COPCs (Addendum 10, Appendix 4.9-1, CIAR #251).

The screening process for the multimedia assessment was based on guidance from the US EPA (2003) and California EPA (1994) using physical/chemical properties of the COPCs. Following this guidance, only those COPCs with low volatility indicating potential to be present in media other than air and those COPCs which may bioaccumulate in plant or animal tissue over time were included (details of the screening methodology are provided in JRP IR-4.9 (Addendum 10, , Appendix 4.9-1, CIAR #251).

All metals were assumed to persist in the environment and were automatically included in consideration of the multimedia assessment except for those parameters considered innocuous or predicted at concentrations consistent with measured background. The following parameters were screened out of the human health multimedia assessment:

- Bismuth – used in the treatment of upset stomach, heartburn and diarrhea (it is the active ingredient in Pepto Bismol®) and considered an innocuous parameter.
- Calcium – predicted at concentrations consistent with measured background and is an essential nutrient and considered an innocuous parameter.

- Chloride – predicted at concentrations consistent with measured background.
- Fluoride – considered beneficial in the prevention of dental caries and predicted concentrations in surface water are lower than the Health Canada drinking water quality guideline (Health Canada 2019).
- Iron – no evidence exists of dietary iron toxicity in the general population (Health Canada 2019) and is considered an innocuous parameter.
- Silver – predicted at concentrations consistent with measured background.
- Lithium – predicted at concentrations consistent with measured background.
- Potassium – an essential nutrient and an innocuous parameter.
- Magnesium – an essential nutrient and no evidence of adverse health effects from magnesium in drinking water (Health Canada 2019) and is considered an innocuous parameter.
- Nitrate and Nitrite – chemicals are non-bioaccumulating and predicted concentrations meet (are lower) than drinking water quality standards in Canada.
- Phosphorus – the second most abundant mineral within the body and considered an innocuous parameter.

3.3 Indigenous Conceptual Site Model

An Indigenous Group specific conceptual site model (CSM) is provided in Figure 3-1. This CSM illustrates an overview of the results of the problem formulation. This model was designed to represent predicted exposures for all potential Indigenous receptors.

3.3.1 Indigenous Exposure Pathway Identification

In the "*Grassy Mountain Coal Project Environmental Impact Assessment Updated Human Health and Wildlife Screening Risk Assessment*" (Addendum 10, Appendix 4.9-1, CIAR #251), direct inhalation of air was assumed to be the primary exposure pathway with several secondary pathways also identified for the multimedia assessment (including both ingestion and dermal contact). This response includes those same potential water-based exposure pathways (surface and groundwater) with consideration of using predicted concentrations from JRP IR-6.26, updated model predictions. This addendum to the HHRA assessment includes the following exposure pathway considerations:

- COPCs in air deposited onto soil in the surrounding area. Receptors may then be exposed by direct contact with soil, surface water, inadvertent ingestion of soil, and inhalation of dust.
- COPCs in local vegetation, through direct deposition from air or uptake from affected soils. Receptors may then be exposed by ingestion of local vegetation.
- COPCs in soil, plants, and water can be ingested by local wildlife. Receptors may then be exposed by ingestion of local wild game.

- COPCs in water (both groundwater and surface water) within the LSA (including the EPL) associated with Project activities, which may impart a direct effect on surface water receptors. Receptors may then be exposed through ingestion of surface water, contact with surface water, ingestion of wild fish and game. Aquatic vegetation and fish were considered in order to conservatively estimate total potential exposure to the human receptor.

A qualitative assessment of potential human exposure to groundwater *via* drinking water wells was conducted (EIA, CR #3, Section 5.0, CIAR #42). There are no confirmed domestic wells identified within the proposed mine permit boundary. The potential for domestic wells to be drilled and completed within the mine permit boundary is low, as the underlying bedrock units are not very permeable. The primary unit that could be considered for the completion of domestic wells would be the surficial deposits associated with Gold Creek or Blairmore Creek (alluvium). Groundwater quality in those aquifers would be similar to the quality of the associated surface water and the groundwater would be expected to be classified as *groundwater under the influence of surface water* (GWUDI). The bedrock formations (shale or sandstone) are competent units with limited porosity, except where occasional fractures are encountered, which can be time consuming and expensive to target. The few industrial wells present within the LSA, and monitoring wells installed for the assessment of the Project, indicated that wells completed in bedrock had low head and limited available yield.

Project activities may release selenium, nitrate and nitrite which will be actively managed and treated on Site. The Project is designed so the mining operations will last 25 years, followed by approximately 50 years of active water management and reclamation. During this period, the Project will be controlled by Benga and no external users will have access to the Site. The average residence time for groundwater in the system will generally be greater than 50 years and therefore provides ample time for attenuation of selenium and nitrate to occur. In the unlikely event that a domestic use water well would be drilled within the mine permit boundary once the project is reclaimed, groundwater will have returned to baseline conditions. Therefore, human consumption of groundwater within the RSA by way of a domestic use water well was not considered as a component of the HHRA-update.

A summary of the applicable exposure pathway for Indigenous receptor groups is presented in Table 3-3.

Table 3-3 Multimedia Exposure Pathways	
Exposure Pathway	**Receptor Groups**
Direct Contact with COPCs in Soil	Indigenous Other Area Residents
Ingestion of Local Vegetation	Indigenous Agricultural
Ingestion of Wildlife	Indigenous
Direct Contact and Ingestion of Surface Water	Indigenous
Ingestion of Local Fish	Indigenous

4.0 EXPOSURE ASSESSMENT

The exposure assessment involved the estimation of the amount of each COPC that receptors may be exposed to, based on reasonable worst-case assumptions.

4.1 Inhalation

The results of the inhalation health exposure assessment are presented in the *Grassy Mountain Coal Project Environmental Impact Assessment Updated Human Health and Wildlife Screening Risk Assessment* (Addendum 10, Appendix 4.9-1, CIAR #251). The results of the inhalation assessment remain unchanged in consideration of the water-based exposure pathway update.

4.2 Multimedia Exposure

The multimedia exposure assessment evaluated secondary exposure through oral and dermal routes. The processes involved are only relevant for chemicals that can potentially accumulate in media other than air; many of the COPC associated with Project emissions are too volatile to be present in soil, water or food.

The COPCs assessed in the multimedia assessment are provided in Table 4-1.

Table 4-1 Chemicals of Potential Concern (COPCs) – Multimedia Exposure			
Chemical Groups	**Chemicals**		
Metals	• Aluminum • Antimony • Arsenic • Barium • Beryllium • Cadmium • Chromium (II, III and VI)	• Cobalt • Copper • Lead • Manganese • Mercury • Molybdenum	• Nickel • Selenium • Thallium • Uranium • Vanadium • Zinc
Polycyclic Aromatic Hydrocarbons (PAH)	• Acenaphthene • Acenaphthylene • Anthracene • Benzo[a]anthracene • Benzo[a]pyrene	• Benzo[b]fluoranthene • Benzo[g,h,i]perylene • Benzo[k]fluoranthene • Chrysene • Dibenzo[a,h]anthracene	• Fluoranthene • Fluorene • Indeno[1,2,3-cd]pyrene • Phenanthrene • Pyrene
Volatile Organic Compounds (VOCs)	Formaldehyde		

The multimedia assessment included consideration of background/ambient concentrations of COPCs in the Baseline and Application cases, combined with predictive modelling based on Project air emissions.

The multimedia modelling equations published by US EPA (2005) were used to predict the concentrations of airborne COPCs occurring in soil, surface water, plants, and wild game. Deterministic calculations were used based on predicted air concentration and deposition rates, published physical-chemical properties of the COPCs, expected physical conditions within the study area, and physical characteristics of human receptors. Reasonable worst-case assumptions were used in the calculations. Complete details on the model inputs, equations, and a sample calculation are provided in JRP IR-4.9 (Addendum 10, Appendix 4.9-1, Appendix B: Multimedia Model Equations and Sample Calculations, CIAR #251). The multi-media model predicted total exposure doses as mg/kg body weight/day for each receptor age group and location, each of which were carried forward into the risk characterization (Addendum 10, Appendix 4.9-1, Appendix C: Detailed Multimedia Model Results, CIAR #251).

An HHRA baseline sampling program was conducted July 22-31, 2014 and September 5-9, 2014. The HHRA baseline sampling program included the collection and chemical analysis of vegetation and soil samples. Within the program, efforts were made to collect berries and leaves typically consumed

through local harvesting; the results were dependant on the time of year samples were collected and the availability of specific species in the areas sampled. Complete results from the soil and vegetation sampling program are provided in JRP IR-4.9 (Addendum 10, Appendix 4.9-1, Appendix D: Baseline Sampling Program, CIAR #251). A total of 21 soil samples and 25 vegetation samples were collected from the soils and vegetation LSAs respectively and were analyzed for metals and PAHs. Where there were enough samples, the 95th percentile background soil concentrations were applied to the baseline and application scenarios (AHW 2011). These concentrations were included in exposure calculations for the HHRA. Where media concentrations were measured as below detection limit, the input value used for the exposure modelling was the highest of either half the detection limit, or the concentration predicted *via* deposition and uptake in the multi-media model.

5.0 TOXICITY ASSESSMENT

The toxicity assessment involves establishing the relationship between the amount of a chemical to which a person is exposed over a specified duration, and the potential for adverse health effects. The exposure limit, or the amount of chemical identified to be a safe exposure concentration is the toxicity reference value (TRV). Within the toxicity assessment step of the HHRA, TRVs are identified for all COPCs and exposure pathways.

The TRVs were identified for both acute and chronic inhalation exposures. For those chemicals evaluated under the multimedia assessment, chronic oral TRVs were also identified. The TRVs were obtained from recognized regulatory agencies, including:

- Alberta Environment and Parks (AEP);
- Health Canada;
- United States Environmental Protection Agency (US EPA);
- World Health Organization (WHO);
- Agency for Toxic Substances and Disease Registry (ATSDR);
- California Office of Environmental and Human Health Assessment (OEHHA);
- Texas Commission on Environmental Quality (TCEQ);
- Netherlands National Institute for Public Health and the Environment (RIVM); and
- Other agencies where appropriate for specific chemicals.

The basis for each available TRV was evaluated to select the most appropriate value, giving consideration to consistency with Alberta approaches, scientific defensibility, incorporation of the most current information, and conservatism.

Selected TRVs for acute and chronic inhalation are summarized in *the Grassy Mountain Coal Project Environmental Impact Assessment Updated Human Health and Wildlife Screening Risk Assessment* (Addendum 10, Appendix 4.9-1, CIAR #251). As this HHRA-update specifically evaluated the potential for adverse effect in consideration of water-based exposure pathway these tables remain unadjusted and are not repurposed for this report. A summary of TRV values used in calculation of the risk(s) associated with multimedia exposure are detailed in Table 5-1.

Table 5-1 Toxicity Reference Values (TRVs) - Chronic Oral Exposure Limits

	Chemical	Exposure Limit (mg/kg bw/d)	Agency	Toxicity Endpoint
PAHs and VOCs	Acenaphthene	0.060	US EPA	liver
	Acenaphthylene	0.060	US EPA	liver
	Anthracene	0.3	US EPA	NOAEL
	Benzo[a]anthracene	B[a]P equivalent	-	gastrointestinal tumours
	Benzo[a]pyrene	0.0000014	US EPA	gastrointestinal tumours
	Benzo[b]fluoranthene	B[a]P equivalent	-	gastrointestinal tumours
	Benzo[g,h,i]perylene	B[a]P equivalent	-	gastrointestinal tumours
	Benzo[k]fluoranthene	B[a]P equivalent	-	gastrointestinal tumours
	Chrysene	B[a]P equivalent	-	gastrointestinal tumours
	Dibenzo[a,h]anthracene	B[a]P equivalent	-	gastrointestinal tumours
	Fluoranthene	B[a]P equivalent	-	gastrointestinal tumours
	Fluorene	0.040	US EPA	kidney, liver, spleen
	Indeno[1,2,3-cd]pyrene	B[a]P equivalent	-	gastrointestinal tumours
	Phenanthrene	B[a]P equivalent	-	gastrointestinal tumours
	Pyrene	0.030	US EPA	kidney
	Formaldehyde	0.150	Health Canada	kidney and GI
Metals	Aluminium	0.143	WHO	-
	Antimony	0.0002	Health Canada	Serum glucose and haematuria
	Arsenic	0.0000056	Health Canada	cancer (bladder, lung, liver)
	Barium	0.2	US EPA	kidney
	Beryllium	0.002	US EPA	gastrointestinal
	Cadmium	0.0005	US EPA	kidney

Table 5-1 Toxicity Reference Values (TRVs) - Chronic Oral Exposure Limits

	Chemical	Exposure Limit (mg/kg bw/d)	Agency	Toxicity Endpoint
	Chromium III	1.5	US EPA	-
	Chromium VI	0.0009	ATSDR	gastrointestinal
	Cobalt	0.0014	RIVM	cardiovascular
	Copper	0.091 (0 - 4 yrs) 0.111 (5 - 11 yrs) 0.126 (12 - 19 yrs) 0.141 (20+ yrs)	Health Canada	liver and gastrointestinal
	Manganese	0.047	US EPA	nervous system
	Mercury	0.0003	US EPA	kidney
	Molybdenum	0.005	US EPA	uric acid levels
	Nickel	0.011	OEHHA	perinatal mortality
	Selenium	0.005	US EPA	selenosis
	Thallium	0.00001	US EPA	hair follicle atrophy
	Uranium	0.0006	Health Canada	kidney
	Vanadium	0.002	RIVM	developmental
	Zinc	0.3	US EPA	ESOD activity

5.1 Mixtures

Receptors are potentially exposed to mixtures of chemicals, and in these mixtures, there is the potential for chemical interactions to affect toxicity. Consistent with Health Canada (2010a) recommendations, where chemicals have similar effects on the same target organs, they were assumed to have additive toxicity (*i.e.,* the toxic effects are combined).

As part of the toxicity evaluations, chemicals were assigned to toxicity groups based on critical effects and target organs. These groups are summarized in Table 5-2 for chronic oral exposures. All COPCs within a toxicity group were assumed to have additive toxicity. Potential toxicity associated with these chemical groups was evaluated in this HHRA-update with consideration of surface and groundwater exposures.

Table 5-2 Toxicity Endpoint Groups[1]

Exposure Pathway and Duration	Toxicity Endpoint	COPC
Chronic Oral	Gastrointestinal	Beryllium, Total Chromium, Formaldehyde, Copper
	Liver	Acenaphthene, Acenaphthylene, Fluorene, Aluminum, Antimony, Copper, Selenium, Fluoranthene
	Kidney	Barium, Cadmium, Formaldehyde, Fluoranthene, Fluorene, Mercury, Pyrene, Uranium
	Reproductive	Aluminium, Lead, Nickel, Vanadium
	Gastrointestinal Tumours	Benzo[a]pyrene group

[1]Toxicity endpoint groups were updated in response to IR AER-170 (Addendum 5, CIAR #69).

5.2 Multiple-Exposure Route Potential

Receptors are potentially exposed to both individual chemicals and chemical mixtures originating from chronic inhalation exposure as well as multimedia exposures (oral and dermal) which have similar critical effects pathways (*e.g.,* liver, kidney, neurological and lung). Additive risk is more than a chemical by chemical evaluation and specifically evaluates the potential for human health risk due to cumulative exposure to all COPCs from all pathways (including water-based pathways).

All COPCs within a toxicity group were assumed to have additive toxicity irrespective of their exposure route (inhalation, oral or dermal).

6.0 RISK CHARACTERIZATION

Risk characterization is the stage where the results of the exposure and toxicity assessments are combined to evaluate potential risks to human receptors.

Risks are characterized using hazard quotients (HQ) for non-carcinogenic COPCs. An HQ is simply the ratio of the predicted exposure to the appropriate exposure limit (TC/RfC or TDI/RfD). An HQ less than 1.0 indicates that predicted exposures are less than the TRV and adverse effects are not predicted. In response to IR HC-R2-11 (Addendum 8, Part B, CIAR #89) the potential risks of adverse health effects were compared to a more conservative HQ of 0.2 instead of 1.0 so as to account for potential exposures from background sources not included in the HHRA (*e.g.,* store bought foods and consumer products).

For non-threshold chemicals, the potential risk of adverse health effects was assessed using an incremental lifetime cancer risk (ILCR). The ILCR was calculated by multiplying the predicted exposure by the appropriate slope factor or unit risk. An ILCR of less than $1x10^{-5}$ indicates that the predicted risks are less than 1 in 100,000 a value considered "essentially negligible" by both Alberta and Federal health agencies (AHW 2011; Health Canada 2010a,b).

Due to the number of conservative assumptions purposefully built into the HHRA, an HQ greater than 0.2 or an ILCR value greater than 1×10^{-5} does not automatically indicate a potential risk of adverse health effects. Instead, it is an indication that additional in-depth assessment is required for the individual risk result. The additional assessment includes a review of the conservative assumptions made in the toxicity and exposure assessment steps of the HHRA. The purpose of the review is to determine whether the result represents a potential risk of adverse health effects or simply are the result of the conservative assumptions made during the HHRA calculations.

7.0 RESULTS AND DISCUSSION

The HHRA assessed potential health risks at the maximum point of impingement (MPOI) in the RSA (RSA-MPOI) as well as risks relating to human health exposure caused by surface water exposures at Blairmore Creek, Gold Creek, the EPL (at Closure), and the Oldman Reservoir. Depositional assumptions to surface water bodies used the RSA-MPOI estimates as a conservative approximation of the potential for risk as this conservatively represents the highest levels of predicted human exposure.

7.1 Acute and Chronic Inhalation

The results of the inhalation health exposure assessment are presented in the *Grassy Mountain Coal Project Environmental Impact Assessment Updated Human Health and Wildlife Screening Risk Assessment* (Addendum 10, Appendix 4.9-1, CIAR #251). The results of the inhalation assessment remain unchanged in consideration of the water-based exposure pathway update.

7.2 Chronic Multimedia Exposure

7.2.1 HQ and ILCR Results

Long-term (chronic) risks from the multimedia exposure assessment were evaluated for COPCs emitted from the Project which could potentially accumulate in the environment. This assessment focuses on secondary exposure to these COPCs through oral and dermal exposure pathways.

HQ and cumulative ILCR results were calculated assuming Indigenous receptor characteristics as they represent the most sensitive receptor group based on their assumed lifetime exposure within the LSA and RSA, and a higher assumed ingestion rate of traditional and country foods (local fish, wild

game and vegetation) than other receptor groups. HQs and cumulative ILCR values for all other receptors at the same locations would inherently be lower. It was conservatively assumed that the Indigenous receptor lived at, and harvested food from all the HHRA receptor locations including the RSA-MPOI locations.

Risks for non-threshold substances were assessed based on the incremental contribution of the project. Thus, the potential cumulative ILCR were assessed based on exposure to Project emissions only.

As described in IR HC-R2-11 (Addendum 8, Part B, CIAR #89), following review, a refinement of the multimedia model input assumptions and parameters for background exposure was conducted. An HQ of 0.2 was used as a screening level benchmark.

Predicted HQs (threshold compounds) for the most sensitive receptor age group (toddler) and ILCRs (carcinogens) for a composite lifetime receptor are summarized in Table 7-1 (EPL), Table 7-2 (Blairmore Creek), Table 7-3 (Gold Creek) and Table 7-4 (Oldman Reservoir).

Table 7-1 Predicted Hazard Quotients and ILCR Results for the Multimedia Assessment End Pit Lake (EPL)[1]

Parameter	Project	Baseline[2]	Application
HQ – Toddler Receptor			
Aluminium	1.1E-02	**3.2E+00**	**3.2E+00**
Antimony	**7.1E-01**	**2.1E-01**	**9.3E-01**
Barium	3.8E-02	**1.0E+00**	**1.0E+00**
Beryllium	4.4E-02	5.5E-03	5.0E-02
Cadmium	1.3E-01	**2.1E+00**	**2.1E+00**
Chromium II/III	1.6E-04	2.4E-04	3.9E-04
Cobalt	**1.2E+00**	**2.9E-01**	**1.5E+00**
Copper	9.4E-03	2.0E-01	**2.1E-01**
Lead	3.6E-02	**1.1E+00**	**1.1E+00**
Manganese	**5.7E-01**	**1.1E+01**	**1.2E+01**
Mercury	2.4E-03	-	2.4E-03
Methylmercury	1.2E-04	-	1.2E-04
Molybdenum	1.7E-01	1.3E-01	**3.0E-01**
Nickel	**4.8E-01**	5.7E-02	**5.4E-01**

Table 7-1 Predicted Hazard Quotients and ILCR Results for the Multimedia Assessment End Pit Lake (EPL)[1]

Parameter	Project	Baseline[2]	Application
Selenium	**2.3E-01**	**2.1E-01**	**4.3E-01**
Silver	7.7E-05	-	7.7E-05
Thallium	**3.0E-01**	**9.6E+01**	**9.9E+00**
Uranium	5.5E-02	-	5.5E-02
Vanadium	**3.0E-01**	**3.0E-01**	**6.0E-01**
Zinc	2.2E-02	**5.8E-01**	**6.0E-01**
ILCR – Composite Receptor			
Arsenic	8.6E-06	-	-
Chromium VI	2.5E-06	-	-

[1]Multimedia assessment includes consideration of ingestion (water, soil, sediment, food) and dermal contact.

[2]Baseline contribution is based on background soil and vegetation contribution. Pre-existing surface water concentrations were not included in estimating baseline contribution as no pre-existing waterbody exists within the mine footprint.

