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Wetland Treatment Evaluation - Star and Orion South Diamond Project

January 21, 2013

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Wetland Treatment Evaluation

Star and Orion South Diamond Project

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ACRONYMS

AG	autogenous grinding
CEAA	Canadian Environmental Assessment Agency
Coarse PK Pile	coarse processed kimberlite pile
COCs	constituents of concern
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EQGs	Canadian Environmental Quality Guidelines
FalC	Fort à la Corne
FWS	free water surface wetland
HSSF	horizontal subsurface flow wetlands
ITRC	Interstate Technology and Regulation Council
Orion South Pit	Orion South Kimberlite open pit
PK	processed kimberlite
PKCF	Fine Processed Kimberlite Containment Facility
Project	Star and Orion South Diamond Project
Shore	Shore Gold, Inc.
SMOE	Saskatchewan Ministry of Environment
Star Pit	Star Kimberlite open pit
SRBs	sulfate reducing bacteria

SSF	subsurface flow wetland
VFW	vertical flow wetlands

1. Introduction

On behalf of Shore Gold, Inc. (Shore), ARCADIS has prepared this report to evaluate proposed on-site wetland treatment for a volume of seepage to be captured from the Fine Processed Kimberlite Containment Facility (PKCF) at the Star and Orion South Diamond Project (Project). As part of the Water Management Alternative Assessment, included in the Environmental Impact Statement (EIS; AMEC 2012), Shore proposed a portion of the captured seepage from the PKCF would be effectively treated through discharge to a complex of naturally occurring (native) wetlands found on-site. Through a sequence of biotic and abiotic processes, these wetlands would treat constituents prior to being carried downstream into the Saskatchewan River.

The overall goal of this report is to assist Shore with preparing a formal response to federal and provincial review comments specific to wetland treatment. This report provides additional background to wetland treatment systems and processes, a quantitative comparison of modeled concentrations to regulatory water quality standards and guidelines, calculations of potential loading within the wetlands, as well recommendations to meet these guidelines and regulations. Table 1 provides a summary evaluation of relevant wetland treatment topics, with a focus on the following:

- Evaluate whether the native wetlands will be capable of passively treating the proposed discharges to applicable water/soil criteria.

- Evaluate the assimilative capacity of wetlands (defined as natural absorption or treatment with no significant ecosystem change and no elevated output) for treating identified constituents of concern (COCs) within the context of the long-term treatment and remediation plan. This evaluation will take into consideration treatment under both frozen and non-frozen conditions.

- Evaluate the risk of potential leaching of COCs from sediments once the assimilative capacity has been reached in wetland, and the wetland is no longer used for seepage treatment.

1.1 Project Location

The Project is located in central Saskatchewan within the Fort à la Corne (FalC) Provincial Forest, approximately 60 kilometers east of the City of Prince Albert. The kimberlites are located immediately north of the Saskatchewan River, and downstream of the convergence of the North and South Saskatchewan Rivers. Appendix A includes a site location map or other relevant figures previously presented in the EIS (AMEC 2012).

1.2 Project Background

Shore has been exploring the Star Kimberlite since 1996. The Project includes the excavation of two open pits: one to mine the Star Kimberlite deposit and the other to mine the Orion South Kimberlite deposit. Collectively, the construction and operation of these two open pit mines, the processing facilities, and the associated infrastructure to commercially extract diamonds from these kimberlites, includes the following major components:

1. Star Kimberlite open pit (Star Pit);
2. Orion South Kimberlite open pit (Orion South Pit);
3. Overburden and rock storage pile;
4. Coarse processed kimberlite pile (Coarse PK Pile);
5. Processed Kimberlite Containment Facility (PKCF);
6. Processing plant; and
7. Other infrastructure.

Overburden from the Star and Orion South open pits will be excavated with an in-pit crush and convey system using hydraulic shovels to place material into a mobile crusher, which will feed a conveyor system for transport of material to a stacker at the overburden and rock storage pile. Kimberlite will be excavated using a separate system, in which hydraulic shovels will load heavy haul trucks that will dump ore using a short haul into a semi-mobile sizer, which will feed an ore conveyor for transport of kimberlite to the plant. The process plant will liberate diamonds from the host rock using autogenous grinding (AG) mills. Fine material from the AG mills will then be pumped in two separate pipes via slurry to the PKCF. Coarse material from the AG milling process will be sent to the Dense Media Separation plant. The Dense Media Separation sorts material by density with the lighter minerals (or floats) being transported to the Coarse PK Pile, and the heavy material being sent to the diamond recovery circuit. Diamonds will be separated from the other heavy minerals. Shore will mine ore from Star and Orion South at 45,000 tons per day.

Process water required in the plant will be supplied by a combination of pit dewatering, shallow groundwater and surface water, and managed through the PKCF. Process water may be recycled from the PKCF to supply the AG mills, with makeup water sourced from pit dewatering operations where possible. Excess groundwater from pit dewatering will be discharged to the Saskatchewan River or managed as appropriately. The site-wide water balance is described further below (Section 2 and 4), and included as Appendix 6.2.7 of the EIS.

When the Star pit mining is complete, all fine PK and process water from Orion South will be placed into the Star pit, thus reducing environmental impacts and Project costs. Some overburden from later phases of the Project will be backfilled into the southern edge of the Star pit during mining.

The potential life of mine Project schedule is as follows:

- Construction and Commissioning – Year 1 to Year 4;
- Operation – Year 4 to Year 23; and
- Closure and Decommissioning – Year 23 to Year 25.

The operational life of the mine and associated infrastructure may be extended beyond 20 years in order to either process other inferred and probable reserves in the Star and Orion South Kimberlites and / or mine other kimberlites in the area. However, all modeling utilized by this evaluation assumes a mine life of 25 years and is not inclusive of a site closure water balance model.

1.3 Regulatory Background

In 2012, Shore submitted a revised EIS to the Saskatchewan Ministry of Environment (SMOE) and Government of Canada that described the Environmental Impact Assessment (EIA) completed for the Project. The EIA was completed consistent with guidance outlined in the project-specific guidelines (SMOE 2009) and the Comprehensive Study Scoping Document prepared by Canadian Environmental Assessment Agency (CEAA), Fisheries and Oceans Canada, Natural Resources Canada, and Transport Canada (CEAA 2010).

In Saskatchewan, the EIA occurs under the terms of the Canada-Saskatchewan Agreement in EA Cooperation (Government of Saskatchewan 2005). Under this agreement, projects that require an environmental assessment by both the federal and provincial governments undergo a single assessment, administered cooperatively by both governments

The original Draft EIS which was submitted in December 2010 was based upon the - Orion South Diamond Project Pre-Feasibility Study. This revised EIS, which was based upon the Feasibility Study of the Star - Orion South Diamond Project, incorporated responses to all the review comments and information requests from the 2010 draft.

As noted above, federal and provincial comments to the revised EIS were received in October 2012. The objective of this report is to assist Shore with a formal response to comments relative to proposed wetland treatment of a portion of seepage required by the Project.

2. Seepage Characterization

As presented in the EIS, a life of mine site-wide water balance model has been developed for the Project to provide a tool for quantifying the volume of water at various nodes within the mine's water management system at any time. The water balance model developed for the Project tracks the volume of water that is gained and lost on a monthly basis for a period of 25 years. In addition, the model tracks a set of chemical parameters within the water for the projected mine life. The period modeled begins a year prior to the start of construction to determine the baseline conditions and ends at the completion of the Operations Phase. Appendix A includes a map of Project facilities and surface drainage basins during Construction and Operations Phases of the Project as previously presented in the EIS.

This report focuses on the treatment of seepage from the site facilities; specifically, the EIS proposed treatment of leachate collected from the PKCF and potentially the Coarse PK pile. Seepage will be captured in perimeter ditches[1], both through active and passive interception, at a rate of approximately 1 000 m^3/day. This evaluation conservatively assumes that the wetlands will be used to treat the majority of seepage (i.e., 90%). However, it is recognized that Shore will have the ability to pump seepage back to the PKCF if water quality is unacceptable for discharge to the native wetlands found on or proximate to the mine site (i.e., Duke Ravine, East Ravine).

In addition to leachate collection and reuse, deep wells will be installed around the mine pits to draw down the water level in the Mannville aquifer, thereby reducing groundwater seepage into the pits. It is estimated that the dewatering wells will pump at a rate that will vary from 85 000 m^3/day to 120 000 m^3/day over the life of the mine. The peak Mannville aquifer dewatering rate will occur in Year 19. The dewatering wells will pump directly to the Saskatchewan River via the diffuser or to the Process Tank if make-up water is needed for processing or use at other site facilities.

The EIS noted that no available data quantifying the rate of seepage loss at the various other facilities was available. Therefore, the EIA assumed that seepage from the Runoff Pond and Coarse PK Pile would occur at the natural recharge rate of 19

[1] At Star pit, the upper collection ditch will be constructed at an elevation of approximately 390 meters above sea level (masl). This ditch will collect surficial residual passive inflows and any runoff from direct precipitation on pit walls above the collection ditch. A similar collection ditch will be constructed for Orion South pit, at an elevation of approximately 400 masl.

mm/year (distributed equally over each month) (AMEC 2012). For all other site facilities it was assumed that there would be no seepage in excess of the infiltration considered as part of the runoff calculation.

2.1 Seepage Chemistry Modeling

The chemical parameters that were modeled as part of the site-wide water balance model are listed in Table 2. They include four conventional parameters, five nutrients, 10 major ions, and 23 total and dissolved metals. Water quality at each of the Project facilities were calculated by using fully-mixed reservoirs (boxes), and chemical species were modeled without chemical reactions or decay within the system. Concentrations of chemical parameters were calculated on a monthly basis, with the sources being well mixed over the month. This approach leads to a conservative (potential worst case) estimation of water quality. The main case was modeled as water quality at mean climatic conditions; wet and dry conditions were also modeled to provide a sensitivity analysis of predicted water quality (AMEC 2012). This evaluation focuses on treatment of seepage captured from the PKCF as well as from the Coarse PK Pile, consistent with the EIS (AMEC 2012).

Results of the modeling are summarized in Tables 3 and 4. Results were compared to the following regulatory standards or guidelines to determine the COCs within the modeled seepage:

1. Canadian Environmental Quality Guidelines (EQGs) for the Protection of Aquatic Life (CCME 2012)

2. Saskatchewan Surface Water Quality Objectives for the Protection of Aquatic Life (MOE 2006)

3. Canada Metal Mining Effluent Regulations (2012)

4. Saskatchewan Mineral Industry Environmental Protection Regulations (1996)

The EIS assumed a portion of the captured seepage from PKCF and Coarse PK Pile, in perimeter ditches, would be discharged to the surrounding native wetlands for passive treatment. As mentioned above, AMEC (2012) assumed treatment efficiencies based upon a preliminary literature review. This literature review was expanded upon for this evaluation, and discussed below in Sections 3 and 4. Derived treatment efficiencies from both AMEC (2012) and by ARCADIS for this evaluation are included in Table 5.

2.2 Regulatory Drivers

For the purposes of this report, COCs were determined by those chemical parameters that exceed the Canadian Environmental Quality Guidelines (EQGs) Applicable to Aquatic Life (CCME 2012). CCME EQGs provide science-based targets in the environment for protecting the designated uses of atmospheric, terrestrial, and aquatic ecosystems. In addition, those parameters that exceeded regulatory standards of the Metal Mining Effluent Regulation (2012) were also identified as a COC. Guidelines for Canadian Drinking Water Quality (Health Canada 2012) were not used in this evaluation to determine COCs.

EQGs are defined by the CCME (1999) as "*numerical concentrations or narrative statements that are recommended as levels that should result in negligible risk to biota, their functions, or any interactions that are integral to sustaining the health of ecosystems and the designated resource uses they support*." They are intended to provide protection of freshwater and marine life from anthropogenic stressors such as chemical inputs or changes to physical components (e.g., pH, temperature, and debris). More specifically, they are meant to protect all forms of aquatic life and all aspects of the aquatic life cycles, including the most sensitive life stage of the most sensitive species over the long term.

2.3 Constituents of Concern

The following chemical parameters modeled within the projected seepage, as documented in the EIS, exceed Canadian EQGs and were determined to be COCs (see Tables 3 and 4):

1. Chloride. The projected mean, median, 95th percentile, and maximum concentrations, with and without wetland treatment, are anticipated to exceed the long term exposure CCME EQG of 120 milligrams per liter (mg/L). For the PKCF, only the 95th percentile, and maximum concentrations, with and without treatment, will exceed the short term exposure CCME EQG of 640 mg/L. For the Coarse PK Pile, all projected concentrations, with and without wetland treatment, will exceed the short term exposure CCME EQG. It is important to note that background concentrations in the Mannville aquifer based upon a 20 day pump test in 2010

ranged from 1600 to 1700 mg/L, far exceeding the short term exposure CCME EQG.

2. Boron. The projected 95th percentile and maximum concentrations, with and without wetland treatment, are anticipated to exceed the CCME EQG of 1.5 mg/L. It is important to note that background concentrations in the Mannville aquifer based upon a 20 day pump test in 2010 ranged from 1.9 to 2.1 mg/L, exceeding the CCME EQG.

3. Cadmium. The projected mean, median, 95th percentile, and maximum concentrations, without wetland treatment, are anticipated to exceed the CCME EQG of 0.00006 mg/L (or 0.06 µg/L). With wetland treatment (efficiency of 65% as assumed by AMEC (2012)), the maximum projected concentrations are anticipated to exceed the CCME EQG. It is also important to note that the background concentrations measured in surrounding wetlands (i.e., East Ravine, Duke Ravine) were both equivalent to the CCME EQG for cadmium.

4. Chromium. The projected mean, median, 95th percentile and maximum concentrations, without wetland treatment, are anticipated to exceed the CCME EQG of 0.001 mg/L. With wetland treatment (assuming a treatment efficiency of 67%), all of the projected concentrations are anticipated to meet the CCME EQG. It is important to note that the background concentrations measured in the East Ravine and Duke Ravine exceeded the CCME EQG for chromium.

5. Selenium. The projected 95th percentile and maximum concentrations, without wetland treatment, are anticipated to exceed the CCME EQG of 0.001 mg/L. With wetland treatment (assuming a treatment efficiency of 100%), all of the projected concentrations are anticipated to meet the CCME EQG for selenium.

6. Zinc. The projected 95th percentile and maximum concentrations, without wetland treatment, are anticipated to exceed the CCME EQG of 0.03 mg/L. With wetland treatment (assuming a treatment efficiency of 99%), all of the projected concentrations are anticipated to meet the CCME EQG.

Authorized limits as defined by Metal Mining Effluent Regulations (2012) were all met with and without wetland treatment for projected seepage water quality.

3. Wetland Biogeochemistry

Wetlands have long been appreciated for their abilities to function as a sink for a wide variety of organic and inorganic chemicals, being capable of assimilating large amounts of environmental contaminants (Dinges 1982, Groudev et al. 2001). Given this ability to function as a biological filter, wetlands and their intrinsic biogeochemical processes have emerged as a viable option for solving a range of environmental and water quality problems. Over the past three decades, a great deal of research has been published that documents how native and constructed wetlands can be used for the treatment of a variety of waste waters to remove contaminants and reduce the risk to both human as well as native flora and fauna. By protecting the native biota, this also protects the processes that are integral to sustaining healthy ecosystems and the designated resource uses they support.

Wetlands are generally located in areas of low elevations and a high water table. They are characteristically poorly drained and retain water during times of high precipitation. Water is received from upgradient sources (i.e., uplands), and frequently transported through wetlands to aquatic ecosystems. Physical, chemical, and biological processes that occur in the soils of both uplands and wetlands regulate the fate (i.e., availability) of contaminants. More specifically, both upland and wetland habitats can function as either a sink or source for contaminants as illustrated in Figure 1 and detailed below.

- Sink: Transformation of contaminants to biologically unavailable forms.
- Source: Transportation of contaminants to a downgradient ecosystem.
- Transformer: Contaminants added to a wetland can be transformed and released in a different chemical form, to the downstream aquatic ecosystem.

As noted above, the primary driver of wetland processes is biogeochemistry. Biogeochemistry governs the exchange or flux of materials between living and nonliving components of the biosphere. Wetland biogeochemistry includes natural processes by which an element or compound is transformed within a wetland, including means by which various forms are interchanged between solid, liquid and gaseous phases. Biogeochemistry allows us to predict the exchange and transport of elements or compounds that occur naturally within a wetland or enter the system through anthropogenic sources, including exchange or transport to other ecosystems (e.g., atmosphere, aquatic ecosystem). Biogeochemical processes are the primary mechanisms that serve to treat contaminants within a wetland.

3.1 Wetland Definition

For the purposes of this evaluation, a wetland is defined as "consisting of a biologically active soil or sediment in which the content of water in or the overlying floodwater is great enough to inhibit oxygen diffusion into the soil/sediment and stimulate anaerobic biogeochemical processes and support hydrophytic vegetation" (Reddy and DeLuane 2008). Consistent with this definition, there are three major components that constitute a wetland:

- Hydrology – presence of water at or near the surface for a period of time.
- Hydrophytic vegetation – wetland plants adapted to saturated soil conditions.
- Hydric soils – saturated soil conditions exhibiting temporary or permanent anaerobiosis (absence of dissolved oxygen).

The biogeochemical transformations within a wetland are strongly governed by the hydrology, which influences both vegetation and soils. It is important to note that transformations within a wetland include both anaerobic as well as aerobic processes.

3.2 Biogeochemical Processes

As noted above, wetlands have the ability to function as a sink and remove or filter pollutants from water directed through them. Treatment mechanisms are dependent on the specific contaminant, site conditions, and remedial and/or regulatory objectives. Figure 2 depicts both the abiotic (physical/chemical) and biotic (microbial/phytological) processes that take place in a wetland. The discussion below deals with the abiotic and biotic processes separately.

3.2.1 Abiotic Wetland Processes

Primary physical and chemical processes responsible for contaminant filtering or removal in a wetland include:

- Settling, sedimentation
- Sorption
- Chemical oxidation/reduction – precipitation

- Photodegredation / oxidation
- Volatilization

Removal of particulates and/or suspended solids can occur through natural settling in a wetland. Sorption, which is the chemical processes of a contaminant attaching to another substance, can result in either short-term retention or long-term immobilization within a wetland substrate. Sorption includes the combined processes of adsorption (i.e., the physical adherence or binding of ions and molecules onto the surface of another phase) or absorption (i.e., the incorporation of a substance in one state into another of a different state). Similarly, chemical precipitation involves the conversion of metals in the influent stream to an insoluble solid form that settles out. Photodegredation involves the degradation/oxidation of compounds in the presence of sunlight. Volatilization occurs when compounds with significant vapor pressures partition to the gaseous state. Figure 3 conceptually illustrates these processes.

3.2.2 Biotic Wetland Processes

Biotic processes are also major contributors for contaminant removal within a wetland. Microbial/phytological processes that occur in a wetland include:

- Aerobic / anaerobic biodegradation or biotransformation (e.g., alteration of the chemical speciation of a metal through changes in oxidation-reduction potential (Eh) (i.e., redox transformation).
- Phytoaccumulation/phytostabilization
- Phytodegredation/rhizodegredation
- Phytovolatilization/evapotranspiration

In both aerobic and anaerobic environments, metabolic processes of microorganisms are critical to treatment of organic compounds and inorganic chemical species within a wetland. Organic compounds are biodegraded (with complex organic molecules degraded by microbial metabolic processes into simple molecules or completely degraded to CO_2 and H_2O). Inorganic chemical species cannot be destroyed; however, microbial processes can transform these into less mobile forms by facilitating sorption onto soil organic matter and precipitation through redox transformation. Phytoaccumulation or phytostabilization occurs when a plant uptakes a contaminant from a wetland and stores it in above or below ground biomass. Rhizodegredation is where a plant provides an exudate that enhances microbial activity, resulting in adegradation of organic compounds or biotransformation of inorganic chemical species. Phytodegredation similarly breaks down a contaminant, via plant produced enzymes, that enters the plant during transpiration. Finally, phytovolatilization is the uptake and subsequent transpiration of volatile compounds through the leaves. Figure 4 conceptually illustrates these processes.

3.2.3 Critical Processes to COC Treatment

Based upon the COCs identified in Section 2.3, the primary mechanisms of contaminant removal will include physical, chemical, as well as biological processes. This report focuses on metals (i.e., 5 of the 6 COCs); effectiveness to treat high levels of chloride in a wetland has been documented to be very poor. Section 4 includes a discussion of the processes critical for treatment of each COC.

3.3 Characterization of On-Site Wetlands

Retention capacity of a wetland is necessary to determine the effectiveness and long-term viability of treatment. Critical to these calculations is a characterization of on-site wetlands where the seepage will be discharged. Four large wetland complexes associated with Duke Ravine, East Ravine, FalC Ravine and Wapiti Ravine can be found in close proximity of the PKCF and all drain into the Saskatchewan River. These wetlands are a complicated system of different wetland classification types, including bogs, swamps, marshes and open waters. For the purposes of this report, it is assumed regional draw down of groundwater will not adversely affect the ecological functioning of these three wetland complexes (AMEC 2012). Adverse effects of potential groundwater drawdown will be compensated for by inputs from the facility operations.

Shore conducted surveys to characterize each of the wetlands in terms of hydrology, soils, and vegetative community. Soils were generally comprised of an organic stratum of varying thickness, overlaying mineral strata of sands and loamy sands. Soils were dark and anoxic, with high levels of organic material (averaging about 30% total organic carbon). The average depth of the O horizon varies, however it can be assumed to dominate the biologically active zone of a wetland (i.e., 30 centimeters [cm] or average depth of root systems). This is consistent with evaluation of metals treatment in native and constructed wetlands. The water found within the wetland generally had a neutral to basic pH, with an average total alkalinity at 250 mg

$CaCO_3$/L, and no detectable nitrate or nitrite (likely indicating suboxic or anaerobic conditions). Water levels were frequently at the soil surface. Soil and water chemistry results are presented in Appendix B. A location of the sample locations is illustrated in Figure 5.

The tree layers contained a variety of species including trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), jack pine (*Pinus banksiana*), black spruce (*Picea mariana*), white spruce (*Picea glauca*), and larch (*Larix laricina*). Several species of willows (*Salix* sp.) were also identified. Shrub species included such species as bog birch (*Betula pumila*), marsh Labrador tea (*Rhododendron tomentosum*), and lingonberry (*Vaccinium vitis-idaea*). Herbaceous species included marsh reed grass (*Calamagrostis canadensis*), arrow-leaved coltsfoot (*Petasites sagittatus*), water sedge (*Carex aquatilis*) and horsestail (*Equisetum arvense*). In addition, some small bogs were found in association with the larger swamps, dominated by such species as peat moss (Sphagnum) and feather moss (*Hylocomium splendens*).

To support an evaluation of treatment capacity with existing wetlands, ARCADIS utilized existing wetland data (Appendix B) as well as recent (2010) aerial photography (Figure 5) to estimate the geographical extent of wetlands in the different drainages. In addition, the wetland areas were differentiated as either wetland habitat, encompassing emergent, scrub-shrub, and forested wetland habitats, or open water habitat, encompassing streams and/or ponded areas. A map of these areas is included as Figure 6. It is important to note that this is not a formal wetland delineation, but only an approximation based upon existing data sources and aerial photography to support calculations for potential treatment capacity of existing on site wetlands.

3.4 Seasonal Performance

It is critical to note that climate influences all stages of proposed wetland treatment. In many cold climates, constructed wetlands have been documented to effectively treat seepage or wastewater to stipulated regulatory levels. This sometimes requires storage of water during the winter months, or continual treatment through subsurface flow (SSF) wetlands year round.

Three primary concerns for wetland treatment of wastewaters in cold climates should be considered in any wetland treatment evaluation: ice formation, hydrology, and biological or microbiological mediated processes. While snow and ice can affect the engineered components of a constructed wetland, it must be recognized that they can provide a thermal benefit in native wetlands by insulating at the soil surface and effectively slowing the cooling of underlying water. The Project is not within the permafrost zone, so it can be anticipated that subsurface flows continue throughout the winter.

Hydrology of a wetland during the winter can be influenced by low evapotranspiration. As well, there may be seasonal variation in the anticipated seepage captured in perimeter ditches. Finally, in cold periods, nutrient uptake, oxygen transport to the roots and microbial rhizosphere activity ceases or greatly slows down. Lack of these processes may result in accumulation of total suspended solids, and potentially decrease hydrologic conductivity. In contrast, anaerobic microbial processes, such as sulfate reduction (critical for metals treatment) are less affected by cold temperatures. Studies of iron and sulfur cycling in a constructed wetland showed that when water temperature was 1°C, sulfate reducing bacteria (SRBs) were most effective at iron removal through iron sulfide mineral precipitation (Fortin et al., 2010). Measurement of the flux of microbially-generated gases (CO_2 and CH_4) from high-latitude wetlands also indicate that microbial respiration is minimally affected by cold temperatures (Panikov 1999).

For the proposed Project, it should be expected that low temperatures will only have a minor influence on the physical and chemical processes for metals attenuation. Macrobiological processes (plant growth) will be significantly influenced, although microbiological processes will likely not be affected. While metals treatment may be possible year round (as further discussed in Section 4), seasonal alternatives still exist on the site (i.e., recycling of seepage back into PKCF).

4. Wetland Treatment

This section is intended to provide a detailed evaluation of wetland treatment of the identified COCs. The mechanisms of treatment will vary between each of the COCs; however, there is significant overlap between the five metals requiring treatment. Critical to the functioning of the wetland treatment systems, this section also evaluates the loading or assimilative capacity of a wetland ecosystem to passively treat COCs. More specifically, whether the wetland is able to settle or transform contaminants to biologically unavailable forms and not pose long-term risks to the native ecosystem. The goal is for the wetlands to function as a sink during operations where no significant ecosystem change occurs, and to prevent against the wetland becoming a source or transformer during operations or after mine closure.

The following section addresses each COC separately, and is further organized to summarize the AMEC (2012) water quality predictions, potential treatment efficiencies, long-term loading and/or assimilative capacity of the wetlands, and treatment recommendations. Data summaries and comparisons to CCME EQGs and Metal Mining Effluent Regulations are included as Table 3 and 4. AMEC (2012) plots of model output are included as Appendix C.

4.1 Chloride

Due to a relatively low biological demand for chloride in a wetland, the total chloride mass balance is usually relatively constant between measured inflows and outflows of a naturally occurring wetland or constructed wetland. As a result, chloride is actually frequently used as a tracer within experiments designed to confirm a water budget or water movement within a wetland. However, high levels of chloride can have an adverse affect on wetlands, principally the vegetative community. For example, high chloride levels will favor more salt tolerant species, and can lead to a change in species composition of a vegetative community.

4.1.1 AMEC Modeling

The background concentration of chloride in the Manville deep aquifer water is 1 600 mg/L[2], in comparison to concentrations of 7.0, 2.0, 2.0 and 2.0 mg/L in shallow groundwater, overburden leachate, East Ravine, and Duke Ravine, respectively.

Seepage modeling for the PKCF predicts increasing concentrations of chloride in Year 4 (after beginning of site operation). Seasonal fluctuations are expected, but there is an anticipated continual increase over time. The predicted mean concentration is 485 mg/L, with a median concentration of 539 mg/L. The 95th percentile and maximum concentrations are expected to be 805 mg/L and 849 mg/L, respectively.

Concentrations of chloride in the seepage from the Coarse PK Pile are expected to be greater than in the PKCF. The predicted mean concentration is 835 mg/L, with a median concentration of 897 mg/L. The 95th percentile and maximum concentrations are expected to be 1420 mg/L and 1420 mg/L, respectively.

All projected concentrations for the PKCF, with and without wetland treatment, are anticipated to exceed the long term exposure CCME EQG of 120 milligrams per liter (mg/L). However, only the 95th percentile, and maximum concentrations, with and without treatment, will exceed the short term exposure CCME EQG of 640 mg/L (CCME 2012). For the Coarse PK Pile, all projected concentrations, with and without wetland treatment, will exceed the long term and short term exposure CCME EQG. There is no regulatory level associated with chloride as defined by the Metal Mining Effluent Regulations (2012).

4.1.2 Literature Treatment Efficiency

AMEC (2012) modeling assumed no treatment of chloride within the wetland, and therefore anticipated concentrations at the inlet and outlet of the wetland were assumed to be equivalent. This assumption is consistent with literature (Kadlec and

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[2] Manville water background concentrations presented herein are based upon a 20 day pump test conducted in 2010. Shallow groundwater, overburden leachate, East Ravine, and Duke Ravine background levels are based upon data presented in EIS (AMEC 2012).

Wallace 2009, Robinson et al. 1999), which also suggests there will be no treatment of chloride within the wetland.

4.1.3 Loading

Given the low biological demand of chloride within a wetland, it is assumed there will be no loading in wetland soils/sediments. As noted above, there may be adverse affects of chloride on the ecological functioning of the wetland. Due the anticipated high levels of chloride, elevated levels of chlorine can be anticipated in the plant water content.

4.1.4 Recommendations

It is anticipated that chloride levels in the seepage from the PKCF and Coarse PK Pile will consistently exceed the CCME EQG of 120 mg/L and in some instances, exceed the short term guideline. Effective treatment of chloride through a wetland has not been documented and is not expected to result in any reductions. Increased chloride concentrations in water flowing through wetlands has the potential to affect wetland vegetation (both plant health and species composition), and therefore wetland functioning over the long term. Tolerance of high chloride levels in terrestrial and aquatic vegetation has been shown to vary between species. More specifically, threshold values, derived from experimental data from road side studies looking at effects of road salts, ranged from 215 to 1500 mg/L chloride in growing media (i.e., water solution for wetland vegetation, or applied soil solution for woody species) (Environment Canada 2001). The lower range of this threshold exceeds the CCME EQG of 120 mg/L, and potential elevated levels can be expected to affect plant species differently.

Due to anticipated higher levels of chloride, Shore is committed to recycling peak events as well as potentially Coarse PK Pile water to the PKCF. In addition, Shore is committed to monitoring chloride levels in the naturally occurring wetlands as part of the soil vegetation monitoring described in the Revised EIS (AMEC 2012). Monitoring will be structured to facilitate an evaluation of the effects of seepage water on the health and functioning of the wetland. Additional details of the monitoring program will be developed during the detailed design phase, and also will rely heavily on adaptive management in order to effectively respond to the data obtained during monitoring. However, monitoring could include, but is not limited to: pore water chloride concentrations at various soil depths, chloride concentration of plant tissue, total vegetative cover across wetland, and species composition of wetland. These data should be collected at upgradient and downgradient extents of wetland(s).

4.2 Boron

The aqueous chemistry of the boron is dependent upon concentration and pH. Boron is an essential micronutrient for plants; however, levels required for optimal growth vary between species. More importantly, there is typically a small concentration range between deficiency and toxicity (Sartaj et al. 1999).

4.2.1 AMEC Modeling

Background concentration of total boron in the Manville water is 2.0 mg/L, with lower concentrations measured at other locations as follows:<0.01, 0.16, 0.03 and 0.03 mg/L in shallow groundwater, overburden leachate, East Ravine, and Duke Ravine, respectively.

Seepage modeling for the PKCF predicts increasing concentrations of boron after Year 3 (beginning of mine operations). Seasonal fluctuations are expected, but with a continual increase over time in both the expected low and high concentrations. The predicted mean concentration is 1.3 mg/L, with a median concentration of 1.4 mg/L. The 95th percentile and maximum concentrations are expected to be 2.3 mg/L and 2.5 mg/L, respectively.

Concentrations of boron in the Coarse PK Pile were expected to be similar to that in the PKCF. The predicted mean concentration is 1.3 mg/L, with a median concentration of 1.5 mg/L. The 95th percentile and maximum concentrations are expected to be 1.9 mg/L and 1.9 mg/L, respectively.

The CCME EQG for boron is 1.5 mg/L. Seepage from the PKCF will exceed this threshold guideline only in the 95th percentile and maximum concentrations. Specific to the Coarse PK Pile, seepage will meet the CCME EQG for the projected median, and exceed it in the 95th percentile, and maximum concentrations. There is no regulatory level associated with boron as defined by the Metal Mining Effluent Regulations (2012).

4.2.2 Literature Treatment Efficiency

Modeling assumed 15% efficiency for wetland treatment of boron. This initial estimate was based upon removal of trace elements using three sub-surface flow constructed wetlands in the Czech Republic (Kropfelova et al. 2009). The study investigated removal efficiencies over a period of approximately two years.

Boron removal mechanisms in a wetland are commonly association with boron adsorbing to both crystalline and amorphous iron and aluminum oxides (Goldberg 1997). The optimum pH for this mechanism is 8.0 (Kadlec and Wallace 2009). In addition, peat has been shown to have a strong affinity for boron (Sartaj and Fernandes 2005).

A review of existing literature demonstrates a wide range of treatment efficiencies for boron within constructed wetlands (Kadlec and Wallace 2009). Specifically, the median concentration reduction across 13 treatment systems was 5%, and the maximum reduction of 91%. The highest efficiency was demonstrated using vertical flow peat filters (Sartaj et al. 1999). In addition, the highest efficiencies are commonly associated with the highest concentrations in the treated wastewater.

Given the variability of treatment efficiencies in the literature, it is still assumed that the native wetlands will provide 15% treatment of boron between the inflow and outflow concentrations. This is a conservative estimate that also takes into consideration that the lowest concentrations are commonly associated with the lowest efficiencies in treatment wetlands. However, it is recognized that the significant organic soils within the on-site wetlands may be more effective in removing boron than the assumed 15% efficiency.

The modeled seepage concentrations will exceed the CCME EQG after wetland treatment for the 95th percentile, and maximum concentrations in both the PKCF and Coarse PK Pile. Therefore, only the most extreme events will have the potential to exceed the CCME EQG.

4.2.3 Loading

As noted above, it is assumed that the daily seepage production is 1 000 m^3, and wetland treatment will be required for 90% of this seepage. The calculations conservatively assume that treatment will be required 365 days per year, and that no recycling back to the PKCF will occur. This equates to 328 500 m^3/year. Given the potential dominance of abiotic processes for metals removal in a wetland systems (i.e., sorption to organics and iron/aluminum minerals), effective year round treatment is assumed.

Consistent with calculations presented in Sartaj et al. (1999), the estimate of loading assumes the median expected concentration of boron – approximately 1.4 mg/L. Based upon modeling presented in Sartaj et al. (1999), each gram of peat is capable of removing at least 0.1 mg of boron. The peat requirement to treat boron is as follows:

Peat requirement = (3.3×10^5 m^3/year x 1000 L/m^3 x 1.4 mg/L) / 0.1 mg/g of peat

4.62×10^9 g of peat per year (dry basis)

4.62×10^3 tons of peat per year (dry basis)

Assuming 1 hectare is equivalent to 2200 tons of dry peat conservatively based on an average peat depth of 0.5 meters[3] and a dry peat density of 400 kg/m^3, the loading rate will be approximately 2.1 hectares per year. The projected maximum concentration (i.e., 2.5 mg/L) would require approximately 3.8 hectares per year. If the estimate of length of treatment efficiency accounts for only the 15% of seepage that is captured by the wetlands (i.e., 85% percent passes through wetland and reports to aquatic ecosystems), then the loading rate would be 0.3 hectares per year for the median concentration and 0.6 hectares per year for the maximum concentration.

4.2.4 Recommendations

Given the low efficiencies of boron treatment, the extreme events in the water quality model will exceed the CCME EQG for boron. In addition, the loading rates are shown to be relatively high when compared to the other COCs. Consistent with published literature, projected life spans of constructed wetlands for boron treatment can be relatively short (i.e., < 5 years) (Sartaj et al. 1999). If the naturally occurring wetlands that receive seepage are efficient at capturing boron, then their loading rate will range from 2.1 to 3.8 hectares per year.