Table 7-2 Predicted Hazard Quotients and ILCR Results for the Multimedia Assessment Blairmore Creek[1]

Parameter	Project	Baseline[2]	Application
HQ – Toddler Receptor			
Acenaphthene[3]	8.4E-08	1.3E-02	1.3E-02
Acenaphthylene[3]	8.6E-07	8.9E-03	8.9E-03
Anthracene[3]	2.1E-07	2.8E-03	2.8E-03
Fluorene[3]	9.7E-06	4.9E-02	4.9E-02
Pyrene[3]	2.4E-06	6.4E-02	6.4E-02
Fluoranthene[3]	1.2E-05	4.9E-02	4.9E-02
Formaldehyde[3]	1.4E-07	2.5E-07	3.1E-07
Aluminium	7.5E-03	**3.2E+00**	**3.2E+00**
Antimony	**3.3E-01**	**2.5E-01**	**5.8E-01**
Barium	2.0E-01	**1.1E+00**	**1.3E+00**
Beryllium	8.1E-04	1.9E-02	1.9E-02
Cadmium	1.2E-01	**2.1E+00**	**2.2E+00**
Chromium II/III	2.2E-05	2.6E-04	2.8E-04
Cobalt	3.8E-02	**3.0E-01**	**3.3E-01**
Copper	3.6E-03	2.0E-01	2.0E-01

Table 7-2 Predicted Hazard Quotients and ILCR Results for the Multimedia Assessment Blairmore Creek[1]

Parameter	Project	Baseline[2]	Application
Lead	3.7E-02	**1.1E+00**	**1.1E+00**
Manganese	2.2E-02	**1.1E+01**	**1.1E+01**
Mercury	1.2E-03	2.0E-04	1.2E-05
Methylmercury	**3.0E-01**	4.5E-02	**3.2E-01**
Molybdenum	1.3E-01	1.4E-01	**2.7E-01**
Nickel	3.0E-02	6.1E-02	9.0E-02
Selenium[4]	**3.4E-01**	**5.9E-01**	**5.7E-01**
Silver	-	2.4E-04	4.6E-04
Thallium	**2.7E-01**	**1.0E+01**	**1.0E+01**
Uranium	1.6E-02	3.1E-02	4.6E-02
Vanadium	6.5E-02	**3.2E-01**	**3.8E-01**
Zinc	1.1E-02	**5.8E-01**	**5.9E-01**
ILCR – Composite Receptor			
Benz[a]anthracene[3]	2.2E-09	-	-
Benzo[a]pyrene[3]	8.0E-07	-	-
Benzo[b]fluoranthene[3]	4.1E-07	-	-
Benzo[g,h,i]perylene[3]	7.4E-09	-	-
Benzo[k]fluoranthene[3]	8.0E-08	-	-
Chrysene[3]	2.8E-08	-	-
Dibenzo[a,h]anthracene[3]	1.0E-06	-	-
Fluoranthene[3]	2.1E-08	-	-
Indeno[1,2,3-cd]pyrene[3]	2.5E-08	-	-
Phenanthrene[3]	8.9E-09	-	-
Arsenic	9.7E-07	-	-
Chromium VI	4.9E-08	-	-

[1]Multimedia assessment includes consideration of ingestion (water, soil, sediment, food), contributions from air (aerial deposition) and dermal contact.

[2]Baseline concentrations based on data provided in JRP IR-6.26 and baseline soil and vegetation assessment as described within Addendum 10, Appendix 4.9-1, CIAR #251.

[3]HQ and ILCR results are the same as those presented in "*Grassy Mountain Coal Project Environmental Impact Assessment Updated Human Health and Wildlife Screening Risk Assessment*" (Addendum 10, Appendix 4.9-1, CIAR #251) as consideration of groundwater contribution had no effect on predicted surface water concentration(s). Values presented are worst-case mine site estimates from the maximum point of impingement (MPOI) relating to aerial deposition.

[4]Due to the ameliorating effect of sulphate HQ results are lower for application than baseline (project contributions increase sulphate concentrations in Blairmore Creek).

Table 7-3 Predicted Hazard Quotients and ILCR Results for the Multimedia Assessment Gold Creek[1]

Parameter	Project	Baseline[2]	Application
HQ – Toddler Receptor			
Acenaphthene[3]	8.4E-08	1.3E-02	1.3E-02
Acenaphthylene[3]	8.6E-07	8.9E-03	8.9E-03
Anthracene[3]	2.1E-07	2.8E-03	2.8E-03
Fluorene[3]	9.7E-06	4.9E-02	4.9E-02
Pyrene[3]	2.4E-06	6.4E-02	6.4E-02
Fluoranthene[3]	1.2E-05	4.9E-02	4.9E-02
Formaldehyde[3]	1.4E-07	2.5E-07	3.1E-07
Aluminium	3.3E-03	**3.2E+00**	**3.2E+00**
Antimony	3.8E-02	**2.5E-01**	**2.8E-01**
Barium	1.1E-02	**1.1E+00**	**1.1E+00**
Beryllium	2.8E-03	1.9E-02	2.1E-02
Cadmium	5.9E-02	**2.1E+00**	**2.2E+00**
Chromium II/III	1.1E-05	2.6E-04	2.7E-04
Cobalt	4.7E-02	**3.0E-01**	**3.4E-01**
Copper	4.7E-03	2.0E-01	2.0E-01
Lead	3.0E-02	**1.1E+00**	**1.1E+00**
Manganese	2.0E-02	**1.1E+01**	**1.1E+01**
Mercury	7.9E-04	2.0E-04	8.3E-04
Methylmercury	1.5E-01	4.5E-02	1.7E-01
Molybdenum	6.3E-03	1.4E-01	1.4E-01
Nickel	3.2E-02	6.1E-02	9.2E-02
Selenium	**7.1E-01**	**7.1E-01**	**9.7E-01**
Silver	-	2.4E-04	2.4E-04
Thallium	1.1E-01	**1.0E+01**	**1.0E+01**
Uranium	5.5E-03	3.1E-02	3.5E-02
Vanadium	5.7E-02	**3.2E-01**	**3.7E-01**
Zinc	1.1E-02	**5.8E-01**	**5.9E-01**
ILCR – Composite Receptor			
Benz[a]anthracene[3]	2.2E-09	-	-
Benzo[a]pyrene[3]	8.0E-07	-	-
Benzo[b]fluoranthene[3]	4.1E-07	-	-
Benzo[g,h,i]perylene[3]	7.4E-09	-	-

Table 7-3 Predicted Hazard Quotients and ILCR Results for the Multimedia Assessment Gold Creek[1]

Parameter	Project	Baseline[2]	Application
Benzo[k]fluoranthene[3]	8.0E-08	-	-
Chrysene[3]	2.8E-08	-	-
Dibenzo[a,h]anthracene[3]	1.0E-06	-	-
Fluoranthene[3]	2.1E-08	-	-
Indeno[1,2,3-cd]pyrene[3]	2.5E-08	-	-
Phenanthrene[3]	8.9E-09	-	-
Arsenic	9.3E-07	-	-
Chromium VI	1.2E-07	-	-

[1]Multimedia assessment includes consideration of ingestion (water, soil, sediment, food), contributions from air (aerial deposition) and dermal contact.

[2]Baseline concentrations based on data provided in IR6.26 and baseline soil and vegetation assessment as described within Addendum 10, Appendix 4.9-1, CIAR #251.

[3]HQ and ILCR results are the same as those presented in "*Grassy Mountain Coal Project Environmental Impact Assessment Updated Human Health and Wildlife Screening Risk Assessment*" (Addendum 10, Appendix 4.9-1, CIAR #251) as consideration of groundwater contribution had no effect on predicted surface water concentration(s). Values presented are worst-case mine site estimates from the maximum point of impingement (MPOI) relating to aerial deposition.

Table 7-4 Predicted Hazard Quotients and ILCR Results for the Multimedia Assessment Oldman Reservoir[1]

Parameter	Project	Baseline[2]	Application
HQ – Toddler Receptor			
Aluminium	0.0E+00	**3.2E+00**	**3.2E+00**
Antimony	0.0E+00	**2.1E-01**	**2.1E-01**
Barium	7.7E-03	**1.1E+00**	**1.1E+00**
Beryllium	2.9E-04	3.5E-02	3.5E-02
Cadmium	3.7E-03	**2.8E+00**	**2.8E+00**
Chromium II/III	9.5E-07	4.1E-04	4.2E-04
Cobalt	2.1E-03	**3.1E-01**	**3.2E-01**
Copper	1.7E-04	2.0E-01	2.0E-01
Lead	3.5E-04	**1.2E+00**	**1.2E+00**
Manganese	1.1E-03	**1.1E+01**	**1.1E+01**
Mercury	1.3E-05	2.5E-04	2.6E-04
Methylmercury	5.1E-03	9.5E-02	1.0E-01
Molybdenum	3.9E-03	1.5E-01	1.6E-01

Table 7-4 Predicted Hazard Quotients and ILCR Results for the Multimedia Assessment Oldman Reservoir[1]

Parameter	Project	Baseline[2]	Application
Nickel	1.6E-03	6.2E-02	6.4E-02
Selenium	2.1E-02	**2.3E-01**	**2.5E-01**
Silver	-	-	-
Thallium	0.0E+00	**9.6E+00**	**9.6E+00**
Uranium	-	-	-
Vanadium	2.2E-03	**4.1E-01**	**4.1E-01**
Zinc	5.2E-04	**5.9E-01**	**5.9E-01**
ILCR – Composite Receptor			
Arsenic	4.4E-08	-	**-**
Chromium VI	1.6E-08	-	**-**

[1]Multimedia assessment includes consideration of ingestion (water, soil, sediment, food) and dermal contact.

[2]Baseline concentrations based on data provided in JRP IR-6.26 and assumed regional similarity with baseline soil and vegetation measurements as described within Addendum 10, Appendix 4.9-1, CIAR #251.

Results presented in Tables 7-1 through 7-4 are summarized as follows:

- Apart from cobalt in the EPL none of the assessed COPCs under any of the Project case scenarios exceeded a target HQ of 1.0.
- None of the carcinogenic COPCs under any of the Project case scenarios exceeded a target ILCR of 1 in 100,000 (1.E-05).
- A number of COPCs exceeded the target HQ of 0.2 under the Project case at the EPL which included:
  - Antimony;
  - Manganese;
  - Nickel;
  - Selenium;
  - Thallium; and
  - Vanadium.
- A number of COPCs exceeded the target HQ of 0.2 under the Project case at Blairmore Creek which included:
  - Antimony;
  - Methylmercury;
  - Selenium; and
  - Thallium.

- Apart from selenium the Project does not contribute to any COPCs exceeding a target HQ of 0.2 at Gold Creek;
- Several COPCs exceeded a target HQ of 0.2 (antimony, barium, copper, molybdenum, nickel, selenium, vanadium and zinc) and a target HQ of 1.0 (aluminum, cadmium, cobalt, lead, manganese and thallium) under the Application case at a variety of locations. These results are often the cause of naturally elevated concentrations in the background vegetation and soil and are consistent with those results originally reported in the *Grassy Mountain Coal Project Environmental Impact Assessment Updated Human Health and Wildlife Screening Risk Assessment* (Addendum 10, Appendix 4.9-1, CIAR #251).

It should be noted that Baseline, Project, and Application cases included predicted exposures estimated for three exposure pathways: inhalation (air, soil); ingestion (soil, surface water, fish, wild game, vegetation); dermal (swimming). Therefore, Benga considers that a comparison with an HQ of 0.2 is overly conservative. In addition, as stated in HHRA guidance (AHW 2011; Health Canada 2010a), an HQ greater than 1.0 is not necessarily an indication of potential risk and additional assessment of the assumptions built into the HHRA is required to determine whether potential risk of adverse health effects is indicated.

A review of the risk results presented in Tables 7-1 through 7-4 was conducted for all COPCs which exceeded a target HQ of 0.2 to determine whether the predicted HQ indicate a risk of potential adverse health effects; a discussion of each is presented below.

7.2.1.1 Aluminum

Aluminum is a common element that makes up about 8% of the earth's crust, is typically found in soil at concentrations of 1-30% and has relatively low toxicity to humans (Krewski *et al*. 2007). The TRV developed for aluminum is not based on a human health effect study; rather, it is based on several different animal dietary studies with an uncertainty factor applied (WHO 2007). It was further noted that a lower bioavailability of aluminum compounds in food items likely exists as compared to the reviewed dietary studies. There is no AEP (2019) guideline for aluminum concentration in soil and there is "*no consistent, convincing evidence that aluminum in drinking water causes adverse health effects in humans*" (Health Canada 2019).

Due to low inherent toxicity and the fact that measured concentrations are consistent with what would be expected to naturally occur in background; aluminum is not considered to be a human health concern for the Project.

7.2.1.2 Antimony

Antimony HQ results were predicted to be greater than 0.2 but less than 1.0 for both Project and Application cases for both the EPL and Blairmore Creek and greater than 0.2 but less than 1.0 for only the Application case at both Gold Creek and the Oldman Reservoir. The drinking water quality guideline for the protection of human health is set at 0.006 mg/L (Health Canada 2019). Predicted Application case surface water concentrations were highest at the EPL (0.003 mg/L), followed by Blairmore Creek (0.001 mg/L) and both Gold Creek and the Oldman Reservoir (<0.001 mg/L). Therefore, as predicted surface water concentrations are below Canadian drinking water quality guidelines exposure to antimony through drinking water is not considered to be a human health concern for the Site.

Predicted HQ results are driven primarily through background exposure estimates which are considered an artifact of the conservatism built into the human health exposure model (Addendum 10, Appendix 4.9-1, CIAR #251). As no HQ greater than 1.0 was predicted, antimony is not considered a human health concern.

7.2.1.3 Barium, Cadmium, Copper, Lead, Manganese, Thallium and Zinc

For each of these chemicals the predicted HQ values for the Application case scenario are as a result of background measured concentrations. In all cases Project case contribution predictions were less than 0.2 and the additional consideration of groundwater contribution to the human health risk model has had no material effect on the conclusions of the updated HHRA provided in Addendum 10, Appendix 4.9-1, CIAR #251. A more detailed risk discussion with respect to background concentrations and their low likelihood for adverse effect is provided for these metals within the *Grassy Mountain Coal Project Environmental Impact Assessment Updated Human Health and Wildlife Screening Risk Assessment* (Addendum 10, Appendix 4.9-1, CIAR #251) report.

7.2.1.4 Cobalt

Cobalt concentrations were predicted to exceed a target HQ of 1.0 at the EPL. At all other locations (Blairmore Creek, Gold Creek and the Oldman Reservoir) predicted HQ values were less than 1.0 and driven by background. As a result, the discussion presented herein focuses on consideration of the EPL. Cobalt is not considered a human health risk at Blairmore Creek, Gold Creek or the Oldman Reservoir.

There are no soil or groundwater quality guidelines available in relation to adverse effects on human heath at either the Provincial or Federal level. The toxicological reference value (TRV) used in the HHRA is based on as single study in which cardiomyopathy was noted during an 8-month exposure study *via* the consumption of cobalt beer (Vermeire *et al.* 1991). The study notes that simultaneous consumption of alcohol may have enhanced cardiac effect and confidence in the TRV is low. The

study reported a tolerable daily intake (TDI) of 0.0014 mg/kg bw/day and within the EPL the calculated Application case exposure was modeled to be 0.0002 mg/kg bw/day. Provided the low level of confidence in the study and the fact that the reported TDI is 7.6 times higher than the modelled dose assuming a person was to consume all their daily drinking water from the EPL over an extended period (chronic exposure), cobalt is not considered a human health risk.

7.2.1.5 Methylmercury

Methylmercury (MeHg) is not a COPC identified in the Project air emissions; however, elemental mercury was identified as a COPC due to its occurrence in soils and rock and therefore road and blasting dust was identified as a potential source of elemental mercury. In addition, MeHg was also predicted to occur as a result of surficial run-off and groundwater contribution.

An estimate of potential risk of adverse human health effects associated with exposure to MeHg *via* dietary exposure was conducted. The results of this assessment indicated that potential exposure to MeHg *via* consumption of fish does not pose a risk of adverse health effects. Details of the methods and assumption applied in the MeHg assessment are provided below.

Methylmercury concentrations are higher in large-bodied, longer-living animals; those at the top of the food chain like predatory fish. Methylmercury is produced primarily under anaerobic conditions, methylated mostly by anaerobic bacteria, particularly sulfate reducers and methanogens in aquatic sediments (Environment and Climate Change Canada 2017). Therefore, the anaerobic conditions of lake sediments, rather than rivers, streams or creeks, have a higher potential for MeHg formation. To conservatively estimate the potential upper boundary of MeHg that may bioaccumulate in fish, a review of available lake conversion or translation factors for total to MeHg, along with bioaccumulation factors (BAF) for predatory fish relevant to human consumption from regulatory agencies were completed.

Due to the complexities in food chain modelling for mercury, methylmercury in fish has been reported to be more accurately estimated from dissolved methyl-mercury concentrations *via* a bioaccumulation factor (US EPA 2001 and 2009; RIVM 2015). The US EPA has published a translation factor which can be used to estimate the proportion of dissolved MeHg from total mercury in surface water (US EPA, 2001, 2009). Published translation factors are available for rivers, estuaries and lakes. The translation factor of 0.032 (dissolved MeHg/total Hg) for lakes was applied herein. The national BAF designed to estimate the central tendency of the concentrations of mercury in fish of a given trophic level from an average concentration from the US EPA (2001) was applied to estimate bioaccumulation in fish; a value of 2,670,000 was applied.

Health Canada has published a tolerable daily intake (TDI) for MeHg of 0.47 µg/mg-bw/d for the general adult population and 0.2 µg/mg-bw/d for women of child-bearing age and children <12 years old (Health Canada 2010c; Health Canada 2007). The TDI of 0.2 µg/mg-bw/d was applied herein for all age groups.

Except for Blairmore Creek all remaining HQs were below 0.2 and no locations reported an HQ greater than 1.0. Multiple levels of conservatism were applied in this this assessment, these include:

- The application of the translation factor for lakes, which is higher relative to aerobic systems like rivers and creeks, assumes that fish are exposed only to lake water. Blairmore Creek is characterized as a low order stream.
- The use of the maximum available BAF of 2,670,000 assumes that all fish consumed are from trophic level four (food chain apex), while in reality fish from both trophic level three and four are reported as traditional food items (Chan *et al*. 2016).
- The additive contribution of the maximum predicted air concentrations from within the RSA-MPOI is a highly conservative assumption.

Given the conservatism built into the evaluation of methylmercury in combination with a derived HQ result that is below 1.0, methylmercury is not considered to be a human health concern.

7.2.1.6 Molybdenum

Molybdenum is an essential dietary nutrient which is a constituent of several mammalian enzymes. The TRV selected for use in the current HHRA is based on the results of a 6-year to lifetime dietary exposure study correlated to the dietary intake of molybdenum with serum uric acid levels from the US EPA (1993). Based on the results of the study, a molybdenum intake of 0.14 mg/kg bw/day could result in serum uric acid levels elevated above the average range of the adult population; this level was designated as a LOAEL. Confidence in the value is considered high and the final chronic oral value applied within the HHRA was 0.005 mg/kg bw/day based on a cumulative uncertainty factor (UF) of 30 (3-fold reduction for protection of sensitive individuals and a 10-fold reduction for the use of a LOAEL).

Predicted total daily exposure for the toddler was estimated at 0.002 mg/kg bw/day under the application-case scenario. This value is below the TRV established by the US EPA and well below that of the less-conservative tolerable daily intake (TDI) value published by Health Canada (2010c) of 0.023 mg/kg bw/day for ages 0 to 11 years. Had the less conservative value published by Health Canada been selected the resultant application-case HQ within the EPL (the area of highest predicted human exposure) would have been calculated as 0.09 which is well below the target HQ value of 0.2. Therefore, molybdenum concentrations predicted within the HHRA are not considered to pose a human health concern.

7.2.1.7 Nickel

Metallic nickel and nickel alloys are considered possible human carcinogens by the International Agency for Research on Cancer (IARC) (Group 2B) and as reasonably expected to be human carcinogens by the National Toxicology Program (NTP) (Group R). However, no defensible slope factors are available for nickel exposure *via* ingestion and consistent with Health Canada (2010c) nickel is treated as a non-carcinogen through oral exposure (ingestion).

Nickel concentrations were predicted to exceed a target HQ of 0.2 within the EPL for both the project and application case scenarios but did not exceed an HQ of 1.0. Exposure was as a result of direct ingestion (chronic ingestion of the EPL water) and modelled human exposure for the project and application case were calculated as 0.0051 and 0.0052 mg/kg bw/day, respectively. In comparison, the current Health Canada (2010c) TDI for nickel (which includes water-soluble forms [nickel sulphate and nickel chloride] as well as more stable forms such as nickel-bearing sulphide minerals and nickel oxide) is 0.011 mg/kg bw/day.

Food containing nickel is the major source of exposure in the general population and the average person ingests approximately 0.17 mg/day (Agency for Toxic Substance and Disease Registry [ATSDR] 2005). The equivalent daily dose for a toddler, assuming an exposure of 0.17 mg/day and an average body weight of 16.5 kg is 0.010 mg/kg. This is well aligned with the Canadian Environmental Protection Agency (CEPA) "*Priority Substances List Assessment Report for Nickel and its Compounds*" report which cited food as the major source of exposure for the general population with an average person aged between 0.5 to 4.0 years having an estimated intake of 0.016 mg/kg bw/day (CEPA 1994).

Although no water quality guideline currently exists for comparison within Canada, the World Health Organization (WHO) provides a drinking-water quality guideline for nickel of 0.07 mg/L (WHO 2005). This guideline, which is based on consideration of individuals who had been exposed to drinking water containing nickel on an empty stomach, accounts for consideration that only 20% of the daily intake be apportioned to drinking water. Predicted concentrations within the EPL are anticipated at 0.14 mg/L which is twice that of the WHO (2005) guideline.

Risk results presented within the HHRA included consideration that 100% of a persons daily drinking water consumption is obtained from the EPL over a duration of chronic-exposure, a highly conservative assumption. Therefore, while the potential for risk due to drinking water contained within the EPL was modeled, the predictive risk is based largely on a person's cumulative exposure to nickel through diet (food and water). As the EPL concentrations are not based on measured values, but rather a modeled worst-case scenario, the results indicated herein are supportive of further consideration to be taken with respect to the management of the EPL at time of creation (end of mine life) when actual surface water concentrations (data) and meaningful dietary contributions can be

ascertained. Risk results as presented within this section are an indication that additional consideration should be taken to assure protection of human health, not that adverse human health effect will occur as a result of exposure to water in the EPL.

7.2.1.8 Selenium

Selenium HQ results exceeded a target HQ of 0.2 but remained below an HQ of 1.0 at all locations. Except for the EPL, HQ results are driven by the fish ingestion pathway due to predicted fish tissue concentrations.

The maximum acceptable concentration (MAC) for selenium in drinking water is 0.05 mg/L and is based on "*chronic selenosis symptoms, such as hair loss, nail anomalies or loss, skin anomalies and garlic odour of the breath*" (Health Canada 2014). At the EPL, the predicted surface water concentration is 0.03 mg/L. Provided that the EPL meets the current drinking water quality guidelines presented by Health Canada, and given that the multimedia model predicts an HQ of less than 1.0, selenium is not considered a human health concern at the EPL, in the event fish become present.

At all other study locations human exposure predictions are driven by predicted concentration of selenium in fish tissue. Trophic transfer mechanisms are complex and are highly dependent upon the ameliorating affect of sulphate within the system. Detailed information with respect to the various levels of conservatism built into predicting fish tissue concentrations is provided JRP IR-6.28. Predicted surface water concentrations at Blairmore Creek (Figure 6.25-4), Gold Creek (Figure 6.25-5), and the Oldman Reservoir (Figure 6.26-7) are all over an order of magnitude lower than the drinking water quality guideline. Based on the various levels of conservatism built within the fish tissue prediction model, the fact that surface water concentrations are well below drinking water criteria and given the fact that predicted HQ results are less than 1.0 in the multimedia model, selenium is not considered a human health risk.

7.2.1.9 Vanadium

Vanadium HQ results exceeded a target HQ of 0.2 but remained below an HQ of 1.0 at all locations. Except for the EPL, application-case HQ results were driven entirely by measured background concentrations in soil. Vanadium is not considered a human health risk at Blairmore Creek, Gold Creek or the Oldman Reservoir.

The vanadium project-case HQ result is a consequence of the assumption that a person will obtain 100% of their daily drinking water from the EPL, a highly conservative assumption. Presently, there is no Canadian drinking water quality guideline to compare the predicted surface water concentration within the EPL; therefore, the search was extended internationally. The Italian Ministry of Health has proposed a parametric value of 0.14 mg/L (Directive 98/83/EC), derived from a chronic

toxicity study in rats receiving sodium metavanadate drinking water over a lifetime of exposure (Boscolo *et al.* 1994). This concentration is considered as the limit set for the total presence of vanadium in water intended for human consumption without adverse effect and includes in its derivation an anticipation for alternative exposure routes (vanadium exposure through food) (Crebelli and Leopardi 2012). The guideline value is therefore considered a suitable comparison within the HHRA. As the concentration of vanadium within the EPL (0.016 mg/L) is nearly an order of magnitude lower than the Italian Ministry of Health drinking water quality guideline vanadium concentration within the EPL are not considered a human health concern.

7.3 Additive Risk Results for Multiple Contaminant Exposure (Mixtures)

Chemicals that have similar effects on the same target organs were assumed to have additive toxicity (*i.e.,* the toxic effects are combined). The results of the additive toxicity assessment to multiple contaminant exposures are provided below in Table 7-5 (EPL), Table 7-6 (Blairmore Creek), Table 7-7 (Gold Creek) and Table 7-8 (Oldman Reservoir).

Table 7-5 Predicted Additive Hazard Quotients and ILCR Results by Toxicity Groups for Multimedia Exposures (Oral and Dermal)[1] - EPL

Toxicity Endpoint	End Pit Lake		
	Project	Baseline	Application
Gastrointestinal (HQs)	5.4E-02	2.1E-01	**2.5E-01**
Liver (HQs)	9.6E-01	**3.8E+00**	**4.8E+00**
Kidney (HQs)	2.3E-01	**3.1E+00**	**3.2E+00**
Reproductive (HQs)	8.3E-01	**4.6E+00**	**5.1E+00**

[1]Considers air, groundwater, surface water and food ingestion as possible sources of exposure.

Table 7-6 Predicted Additive Hazard Quotients and ILCR Results by Toxicity Groups for Multimedia Exposures (Oral and Dermal)[1] – Blairmore Creek

Toxicity Endpoint	Blairmore Creek		
	Project	Baseline	Application
Gastrointestinal (HQs)	4.4E-03	2.3E-01	2.2E-01
Liver (HQs)	3.4E-01	**4.4E+00**	**4.7E+00**
Kidney (HQs)	3.4E-01	**3.4E+00**	**3.7E+00**
Reproductive (HQs)	1.3E-01	**4.7E+00**	**4.8E+00**
Gastrointestinal Tumours (ILCR)	2.4E-06	-	-

[1]Considers air, groundwater, surface water and food ingestion as possible sources of exposure.

Table 7-7 Predicted Additive Hazard Quotients and ILCR Results by Toxicity Groups for Multimedia Exposures (Oral and Dermal)[1] – Gold Creek			
Toxicity Endpoint	**Gold Creek**		
	Project	**Baseline**	**Application**
Gastrointestinal (HQs)	7.5E-03	2.2E-01	2.2E-01
Liver (HQs)	7.6E-01	**4.5E+00**	**4.8E+00**
Kidney (HQs)	7.6E-02	**3.4E+00**	**3.5E+00**
Reproductive (HQs)	1.2E-01	**4.7E+00**	**4.8E+00**
Gastrointestinal Tumours (ILCR)	2.4E-06	-	-

[1]Considers air, groundwater, surface water and food ingestion as possible sources of exposure.

Table 7-8 Predicted Additive Hazard Quotients and ILCR Results by Toxicity Groups for Multimedia Exposures (Oral and Dermal)[1] – Oldman Reservoir			
Toxicity Endpoint	**Oldman Reservoir**		
	Project	**Baseline**	**Application**
Gastrointestinal (HQs)	4.6E-04	2.4E-01	2.4E-01
Liver (HQs)	2.1E-02	**3.8E+00**	**3.9E+00**
Kidney (HQs)	1.1E-02	**3.9E+00**	**3.9E+00**
Reproductive (HQs)	4.2E-03	**4.9E+00**	**4.9E+00**

[1]Considers air, groundwater, surface water and food ingestion as possible sources of exposure.

Results presented in Tables 7-5 through 7-8 include exposure to COPCs occurring in surface water as well as COPC deposited from air onto water. Baseline results also included exposure to measured vegetation and soil concentrations. A summary is as follows:

- No additive HQ results for the Project were greater than 1.0 and no ILCR results exceeded a value of 1 in 100,000 (1.0E-05).
- Application-case exceedances were driven almost entirely as a result of the Baseline case and therefore were driven by background concentrations through oral (multimedia) exposure. This is in alignment with the results as previously discussed in the *Grassy Mountain Coal Project Environmental Impact Assessment Updated Human Health and Wildlife Screening Risk Assessment* (Addendum 10, Appendix 4.9-1, CIAR #251) report.

7.4 Chronic Multiple Exposure (Inhalation & Ingestion) Cumulative Risk Results

The combined HQ results for multimedia (oral and dermal) and chronic inhalation exposure routes which have a similar critical effects pathways (liver and kidney) are provided below in Table 7-9 (EPL), Table 7-10 (Blairmore Creek), Table 7-11 (Gold Creek) and Table 7-12 (Oldman Reservoir). No change in predicted risks were observed with the combination of chronic inhalation HQs and ILCR and multimedia HQs.

Table 7-9 Predicted Additive Hazard Quotients by Toxicity Groups for Multimedia (Oral and Dermal) and Chronic Inhalation Exposures *via* Similar Critical Effects Pathways – EPL

Toxicity Endpoint	End Pit Lake		
	Project	Baseline	Application
Liver (HQs)	9.6E-01	**3.8E+00**	**4.8E+00**
Kidney (HQs)	2.3E-01	**3.1E+00**	**3.2E+00**

Table 7-10 Predicted Additive Hazard Quotients by Toxicity Groups for Multimedia (Oral and Dermal) and Chronic Inhalation Exposures *via* Similar Critical Effects Pathways – Blairmore Creek

Toxicity Endpoint	Blairmore Creek		
	Project	Baseline	Application
Liver (HQs)	6.7E-01	**4.4E+00**	**4.7E+00**
Kidney (HQs)	3.4E-01	**3.4E+00**	**3.7E+00**

Table 7-11 Predicted Additive Hazard Quotients by Toxicity Groups for Multimedia (Oral and Dermal) and Chronic Inhalation Exposures *via* Similar Critical Effects Pathways – Gold Creek

Toxicity Endpoint	Gold Creek		
	Project	Baseline	Application
Liver (HQs)	7.6E-01	**4.5E+00**	**4.8E+00**
Kidney (HQs)	7.6E-02	**3.4E+00**	**3.5E+00**

Table 7-12 Predicted Additive Hazard Quotients by Toxicity Groups for Multimedia (Oral and Dermal) and Chronic Inhalation Exposures *via* Similar Critical Effects Pathways – Oldman Reservoir

Toxicity Endpoint	Oldman Reservoir		
	Project	Baseline	Application
Liver (HQs)	2.1E-02	**3.8E+00**	**3.9E+00**
Kidney (HQs)	1.2E-02	**3.9E+00**	**3.9E+00**

8.0 ASSESSMENT OF UNCERTAINTY

Risk assessments are subject to several uncertainties. Typically, these uncertainties are addressed using conservative assumptions to ensure that predictions are protective of human health. Specific sources of uncertainty for the present assessment include:

- Concentrations of chemicals in ambient air can be highly variable. To address this, worst-case concentrations were used to assess human health risks. Risk quotients were calculated based on the MPOI, while exposure is more likely to occur at specific receptor locations, resulting in a likely over-prediction of risks. This applies specifically in the additive risk and chronic multiple exposure risk scenarios (Sections 7.3 and 7.4).
- The existing sources within the study area (EIA, Section E.1.2, CIAR #42) likely contribute to baseline exposures of COPCs but there is uncertainty in the magnitude of this contribution; therefore, rather than assessing the incremental contribution of the Project to risks for non-threshold substances, the combined baseline and Project exposures were assessed against incremental exposure limits.
- Indigenous populations may harvest country foods (local vegetation and wildlife) from locations other than where they live. Most Indigenous groups live on reserve and in urban centers outside of the Crowsnest Pass; however, for the HHRA, this receptor type was assumed to live at all the HHRA receptor locations, harvesting foods from the highest predicted concentration areas, and therefore results in a highly conservative estimate of chronic exposure.
- Toxic interactions between chemicals are generally poorly known. This was addressed by assuming additive interactions between chemicals producing similar effects on the same organs.
- Organic chemicals may be metabolized by plants and animals; however, the extent of metabolization is often uncertain. As a result, metabolization was not generally accounted for, resulting in likely over-prediction of COPC concentrations in plants and animals.

- Additional conservative assumptions were made in order to avoid under predicting potential exposure and risk to human receptors, including:
  - assuming COPC concentrations would persist for 80 years;
  - chronic exposure was assumed to occur 7 days per week, 365 days per year;
  - no transformation processes which would reduce exposure potentials for metals or organic COPCs in soil were assumed conversely enrichment factors were applied;
  - COPCs were all assumed to be fully bioavailable in food;
  - all food eaten by receptors was assumed to be derived from the study area, with wild game spending their entire lifespan within the study area; and
  - dermal exposure was assumed to occur year-round.
- A large body of relevant literature has been published regarding selenium transport through the trophic systems. For the current assessment maximum bioconcentration and trophic transfer values were applied.
- Input data for HHRA includes predicted concentrations of COPC in air, soil and water each from their relative discipline assessment. The models used to predict COPC concentrations in these media also include numerous conservative assumptions which impact the result of the HHRA.

Overall, the risk assessment is believed to provide a conservative estimate of potential human health risks, and likely over-predicts risks for many scenarios.

9.0 SUMMARY AND CONCLUSIONS

The results of the HHRA demonstrate that emissions from the Project are not predicted to pose a risk of adverse health effects at the receptor locations accessible to the general public (Blairmore Creek, Gold Creek, Oldman reservoir). While risk quotients greater than 1.0 were predicted, they were identified to be within the margins of safety considered within the HHRA and in most cases relate to naturally elevated concentration measured in background.

Due to the conservative assumptions applied in the air dispersion modelling, groundwater and surface water transport modelling and within the HHRA itself, the risk results presented for the Blairmore Creek, Gold Creek and the Oldman Reservoir were not considered to be indicative of a potential risk of adverse human health effects.

While not independently assessed, consideration of the Crowsnest River was addressed as surface water concentrations would be lower than those predicted at Blairmore Creek. Therefore, consideration of the potential for human health risk within Blairmore Creek is inherently protective of

the Crowsnest River and likewise the project is not considered to pose a potential of adverse human health effects within the Crowsnest River.

Predicted risks for the EPL were within acceptable limits in most cases; however, HQs associated with the Project's contributions from end pit high walls to surface water were a substantial contributor to the application HQ results. Given consideration of the apportionment to drinking water of 20% and the margins of safety built into the HHRA (assumptions that 100% of a person drinking water is obtained from the EPL) the results of the HHRA are not considered indicative of a human health concern. However, management considerations of the EPL are warranted and actual measured concentrations at the time of EPL creation should be used to revisit the HHRA assessment.

Air quality monitoring (as described in CR #1a, Section 6.6, CIAR #42; and Addendum 10, Appendix 1.3-1: Draft Air Quality Monitoring and Adaptive Management Plan, CIAR #251) should be undertaken to validate the predicted air concentrations and confirm the conclusion that Project emissions do not pose any risk of adverse health effect. Surface water concentrations within the EPL should be assessed and monitored as a component of the mine closure strategy to assure measured concentrations are not of human health concern.

10.0 LIMITATIONS OF LIABILITY AND CLOSURE

This report has been prepared for Benga Mining Ltd. and pertains solely to the Grassy Mountain Coal Project. The HHRA was based, in part, on site-data and analysis collected and reported by others and was limited to a study of those parameters specifically addressed in these reports. The contents of this report are predicated on the fact that all data provided by others is accurate. MEMS has not sought to independently verify the data provided by others unless otherwise noted. MEMS does not accept responsibility for any deficiency, misstatements or inaccuracies contained in this report as a result of data omissions or misinterpretations by others.

Risk assessments involve a number of uncertainties and limitations. Therefore, the use of the results presented herein to develop site management strategies may either be overly protective or may not necessarily provide complete protection to human receptors or prevent damage of property in all circumstances. Given the assumptions used herein, the HHRA provides a conservative estimate of the risks involved. The services performed in the preparation of this report were conducted in a manner consistent with the level of skill and care ordinarily exercised by professional engineers and scientists practising under similar conditions.

This report has been prepared for the sole and exclusive use of Benga Mining Ltd., who may rely on this report for specific application to this project site. Any other use, or any use of this report by any other party, is prohibited without the express written consent of Benga Mining Ltd. and MEMS.

MEMS accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on the unauthorized use of this report.

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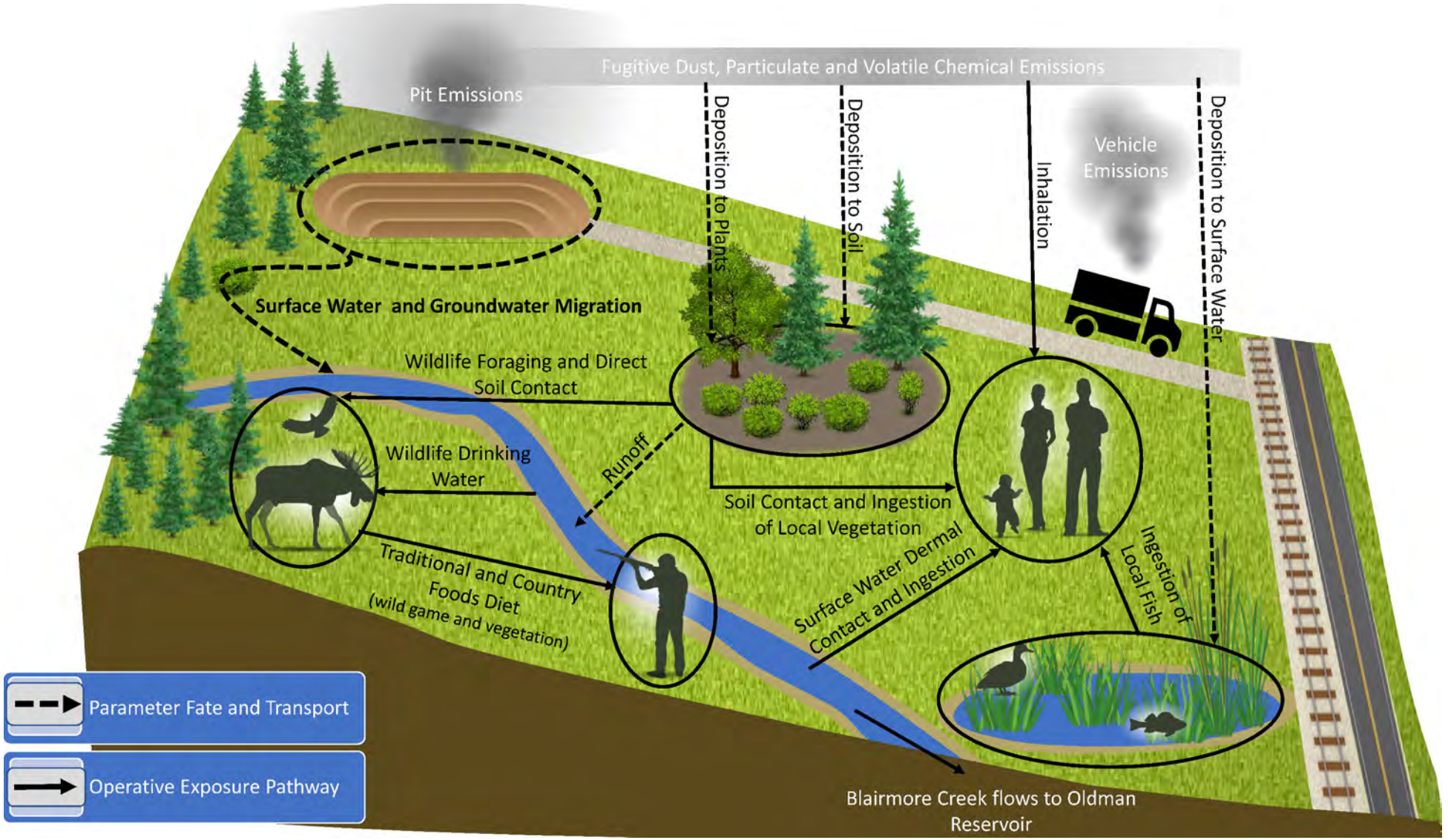

RIVERSDALE RESOURCES

GRASSY MOUNTAIN COAL PROJECT

MILLENNIUM EMS Solutions Ltd.

CONCEPTUAL SITE MODEL (CSM) FOR AN INDIGENOUS HUMAN RECEPTOR

Data Source: MEMS, 2020

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FIGURE
3-1

Document Path: K:\Active Projects 2014\AP 14-00201 to 14-00250\14-00201\MXD\Final Figures\Landuse\ResubmissionInformation Request 3\Fig 3-1 CSM Indigenous Human Receptor 14-00201.mxd

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APPENDIX 6.28-1: WILDLIFE RISK ASSESSMENT - ADDENDUM 1

MILLENNIUM
EMS Solutions Ltd.

#148, 2257 Premier Way
Sherwood Park, AB T8H 2M8
tel: 780.496.9048
fax: 780.496.9049

Suite 202, 701 64 Avenue SE
Calgary, AB T2H 2C3
tel: 403.592.6180
fax: 403.283.2647

#102, 11312 98 Avenue
Grande Prairie, AB T8V 8H4
tel: 780.357.5500
fax: 780.357.5501

toll free: 888.722.2563
www.mems.ca

Wildlife Risk Assessment – Addendum 1

Prepared for:
Benga Mining Limited

Prepared by:
Millennium EMS Solutions Ltd.
Suite 202, 701 – 64 Avenue SE
Calgary, AB T2H 2C3

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File #14-00201

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1.0 INTRODUCTION

Benga provided the *Grassy Mountain Coal Project Environmental Impact Assessment Updated Human Health and Wildlife Screening Risk Assessment* in Addendum 10, as a response to JRP IR-4.9 (Addendum 10, Appendix 4.9-1, CIAR#251). The following provides an addendum to the wildlife screen risk assessment (WRA) to provide additional information associated with aquatic-related wildlife receptors.