As noted above, approximate wetland boundaries were remotely delineated using current aerial photography as well as on site wetlands data. Specifically, suitable wetland areas were delineated in the headwaters of four of the drainages (Figure 6). A

[3] This was a conservative estimate of peat depth based upon field data in both Duke Ravine and East Ravine. The average depth of organic soils in the Duke Ravine and East Ravine was 0.45 m and 0.90 m, respectively.

summary of wetland area, average depth of organic soils, and volume of organic soils is included as Table 6. In addition, open water habitats were also delineated downgradient of these wetlands. Open water habitats across the site are heavily influenced by beaver activity, and therefore retention time is higher given the repeated impoundments throughout the stream system. While the predominant substrate in these ponded riparian areas as well as submerged aquatic vegetation is unknown, it can be assumed that these areas will provide additional polishing for metals treatment. If longer retention times are required for additional treatment, then beaver activities could be mimicked in these stream corridors (i.e., building more impoundments) and adjacent floodplain wetlands could be engaged.

Based upon AMEC modeling, treatment of boron will be required between Year 3 and Year 25. Assuming a 22 year treatment interval and an effective removal of boron by naturally occurring wetlands, then the total treatment area required will range from 46.2 to 83.6 hectares. The Duke Ravine wetlands were estimated to be approximately 77 hectares in size, and the East Ravine wetlands 27 hectares (east branch) and 24 hectares (west branch). Therefore, suitable area exists on site if wetlands in multiple drainages are utilized.

To minimize long-term loading of on site wetlands with boron, as well as address the potential exceedances for peak events, a pre-treatment option could be considered that includes either a vertical flow or subsurface flow wetland where water is passed through cells of peat. To begin, Sartaj et al. (1999) demonstrated high efficiency (i.e., 91%) by utilizing a vertical flow wetland consisting of peat soils. Given the habitat variability across the naturally occurring on-site wetlands, it is uncertain if these wetlands can capture boron as efficiently. In addition, by managing the treatment of boron within a constructed wetland system, Shore would have a cost-effective strategy that allows adaptive management of treatment efficiencies. As percent removal of boron decreases due to loading in a constructed wetland, Shore would have the ability to replace the peat and prevent exceedances of the CCME EQG during peak events. In such a system, the native on-site wetlands would provide polishing of treated seepage. This option will be evaluated as a contingency during detailed design.

It also has to be recognized that boron becomes phytotoxic at concentrations only slightly higher than the optimal range. The projected peak concentrations (95^{th} percentile and maximum) extend up to 2.5 mg/L; above the CCME EQG of 1.5 mg/L. Tolerance to elevated boron levels has been shown to be species specific, with a wide range of sensitivities. To minimize potential short or long term adverse effects to on site wetlands, the pre-treatment option would also provide an initial buffer prior to discharge to native wetlands.

4.3 Cadmium

Cadmium is a naturally occurring metal with no known nutritional requirement for biota. In addition, freshwater biota are known to be very sensitive to elevated cadmium levels.

4.3.1 AMEC Modeling

Background concentrations of total cadmium are 0.00014, <0.0005, <0.0005, 0.00006 and 0.00006 in the Manville water, shallow groundwater, overburden leachate, East Ravine, and Duke Ravine, respectively.

Seepage modeling for the PKCF predicts increasing concentrations of cadmium starting in Year 3 (beginning of site operations). Seasonal fluctuations are expected, with a spike in the first year of mining operations. Following Year 4, concentrations are expected to decrease and become stable at approximately Year 10. A slight decrease occurs again after Year 18. The predicted mean concentration is 0.00008 mg/L, with a median concentration of 0.00009 mg/L. The 95th percentile and maximum concentrations are expected to be 0.0002 mg/L and 0.0002 mg/L, respectively.

Concentrations of cadmium in the Coarse PK Pile are expected to be similar to that in the PKCF. The predicted mean concentration is 0.00008 mg/L, with a median concentration of 0.00009 mg/L. The 95th percentile and maximum concentrations are expected to be 0.0002 mg/L and 0.0002 mg/L, respectively.

These data compare to the CCME EQG of 0.00006 mg/L. Conservatively, the lowest median hardness was used to calculate this guideline (AMEC 2012). To start, background levels exceed this standard in Manville Formation water, as well as naturally in the East Ravine and Duke Ravine. Seepage from the PKCF and the Coarse PK Pile will exceed this threshold guideline for all four projected concentrations (i.e., mean, median, 95th percentile, maximum). There is no regulatory level associated with cadmium as defined by the Metal Mining Effluent Regulations (2012).

4.3.2 Literature Treatment Efficiency

Cadmium removal within a wetland is accomplished by particulate settling and trapping, chemical precipitation or co-precipitation, and to the least extent plant uptake. Wetlands have been documented to be extremely efficient in removing cadmium from wastewaters. AMEC (2012) modeling assumed 65% efficiency for wetland treatment of cadmium. This estimate was based upon two literature references: (1) Interstate Technology and Regulation Council (ITRC) (2003) that summarized existing research, and (2) Loer et al. (1999) that used a treatment system that consisted of a steep cascade aerator, into a sedimentation basin, followed by a constructed free water surface wetland (FWS), and finally discharging into a borrow pit pond.

Kaldec and Wallace (2009) also conducted a literature review of research focused on efficiency removal of cadmium in constructed wetlands. For 15 FWS wetlands, the median concentration reduction was 79%. Removal rates were positively correlated with inlet concentrations, with increasing removals as a response to increasing inlet concentrations. For four horizontal subsurface flow wetlands (HSSF), removal efficiencies varied with a median efficiency of 39%. This low value is the result of one unpublished study that reported an increase of cadmium as wastewater moved through the constructed wetland.

It is recommended that the treatment efficiency be revised to 79%, consistent with the most recent literature review (Kaldec and Wallace 2009). The diversity of conditions documented within the native wetlands likely support processes similar to those performed in both FWS and HSSF treatment wetlands. To support this proposed increase, the literature review identified six treatment systems for mine water that had a mean efficiency of 91%. Assuming 79% efficiency, the projected seepage concentrations will not exceed the CCME EQG after wetland treatment for the four projected concentrations (i.e., mean, median, 95^{th} percentile, maximum).

4.3.3 Loading

Loading calculations assume treatment is required for 328 500 m^3/year of seepage, conservatively assuming year round treatment without recycling back to the PKCF. In addition, loading calculations conservatively assume the projected median concentration of 0.00009 mg/L prior to discharge to a wetland. Finally, peat has been documented to have a capacity in excess of 200 mg/g, a good portion of which was nonexchangeable (Fine et al. 2005).

Peat requirement = (3.3×10^5 m^3/year x 1000 L/m^3 x .00009 mg/L) / 200 mg/g of peat

148 g of peat per year (dry basis)

0.0002 tons of peat per year (dry basis)

Assuming 1 hectare is equivalent to 2200 tons of dry peat conservatively based on an average peat depth of 0.5 meters and a dry peat density of 400 kg/m^3, the loading rate will be approximately 9.1×10^{-8} hectares per year. The projected maximum concentration (i.e., 0.0002 mg/L) would require approximately 1.8×10^{-7} hectares per year. If the estimate of length of treatment efficiency accounts for 79% of seepage that is captured by the wetlands, then the loading rate would be 4.5×10^{-8} hectares per year for the median concentration and 1.4×10^{-6} hectares per year for the maximum concentration.

4.3.4 Recommendations

Based upon the loading rates presented above, and assuming a 22 year treatment interval, the maximum loading concentrations would require far less than 1 hectare of land over the mine life. Consistent with wetland data presented above for boron, as well as in Figure 6 and Table 6, suitable wetland area exists on site to treat cadmium.

However, two concerns exist based upon existing data and modeling:

1. Background concentrations in Duke Ravine and East Ravine are equivalent to CCME EQG. Therefore, exceedances may already occur naturally.

2. Maximum concentrations (i.e., peak events) will likely exceed the CCME EQG for PKCF seepage even with treatment by natural wetlands.

Consistent with recommendations for treatment of boron, pre-treatment alternatives could be evaluated during detailed design to provide additional treatment prior to discharging to natural wetlands if the maximum concentrations that are expected to exceed the CCME EQG are of concern. In addition, if pre-treatment was determined to be necessary for boron, then this system would likely also treat cadmium with similar biogeochemical processes.

4.4 Chromium

In surface waters, chromium typically occurs in the trivalent [Cr(III))] or hexavalent [Cr(VI)] forms. Cr(VI) is the most toxic form of chromium, and readily converts to the less toxic Cr(III) in surface waters, especially when organic matter is present. Trivalent chromium hydroxides and chlorides are relatively insoluble and their formation may significantly reduce availability to freshwater biota.

Due to the two valence states, there is an issue of interconversions of Cr(III) and Cr(VI). In general, wetlands are effective at converting Cr(VI) to the less toxic Cr(III). The reverse reaction is also possible via oxidation by MnO_2 (Eary and Ral 1987). However the reverse reaction occurs very slowly at circumneutral pH and is inhibited by the presence of organic matter and is therefore unlikely in the native wetland system.

4.4.1 AMEC Modeling

Background concentrations of total chromium are <0.0005, <0.0005, 0.006, 0.0039 and 0.00167 mg/L in the Manville Formation water, shallow groundwater, overburden leachate, East Ravine, and Duke Ravine, respectively.

Seepage modeling for the PKCF predicts increasing concentrations of chromium beginning in Year 3 (start of mining operations). Chromium is a component of the kimberlite minerals, and therefore is expected in seepage due to leaching and weathering of these minerals. Seasonal fluctuations are expected, with the highest predicted concentrations occurring in Year 4. Following Year 4, concentrations are expected to decrease for two years and generally stabilize through Year 23. The predicted mean concentration is 0.0011 mg/L, with a median concentration of 0.0013 mg/L. The 95^{th} percentile and maximum concentrations are expected to be 0.0017 mg/L and 0.0020 mg/L, respectively. Concentrations of chromium in the Coarse PK Pile are predicted to be identical to those presented above for the PKCF.

This compares to the CCME EQG of 0.001 mg/L. The guideline for Cr(VI) was used because its guideline is more stringent than the Cr (III) guideline of 0.009 mg/L (AMEC 2012). Note background levels exceed this standard in the overburden seepage, as well as naturally in the East Ravine and Duke Ravine. Seepage from the PKCF and the Coarse PK Pile is anticipated to exceed or be equivalent to the CCME EQG for all four modeled concentrations (i.e., mean, median, 95^{th} percentile and maximum). There is no regulatory level associated with chromium as defined by the Metal Mining Effluent Regulations (2012).

4.4.2 Literature Treatment Efficiency

Chromium removal from within a wetland is accomplished by chemical reductive precipitation, partitioning to sediments, and to the least extent, by plant uptake. Wetlands have been documented to be efficient in removing chromium from wastewaters (and further discussed below). AMEC (2012) modeling assumed 67% efficiency for wetland treatment of chromium. This estimate was based upon two literature references: (1) ITRC (2003) that summarized existing research, and (2) Loer et al. (1999) that used a treatment system that consisted of a steep cascade aerator, into a sedimentation basin, into a constructed free water surface wetland, and finally discharging into a borrow pit pond.

Kaldec and Wallace (2009) also conducted a literature review of research focused on efficiency removal of chromium in constructed wetlands. For 14 FWS wetlands, the median concentration reduction was 68%. Removal rates were positively correlated with inlet concentrations, with increasing removals as a response to increasing inlet concentrations. For HSSF, chromium is generally released from the systems with the increase in outflow concentrations as compared to inflow. For vertical flow wetlands (VFW), positive reduction was shown in two systems and no removal in three others.

It is recommended that the treatment efficiency be revised to 68%, consistent with the most recent literature review (Kaldec and Wallace 2009) for FWS treatment. Regardless, this small change will not change the long-term treatment results when comparing against CCME EQGs. Assuming 68% treatment efficiency, the projected seepage concentrations are not anticipated to exceed the CCME EQG after wetland treatment for the range of projected concentrations (i.e., mean, median, 95^{th} percentile, maximum).

4.4.3 Loading

The loading calculations assume treatment required for 328 500 m^3/year of seepage, and conservatively assume year round treatment with no recycling back to the PKCF. In addition, loading calculations conservatively assume the projected median concentration of 0.0013 mg/L prior to discharge to a wetland. Finally, peat has been documented to have a capacity of approximate 15.3 mg/g for Cr(VI) (Sharma and Forster 1993)

Peat requirement = (3.3 x 10^5 m^3/year x 1000 L/m^3 x .0013 mg/L) / 15.3 mg/g of peat

28,039 g of peat per year (dry basis)

0.028 tons of peat per year (dry basis)

Assuming 1 hectare is equivalent to 2200 tons of dry peat conservatively based on an average peat depth of 0.5 meters and a dry peat density of 400 kg/m^3, the loading rate will be approximately 1.3 x 10^{-5} hectares per year. The projected maximum concentration (i.e., 0.0002 mg/L) would require approximately 1.9 x 10^{-5} hectares per year. If the estimate of length of treatment efficiency accounts for 68% of seepage that is captured by the wetlands, then the loading rate would be 6.8 x 10^{-6} hectares per year for the median concentration and 1.3 x 10^{-5} hectares per year for the maximum concentration.

4.4.4 Recommendations

Similar to that of cadmium, based upon the loading rates presented above, and assuming a 22 year treatment interval, the maximum loading concentrations would require far less than 1 hectare of land over the mine life. Consistent with wetland data presented above for boron, as well as in Figure 6 and Table 6, suitable wetland area exists on site to treat cadmium.

The only concern for meeting the CCME EQG for chromium after wetland treatment is that the documented background concentrations in both the Duke Ravine and East Ravine already exceed this guideline. While treatment potential for chromium exists with on site wetlands, it must be recognized that exceedances already occur naturally.

If pre-treatment options are selected for other COCs such as boron, then additional treatment of chromium will occur prior to discharging to natural wetlands. In either case, suitable wetland areas exist within the site to effectively treat chromium within seepage from the PKCF or Coarse PK Pile.

4.5 Selenium

Selenium is a metalloid, with reactivity and chemistry similar to sulfur. Of the four oxidation states that exist, organic selenium has been shown to be more mobile and bioaccumulative than the others. Selenium has the narrowest concentration range for what is beneficial for biota and what is detrimental. It is likely that selenium will be present in PKCF and Coarse PK seepage in an oxidized form, specifically selenate (SeO_4^{2-}). In this form, it is subject to biotransformation in the wetland system to the reduced chemical forms such as elemental selenium (Se(0), selenite (SeO_3^{2-}) and selenide (Se^{2-}) in association with iron (FeSe). All of the reduced forms have lower solubility than the selenate anion.

4.5.1 AMEC Modeling

Background concentrations of total selenium are 0.000492, 0.0001, 0.0004, 0.00011 and 0.00019 mg/L in the Manville Formation water, shallow groundwater, overburden leachate, East Ravine, and Duke Ravine, respectively.

Seepage modeling for the PKCF predicts increasing concentrations of selenium after Year 3. Seasonal fluctuations are expected. The predicted mean concentration is 0.0007 mg/L, with a median concentration of 0.0008 mg/L. The 95th percentile and maximum concentrations are expected to be 0.0015 mg/L and 0.0017 mg/L, respectively.

Concentrations of selenium in the Coarse PK Pile are expected to be relatively similar to the PKCF concentrations. The predicted mean concentration is 0.0006 mg/L, with a median concentration of 0.0006 mg/L. The 95th percentile and maximum concentrations are expected to be 0.0007 mg/L and 0.0007 mg/L, respectively.

These predictions compare well to the CCME EQG of 0.001 mg/L. Seepage from the PKCF is anticipated to exceed this threshold guideline only for the extreme events – 95th percentile and maximum concentrations. Seepage from the Coarse PK Pile is not anticipated to exceed the threshold guideline. There is no regulatory level associated with selenium as defined by the Metal Mining Effluent Regulations (2012).

4.5.2 Literature Treatment Efficiency

The previous modeling assumed 100% removal efficiency for wetland treatment of selenium. This estimate was based upon Eckhardt et al. (1999) that demonstrated selenium levels were below detection limits after treatment with a FWS wetland followed by a HSSF wetland.

Kaldec and Wallace (2009) also conducted a literature review of research focused on efficiency removal of selenium in constructed wetlands. For 15 FWS wetlands, the mean concentration reduction was 25% and the maximum was 68%. For only published research, the mean concentration reduction was 31%.

It is recommended that the treatment efficiency be conservatively lowered to 31%, consistent with the most recent literature review (Kaldec and Wallace 2009). However, it should be recognized that higher efficiencies are possible with constructed wetlands. Specifically, a system that incorporates both FWS and HSSF processes. Consistent with concentrations prior to wetland treatment, the only anticipated exceedances will occur under extreme events -the 95th percentile, or maximum concentrations.

4.5.3 Loading

Wetlands remove selenium by reduction to insoluble forms which are deposited in the sediments, by accumulation into plant tissues, and by volatilization to atmosphere. Reduction occurs when selenate and selenite are reduced to elemental selenium and iron selenide minerals, and then subsequently sequestered in plants and sediments. It has also been shown that significant losses of selenium occur through biologically mediated methylation and volatilization. Hanson et al. (1998) showed that biological volatilization may account for as much as 10-30% of the total selenium removed which is consistent with the Bañuelos et al. study (2005), which estimated 7-18% of the selenium in agricultural drainage sediment containing 3.0 – 8.0 µg/g of total selenium was removed via volatilization. Finally, research has shown that very little selenium is stored in plant tissue over the long term (i.e., several years) (Gao et al. 2003).

The loading calculation approach for selenium was similar to the approach used for other COCs; specifically, year round treatment of 328 500 m^3/year of seepage with no recycling back to the PKCF, and a median selenium concentration of 0.0008 mg/L entering the wetland. It is assumed that the peat soils have a capacity for 7.4 µg/g of selenium. This is consistent with average selenium loading of 7.4 and maximum concentrations of 22 µg/g obtained by Schuler et al. (1990) for loamy sediments in the Kesterson Reservoir. These results are also consistent with the total selenium content of 7.43 µg/g in sediment obtained from the Benton Lake wetland system (Zhang and Moore 1997).

Peat requirement = (3.3×10^5 m^3/year x 1000 L/m^3 x .0008 mg/L) /0.0074 mg/g of peat

3.57×10^7 g of peat per year (dry basis)

35.7 tons of peat per year (dry basis)

Assuming 1 hectare is equivalent to 2200 tons of dry peat conservatively based on an average peat depth of 0.5 meters and a dry peat density of 400 kg/m^3, the loading rate will be approximately 1.6 x 10^{-2} hectares per year. The projected maximum concentration (i.e., 0.0002 mg/L) would require approximately 3.4 x 10^{-2} hectares per year. If the estimate of length of treatment efficiency accounts for 31% of seepage that is captured by the wetlands, then the loading rate would be 5.0 x 10^{-3} hectares per year for the median concentration and 1.1 x 10^{-2} hectares per year for the maximum concentration.

4.5.4 Recommendations

Of the five metal COCs, selenium has one of the highest relative loading capacities within a wetland. However, the limiting COC for treatment remains boron. Similar to that of cadmium and chromium, based upon the loading rates presented above, and assuming a 22 year treatment interval, the maximum loading concentrations would require less than 1 hectare of land over the mine life. Consistent with wetland data presented above, as well as in Figure 6 and Table 6, suitable wetland area exists on site to treat selenium.

The only concern at this time is potential exceedances of the peak concentrations (i.e., 95th percentile, maximum) after wetland treatment. Given the assumed lower efficiency to treat selenium, exceedances during peak events are possible.

If pre-treatment options are selected for other COCs such as boron, then additional treatment of selenium can be anticipated prior to discharging to natural wetlands. In either case, suitable wetland areas exist within the site to effectively treat selenium within seepage from the PKCF or Coarse PK Pile under average concentration conditions.

4.6 Zinc

Zinc is an essential element to both plants and elements. Within surface waters, it is commonly present in particulate forms with very little ionic Zinc(II). The ratio of free ionic to total zinc is often less than 1% (Westerstrand et al. 2006). The greatest risk with zinc is loading of wetland soils and/or sediments.

4.6.1 AMEC Modeling

Background concentrations of total zinc are 0.0634, 0.069, 0.509, 0.016 and 0.0073 mg/L in the Manville Formation water, shallow groundwater, overburden leachate, East Ravine, and Duke Ravine, respectively.

Seepage modeling for the PKCF predicts a peak of concentrations during the first year of operations (Year 4). Seasonal fluctuations are expected, and a decrease in concentrations prior to stabilizing in Year 10. A slight decrease is then anticipated after Year 18. The predicted mean concentration is 0.025 mg/L, with a median concentration of 0.027 mg/L. The 95th percentile and maximum concentrations are expected to be 0.042 mg/L and 0.050 mg/L, respectively.

Concentrations of zinc in the Coarse PK Pile are expected to be relatively similar to the PKCF leachate concentrations. The predicted mean concentration is 0.026 mg/L, with a median concentration of 0.029 mg/L. The 95th percentile and maximum concentrations are expected to be 0.041 mg/L and 0.050 mg/L, respectively.

This compares to the CCME EQG of 0.03 mg/L. Seepage from the PKCF and Coarse PK Pile is anticipated to meet this threshold guideline for mean and median concentrations and exceed for the 95th percentile, and maximum concentrations. The regulatory level associated with zinc as defined by the Metal Mining Effluent Regulations (2012) is 0.5 mg/L. All modeled concentrations are well below this threshold.

4.6.2 Literature Treatment Efficiency

The previous modeling assumed 99% efficiency for wetland treatment of zinc. This estimate was based upon Eckhardt et al. (1999), which demonstrated significant decreases of zinc levels after treatment with a surface flow wetland followed by a subsurface flow wetland.

Kaldec and Wallace (2009) conducted a literature review of research focused on efficiency removal of zinc in constructed wetlands. To begin, zinc is removed in wetlands when the incoming amounts are greater than the background. For 26 FWS wetlands, the median concentration reduction was 68%. Removal rates were positively correlated with inlet concentrations, with increasing removals as a response to increasing inlet concentrations. Similarly, treatment with HSSF and VFW had median removal rates of 77%.

It is recommended that the treatment efficiency be conservatively lowered to 68%, consistent with the most recent literature review (Kaldec and Wallace 2009). Regardless, this small change will not change the long-term treatment results when comparing against CCME EQGs. Assuming 68% treatment efficiency, the projected seepage concentrations will not exceed the CCME EQG after wetland treatment for the range of projected concentrations (i.e., mean, median, 95% percentile, maximum).

4.6.3 Loading

Wetlands remove zinc by particulate settling and trapping, chemical precipitation and co-precipitation, partitions to sediments, and to the least extent, plant uptake. Precipitation can occur by forming very insoluble compounds with sulfide and carbonate mineral phases. Co-precipitation can occur with iron, manganese, and aluminum oxyhydroxides.

Similar to calculations of boron loading, Sartaj et al. (1999) also estimated that every gram of peat is capable of removing at least 0.1 mg of zinc. While the study showed potentially higher sorption rates to peat, 0.1 mg /g of peat was conservatively used. Again, the calculations assumed 328 500 m^3/year of seepage. Given the potential dominance of abiotic processes for metals removal in a wetland systems (i.e., sorption to organics and iron/aluminum minerals), effective year round treatment is assumed. The median concentration of zinc is assumed to be 0.027 mg/L.

Peat requirement = (3.3×10^5 m^3/year x 1000 L/m^3 x 0.027 mg/L) / 0.1 mg/g of peat

8.91×10^7 g of peat per year (dry basis)

89.1 tons of peat per year (dry basis)

Assuming 1 hectare is equivalent to 2200 tons of dry peat conservatively based on an average peat depth of 0.5 meters and a dry peat density of 400 kg/m^3, the loading rate will be approximately 4.1×10^{-2} hectares per year. The projected maximum concentration (i.e., 0.05 mg/L) would require approximately 7.5×10^{-2} hectares per year. If the estimate of length of treatment efficiency accounts for only the 15% of seepage that is captured by the wetlands, then the loading rate would be 2.7×10^{-2} hectares per year for the median concentration and 5.1×10^{-2} hectares per year for the maximum concentration.

4.6.4 Recommendations

Based upon the loading rates presented above, and assuming a 22 year treatment interval, the maximum loading concentrations would require less than approximately 2 hectare of wetlands over the mine life. Consistent with wetland data presented above, as well as in Figure 6 and Table 6, suitable wetland area exists on site to treat zinc.

There are no concerns at this time, and effective treatment with on site wetlands can be expected. If pre-treatment options are selected for other COCs such as boron, then additional treatment of zinc can be anticipated prior to discharging to natural wetlands.

5. Conclusions

Based upon Canadian CCME EQGs, this evaluation identified six COCs in the modeled water quality that may exceed the EQG's and may benefit from effective treatment in on-site wetlands. The mechanisms of treatment within wetland ecosystems will vary between each of the COCs; however, there is significant overlap between the five metals requiring treatment. Specifically, metals treatment in wetlands is assumed to be predominantly accomplished by the following biotic and abiotic processes: settling and trapping of particulate, chemical precipitation or co-precipitation, sorption to organic substrates, plant uptake, and volatilization to atmosphere. The overall goal for wetland treatment is for the wetlands to function as a sink for these five COCs during projected mining operations where no significant ecosystem change occurs, and to prevent against the wetland becoming a source or transformer during operations or after mine closure.

The sixth COC, chloride, is not expected to be treated by wetlands with anticipated outflows comparable to the inflows due to the low biological demand. As such, it is anticipated that chloride levels in the seepage from the PKCF and Coarse PK Pile will consistently exceed the CCME EQG of 120 mg/L and in some instances, exceed the short term guideline of 640 mg/L. Increased chloride concentrations in water flowing through wetlands has the potential to affect wetland vegetation (both plant health and species composition), and therefore wetland functioning over the long term. However, experimental studies on the effects of road salts have shown varying tolerance to high chloride levels between terrestrial and aquatic plant species (Environment Canada 2001). More specifically, the lower range of a threshold to chloride levels for wetland and woody vegetation exceeds the CCME EQG of 120 mg/L; and therefore potential elevated levels can be expected to affect plant species differently.

Shore is committed to recycling peak events as well as potentially Coarse PK Pile water to the PKCF. In addition, Shore is committed to monitoring chloride levels in the naturally occurring wetlands as part of the soil vegetation monitoring described in the Revised EIS (AMEC 2012). Monitoring will be structured to facilitate an evaluation of the effects of seepage water on the health and functioning of the wetland. Additional details of the monitoring program will be developed during the detailed design phase, and also will rely heavily on adaptive management in order to effectively respond to the data obtained during monitoring. However, monitoring could include, but is not limited to: pore water chloride concentrations at various soil depths, chloride concentration of plant tissue, total vegetative cover across wetland, and species composition of wetland. These data will be collected at a minimum in the upgradient and downgradient extents of wetland(s).

Of the five metal COCs, boron was identified as the limiting constituent for long-term wetland treatment. Consistent with published literature, the potential treatment efficiencies are relatively low and the loading rates are relatively high when compared to the other COCs. If the naturally occurring wetlands that receive seepage are efficient at capturing boron, then their loading rate will range from 2.1 to 3.8 hectares per year.

Approximate wetland boundaries were remotely delineated using current aerial photography as well as on site wetlands data to evaluate if suitable area exists to treat the five metal COCs. In all cases, it was determined that sufficient onsite wetlands exist across the four drainages to treat anticipated metal concentrations. In addition, it was recognized that downgradient open water habitats also have the potential to provide additional treatment. If longer retention times are required to provide additional treatment, then beaver activities could be mimicked in these stream corridors (i.e., building more impoundments) and adjacent floodplain wetlands could be engaged.

Treatment efficiencies for the five metal COCs are primarily based upon literature of constructed wetland designs. While a few studies which evaluate natural wetland treatment are referenced and utilized herein, the predominance of literature focuses on controlled engineered systems. An engineered controlled system includes a treatment cell or sequence of treatment cells that are homogenous by design. Therefore, mimicked systems can be expected to have similar treatment efficiencies. By utilizing a natural system for treatment of seepage, the heterogeneous nature of the existing on site wetlands, and therefore potential variability in treatment, must be recognized. Existing data demonstrates a range of habitats throughout the wetlands, as well as a variable depth of organic soil horizon. However, the organic soil horizons occur throughout the geographical extent of the five on site wetland systems, and frequently exceed depths of 30 cm. Based upon this existing wetlands data, it is assumed that all of the delineated wetlands provide potential treatment capacity for the five metal COCs. However, at the same time, it is also recognized that natural variability of treatment efficiencies will potentially occur within and between the different wetland systems.

The potential variability of treatment efficiencies in natural wetlands is planned to be addressed through monitoring and adaptive management. The long term monitoring program will evaluate loading and treatment efficiencies in on site natural wetlands, and include at a minimum: metals concentration in surface waters throughout wetland, metal concentrations at various soil depths, metals concentration in plant tissue, total vegetative cover across wetland, and species composition of wetland. This data will allow Shore to more adaptively address fluctuations that may occur in metals treatment.

During operations, using only wetland treatment is expected to result in exceedances of CCME EQCs for certain metals in extreme cases (i.e., 95% and maximum cases). In these situations, collected seepage will be pumped back to the PKCF prior to passing through the wetlands. Treatment would resume once levels return to lower values.

An alternative to be evaluated during detailed design would be the construction of a pre-treatment wetland where seepage would be passed through prior to discharge to naturally occurring on site wetlands. This system could be as simple as passing seepage through vegetated or un-vegetated cells of peat. However, final design would be dependent upon final target for metals treatment. Pre-treatment would also provide the following additional benefits:

a. Provides strategy to address peak events for boron, cadmium and selenium that are anticipated to exceed defined CCME EQGs; and

b. Addresses potential that peak concentrations (i.e., 95th percentile, maximum) of boron may be phytotoxic to native wetland vegetation;

c. Provides Shore with a cost-effective strategy that allows adaptive management of treatment efficiencies while minimizing risk to native on site wetlands. In addition, reliance on an engineered controlled system provides less long-term risk (for potentially exceeding CCME EQGs), and provides Shore with greater confidence that maximum treatment efficiencies are being realized for the five metal COCs. In addition, as efficiencies decreases due to loading in a constructed wetland, Shore would have the ability to replace the peat and prevent future exceedances.

6. References

AMEC. 2012. Star-Orion South Diamond Project Revised Environmental Impact Statement. Prepared for Shore Gold, Inc. August 10, 2012.

Bañuelos G.S., Terry N., LeDuc D.L., Pilon-Smits E.A.H., and B. Mackey. 2005. Field trial of transgenic Indian mustard plants shows enhanced phytoremediation of selenium-contaminated sediment. *Environmental Science and Technology* 39:1771-1777.

Canadian Council of Ministers of the Environment. 2012. Canadian Water Quality Guidelines for the Protection of Wildlife. (http://ceqg-rcqe.ccme.ca/)

Canadian Minister of Justice. 2010. Canadian Environmental Assessment Act. Revised July 12, 2010.

Canadian Minister of Justice. 2012. Metal Mining Effluent Regulations. SOR/2002-222. Last amended on March 2, 2012.

Center for Watershed Protection. 2006. Direct and Indirect Impacts of Urbanization on Water Quality. Wetlands and Watersheds Article #1. Prepared for Office of Wetlands, Oceans and Watersheds. U.S. Environmental Protection Agency. December 2006.

Dinges, R. 1982. Natural Systems for Water Pollution Control. Van Nostrand Reinhold, New York, New York.

Eary L.E., and D. Ray. 1987. Kinetics of chromium(III) oxidation to chromium(IV) by reaction with manganese dioxide. *Environmental Sciences and Technology* 21: 1187-1193.

Eckhardt D.A.V., Surface J.M., and J.J.Peverly. 1999. A constructed wetland system for treatment of landfill leachate. In: *Constructed Wetlands for the Treatment of Landfill Leachate*, Mulamoottil G., McBean E., Rovers F.A. (eds) CRC Press: Boca Raton, Florida.

Environment Canada (EC). 2001. Priority Substances List Assessment Report: Road Salts. Canadian Environmental Protection Act, 1999

Fine P., Scagnossi A., Chen Y., and U. Mingelgrin. 2005. Practical and mechanistic asects of the removal of cadmium from aqueous solutions using peat. *Environmental Pollution* 138(2): 358-367.

Fortin, D., Goulet, R., and Roy, M. 2000. Seasonal cycling of Fe and S in a constructed wetland: the role of sulfate reducing bacteria. *Geomicrobiology Journal* 17(3): 221-235.

Gao X., Gao T., and L. Zhang. 2003. Solution–solid growth of α-monoclinic selenium nanowires at room temperature. *Journal of Materials Chemistry* 13(1): 6-8.

Goldberg S. 1997. Reactions of boron with Soils. *Plant and Soil* 193:35-48.

Groudev, S.N., Spasova, I.I., and P.S. Georgiev 2001. In situ bioremediation of soils contaminated with radioactive elements and toxic heavy metals. *International Journal of Mineral Processing* 62(1): 301-308

Government of Saskatchewan. 2007. Agreement on Environmental Assessment Cooperation. Accessed November 10, 2010 from http://www.environment.gov.sk.ca/

Hansen, D., Duda P.J., Zayed A., and N. Terry. 1998. Selenium Removal by Constructed Wetlands: Role of Biological Volatilization. *Environmental Science and Technology* 32: 591-597.

Health Canada (2012). Guidelines for Canadian Drinking Water Quality—Summary Table. Water, Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario.

Interstate Technology and Regulation Council. 2003. Technical and Regulatory Guidance Document for Constructed Treatment Wetlands.

Kadlec R. and S.D. Wallace. 2009. *Treatment Wetlands*, Second Edition. CRC Press: Boca Raton, Florida.

Kropfelova, L, Vymazal, J., Svehla, J., and J.Stıchova. 2009. Removal of trace elements in three horizontal sub-surface flow constructed wetlands in the Czech Republic. *Environmental Pollution* 157: 1186–1194

Loer, J.K. Scholz-Barth K., Kadlec, R., Wetzstein D., and J. Julik. 1999. An integrated natural system for leachate treatment. In: Mulamoottil, G., E. A. McBean, and F. Rovers, eds., *Constructed Wetlands for the Treatment of Landfill Leachates*. Boca Raton, Florida.: Lewis Publishers, Inc.

Saskatchewan Environment. 2006. Surface Water Quality Objectives. EPB 356, July 2006.

Panikov, N.S. 1999. Understanding and prediction of soil microbial community dynamics under global change. *Applied Soil Ecology* 11: 161-176.

Reddy, K.R., and R.D. DeLuane. 2008. *Biogeochemistry of Wetlands*. CRC Press: Boca Raton, Florida.

Robinson, H., Harris G., Carville M., Carr M., and S. Last. 1999. The use of an engineered reed bed system to treat leachates at Monument Hill landfill site. In: Mulamoottil, G., E. A. McBean, and F. Rovers, eds., *Constructed Wetlands for the Treatment of Landfill Leachates*. Lewis Publishers, Inc.: Boca Raton, Florida.

Sartaj M., and L. Fernandes. 2005. Adsorption of Boron from Landfill Leachate by Peat and the Effect of Environmental Factors. *Journal of Environmental Engineering and Science* 4 (1): 19-28.

Sartaj M., Fernandes, L., and N. Castonguay. 1999. Treatment of leachate from a landfill receiving industrial, commercial, institutional, and construction/demolition wastes in an engineered wetland. In: Mulamoottil, G., E. A. McBean, and F. Rovers, eds., *Constructed Wetlands for the Treatment of Landfill Leachates*. Lewis Publishers, Inc.: Boca Raton, Florida.

SMOE. 2009. Final Project Specific Guidelines for the Preparation of an Environmental Impact Statement. Star-Orion South Diamond Project. Fort à la Corne Provincial Forest, Saskatchewan. Shore Gold Inc. Province of Saskatchewan, Ministry of Environment, November 2009.