This addendum provides the following:

- screening of all wildlife health COPC *via* water-based pathways for the tendency to bioaccumulate in lotic and lentic aquatic systems including Blairmore Creek, Gold Creek, mine facilities such as sedimentation ponds, the planned end pit lake for the post-closure period, and the Oldman Reservoir. Selenium has been included as a COPC;
- the consideration of selenium loadings to the Oldman Reservoir and subsequent uptake into aquatic organisms in the Oldman Reservoir and provide a rationale for any screening-out of other COPC;
- the inclusion of receptors which have diets comprised in whole or in part of aquatic-based prey;
- the inclusion of the ingestion of fish and ingestion of prey which are water-based (such as aquatic invertebrates) in the calculation of hazard quotients for COPC which accumulate in aquatic food chains, including, but not limited to, selenium;
- Exposure Ratios for the representative receptors with an accompanying risk characterization narrative (including an uncertainty analysis); and
- a multi-media exposure risk characterization for representative receptors.

2.0 CHEMICALS OF POTENTIAL CONCERN

2.1 Bioaccumulation Screening

Screening for potential multimedia exposure was conducted in the *Grassy Mountain Coal Project Environmental Impact Assessment Updated Human Health and Wildlife Screening Risk Assessment* (Addendum 10, JRP IR-4.9, Appendix 4.9-1, Appendix H, CIAR #251). This previously completed WRA included assessment of all chemicals of potential concern (COPCs) from direct and indirect exposure to air emissions for potential to bioaccumulate in plant or animal tissue.

Any COPCs that met one of the following criteria were identified as having the potential to bioaccumulate in the previous assessment:

- Molecular weight >200 g/mol;
- Henry's Law constant <1.0x10^{-5} atm-m^3/mol;
- Vapour pressure <1.0x10^{-3} mm Hg; and
- Log octanol-water partition coefficient (log Kow) >3.5 (indicating a potential to bioaccumulate).

From the previously completed WRA, the list of COPCs with the potential to bioaccumulate included:

- polycyclic aromatic hydrocarbons (PAH);
- formaldehyde; and
- all metals.

The contribution of these compounds *via* air deposition to aquatic habitats was previously evaluated as part of the initial wildlife risk assessment (Addendum 10, JRP IR-4.9, Appendix 4.9-1, Appendix H, CIAR#251), including as noted above the potential to bioaccumulate in terrestrial receptors.

For this addendum to the WRA, a review of the organic carbon partition coefficient (Koc) was conducted for each PAH to evaluate the potential for chemical transport *via* groundwater mediated pathways. The Koc is the ratio of a chemical's concentration adsorbed per unit mass of soil, to its concentration in water and gives an indication of the aqueous mobility of a substance. A high value means the compound is strongly adsorbed to soil/ organic matter and would not be of concern for groundwater mediated pathways. PAH in the assessment have Koc values ranging from 5,263 – 1,584,893 (CCME, 2008) indicating these compounds have very high affinities for soil and would not be transported significantly *via* groundwater; as such they have not been considered further.

The supporting documentation for the Canadian Drinking Water Quality Guidelines states the following, "*Formaldehyde biodegrades rapidly in water, and since it can be readily degraded by bacteria in the soil, bioaccumulation does not occur*" (Federal-Provincial-Territorial Committee on Drinking Water, 1997). As such, formaldehyde was screened out and only metals were considered further.

Canada's persistence and bioaccumulation regulations (*Canadian Environmental Protection Act*, 1999; registration 2000-03-23) were applied to enable bioaccumulation screening. This guidance states:

> *A substance is bioaccumulative*
>
> *(a) when its bioaccumulation factor is equal to or greater than 5,000;*

*(b) if its bioaccumulation factor cannot be determined in accordance with a method referred to in section 5 (*generally recognised methods of the Organization for Economic Co-operation and Development or scientific community*), when its bioconcentration factor is equal to or greater than 5,000;*

(c) if neither its bioaccumulation factor nor its bioconcentration factor can be determined in accordance with a method referred to in section 5, when the logarithm of its octanol-water partition coefficient is equal to or greater than 5.

Published bioconcentration factors for all metals were compiled and presented in Table 2-1. Preference was given to bioconcentration factors published by regulatory agencies, followed by primary scientific literature. Compounds determined to be bioaccumulative and carried for further assessment included: silver, mercury, phosphorus, potassium, lead and thallium.

Table 2-1 Bioconcentration Factors for all Metals

Parameter	Bioconcentration Factor[a] (unitless)		
	Aquatic Invertebrates	Algae	Fish
Total Silver (Ag)	298	10696	87.7
Dissolved Aluminium (Al)	4066	600	3
Total Arsenic (As)	73	293	114
Total Barium (Ba)	200	260	633
Total Beryllium (Be)	45	141	62
Total Bismuth (Bi)		<4200	15[b]
Total Calcium (Ca)			1000[b]
Total Cadmium (Cd)	3461	782	907
Total Chloride (Cl)	Does not bioconcentrate (CEQG, 2011)[g]		
Total Cobalt (Co)	<5000[d]		
Total Chromium (Cr)	3000	4406	19
Total Copper (Cu)	3718	541	710
Total Fluoride (F)	Does not bioconcentrate (CEQG, 2002)[e]		

Table 2-1 Bioconcentration Factors for all Metals

Parameter	Bioconcentration Factor[a] (unitless)		
	Aquatic Invertebrates	Algae	Fish
Dissolved Iron (Fe)			<100[c]
Total Mercury (Hg)	55000g	80000g	11168[g]
Total Potassium (K)			10000[j]
Total Lithium (Li)			1[b]
Total Magnesium (Mg)			50[b]
Total Manganese (Mn)			500[b]
Total Molybdenum (Mo)			10[b]
Total Sodium (Na)			20
Total Ammonium (NH4)	Does not bioconcentrate (CEQG, 2010)[f]		
Total Nickel (Ni)	28	61	78
Total Nitrite (NO2)	Does not bioconcentrate[i]		
Total Nitrate (NO3)	Does not bioconcentrate (CEQG, 2012)[h]		
Total Phosphorus (P)			5000[b]
Total Lead (Pb)	5059	1706	0.09
Total Sulphide (S)			1000[b]
Total Antimony (Sb)	7		40
Total Selenium (Se)	1262	1845	129
Total Silicon (Si)			20[b]
Total Tin (Sn)			3000[b]
Total Sulphate (SO4)	Does not bioconcentrate (Health Canada, 1994)		
Total Strontium (Sr)			60[b]
Total Titanium (Ti)			1000[b]
Total Thallium (Tl)	15000	15000	10000

Table 2-1 Bioconcentration Factors for all Metals

Parameter	Bioconcentration Factor[a] (unitless)		
	Aquatic Invertebrates	Algae	Fish
Total Uranium (U)			10[b]
Total Vanadium (V)			200[b]
Total Zinc (Zn)	4578	2175	
Total Zirconium (Zr)			300[b]

Notes:
BOLD – parameter carried for further evaluation
a - US EPA, 1999 - Appendix C
b - Karlsson *et al*., 2002
c - Andersen, 1997
d - CEPA, 1999
e - CCME, 2002
f - CCME, 2010
g - CCME, 2011
h - CCME, 2012
i - US EPA, n.d.

2.2 Surface Water Screening

Modelled surface water concentrations considering the "upper-case" rather than "best estimate" modelling source terms were applied in this addendum to the WRA, as provided in Addendum 11, JRP IR-6.26. Surface water screening was conducted for the proposed water management features, which included the End Pit Lake (EPL) (at closure), North East Sedimentation Pond (NESP), East Sedimentation Pond (ESP), as well as Blairmore Creek, Gold Creek, and the Oldman Reservoir.

Risks for the proposed mine water management features (EPL, NESP, ESP) were assessed based on the proposed plan for these habitats to remain post-closure and it was assumed that risks to wildlife in other aquatic habitats during operations would be addressed through monitoring, and if necessary, operational exposure controls, therefore they are not evaluated further herein.

Contribution of deposition of COPC from air were included in this addendum with the methods for their calculation was provided in updated WRA (Addendum 10, JRP IR-4.9, Appendix 4.9-1,

CIAR#251). With the exception of selenium at Gold Creek, the COPC contribution from air was assumed to be equal to the concentrations predicted at the maximum point of impingement (MPOI). For selenium at Gold Creek, the air contributions were assumed to be equal to the deposition predicted for the human receptor location R12 close to the creek (Addendum 10, JRP IR-4.9, Appendix 4.9-1, Figure A.4, CIAR#251). This location is much nearer to Gold Creek and thus provides a more accurate estimate of potential deposition.

Monthly predicted total metals concentrations were provided for the assessed habitats noted above as per the updated modeling conducted to support with Addendum 11, JRP IR-6.27. The 95th percentile of operations and closure concentrations (beginning in 2043) were applied. Surface water screening of provided operations, closure, application concentrations (maximum) against available surface water screening guidelines protective of freshwater aquatic life was completed. The hierarchy of guideline application began with *Environmental Quality Guidelines for Alberta Surface Waters* (2018), then Canadian Environmental Quality Guidelines, followed by other provincial jurisdictions and lastly the United States Environmental Protection Agency (US EPA).

The combined loadings from the Project site and background loadings were assumed to flow to the Oldman Reservoir and mix completely with the full volume in the reservoir. Inflows and outflows from the reservoir were estimated based on the synthetic hydrograph developed for a 50-year period for the Oldman Reservoir catchment. The assumed volume of the reservoir (380 Mm^3) and background total selenium concentration were adopted from Mitchell (2001). Again, monthly concentrations were calculated using a simple mass balance approach where influent selenium loads were fully mixed with the reservoir volume. Loadings in the discharge from the reservoir was calculated as the concentration calculated in the previous monthly timestep multiplied by the flow out of the reservoir (which was assumed to be equal to the flow into the reservoir) (Addendum 11, JRP IR-6.26, Figure 6.26-7).

A summary of the results of the surface water screening (Appendix A) are presented in Table 2-2.

Table 2-2 Surface Water Screen - Chemicals of Potential Concern (mg/L)

Parameter	Surface Water Screening Guidelines						
	EQG Aquatic Life, AB[a]	AB Tier 1, Table C-11[c]	CCME CEQG[b]	BC Water Quality Guidelines[d]	Ontario Water Quality Criteria[e]	US, EPA 1995, 2005	Applied Screening Value
Total Silver (Ag)	0.00025	0.0001		0.00005	0.0001		2.50E-04
Dissolved Aluminium	0.05			0.007	0.015		5.00E-02
Total Arsenic (As)	0.005	0.005	0.005	0.005	0.1		5.00E-03
Total Barium (Ba)		1		1			1.00E+00
Total Beryllium (Be)					0.011		1.10E-02
Total Bismuth (Bi)							-
Total Calcium (Ca)							-
Total Cadmium (Cd)			0.00009		0.0001		9.00E-05
Total Chloride (Cl)	120	120	120	150			1.20E+02
Total Cobalt (Co)	0.0008			0.004	0.0009		8.00E-04
Total Chromium (Cr)	0.001	0.001			0.001		1.00E-03
Total Copper (Cu)	0.007	0.007			0.001		7.00E-03
Total Fluoride (F)			0.12	1			1.00E+00
Dissolved Iron (Fe)	0.3	0.3	0.3	0.35			3.00E-01
Total Mercury (Hg)	0.000005	0.000005	0.000016		0.0002		5.00E-06
Total Potassium (K)							-
Total Lithium (Li)							-
Total Magnesium (Mg)						82	8.20E+01
Total Manganese (Mn)			0.12				1.20E-01
Total Molybdenum (Mo)	0.073		0.073		0.04		7.30E-02
Total Sodium (Na)							-
Total Ammonium (NH4)			0.019				1.90E-02
Total Nickel (Ni)			0.025		0.025		2.50E-02
Total Nitrite (NO2)	0.02			0.02			2.00E-02
Total Nitrate (NO3)	3	3	13	3			3.00E+00
Total Phosphorus (P)			0.035[k]	0.005			3.50E-02

Table 2-2 Surface Water Screen - Chemicals of Potential Concern (mg/L)

Parameter	Surface Water Screening Guidelines						
	EQG Aquatic Life, AB[a]	AB Tier 1, Table C-11[c]	CCME CEQG[b]	BC Water Quality Guidelines[d]	Ontario Water Quality Criteria[e]	US, EPA 1995, 2005	Applied Screening Value
Total Lead (Pb)	0.001				0.005		1.00E-03
Total Sulphide	0.0019	0.0019					1.90E-03
Total Antimony (Sb)					0.02		2.00E-02
Total Selenium (Se)	0.002	0.002	0.001		0.1		1.00E-03
Total Silicon (Si)							-
Total Tin (Sn)							-
Total Sulphate (SO4)	128			128			1.28E+02
Total Strontium (Sr)						1.5	1.5
Total Titanium (Ti)							-
Total Thallium (Tl)	0.0008		0.0008		0.0003		3.00E-04
Total Uranium (U)	0.015		0.015		0.005		5.00E-03
Total Vanadium (V)						0.02	2.00E-02
Total Zinc (Zn)	0.03	0.03		0.0075	0.02		7.50E-03
Total Zirconium (Zr)					0.004		4.00E-03

Notes:

Concentrations expressed in milligrams per kilogram (mg/L).

a - Alberta Government Environmental Quality Guidelines for Alberta Surface Waters (2018)

b - Canadian Environmental Quality Guidelines, 2003

c - Alberta Tier 1 *Soil and Groundwater Remediation Guidelines*, 2019

d - British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife & Agriculture, 2019

e - Ontario Water Management

Bismuth, calcium, lithium, sodium, silicon, tin, titanium have no available surface water screening values from reviewed regulatory agencies. This lack of screening criteria indicates that at environmentally relevant concentrations adverse effect from exposure to these compounds has not been identified, many being considered innocuous. Additionally, none of these compounds were identified as bioaccumulative in aquatic food webs and as such were not considered further.

COPC that were carried forward based on guideline screening and/or determined to be bioaccumulative included ammonium arsenic, cadmium, chromium, cobalt, copper, lead, manganese, mercury, nickel, nitrate, nitrite, phosphorus, potassium, selenium, silver, sulphide, sulphate, thallium, and zinc.

3.0 AQUATIC WILDLIFE RECEPTORS

The selected aquatic wildlife receptors are intended to act as surrogate mammalian and avian species that represent specific feeding guilds. In some of the habitats evaluated, the selected receptors may not be present; however, they are surrogates for a specific feeding guild and are deemed to be appropriate representatives due to their specific diet composition.

Risk assessment is an iterative process, and initial receptor selection included herbivorous, piscivorous and insectivorous birds and mammals. If risk was predicted for one of these feeding guilds an omnivorous receptor was subsequently evaluated. Overall selection of aquatic receptors considered dietary composition, contaminant sensitivity, the availability of exposure characteristics, and information requested in the preamble of Addendum 11, JRP IR-6.28.

Selected aquatic wildlife receptors applied to all habitats are presented in Table 3-1. Unless noted, receptor characteristics for surrogate species were obtained from Environment Canada (2012) and are summarized in Table 3-2.

Table 3-1 Selected Aquatic Wildlife Receptors

Species	Justification for Inclusion	Feeding Guild
Northern River Otter	High fish ingestion rate	Piscivorous mammal
Beaver	Strict herbivore	Herbivorous mammal
Little Brown Bat	Strict insectivore	Insectivorous mammal
American Dipper	Habitat preference, JRP instruction	Insectivorous bird
Goose	Strict herbivore	Herbivorous bird
Great Blue Heron	Habitat preference, JRP instruction	Piscivorous bird
Mallard duck	Habitat preference, availability of defensible receptor characteristics	Omnivorous Bird

Table 3-2 Aquatic Wildlife Receptor Characteristics for Surrogate Species

Parameter	Aquatic						
	Mammalian Receptors			Avian Receptors			
	Northern River Otter	Beaver[1]	Little Brown Bat[2,3,4]	American dipper[5,6]	Goose[7]	Great Blue heron	Mallard duck
	Piscivore	Herbivore	Insectivore	Insectivore	Herbivore	Piscivore	Omnivore
Body Mass (kg)	7.5	20	0.0075	0.055	3.447	2.3	1.2
Home Range (ha)	900	201	0.1	0.224	170	16.6	9.2
Food Ingestion Rate (kg-dry weight/kg-bw/day)	0.03	0.07	0.0025	0.012	0.033	0.045	0.05
Soil Ingestion Rate (kg/kg-bw/day)	NI	NI	NI	NI	NI	NI	NI
Sediment Ingestion Rate (kg/kg-bw/day)	0.0006	0.0014	0.00005	0.00024	0.00066	0.0009	0.001
Water Ingestion Rate (L/kg-bw/day)	0.08	0.1	0.0011	0.0085	0.189	0.04	0.06
Inhalation Rate (m^3/day)	2.7357886	5.99594345	0.01030652	0.04382242	1.06056	0.76	0.48
Diet Composition:							
- Plants (%)	0	75	0	0	0	0	5
- Soil Invertebrates (%)	0	0	13	0	0	0	0
- Benthic Invertebrates (%)	0	0	0	0	0	0	0
- Vertebrates (%)	0	0	0	0	0	0	0
- Aquatic Plants (%)	0	25	0	0	99	0	50
- Aquatic Invertebrates (%)	15	0	87	75	1	10	40

Table 3-2 Aquatic Wildlife Receptor Characteristics for Surrogate Species

Parameter	Aquatic						
	Mammalian Receptors			Avian Receptors			
	Northern River Otter	Beaver[1]	Little Brown Bat[2,3,4]	American dipper[5,6]	Goose[7]	Great Blue heron	Mallard duck
- Fish (%)	80	0	0	25	0	65	5
- Small Mammals (%)	5	0	0	0	0	25	0
Food Ingestion Rate for all dietary items (kg/d)	0.225	1.4	0.00001875	0.00066	0.113751	0.1035	0.06

Unless noted all receptor characteristics taken from Federal Contaminated Sites Action Plan, Ecological Risk Assessment Guidance - Module 3, 2012

1 - Aleksiuk, M., 1968.

2 - US EPA, 1999.

3 - Sample *et al*., 1996

4 - Anthony and Kunz, 1977.

5 - Morrissey *et al*.. 2005

6 - Price and Brock, 1983.

7 - Ministry of Sustainable Development Environment and Fight against Climate Change, Government of Quebec, 2020.

3.1 Receptor Context & Selection Rationale

Northern River Otter (*Lontra Canadensis*), piscivorous mammal. The river otter is an opportunistic forager that primarily eats fish but will consume other aquatic animals when necessary. River otters can live in freshwater or marine waters and prefer to inhabit the wooded shores of coastlines, lakes, rivers and estuaries. Their home range is highly dependent on available food sources and habitat quality. The river otter was selected as surrogate receptor based on its relative high fish ingestion rate and preference for habitat in the project area.

Beaver *(Castor canadensis),* herbivorous mammal. The beaver is a semi-aquatic herbivorous mammal whose preferred diet includes leaves, bark, twigs, and aquatic plants (Aleksiuk, 1968). Beavers live in forested regions and burrow in the banks of rivers and lakes and build dams and lodges on water courses out of logs, branches, and mud. Beavers are mainly nocturnal and are most active from dusk to dawn. Beavers are active all winter and swim and forage in water beneath surface ice. The beaver was selected as a representative receptor for herbivorous aquatic mammals due to their strict herbivore diet, and their preference for the type of habitat found in the project area.

Little Brown Bat *(Myotis lucifugus),* insectivorous mammal. They do not have any contact with submerged sediments, resulting in a diet primarily consisting of insects captured in flight in open forest canopies, open shorelines, basins of water bodies and wetlands (US EPA, 1999a). Some of their prey spend the first part of their lives in bodies of water, a potential to contaminant exposure. Little brown bats forage along the edges of bodies of waters and vegetated habitats (Crampton and Robert, 1998). Bats inhabiting Canada do not usually migrate, making them year-round residents, hibernating part of the year. The little brown bat was selected as a representative insectivore for its habitat preference and strict insectivore diet.

American Dipper *(Cinclus mesicanus)*, insectivorous bird. The American Dipper is a year-round resident of freshwater streams. Its diet is comprised entirely of aquatic-based food (small fish, fish eggs and benthic macro-invertebrates). American Dippers seasonally migrate up and downstream within a watershed, impacting their diets. The migratory dippers will consume a higher number of insects relative to the river resident dippers (Nagy, 1987). This avian insectivore was chosen as a representative receptor due to their aquatic-based diet composition, preference for habitat in the project area and instruction from the JRP.

Mallard Duck (*Anas platyrhynchos*), omnivorous aquatic bird. The mallard is an adaptable bird and may nest near lakes, ponds, rivers, woodland pools; however, it prefers natural grasslands that surround sloughs or marshy areas. The mallard is a surface-feeding duck, which consumes insects and larvae, aquatic invertebrates and aquatic vegetation, but also seeds and grains (Palmer, 1976). The mallard was selected as a representative omnivorous bird due to its preference for the type of

habitat found in the project area, availability of preferred food sources, and the availability of defensible exposure characteristics.

Great Blue Heron *(Ardea herodias)*, piscivorous bird. The diet of the heron consists predominantly of fish, but will eat amphibians, crustaceans, insects, reptiles and mammals (US EPA, 1993). These migratory birds breed in Canada during the winter and will inhabit themselves along the margins of most freshwater and saltwater bodies (Kushlan, 1978). The location of their nesting grounds can be generally close to their foraging ground in tall trees; however, rock ledges or sea cliffs are also common (Palmer, 1962). This bird was selected as a representative receptor due to their high fish ingestion rate, and habitat preference type.

Canada Goose (*Branta canadensis*), herbivorous bird. This waterfowl species has an almost exclusive vegetarian diet. The Canada goose is the most widespread and abundant goose in North America, migrating away from their breeding grounds during late summer and early autumn. The Canada Goose is a versatile bird that breeds in climates ranging from the lake shores and coastal marshes in the arctic tundra through temperate climates (US EPA, 1993). Canada Goose families are predominantly on land but are found close to water. The goose was selected based on a strict plant diet, allocated entirely for aquatic plants.

4.0 AQUATIC WILDLIFE EXPOSURE

Exposure for all aquatic wildlife included the ingestion of surface water, sediment, aquatic and terrestrial plants, fish, aquatic invertebrates and prey, based on the individual surrogate receptor characteristics. As previously stated in section 2.2, exposure was assessed based on the inhalation of COPC by wildlife predicted in air at the maximum-point-of-impingement for mine facilities. Predicted deposition of COPC was added to modelled surface water concentrations to evaluate exposure. With the exception of selenium at Gold Creek, predicted deposition from air was assumed to equal the concentrations predicted at the maximum-point-of-impingement; for Gold Creek concentrations predicted for human receptor location R12 were used (Addendum 10, JRP IR-4.9, Appendix 4.9-1, Figure A.4, CIAR #251).

Chemical concentrations in environmental media (other than surface water) were estimated as part of the human health risk assessment (Addendum 10, JRP IR-4.9, Appendix 4.9-1, Appendix E, CIAR #251). The estimated concentrations from the regional study area maximum point of impingement (RSA-MPOI) applied in the human health risk assessment were directly applied. These included concentrations for vegetation such as cattails, and prey tissue for receptors that consume small terrestrial-based mammals. It should be noted that applying the RSA-MPOI concentrations is extremely conservative when evaluating population level endpoints for ecological receptors.

The following equations from (Addendum 10, JRP IR-4.9, Appendix 4.9-1, Appendix E, CIAR #251) were used to calculate wildlife exposure doses, and have not been presented again:

- Ingestion of surface water – Equation 16;
- Ingestion of sediment – Equation 15;
- Ingestion of terrestrial plant (plants and berries) – Equation 18;
- Ingestion of fish – Equation 18; and
- Ingestion of prey – Equation 18.

Food ingestion rates were calculated as a fraction of the total food ingestion rates recommended by Environment Canada (2012) based on species dietary composition.

Selenium exposure and food-web modelling was unlike all other COPC. The rationale and calculation of selenium concentrations in periphyton, aquatic invertebrates and fish tissue – along with worked example equations are presented in Appendix B.

5.0 WILDLIFE DAILY THRESHOLD EXPOSURE DOSES

Wildlife oral toxicity reference values referred to as daily threshold exposure doses (DTED) published by CCME, ORNL, and US EPA were identified. The methodology of DTED selection, consideration given to endangered species and chemical specific summaries are presented in Appendix C.

Due to the physiological differences between mammals and birds, separate mammalian and avian DTEDs are specified herein. The selected DTED values are summarized below in Table 4-1. Compounds with no available DTED are identified below and were not evaluated further. The lack of available toxicology for these chemicals is generally an indication of their innocuous nature.

Table 4-1 Selected Daily Threshold Exposure Doses

Chemical	Mammalian DTED		Avian DTED	
	Value (mg/kg/d)	Test Species	Value (mg/kg/d)	Test Species
Ammonium	No data			
Arsenic	1.26	mouse	2.24	chicken
Cadmium	0.456	Sheep	20 1.47[a]	Mallard duck
Chromium	3.28 Cr (VI)	Various	5 2.66[a]	Various

Table 4-1 Selected Daily Threshold Exposure Doses

Chemical	Mammalian DTED		Avian DTED	
	Value (mg/kg/d)	Test Species	Value (mg/kg/d)	Test Species
Cobalt	7.33	Various	7.61	Various
Copper	5.6	Pig	5.23	Hen
Lead	80	Rat	1.8	Quail
Manganese	284	Rat	977	Quail
Mercury (inorganic)	1.01	Mink	0.9	Quail
Methylmercury (organic)	0.015	Mink	0.0064	Mallard
Nickel	25	Rat	107 77.4[a]	Mallard
Nitrite	No data			
Nitrate	1130	Guinea pig	No data	No data
Potassium	No data			
Phosphorus	No data			
Selenium	0.33	Rat	0.3	Chicken
Silver	6.02	Pig	2.02	Turkey
Sulphate	No data			
Sulphide	No data			
Thallium	0.03	Sheep	No data	No data
Zinc	10	Sheep	131 66.1[a]	Chicken

a - value applied for threatened/endangered species.

NB: This lower value was conservatively applied where available for all receptors.

6.0 AQUATIC WILDLIFE RISK

Potential risk to aquatic wildlife receptors was determined by comparing the ratio of predicted total exposure to the DTEDs to a threshold of 1.0. This ratio is referred to has an exposure ratio, where values above 1.0 indicate the potential for adverse effects. Tables D1 to D6 in Appendix D provide the exposure ratios for all scenarios and receptors included in the ecological risk assessment.

Except for selenium, the calculated exposure ratios for all COPCs, for all surrogate aquatic wildlife species in all habitats evaluated were below 1.0.

Selenium exposure ratios of 1.7 and 3.8 were calculated for the insectivorous and omnivorous birds in the EPL, respectively. All other exposure ratios for selenium in other habitats assessed were below 1.0.

7.0 UNCERTAINTY ASSESSMENT

- The uptake of selenium in the presence of differing sulphate concentrations was studied in three primary producers. The relationship developed based on the laboratory study was calibrated with measured enrichment in Blairmore Creek. The derived regression equation for Blairmore Creek was also applied to Gold Creek. While this application carries some uncertainty as water chemistry and the primary producer community composition between systems is naturally variable, based on both systems being lotic and connected this application was believed to be reasonable.
- It was assumed that the relationship observed between selenium and sulphate in the studied primary producers would apply to periphyton broadly in the habitats evaluated, which carries uncertainty. This relationship has been documented in regulatory guidance (US EPA, 2016) and a within a body of scientific literature and while small deviations in enrichment may exist between species, the consistency of this documented relationship would suggest this assumption is reasonable.
- Receptor characteristics for all the bat species listed by the preamble to Addendum 11, JRP IR-6.28 were not available. As per CCME ecological risk assessment guidance, a surrogate receptor was identified based on a compilation of the available receptor characteristics for bats. While this is believed to be appropriate and the best approach given the limited available data, individual species present in the project area may have different receptors characteristics. The magnitude of these receptor characteristic deviations on predicted risk is uncertain but is not expected to be significant.
- The EPL, NESP and ESP are assumed to be non-fish bearing with the waterbody itself not being accessible by fish. Wildlife exposure from the consumption of fish from these habitats is therefore nil. While the EPL has no connection to fish bearing waters the potential for this habitat to support fish is unknown.

8.0 CONSERVATISM AND CONCLUSIONS

Ecological risk assessment, and risk assessment in general, is by-design a conservative process which aims to estimate reasonable worst-case exposure for surrogate receptors. As such, predicted risk (exposure ratios) above a threshold of 1.0 does not indicate adverse effect but rather the potential for

adverse effect at the population level under reasonable worst-case exposure. Major elements of conservatism included in the current assessment include:

- the application of modelled surface water "upper-case" source terms rather than "best-estimate" were applied to derive modelled numbers;
- the 95th percentile of modelled surface water concentrations for operations and closure were applied and the application case evaluated considered the maximum of both; and
- aquatic wildlife receptors were assumed to obtain 100% of food sources from the habitat evaluated, meaning no consideration of home range or migration factor were applied.

Conclusions:

- The potential for risk from exposure to selenium is predicted in the EPL (at closure) for insectivorous and omnivorous birds, driven by the ingestion of invertebrates. The results indicate the potential for adverse effect under the predicted upper bounds of exposure. Based on this, management considerations of the EPL are warranted and actual measured concentrations at the time of EPL creation should be used to revisit this model prediction.
- Risk from other evaluated COPC was not predicted for aquatic wildlife in all other habitats evaluated (NESP, ESP, Blairmore Creek, Gold Creek, and the Oldman Reservoir).

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APPENDIX A – CONSTITUENTS OF POTENTIAL CONCERN (COPC) SCREENING

Surface Water Concentrations (mg/L)

Parameter	Applied Screening Value (mg/L)	NESP & ESP[1,2]			Pit Lake[3]			Blairmore Creek[1,2]			Gold Creek[1,2]			Oldman Reservoir[1]			Car6ed as COPC? (yes/no)
		Project	Background	Application	Project	Background	Application	Project	Background	Application	Project	Background	Application	Project	Background	Application	
Total Silver (Ag)	2.50E-04	0.00E+00	1.75E-05	1.75E-05	1.04E-05	0.00E+00	1.04E-05	1.65E-05	1.75E-05	3.40E-05	4.00E-08	1.75E-05	1.75E-05	-	-	-	Yes[7]
Dissolved Aluminum (Al)	5.00E-02	0.00E+00	5.13E-03	5.13E-03	4.29E-02	0.00E+00	4.29E-02	2.80E-02	5.13E-03	3.32E-02	1.25E-02	5.13E-03	1.77E-02	5.36E-05	6.15E-03	6.20E-03	Yes
Total Arsenic (As)	5.00E-03	0.00E+00	1.90E-04	1.90E-04	**6.91E-03**	0.00E+00	**6.91E-03**	2.47E-04	1.90E-04	4.37E-04	2.32E-04	1.90E-04	4.22E-04	1.72E-05	4.00E-04	4.17E-04	No
Total Barium (Ba)	1.00E+00	0.00E+00	8.14E-02	8.14E-02	2.03E-01	0.00E+00	2.03E-01	1.50E-01	8.14E-02	2.32E-01	3.90E-03	8.14E-02	8.53E-02	5.95E-03	1.07E-01	1.13E-01	No
Total Beryllium (Be)	1.10E-02	0.00E+00	4.42E-04	4.42E-04	2.39E-03	0.00E+00	2.39E-03	0.00E+00	4.42E-04	4.42E-04	6.76E-05	4.42E-04	5.09E-04	9.77E-06	1.00E-03	1.01E-03	No
Total Bismuth (Bi)	-	0.00E+00	0.00E+00	0.00E+00	2.78E-07	0.00E+00	2.78E-07	6.20E-10	0.00E+00	6.20E-10	9.64E-09	0.00E+00	9.64E-09	-	-	-	Yes[4]
Total Calcium (Ca)	-	0.00E+00	5.03E+01	5.03E+01	3.20E+01	0.00E+00	3.20E+01	2.65E+01	5.03E+01	7.68E+01	6.00E-02	5.03E+01	5.04E+01	1.81E+00	4.50E+01	4.68E+01	No
Total Cadmium (Cd)	9.00E-05	0.00E+00	1.32E-05	1.32E-05	**1.77E-03**	0.00E+00	**1.77E-03**	**1.51E-04**	1.32E-05	**1.64E-04**	6.10E-05	1.32E-05	7.42E-05	5.26E-06	**1.00E-03**	**1.01E-03**	Yes
Total Chloride (Cl)	1.20E+02	0.00E+00	4.25E-01	4.25E-01	6.90E-01	0.00E+00	6.90E-01	1.53E+00	4.25E-01	1.95E+00	1.11E-02	4.25E-01	4.36E-01	5.06E-02	7.50E-01	8.01E-01	No
Total Cobalt (Co)	8.00E-04	0.00E+00	2.67E-04	2.67E-04	**4.52E-02**	0.00E+00	**4.52E-02**	**1.20E-03**	2.67E-04	**1.46E-03**	**1.53E-03**	2.67E-04	**1.80E-03**	8.06E-05	**1.00E-03**	**1.08E-03**	Yes
Total Chromium (Cr)	1.00E-03	0.00E+00	5.19E-04	5.19E-04	**6.29E-03**	0.00E+00	**6.29E-03**	5.72E-04	5.19E-04	**1.09E-03**	2.00E-04	5.19E-04	7.19E-04	3.24E-05	**6.00E-03**	**6.03E-03**	Yes
Total Copper (Cu)	7.00E-03	0.00E+00	3.91E-04	3.91E-04	**2.29E-02**	0.00E+00	**2.29E-02**	5.09E-04	3.91E-04	9.00E-04	7.80E-04	3.91E-04	1.17E-03	4.37E-05	1.00E-03	1.04E-03	Yes
Total Fluoride (F)	1.00E+00	0.00E+00	0.00E+00	0.00E+00	6.83E-01	0.00E+00	6.83E-01	2.18E-01	0.00E+00	2.18E-01	2.21E-02	0.00E+00	2.21E-02	6.42E-03	2.10E-01	2.16E-01	No
Dissolved Iron (Fe)	3.00E-01	0.00E+00	2.43E-02	2.43E-02	**2.02E+01**	0.00E+00	**2.02E+01**	7.32E-03	2.43E-02	3.16E-02	0.00E+00	2.43E-02	6.26E-03	2.02E-03	8.00E-02	8.20E-02	No
Total Mercury (Hg)	5.00E-06	0.00E+00	2.75E-07	2.75E-07	**1.55E-05**	0.00E+00	**1.55E-05**	3.02E-06	2.75E-07	3.30E-06	5.10E-07	2.75E-07	7.85E-07	8.53E-08	1.60E-06	1.69E-06	Yes
Total Potassium (K)	-	0.00E+00	6.31E-01	6.31E-01	3.85E+00	0.00E+00	3.85E+00	1.38E+00	6.31E-01	2.02E+00	1.03E-01	6.31E-01	7.34E-01	5.39E-02	8.40E-01	8.94E-01	Yes[5]
Total Lithium (Li)	-	0.00E+00	4.17E-03	4.17E-03	1.76E-02	0.00E+00	1.76E-02	9.35E-03	4.17E-03	1.35E-02	4.42E-04	4.17E-03	4.61E-03	-	-	-	No
Total Magnesium (Mg)	8.20E+01	0.00E+00	1.09E+01	1.09E+01	1.68E+01	0.00E+00	1.68E+01	2.76E+01	1.09E+01	3.85E+01	2.40E-01	1.09E+01	1.11E+01	9.87E-01	1.19E+01	1.29E+01	No
Total Manganese (Mn)	1.20E-01	0.00E+00	4.84E-03	4.84E-03	**7.25E-01**	0.00E+00	**7.25E-01**	2.84E-02	4.84E-03	3.32E-02	2.50E-02	4.84E-03	2.99E-02	1.36E-03	6.00E-03	7.36E-03	Yes
Total Molybdenum (Mo)	7.30E-02	0.00E+00	1.13E-03	1.13E-03	2.30E-02	0.00E+00	2.30E-02	1.65E-02	1.13E-03	1.76E-02	7.27E-04	1.13E-03	1.86E-03	4.85E-04	3.00E-03	3.48E-03	No
Total Sodium (Na)	-	0.00E+00	3.13E+00	3.13E+00	3.55E+00	0.00E+00	3.55E+00	9.95E+00	3.13E+00	1.31E+01	3.20E-02	3.13E+00	3.16E+00	3.36E-01	5.60E+00	5.94E+00	No
Total Ammonium (NH4)	1.90E-02	0.00E+00	**5.00E-02**	**5.00E-02**	**5.91E-01**	0.00E+00	**5.91E-01**	**3.30E+00**	**5.00E-02**	**3.35E+00**	1.84E-02	**5.00E-02**	**6.84E-02**	-	-	-	Yes[4]
Total Nickel (Ni)	2.50E-02	0.00E+00	6.61E-04	6.61E-04	**1.42E-01**	0.00E+00	**1.42E-01**	4.43E-03	6.61E-04	5.09E-03	4.74E-03	6.61E-04	5.41E-03	2.65E-04	1.00E-03	1.27E-03	Yes
Total Nitrite (NO2)	2.00E-02	0.00E+00	1.00E-03	1.00E-03	**1.07E-01**	0.00E+00	**1.07E-01**	2.17E-03	1.00E-03	3.17E-03	3.34E-03	1.00E-03	4.34E-03	-	-	-	Yes
Total Nitrate (NO3)	3.00E+00	0.00E+00	7.18E-02	7.18E-02	**4.67E+00**	0.00E+00	**4.67E+00**	2.95E-01	7.18E-02	3.67E-01	1.45E-01	7.18E-02	2.17E-01	-	-	-	Yes
Total Phosphorus (P)	3.50E-02	0.00E+00	2.66E-03	2.66E-03	**6.09E-01**	0.00E+00	**6.09E-01**	9.77E-03	2.66E-03	1.24E-02	2.11E-02	2.66E-03	2.37E-02	-	-	-	Yes[5]
Total Lead (Pb)	1.00E-03	0.00E+00	5.42E-05	5.42E-05	4.79E-04	0.00E+00	4.79E-04	1.17E-04	5.42E-05	1.71E-04	1.46E-05	5.42E-05	6.87E-05	4.74E-06	1.00E-03	**1.00E-03**	Yes[6]
Total Sulphide	1.90E-03	0.00E+00	1.82E-03	1.82E-03	**4.74E+01**	0.00E+00	**4.74E+01**	**2.80E+01**	1.82E-03	**2.80E+01**	**1.63E+00**	1.82E-03	**1.63E+00**	-	-	-	Yes
Total Antimony (Sb)	2.00E-02	0.00E+00	1.25E-04	1.25E-04	3.83E-03	0.00E+00	3.83E-03	1.27E-03	1.25E-04	1.39E-03	1.19E-04	1.25E-04	2.44E-04	-	-	-	No
Total Selenium (Se)	1.00E-03	0.00E+00	7.77E-04	7.77E-04	**3.03E-02**	0.00E+00	**3.03E-02**	**4.04E-03**	7.77E-04	**4.82E-03**	**3.06E-03**	7.77E-04	**3.84E-03**	2.09E-04	2.00E-04	4.09E-04	Yes
Total Silicon (Si)	-	0.00E+00	0.00E+00	0.00E+00	1.34E+00	0.00E+00	1.34E+00	9.18E-01	0.00E+00	9.18E-01	4.36E-02	0.00E+00	4.36E-02	-	-	-	Yes[5]
Total Tin (Sn)	-	0.00E+00	4.26E-03	4.26E-03	3.52E-05	0.00E+00	3.52E-05	0.00E+00	4.26E-03	4.26E-03	0.00E+00	4.26E-03	4.26E-03	-	-	-	No
Total Sulphate (SO4)	1.28E+02	0.00E+00	1.94E+01	1.94E+01	**1.90E+02**	0.00E+00	**1.90E+02**	**5.96E+02**	1.94E+01	**6.15E+02**	6.75E+00	1.94E+01	2.61E+01	1.23E+01	2.69E+01	3.92E+01	Yes
Total Strontium (Sr)	-	0.00E+00	0.00E+00	0.00E+00	8.72E-02	0.00E+00	8.72E-02	6.41E-02	0.00E+00	6.41E-02	2.91E-03	0.00E+00	2.91E-03	-	-	-	No
Total Titanium (Ti)	-	0.00E+00	3.82E-04	3.82E-04	7.88E-05	0.00E+00	7.88E-05	0.00E+00	3.82E-04	3.82E-04	0.00E+00	3.82E-04	3.82E-04	-	-	-	No
Total Thallium (Tl)	3.00E-04	0.00E+00	4.42E-05	4.42E-05	8.12E-05	0.00E+00	8.12E-05	2.03E-05	4.42E-05	6.45E-05	1.18E-06	4.42E-05	4.54E-05	-	-	-	Yes
Total Uranium (U)	5.00E-03	0.00E+00	4.42E-04	4.42E-04	8.84E-04	0.00E+00	8.84E-04	1.73E-04	4.42E-04	6.14E-04	1.46E-05	4.42E-04	4.56E-04	-	-	-	No
Total Vanadium (V)	2.00E-02	0.00E+00	3.28E-04	3.28E-04	1.63E-02	0.00E+00	1.63E-02	6.98E-04	3.28E-04	1.03E-03	5.52E-04	3.28E-04	8.80E-04	4.11E-05	2.00E-03	2.04E-03	No
Total Zinc (Zn)	7.50E-03	0.00E+00	3.25E-03	3.25E-03	**1.77E-01**	0.00E+00	**1.77E-01**	6.00E-03	3.25E-03	**9.25E-03**	6.10E-03	3.25E-03	**9.35E-03**	4.03E-04	6.00E-03	6.40E-03	Yes
Total Zirconium (Zr)	4.00E-03	0.00E+00	0.00E+00	0.00E+00	6.27E-05	0.00E+00	6.27E-05	1.40E-07	0.00E+00	1.40E-07	2.18E-06	0.00E+00	2.18E-06	-	-	-	No

Note:

[1]Surface water concentrations obtained from JRP IR-6.26.

[2]Surface water concentrations run in risk assessment model include concentrations as presented above in addition to the maximum point of impingement (MPOI) atmospheric deposition as presented within the "*Grassy Mountain Coal Project Environmental Impact Assessment Updated Human Health and Wildlife Screening Risk Assessment*" (Addendum 10, Appendix 4.9-1, CIAR #251).

[3]Atmospheric deposition direct to water surface as a result of mine activities are not included as the EPL will only exist post-closure.

[4]No background value to compare.

[5]No toxicity information sufficient to develop a TRV.

[6]Adjustment based on individual hardness.

[7]Retained as COPC due to potential for bioaccumulation.

APPENDIX B – AQUATIC FOOD WEB MODELLING

Selenium Aquatic Food Web Model

The *Grassy Mountain Coal Project Environmental Impact Assessment Updated Human Health and Wildlife Screening Risk Assessment* (Addendum 10, JRP IR-4.9, Appendix 4.9-1, CIAR#251) included direct and indirect exposure to air emissions of chemicals of potential concern (COPCs) from the Project. The associated worked exposure calculations from environmental media were provided in the updated Human Health and Wildlife Screening Risk Assessment and are not presented again herein. The following presents the rationale and basis of the aquatic selenium food web model applied to estimate risk as part of the addendum to the wildlife risk assessment.