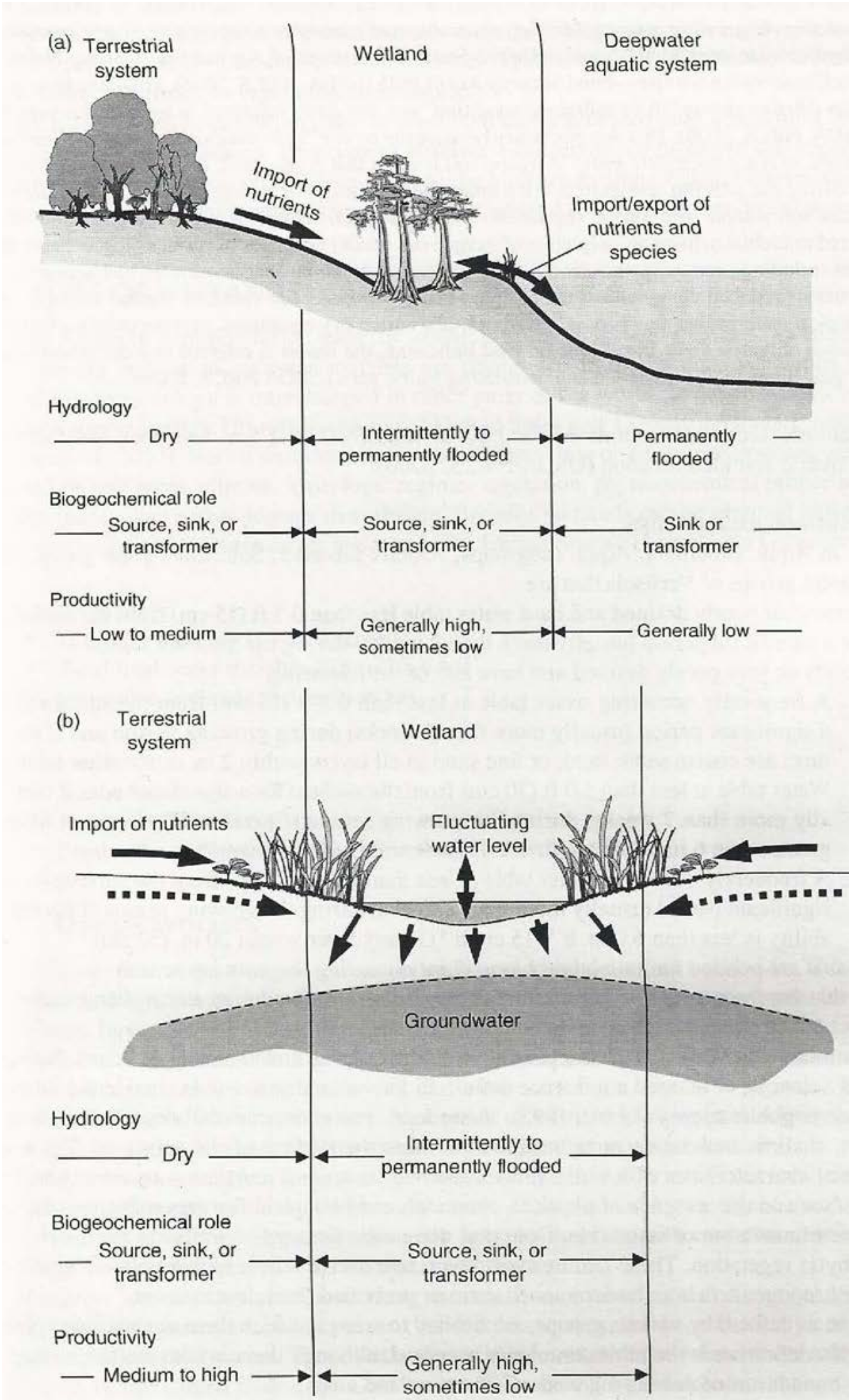
Sharma D.C., and C.F. Forster. 1993. Removal of hexavalent chromium using sphagnum moss peat. *Water Resources* 27: 1201-1208.

Schuler, C.A., Anthony R.G., and H.M. Ohlendorf. 1990. Selenium in wetlands and waterfowl foods at Kesterson Reservoir, California,1984. *Arch. Environ. Contam. Toxicol*. 19:845–853.

Westerstrand M., Karlsson K., Ingri J., and M. Viklander. 2006. Physiochemical speciation of gully pot mixture. *Water Research* (submitted January 2006).

Zhang Y., and J.N. Moore. 1997. Reduction potential of selenate in wetland sediment. *Journal of Environmental Quality* 20(3): 910-916.

FIGURES



NOTES:

1. Illustration from Reddy and DeLaune (2008), Biogeochemistry of Wetlands.

2. Figure intended to illustrate biogeochemical role of different habitats, and continuum with deepwater aquatic ecosystems and groundwater.

Shore Gold, Inc.
Star and Orion South Diamond Project

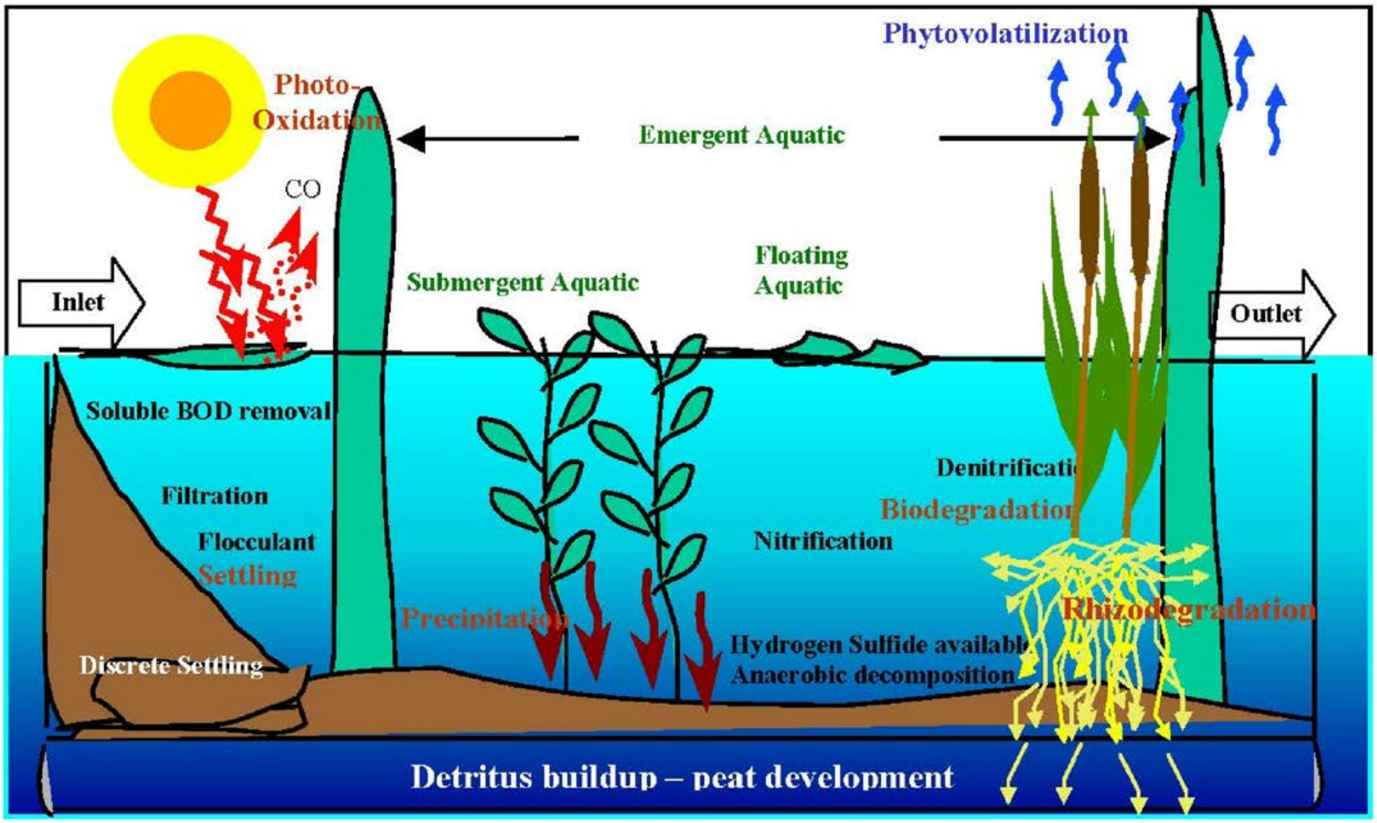
WETLAND TREATMENT EVALUATION

WETLAND CONTINUUM TO AQUATIC ECOSYSTEM

ARCADIS

FIGURE
1

CITY: CRAN DIV/GROUP: ENV DJP
C/My Documents/GIS/Shore Gold/Mxd/Figure 1.mxd



NOTES:

1. Illustration from it Interstate Technology and Regulatory Council (2009), Technical and Regulatory Guidance Document for Constructed Treatment Wetlands.

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Star and Orion South Diamond Project

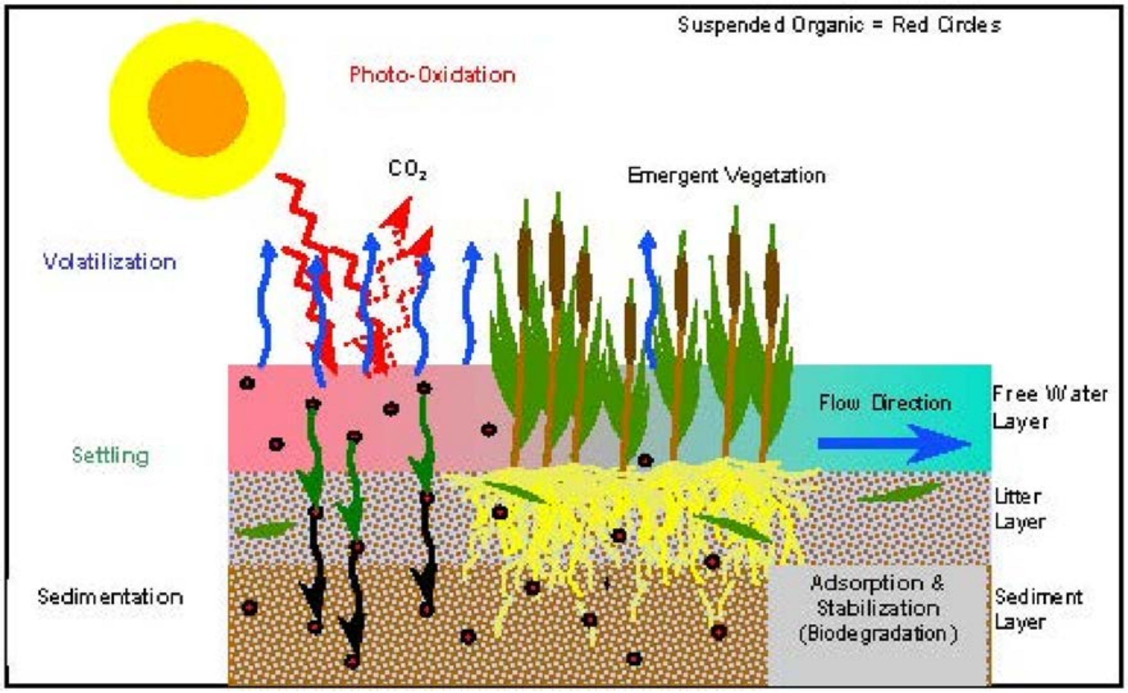
WETLAND TREATMENT EVALUATION

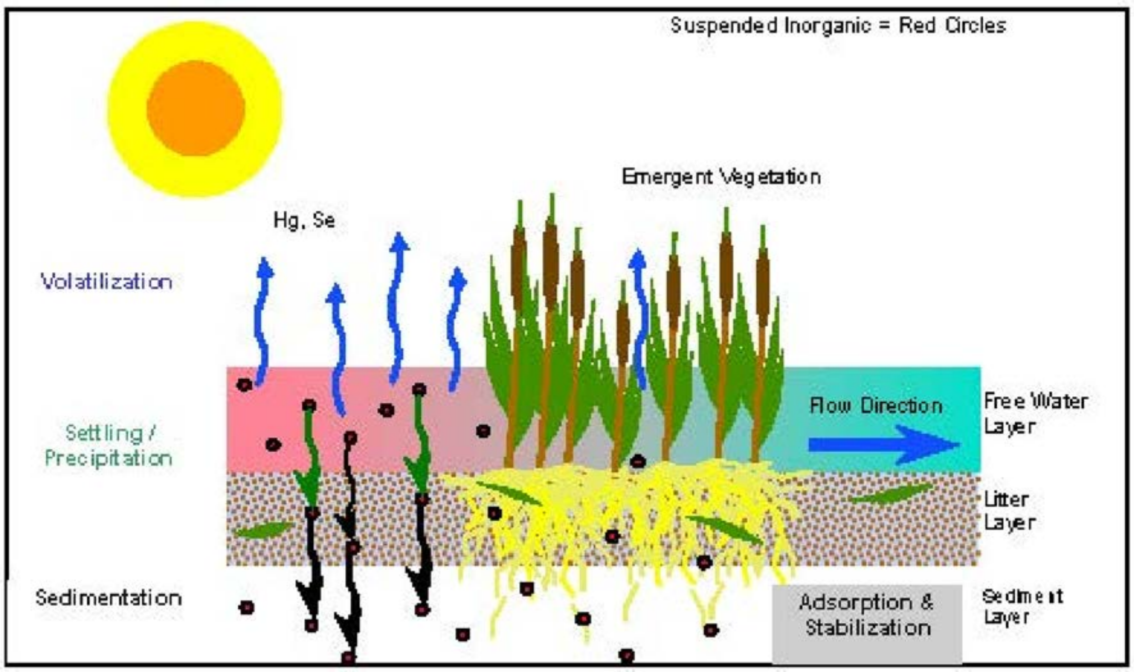
PROCESSES OCCURING IN A WETLAND

ARCADIS

FIGURE **2**

CITY: CRAN DIV/GROUP: ENV DJP
C/My Documents/GIS/Shore Gold/Mxd/Figure 2.mxd





NOTES:

1. Illustration from it Interstate Technology and Regulatory Council (2009), Technical and Regulatory Guidance Document for Constructed Treatment Wetlands.

2. Top illustration treatment of organic compounds, the bottom illustration depicts treatment of inorganic compounds.

Shore Gold, Inc.
Star and Orion South Diamond Project

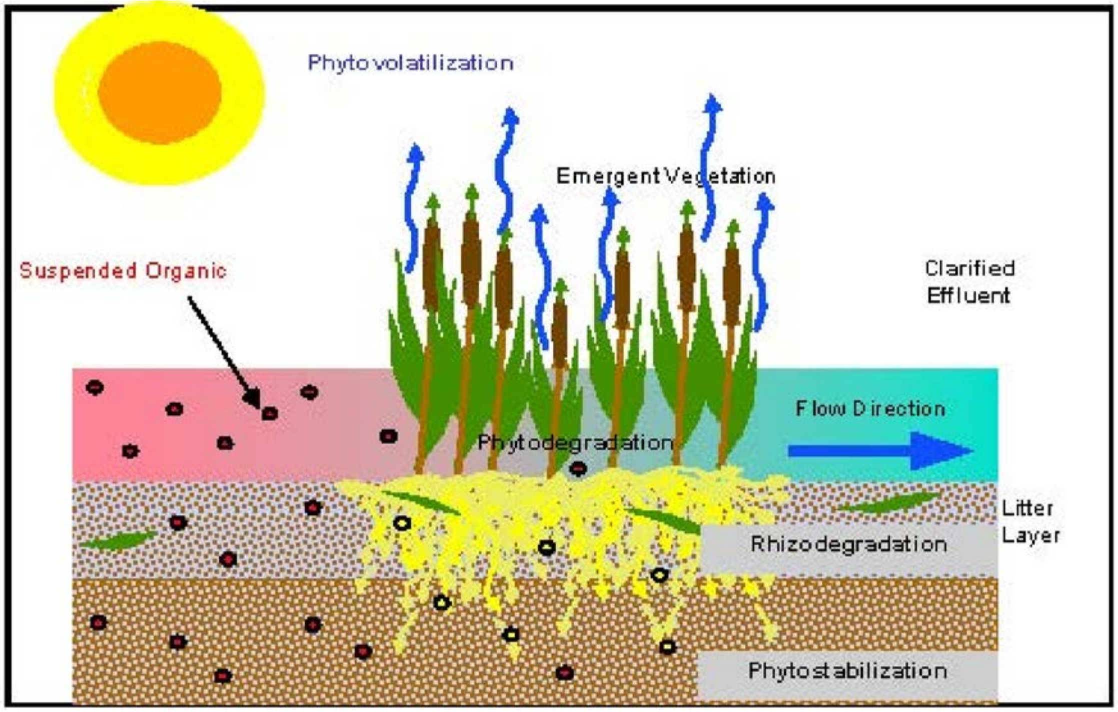
WETLAND TREATMENT EVALUATION

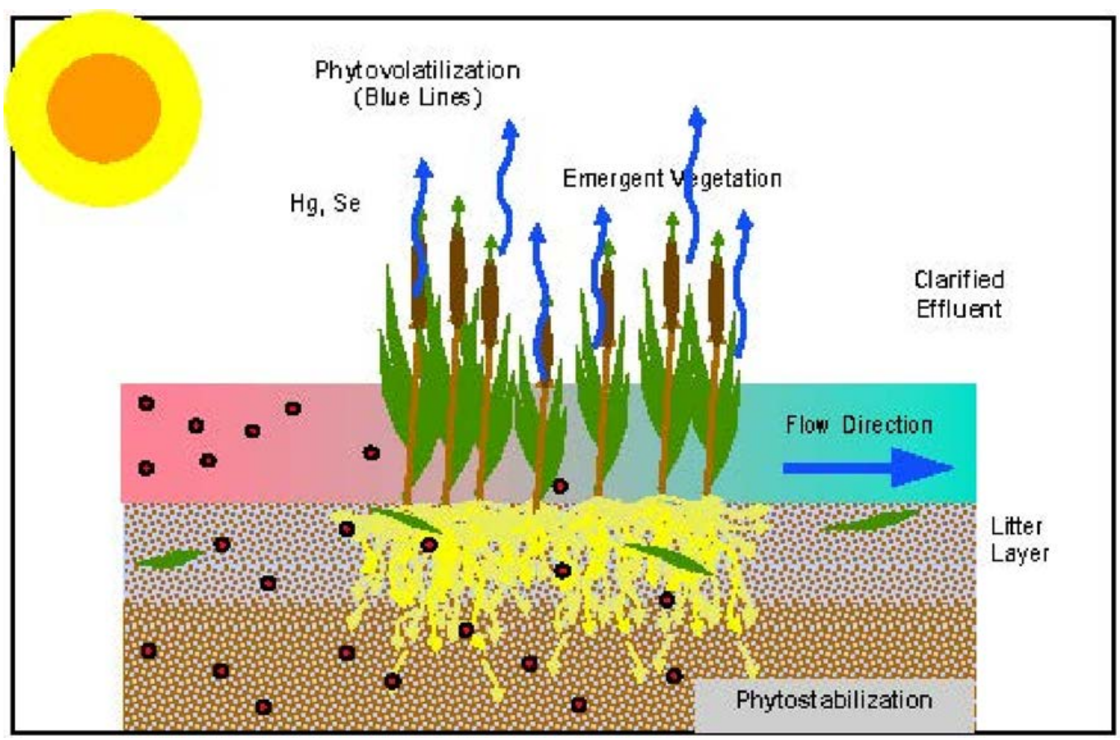
ABIOTIC TREATMENT PROCESSES OCCURING IN A WETLAND

ARCADIS

FIGURE 3

CITY: CRAN DIV/GROUP: ENV DJP
C/My Documents/GIS/Shore Gold/Mxd/Figure 3.mxd





NOTES:

1. Illustration from it Interstate Technology and Regulatory Council (2009), Technical and Regulatory Guidance Document for Constructed Treatment Wetlands.

2. Top illustration treatment of organic compounds, the bottom illustration depicts treatment of inorganic compounds.

Shore Gold, Inc.
Star and Orion South Diamond Project

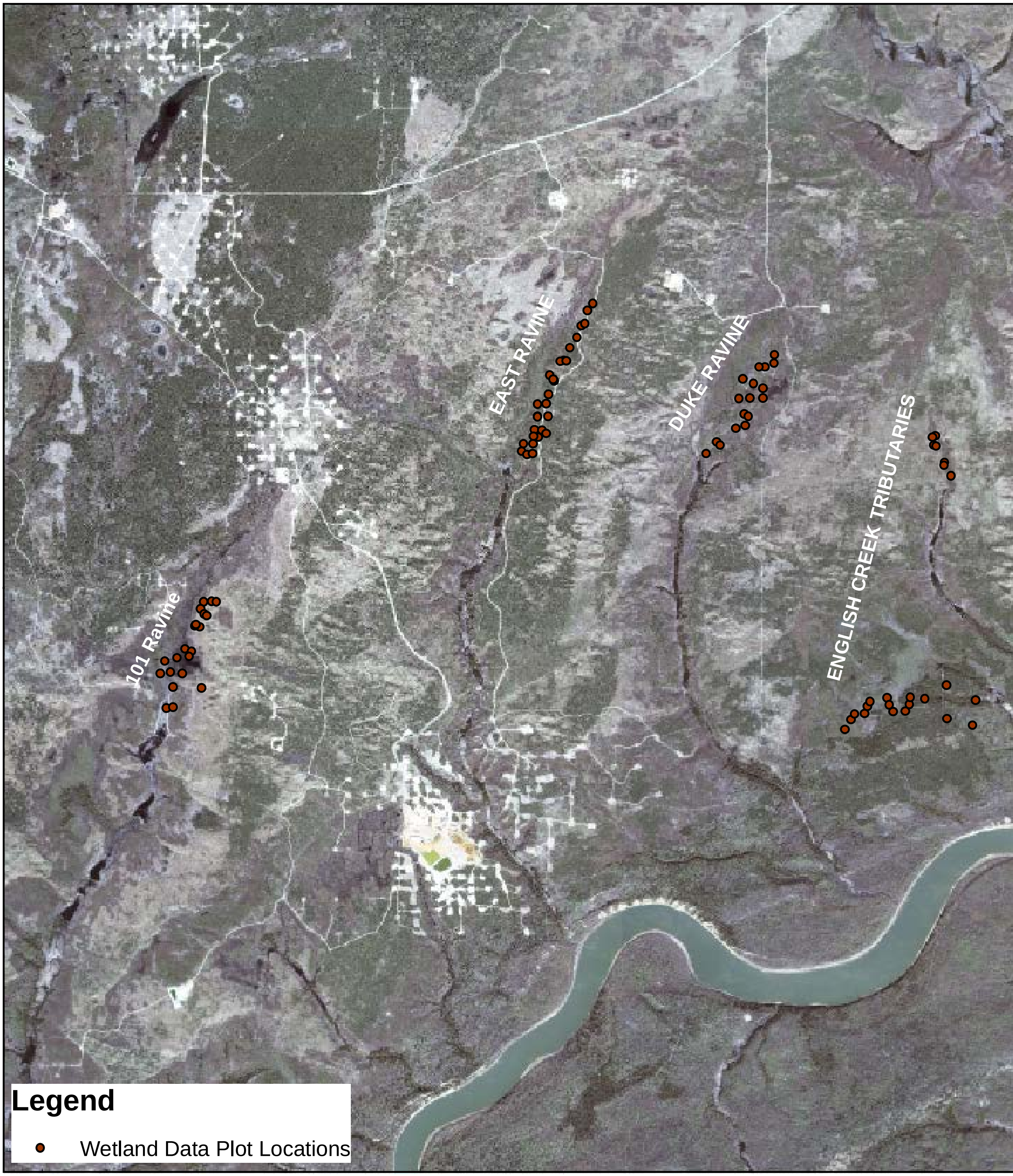
WETLAND TREATMENT EVALUATION

BIOTIC TREATMENT PROCESSES OCCURING IN A WETLAND

ARCADIS

FIGURE 4

CITY: CRAN DIV/GROUP: ENV DJP
C/My Documents/GIS/Shore Gold/Mxd/Figure 4.mxd



NOTES:

1. Aerial photograph (2010) provided by Shore Gold, Inc.

2. Data point locations provided by Shore Gold, Inc.

Shore Gold, Inc.
Star and Orion South Diamond Project

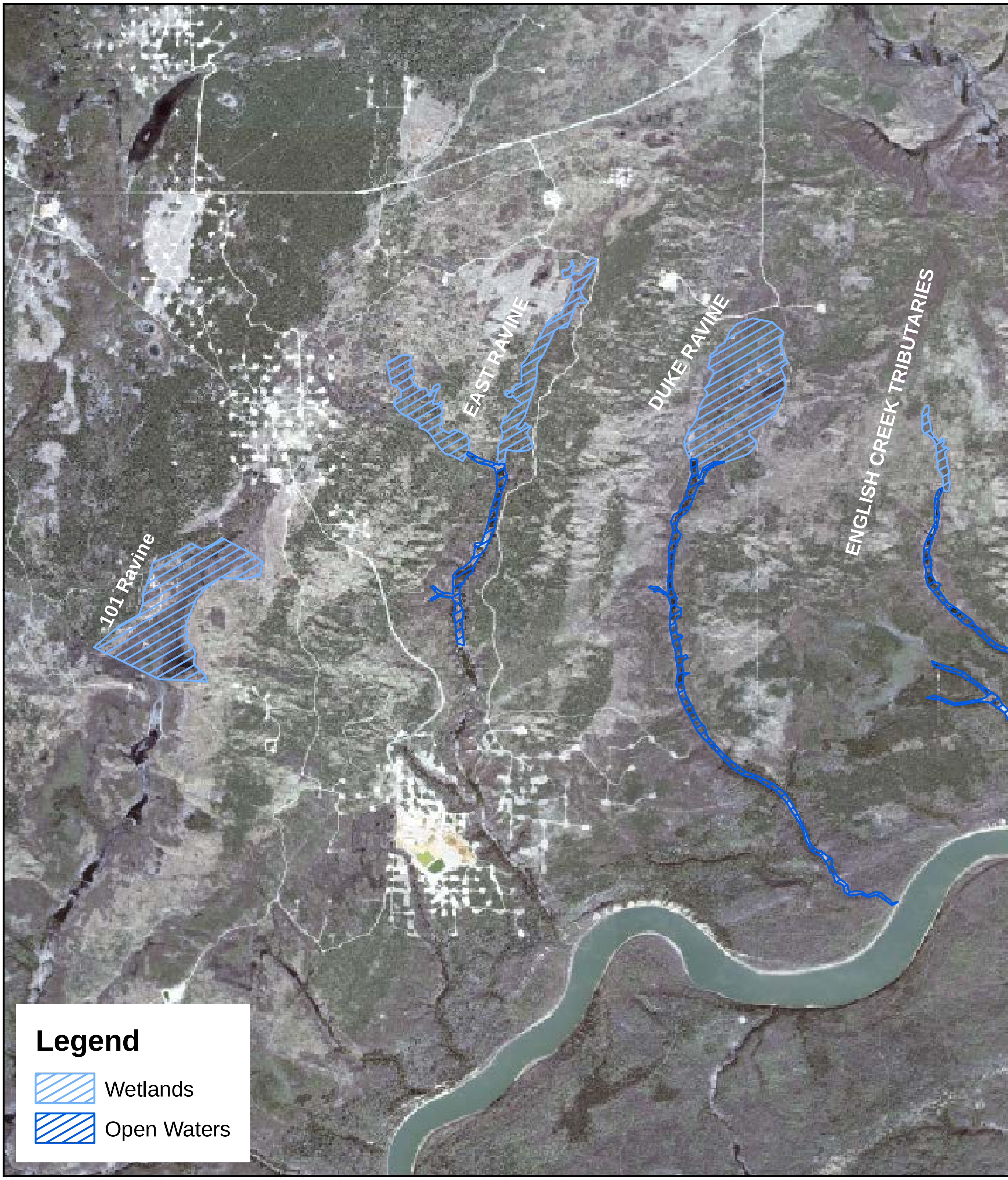
WETLAND TREATMENT EVALUATION

WETLAND DATA PLOT LOCATIONS

ARCADIS

FIGURE 5

CITY: CRAN DIV/GROUP: ENV DJP
C/My Documents/GIS/Shore Gold/Mxd/Figure 5.mxd



NOTES:

1. Aerial photograph (2010) provided by Shore Gold, Inc.

2. Approximate geographical extent of wetlands delineated by ARCADIS based upon existing aerial photography and on site data collection.

3. Wetland boundaries only delineated outside of extent of proposed mine infrastructure.

Shore Gold, Inc.
Star and Orion South Diamond Project

WETLAND TREATMENT EVALUATION

APPROXIMATE GEOGRAPHICAL EXTENT OF WETLAND AND OPEN WATER HABITATS

ARCADIS

FIGURE 6

CITY: CRAN DIV/GROUP: ENV DJP
C/My Documents/GIS/Shore Gold/Mxd/Figure 6.mxd

TABLES

Table 1. Regulatory Comments Pertaining to Proposed Wetland Treatment of Seepage at the Star and Orion South Diamond Project.

Item #	Ministry / Branch Commenting:	Comment Type	Page #	Section in EIS:	2011 Technical Review Comment	Proponent Response to 2011 Comment	2012 Technical Review Comments:
3	Industrial Branch	Type I	page 6-130	Section 6.2.6.4 Effects Assessment – Potential Effects to Surface Water Features		Shore has indicated that they wish to treat process and other potential waste waters utilizing existing wetlands surrounding the proposed PKCF and Coarse PK piles. Shore has also stated: "Many of the nearby wetlands are within the footprint of the mine infrastructure and the effects on surface water features such as wetlands were not modelled. Given the presence of clay sediments within the surficial sediments, it is likely that the wetlands formed in poorly drained areas that collect water during periods of high flow and snow melt. As such, they will be somewhat protected from the relatively small drawdowns predicted by the SRK (2011a) model for the surficial aquifer".	• How well will the wetlands continue to function as wetlands given the activities associated with pit dewatering? The company proposes to draw down the natural groundwater water levels so it should be expected that there will likely be some change anticipated to the functionality of the wetlands – what is that predicted loss of functionality in advance of subjecting the wetlands to process waters ? • Shore will need to compare the total wetlands carrying capacity as a passive treatment system with proposed discharges to the wetlands both for frozen and non-frozen conditions. • What treatment options for the proposed discharges are proposed if the wetlands fail to function as proposed? • Shore indicates that process water will continually discharge to the same location during the winter months. (Section 2.6.5 Processed Kimberlite Containment Facility (PKCF) – page 2-49) What is the potential for sedimentation and ice damning to occur and what options are in place to mitigate upset situations? • If sedimentation build up occurs what are the planned maintenance procedures and how does Shore propose to deal with the sediments? • Will there be potential erosional issues and what are the contingencies for those? • What type of distribution system is planned for the discharge? • Will the wetlands be capable of treating the discharges to appropriate water/soil criteria and if not at what rates will discharges occur. • Where and when will these discharges occur and for how long? • What will the short/long term effects be on the downstream environments? • What is the contingency plan if a forest fire were to change the regime of the wetlands? • What is the contingency plan if the local environment experiences either short and long term droughts or very wet seasons? • Has Shore identified a reference wetland with which to compare ecologically - and on an ongoing basis to the potentially impacted wetlands. • What is proposed for decommissioning of the wetlands when no longer required or functional?
48	Technical Resources Branch		page 6-130	Section 6.2.6.4 Effects Assessment – Potential Effects to Surface Water Features			Which mapped wetland areas will be used for treatment? What level of treatment efficacy is expected? Is the expectation that the "natural" wetland will become an predominantly artificially supported wetland due to lowered water table? Will a lowered water table increase ground water recharge potential from the wetland areas loaded with surface input, thus chronically leaching contaminants into the surficial aquifer? Contaminant accrual in the wetland(s)may tend to approach an equilibrium state over time, so that sediments may also supply metals to the overlying water according to redox and pH cycles. Also, the usage will likely accelerate wetland infilling rate. How have these effects been considered in the wetland usage and remediation plan?
59	Fish and Wildlife	Type I		2.6.9.1, 6.2.4.1, 6.2.7.5, 6.3.1.6			Passive wetland treatment is now proposed for process and other waste water sources. Additional detail must be provided including volumes to be treated, effectiveness of treatment, wetlands to be used, etc. Monitoring will also be required for metal levels in wetlands and country foods in or near these areas.

Table 1. Regulatory Comments Pertaining to Proposed Wetland Treatment of Seepage at the Star and Orion South Diamond Project.

Item #	Ministry / Branch Commenting:	Comment Type	Page #	Section in EIS:	2011 Technical Review Comment	Proponent Response to 2011 Comment	2012 Technical Review Comments:
11	NRCan		Section 2. Project Description, section 2.6.9.1		Physical Environment	New Comment #5. Seepage from the PKCF will be treated by using a natural wetland system, or pumped back into either the PKCF or the PKCF polishing pond. The system used will depend upon the water quality at the time. Processed kimberlite static leaching tests (Table 5.2.3-7) showed that elevated concentrations of chromium and nickel may occur. In addition, results from laboratory column leach tests suggest that processed kimberlite may leach Al, As, Co, Cr, Fe, Mb, and Tl.	NRCan requests that the proponent assess the ability of the natural wetland to mitigate the metals identified through the static leaching and the laboratory column leach tests over both the short and long term, and explain what quality criteria that will govern the decision for recycling the seepage back to PKCF, to the PKCF polishing pond and to the natural wetland.
2	EC		Attachement 1, Provincial and Federal Technical Comments in Information Requests, Comment Ref 152	page 6-161, page 3-22,	Physical Environment	As proposed, the surrounding wetlands will be used as a passive effluent treatment system to treat seepage or runoff from the PKCF and the Coarse PK pile. The EIS states that runoff and seepage from the overburden pile will flow to the 101 Ravine and sedimentation will be prevented if required. This may be a viable approach. However, as per Shore Gold's response to question 152 of the Federal Information Requests, 23.9Mm3 or 4% of the total volume of the overburden has been identified as potentially acid generating, and that the ARD/metal leaching tests indicate that the MMER limits may be exceeded for nickel.	EC does not believe that the revised EIS sufficiently documents the basis upon which Shore Gold has concluded that wetlands treatment will be adequate to protect water quality in the long term and that the potential ARD/metal leaching issue from runoff and seepage from the overburden pile is adequately assessed. These deficiencies should be addressed by Shore Gold.

Table 2. Modeled Chemical Parameters in Seepage

Conventional Parameters	Nutrients	Major Ions	Total and Dissolved Metals	
Total dissolved solids	Ammonia as nitrogen	Bicarbonate	Aluminum	Manganese
Specific conductivity	Nitrate	Calcium	Antimony	Molybdenum
Total alkalinity	Total phosphorus	Carbonate	Arsenic	Nickel
Chemical oxygen demand	Total organic carbon	Chloride	Barium	Selenium
	Dissolved organic carbon	Flouride	Boron	Silver
		Hydroxide	Cadmium	Strontium
		Magnesium	Chromium	Thallium
		Potassium	Cobalt	Tin
		Sodium	Copper	Titanium
		Sulfate	Iron	Uranium
			Lead	Vanadium
				Zinc

Table 3. Projected Water Quality in Seepage - General Parameters

Constituent		AMEC Modeling (2012)				ARCADIS Modeling (2012)		Guidelines			
								For Aquatic Life		Liquid Effluent	
								Canadian Environmental Quality Guidelines (CCME 2011)	SK Water Quality Objectives (MOE 2006)	SK Mineral Industry Environmental Protection (1996)	CA Metal Mining Effluent Regulations (2012)
		PKCF Perimeter Ditch WITH NO Wetland Treatment	PKCF Perimeter Ditch WITH Wetland Treatment	Coarse PK Pile WITH NO Wetland Treatment	Coarse PK Pile WITH Wetland Treatment	PKCF Perimeter Ditch WITH Wetland Treatment	Coarse PK Pile WITH Wetland Treatment				
Total Alkalinity (mg/L)											
								-	-	-	-
	mean	248.3615891	52.1559337	297.5129617	62.47772195	-	-				
	medium	269.9473299	56.68893927	337.269366	70.82656687	-	-				
	95%	418.294837	87.84191577	414.2991049	87.00281204	-	-				
	Maximum	448.9344198	94.27622816	414.3219739	87.00761451	-	-				
Total Dissolved Solids (mg/L)											
								-	-	-	-
	mean	1186.226866	486.353015	1999.6029	819.8371891	-	-				
	medium	1316.471072	539.7531395	2158.945631	885.1677088	-	-				
	95%	1943.383209	796.7871157	3336.936247	1368.143861	-	-				
	Maximum	2043.121852	837.6799594	3337.469394	1368.362451	-	-				
Total Hardness (mg/L)											
								-	-	-	-
	mean	223.8801791	223.8801791	322.6824911	322.6824911	-	-				
	medium	247.2623384	247.2623384	359.7420934	359.7420934	-	-				
	95%	354.8115538	354.8115538	482.1580579	482.1580579	-	-				
	Maximum	370.9921271	370.9921271	482.1935835	482.1935835	-	-				
Specific Conductivity (uS/cm)											
								-	-	-	-
	mean	2937.664048	2937.664048	3796.277689	3796.277689	-	-				
	medium	3179.665179	3179.665179	4170.99389	4170.99389	-	-				
	95%	5279.555125	5279.555125	5940.02893	5940.02893	-	-				
	Maximum	5766.086222	5766.086222	5940.620823	5940.620823	-	-				

Table 3. Projected Water Quality in Seepage - General Parameters

Constituent		AMEC Modeling (2012)				ARCADIS Modeling (2012)		Guidelines			
								For Aquatic Life		Liquid Effluent	
								Canadian Environmental Quality Guidelines (CCME 2011)	SK Water Quality Objectives (MOE 2006)	SK Mineral Industry Environmental Protection (1996)	CA Metal Mining Effluent Regulations (2012)
		PKCF Perimeter Ditch WITH NO Wetland Treatment	PKCF Perimeter Ditch WITH Wetland Treatment	Coarse PK Pile WITH NO Wetland Treatment	Coarse PK Pile WITH Wetland Treatment	PKCF Perimeter Ditch WITH Wetland Treatment	Coarse PK Pile WITH Wetland Treatment				
Calcium (mg/L)											
								-	-	-	-
	mean	54.12709318	20.02702448	81.00628395	29.97232506	-	-				
	medium	60.86703541	22.5208031	90.197187	33.37295919	-	-				
	95%	83.86561407	31.0302772	121.8719934	45.09263757	-	-				
	Maximum	86.85094729	32.1348505	121.8803755	45.09573895	-	-				
Carbonate (mg/L)											
								-	-	-	-
	mean	0.27235597	0.057194754	0.372310308	0.078185165	-	-				
	medium	0.31176869	0.065471425	0.426870247	0.089642752	-	-				
	95%	0.399092572	0.08380944	0.499996116	0.104999184	-	-				
	Maximum	0.406176872	0.085297143	0.5	0.105	-	-				
Potassium (mg/L)											
								-	-	-	-
	mean	19.94297008	3.390304913	30.03384358	5.105753409	-	-				
	medium	21.80244918	3.706416361	32.52591977	5.529406362	-	-				
	95%	34.53600701	5.871121192	49.41695123	8.40088171	-	-				
	Maximum	37.13383896	6.312752623	49.42435374	8.402140135	-	-				
Sodium (mg/L)											
								-	-	-	-
	mean	406.7454654	231.8449153	635.6603217	362.3263834	-	-				
	medium	443.9429571	253.0474856	686.4067585	391.2518524	-	-				
	95%	698.8168014	398.3255768	1057.823698	602.959508	-	-				
	Maximum	748.4326271	426.6065975	1057.961297	603.0379391	-	-				

Table 3. Projected Water Quality in Seepage - General Parameters

Constituent		AMEC Modeling (2012): PKCF Perimeter Ditch WITH NO Wetland Treatment	AMEC Modeling (2012): PKCF Perimeter Ditch WITH Wetland Treatment	AMEC Modeling (2012): Coarse PK Pile WITH NO Wetland Treatment	AMEC Modeling (2012): Coarse PK Pile WITH Wetland Treatment	ARCADIS Modeling (2012): PKCF Perimeter Ditch WITH Wetland Treatment	ARCADIS Modeling (2012): Coarse PK Pile WITH Wetland Treatment	Guidelines – For Aquatic Life: Canadian Environmental Quality Guidelines (CCME 2011)	Guidelines – For Aquatic Life: SK Water Quality Objectives (MOE 2006)	Guidelines – Liquid Effluent: SK Mineral Industry Environmental Protection (1996)	Guidelines – Liquid Effluent: CA Metal Mining Effluent Regulations (2012)
Ammonia as Nitrogen (mg/L)											
								7.0 - 48.3 (a1)	see table (same)	0.5	-
	mean	0.557324214	0.050159179	0.953137917	0.085782412	-	-				
	medium	0.618813345	0.055693201	1.023337996	0.09210042	-	-				
	95%	0.922983331	0.0830685	1.618305159	0.145647464	-	-				
	Maximum	0.973174615	0.087585715	1.61863108	0.145676797	-	-				
Nitrate (mg/L)											
								2.9 (a2)	-	-	-
	mean	0.016348813	0.001961858	0.04132435	0.004958922	-	-				
	medium	0.018850646	0.002262078	0.04758842	0.00571061	-	-				
	95%	0.022999364	0.002759924	0.050215495	0.006025859	-	-				
	Maximum	0.02312271	0.002774725	0.051648038	0.006197765	-	-				
Sulfate (mg/L)											
								-	-	-	-
	mean	289.0257431	109.8297824	411.9583297	156.5441653	-	-				
	medium	313.8019975	119.2447591	447.6842727	170.1200236	-	-				
	95%	510.8529998	194.1241399	669.8766638	254.5531323	-	-				
	Maximum	553.6469165	210.3858283	669.9611147	254.5852236	-	-				
Chloride (mg/L)											
								120	-	-	-
	mean	485.2241176	485.2241176	835.4223159	835.4223159	485.2241176	835.4223159				
	medium	538.987965	538.987965	896.8159033	896.8159033	538.987965	896.8159033				
	95%	804.6833154	804.6833154	1419.517216	1419.517216	804.6833154	1419.517216				
	Maximum	848.7525985	848.7525985	1419.703737	1419.703737	848.7525985	1419.703737				

Table 3. Projected Water Quality in Seepage - General Parameters

Constituent		AMEC Modeling (2012)				ARCADIS Modeling (2012)		Guidelines			
								For Aquatic Life		Liquid Effluent	
								Canadian Environmental Quality Guidelines (CCME 2011)	SK Water Quality Objectives (MOE 2006)	SK Mineral Industry Environmental Protection (1996)	CA Metal Mining Effluent Regulations (2012)
		PKCF Perimeter Ditch WITH NO Wetland Treatment	PKCF Perimeter Ditch WITH Wetland Treatment	Coarse PK Pile WITH NO Wetland Treatment	Coarse PK Pile WITH Wetland Treatment	PKCF Perimeter Ditch WITH Wetland Treatment	Coarse PK Pile WITH Wetland Treatment				
Total Phosphorus (mg/L)											
								-	-	-	-
	mean	0.014948135	0.014948135	0.025274212	0.025274212	-	-				
	medium	0.016601217	0.016601217	0.027275808	0.027275808	-	-				
	95%	0.024516298	0.024516298	0.042230369	0.042230369	-	-				
	Maximum	0.025782272	0.025782272	0.042240475	0.042240475	-	-				
Fluoride (mg/L)											
								-	-	-	-
	mean	0.74472939	0.74472939	1.256384558	1.256384558	-	-				
	medium	0.827510392	0.827510392	1.355107835	1.355107835	-	-				
	95%	1.22240034	1.22240034	2.104270245	2.104270245	-	-				
	Maximum	1.285794467	1.285794467	2.104400257	2.104400257	-	-				
Hydroxide (mg/L)											
								-	-	-	-
	mean	0.272377491	0.272377491	0.372323644	0.372323644	-	-				
	medium	0.31179938	0.31179938	0.426886275	0.426886275	-	-				
	95%	0.399137139	0.399137139	0.500010428	0.500010428	-	-				
	Maximum	0.406228008	0.406228008	0.500014312	0.500014312	-	-				
Magnesium (mg/L)											
								-	-	-	-
	mean	20.01831708	20.01831708	27.79233942	27.79233942	-	-				
	medium	21.99061155	21.99061155	30.77852534	30.77852534	-	-				
	95%	33.41998805	33.41998805	42.35197318	42.35197318	-	-				
	Maximum	35.61671052	35.61671052	42.36396489	42.36396489	-	-				

Table 3. Projected Water Quality in Seepage - General Parameters

Constituent		AMEC Modeling (2012)				ARCADIS Modeling (2012)		Guidelines			
								For Aquatic Life		Liquid Effluent	
								Canadian Environmental Quality Guidelines (CCME 2011)	SK Water Quality Objectives (MOE 2006)	SK Mineral Industry Environmental Protection (1996)	CA Metal Mining Effluent Regulations (2012)
		PKCF Perimeter Ditch WITH NO Wetland Treatment	PKCF Perimeter Ditch WITH Wetland Treatment	Coarse PK Pile WITH NO Wetland Treatment	Coarse PK Pile WITH Wetland Treatment	PKCF Perimeter Ditch WITH Wetland Treatment	Coarse PK Pile WITH Wetland Treatment				
Bicarbonate (mg/L)											
								-	-	-	-
	mean	197.277016	41.42817336	293.1875711	61.56938993	-	-				
	medium	224.0988784	47.06076447	327.7248454	68.82221753	-	-				
	95%	302.0276397	63.42580433	434.910853	91.33127913	-	-				
	Maximum	311.5077226	65.41662175	434.9268153	91.33463121	-	-				

Canadian Environmental Quality Guidelines - CEQG (CCME 2011)

a1 = Guideline is dependent on temperature and pH. The value ranges between 6.98 mg/L (pH= 7.0,temperature= 15oC) and 48.3 mg/L (pH= 6.5, temperature= 5oC).

a2 = Guideline is converted to Nitrate-N.

a3 = Guideline is converted to Nitrite-N.

a4 = Guideline = 5 µg/L at pH < 6.5, [Ca2+] < 4 mg/L and DOC < 2 mg/L; Guideline = 100 µg/L at pH ≥ 6.5, [Ca2+] ≥4 mg/L and DOC ≥ 2 mg/L.

a5 = Cadmium guideline = 10[0.86 [log(hardness)] - 3.2]. Conservatively, the lowest median hardness for this site was used to calculate the guidelines

a6 = Guideline is for hexavalent chromium (CrVI) because its guideline is more stringent than the trivalent chromium guideline of 8.9 ug/L

a7 = Copper guideline is dependent on [CaCO3] with a minimum of 2 µg/L. Guideline = e0.8545[ln(hardness)]-1.465*0.2. Conservatively, the lowest median hardness for this site was used to calculate the guidelines.

a8 = Lead guideline is dependent on [CaCO3]. Guideline = e1.273[ln(hardness)]-4.705. Conservatively, the lowest median hardness for the site was used to calculate the guideline.

a9 = Nickel guideline is dependent on [CaCO3]. Nickel guideline is dependent on [CaCO3]. Guideline = e0.76[ln(hardness)]+1.06. Conservatively, the lowest median hardness for this site was used to calculate the guideline

Saskatchewan Surface Water Quality Objectives (MOE 2006)

b1 = Cadmium Objective: 0.017 ug/L where hardness is 0 - 48.5 mg/L; 0.032 ug/L where hardness is48.5 - 97; 0.058 where hardness is 97 - 194; 0.10 ug/L where hardness is >194.

b2 = The objective was developed by the Industrial, Uranium and Hardrock Mining Unit of Saskatechewan Environment

The Mineral Industry Environmental protection Regulations, 1996

c1 = Maximum monthly arithmetic mean concentration.

Table 4. Projected Water Quality in Seepage - Metals

Constituent		AMEC Modeling (2012)				ARCADIS Modeling (2012) - For COCs		Guidelines			
								For Aquatic Life		Liquid Effluent	
								Environmental Quality Guidelines (CCME 2011)	SK Water Quality Objectives (MOE 2006)	CA Metal Mining Effluent Regulations (2012)	SK Mineral Industry Environmental Protection (1996)
		PKCF Perimeter Ditch WITH NO Wetland Treatment	PKCF Perimeter Ditch WITH Wetland Treatment	Coarse PK Pile WITH NO Wetland Treatment	Coarse PK Pile WITH Wetland Treatment	PKCF Perimeter Ditch WITH Wetland Treatment	Coarse PK Pile WITH Wetland Treatment				
Aluminum (mg/L)											
								0.005 or 0.1 (a4)	0.005 or 0.1 (a4)	-	-
	mean	0.002048417	2.04842E-05	0.002707898	2.7079E-05	-	-				
	medium	0.002247186	2.24719E-05	0.003212726	3.21273E-05	-	-				
	95%	0.003507066	3.50707E-05	0.003592289	3.59229E-05	-	-				
	Maximum	0.003647601	3.6476E-05	0.00370498	3.70498E-05	-	-				
Antimony (mg/L)											
								-	-	-	-
	mean	0.000212439	6.16073E-05	0.000168389	4.88328E-05	-	-				
	medium	0.000223591	6.48414E-05	0.000193674	5.61655E-05	-	-				
	95%	0.000378241	0.00010969	0.000204087	5.91853E-05	-	-				
	Maximum	0.000417174	0.00012098	0.000205294	5.95351E-05	-	-				
Arsenic (mg/L)											
								0.005	0.005	0.5 (c1)	0.5 (c1)
	mean	0.000272636	2.99899E-05	0.00025095	2.76045E-05	-	-				
	medium	0.000294931	3.24424E-05	0.000265098	2.91608E-05	-	-				
	95%	0.000438858	4.82744E-05	0.000349291	3.8422E-05	-	-				
	Maximum	0.000460647	5.06712E-05	0.000356717	3.92388E-05	-	-				
Barium (mg/L)											
								-	-	-	1.0 (d2)
	mean	0.095723869	0.048819173	0.09601655	0.048968441	-	-				
	medium	0.102785295	0.0524205	0.108965666	0.05557249	-	-				
	95%	0.18132745	0.092476999	0.17878007	0.091177836	-	-				
	Maximum	0.221032459	0.112726554	0.224275602	0.114380557	-	-				

Table 4. Projected Water Quality in Seepage - Metals

Constituent		AMEC Modeling (2012)				ARCADIS Modeling (2012) - For COCs		Guidelines			
								For Aquatic Life		Liquid Effluent	
								Environmental Quality Guidelines (CCME 2011)	SK Water Quality Objectives (MOE 2006)	CA Metal Mining Effluent Regulations (2012)	SK Mineral Industry Environmental Protection (1996)
		PKCF Perimeter Ditch WITH NO Wetland Treatment	PKCF Perimeter Ditch WITH Wetland Treatment	Coarse PK Pile WITH NO Wetland Treatment	Coarse PK Pile WITH Wetland Treatment	PKCF Perimeter Ditch WITH Wetland Treatment	Coarse PK Pile WITH Wetland Treatment				
Beryllium (mg/L)											
								-	-	-	-
	mean	4.47389E-05	2.05799E-05	4.57378E-05	2.10394E-05	-	-				
	medium	5.09679E-05	2.34452E-05	5.31845E-05	2.44649E-05	-	-				
	95%	6.52834E-05	3.00304E-05	5.51809E-05	2.53832E-05	-	-				
	Maximum	6.77438E-05	3.11622E-05	5.5182E-05	2.53837E-05	-	-				
Boron (mg/L)											
								1.5	-	-	-
	mean	1.290179386	1.096652478	1.2756495	1.084302075	1.096652478	1.084302075				
	medium	1.434901876	1.219666595	1.465254573	1.245466387	1.219666595	1.245466387				
	95%	2.284491047	1.94181739	1.861456734	1.582238224	1.94181739	1.582238224				
	Maximum	2.459803447	2.09083293	1.86160876	1.582367446	2.09083293	1.582367446				
Cadmium (mg/L)											
								0.00006 (a5)	0.000017 to 0.0001 (b1)	-	-
	mean	8.20245E-05	2.87086E-05	8.08721E-05	2.83053E-05	1.72251E-05	1.69832E-05				
	medium	8.96177E-05	3.13662E-05	9.19654E-05	3.21879E-05	1.88197E-05	1.93127E-05				
	95%	0.00014917	5.22094E-05	0.000147846	5.17461E-05	3.13256E-05	3.10477E-05				
	Maximum	0.00018053	6.31856E-05	0.000184291	6.4502E-05	3.79113E-05	3.87012E-05				
Chromium (mg/L)											
								0.001 (a6)	0.001	-	-
	mean	0.001153939	0.0003808	0.001083217	0.000357462	0.000784678	0.000736587				
	medium	0.001359973	0.000448791	0.00127549	0.000420912	0.000924782	0.000867333				
	95%	0.001665893	0.000549745	0.001746342	0.000576293	0.001132807	0.001187513				
	Maximum	0.001952109	0.000644196	0.002092379	0.000690485	0.001327434	0.001422818				

Table 4. Projected Water Quality in Seepage - Metals

Constituent		AMEC Modeling (2012): PKCF Perimeter Ditch WITH NO Wetland Treatment	AMEC Modeling (2012): PKCF Perimeter Ditch WITH Wetland Treatment	AMEC Modeling (2012): Coarse PK Pile WITH NO Wetland Treatment	AMEC Modeling (2012): Coarse PK Pile WITH Wetland Treatment	ARCADIS Modeling (2012) - For COCs: PKCF Perimeter Ditch WITH Wetland Treatment	ARCADIS Modeling (2012) - For COCs: Coarse PK Pile WITH Wetland Treatment	Guidelines - For Aquatic Life: Environmental Quality Guidelines (CCME 2011)	Guidelines - For Aquatic Life: SK Water Quality Objectives (MOE 2006)	Guidelines - Liquid Effluent: CA Metal Mining Effluent Regulations (2012)	Guidelines - Liquid Effluent: SK Mineral Industry Environmental Protection (1996)
Cobalt (mg/L)											
								-	-	-	-
	mean	0.000110204	0.000101388	0.000115226	0.000106008	-	-				
	medium	0.000121115	0.000111426	0.000133947	0.000123231	-	-				
	95%	0.000172087	0.00015832	0.000137213	0.000126236	-	-				
	Maximum	0.000182494	0.000167895	0.000138542	0.000127458	-	-				
Copper (mg/L)											
								0.004 (a7)	0.002 to 0.004	0.3	0.3
	mean	0.001436188	0.000157981	0.00151927	0.00016712	-	-				
	medium	0.001607942	0.000176874	0.001742563	0.000191682	-	-				
	95%	0.002461864	0.000270805	0.002240136	0.000246415	-	-				
	Maximum	0.002614123	0.000287554	0.002242302	0.000246653	-	-				
Iron (mg/L)											
								0.3	0.3	-	-
	mean	0.106786962	0.003203609	0.126377105	0.003791313	-	-				
	medium	0.123021719	0.003690652	0.144128996	0.00432387	-	-				
	95%	0.176270267	0.005288108	0.195215649	0.005856469	-	-				
	Maximum	0.182417629	0.005472529	0.195508232	0.005865247	-	-				
Lead (mg/L)											
								0.007 (a8)	.001 to .007	0.2	0.2
	mean	0.000415032	8.30063E-05	0.000337987	6.75974E-05	-	-				
	medium	0.000437752	8.75505E-05	0.000390515	7.81029E-05	-	-				
	95%	0.000772229	0.000154446	0.000433819	8.67638E-05	-	-				
	Maximum	0.000858455	0.000171691	0.000433973	8.67947E-05	-	-				

Table 4. Projected Water Quality in Seepage - Metals

Constituent		AMEC Modeling (2012)				ARCADIS Modeling (2012) - For COCs		Guidelines			
								For Aquatic Life		Liquid Effluent	
								Environmental Quality Guidelines (CCME 2011)	SK Water Quality Objectives (MOE 2006)	CA Metal Mining Effluent Regulations (2012)	SK Mineral Industry Environmental Protection (1996)
		PKCF Perimeter Ditch WITH NO Wetland Treatment	PKCF Perimeter Ditch WITH Wetland Treatment	Coarse PK Pile WITH NO Wetland Treatment	Coarse PK Pile WITH Wetland Treatment	PKCF Perimeter Ditch WITH Wetland Treatment	Coarse PK Pile WITH Wetland Treatment				
Manganese (mg/L)											
								-	-	-	-
	mean	0.040467843	0.003642106	0.046970532	0.004227348	-	-				
	medium	0.046638022	0.004197422	0.053554804	0.004819932	-	-				
	95%	0.065980556	0.00593825	0.072266751	0.006504008	-	-				
	Maximum	0.068165867	0.006134928	0.072274525	0.006504707	-	-				
Molybdenum (mg/L)											
								0.073	-	-	-
	mean	0.010607397	0.004667255	0.006671495	0.002935458	-	-				
	medium	0.010350638	0.004554281	0.007761724	0.003415159	-	-				
	95%	0.021255676	0.009352497	0.008462666	0.003723573	-	-				
	Maximum	0.024210049	0.010652422	0.009110914	0.004008802	-	-				
Nickel (mg/L)											
								0.15 (a9)	0.025 to 0.15	0.5	0.5
	mean	0.001418367	0.001148877	0.001268843	0.001027763	-	-				
	medium	0.001432402	0.001160246	0.00147011	0.001190789	-	-				
	95%	0.002765202	0.002239814	0.001519909	0.001231127	-	-				
	Maximum	0.00312746	0.002533242	0.001543702	0.001250398	-	-				
Selenium (mg/L)											
								0.001	0.001	-	-
	mean	0.000794965	0	0.000554018	0	0.000548526	0.000415513				
	medium	0.00079647	0	0.000637636	0	0.000549564	0.000478227				
	95%	0.001539462	0	0.000666824	0	0.001062229	0.000500118				
	Maximum	0.001739955	0	0.000670681	0	0.001200569	0.000503011				

Table 4. Projected Water Quality in Seepage - Metals

Constituent		AMEC Modeling (2012)				ARCADIS Modeling (2012) - For COCs		Guidelines			
								For Aquatic Life		Liquid Effluent	
								Environmental Quality Guidelines (CCME 2011)	SK Water Quality Objectives (MOE 2006)	CA Metal Mining Effluent Regulations (2012)	SK Mineral Industry Environmental Protection (1996)
		PKCF Perimeter Ditch WITH NO Wetland Treatment	PKCF Perimeter Ditch WITH Wetland Treatment	Coarse PK Pile WITH NO Wetland Treatment	Coarse PK Pile WITH Wetland Treatment	PKCF Perimeter Ditch WITH Wetland Treatment	Coarse PK Pile WITH Wetland Treatment				
Silver (mg/L)											
								0.0001	0.0001	-	-
	mean	2.13608E-05	5.12659E-06	2.00385E-05	4.80924E-06	-	-				
	medium	2.5533E-05	6.12792E-06	2.30114E-05	5.52273E-06	-	-				
	95%	3.25616E-05	7.81478E-06	3.33522E-05	8.00453E-06	-	-				
	Maximum	3.83476E-05	9.20343E-06	4.02248E-05	9.65395E-06	-	-				
Strontium (mg/L)											
								-	-	-	-
	mean	1.185242431	1.114127885	1.114127885	1.185242431	-	-				
	medium	1.360750873	1.279105821	1.279105821	1.360750873	-	-				
	95%	1.948609917	1.831693322	1.831693322	1.948609917	-	-				
	Maximum	2.020045539	1.898842806	1.898842806	2.020045539	-	-				
Thallium (mg/L)											
								0.0008	-	-	-
	mean	0.000147947	0.000146468	0.00012845	0.000127166	-	-				
	medium	0.000158486	0.000156901	0.000149226	0.000147733	-	-				
	95%	0.000249239	0.000246746	0.00015227	0.000150747	-	-				
	Maximum	0.000271926	0.000269206	0.000152654	0.000151127	-	-				
Tin (mg/L)											
								-	-	-	-
	mean	5.47794E-05	2.95809E-05	5.20286E-05	2.80955E-05	-	-				
	medium	6.03775E-05	3.26039E-05	6.05942E-05	3.27209E-05	-	-				
	95%	8.55384E-05	4.61908E-05	6.18013E-05	3.33727E-05	-	-				
	Maximum	9.08978E-05	4.90848E-05	6.1809E-05	3.33768E-05	-	-				

Table 4. Projected Water Quality in Seepage - Metals

Constituent		AMEC Modeling (2012)				ARCADIS Modeling (2012) - For COCs		Guidelines			
								For Aquatic Life		Liquid Effluent	
								Environmental Quality Guidelines (CCME 2011)	SK Water Quality Objectives (MOE 2006)	CA Metal Mining Effluent Regulations (2012)	SK Mineral Industry Environmental Protection (1996)
		PKCF Perimeter Ditch WITH NO Wetland Treatment	PKCF Perimeter Ditch WITH Wetland Treatment	Coarse PK Pile WITH NO Wetland Treatment	Coarse PK Pile WITH Wetland Treatment	PKCF Perimeter Ditch WITH Wetland Treatment	Coarse PK Pile WITH Wetland Treatment				
Uranium (mg/L)											
								0.015	0.015 (b2)	-	2.5
	mean	4.12767E-05	1.15575E-05	4.23337E-05	1.18534E-05	-	-				
	medium	4.55701E-05	1.27596E-05	4.65477E-05	1.30334E-05	-	-				
	95%	7.4199E-05	2.07757E-05	7.20842E-05	2.01836E-05	-	-				
	Maximum	8.00484E-05	2.24135E-05	7.50036E-05	2.1001E-05	-	-				
Vanadium (mg/L)											
								-	-	-	-
	mean	0.000568088	0.000431747	0.000494333	0.000375693	-	-				
	medium	0.000583878	0.000443747	0.000325805	0.000247612	-	-				
	95%	0.001197574	0.000910156	0.001094922	0.000832141	-	-				
	Maximum	0.0013183	0.001001908	0.001146404	0.000871267	-	-				
Zinc (mg/L)											
								0.03	0.03	0.5	0.5
	mean	0.024501555	0.000245016	0.025540869	0.000255409	0.007840498	0.008173078				
	medium	0.027072974	0.00027073	0.029237019	0.00029237	0.008663352	0.009355846				
	95%	0.042893032	0.00042893	0.041629364	0.000416294	0.01372577	0.013321397				
	Maximum	0.050012712	0.000500127	0.050487895	0.000504879	0.016004068	0.016156126				

Canadian Environmental Quality Guidelines - CEQG (CCME 2011)

a1 = Guideline is dependent on temperature and pH. The value ranges between 6.98 mg/L (pH= 7.0,temperature= 15oC) and 48.3 mg/L (pH= 6.5, temperature= 5oC).

a2 = Guideline is converted to Nitrate-N.

a3 = Guideline is converted to Nitrite-N.

a4 = Guideline = 5 µg/L at pH < 6.5, [Ca2+] < 4 mg/L and DOC < 2 mg/L; Guideline = 100 µg/L at pH ≥ 6.5, [Ca2+] ≥4 mg/L and DOC ≥ 2 mg/L.

a5 = Cadmium guideline = 10[0.86 [log(hardness)] - 3.2]. Conservatively, the lowest median hardness for this site was used to calculate the guidelines

a6 = Guideline is for hexavalent chromium (CrVI) because its guideline is more stringent than the trivalent chromium guideline of 8.9 ug/L

a7 = Copper guideline is dependent on [CaCO3] with a minimum of 2 µg/L. Guideline = e0.8545[ln(hardness)]-1.465*0.2. Conservatively, the lowest median hardness for this site was used to calculate the guidelines.

a8 = Lead guideline is dependent on [CaCO3]. Guideline = e1.273[ln(hardness)]-4.705. Conservatively, the lowest median hardness for the site was used to calculate the guideline.

Table 4. Projected Water Quality in Seepage - Metals

Constituent	AMEC Modeling (2012)				ARCADIS Modeling (2012) - For COCs		Guidelines			
							For Aquatic Life		Liquid Effluent	
							Environmental Quality Guidelines (CCME 2011)	SK Water Quality Objectives (MOE 2006)	CA Metal Mining Effluent Regulations (2012)	SK Mineral Industry Environmental Protection (1996)
	PKCF Perimeter Ditch WITH NO Wetland Treatment	PKCF Perimeter Ditch WITH Wetland Treatment	Coarse PK Pile WITH NO Wetland Treatment	Coarse PK Pile WITH Wetland Treatment	PKCF Perimeter Ditch WITH Wetland Treatment	Coarse PK Pile WITH Wetland Treatment				

a9 = Nickel guideline is dependent on [CaCO3]. Nickel guideline is dependent on [CaCO3]. Guideline = e0.76[ln(hardness)]+1.06. Conservatively, the lowest median hardness for this site was used to calculate the guideline

Saskatchewan Surface Water Quality Objectives (MOE 2006)

b1 = Cadmium Objective: 0.017 ug/L where hardness is 0 - 48.5 mg/L; 0.032 ug/L where hardness is48.5 - 97; 0.058 where hardness is 97 - 194; 0.10 ug/L where hardness is >194.

b2 = The objective was developed by the Industrial, Uranium and Hardrock Mining Unit of Saskatechewan Environment

The Mineral Industry Environmental protection Regulations, 1996

c1 = Maximum monthly arithmetic mean concentration.

Table 5. Treatment Efficiencies

Parameters	AMEC (2012)		ARCADIS (2012) - COCs	
	Probable Wetland Removal Efficiency	Information Source	Probable Wetland Removal Efficiency	Information Source
Total alkalinity	79%	2	-	-
Bicarbonate	79%	1	-	-
Calcium	63%	1, 2	-	-
Carbonate	79%	1, 2	-	-
Potassium	83%	1, 2	-	-
Sodium	43%	3	-	-
Sulfate	62%	1, 2	-	-
Ammonia as nitrogen	91%	1, 2	-	-
Nitrate	88%	3	-	-
Aluminum	99%	1	-	-
Antimony	71%	4	-	-
Arsenic	89%	6	-	-
Barium	49%	1, 2	-	-
Beryllium	54%	4	-	-
Bismuth	89%	5	-	-
Boron	15%	4	15%	4, 8, 9
Cadmium	65%	2, 6	79%	2, 6, 8
Chromium	67%	2, 6	68%	2, 6, 8
Cobalt	8%	4	-	
Copper	89%	1, 2	-	
Iron	97%	1, 2	-	
Lead	80%	1, 2	-	
Manganese	91%	1, 2	-	
Mercury	75%	1, 2	-	
Molybdenum	56%	4	-	
Nickel	19%	1, 2	-	
Selenium	100%	1	31%	1, 8
Silver	76%	2	-	
Strontium	6%	4	-	
Thallium	1%	7	-	
Tin	46%	4	-	
Uranium	72%	4	-	
Vanadium	24%	4	-	
Zinc	99%	1	68%	1, 8

1. Eckhardt, D.A.V., J.M. Surface, and J.H. Peverly. 1999. A Constructed Wetland System for Treatment of Landfill Leachate, Monroe County, New York. in. Mulamoottil, G., E. A. McBean, and F. Rovers, eds., Constructed Wetlands for the Treatment of Landfill Leachates. Boca Raton, Fla.: Lewis Publishers, Inc.

2. Interstate Technology & Regulatory Council. 1993. Technical and Regulatory Guidance Document for Constructed Treatment Wetlands. ITRC Wetlands Team.

3. Kadlec, R.H. and R.L. Knight, 1996, Treatment Wetlands. New York: Lewis Publishers, Inc.

4. Kropfelova, L., J.Vymazal, J. Svehla, and J.Stıchova. 2009. Removal of trace elements in three horizontal sub-surface flow constructed wetlands in the Czech Republic. Environmental Pollution 157: 1186–1194

5. Lizama, K. A., T.D. Fletcher, and G.Sun. 2011.Removal processes for arsenic in constructed wetlands. Chemosphere 84: 1032-1043
6. Loer, J. K. Scholz-Barth, R. Kadlec, D. Wetzstein, and J. Julik. 1999. An integrated Natural System for Leachate treatment in Mulamoottil, G., E. A. McBean, and F. Rovers, eds., Constructed Wetlands for the Treatment of Landfill Leachates. Boca Raton, Fla.: Lewis Publishers, Inc.

7. Simon, S.M. 2003. Phosphorus Retention and Release of Soils in a Constructed Wetland fo Wastewater Treatment. MS Thesis. University of Florida

8. Kadlecc, R.H. and S. D. Wallace. 2009. Treatment Wetlands - Second Edition. Boca Raton, Fl: CRC Press.

9. Sartaj, M., L. Fernandes, and N. Castonguay. 1999. Treatment of Leachate from a Landfill Receiving Industrial Commercia, Institutional, and Construction / Demolition Wastes in an Engineered Wetland.
in Mulamoottil, G., E. A. McBean, and F. Rovers, eds., Constructed Wetlands for the Treatment of Landfill Leachates. Boca Raton, Fla.: Lewis Publishers, Inc.

Table 6. Summary of On Site Wetland Area, Average Depth of Organic Soils, and Volume of Organic Soils

Drainage	Wetland Area (hectares)*	Open Water Area (hectares)*	Mean Depth of Organic Soils (m)**
Duke Ravine	77.0	25.0	0.4
East Ravine	27.0	13.0	0.9
	24.0	-	0.9
English Creek Tributary	5.0	8.0	1.2
101 Ravine	81.0	5.0	1.1

* Estimated areas derived from interpreation of aerial photography and on site data

** Mean depths derived from Shore on site wetlands data (AMEC 2012)

ARCADIS

Appendix A

Figures from Environmental Impact Statement (AMEC 2012)

Legend

- Contour (10 m)
- Watercourse
- Wetland
- Waterbody
- Indian Reserve
- Mine Facilities

Reference

Base data: NTS 1:50,000 scale
Orthophoto Date 2007 & 2009
Mine facilities: Dated August 30, 2011

CLIENT: Shore Gold Inc.