Selenium is unlike other COPC that bioconcentrate, in that the most consequential step in trophic transfer happens at the base of the food web (US EPA, 2016; BC MOE, 2014). The partitioning of selenium from water into particulates is the most significant step in exposure and termed the 'Enrichment Factor' (EF). Particulates or periphyton in this assessment refers to a complex combination of algae, cyanobacteria, heterotrophic bacteria, and detritus attached to surfaces in aquatic systems; an important food source for higher tropic levels. Guidance from the province of British Columbia (2014) and the US EPA (2016) apply multi-step models including EF and trophic transfer factors that represent successive steps in the food chain to derive water concentrations protective of fish under generic conditions. This guidance recognises that enrichment factors, and to a lesser extent trophic transfer factors, are inversely related to exposure concentration in a non-linear relationship and that enrichment in lotic or lentic habitats is distinct. Separate surface water guidelines have been published by the US EPA (2016) for lentic (standing water) or lotic systems. Based on recognized increased enrichment in lentic systems, food web modelling completed herein was distinct for lotic and lentic habitats. The lentic habitats evaluated in the current assessment included the North East Sedimentation Pond (NESP), East Sedimentation Pond (ESP), End Pit Lake, and the Oldman Reservoir. The lotic evaluated Blairmore and Gold Creeks.

Water-only exposure studies were considered in the derivation of the fish whole-body guideline from BC, and the US EPA recommends a water column concentration in their translation to fish tissue estimation. Based on this, the contribution of selenium from aerial deposition was added to predicted surface water concentrations provided from SRK. Equations outlining the contribution of aerial deposition to surface water have been previously presented in the *Grassy Mountain Coal Project Environmental Impact Assessment Updated Human Health and Wildlife Screening Risk Assessment* (Addendum 10, Appendix 4.9-1, CIAR#251) and not discussed herein. The aggregated surface water concentration was applied in food web modelling to estimate aquatic and fish tissue concentrations for the various habitats. Predicted concentrations in periphyton were only used to predict the selenium concentration in aquatic invertebrates and subsequently fish.

Lotic Habitat Selenium Food Web Modelling

Site-specific selenium enrichment in the lotic habitat of Blairmore Creek was measured in a laboratory study using water from Blairmore Creek and including the influence of varying sulphate concentrations on the selenium partitioning into primary producers (EIA, CR#5, Appendix A1, CIAR#42). This study and others support the inhibition of selenium uptake at the base of the food chain in the presence of sulphate (US EPA, 2016; DeForest *et al*., 2017). Selenium enrichment into primary producers was measured in Blairmore Creek and used to calibrate the regression equation presented in EIA, CR #5, Appendix A1, CIAR #42. The process for the calibration has been previously presented in Addendum 8, Appendix C-3, Windward Risk Assessment. This calibrated equation, presented below as Equation A.1, was used to estimate the concentration in periphyton in the flowing habitats of Blairmore and Gold Creeks.

$$\ln(Cperiphyton) = 0.602 \times \ln(C_{SW-Se}) - 0.409 \times \ln(C_{SW-SO_4}) + 3.024 \qquad \text{Equation A.1}$$

Where:

$C_{Periphyton}$ = selenium concentration (mg/kg dry weight) in particulate material or periphyton in flowing lotic habitats

$C_{SW\text{-}Se}$ = selenium concentration in surface water (µg/L)

$C_{SW\text{-}SO4}$ = sulphate concentration in surface water (mg/L)

The next step in the aquatic food web is the calculation of selenium concentration in aquatic macroinvertebrates from periphyton. Existing non-site-specific regression models for this calculation were reviewed. The regression model developed by Golder (2014) which is based on co-located selenium data for aquatic macroinvertebrates and their food (periphyton) in the Elk Valley watershed was selected. This regression model was selected based on its higher predicted concentration in aquatic macroinvertebrates relative to other models reviewed and relatively close proximity to the project area with likely similar invertebrate community composition. Equation A.2 below was used to predict the selenium concentration in aquatic macroinvertebrates

$$C_{invertebrate-lotic} = 10^{(0.456 \times LOG(C_{periphyton}) + 0.658)} \qquad \text{Equation A.2}$$

Where:

$C_{Periphyton}$ = selenium concentration (mg/kg dry weight) in particulate material or periphyton in flowing lotic habitats

$C_{Invertebrate\text{-}lotic}$ = selenium concentration in invertebrates of lotic habitats (mg/kg dry weight)

The last step in the selenium aquatic food web model predicts the concentration in fish tissue (whole-body dry weight) that wildlife would consume. The US EPA (2016) has the most comprehensive data set with respect to trophic transfer into fish, defined as a trophic transfer factor (TTF_{Fish}). The range of TTF_{Fish} is 0.68 (channel catfish) to 2.67 (black crappie) – both of these noted species are not present in watersheds evaluated; however, to account for interspecies variability in trophic transfer, the upper 80th percentile of all 32 published TTF_{fish} values was applied (1.48). This value is believed to be higher than 'typical' fish trophic transfer for species in the evaluated watershed, for example the published TTF_{fish} for the cutthroat trout is 1.12. This conservative selection is aligned with the objectives of an ecological risk assessment, which is to evaluate risk to receptors considering reasonable worst-case exposure. The selenium concentration in whole-body fish tissue was calculated using Equation A.3.

$$C_{Fish} = C_{Invertebrate-lotic} \times TTF_{Fish} \qquad \text{Equation A.3}$$

Where:

$C_{Invertebrate-lotic}$ = selenium concentration in invertebrates of lotic habitats (mg/kg dry weight).

C_{Fish} = selenium concentration in whole-body fish tissue (mg/kg dry weight).

Lentic Habitat Selenium Food Web Modelling

To account for the higher trophic transfer into periphyton in lentic habitats a different approach was taken. An enrichment factor specific to lentic habitats appropriate for lakes, ponds and reservoirs of 900 L/kg particulate material was applied based on a review of 96 aquatic sites derived from published studies (US EPA, 2016, Figure 3.6) (Equation A.4).

$$C_{periphyton_lentic} = C_{SW} \times EF_{Lentic} \qquad \text{Equation A.4}$$

Where:

$C_{periphyton_lentic}$ = selenium concentration (mg/kg dry weight) in periphyton in lentic habitats.

EF_{Lentic} = enrichment factor, 900 L/kg applied to lentic habitats (post-closure pit lake, sedimentation ponds, Oldman Reservoir).

C_{SW} = selenium concentration in surface water (mg/L).

To account for uncertainties in food chain modelling the US EPA has published a single trophic transfer value that accounts for all dietary pathways into fish; this value is conceptually similar to a bioaccumulation factor and accounts for ecosystems with different consumer species and is meant to eliminate uncertainty in food web modelling (US EPA, 2016). Taxon specific values of composite trophic transfer range from 1.2 (western mosquito fish) to 4.02 (northern pike, n=1 study) were identified; the 80th percentile of all 65 published values was 2.87. To account for the necessary

conservatism required to estimate a reasonable worst-case exposure in a two-step food model, a 95th percentile value of 3.0 was applied for $TTF_{Composite.}$ (Equation A.5).

$$C_{Fish} = TTF_{Composite} \times C_{Periphyton-lentic}$$ Equation A.5

Where:

$C_{periphyton_lentic}$ = selenium concentration (mg/kg dry weight) in periphyton in lentic habitats.

$TTF_{Composite}$ = trophic transfer representing the product of all trophic transfer factors from periphyton through trophic level 4 of predatory fish (unitless).

C_{Fish} = selenium concentration in whole fish tissue (mg/kg dry weight).

While the two-step model presented above was applied to estimate fish tissue concentration, the concentration of selenium in aquatic macroinvertebrates in lentic systems was also required. A separate calculation using the estimated selenium concentration in periphyton was used to derive a concentration in invertebrate tissue, relevant for other consumers of invertebrates, including birds and mammals. The US EPA (2016) has derived trophic transfer factors (TTF) for freshwater aquatic invertebrates. Aquatic invertebrate TTFs have been published ranging from 0.74 for *Daphnia magna* and increasing to 4.58 for a mollusk (*Corbicula fluminea*). The airborne consumption of aquatic invertebrates is an important consideration for bird receptors and bats. As such, the representative invertebrate TTF should ideally be relevant to wildlife invertebrate consumers in and out of the water column. Other reviews for invertebrate uptake have published 75th quartile values of 2.1 for $TTF_{Invertebrates}$ (Deforest, 2017), which is aligned with the upper bounds published values from the US EPA and other field validated trophic transfer for invertebrates (Presser and Luoma, 2010) and was applied herein (Equation A.6).

$$C_{Invertebrate} = TTF_{Invertebrate} \times C_{Periphyton-lentic}$$ Equation A.6

Where:

$C_{periphyton_lentic}$ = selenium concentration (mg/kg dry weight) in periphyton in lentic habitats.

$TTF_{Invertebrate}$ = trophic transfer into invertebrate tissue (unitless).

$C_{Invertebrate}$ = concentration in invertebrate tissue (mg/kg dry weight).

Worked Examples

The worked example below presents only those calculations that are divergent from previously presented multimedia inputs for concentration in fish and invertebrates.

Lotic Habitat Example – Blairmore Creek, Application Case

$$\ln(C_{Periphyton-lotic}) = 0.602 \times \ln(C_{SW-Se}) - 0.409 \times \ln(C_{SW-SO_4}) + 3.024 \quad \text{Equation A.1}$$
$$\ln(C_{Periphyton-lotic}) = 0.602 \times \ln 4.84 - 0.409 \times \ln(615.4) + 3.024$$
$$\ln(C_{Periphyton-lotic}) = 3.84$$

Where:

$C_{Periphyton-lotic}$ = selenium concentration (mg/kg dry weight) in periphyton in flowing lotic habitats

C_{SW-Se} = selenium concentration in surface water (µg/L), 4.84 ug/L – Application.

C_{SW-SO4} = sulphate concentration in surface water (mg/L), 615.4 mg/L – Application.

$$C_{Invertebrate-lotic} = 10^{(0.456 \times LOG(C_{Periphyton}) + 0.658)} \quad \text{Equation A.2}$$
$$C_{Invertebrate-lotic} = 10^{(0.456 \times LOG(3.84) + 0.658)}$$
$$C_{Invertebrate-lotic} = 8.41$$

Where:

$C_{Periphyton}$ = selenium concentration (mg/kg dry weight) in periphyton in flowing lotic habitats.

$C_{Invertebrate-lotic}$ = selenium concentration in invertebrates of lotic habitats (mg/kg dry weight).

$$C_{Fish} = C_{Invertebrate-lotic} \times TTF_{Fish} \times 0.25(\textit{ to convert to weight weight}) \quad \text{Equation A.3}$$
$$C_{Fish} = 8.41 \times 1.48$$
$$C_{Fish} = 3.11$$

Where:

$C_{Invertebrate-lotic}$ = selenium concentration in invertebrates of lotic habitats (mg/kg dry weight).

C_{Fish} = selenium concentration in whole-body fish tissue (mg/kg wet weight).

Wet weights are required for C_{fish} in the calculation of daily exposure doses used in multimedia modelling.

Lentic Habitat Example, Oldman Reservoir, Application Case

$$C_{periphyton_lentic} = C_{SW} \times EF_{Lentic}$$ Equation A.4

$$C_{periphyton_lentic} = 0.0004086 \times 900$$

$$C_{periphyton_lentic} = 0.368$$

Where:

$C_{periphyton_lentic}$ = selenium concentration (mg/kg dry weight) in periphyton in lentic habitats.

EF_{Lentic} = enrichment factor, 900 L/kg applied to lentic habitats (post-closure end pit lake, sedimentation ponds, Oldman Reservoir).

C_{SW} = selenium concentration in surface water (mg/L).

$$C_{Fish} = TTF_{Composite} \times C_{Periphyton-lentic}$$ Equation A.5

$$C_{Fish} = 3 \times 0.368 \times 0.25 \ (to\ convert\ to\ wet\ weight)$$

$$C_{Fish} = 0.276$$

Where:

$C_{periphyton_lentic}$ = selenium concentration (mg/kg dry weight) in periphyton in lentic habitats.

$TTF_{Composite}$ = trophic transfer representing the product of all trophic transfer factors from periphyton through trophic level 4 of predatory fish (unitless).

C_{Fish} = selenium concentration in whole fish tissue (mg/kg wet weight).

Wet weights are required for C_{fish} in the calculation of daily exposure doses used in multimedia modelling.

$$C_{Invertebrate} = TTF_{Invertebrate} \times C_{Periphyton-lentic}$$ Equation A.6

$$C_{Invertebrate} = 2.1 \times 0.368$$

$$C_{Invertebrate} = 0.7728$$

Where:

$C_{periphyton_lentic}$ = selenium concentration (mg/kg dry weight) in periphyton in lentic habitats.

$TTF_{Invertebrate}$ = trophic transfer into invertebrate tissue (unitless).

$C_{Invertebrate}$ = concentration in invertebrate tissue (mg/kg dry weight).

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DeForest, DK, Brix, K., Elphick, J., Rickwood, C., deBruyn, A., Tear, L., Adams, W. 2017. Lentic, lotic, and sulfate-dependent waterborne selenium screening guidelines for freshwater systems. Environ Toxicol Chem., 36(9).

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Golder 2014 and Golder 2018. Elk Valley Selenium Bioaccumulation Model Update. Technical Memorandum.

US Environmental Protection Agency (US EPA). 2016. Aquatic Life Ambient Water Quality Criterion for Selenium – Freshwater 2016. Office of Water, Office of Science and Technology. Washington, D.C.

APPENDIX C – WILDLIFE DAILY THRESHOLD EXPOSURE DOSES (DTEDS)

Wildlife Daily Threshold Exposure Doses (DTED)

Methodology

A search of current wildlife toxicity values was conducted February 2020. The following resources were reviewed, listed in order of preference:

- US EPA: ECOTOX Database;
- US Department of Energy;
- Oak Ridge National Laboratory (ORNL): Risk Assessment Information System;
- California EPA: CalEcotox Database (all birds and mammals);
- US Geological Survey: Wildlife and Contaminants Online;
- CCME: *Canadian Tissue Residue Guidelines for the Protection of Wildlife Consumers of Aquatic Biota*;
- CCME: *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* (2006); and
- Google Scholar for relevant journal articles.

Wildlife toxicity reference values published by various regulatory agencies are summarized below. The general approaches taken by these agencies include:

- Canadian Council of Ministers of the Environment (CCME) – Values used by CCME to develop soil quality guidelines are the LOAEL for the species determined to be most at threat (based on sensitivity to contaminant and the ratio of ingestion rate to body weight), considering a minimum of two oral mammalian studies and one oral avian study, preferably including a grazing herbivore with a high ingestion rate to body weight ratio. Uncertainty factors between one and five may be applied. Only one DTED is typically specified and used to derive soil quality guidelines, unless the chemical biomagnifies and higher trophic levels are also evaluated (CCME, 2006).
- CCME – When selecting DTEDS for an ecological risk assessment, population based critical endpoints (reproduction and mortality) are given priority. Non-population effects such as growth are not considered appropriate.
- US Department of Energy, Oak Ridge National Laboratory (ORNL) – NOAEL and LOAEL values were obtained from studies by ORNL. One avian and one mammal study were identified as critical studies based on endpoints and relevance to wildlife; in some cases NOAELs and LOAELs were extrapolated from available data (Sample *et al.*, 1996). Based on the methodologies employed, the LOAEL values specified by ORNL are expected to have a similar level of protection to the CCME values.

- US Environmental Protection Agency (US EPA) – a large number of studies were reviewed by US EPA to develop ecological soil screening levels. The toxicity benchmark was set as the lower of the geometric mean of growth and reproduction NOAEL values, or the highest bounded NOAEL that is less than the lowest bounded LOAEL (US EPA, 2003). The US EPA values are generally more conservative than the CCME values.

In general, values developed or endorsed by Environment Canada, including those published by CCME, are given preference. However, CCME evaluate only the most sensitive receptor for the food ingestion pathway, and therefore generally only specify either a mammalian DTED or an avian DTED instead of both. Due to the physiological differences between mammals and birds, separate mammalian and avian DTEDs are specified herein where possible. Also, since the reviews undertaken by US EPA and ORNL may incorporate additional studies or newer data, values published by other agencies are evaluated even where CCME has specified a value. Each chemical of concern is evaluated on a case-by-case basis below.

Threatened/Endangered Species

The level of protection considered to be appropriate for the protection of ecological systems in general may not be sufficiently protective of threatened or endangered species in all cases. If the effect on which the DTED is based is significant (mortality or reproduction effects), additional conservatism may be required. The US EPA toxicity reference values are expected to be sufficiently protective of threatened and endangered species, since they are set below the level at which any effects are observed in a large database of studies. In the absence of US EPA values, uncertainty factors may be applied on a case-by-case basis as described below.

REFERENCES

CCME (Canadian Council of Ministers of the Environment). 2006. A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines. 2006 Revision. PN 1332.

Sample, B.E., D.M. Opresko and G.W. Suter II. 1996. Toxicological Benchmarks for Wildlife: 1996 Revision. US Department of Energy, Office of Environmental Management. Oak Ridge National Laboratory. ES/ER/TM-86/R3.

US EPA. 2003. Guidance for Developing Ecological Soil Screening Levels. Office of Solid Waste and Emergency Response. Washington, DC. OSWER Directive 9285.7-55.

Summary Table

Chemical	Mammalian DTED		Avian DTED	
	Value (mg/kg/d)	Test Species	Value (mg/kg/d)	Test Species
Ammonium	No data			
Arsenic	1.26	mouse	2.24	chicken
Bismuth	No data			
Cadmium	0.456	Sheep	20 1.47[a]	Mallard duck
Chromium	3.28 Cr (VI)	Various	5 2.66[a]	Various
Cobalt	7.33	Various	7.61	Various
Copper	5.6	Pig	5.23	Hen
Lead	80	Rat	1.8	Quail
Manganese	51.5	Rat	179	Quail
Mercury (inorganic)	1.01	Mink	0.9	Quail
Methylmercury (organic)	0.015	Mink	0.0064	Mallard
Nickel	25	Rat	107 77.4[a]	Mallard
Nitrite	No data			
Nitrate	1130	Guinea pig	No data	No data
Potassium	No data			
Selenium	0.33	Rat	0.3	Chicken
Silver	6.02	Pig	2.02	Turkey
Silicon	No data			
Sulphate	No data			
Sulphide	No data			
Thallium	0.03	Sheep	No data	No data
Zinc	10	Sheep	131 66.1[a]	Chicken

a - value applied for threatened/endangered species.

NB: This lower value was applied where available for all receptors.

Inorganics

Arsenic

Avian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
ORNL (Sample *et al*. 1996)	5.14	mallard ducks	mortality	used the NOAEL instead of the LOAEL as the toxicological endpoint was mortality.
US EPA (2005)	2.24	chickens	reproductive effects, growth and mortality	NOAEL; LOAEL NR

The US EPA value based on reproduction is applied for all avian receptors.

Mammalian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
CCME 1997	4	rabbit	mortality	LD_{50} with UF of 2; BW = 3 kg
ORNL (Sample *et al*. 1996)	1.26	mice	reproductive effects (litter size)	only one dose level administered; BW = 0.03 kg
US EPA (2005)	1.04	dogs	growth	NOAEL used; LOAEL = 1.66

CCME has specified a DTED for this substance; however, since this value is based on mortality, the more conservative ORNL value based on a reproduction is applied for the mammalian receptor. The US EPA values was not selected as the study's critical effect is not identified as a population-based effect (growth).

REFERENCES

CCME. 1997 (revised 1999). Canadian Soil Quality Guidelines for Arsenic – Environmental and Human Health. Prepared by the CCME Subcommittee on Environmental Quality Criteria for Contaminated Sites. Winnipeg, Manitoba.

Sample, B.E., D.M. Opresko and G.W. Suter II. 1996. Toxicological Benchmarks for Wildlife: 1996 Revision. US Department of Energy, Office of Environmental Management. Oak Ridge National Laboratory. ES/ER/TM-86/R3.

US EPA. 2005. Ecological Soil Screening Levels for Arsenic – Interim Final. Office of Solid Waste and Emergency Response. Washington, DC. OSWER Directive 9285.7-62.

Cadmium

Avian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
ORNL (Sample *et al.* 1996)	20	mallards	reproductive effects	
US EPA (2005)	1.47			geometric mean of NOAELs

The ORNL value provides a level of protection is similar to CCME guidelines. However, the more conservative US EPA value is applied.

Mammalian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
CCME 1997	0.456	sheep	clinical signs/lesions	BW = 45 kg
ORNL (Sample *et al.* 1996)	10	rats	reproductive effects	BW = 0.303 kg
US EPA (2005)	0.77	rats	growth	NOAEL used; LOAEL = 7.7

CCME has specified a mammalian DTED, and this value is lower than those specified by ORNL or US EPA; therefore, the CCME value is applied herein.

REFERENCES

CCME. 1997 (revised 1999). Canadian Soil Quality Guidelines – Cadmium (Environmental Effects). National Guidelines and Standards Office, Environment Canada.

Sample, B.E., D.M. Opresko and G.W. Suter II. 1996. Toxicological Benchmarks for Wildlife: 1996 Revision. US Department of Energy, Office of Environmental Management. Oak Ridge National Laboratory. ES/ER/TM-86/R3.

US EPA. 2005. Ecological Soil Screening Levels for Cadmium – Interim Final. Office of Solid Waste and Emergency Response. Washington, DC. OSWER Directive 9285.7-65.

Chromium

Avian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
US EPA (2005)	2.66 – Cr(III)	NA		geometric mean of NOAELs
ORNL (Sample *et al.* 1996)	5 – Cr(III)	black duck	reproduction	NOAEL = 1 mg/kg/d

The ORNL value provides a level of protection is similar to CCME guidelines. However, the US EPA value is applied as it defined the test species is a more conservative value.