PROJECT: Star - Orion South Diamond Project

Project Components

0 1 2 km

Figure 2.1-1

DATE: June, 2012

GIS TRACKING NUMBER: X-Other-025_v10

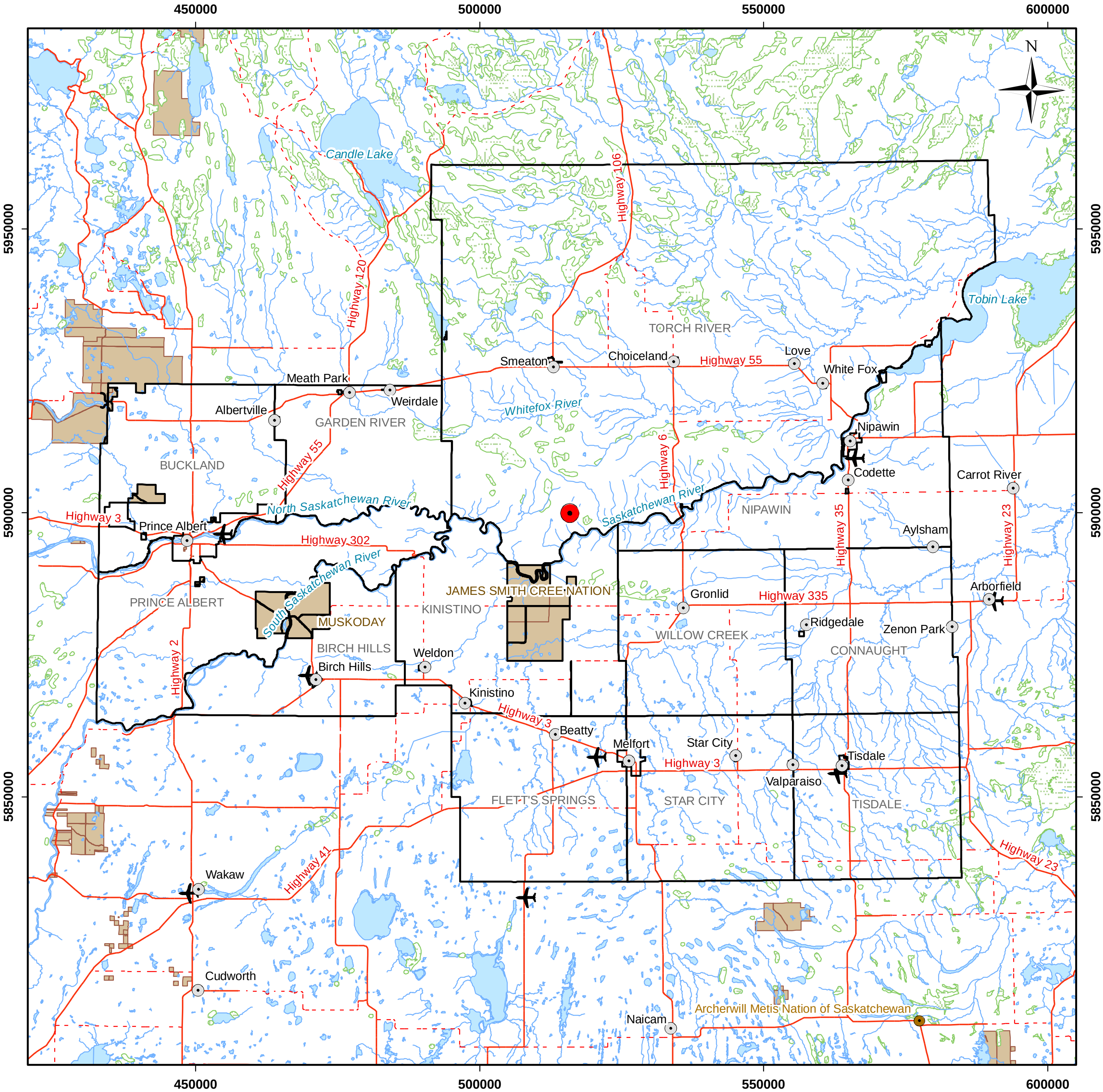
PROJECT No: SX0373302

PROJECTION & DATUM: UTM Zone 13 NAD27

DRAWN BY: EO

amec

Y:\GIS\Projects\SX\SX03733_Shore-Gold_Diamond_1\Mapping\19_Other\Baseline\X-Other-025_v10.mxd



Legend

- Project Location
- Airport
- Regional Study Area Communities
- Metis Nation
- Paved Highway
- Unpaved Highway
- Watercourse
- Waterbody
- Wetland
- Rural Municipality
- Indian Reserve

Reference
Base data: NRCan National Road Network;
NTS 1:250,000 scale: GeoSask
Indian Reserve/ Municipality Boundaries: GeoSask
Mine facilities: Amec, dated 19 February 2009

Scale: 1:1,000,000
10 5 0 10 20
Kilometers

Y:\GIS\Projects\SX\SX03733_Shore-Gold_Diamond_1\Mapping\19_OtherBaseline\X-Other-036.mxd

CLIENT: Shore Gold Inc.		
PROJECT: Star - Orion South Diamond Project		
Project Location		
DATE: November 15, 2010	ANALYST: EO	Figure 2.4-1
JOB No: SX03733	QA/QC: EO	TRACKING NO: X-Other-036
GIS FILE: X-Other-036.mxd		amec
PROJECTION: UTM Zone 13	DATUM: NAD27	

ARCADIS

Appendix B

Background Concentration Data
(AMEC 2012)

- East Ravine background concentrations were adopted from the water quality results from sampling location ERS-01; and
- Duke Ravine background concentrations were adopted from the water quality results from sampling location DSS-01.

Table 3.7: Background concentrations for conventional parameters of Mannville water, shallow groundwater, overburden leachate, East and Duke Ravine flow.

		Mannville water	Shallow GW	Overburden	East Ravine	Duke Ravine
Conventional Parameters						
Chemical Oxygen Demand	mg/L	58.5	6	6[a]	19.6	16.4
pH	pHunit	9.05	7.95	8.6	8.156	8.279
Specific conductivity	uS/cm	7747.5	382	609	404.5	403.5
Sum of Ions	mg/L	4590	330	542.5	241.4	352.7
Total alkalinity	mg/L	246.56	237	322.5	224.0	213.7
Total dissolved solids	mg/L	4420.8	242	351.5	235.7	217.9
Total hardness	mg/L	149.67	226	275.5	208.5	218.2
Major Ions						
Bicarbonate	mg/L	178.29	240	374	270.6	253.2
Calcium	mg/L	15.11	59	75	63.4	61.6
Carbonate	mg/L	48.04	<1	9.5	1.8	4.0
Chloride	mg/L	2193.3	7	2	1.5	2.4
Fluoride	mg/L	0.702	0.13	0.325	0.120	0.123
Hydroxide	mg/L	4.5	<1	<1 [a]	0.6	0.5
Magnesium	mg/L	27.24	13	21.5	14.2	14.9
Potassium	mg/L	60.92	1	4.45	2.0	1.66
Sodium	mg/L	1627.5	4.2	29.5	3.9	4.45
Sulfate	mg/L	423.3	5.4	26.7	4.7	7.9
Nutrients						
Ammonia as nitrogen	mg/L	1.94	0.02	0.02 [a]	0.095	0.03
Dissolved organic carbon	mg/L	6.68	1.2	1.2 [a]	4.6	4.93
Nitrate	mg/L	7.85	0.35	<0.04	0.2	2.9
Nitrite+Nitrate, nitrogen	mg/L	1.82	n/a	n/a	0.034	0.66
Total Kjeldahl nitrogen	mg/L	2.2	0.9	0.9 [a]	0.73	20.5
Total nitrogen	mg/L	16.56	n/a	n/a	12.9	-
Total organic carbon	mg/L	7.91	1.5	1.5 [a]	5.7	5.15
Total phosphorus	mg/L	0.75	0.0028	0.0028 [a]	0.062	0.038

Note: [a] Overburden leachate water chemistry for the specific parameters were not available. Values adopted from shallow groundwater.

Table 3.8: Background concentrations of total metals of Mannville water, shallow groundwater, overburden leachate, East and Duke Ravine flow

		Mannville water	Shallow GW *	Overburden*	East Ravine	Duke Ravine
Total Metals						
Aluminum-T	mg/L	8.18	<0.0005	0.905	0.117	0.213
Antimony-T	mg/L	0.000225	<0.0002	<0.0002 [a]	0.00012	0.0001
Arsenic-T	µg/L	1.25	0.2	7.2	4.7	2.8
Barium-T	mg/L	0.173	0.31	0.16	0.43	0.205
Boron-T	mg/L	3.158	<0.01	0.155	0.028	0.029
Cadmium-T	mg/L	0.00014	<0.0005	<0.0005	0.00006	0.00006
Chromium-T	mg/L	0.275	<0.005	0.006	0.0039	0.00167
Cobalt-T	mg/L	0.0457	0.0001	0.0001 [a]	0.00050	0.00039
Copper-T	mg/L	0.0271	<0.0002	0.0052	0.0024	0.00129
Iron-T	mg/L	31.68	0.001	4.15	1.3	1.08
Lead-T	mg/L	0.00908	<0.0001	0.00545	0.00051	0.00051
Manganese-T	mg/L	0.448	0.0037	0.15	0.34	0.047
Molybdenum-T	mg/L	0.0034	0.001	0.001 [a]	0.00106	0.0032
Nickel-T	mg/L	0.847	<0.0001	<0.0001 [a]	0.0030	0.00148
Selenium-T	mg/L	0.000492	0.0001	0.0004	0.00011	0.00019
Silver-T	mg/L	0.000221	<0.0001	<0.0001 [a]	0.00006	0.00005
Strontium-T	mg/L	0.699	0.08	0.08	0.17	0.159
Thallium-T	mg/L	0.000183	<0.0002	<0.0002 [a]	0.00010	0.0001
Tin-T	mg/L	0.000433	<0.0001	<0.0001 [a]	0.0001	0.0144
Titanium-T	mg/L	0.709	<0.0003	<0.0003 [a]	0.0036	0.0070
Uranium-T	µg/L	0.9889	0.0004	3.8	0.38	0.63
Vanadium-T	mg/L	0.164	<0.0001	<0.0001 [a]	0.00095	0.0017
Zinc-T	mg/L	0.0634	0.069	0.509	0.016	0.0073

Note: * Total metals concentrations were not provided for overburden leachate, assumed total metals concentrations equals to dissolved metals concentrations. [a] Overburden leachate water chemistry for the specific parameters were not available. Values adopted from shallow groundwater.

Table 3.9: Background concentrations of dissolved metals of Mannville water, shallow groundwater, overburden leachate, East and Duke Ravine

	unit	Mannville water *	Shallow GW	Overburden	East Ravine	Duke Ravine
Dissolved Metals						
Aluminum-D	mg/L	8.177	<0.0005	0.905	0.0102	0.083
Antimony-D	mg/L	0.000225	<0.0002	<0.0002 [a]	0.0001	0.00012
Arsenic-D	µg/L	1.254	0.2	7.2	2.02	2.38
Barium-D	mg/L	0.173	0.31	0.16	0.396	0.199
Boron-D	mg/L	3.158	<0.01	0.155	0.027	0.028
Cadmium-D	mg/L	0.000142	<0.0005	<0.0005	0.00005	0.00025
Chromium-D	mg/L	0.275	<0.005	0.006	0.065	0.0276
Cobalt-D	mg/L	0.0457	0.0001	0.0001 [a]	0.00013	0.00089
Copper-D	mg/L	0.0271	<0.0002	0.0052	0.0009	0.0028
Iron-D	mg/L	31.68	0.001	4.15	0.032	0.57
Lead-D	mg/L	0.00908	<0.0001	0.00545	0.00007	0.00051
Manganese-D	mg/L	0.448	0.0037	0.15	0.093	0.062
Molybdenum-D	mg/L	0.00344	0.001	0.001 [a]	0.0011	0.00099
Nickel-D	mg/L	0.847	<0.0001	0.00005 [a]	0.00137	0.0124
Selenium-D	mg/L	0.000492	0.0001	0.0004	0.00011	0.00012

	unit	Mannville water *	Shallow GW	Overburden	East Ravine	Duke Ravine
Silver-D	mg/L	0.000221	<0.0001	0.00005 [a]	0.00005	0.00005
Strontium-D	mg/L	0.699	0.08	0.08 [a]	0.153	0.163
Thallium-D	mg/L	0.000183	<0.0002	0.0001 [a]	0.0001	0.0001
Tin-D	mg/L	0.000433	<0.0001	0.00005 [a]	0.00006	0.00011
Titanium-D	mg/L	0.709	<0.0003	0.00015 [a]	0.00044	0.003
Uranium-D	µg/L	0.9889	0.0004	3.8	0.29	0.56
Vanadium-D	mg/L	0.164	<0.0001	0.00005 [a]	0.05	0.05
Zinc-D	mg/L	0.0634	0.069	0.509	0.0065	0.015

Note: *Dissolved metals concentrations were not provided for Mannville water, assumed dissolved metal concentrations equals to total metals concentrations.

The background water quality for creeks was presented in the model as averages of baseline concentrations and thus free of spikes and uncertainties that might be caused by differences in detection limits. The below detection concentrations of certain parameters were replaced by ½ MDL levels. This has to be taken into account in results interpretation as in some cases it might overestimate a background level for a parameter.

Some of small streams (e.g. few unnamed tributaries) were represented with water quality data taken from studied watersheds of similar size and location with the study area. This is a valid assumption that followed hydrological similarity and thus, similar surface-groundwater interaction pattern that reflects in water quality of streams as well.

3.4 WATER QUALITY MODELLING RESULTS

The chemical parameters which were modelled are listed in Table 3.10:

Table 3.10: Chemical parameters predicted in the water quality model

Conventional parameters	Major Ions	Total and Dissolved Metals	
Total dissolved solids	Bicarbonate	Aluminum	Manganese
Specific conductivity	Calcium	Antimony	Molybdenum
Total alkalinity	Carbonate	Arsenic	Nickel
Chemical Oxygen Demand	Chloride	Barium	Selenium
Nutrients	Fluoride	Boron	Silver
Ammonia as nitrogen	Hydroxide.	Cadmium	Strontium
Nitrate	Magnesium	Chromium	Thallium
Total phosphorus	Potassium	Cobalt	Tin
Total organic carbon	Sodium	Copper	Titanium
Dissolved organic carbon	Sulfate	Iron	Uranium
		Lead	Vanadium
			Zinc

2010 Orion South Pumptest

Group #			OSPT	OSPT	OSPT	OSPT	OSPT	OSPT	OSPT	OSPT	OSPT
Sample #			**#10064**	**#10065**	**#10066**	**#10067**	**#10068**	**#10071**	**#10072**	**#10073**	**#10074**
Date			**26-Oct-10**	**29-Oct-10**	**2-Nov-10**	**4-Nov-10**	**7-Nov-10**	**11-Nov-10**	**12-Nov-10**	**14-Nov-10**	**14-Nov-10**
Analyte	**Units**	**MIEPR**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**	**Results**
Aluminum	mg/L		0.021				0.005		0.0021		0.0024
Antimony	mg/L		<0.002				<0.002		<0.0002		<0.0002
Arsenic	ug/L	500	<1				<1		0.3		0.2
Barium	mg/L		0.013				0.011		0.010		0.010
Beryllium	mg/L		<0.001				<0.001		<0.0001		<0.0001
Bicarbonate	mg/L		473	476	477	477	474	474		474	
Boron	mg/L		2.1				2.0		2.0		1.9
Cadmium	mg/L		<0.0001				<0.0001		0.00001		0.00001
Calcium	mg/L		138	136	133	133	136	134		134	
Carbonate	mg/L		<1	<1	<1	<1	<1	<1		<1	
Chloride	mg/L		1600	1600	1600	1560	1600	1700		1700	
Chromium	mg/L		<0.005				<0.005		<0.0005		<0.0005
Cobalt	mg/L		0.001				<0.001		0.0001		0.0001
Copper	mg/L	0.3	0.010				0.005		0.0032		0.0024
Fluoride	mg/L		2.2	2.2	2.3	2.2	2.2	2.3		2.5	
Hydroxide	mg/L		<1	<1	<1	<1	<1	<1		<1	
Iron	mg/L		0.36				0.29		0.24		0.23
Lead	mg/L	0.2	<0.001				<0.001		0.0005		0.0003
Magnesium	mg/L		47	46	45	45	46	45		45	
Manganese	mg/L		0.099				0.092		0.087		0.086
Molybdenum	mg/L		<0.001				<0.001		0.0002		0.0001
Nickel	mg/L	0.5	0.002				<0.001		0.0005		0.0005
Nitrate	mg/L		<0.04	<0.04	<0.04	<0.04	<0.04	<0.04		<0.04	
P. Alkalinity			<1	<1	<1	<1	<1	<1		<1	
pH	pH units		7.82	7.82	7.82	7.88	7.79	7.74		7.73	
Phosphorus	mg/L		0.06				0.06		0.05		0.05
Potassium	mg/L		57	57	58	58	57	56		56	
Selenium	mg/L		<0.001				<0.001		0.0003		0.0002
Silver	mg/L		<0.0001				<0.0001		<0.00001		<0.00001
Sodium	mg/L		1190	1210	1270	1250	1210	1210		1220	
Specific conductivity	µS/cm		6420	6530	6470	6530	6450	6160		6180	
Strontium	mg/L		2.6				2.5		2.50		2.48
Sulfate	mg/L		740	750	740	750	750	740		740	
Sum of ions	mg/L		4240	4280	4320	4270	4270	4360		4370	
Thallium	mg/L		<0.002				<0.002		<0.0002		<0.0002
Tin	mg/L		<0.001				<0.001		<0.0001		<0.0001
Titanium	mg/L		<0.002				<0.002		0.0002		<0.0002
Total alkalinity	mg/L		388	390	391	391	389	389		389	
Total dissolved solids	mg/L		3960	3960	3970	3960	3950	3950		3950	
Total hardness	mg/L		537	528	517	517	528	519		519	
Uranium	ug/L	2500	<1				<1		<0.1		<0.1
Vanadium	mg/L		<0.001				<0.001		0.0002		0.0002
Zinc	mg/L	0.5	0.16				0.021		0.014		0.011

Appendix C

Site Wetland Characterization Data (AMEC 2012)

ite	Observer	Date	UTM N	E	Photo?	Depth to Water	Slope Position	Drainage	Slope	Aspect	Topography	Horizon	Depth Upper	Lower	Von Post/ Texture	Color	Stoniness	Consistency	Samples?	Field pH	EC	Temp	Fizz?	% Water	% tree	% shrub	Trees (10x10) Species	count	height	Shrubs (10x10) Species	Cover	Shrubs (10x10) Species	Cover	Comments
01 (1)	ER/CW	12-Aug-11	5902206	516268	No	0	depression	VP	0	na	level	Om	0	50	H3	Black	0	VL	No	6.4	336	17.6	No	15	50	5	Salix Sp.	Many	6	Bog birch	1	Salix Sp.	1	Wetland width approx. 10m, plot location in center of wetland width
												Om	50	85	H5	Dark Brown	0	VL										tA	35	8	Marsh reed grass	7	Current	1	
												Oh	85	100	H6	Dark Brown	0	VL										bPo	20	8	Fireweed	+	Feather Moss	1	
												CG	100	+	Sandy Loam	Grey	0	VL													Dewberry	+	Woodsy leafy moss	2	
01 (2)	ER/CW	12-Aug-11	5902140	516217	No	0	depression	VP	0	na	level	Om	0	40	H3	Black	0	VL	No					60	80	5	Same as 01 (1)			Same as 01 (1)				Small channel at 516214E 5902145N
												CG	40	+	Loamy Sand	Grey	0	VL																Organic depth at the center of channel is (0-100cm Om H4, 100+ cG)
																																		West side of wetland 516210E, 5902152N (0-35cm Om H3, 35+ cm cG)
01(3)	ER/CW	12-Aug-11	5902024	516195	No	0	level	VP	0	na	level	Om	0	75	H3	Black	0	VL	No					50	5	70	Salix Sp.	Many	3	Salix Sp.	2	Dewberry	+	Small channel appears to be 2m West of plot
												Om	75	110	H4	Dark Brown	0	VL													Water Sedge	7			West side of a open pond meets upland @ 516181, 5901091N.
												CG	110	+	Sandy Loam	Grey	0	VL													Marsh Reed Grass	1			East side od pond meets wepland @ 516206E, 5902080N.
01 (4)	ER/CW	12-Aug-11	5902003	516163	No	5 cm	level	P	0	na	level	Om	0	20	H4	Black	0	VL	No															Forbs were indicative of tA overstory
												CG	20	+	Sandy Loam	Grey	0	VL																
01 (5)	ER/CW	12-Aug-11	5901896	516125	No	0	level	VP	0	na	level	Om	0	45	H4	Black	0	VL	No															5cm LFH into Bg horizon at 5 m East of plot.
												CG	45	+	Sandy Loam	Grey	0	VL																West side of wetland @ 516100E 5901902N - OmH4 (0-30cm)
01 (6)	ER/CW	12-Aug-11	5901804	516060	Yes - #1a	0	level	VP	0	na	level	Om	0	70	H4	Black	0	VL	No	6.4	528	16.8	No	50	30	40	wB	20	5	Marsh Reed Grass	1			East side of beaver pond @ 516094, 5901789
												Om	70	120	H3	Dark Brown	0	VL										Salix sp.	Many	5	Water Sedge	6			Upland/Wetland border @ 516081, 5901707
												Om	120	210+	H5	Light Brown	0	VL										wS	20	2	Bog Birch	+			Small channel @ 516053, 5901804 (0.5m wide, not flowing
																												jP	5	3	Arrow leaved coltsfoot	+			
01 (7)	ER/CW	12-Aug-11	5901683	516025	No	5 cm	level	VP	0	na	level	Om	0	30	H3	Black	0	VL	No	7.04	602	15.1	No	20	40	40	wS	Many	4	Arrow leaved coltsfoot	+	Marsh reed grass	1	East side of wetland at 516038E 5901687N.
												Om	30	65	H6	Brown	0	M										jP	10	4	Water Sedge	+	Feather Moss	1	
												CG	65	+	Loamy Sand	Grey	0	M										tA	Many	6	Solomon Seal	+	Bishops Cap	+	
																												Salix Sp.	Many	3				
01 (8)	ER/CW	12-Aug-11	5901687	516004	No	0	level	VP	0	na	level	Om	5	80	H4	Dark Brown	0	VL	No															West side of wetland at 515972E 5901680N.
												CG	80	+	Loamy sand	Grey	0	VL																
01 (9)	ER/CW	12-Aug-11	5901679	515973	No	5 cm	level	I	0	na	level	Om	0	40	H3	Black	0	VL	No	6.95	368	14.1	No	20	40	40	tL	Many	3	Bog birch	1	Water Sedge	1	Frozen at a depth of 40 cm.
													***Frozen at 40 cm						40cm		392	8.2					jP	Many	3	Labrador Tea	+	Salix Sp.	+	
																												bS	Many	2				
01(10)	ER/CW	12-Aug-11	5901556	515879	No	10 cm	level	VP	0	na	level	Om	0	15	H3	Black	0	VL	No															East side of wetland at 515870E 5901555N
												Om	15	55	H4	Dark Brown	0	VL																
												CG	55	+	Loamy Sand	Grey	0	VL																
01(11)	ER/CW	12-Aug-11	5901506	515917	No	18cm	level	VP	0	na	level	Of	0	10	H1	Black	0	VL	No															
												Om	10	15	H4	Brown	0	VL																
												Ah	15	18	Loamy Sand	Brown	0	VL																
												Cg	18	+	Loamy Sand	Grey	0	VL																
01(12)	ER/CW	12-Aug-11	5901517	515907	Yes - #3a	0	level	VP	0	na	level	Om	0	50	H3	Black	0	VL	Yes	7.2	454	16.7	No	20	30	40	wS	35	5	Horsetail	+	Woodsy leafy moss	+	
												CG	50	+	Loamy Sand	Grey	0	M										tA	10	3	Labrador Tea	+	Bog Birch	1	
																												Salix Sp.	20	3	Water Sedge	7			
01(13)	DP/CW	15-Aug-11	5901383	515864	No	0	level	VP	0	na	level	Om	0	100	H3	Dark Brown	0	VL	No					25	20	50	jP	80	3	bS	3	Labrador Tea	1	East side of wetland at 515675E 5901382N.
												CG	100	+	Loamy Sand	Grey	0	VL										bS	20	2	Salix Sp.	+	Water Sedge	1	
																															Bog birch	+	Peat Moss	2	
																																	Feather Moss	2	
01(14)	DP/CW	15-Aug-11	5901294	515769	No	10 cm	level	VP	0	na	level	Om	0	40	H3	Dark Brown	0	VL	No															
												***Frozen	40																					
01(15)	DP/CW	15-Aug-11	5901683	516025	No	5 cm	level	VP	0	na	level	Of	0	20	H2	Dark Brown	0	VL	No															West edge of wetland at 515750E 5901298N
												Om	20	210+	H3	Black	0	VL																
01(16)	DP/CW	15-Aug-11	5901297	515844	No	0	dep	VP	0	na	level	Of	0	30	H2	Black	0	VL	Yes	7.6	471	18.8	No	50	35	20	tL	35	4	Salix Sp.	+	Feather Moss	1	
												Om	30	100	H3	Dark Brown	0	VL										jP	10	2	Water Sedge	6	Current	+	
												CG	100	+	Loamy Sand	Grey	0	M										bS	5	2	Bog birch	1			
01(17)	Skipped, obvious upland																																	
01(18)	DP/CW	15-Aug-11	5901185	515861	No	0	level	I	0	na	level	Om	0	15	H3	Dark Brown	0	VL	No					0	60	20	tA	10		Gooseberry	+	Knights Plume Moss	+	East side of wetland at 515881E 5901185N.
												Cg	30	+	Sandy Loam	Mottled	0	M										jP	Many		Fireweed	+	Feather Moss	2	
																												bS	30		Horsetail	4	Palmate Leaved Coltsfo	+	
																												Salix Sp.	10		Labrador Tea	3			
01(19)	DP/CW	15-Aug-11	5901184	515769	No	0	dep	VP	0	na	level	Oh	0	15	H2	Black	0	VL	No															
												Om	15	45	H3	Black	0	VL																
												***Frozen at 45																						
01(20)	DP/CW	15-Aug-11	5901181	515769	No	0	level	VP	0	na	level	Oh	0	25	H2	Black	0	VL	No															West side of wetland at 515730E, 5901180N
												Om	25	120	H3	Black	0	VL																
												Om	120	210+	H4	Brown	0	VL																
01(21)	DP/CW	15-Aug-11	5901062	515738	No	0	toe	VP	0	na	level	Om	0	210+	H3	Dark Brown	0	VL	Yes	7.25	292	13.3	NA	20	10	40	tL	8	5	bS	1	Water Sedge	+	West side of wetland at 515723E 5901071N
																												jP	20	4	Bog birch	4	Feather Moss	2	
																												bS	20	3	Labrador Tea	1	Peat Moss	3	
01(22)	DP/CW	15-Aug-11	5901059	515808	Yes #1	0	level	VP	0	na	level	Of	0	20	H2	Black	0	VL	No															
												Om	20	60	H4	Dark Brown	0	VL																
												Oh	60	105	H6	Grey Brown	0	M																
												CG	105	+	Sandy Loam	Grey	0	M																
01(23)	DP/CW	15-Aug-11	5901028	515845	No	30	lower	I	2_5	W	incline	Oh	0	80	H2	Black	0	VL	No															East side of wetland at 515865E 5901030N.
												Om	80	150	H4	Dark Brown	0	M																
												CG	150	+	Loamy Sand	Dark Brown	0	M																
01(24)	Skipped, obvious upland																																	
01(25)	DP/CW	15-Aug-11	5900995	515777	No	25	level	VP	0	na	level	Om	0	80	H3	Black	0	VL	No					5	35	35	bS	Many	7	Labrador Tea	5	Feather Moss	1	East side of wetland at 515855E 5901000N.
												CG	80	+	Sandy Loam	Grey	0	L										tL	Many	4	Lingonberry	2	Bog Birch	1	
																												jP	35	3	Peat Moss	4	Fireweed	+	
01(26)	DP/CW	15-Aug-11	5901002	515729	Yes #2	0	level	VP	0	na	level	Om	0	120	H3	Dark Brown	0	VL	Yes	7.44	263	12.7	No											
												Om	120	170	H5	Brown	0	VL																
												Oh	170	210	H7	Brown	0	L																
01(27)	Skipped, obvious upland																																	
01(28)	DP/CW	15-Aug-11	5900936	515725	Yes #4a	20	level	VP	0	na	level	Om	0	45	H3	Dark Brown	0	VL	No															
												CG	45	+	Sandy Loam	Grey	0	VL																
01(29)	DP/CW	15-Aug-11	5900933	515640	No	5	level	VP	0.5-2	E	level	Om	0	20	H2	Black	0	VL	No					20	15	25	jP	Many	3	Peat Moss	7	Lingonberry	+	
												CG	20	210+	H3	Dark Brown	0	VL										bS	Many	3	Labrador Tea	5			
																												tL	10	4	Bog birch	2			
01(30)	DP/CW	15-Aug-11	5900868	515626	No	0	dep	VP	0.5-2	W	level	Of	0	10	H2	Black	0	VL	No															West edge of wetland at 515609E 5900868N
												Om	10	40	H3	Dark Brown	0	VL																
												Om	40	210+	H5	Dark Brown	0	VL																
01(31)	DP/CW	15-Aug-11	5900838	515670	No	10	level	I	0	na	level	Om	0	50	H5	Dark Brown	0	VL	No															
												CG	50	+	Loamy Sand	Grey	0	VL																
01(32)	DP/CW	15-Aug-11	5900847	515721	No	10	level	MW	0	na	level	LFH	0	15		Black	0	VL	No					5	70	5	tA	Many	6	wS	+	Labrador Tea	2	East side of wetland at 515739E 5900868N.
												Cg	30	+	Loamy Sand	Mottled	0	VL										jP	Many	6	Palmate Leaved Coltsfoo	+	Marsh Reed Grass	1	
																												wB	Many	6	Horsetail	2	Peat Moss	3	
																															Bunchberry	1	Blueberry	+	
																															Dewberry	+			

Site	Observer	Date	UTM N	E	Photo?	Depth to Water	Slope Position	Drainage	Slope	Aspect	Topography	Horizon	Depth Upper	Lower	Von Post/ Texture	Color	Stoniness	Consistency	Samples?
02(1)	BD/CW	23-Aug-11	5901740	517912	No	50	level	I	0	na	level	Om	0	45	H3	Black	0	VL	No
												CG	45	+	Loamy Sand	Dark Brown	0	VL	
02(2)	BD/CW	23-Aug-11	5901661	517905	No	80	level	MW	0	na	level	LFH	0	10		Black	0	VL	No
												A	10	+	Loamy Sand	Brown	0	VL	
02(3)	BD/CW	23-Aug-11	5901629	517820	No	0	level	VP	0	na	level	Om	0	60	H3	Black	0	VL	No
												CG	60	+	Sandy Loam	Grey	0	VL	
02(4)	BD/CW	23-Aug-11	5901629	517770	No	20	level	VP	0	na	level	Om	0	25	H3	Black	0	VL	No
												CG	25	+	Loamy Sand	Grey	0	VL	
02(5)	DP/CW	23-Aug-11	5901523	517623	No	0	toe	P	0.5-2	E	level	Om	0	15	H3	Black	0	VL	No
												CG	15	+	Sandy Loam	Grey	0	VL	
02(6)	DP/CW	23-Aug-11	5901479	517720	Yes #3	0	level	VP	0	na	level	Om	0	40	H3	Black	0	VL	Yes
												CG	40	+	Loamy Sand	Grey	0	VL	
02(7)	DP/CW	23-Aug-11	5901440	517804	No	5	level	VP	0	na	level	Om	0	30	H3	Dark Brown	0	VL	No
												Oh	30	70	H6	Dark Grey	0	VL	
												CG	70	+	Loamy Sand	Grey	0	VL	
02(8)	DP/CW	23-Aug-11	5901349	517804	Yes #4	60	level	I	0	na	level	LFH	0	20	H2	Black	0	VL	No
												A	20	+	Loamy Sand	Grey Brown	0	L	
02(9)	DP/CW	23-Aug-11	5901349	517685	No	0	level	VP	0	na	level	Om	0	25	H3	Black	0	VL	No
												CG	25	+	Loamy Sand	Grey	0	L	
02(10)	DP/CW	23-Aug-11	5901343	517590	No	30	toe	MW	0.5-2	E	level	LFH	0	25	H3	Black	0	VL	No
												A	25	+	Sand	Brown grey	0	L	
02(11)	DP/CW	23-Aug-11	5901204	517634	No	5	level	P	0	na	level	Om	0	15	H3	Black	0	VL	No
												CG	15	+	Loamy Sand	Grey Brown	0	L	
02(12)	DP/CW	23-Aug-11	5901182	517672	Yes#5	50	level	I	0	na	level	LFH	0	5		Black	0	VL	No
												A	5	+	Sand	Brown	0	VL	
02(13)	DP/CW	23-Aug-11	5901101	517644	No	45	dep	P	0.5-2	W	incl.	Oh	0	20	H2	Black	0	VL	No
												Om	20	25	H3	Black	0	VL	
												CG	25	+	Loamy Sand	Grey Brown	0	M	
02(14)	BD/CW	23-Aug-11	5901073	517560	No	5	toe	VP	0.5-2	W	incl.	Om	0	30	H3	Black	0	VL	Yes
												Om	30	145	H5	Black	0	M	
												CG	145	+	Loamy Sand	Grey	0	F	
02(15)	BD/CW	23-Aug-11	5900950	517386	No	20	toe	P	0.5-2	E	incl.	Oh	0	10	H2	Black	0	VL	No
												Cg	10	+	Sand	Brown grey	0	L	
02(16)	BD/CW	23-Aug-11	5900920	517419	Yes #6	0	dep	VP	0	na	level	Om	0	60	H3	Black	0	VL	Yes
												Om	60	85	H5	Black	0	VL	
												CG	85	+	Sand	Grey	0	VL	
02 (17)	BD/CW	23-Aug-11	517294	5900844	Yes #7,8,9,10														

Site	Field pH	EC	Temp	Fizz?	% Water	% tree	% shrub	Trees (10x10) Species	count	height	Shrubs (10x10) Species	Cover	Shrubs (10x10) Species	Cover	Comments
02(1)															Wetland width approx. 40m, plot location in center of wetland width
02(2)															
02(3)															
02(4)					5	20	70	bS	Many	3	Salix Sp.	2	Knights Plume Moss	+	West edge of wetland @517760E 5901631N
								tA	Many	4	Water Sedge	3	Arrow Leaved Coltsfoo	1	
								Salix Sp.	Many	3	Peat Moss	1	Palmate Leaved Coltsfo	+	
								jP	5	4	Feather Moss	1			
02(5)															
02(6)	6.94	503	13.5	No	5	60	20	Salix Sp.	Many	3	Water Sedge	4			
								tA	Many	3	Marsh Reed Grass	3			
								jP	30	4	Labrador Tea	+			
								bS	30	3	Horsetail	+			
								tL	2	5	Feather Moss	+			
02(7)															
02(8)					0	30	25	bPo	Many	4	Labrador Tea	2	Arrow Leaved Coltsfoo	+	
								tA	30	3	Shrubby Cinquefoil	+	Prickly Rose	+	
								jP	Many	4	Strawberry	+	Palmate Leaved Coltsfo	+	
								bS	Many	3	Fireweed	+			
02(9)															
02(10)															West edge of wetland at 517582E 5901343N
02(11)					0	75	10	tA	Many	5	Horsetail	1	Fireweed	+	
								bS	30	3	Marsh Reed Grass	1	Prickly Rose	+	
											Palmate Leaved Coltsfo	+	Twinflower	+	
02(12)															East edge of wetland at 517705 5901173
02(13)															East edge of wetland at 5901103N 517684E.
02(14)	6.85	296	17.5	No	5	65	10	tA	Many	7	River Alder	2	Leafy Woodsy Moss	+	Small Neaver Pond just west of plot
								wB	20	7	Violet	+	Fireweed	+	West edge of wetland at 5901075N 517539E.
											Water Sedge	3	Dewberry	+	
02(15)															
02(16)	7.39	318	23.1	No	50	0	20				River Alder	1	Marsh Reed Grass	1	East side of wetland at 517470E 5900921N.
											Marsh Merigold	+	Water Moss	2	Very slow moving wide, pitted channel. Defined channel 2' deep and
											Salix Sp.	+			3' wide 5m east of 02(16).
02 (17)															No plot, open water. Beaver damn flooding entire wetland. Pond approx 60m wide, 60m long, fills entire wetland. No peat, mineral soil under pond. Flowing Spring at 517399E 5900901N.

Site	Observer	Date	UTM N	E	Photo?	Depth to Water	Slope Position	Drainage	Slope	Aspect	Topography	Horizon	Depth Upper	Lower	Von Post/ Texture	Color	Stoniness	Consistency	Samples?	Field pH	EC	Temp	Fizz?	% Water	% tree	% shrub	Trees (10x10) Species	count	height	Shrubs (10x10) Species	Cover	Shrubs (10x10) Species	Cover	Comments
03(1)	BD/CW	24-Aug-11	5901005	519360	No	5	dep	P	0.5-2	W	incl	Om	0	40	H3	Black	0	VL	No															East edge of wetland at 519370E, 5901006N.
												CG	40	+	Loamy Sand	Grey	0	VL																
03(2)	BD/CW	24-Aug-11	5900995	519337	Yes #11	20	toe	VP	09-May	E	incl	Om	0	65	H4	Dark Brown	0	VL	No					5	50	30	tA	Many	6	River Alder	+	Labrador Tea	+	West edge of wetland at 519333E, 5900994N.
												CG	65	+	Loamy Sand	Grey	0	VL									bS	20	4	Willow Sp.	+	Fireweed	+	
																											wB	10	6	Bunchberry	+	Prickly Rose	+	
																											jP	25	4	Blueberry	+	Marsh Reed Grass	4	
03(3)	BD/CW	24-Aug-11	5900920	519351	No	5	toe	VP	2_5	na	incl	Om	0	80	H3	Dark Brown	0	VL	No															West edge of wetland 3m west of plot
												Oh	80	210+	H6	Dark Brown	0	F																
03(4)	BD/CW	24-Aug-11	5900913	519369	Yes #12	5	dep	VP	0	na	level	Om	0	120	H3	Dark Brown	0	VL	Yes	7.11	214	10.7	No	5	25	30	jP	Many	3	bS	+	Water Sedge	3	
												Om	120	210+	H4	Brown	0	F									bS	30	3	Salix Sp.	+	Fireweed	+	
																														Labrador Tea	4	River Alder	+	
																														Peat Moss	4			
03(5)	BD/CW	24-Aug-11	5900765	519447	Yes #13	0	toe	VP	2_5	W	incl	Om	0	90	H3	Dark Brown	0	VL	No															E. edge of wetland 5m from plot.
												Om	90	120	H5	Black	0	F																
												CG	120	+	Loamy Sand	Grey		F																
03(6)	BD/CW	24-Aug-11	5900739	519444	No	0	dep	VP	0	na	level	Om	0	50	H3	Dark Brown	0	VL	No															W. edge of wetland 5m from plot. Meandering channel @ 519438E 5900758N. 0.5-1m wide, 0.5m deep, strong flow.
												CG	50	+	Loamy Sand	Grey	0	VL																
03(7)	BD/CW	24-Aug-11	5900646	519506	Yes #14	10	dep	VP	0	na	level	Om	0	60	H3	Dark Brown	0	VL	Yes	6.94	232	14.3	No	0	70	20	jP	Many	5	River Alder	2	Salix Sp.	+	Meandering flowing creek at 519487E. 1-2m wide x 0.5m deep. Sand creekbed.
												Om	60	200	H5	Dark Brown	0	F									bS	20	3	Lab Tea	2	Peat Moss	1	
												CG	200	+	Loamy Sand	Grey	0	L												Lingonberry	+			
03(8)	BD/CW	24-Aug-11	5900646	519506	No	30	toe	VP	2_5	W	level	Om	0	90	H3	Black	0	VL	No															
												Om	90	+	Loamy Sand	Grey	0	L																

***Entire wetland is very small, approx. 30mx400m, and 120m of length has a flowing channel.

Site	Observer	Date	UTM N	E	Photo?	Depth to Water	Slope Position	Drainage	Slope	Aspect	Topography	Horizon	Depth Upper	Lower	Von Post/ Texture	Color	Stoniness	Consistency	Samples?	Field pH	EC	Temp	Fizz?	% Water	% tree	% shrub	Trees (10x10) Species	count	height	Shrubs (10x10) Species	Cover	Shrubs (10x10) Species	Cover	Comments
04(1)	DP/CW	26-Aug-11	5898352	518546	No	0	level	VP	0	NA	level	Om	0	50	H3	Black	0	VL	No															
												Om	50	75	H5	Black	0	VL																
												CG	75	85	Silt loam	Grey	0	VL																
												CG	85	+	Loamy sand	Grey	0	VL																
04(2)	DP/CW	26-Aug-11	5898439	518600	Yes #18	0	level	VP	0	NA	level	Om	0	40	H3	Black	0	VL	No					5	20	55	bS	Many	3	bS	2	Feather Moss	2	
												CG	40	+	Frozen												jP	10	3	Labrador Tea	+	Salix Sp.	+	
																											tA	2	3	Peat Moss	1	Water Sedge	+	
04(3)	DP/CW	26-Aug-11	5898492	518633	No	0	level	VP	0	NA	level	Om	0	50	H3	Black	0	VL	No															
												Om	50	+	Frozen																			
04(4)	DP/CW	26-Aug-11	5898495	518721	No	5	level	VP	0	NA	level	Om	0	50	H3	Black	0	VL	No															
												Cg	50	60	Sand	Brown	0	VL																
												Cg	60	+	Loam	Grey	0	VL																
04(5)	DP/CW	26-Aug-11	5898562	518750	No	0	level	VP	0	NA	level	Om	0	50	H3	Black	0	VL	Yes	7.01	441	15.9	No	5	40	30								
												Cg	50	+	Sand	Brown	0	VL																
04(6)	DP/CW	26-Aug-11	5898605	518775	Yes #20	0	level	VP	0	NA	level	Om	0	50	H3	Black	0	VL	No															
												Om	50	75	H5	Black	0	VL																
04(7)	DP/CW	26-Aug-11	5898640	518926	No	5	level	VP	0	NA	level	Om	0	50	H3	Black	0	VL	No															
												CG	50	80	Clay loam	Brown G	0	M																
												CG	80	+	Loamy sand	Grey	0	M																
04(8)	DP/CW	26-Aug-11	5898578	518948	No	0	dep	VP	0	NA	level	Om	0	90	H3	Black	0	VL	No															
												Oh	90	210+	H8	Light Bro	0	M																
04(9)	DP/CW	26-Aug-11	5898514	518982	Yes #21	0	level	VP	0	NA	level	Om	0	80	H3	Black	0	VL	No					25	10	70	tL	Many	4	Salix Sp.	2	Peat Moss	1	South edge of wetland at 518944E 5898547N.
												Om	80	+	Loamy sand	Grey	0	VL									bS	20	3	River Alder	+	Water Sedge	2	
																														Feather Moss	1	bPo	+	
04(10)	DP/CW	26-Aug-11	5898517	519090	No	0	level	VP	0	NA	level	Om	0	90	H3	Black	0	VL	No															
												Om	90	+	Sand	Grey	0	VL																
04(11)	DP/CW	26-Aug-11	5898581	519128	Yes #22	0	level	VP	0	NA	level	Om	0	140	H3	Black	0	VL	Yes	7.41	371	12.9	No	20	10	30	tL	30	4	Bog birch	2	bS	+	
												Oh	140	160	H5	Grey bla	0	VL									jP	12	3	Water Sedge	2	Labrador Tea	1	
												CG	160	+	Sandy Loam	Grey	0	VL									bS	10	3	Peat Moss	1	Northern Bog Laurel	+	
																														Feather Moss	2			
04(12)	DP/CW	26-Aug-11	5898645	519137	No	5	level	VP	0	NA	level	Om	0	90	H3	Black	0	VL	No															
												CG	90	+	Loamy Sand	Grey	0	VL																
04(13)	DP/CW	26-Aug-11	5898633	519271	No	0	level	VP	0	NA	level	Om	0	30	H3	Black	0	VL	No					5	25	20	bS	40	7	Labrador Tea	+	Salix Sp.	+	
												CG	30	+	Loamy Sand	Grey	0	VL									Salix Sp.	20	5	Water Sedge	2	Bog birch	+	
																											tA	30	5	Arrow Leaved Coltsfo	+	Beaked Sedge	2	
04(14)	DP/CW	26-Aug-11	5898450	519466	Yes #23	0	toe	VP	2_5	S	Incl.	Of	0	35	H2	Black	0	VL	No															
												Cg	35	+	Clay Loam	Brown	0	F																
04(15)	DP/CW	26-Aug-11	5898754	519463	Yes #25	0	dep	VP	0	NA	level	Om	0	90	H3	Black	0	VL	Yes	7.65	352	20.4	No	10	5	20	tL	10	3	Bog birch	1	Peat Moss	2	Edge of upland at 519468E 5898686N.
												CG	90	+	Loamy sand	Grey	0	L									bS	10	2	Water Sedge	3	Labrador Tea	+	
																											jP	7	2	Marsh Reed Grass	+			Flowing channel at 519462E 5898445N, 4m wide, 1m deep, slow, steady flow. Beaver activity .
04(16)	DP/CW	26-Aug-11	5898390	519700	No	0	dep	MW	0.5_2	S	Incl	Of	0	50	H2	Black	0	VL	No															
												A	50	+	Loamy Sand	Brown	0	VL																
04(17)	DP/CW	26-Aug-11	5898617	519727	Yes #24	5	toe	MW	0.5_2	N	Incl	Of	0	20	H2	Black	0	VL	No															
												Om	20	50	H3	Black	0	VL																
												CG	50	+	Loamy Sand	Grey	0	VL																

Site	Observer	Date	UTM N	E	Photo?	Depth to Water	Slope Position	Drainage	Slope	Aspect	Topography	Horizon	Depth Upper	Lower	Von Post/ Texture	Color	Stoniness	Consistency	Samples?	Field pH	EC	Temp	Fizz?	% Water	% tree	% shrub	Trees (10x10) Species	count	height	Shrubs (10x10) Species	Cover	Shrubs (10x10) Species	Cover	Comments
05(1)	CW	25-Aug-11	5899509	512751	No	30	level	I	0	NA	level	LFH	0	10		Black	0	VL	No															West edge of wetland at 512724E 5899513N
												A	10	+	Sand	Grey Bro	0	M																
05(2)	CW	25-Aug-11	5899512	512822	Yes #15	0	level	VP	0	NA	humm	Of	0	20	H2	Black	0	VL	No					50	5	40	Salix Sp.	10	3	Salix Sp.	1	Water Sedge	3	Entire area floded, heavy beaver activity in area.
												Om	20	100	H3	Black	0	VL												Bog birch	2			
												CG	100	+	Loamy sand	Grey	0	VL																
05(3)	CW	25-Aug-11	5899507	512862	No	0	level	VP	0	NA	level	Om	0	60	H3	Black	0	VL	No															
												CG	60	+	Loamy sand	Black	0	VL																
05(4)	CW	25-Aug-11	5899444	512718	No	0	level	VP	0	NA	humm	Om	0	50	H3	Black	0	VL	No															
												Om	50	65	H5	Black	0	L																
												CG	65	+	Sandy loam	Grey	0	L																
05(5)	CW	25-Aug-11	5899399	512753	No	0	level	VP	0	NA	level	Om	0	30	H1	Black	0	VL	No															Completely flooded, 4-12" of water throughout area
												Om	30	95	H3	Dark bro	0	VL																
												CG	95	+	Loamy sand	Grey																		
05(6)	CW	25-Aug-11	5899380	512775	Yes #16	0	toe	VP	0.5-2	NA	level	Om	0	30	H3	Black	0	VL	Yes	7.07	495	17.8	No	80	30	20	tA	Many	6	Water Sedge	3	Dewberry	+	Completely flooded, 4-12" of water throughout area
												CG	30	+	Loamy sand	Grey	0	VL									Salix Sp.	Many	4	Salix Sp.	1	Fireweed	+	
																											bPo	Many	7	Bishops Cap	+			
05(7)	CW	25-Aug-11	5899277	512712	No	5	toe	VP	0	NA	humm	Om	0	45	H3	Black	0	VL	No															
												Om	45	65	H5	Black	0	VL																
												CG	65	+	Sandy loam	Grey	0	VL																
05(8)	CW	25-Aug-11	5899287	512670	No	5	dep	VP	0	NA	humm	Om	0	60	H3	Black	0	VL	No															
												Oh	60	110	H6	Dark Bro	0	L																
												CG	110	+	Loamy sand	Grey	0	L																
05(9)	CW	25-Aug-11	5899299	512679	No	10	level	P	0.5-2	NA	level	Om	0	40	H3	Black	0	VL	No					25	30	40	tA	Many	4	Salix Sp.	+	Palmate Leaves Coltsf	+	West edge of wetland 5m W of plot.
												CG	40	+	Sandy loam	Black	0	VL									bPo	Many	4	River Alder	1	Horsetail	+	
												CG																		Dewberry	+	Water Sedge	2	
05(10`	CW	25-Aug-11	5899509	512751	No	0	level	VP	0	NA	level	Om	0	120	H3	Black	0	VL	No															
												Oh	120	160	H7	Black	0	M																
												CG	160	+	Loam	Dark Gre	0	M																
05(11)	CW	25-Aug-11	5899082	512581	Yes #19	0	dep	VP	0	NA	level	Om	0	140	H3	Dark Bro	0	VL	Yes	7.24	488	18.4	NA	70	20	30	tL	Many	4	Bog birch	2	Marsh Reed Grass	+	
												Oh	140	210+	H6	Light Bro	0	L									Salix Sp.	Many	3	Salix Sp.	+	Water Sedge	5	
05(12)	CW	25-Aug-11	5899058	512640	No	0	level	VP	0	NA	level	Om	0	45	H3	Black	0	L	No															West edge of wetland 5m E of plot.
												CG	45	+	Loamy sand	Grey	0	L																
05(13)	CW	25-Aug-11	5899012	512619	No	0	toe	VP	0	NA	level	Om	0	60	H3	Black	0	VL	No															
												CG	60	+	Loamy sand	Grey	0	VL																
05(14)	CW	25-Aug-11	5899001	512510	No	0	level	VP	0	NA	level	Om	0	150	H3	Black	0	VL	No					40	35	20	tL	Many	12	Hosetail	1	Feather Moss	2	
												Oh	150	200	H7	Black	0	L									bS	10	6	Marsh Reed Grass	2	River Alder	+	
												CG	200	+	Loam	Dark Gre	0	L												Labrador Tea	+	Salix Sp.	+	
05(15)	CW	25-Aug-11	5898971	512398	No	5	level	VP	0	NA	level	Om	0	120	H3	Black	0	VL	No															
												Oh	120	210+	H6	Black	0	M																
05(16)	CW	25-Aug-11	5898862	512357	No	5	level	VP	0	NA	level	Om	0	45	H3	Black	0	VL	No															Frozen at 45cm, right at mineral contact.
												CG	45	+	Loamy sand	Grey	0	VL																
05(17)	CW	25-Aug-11	5898871	512449	Yes #17	0	level	VP	0	NA	level	Om	0	100	H3	Black	0	VL	Yes	7.22	272	18.7		25	30	60	tL	Many	4	Salix Sp.	+	Water Sedge	2	
												Oh	100	210+	H6	Brown	0	VL									bS	20	2	Bog birch	1	Labrador Tea	1	
																														bS	+	Feather Moss	2	
																														River Alder	+			
05(18)	CW	25-Aug-11	5898860	512555	No	0	level	VP	0	NA	level	Om	0	160	H3-4	Black	0	VL	No															
												CG	160	+	Loam	Grey	0	VL																
05(19)	CW	25-Aug-11	5898728	512730	No	10	level	I	0	NA	level	Om	0	35	H3	Black	0	VL	No															
												CG	35	+	Sandy Loam	Grey	0	VL																
05(20)	CW	25-Aug-11	5898739	512469	No	0	level	VP	0	NA	level	Om	0	110	H3	Black	0	VL	No															
												Oh	110	+	H6	Brown	0	M																
05(21)	CW	25-Aug-11			No	0	level	VP	0	NA	level	Om	0	135	H3	Black	0	VL	No					60	10	70	tL	20	3	Water Sedge	3	Bog birch	+	
												Oh	135	190	H6	Dark bro	0	M									bS	10	3	Feather Moss	2	Labrador Tea	+	
												CG	190	+	Silt Loam	Grey	0	M												River Alder	1	Peat Moss	+	
05(22)	CW	25-Aug-11	5898546	512409	No	0	level	I	0	NA	level	Om	0	25	H3	Black	0	VL	No															
												CG	25	+	Sandy Loam	Grey	0	M																
05(23)	CW	25-Aug-11	5898556	512468	No	0	level	VP	0	NA	level	Om	0	100	H3	Black	0	VL	Yes	7.62	461	16.3	Yes	25	5	40	tL	4	3	Bog birch	4	tL	+	West edge of wetland at 512401E 5898545N
												Om	100	200	H5	Dark Bro	0	M									wB	20	3	Water Sedge	6	Peat Moss	+	Silt loam moderate Fizz.
												CG	200 +		Silt Loam	Grey	0	M												Salix Sp.	+			

Soil Chemistry Results

SOIL														
Group #	Sample #	Description	pH	Nitrate	Total Kjeldahl Nitrogen	Total Nitrogen	Organic Carbon	Bulk Density	Moisture	Gravel	Coarse Sand	Fine Sand	Silt	Clay
			pH units	ug/g	ug/g	ug/g	%	kg/m3	%	wt %	wt %	wt %	wt %	wt %
2011-9436	32730	8/25/2011 04-5	7.26 1:2slurry	<4	10900	10900	10.3	383	71.35	0.25	14.25	1.78	17.73	3.24
2011-9436	32731	8/25/2011 04-11	7.19 1:3slurry	<4	14000	14000	13.9	247	75.80	0.18	1.04	1.32	40.15	6.07
2011-9436	32732	8/25/2011 04-15	6.76 1:2slurry	<4	9560	9560	6.2	305	72.57	0.22	4.44	7.99	22.37	7.16
2011-8767	30436	8/24/2011 03-045	6.13 1:3slurry	<4	14400	14400	38.2	242	79.20					
2011-8767	30437	8/24/2011 03-075	6.53 1:2slurry	<4	12900	12900	32.1	309	79.09					
2011-8767	30438	8/23/2011 02-145	5.78 1:2slurry	<4	12800	12800	19.6	470	71.69					
2011-8767	30439	8/23/2011 02-065	6.38 1:2slurry	<4	9810	9810	27.8	312	77.52					
2011-8767	30440	8/23/2011 02-165	5.98 1:2slurry	<4	11900	11900	27.9	334	75.80					
2011-8767	30441	8/15/2011 01-215	5.68 1slurry	<4	19700	19700	36.2	185	86.91					
2011-8767	30442	8/15/2011 01-165	5.34 1:3slurry	<4	13800	13800	32.7	161	84.77					
2011-8767	30443	8/15/2011 01-265	5.67 1:2slurry	<4	7870	7870	17.2	336	74.93					
2011-8767	30444	01-12	5.77 1:3slurry	<4	17000	17000	36.5	161	85.63					
2011-8765	30445	8/25/2011 05-115	5.42 1:3 slurry	<4	15700	15700	36.3	120	85.37					
2011-8765	30446	8/25/2011 05-235	5.35 1:3slurry	<4	13900	13900	34.1	170	79.83					
2011-8765	30447	8/25/2011 05-065	5.74 1:3slurry	<4	17800	17800	35.9	184	80.01					
2011-8765	30448	8/25/2011 05-175	5.38 1:1slurry	<4	4350	4350	10.9	443	68.62					

Water Chemistry Results

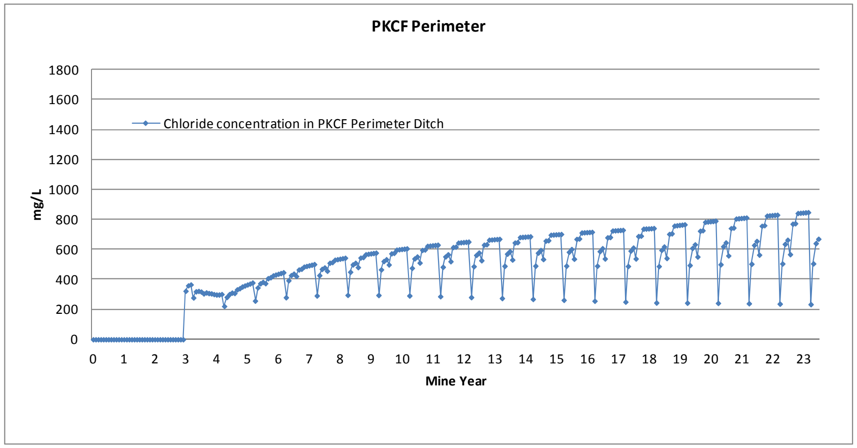
WATER																
Group #	Sample #	Description	Bicarbonate	Carbonate	Hydroxide	P. alkalinity	pH	Specific Conductivity	Total Alkalinity	Nitrite+Nitrate nitrogen	Total Kjeldahl Nitrogen	Total Nitrogen	Organic Carbon	Tannin/lignin	Phosphorus
			mg/L	mg/L	mg/L	mg/L	pH units	uS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
2011-8768	30580	8/12/2011 01-12	272	<1	<1	<1	7.57	418	223	<0.01	5.7	5.7	22	0.8	0.2
2011-8768	30581	8/15/2011 01-21	244	<1	<1	<1	7.45	397	200	<0.25*	4.3	4.3	24	1.0	2.0
2011-8768	30582	8/15/2011 01-26	238	<1	<1	<1	7.50	357	195	<2.5*	88	88	43	1.1	1.4
2011-8768	30583	8/15/2011 01-16	315	<1	<1	<1	7.34	465	258	<0.01	3.8	3.8	36	2.2	0.4
2011-8768	30584	8/23/2011 02-16	294	<1	<1	<1	7.70	429	241	<0.01	22	22	34	1.9	3.5
2011-8768	30585	8/23/2011 02-14	265	<1	<1	<1	7.41	392	217	<2.5*	360	360	79	1.3	4.8
2011-8768	30586	8/23/2011 02-06	466	<1	<1	<1	7.64	668	382	<0.01	14	14	42	2.4	1.8
2011-8768	30587	8/24/2011 03-04	187	<1	<1	<1	7.69	279	153	<0.01	4.0	4.0	15	1.2	1.3
2011-8768	30588	8/24/2011 03-07	218	<1	<1	<1	7.59	311	179	<0.01	13	13	27	0.3	<0.1
2011-8768	30589	8/26/2011 04-05	460	<1	<1	<1	7.25	685	377	<2.5*	320	320	33	2.4	90
2011-8766	30590	8/26/2011 04-11	318	<1	<1	<1	7.48	477	261	<0.01	200	200	17	1.3	4.7
2011-8766	30591	8/26/2011 04-15	318	<1	<1	<1	7.54	448	261	<2.5*	54	54	46	1.5	14
2011-8766	30592	8/25/2011 05-06	395	<1	<1	<1	7.52	596	324	<0.01	23	23	41	2.7	4.1
2011-8766	30593	8/25/2011 05-11	345	<1	<1	<1	7.53	480	283	<0.25*	71	71	55	1.8	6.1
2011-8766	30594	8/25/2011 05-17	222	<1	<1	<1	7.18	322	182	<0.25*	160	160	36	0.7	31
2011-8766	30595	8/25/2011 05-23	378	<1	<1	<1	7.44	558	310	<2.5*	34	34	40	3.4	4.2

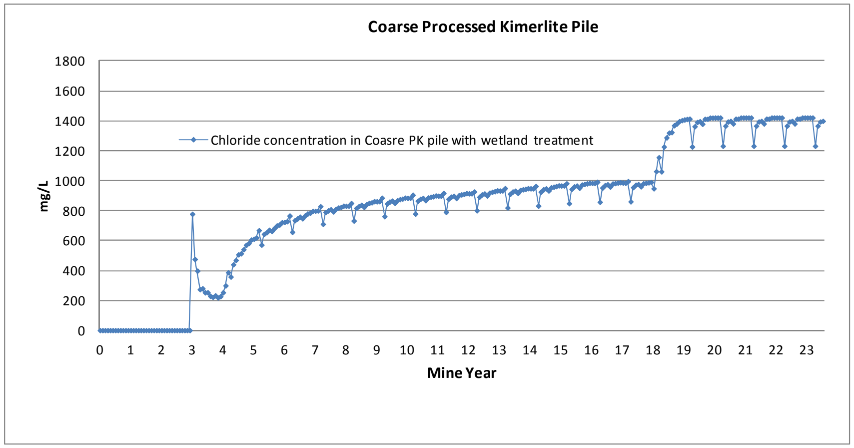
* Increase in detection limit for nitrate due to sample matrix interference

Appendix D

COC Modeling Graphs
(AMEC 2012)

Figure 3-6 Predicted chloride concentrations during construction and operation





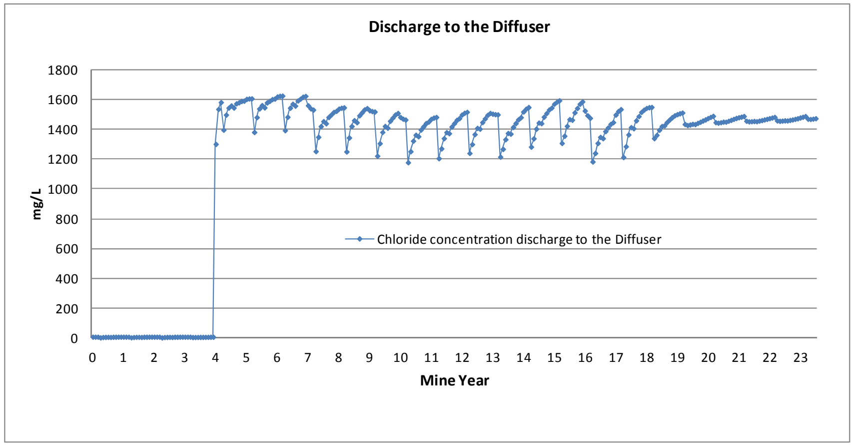
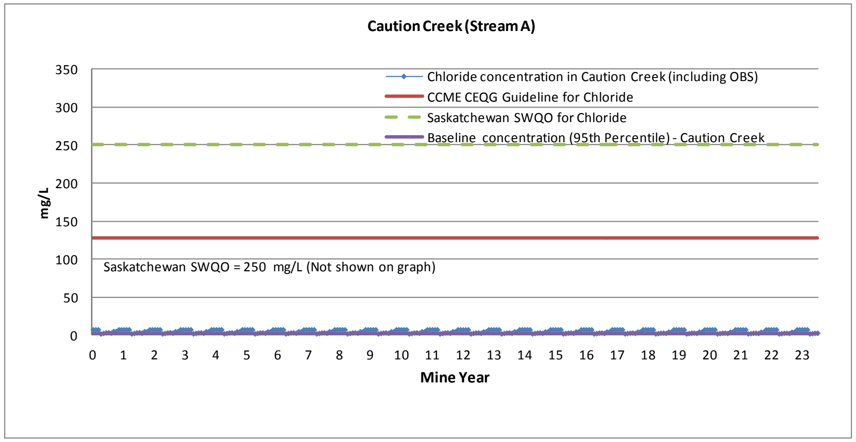
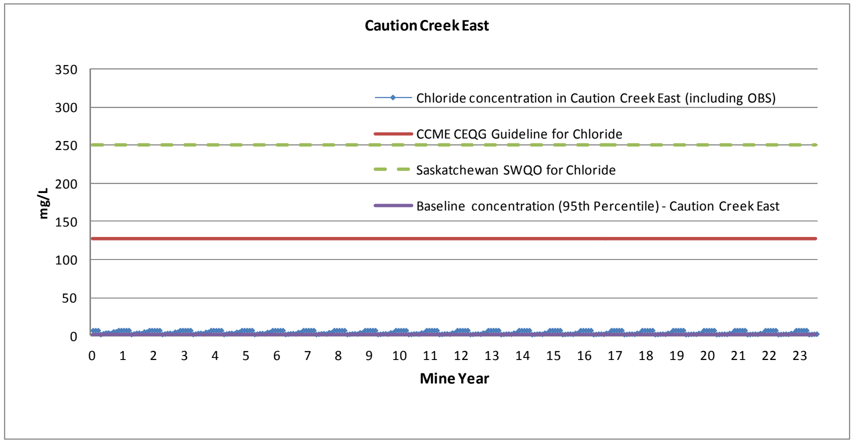
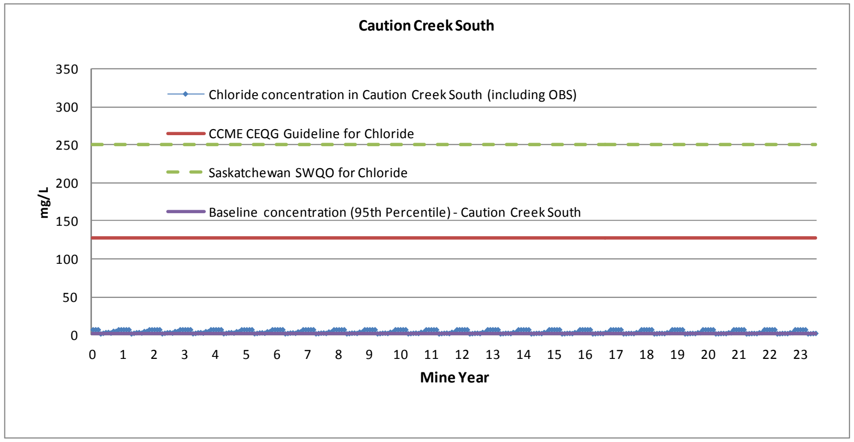


Figure 3-6 Continued







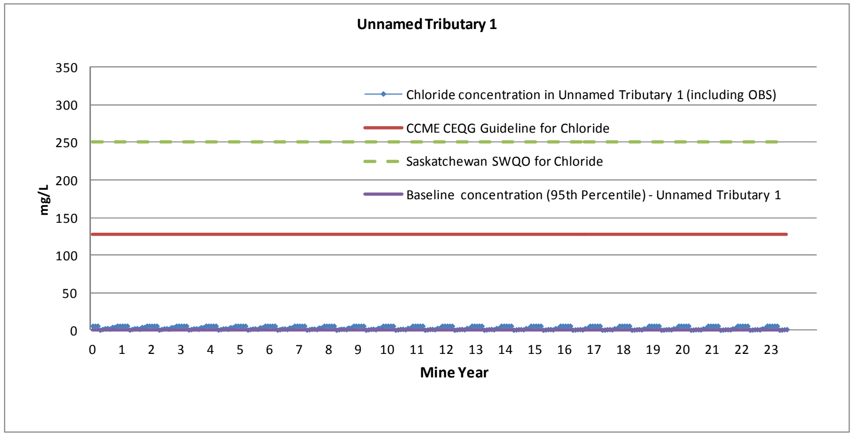
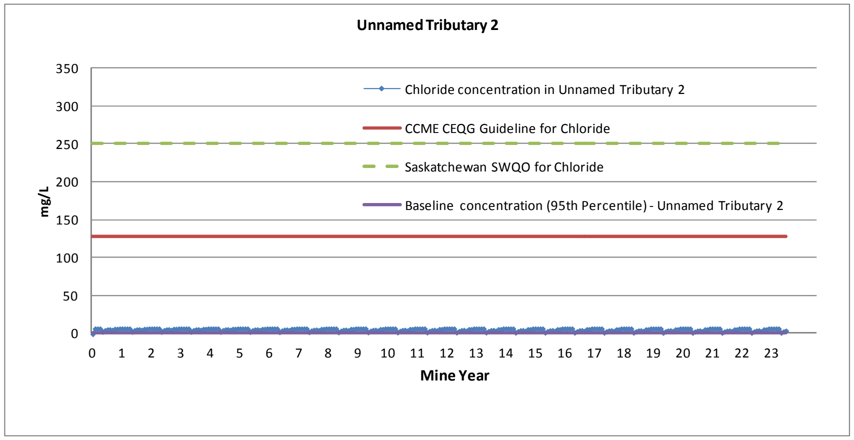
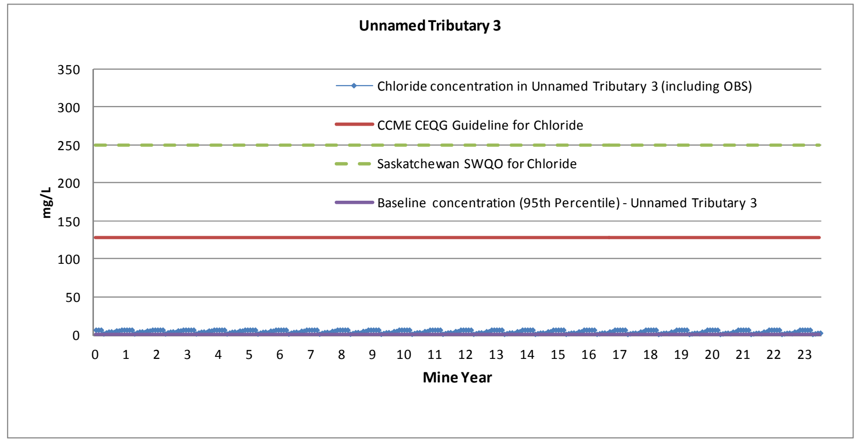
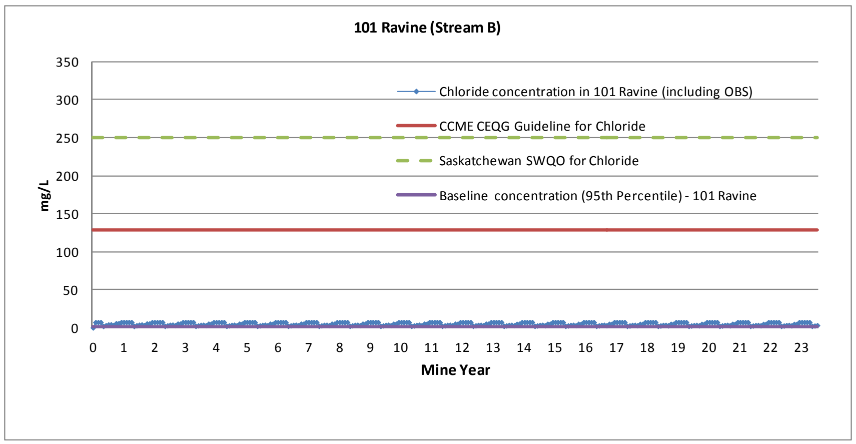


Figure 3-6 Continued







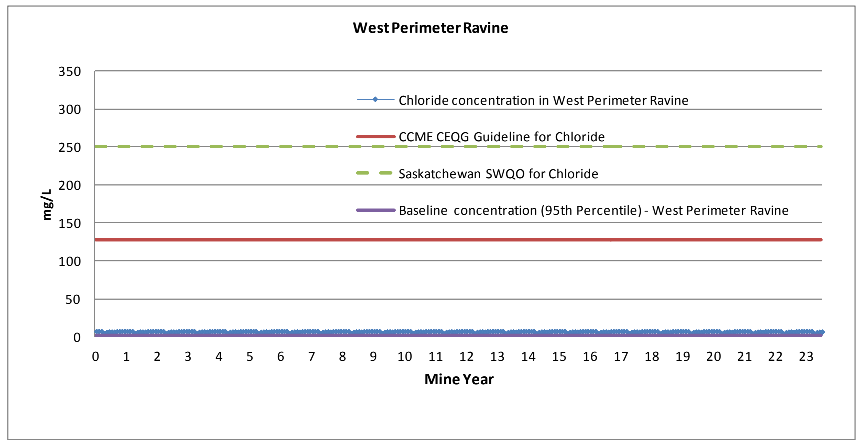
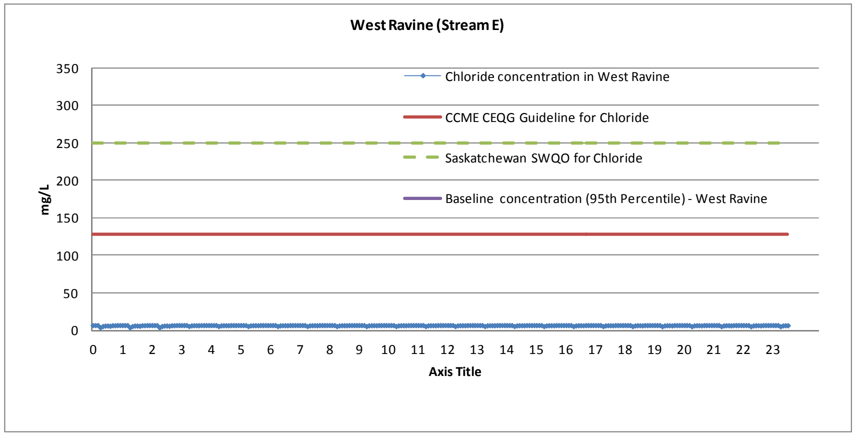
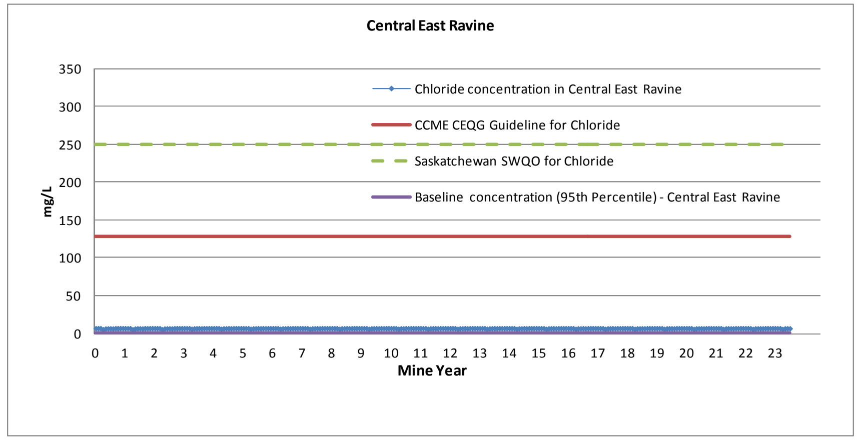
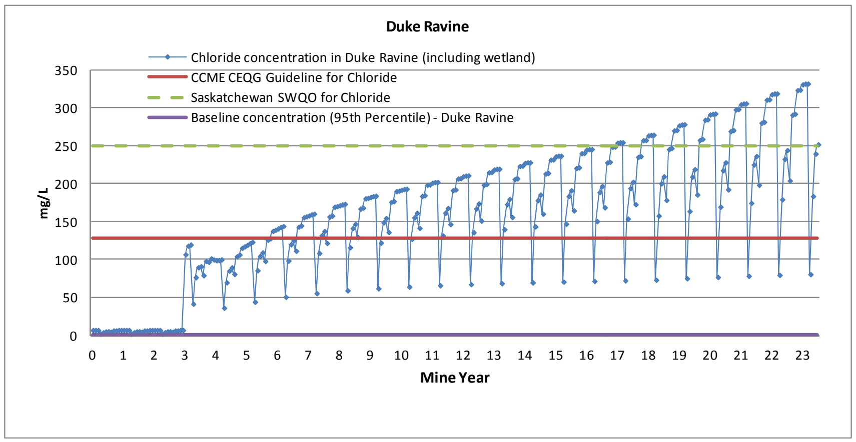