Mammalian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
US EPA (2005)	2.40 – Cr(III) 9.24 – Cr(VI)	NA		geometric mean of NOAELs
ORNL (Sample *et al.* 1996)	2737 – Cr(III)	rat	reproduction/longevity	NOAEL
ORNL (Sample *et al.* 1996)	3.28 – Cr(VI)	rat	body weight, food consumption	NOAEL

The ORNL value for CrVI of 3.28 (mg/kg bw/day) is applied herein, since the level of protection is similar to CCME guidelines and it is based on a population based critical effect (reproduction).

REFERENCES

US EPA. 2005 (revised 2008). Ecological Soil Screening Levels for Chromium – Interim Final. Office of Solid Waste and Emergency Response. Washington, DC. OSWER Directive 9285.7-66.

Cobalt

Avian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
US EPA (2005)	7.61	NA		geometric mean of NOAELs

Only a single TRV was identified; this value is NOAEL-based and is applied for all avian receptors.

Mammalian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
US EPA (2005)	7.33	NA		geometric mean of NOAELs

Only a single TRV was identified; this value is NOAEL-based and is applied for all mammalian receptors.

REFERENCE

US EPA. 2005. Ecological Soil Screening Levels for Cobalt – Interim Final. Office of Solid Waste and Emergency Response. Washington, DC. OSWER Directive 9285.7-67.

Copper

Avian TRV				
Source	**DTED (mg/kg/d)**	**Species**	**Critical Effect**	**Comments**
CCME (1997)	5.23	Hens	Reduced weight gain	Document suggests sheep may need site-specific consideration
ORNL (Sample *et al.*, 1996)	47	Chicks	Growth and mortality	
US EPA (2007)	4.05	Chicken	Food conversion efficiency	

Since CCME has defined a DTED for avian species, and this value is very similar to the US EPA value and lower than the ORNL value, the CCME DTED is applied herein for avian species.

Mammalian TRV				
Source	**DTED (mg/kg/d)**	**Species (Mass)**	**Critical Effect**	**Comments**
ORNL (Sample *et al.*, 1996)	11.7	Mink (1 kg)	Kit mortality	Based on NOAEL since critical effect is mortality
US EPA (2007)	5.6	Pig	Mortality	

The US EPA value is more recent and more conservative and is therefore applied herein.

REFERENCES

CCME. 1997. Canadian Soil Quality Guidelines for Copper – Environmental and Human Health. Prepared by the CCME Subcommittee on Environmental Quality Criteria for Contaminated Sites. Winnipeg, Manitoba.

Sample, B.E., D.M. Opresko and G.W. Suter II. 1996. Toxicological Benchmarks for Wildlife: 1996 Revision. US Department of Energy, Office of Environmental Management. Oak Ridge National Laboratory. ES/ER/TM-86/R3.

US EPA. 2007. Ecological Soil Screening Levels for Copper – Interim Final. Office of Solid Waste and Emergency Response. Washington, DC. OSWER Directive 9285.7-68.

Lead

Avian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
CCME 1997	1.8	quail	egg production	
US EPA (2005)	1.63	chickens	reproductive effects	NOAEL used; LOAEL = 3.26

CCME has specified an avian DTED for lead; this value is very similar to the US EPA value and is therefore applied for all avian receptors herein.

Mammalian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
ORNL (Sample *et al.* 1996)	80	rats	reduced offspring weight and kidney damage	BW = 0.35 kg
US EPA (2005)	4.7	rats	growth	NOAEL used; LOAEL = 8.9

The ORNL value is applied as a mammalian DTED, since the methods used by ORNL are similar to those used by CCME. The US EPA values was not selected as the study's critical effect is not identified as a population based effect (growth).

REFERENCES

CCME. 1997 (revised 1999). Canadian Soil Quality Guidelines for Lead – Environmental and Human Health. Prepared by the CCME Subcommittee on Environmental Quality Criteria for Contaminated Sites. Winnipeg, Manitoba.

Sample, B.E., D.M. Opresko and G.W. Suter II. 1996. Toxicological Benchmarks for Wildlife: 1996 Revision. US Department of Energy, Office of Environmental Management. Oak Ridge National Laboratory. ES/ER/TM-86/R3.

US EPA. 2005. Ecological Soil Screening Levels for Lead – Interim Final. Office of Solid Waste and Emergency Response. Washington, DC. OSWER Directive 9285.7-70.

Manganese

Avian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
ORNL (Sample *et al*. 1996)	977	Japanese quail	growth and behaviour	No LOAEL available; used the NOAEL instead
US EPA (2007)	179			geometric mean of NOAELs

The more current and more conservative US EPA value is applied for avian receptor assessments.

Mammalian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
ORNL (Sample *et al*. 1996)	284	rats	reproductive effects	BW = 0.35 kg
US EPA (2007)	51.5			geometric mean of NOAELs

The more current and more conservative US EPA (2007) value is selected for the mammalian receptor assessment.

REFERENCES

Sample, B.E., D.M. Opresko and G.W. Suter II. 1996. Toxicological Benchmarks for Wildlife: 1996 Revision. US Department of Energy, Office of Environmental Management. Oak Ridge National Laboratory. ES/ER/TM-86/R3.

US EPA (United States Environmental Protection Agency). 2007. Ecological Soil Screening Levels for Manganese – Interim Final. Office of Solid Waste and Emergency Response. Washington, DC. OSWER Directive 9285.7-71

Mercury, Inorganic

Avian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
ORNL (Sample *et al*. 1996)	0.9	Japanese Quail	reproduction	mercuric chloride

The ORNL value is the only avian TRV identified and is therefore applied herein.

Mammalian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
CCME (Environment Canada 1999)	0.38	pigs (80 kg)	clinical toxicological signs	organic mercury
ORNL (Sample *et al*. 1996)	1.01	mink (1 kg)	reproduction	mercuric chloride; based on NOAEL since no effects observed

The CCME value is based on organic mercury; the ORNL value is therefore considered more appropriate as a DTED for inorganic mercury.

REFERENCES

Environment Canada. 1999. Canadian Soil Quality Guidelines for Inorganic Mercury. Scientific Supporting Document. National Guidelines and Standards Office, Environmental Quality Branch, Environment Canada. Ottawa.

Sample, B.E., D.M. Opresko and G.W. Suter II. 1996. Toxicological Benchmarks for Wildlife: 1996 Revision. US Department of Energy, Office of Environmental Management. Oak Ridge National Laboratory. ES/ER/TM-86/R3.

Methylmercury, Organic

Avian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
ORNL (Sample *et al.* 1996)	0.0064	Mallard (1kg)	Reproduction	Methyl Mercury Dicyandiamide, chronic NOAEL with uncertainty factor of 0.1.

The ORNL DTED is selected for the avian receptor assessment. No other DTED was identified in the wildlife toxicity values search.

Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
ORNL (Sample *et al.* 1996)	0.015	Mink (1kg)	Body weight	Methyl Mercury Chloride, subchronic NOAEL with uncertainty factor of 0.1.
ORNL (Sample *et al.* 1996)	0.032	Rat (0.35kg)	Reproduction	Methyl Mercury Chloride, chronic NOAEL.

The ORNL DTED for mink was selected for the mammalian receptor assessment. This value is a lower than the rat DTED and is representative of the species included in the risk assessment.

REFERENCE

Sample, B.E., D.M. Opresko and G.W. Suter II. 1996. Toxicological Benchmarks for Wildlife: 1996 Revision. US Department of Energy, Office of Environmental Management. Oak Ridge National Laboratory. ES/ER/TM-86/R3.

Nickel

Avian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
ORNL (Sample *et al.* 1996)	107 (LOAEL) 77.4 (NOAEL)	mallard duckling	growth, mortality	BW = 0.782 kg
US EPA (2007)	6.71			geometric mean of NOAELs

Since the ORNL values was derived using similar methods to CCME, the lowest NOAEL-based value is applied. In addition, the ORNL value is based on the mallard duck species.

Mammalian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
CCME (Environment Canada 1999)	25	rat	growth and liver enzymes	
ORNL (Sample *et al.* 1996)	80	rat	reproduction	BW = 0.35 kg
US EPA (2007)	1.7	mouse	reproduction	NOAEL

Since CCME has specified a DTED, and it is lower than the ORNL value, the CCME value is applied.

REFERENCES

Environment Canada. 1999. Canadian Soil Quality Guidelines for Nickel. Scientific Supporting Document. National Guidelines and Standards Office, Environmental Quality Branch, Environment Canada. Ottawa.

Sample, B.E., D.M. Opresko and G.W. Suter II. 1996. Toxicological Benchmarks for Wildlife: 1996 Revision. US Department of Energy, Office of Environmental Management. Oak Ridge National Laboratory. ES/ER/TM-86/R3.

US EPA. 2007. Ecological Soil Screening Levels for Nickel – Interim Final. Office of Solid Waste and Emergency Response. Washington, DC. OSWER Directive 9285.7-67

Nitrite

No TRVs for nitrite were identified. A single TRV for nitrate of 1130 mg/kg/d based on reproductive effects in a guinea pig study was identified (Sample *et al.*, 1996)

Phosphorus

No TRVs for phosphorus were identified. Phosphorus is an essential nutrient regulated by most organisms and is not expected to be toxic at environmentally relevant exposure levels. Therefore, no DTEDs are established for this substance.

Potassium

No TRVs for potassium were identified. Potassium is an essential nutrient regulated by most organisms and is not expected to be toxic at environmentally relevant exposure levels. Therefore, no DTEDs are established for this substance.

Selenium

Avian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
CCME 2007	0.3	chickens	hatchability	
ORNL (Sample *et al.* 1996)	1	mallard ducks	reproductive effects	
US EPA (2007)	0.290	chickens	mortality (NOAEL)	

CCME has specified an avian DTED for selenium, and this value is lower than the ORNL value and similar to the US EPA value. The CCME value is therefore applied herein for all bird species. Additional conservatism for threatened/endangered species is not considered warranted due to the very narrow range between the required nutritional dose and toxic dose for this substance, and since the NOAEL-based US EPA value is virtually identical to the CCME value.

Mammalian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
ORNL (Sample *et al*. 1996)	0.33	rats	reproductive effects	selenium in the form of potassium selenate; BW = 0.35 kg
US EPA (2007)	0.143	pig	body weight	NOAEL

The ORNL value was applied since the methodology was similar to the CCME approach and a population based critical effect was used.

REFERENCES

Sample, B.E., D.M. Opresko and G.W. Suter II. 1996. Toxicological Benchmarks for Wildlife: 1996 Revision. US Department of Energy, Office of Environmental Management. Oak Ridge National Laboratory. ES/ER/TM-86/R3.

US EPA. 2007. Ecological Soil Screening Levels for Selenium – Interim Final. Office of Solid Waste and Emergency Response. Washington, DC. OSWER Directive 9285.7-72.

Silver

Avian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
US EPA (2006)	2.02	turkey	growth	LOAEL/10

The only avian TRV identified for silver is the US EPA value; this value is therefore applied as a DTED for all avian species herein.

Mammalian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
US EPA (2006)	6.02	pig	growth	LOAEL/10

The only mammalian TRV identified for silver is the US EPA value; this value is applied as a mammalian DTED.

REFERENCE

US EPA. 2006. Ecological Soil Screening Levels for Silver – Interim Final. Office of Solid Waste and Emergency Response. Washington, DC. OSWER Directive 9285.7-77.

Sulphur

No TRVs for sulphur were identified. Sulphur is an essential nutrient regulated by most organisms, and is not expected to be toxic at environmentally relevant exposure levels. Therefore, no DTEDs are established for this substance.

Thallium

Avian TRV

No avian TRVs for thallium were identified and therefore the mammalian value is applied for avian receptors with a factor of 10 adjustment.

Mammalian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
CCME (Environment Canada 1999)	0.03	sheep (30 kg)	body weight, loss of wool	
ORNL (Sample *et al.* 1996)	0.074	rat (0.365 kg)	reproduction	

Since CCME has specified a DTED, and this value is lower than the ORNL value, the CCME value is applied herein.

REFERENCES

Environment Canada. 1999. Canadian Soil Quality Guidelines for Thallium. Scientific Supporting Document. National Guidelines and Standards Office, Environmental Quality Branch, Environment Canada. Ottawa.

Sample, B.E., D.M. Opresko and G.W. Suter II. 1996. Toxicological Benchmarks for Wildlife: 1996 Revision. US Department of Energy, Office of Environmental Management. Oak Ridge National Laboratory. ES/ER/TM-86/R3.

Zinc

Avian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
ORNL (Sample *et al.* 1996)	131	chickens	reproductive effects	
US EPA (2007)	66.1			geometric mean of NOAELS

The ORNL value is derived using a similar methodology to CCME however, the lower the US EPA value of 68.1 mg/kg/d is applied.

Mammalian TRV				
Source	**DTED (mg/kg-BW/day)**	**Species**	**Critical Effect**	**Comments**
CCME (Environment Canada, 1999)	10	sheep	reproduction	BW = 80 kg
ORNL (Sample *et al*. 1996)	320	rats	reproductive effects	BW = 0.35 kg
US EPA (2007)	75.4			geometric mean of NOAELS

CCME has established a mammalian DTED for zinc; this value is applied herein.

REFERENCES

Environment Canada. 1999. Canadian Soil Quality Guidelines for Zinc. Scientific Supporting Document. National Guidelines and Standards Office, Environmental Quality Branch, Environment Canada. Ottawa.

Sample, B.E., D.M. Opresko and G.W. Suter II. 1996. Toxicological Benchmarks for Wildlife: 1996 Revision. US Department of Energy, Office of Environmental Management. Oak Ridge National Laboratory. ES/ER/TM-86/R3.

US EPA. 2007. Ecological Soil Screening Levels for Zinc – Interim Final. Office of Solid Waste and Emergency Response. Washington, DC. OSWER Directive 9285.7-73.

APPENDIX D – ECOLOGICAL-RISK TABLES

Table D-1 Predicted Exposure Ratio for the Multimedia Assessment End Pit Lake (EPL)

Parameter	Aquatic						
	Mammalian Receptors			Avian Receptors			
	Northern River Otter	Beaver	Little Brown Bat	American Dipper	Goose	Great Blue Heron	Mallard Duck
	Application	Application	Application	Application	Application	Application	Application
Arsenic	7.1E-09	1.5E-04	3.8E-06	2.0E-09	1.6E-04	2.4E-08	1.2E-04
Cadmium	9.1E-03	1.9E-03	5.5E-03	5.8E-03	1.4E-03	2.8E-03	1.3E-02
Chromium II/III (total)	3.9E-03	1.0E-05	4.6E-03	1.0E-02	4.8E-04	4.8E-03	2.1E-02
Cobalt	8.6E-05	1.1E-04	1.4E-03	1.0E-03	4.7E-04	1.3E-04	5.3E-04
Copper	1.0E-02	7.2E-03	6.0E-03	2.3E-02	1.5E-02	1.1E-02	6.0E-02
Lead	2.1E-05	1.1E-05	1.0E-04	1.9E-03	1.0E-03	9.1E-04	4.8E-03
Manganese	2.1E-04	9.8E-03	7.5E-03	7.0E-04	5.5E-03	1.1E-04	4.3E-03
Mercury	2.8E-07	8.0E-08	2.6E-06	3.1E-06	9.6E-07	6.5E-07	1.4E-06
Methylmercury	6.0E-07	1.7E-07	8.2E-08	1.4E-05	4.3E-06	2.9E-06	6.4E-06
Nickel	1.6E-04	8.0E-05	1.1E-03	3.7E-04	1.3E-04	6.7E-05	2.8E-04
Selenium	7.8E-01	6.8E-04	3.9E-01	1.7E+00	6.9E-02	8.6E-01	3.8E+00
Silver-1	3.7E-07	8.9E-09	4.5E-07	2.9E-06	3.6E-07	1.1E-06	4.9E-06
Thallium	2.7E-02	1.4E-05	1.4E-02	5.5E-02	2.2E-03	2.7E-02	1.2E-01
Zinc	5.5E-02	5.7E-03	3.0E-02	1.7E-02	2.3E-03	8.4E-03	3.8E-02

1- Site specific background levels were not available for Silver, therefore baseline and application levels are the same

Table D-2 Predicted Exposure Ratio for the Multimedia Assessment NESP

Parameter	Aquatic																				
	Mammalian Receptors									Avian Receptors											
	Northern River Otter			Beaver			Little Brown Bat			American Dipper			Goose			Great Blue Heron			Mallard Duck		
	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application
Arsenic	8.7E-07	9.7E-06	1.0E-05	2.6E-03	7.6E-04	2.7E-03	2.9E-06	3.4E-05	3.6E-05	1.8E-06	2.3E-05	2.4E-05	4.5E-07	1.6E-04	1.6E-04	5.5E-07	6.1E-06	6.4E-06	7.1E-05	1.6E-04	2.1E-04
Cadmium	1.5E-05	7.2E-05	8.3E-05	1.8E-03	2.3E-03	3.7E-03	8.8E-06	5.5E-04	5.6E-04	9.7E-06	4.6E-05	5.3E-05	4.9E-07	1.1E-03	1.1E-03	4.7E-06	2.2E-05	2.6E-05	4.7E-05	9.5E-04	9.9E-04
Chromium II/III (total)	8.3E-06	3.2E-04	3.3E-04	1.1E-03	2.6E-04	1.1E-03	5.0E-06	2.6E-03	2.6E-03	2.1E-05	8.3E-04	8.4E-04	1.1E-06	4.0E-05	4.1E-05	1.0E-05	4.0E-04	4.1E-04	1.1E-04	1.8E-03	1.9E-03
Cobalt	9.6E-08	5.5E-07	6.2E-07	6.0E-04	2.1E-04	6.8E-04	5.3E-07	4.1E-04	4.1E-04	4.5E-07	6.2E-06	6.5E-06	1.5E-07	1.4E-04	1.4E-04	2.4E-07	9.8E-07	1.2E-06	2.8E-05	1.1E-04	1.3E-04
Copper	2.6E-05	1.8E-04	2.0E-04	2.8E-03	7.8E-03	9.9E-03	1.5E-05	4.9E-04	5.0E-04	5.6E-05	4.0E-04	4.4E-04	2.8E-06	1.4E-02	1.4E-02	2.7E-05	2.0E-04	2.2E-04	2.6E-04	1.2E-02	1.2E-02
Lead	1.1E-06	2.6E-06	3.4E-06	8.6E-05	3.1E-05	9.7E-05	5.8E-07	9.3E-05	9.4E-05	9.6E-05	2.3E-04	3.1E-04	4.4E-06	9.2E-04	9.3E-04	4.7E-05	1.1E-04	1.5E-04	3.9E-04	1.2E-03	1.5E-03
Manganese	3.4E-10	2.5E-06	2.5E-06	3.1E-08	9.8E-03	9.8E-03	1.3E-09	5.2E-03	5.2E-03	2.2E-10	4.7E-06	4.7E-06	8.3E-11	5.2E-03	5.2E-03	9.9E-11	3.2E-06	3.2E-06	5.2E-10	4.0E-03	4.0E-03
Mercury	5.0E-08	1.7E-08	5.5E-08	8.6E-05	2.0E-05	8.6E-05	7.6E-08	6.5E-08	1.2E-07	7.7E-08	7.3E-08	1.3E-07	2.5E-08	2.3E-08	4.2E-08	3.4E-07	9.1E-08	3.5E-07	4.6E-06	1.1E-06	4.6E-06
Methylmercury	3.0E-06	7.4E-07	3.0E-06	5.8E-03	1.3E-03	5.8E-03	2.6E-08	9.6E-09	2.8E-08	2.5E-06	1.0E-06	2.7E-06	9.3E-07	3.7E-07	1.0E-06	4.6E-05	1.1E-05	4.6E-05	6.5E-04	1.5E-04	6.5E-04
Nickel	1.2E-07	8.0E-07	8.8E-07	6.1E-04	1.9E-04	6.6E-04	5.5E-07	8.4E-05	8.4E-05	1.8E-07	1.8E-06	1.9E-06	5.3E-08	3.1E-05	3.1E-05	5.5E-08	3.4E-07	3.8E-07	9.5E-06	2.7E-05	3.4E-05
Selenium	7.0E-05	2.0E-02	2.0E-02	2.3E-03	7.4E-04	2.5E-03	3.6E-05	1.1E-02	1.1E-02	1.6E-04	4.5E-02	4.5E-02	6.3E-06	2.2E-03	2.2E-03	7.8E-05	2.2E-02	2.2E-02	4.6E-04	9.9E-02	9.9E-02
Silver-1	0.0E+00	6.2E-07	6.2E-07	0.0E+00	1.5E-08	1.5E-08	0.0E+00	7.6E-07	7.6E-07	0.0E+00	5.0E-06	5.0E-06	0.0E+00	6.1E-07	6.1E-07	0.0E+00	1.9E-06	1.9E-06	0.0E+00	8.3E-06	8.3E-06
Thallium	3.8E-04	1.5E-02	1.5E-02	1.0E-02	2.4E-03	1.0E-02	1.9E-04	7.9E-03	8.1E-03	7.6E-04	3.0E-02	3.1E-02	3.0E-05	1.2E-03	1.2E-03	3.8E-04	1.5E-02	1.5E-02	2.2E-03	6.7E-02	6.9E-02
Zinc	9.2E-05	1.0E-03	1.1E-03	8.0E-03	7.5E-03	1.4E-02	5.0E-05	1.6E-03	1.7E-03	2.8E-05	3.2E-04	3.4E-04	1.3E-06	1.6E-03	1.6E-03	1.5E-05	1.6E-04	1.7E-04	1.2E-04	1.9E-03	2.0E-03

1- Site specific background levels were not available for Silver, therefore baseline and application levels are the same