Figure 3-6 Continued







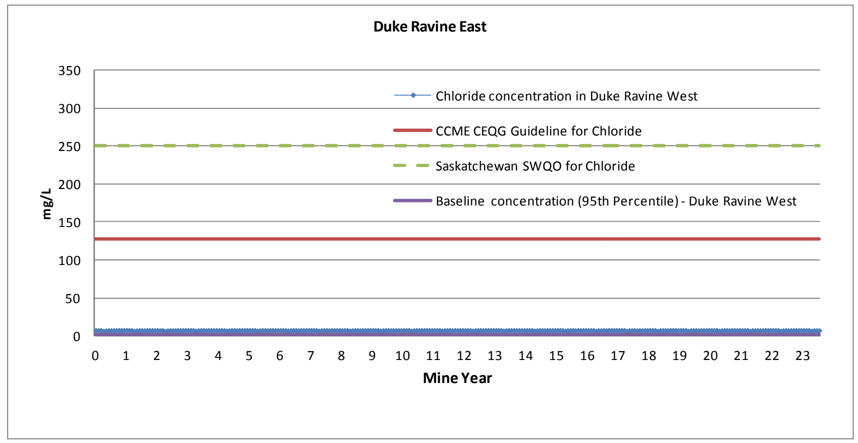
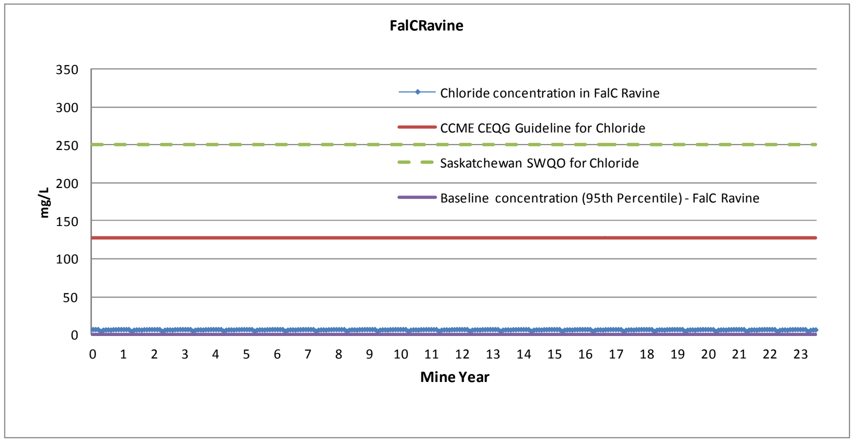
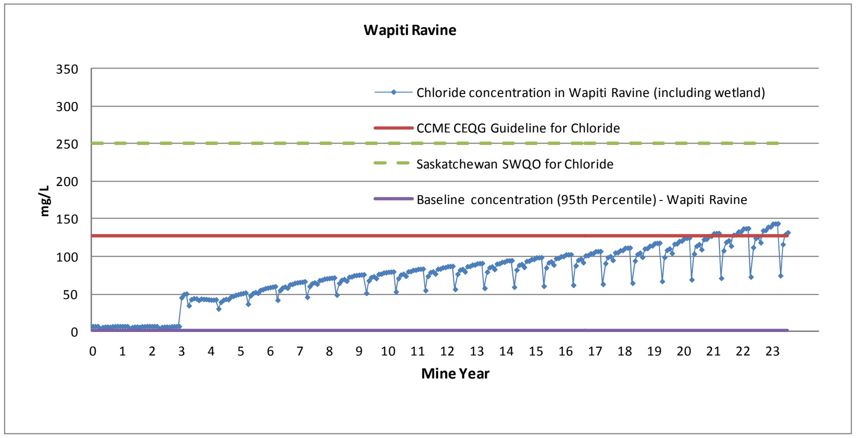
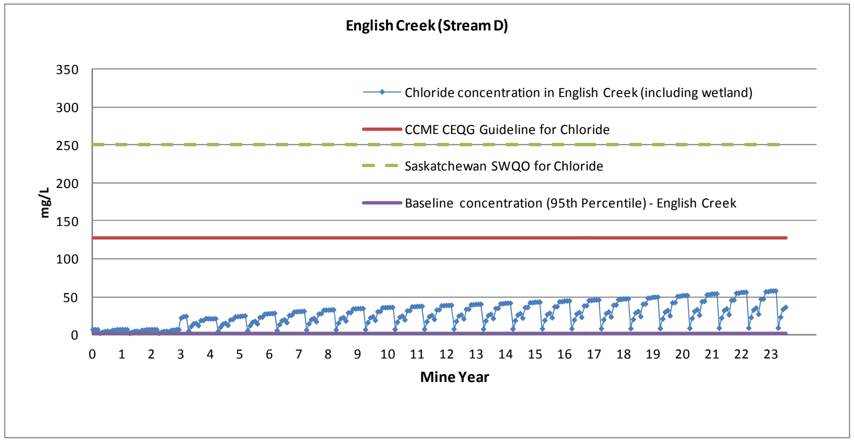


Figure 3-6 Continued







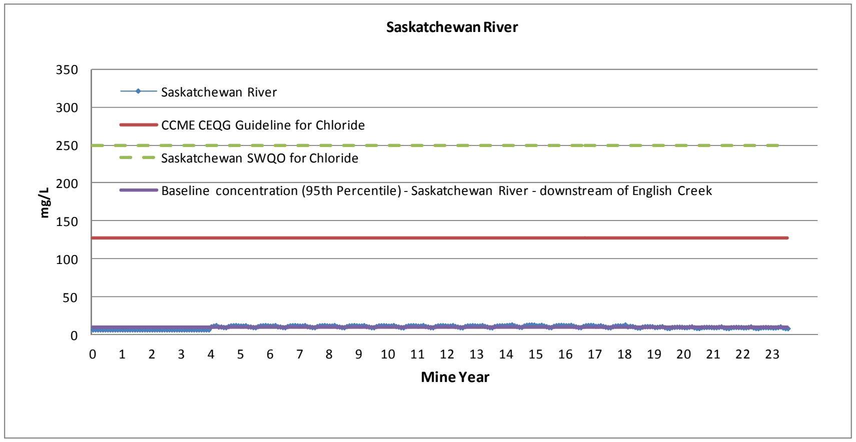
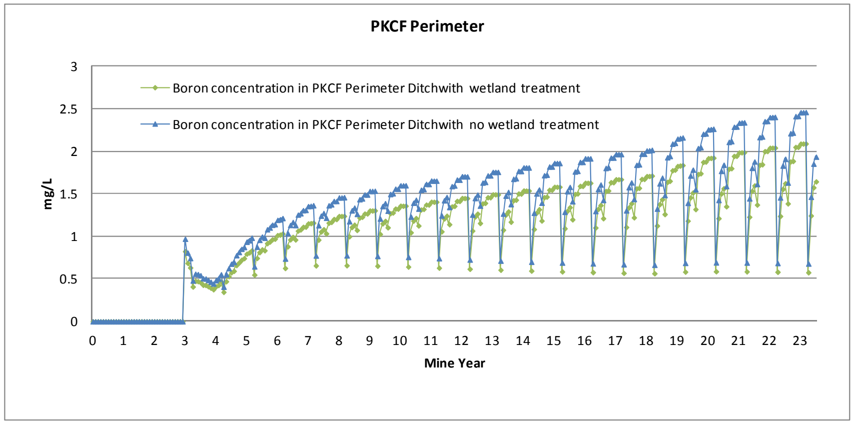
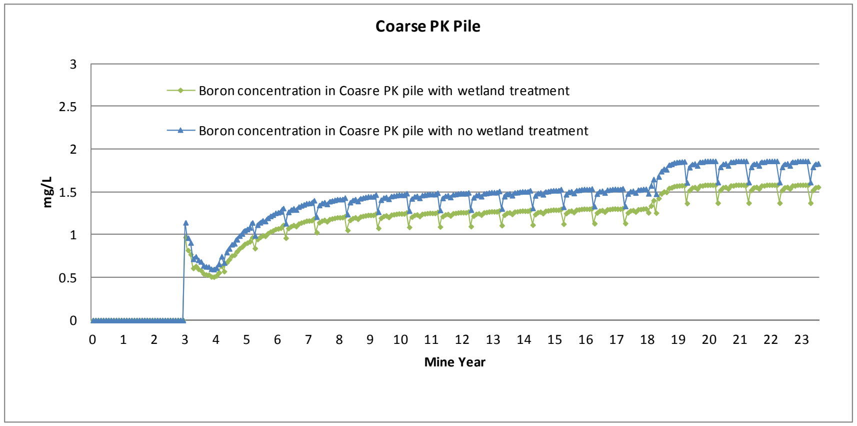
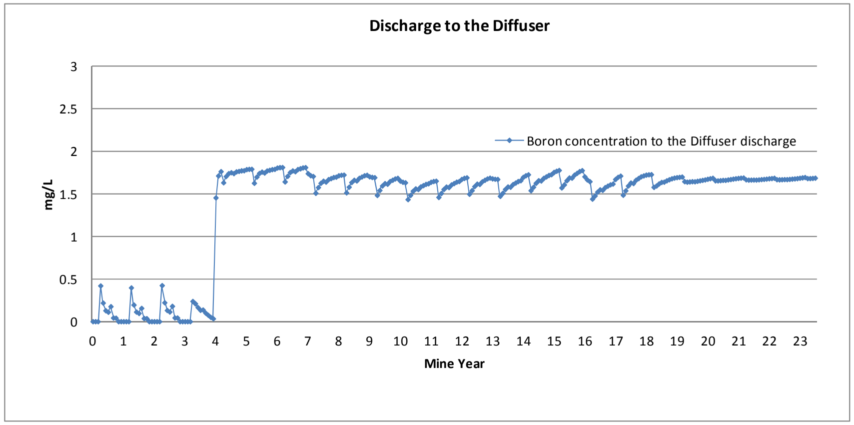


Figure 3-23 Predicted boron concentrations during construction and operation







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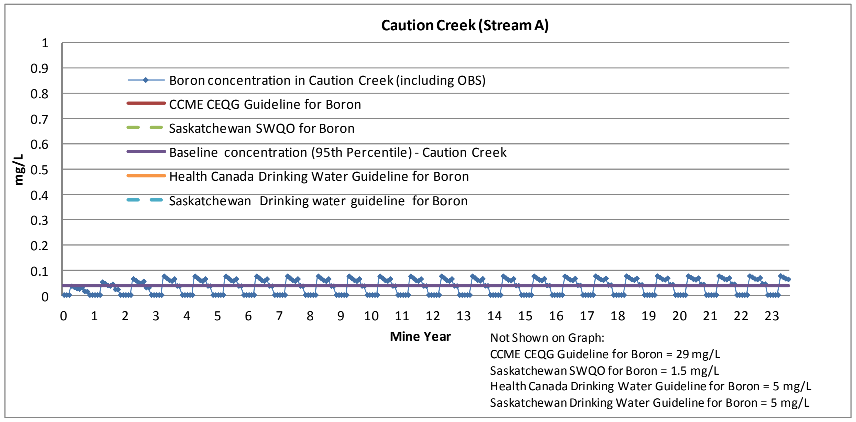
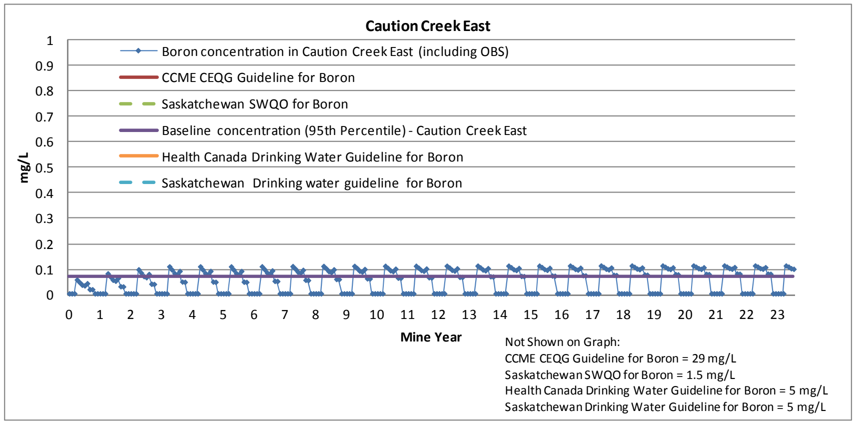
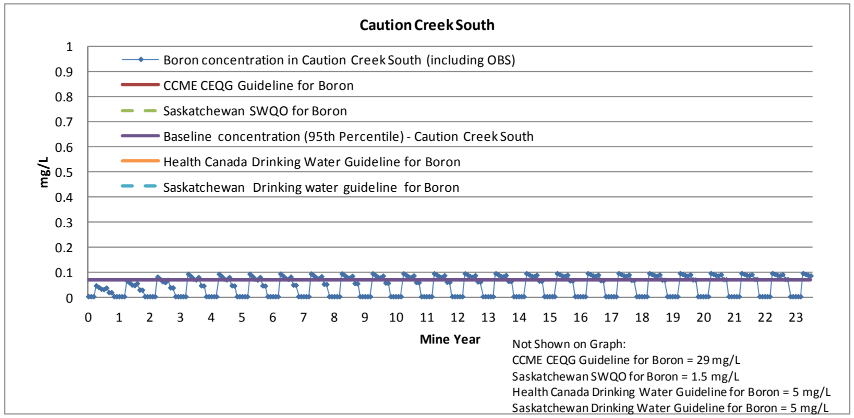






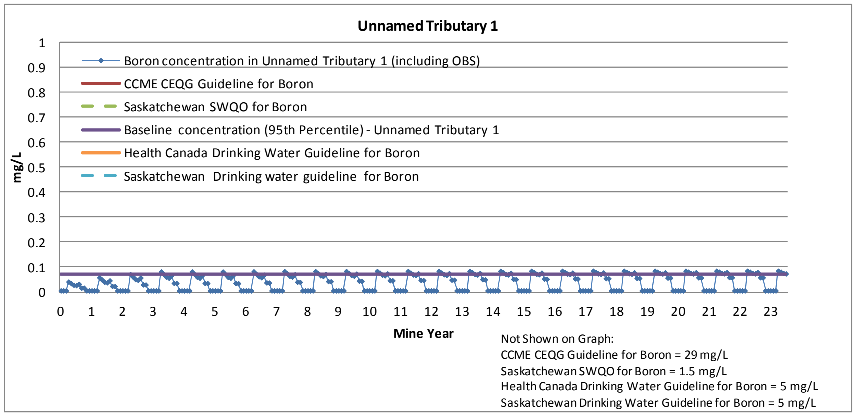
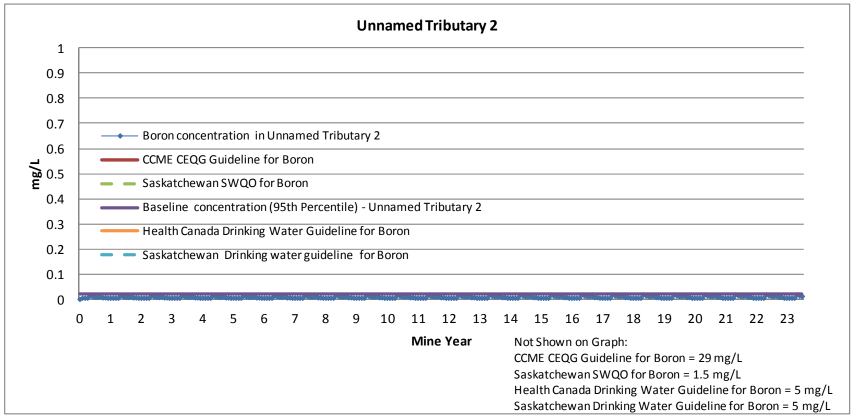
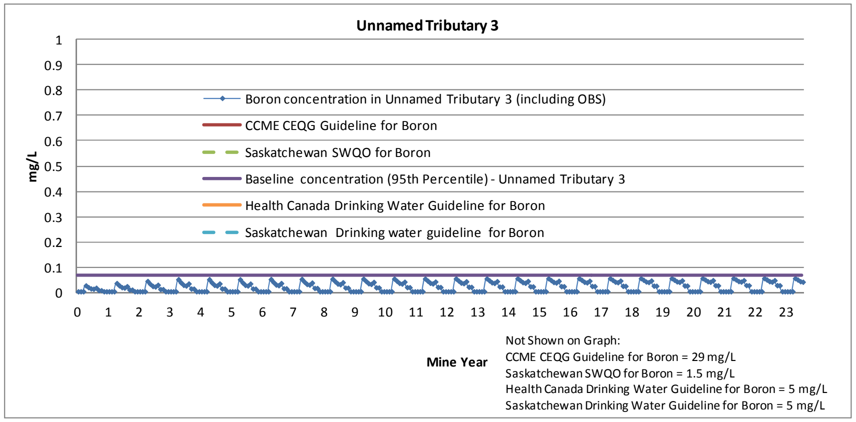
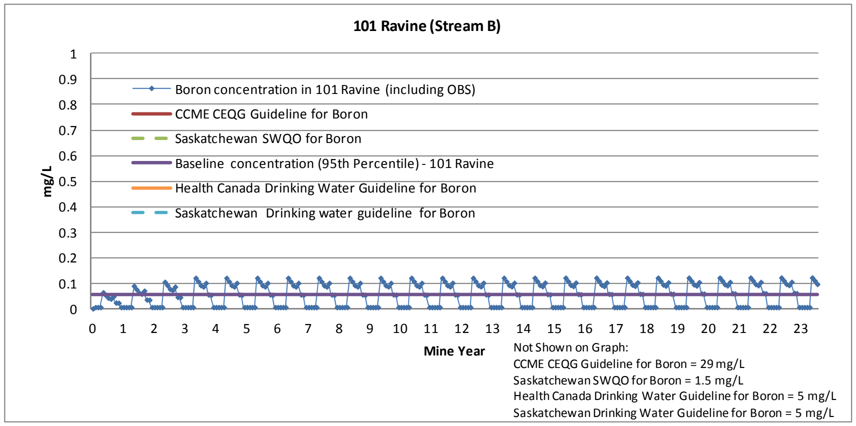
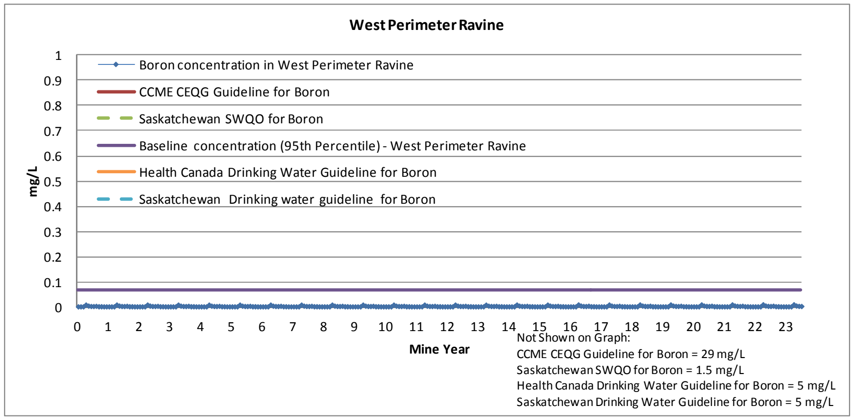


Figure 3-23 Continued









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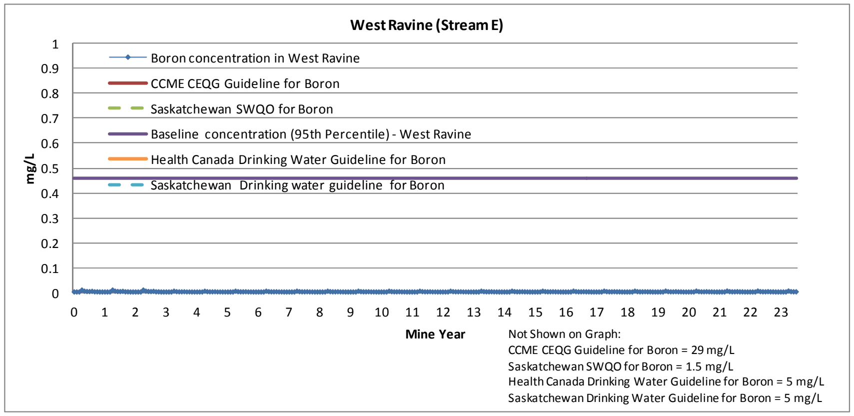

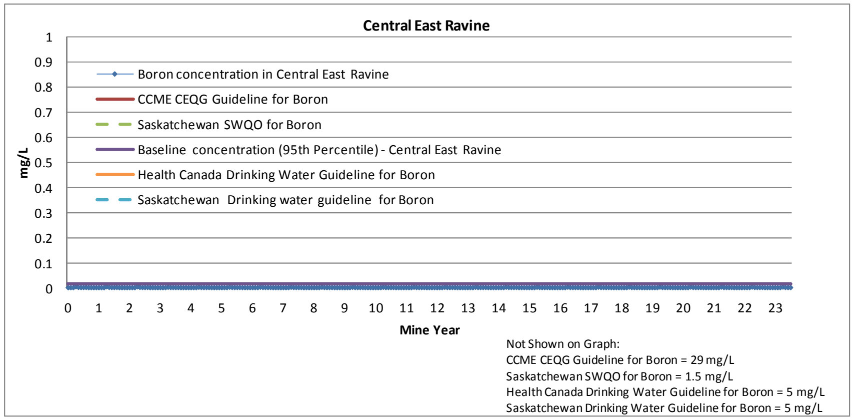

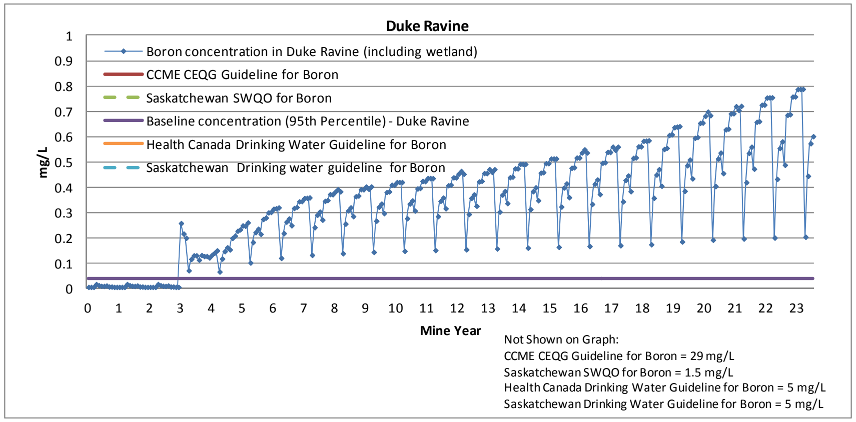

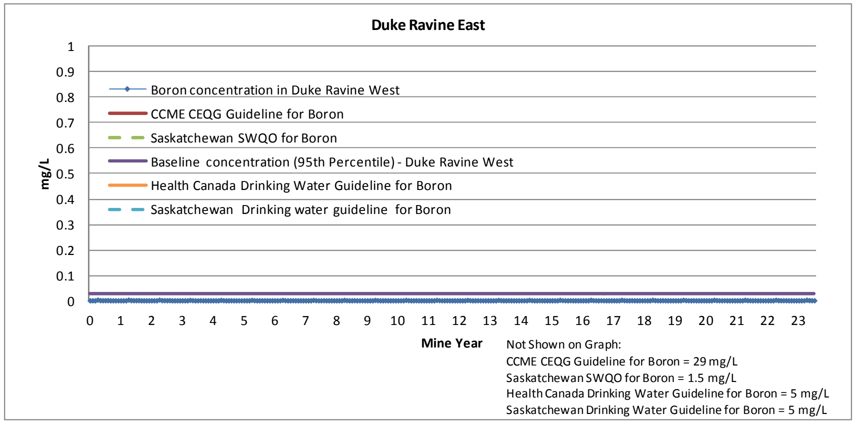

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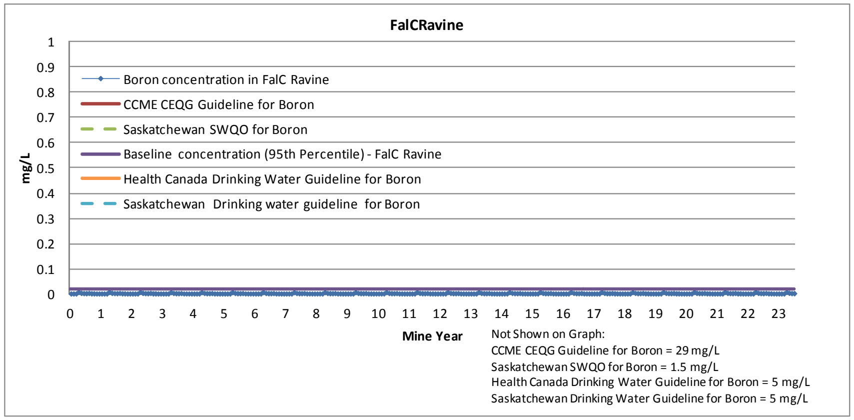
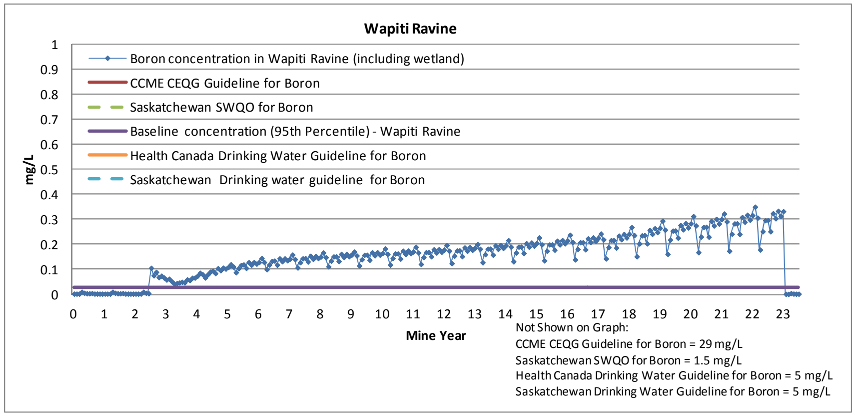
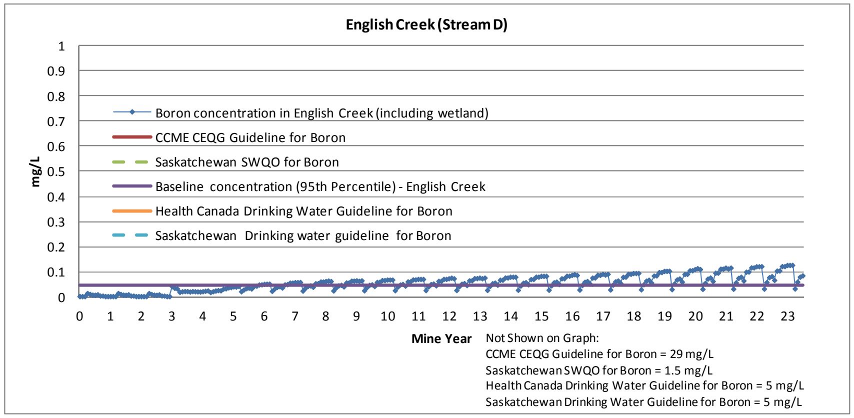






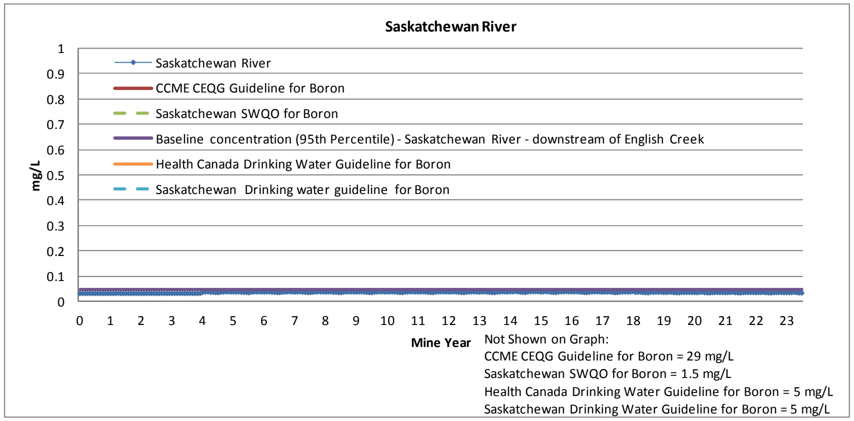
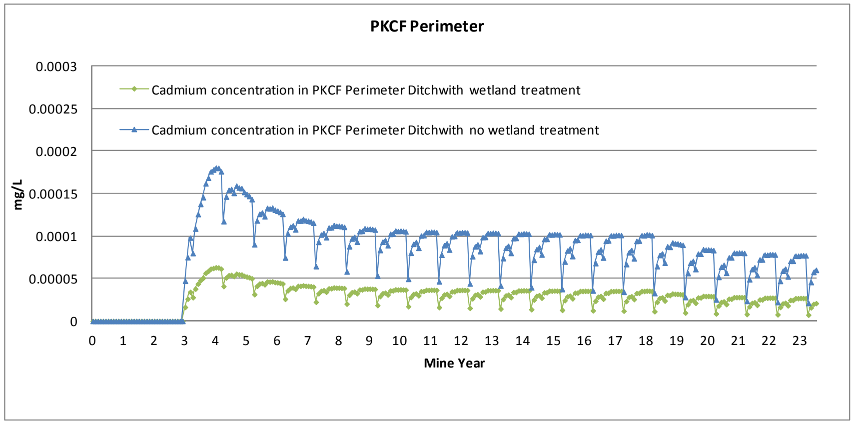
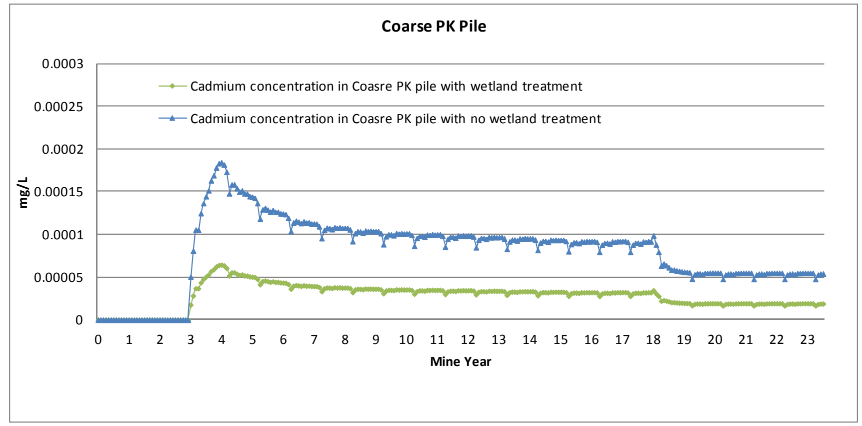