Table D-3 Predicted Exposure Ratio for the Multimedia Assessment ESP

Parameter	Aquatic																				
	Mammalian Receptors									Avian Receptors											
	Northern River Otter			Beaver			Little Brown Bat			American Dipper			Goose			Great Blue Heron			Mallard Duck		
	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application
Arsenic	8.7E-07	9.7E-06	1.0E-05	2.6E-03	7.6E-04	2.7E-03	2.9E-06	3.4E-05	3.6E-05	1.8E-06	2.3E-05	2.4E-05	4.5E-07	1.6E-04	1.6E-04	5.5E-07	6.1E-06	6.4E-06	7.1E-05	1.6E-04	2.1E-04
Cadmium	1.5E-05	7.2E-05	8.3E-05	1.8E-03	2.3E-03	3.7E-03	8.8E-06	5.5E-04	5.6E-04	9.7E-06	4.6E-05	5.3E-05	4.9E-07	1.1E-03	1.1E-03	4.7E-06	2.2E-05	2.6E-05	4.7E-05	9.5E-04	9.9E-04
Chromium II/III (total)	8.3E-06	3.2E-04	3.3E-04	1.1E-03	2.6E-04	1.1E-03	5.0E-06	2.6E-03	2.6E-03	2.1E-05	8.3E-04	8.4E-04	1.1E-06	4.0E-05	4.1E-05	1.0E-05	4.0E-04	4.1E-04	1.1E-04	1.8E-03	1.9E-03
Cobalt	9.6E-08	5.5E-07	6.2E-07	6.0E-04	2.1E-04	6.8E-04	5.3E-07	4.1E-04	4.1E-04	4.5E-07	6.2E-06	6.5E-06	1.5E-07	1.4E-04	1.4E-04	2.4E-07	9.8E-07	1.2E-06	2.8E-05	1.1E-04	1.3E-04
Copper	2.6E-05	1.8E-04	2.0E-04	2.8E-03	7.8E-03	9.9E-03	1.5E-05	4.9E-04	5.0E-04	5.6E-05	4.0E-04	4.4E-04	2.8E-06	1.4E-02	1.4E-02	2.7E-05	2.0E-04	2.2E-04	2.6E-04	1.2E-02	1.2E-02
Lead	1.1E-06	2.6E-06	3.4E-06	8.6E-05	3.1E-05	9.7E-05	5.8E-07	9.3E-05	9.4E-05	9.6E-05	2.3E-04	3.1E-04	4.4E-06	9.2E-04	9.3E-04	4.7E-05	1.1E-04	1.5E-04	3.9E-04	1.2E-03	1.5E-03
Manganese	3.4E-10	2.5E-06	2.5E-06	3.1E-08	9.8E-03	9.8E-03	1.3E-09	5.2E-03	5.2E-03	2.2E-10	4.7E-06	4.7E-06	8.3E-11	5.2E-03	5.2E-03	9.9E-11	3.2E-06	3.2E-06	5.2E-10	4.0E-03	4.0E-03
Mercury	5.0E-08	1.7E-08	5.5E-08	8.6E-05	2.0E-05	8.6E-05	7.6E-08	6.5E-08	1.2E-07	7.7E-08	7.3E-08	1.3E-07	2.5E-08	2.3E-08	4.2E-08	3.4E-07	9.1E-08	3.5E-07	4.6E-06	1.1E-06	4.6E-06
Methylmercury	3.0E-06	7.4E-07	3.0E-06	5.8E-03	1.3E-03	5.8E-03	2.6E-08	9.6E-09	2.8E-08	2.5E-06	1.0E-06	2.7E-06	9.3E-07	3.7E-07	1.0E-06	4.6E-05	1.1E-05	4.6E-05	6.5E-04	1.5E-04	6.5E-04
Nickel	1.2E-07	8.0E-07	8.8E-07	6.1E-04	1.9E-04	6.6E-04	5.5E-07	8.4E-05	8.4E-05	1.8E-07	1.8E-06	1.9E-06	5.3E-08	3.1E-05	3.1E-05	5.5E-08	3.4E-07	3.8E-07	9.5E-06	2.7E-05	3.4E-05
Selenium	7.0E-05	2.0E-02	2.0E-02	2.3E-03	7.4E-04	2.5E-03	3.6E-05	1.1E-02	1.1E-02	1.6E-04	4.5E-02	4.5E-02	6.3E-06	2.2E-03	2.2E-03	7.8E-05	2.2E-02	2.2E-02	4.6E-04	9.9E-02	9.9E-02
Silver-1	0.0E+00	6.2E-07	6.2E-07	0.0E+00	1.5E-08	1.5E-08	0.0E+00	7.6E-07	7.6E-07	0.0E+00	5.0E-06	5.0E-06	0.0E+00	6.1E-07	6.1E-07	0.0E+00	1.9E-06	1.9E-06	0.0E+00	8.3E-06	8.3E-06
Thallium	3.8E-04	1.5E-02	1.5E-02	1.0E-02	2.4E-03	1.0E-02	1.9E-04	7.9E-03	8.1E-03	7.6E-04	3.0E-02	3.1E-02	3.0E-05	1.2E-03	1.2E-03	3.8E-04	1.5E-02	1.5E-02	2.2E-03	6.7E-02	6.9E-02
Zinc	9.2E-05	1.0E-03	1.1E-03	8.0E-03	7.5E-03	1.4E-02	5.0E-05	1.6E-03	1.7E-03	2.8E-05	3.2E-04	3.4E-04	1.3E-06	1.6E-03	1.6E-03	1.5E-05	1.6E-04	1.7E-04	1.2E-04	1.9E-03	2.0E-03

1- Site specific background levels were not available for Silver, therefore baseline and application levels are the same

Table D-4 Predicted Exposure Ratio for the Multimedia Assessment Gold Creek

Parameter	Aquatic																				
	Mammalian Receptors									Avian Receptors											
	Northern River Otter			Beaver			Little Brown Bat			American Dipper			Goose			Great Blue Heron			Mallard Duck		
	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application
Arsenic	1.8E-04	1.2E-04	3.0E-04	2.6E-03	7.6E-04	2.7E-03	4.8E-05	3.7E-05	8.1E-05	4.9E-05	3.3E-05	7.9E-05	8.3E-06	1.6E-04	1.7E-04	1.3E-04	8.4E-05	2.0E-04	1.2E-04	1.7E-04	2.7E-04
Cadmium	1.4E-03	3.0E-04	1.6E-03	1.8E-03	2.3E-03	3.7E-03	2.3E-04	5.7E-04	7.8E-04	3.0E-04	6.6E-05	3.5E-04	1.2E-05	1.1E-03	1.1E-03	4.9E-04	1.1E-04	5.7E-04	6.3E-04	9.8E-04	1.6E-03
Chromium II/III (total)	1.9E-04	3.5E-04	5.3E-04	1.1E-03	2.6E-04	1.1E-03	1.0E-04	2.6E-03	2.7E-03	4.6E-04	8.6E-04	1.3E-03	2.2E-05	4.1E-05	6.2E-05	2.4E-04	4.4E-04	6.6E-04	1.1E-03	1.9E-03	2.8E-03
Cobalt	3.5E-06	6.4E-07	4.0E-06	6.0E-04	2.1E-04	6.8E-04	3.7E-05	4.1E-04	4.5E-04	3.7E-05	6.6E-06	4.3E-05	1.2E-05	1.4E-04	1.5E-04	5.4E-06	1.1E-06	6.3E-06	4.3E-05	1.1E-04	1.5E-04
Copper	1.6E-03	6.8E-04	2.2E-03	2.8E-03	7.8E-03	9.9E-03	2.8E-04	5.1E-04	7.7E-04	1.3E-03	5.3E-04	1.7E-03	5.3E-05	1.4E-02	1.4E-02	2.0E-03	8.4E-04	2.7E-03	2.7E-03	1.2E-02	1.5E-02
Lead	7.7E-06	3.9E-06	1.0E-05	8.6E-05	3.1E-05	9.7E-05	4.1E-06	9.4E-05	9.7E-05	7.0E-04	3.6E-04	9.1E-04	3.1E-05	9.3E-04	9.5E-04	3.4E-04	1.8E-04	4.5E-04	1.7E-03	1.5E-03	2.9E-03
Manganese	7.1E-06	2.5E-06	9.6E-06	2.6E-06	9.8E-03	9.8E-03	8.1E-05	5.2E-03	5.3E-03	2.4E-05	4.7E-06	2.9E-05	7.8E-06	5.2E-03	5.3E-03	3.8E-06	3.2E-06	7.0E-06	1.0E-05	4.0E-03	4.0E-03
Mercury	9.1E-08	2.4E-08	9.6E-08	8.6E-05	2.0E-05	8.6E-05	4.5E-07	1.3E-07	5.0E-07	5.2E-07	1.5E-07	5.8E-07	1.7E-07	4.8E-08	1.8E-07	4.4E-07	1.1E-07	4.5E-07	4.8E-06	1.1E-06	4.9E-06
Methylmercury	3.5E-02	1.0E-02	3.9E-02	5.8E-03	1.3E-03	5.8E-03	3.8E-08	1.2E-08	4.0E-08	1.0E-02	3.0E-03	1.1E-02	1.6E-06	4.8E-07	1.6E-06	1.0E-01	2.9E-02	1.1E-01	9.3E-03	2.7E-03	1.0E-02
Nickel	1.0E-04	1.5E-05	1.1E-04	6.1E-04	1.9E-04	6.6E-04	3.6E-05	8.4E-05	1.2E-04	1.7E-05	2.5E-06	2.0E-05	3.8E-06	3.1E-05	3.5E-05	4.0E-05	5.9E-06	4.5E-05	2.2E-05	2.7E-05	4.7E-05
Selenium	5.4E-01	3.9E-01	5.8E-01	6.5E-05	2.2E-04	2.8E-04	9.0E-02	6.5E-02	9.6E-02	4.5E-01	3.3E-01	4.8E-01	1.5E-02	1.1E-02	1.7E-02	6.8E-01	5.0E-01	7.3E-01	9.3E-01	6.8E-01	9.9E-01
Silver	4.9E-09	2.2E-06	2.2E-06	3.4E-11	1.5E-08	1.5E-08	1.7E-09	7.6E-07	7.7E-07	1.3E-08	5.5E-06	5.5E-06	1.4E-09	6.1E-07	6.1E-07	1.7E-08	7.5E-06	7.5E-06	2.0E-08	8.8E-06	8.8E-06
Thallium	3.2E-03	1.7E-02	1.9E-02	1.0E-02	2.4E-03	1.0E-02	1.5E-03	8.2E-03	9.3E-03	5.9E-03	3.1E-02	3.6E-02	2.3E-04	1.2E-03	1.4E-03	3.2E-03	1.7E-02	2.0E-02	1.4E-02	6.9E-02	8.0E-02
Zinc	7.3E-03	3.4E-03	1.0E-02	8.0E-03	7.5E-03	1.4E-02	1.3E-03	1.7E-03	2.9E-03	8.6E-04	4.0E-04	1.2E-03	3.4E-05	1.6E-03	1.6E-03	1.3E-03	5.8E-04	1.8E-03	1.8E-03	2.0E-03	3.7E-03

Table D-5 Predicted Exposure Ratio for the Multimedia Assessment Blairmore Creek

Parameter	Aquatic																				
	Mammalian Receptors									Avian Receptors											
	Northern River Otter			Beaver			Little Brown Bat			American Dipper			Goose			Great Blue Heron			Mallard Duck		
	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application
Arsenic	1.9E-04	1.2E-04	3.1E-04	2.6E-03	7.6E-04	2.7E-03	5.0E-05	3.7E-05	8.3E-05	5.1E-05	3.3E-05	8.1E-05	8.7E-06	1.6E-04	1.7E-04	1.3E-04	8.4E-05	2.1E-04	1.2E-04	1.7E-04	2.7E-04
Cadmium	2.9E-03	3.0E-04	3.1E-03	1.8E-03	2.3E-03	3.7E-03	4.8E-04	5.7E-04	1.0E-03	6.4E-04	6.6E-05	6.9E-04	2.6E-05	1.1E-03	1.1E-03	1.0E-03	1.1E-04	1.1E-03	1.3E-03	9.8E-04	2.2E-03
Chromium II/III (total)	4.3E-04	3.5E-04	7.7E-04	1.1E-03	2.6E-04	1.1E-03	2.3E-04	2.6E-03	2.9E-03	1.1E-03	8.6E-04	1.9E-03	5.1E-05	4.1E-05	9.0E-05	5.4E-04	4.4E-04	9.7E-04	2.3E-03	1.9E-03	4.1E-03
Cobalt	2.8E-06	6.4E-07	3.3E-06	6.0E-04	2.1E-04	6.8E-04	3.0E-05	4.1E-04	4.4E-04	3.0E-05	6.6E-06	3.6E-05	9.5E-06	1.4E-04	1.5E-04	4.3E-06	1.1E-06	5.3E-06	4.0E-05	1.1E-04	1.5E-04
Copper	1.3E-03	6.8E-04	1.8E-03	2.8E-03	7.8E-03	9.9E-03	2.2E-04	5.1E-04	7.0E-04	9.9E-04	5.3E-04	1.4E-03	4.1E-05	1.4E-02	1.4E-02	1.5E-03	8.4E-04	2.2E-03	2.1E-03	1.2E-02	1.4E-02
Lead	1.2E-05	3.9E-06	1.4E-05	8.6E-05	3.1E-05	9.7E-05	6.4E-06	9.4E-05	1.0E-04	1.1E-03	3.6E-04	1.3E-03	4.8E-05	9.3E-04	9.7E-04	5.4E-04	1.8E-04	6.4E-04	2.6E-03	1.5E-03	3.7E-03
Manganese	8.0E-06	2.5E-06	1.1E-05	2.9E-06	9.8E-03	9.8E-03	9.2E-05	5.2E-03	5.3E-03	2.7E-05	4.7E-06	3.2E-05	8.8E-06	5.2E-03	5.3E-03	4.3E-06	3.2E-06	7.5E-06	1.1E-05	4.0E-03	4.0E-03
Mercury	1.4E-07	2.4E-08	1.4E-07	8.6E-05	2.0E-05	8.6E-05	8.7E-07	1.3E-07	9.2E-07	1.0E-06	1.5E-07	1.1E-06	3.2E-07	4.8E-08	3.4E-07	5.4E-07	1.1E-07	5.6E-07	5.1E-06	1.1E-06	5.1E-06
Methylmercury	7.0E-02	1.0E-02	7.3E-02	5.8E-03	1.3E-03	5.8E-03	5.2E-08	1.2E-08	5.3E-08	2.0E-02	3.0E-03	2.2E-02	2.3E-06	4.8E-07	2.3E-06	2.0E-01	2.9E-02	2.1E-01	1.8E-02	2.7E-03	1.9E-02
Nickel	9.5E-05	1.5E-05	1.1E-04	6.1E-04	1.9E-04	6.6E-04	3.3E-05	8.4E-05	1.2E-04	1.6E-05	2.5E-06	1.8E-05	3.5E-06	3.1E-05	3.4E-05	3.8E-05	5.9E-06	4.3E-05	2.1E-05	2.7E-05	4.6E-05
Selenium	2.7E-01	3.3E-01	2.8E-01	2.3E-03	7.4E-04	2.6E-03	5.5E-02	6.5E-02	5.8E-02	2.7E-01	3.2E-01	2.8E-01	9.6E-03	1.1E-02	1.1E-02	3.4E-01	4.1E-01	3.5E-01	5.6E-01	6.7E-01	5.8E-01
Silver	2.0E-06	2.2E-06	4.2E-06	1.4E-08	1.5E-08	2.9E-08	7.2E-07	7.6E-07	1.5E-06	5.2E-06	5.5E-06	1.1E-05	5.7E-07	6.1E-07	1.2E-06	7.0E-06	7.5E-06	1.4E-05	8.3E-06	8.8E-06	1.7E-05
Thallium	1.0E-02	1.7E-02	2.6E-02	1.0E-02	2.4E-03	1.0E-02	4.7E-03	8.2E-03	1.3E-02	1.9E-02	3.1E-02	4.9E-02	7.4E-04	1.2E-03	1.9E-03	1.0E-02	1.7E-02	2.7E-02	4.2E-02	6.9E-02	1.1E-01
Zinc	7.2E-03	3.4E-03	1.0E-02	8.0E-03	7.5E-03	1.4E-02	1.3E-03	1.7E-03	2.9E-03	8.5E-04	4.0E-04	1.2E-03	3.4E-05	1.6E-03	1.6E-03	1.3E-03	5.8E-04	1.8E-03	1.8E-03	2.0E-03	3.7E-03

Table D-6 Predicted Exposure Ratio for the Multimedia Assessment Oldman Resevoir

Parameter	Aquatic																				
	Mammalian Receptors									Avian Receptors											
	Northern River Otter			Beaver			Little Brown Bat			American Dipper			Goose			Great Blue Heron			Mallard Duck		
	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application	Project	Baseline	Application
Arsenic	1.0E-05	2.4E-04	2.5E-04	7.1E-08	1.5E-04	1.5E-04	2.6E-06	6.4E-05	6.6E-05	2.7E-06	6.3E-05	6.5E-05	4.5E-07	1.7E-04	1.7E-04	6.9E-06	1.6E-04	1.7E-04	2.7E-06	1.8E-04	1.8E-04
Cadmium	9.0E-05	1.7E-02	1.7E-02	6.0E-08	1.9E-03	1.9E-03	1.5E-05	3.4E-03	3.4E-03	2.0E-05	3.8E-03	3.8E-03	8.1E-07	1.3E-03	1.3E-03	3.2E-05	6.1E-03	6.1E-03	3.9E-05	8.3E-03	8.4E-03
Chromium II/III (total)	2.1E-05	3.9E-03	4.0E-03	5.1E-08	9.5E-06	9.6E-06	1.1E-05	4.5E-03	4.5E-03	5.2E-05	9.5E-03	9.6E-03	2.5E-06	4.6E-04	4.6E-04	2.7E-05	4.9E-03	5.0E-03	1.1E-04	2.0E-02	2.1E-02
Cobalt	1.7E-07	2.1E-06	2.3E-06	5.7E-08	7.6E-05	7.7E-05	1.8E-06	4.3E-04	4.3E-04	1.8E-06	2.3E-05	2.5E-05	5.9E-07	1.4E-04	1.4E-04	2.5E-07	3.3E-06	3.5E-06	7.7E-07	1.1E-04	1.1E-04
Copper	6.2E-05	1.4E-03	1.5E-03	4.0E-08	7.2E-03	7.2E-03	1.1E-05	6.3E-04	6.4E-04	4.9E-05	1.1E-03	1.2E-03	2.0E-06	1.4E-02	1.4E-02	7.7E-05	1.8E-03	1.8E-03	9.8E-05	1.3E-02	1.3E-02
Lead	2.0E-07	4.3E-05	4.3E-05	3.1E-10	1.1E-05	1.1E-05	1.1E-07	1.1E-04	1.1E-04	1.8E-05	3.9E-03	3.9E-03	8.0E-07	1.1E-03	1.1E-03	9.0E-06	1.9E-03	1.9E-03	4.0E-05	9.2E-03	9.2E-03
Manganese	3.9E-07	2.9E-06	3.2E-06	1.4E-07	9.8E-03	9.8E-03	4.4E-06	5.2E-03	5.2E-03	1.3E-06	5.8E-06	7.1E-06	4.2E-07	5.2E-03	5.2E-03	2.1E-07	3.4E-06	3.6E-06	5.5E-07	4.0E-03	4.0E-03
Mercury	1.5E-09	2.9E-08	3.0E-08	4.4E-10	8.2E-09	8.7E-09	1.4E-08	2.7E-07	2.8E-07	1.7E-08	3.2E-07	3.3E-07	5.3E-09	9.9E-08	1.0E-07	3.6E-09	6.7E-08	7.1E-08	7.9E-09	1.5E-07	1.6E-07
Methylmercury	1.2E-03	2.2E-02	2.3E-02	9.4E-10	1.8E-08	1.9E-08	4.5E-10	8.5E-09	8.9E-09	3.4E-04	6.4E-03	6.8E-03	2.4E-08	4.5E-07	4.7E-07	3.3E-03	6.2E-02	6.6E-02	2.8E-04	5.3E-03	5.6E-03
Nickel	5.3E-06	2.0E-05	2.5E-05	5.5E-08	5.0E-05	5.0E-05	1.8E-06	8.6E-05	8.8E-05	8.9E-07	3.4E-06	4.3E-06	1.9E-07	3.1E-05	3.1E-05	2.1E-06	7.9E-06	9.9E-06	6.4E-07	2.6E-05	2.6E-05
Selenium	1.6E-02	1.5E-02	3.1E-02	3.3E-06	2.1E-04	2.1E-04	2.7E-03	3.1E-03	5.8E-03	1.3E-02	1.3E-02	2.6E-02	4.7E-04	8.7E-04	1.3E-03	2.0E-02	1.9E-02	3.8E-02	2.7E-02	2.7E-02	5.4E-02
Silver	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Thallium	0.0E+00	1.7E-09	1.7E-09	0.0E+00	1.4E-09	1.4E-09	0.0E+00	4.3E-04	4.3E-04	0.0E+00	3.6E-09	3.6E-09	0.0E+00	1.4E-09	1.4E-09	0.0E+00	1.6E-09	1.6E-09	0.0E+00	1.8E-09	1.8E-09
Zinc	3.7E-04	5.5E-03	5.8E-03	2.1E-07	5.6E-03	5.6E-03	6.7E-05	2.1E-03	2.1E-03	4.3E-05	6.4E-04	6.9E-04	1.7E-06	1.6E-03	1.6E-03	6.4E-05	9.5E-04	1.0E-03	8.8E-05	2.5E-03	2.6E-03