Figure 3-24 Predicted cadmium concentrations during construction and operation





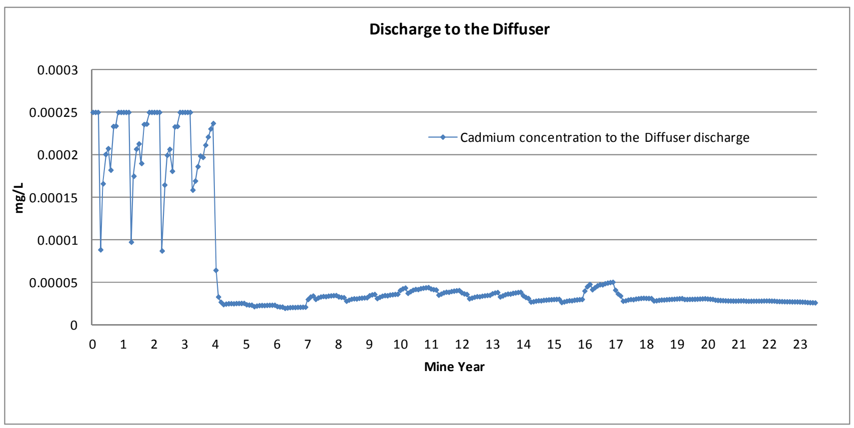


Figure 3-24 Continued

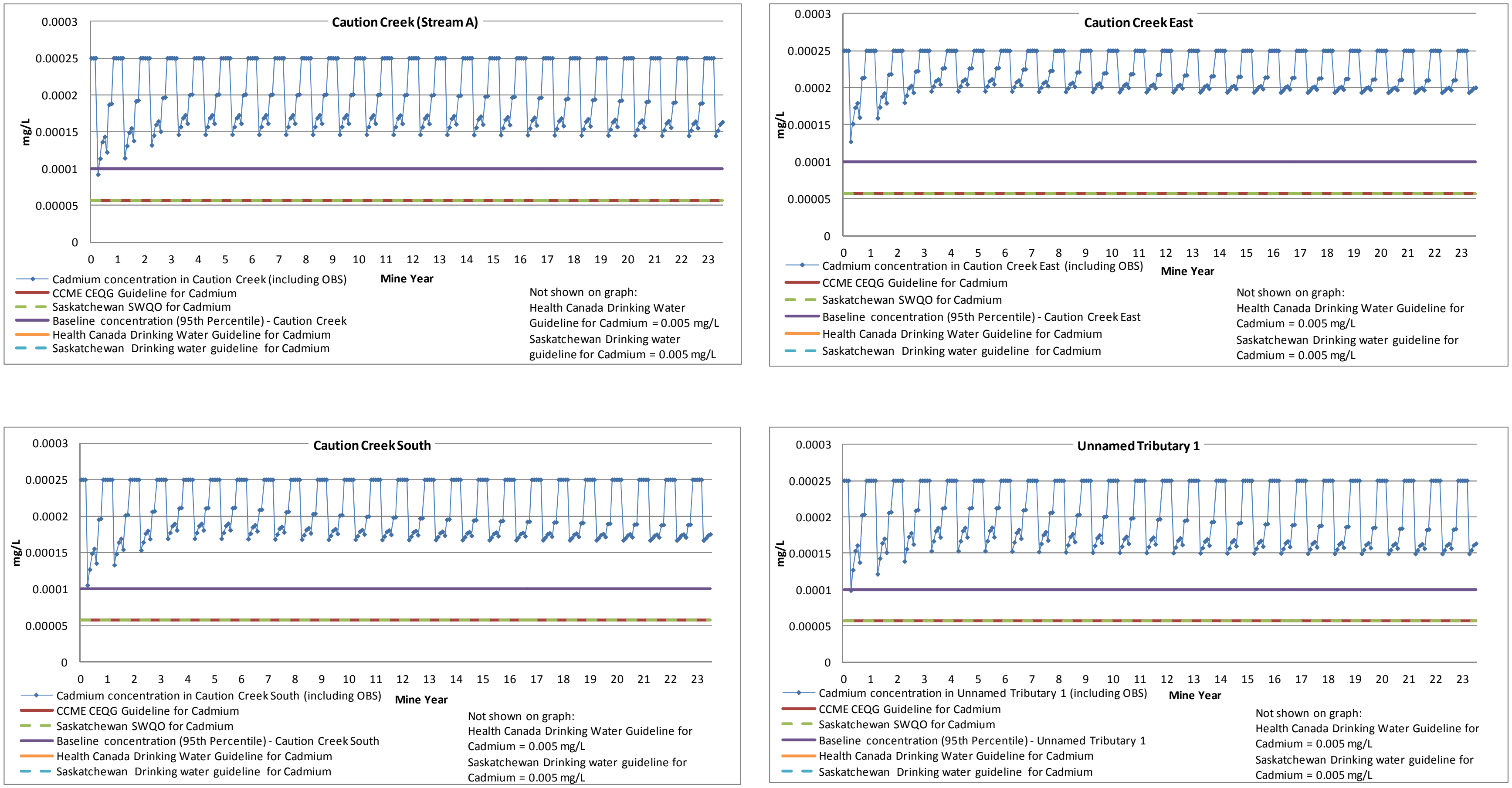
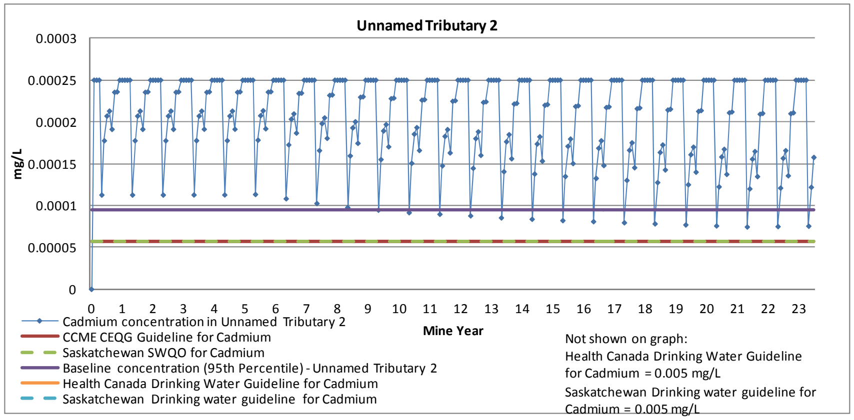
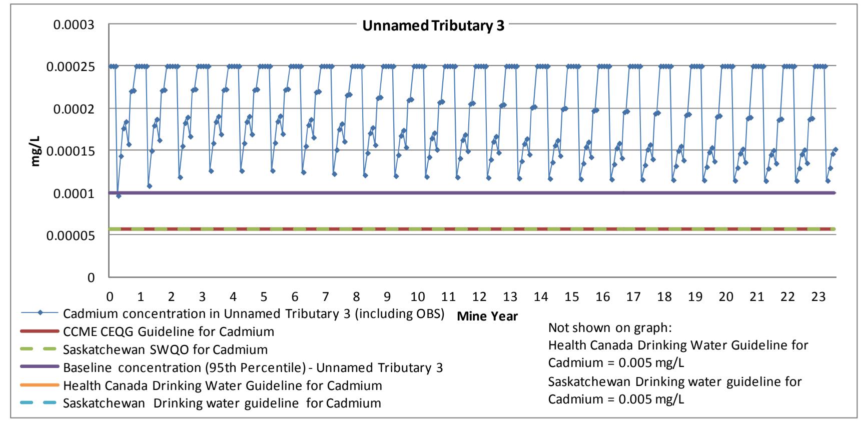
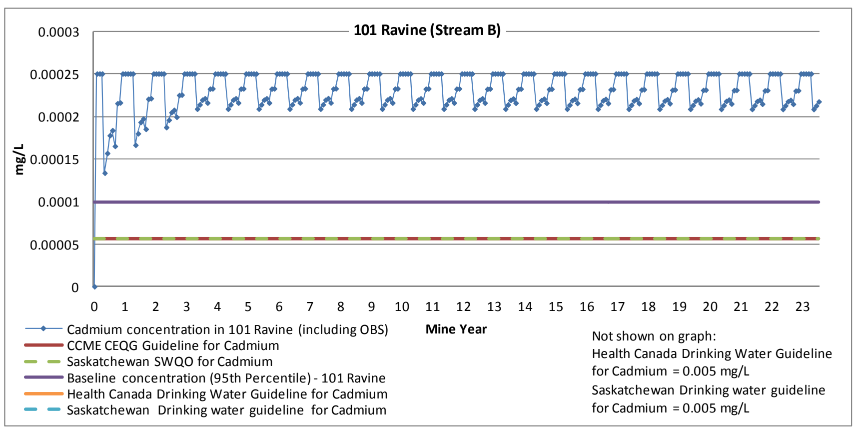
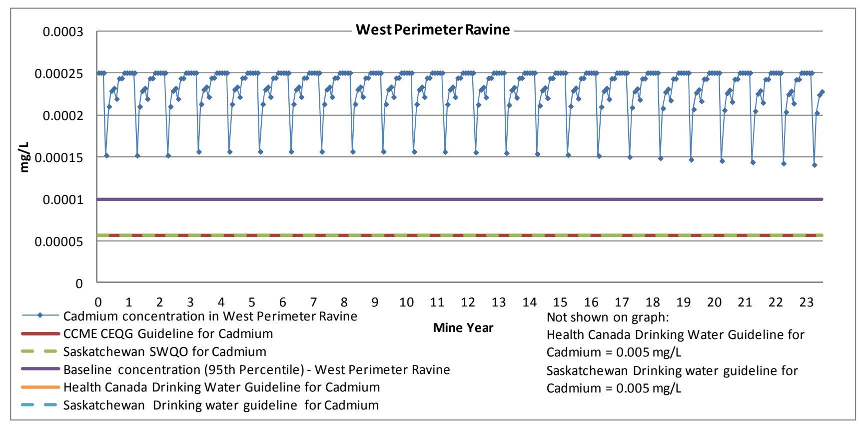


Figure 3-24 Continued









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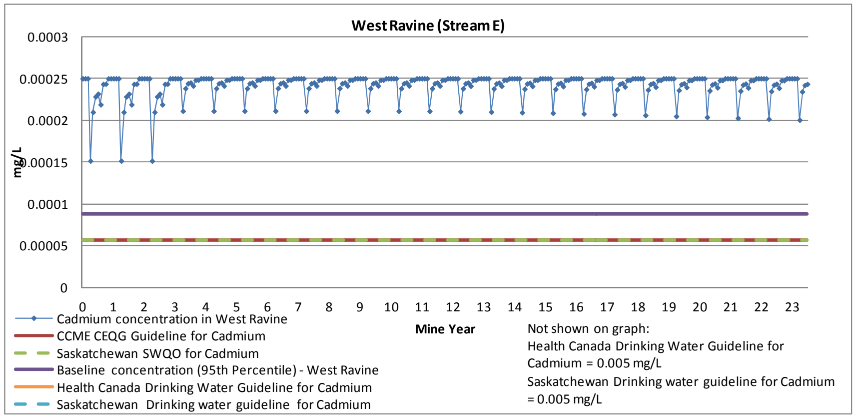

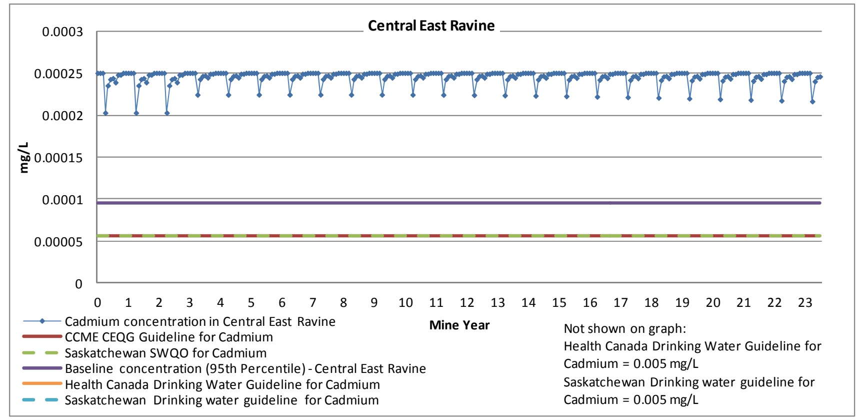

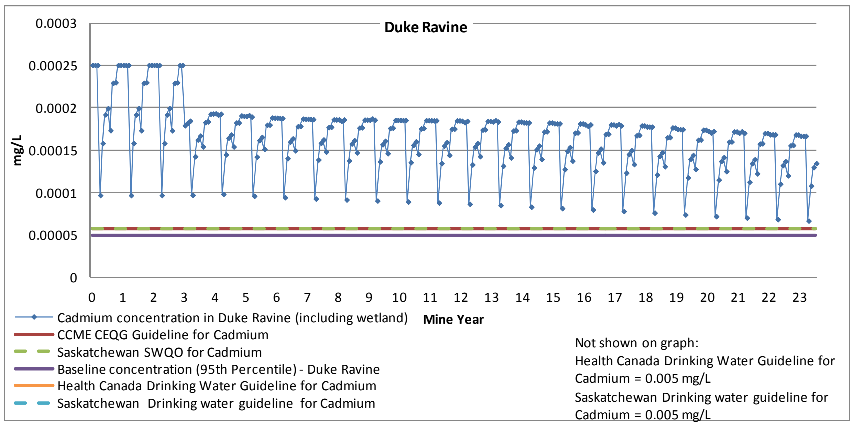

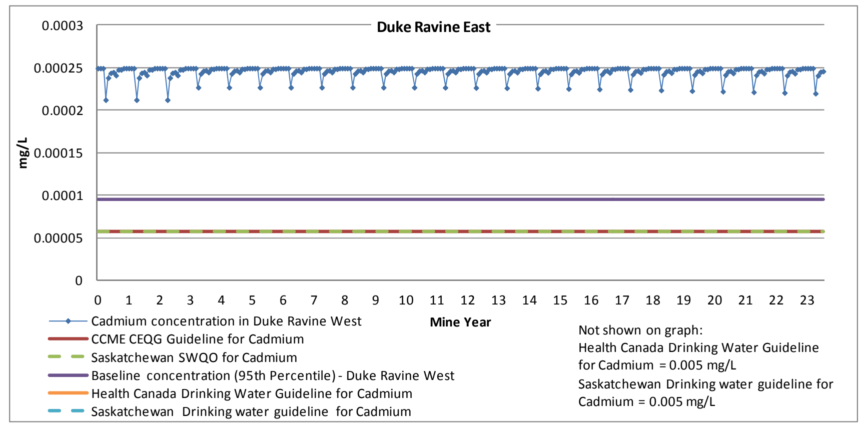

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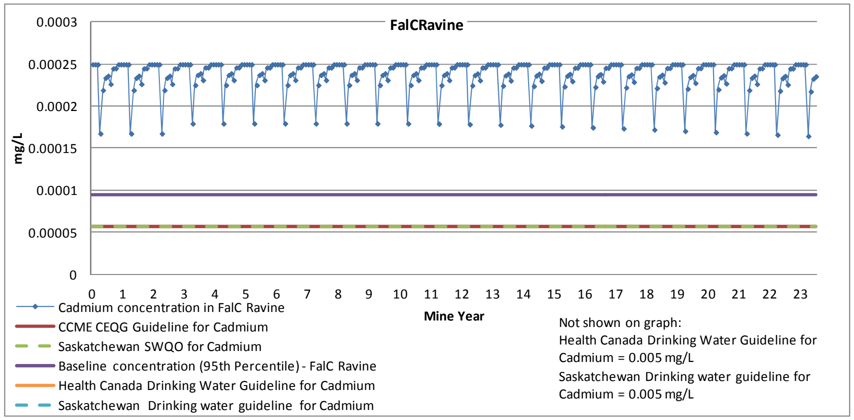
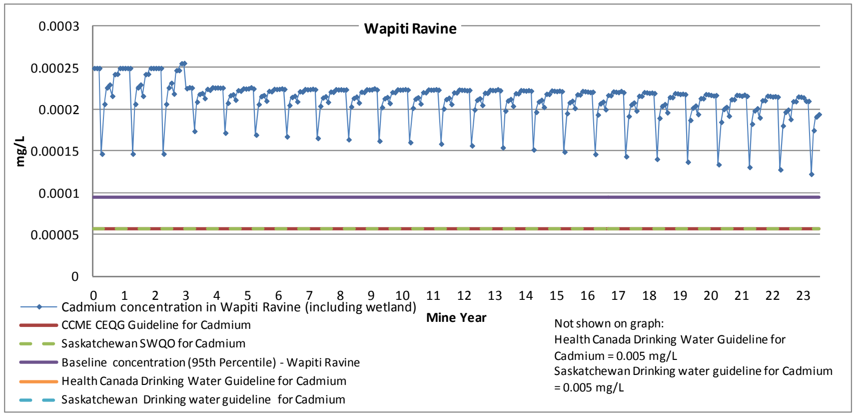
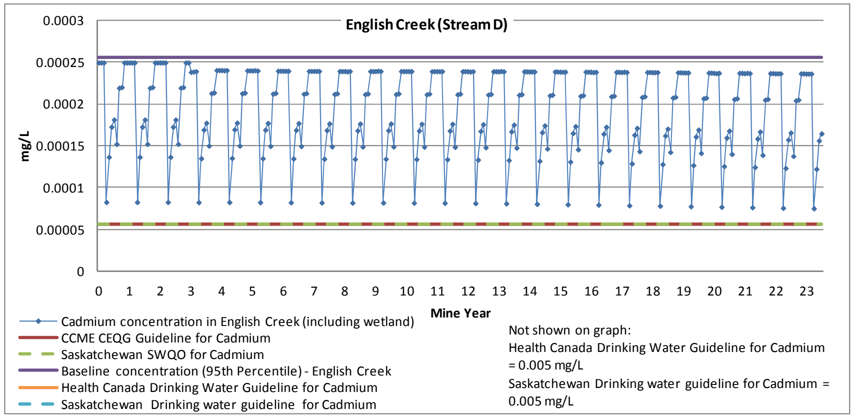






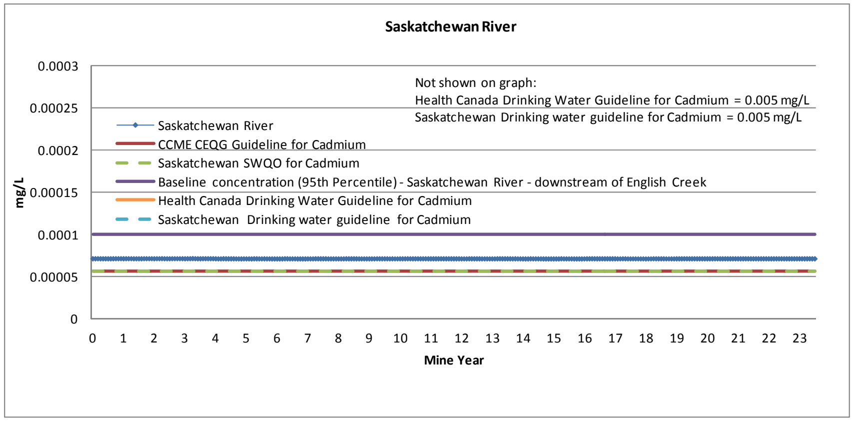
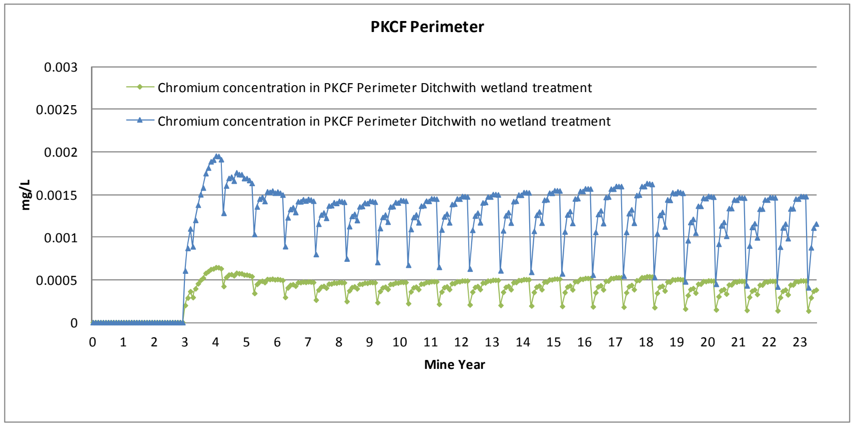
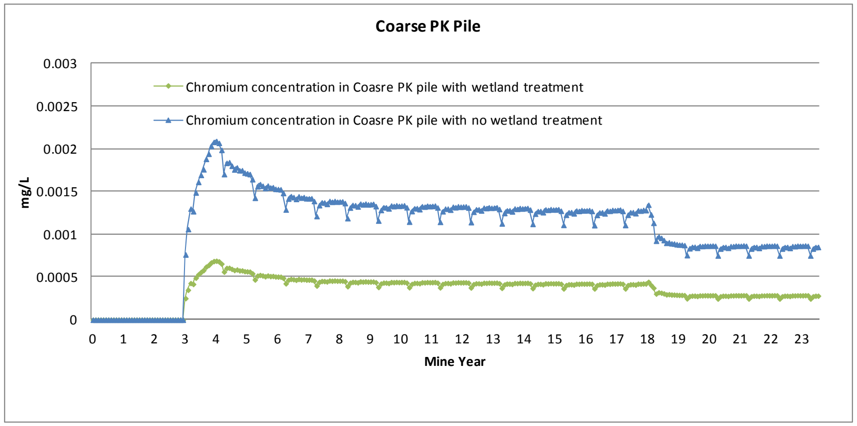


Figure 3-25 Predicted chromium concentrations during construction and operation





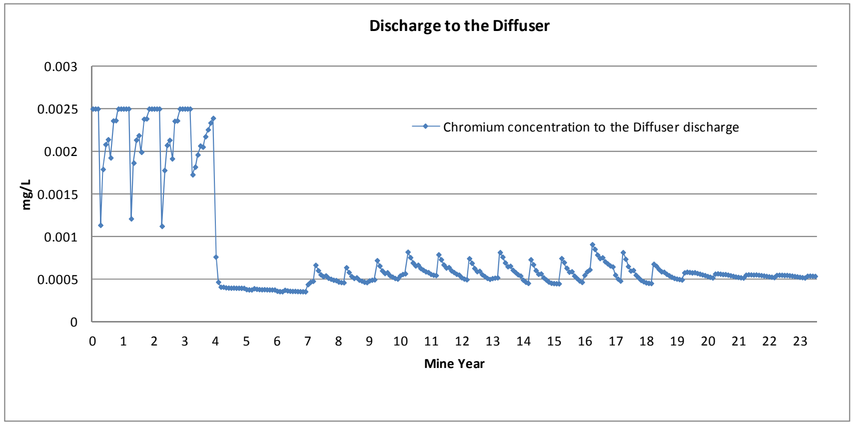
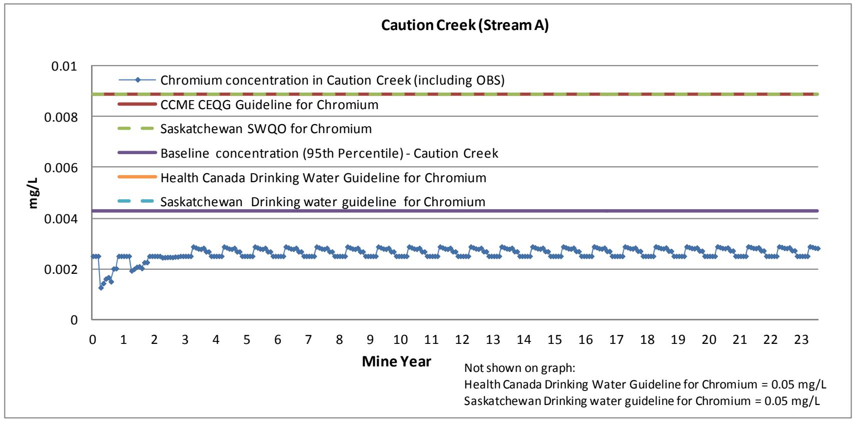
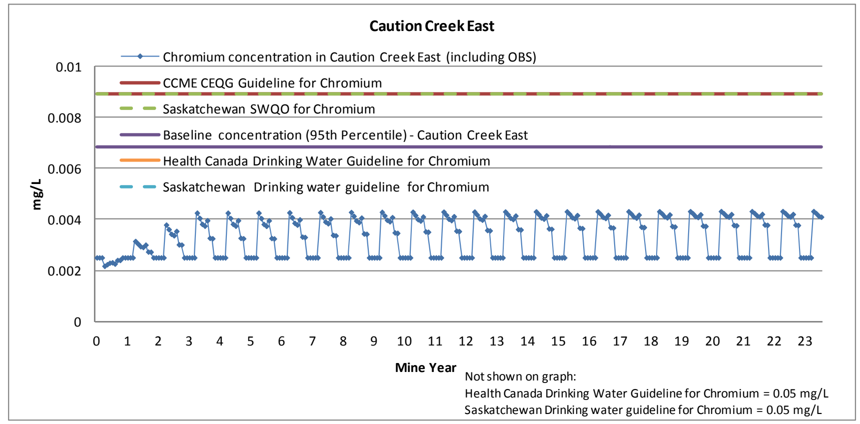
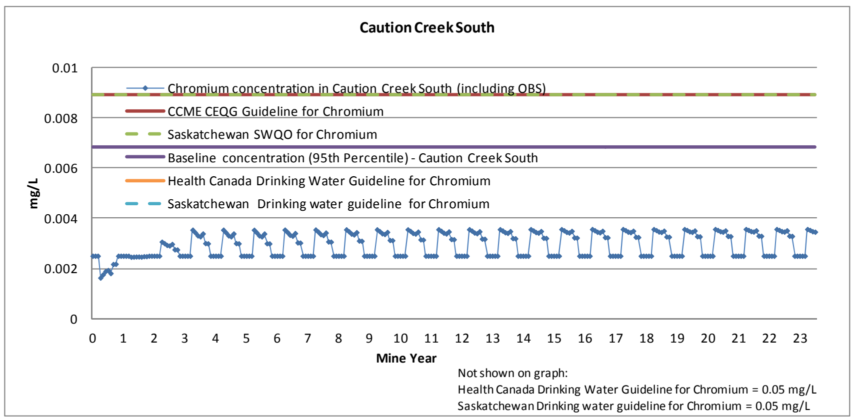


Figure 3-25 Continued







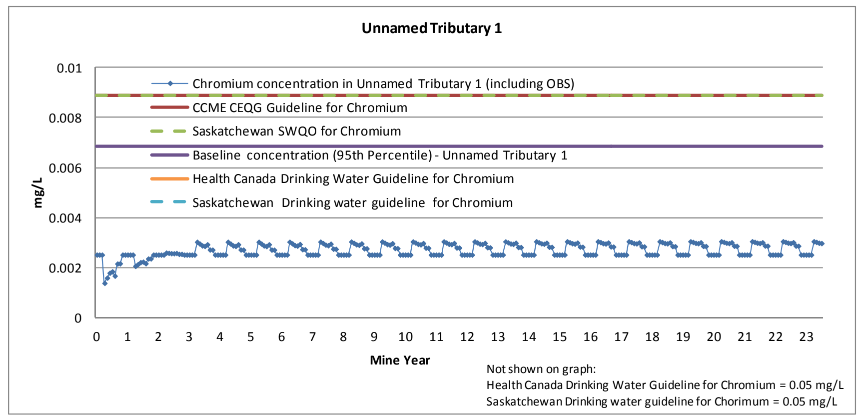
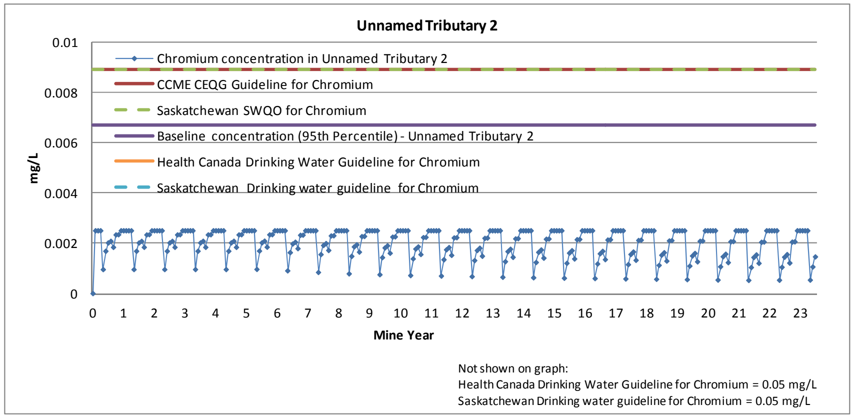
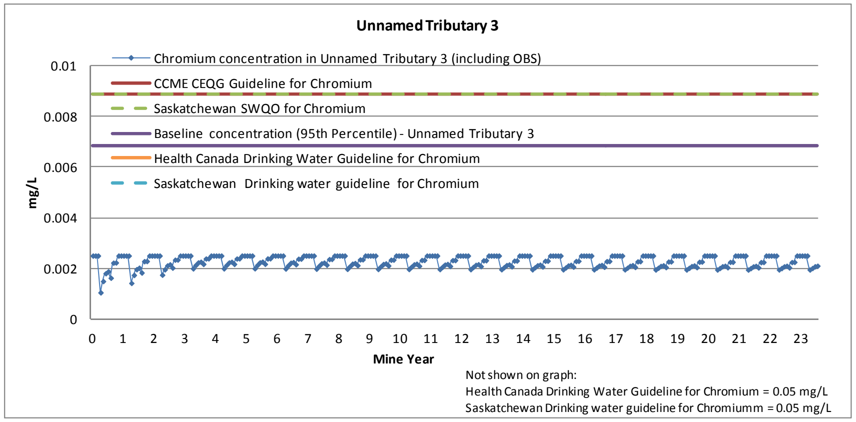
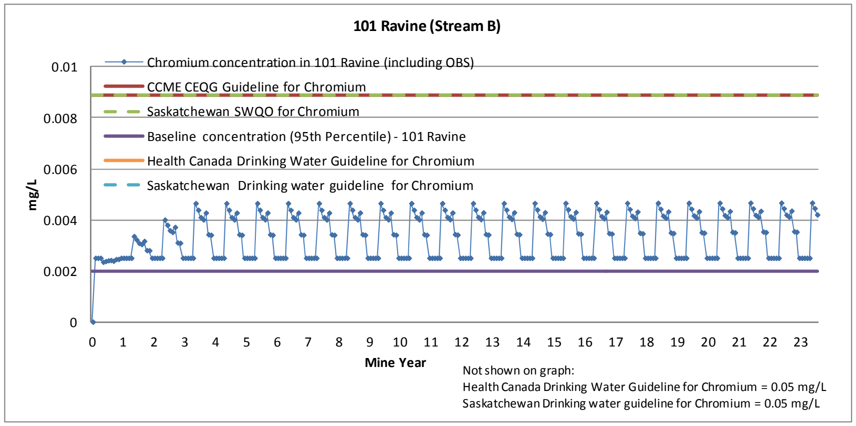
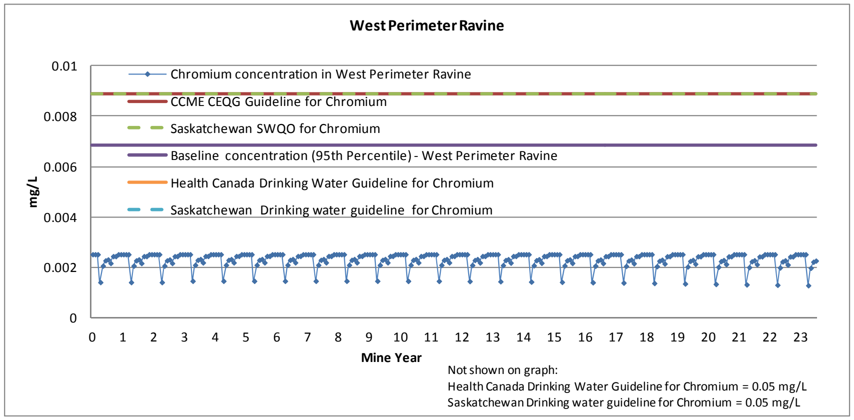


Figure 3-25 Continued









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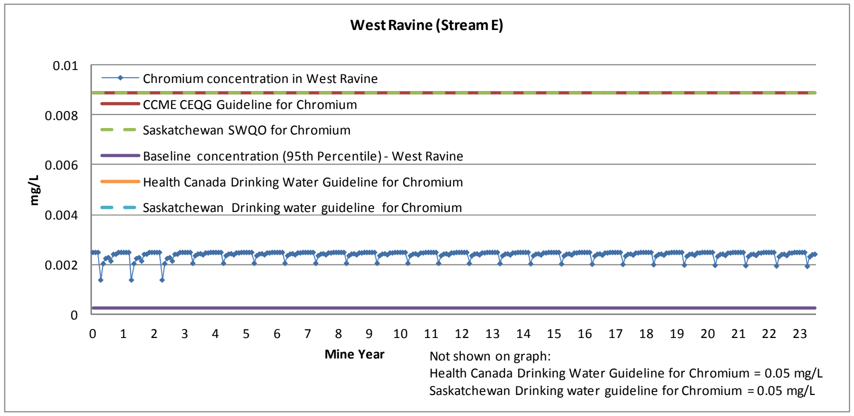

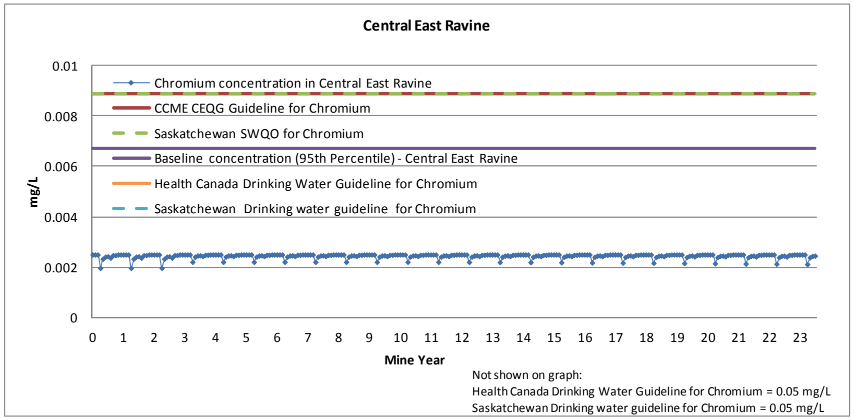

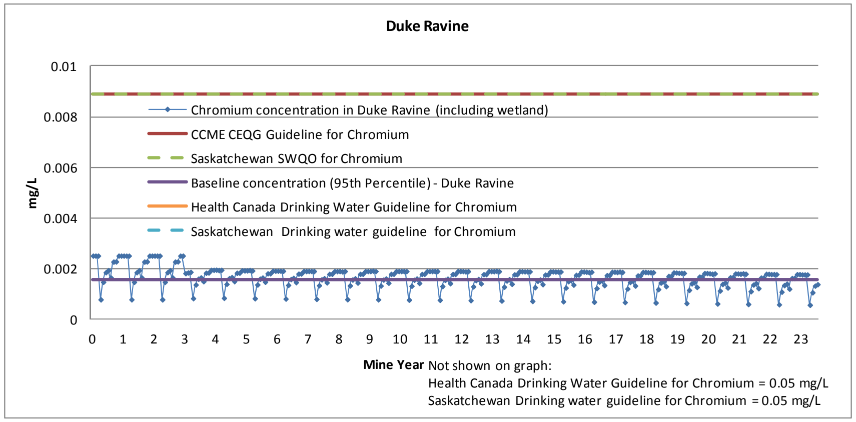

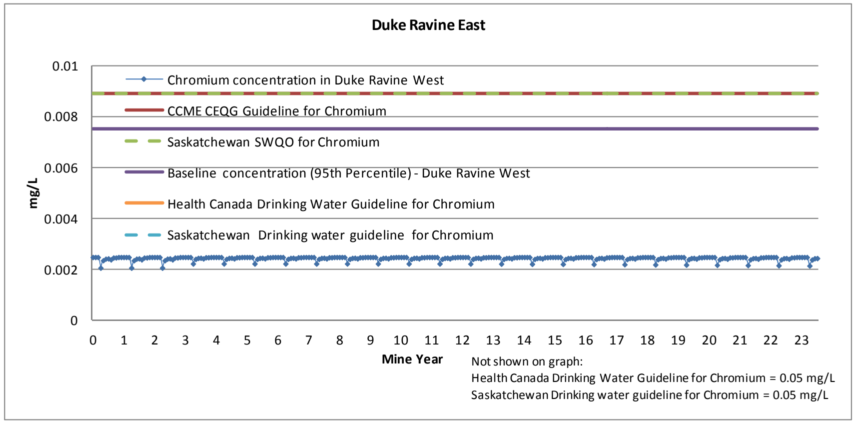

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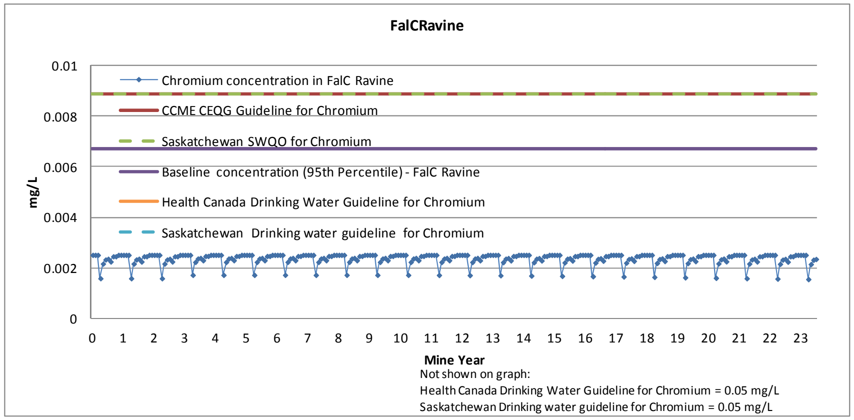
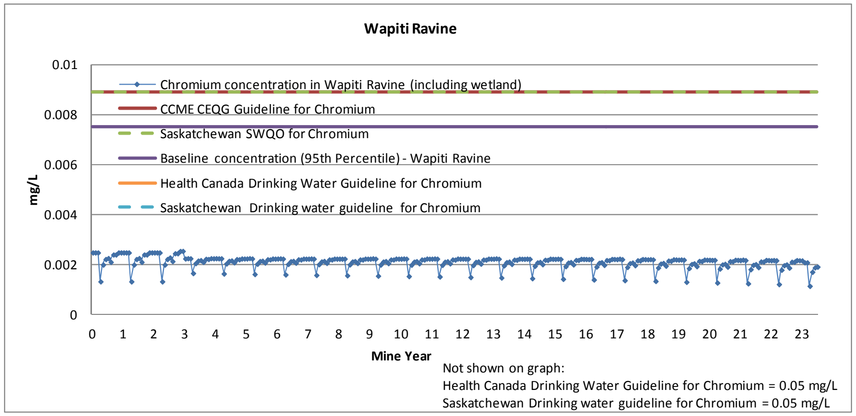
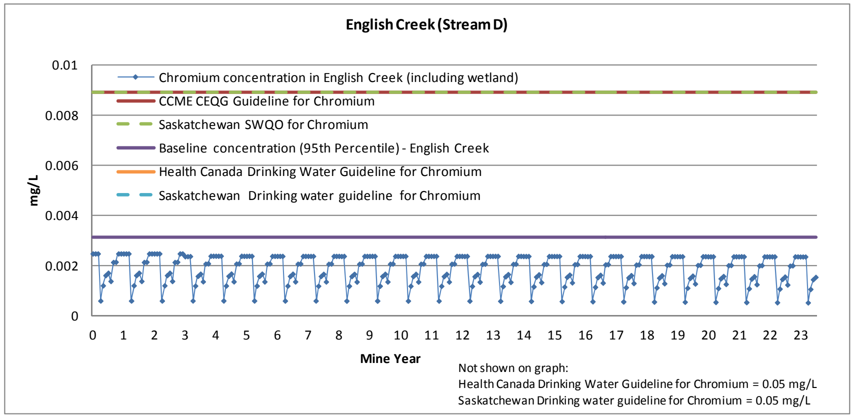






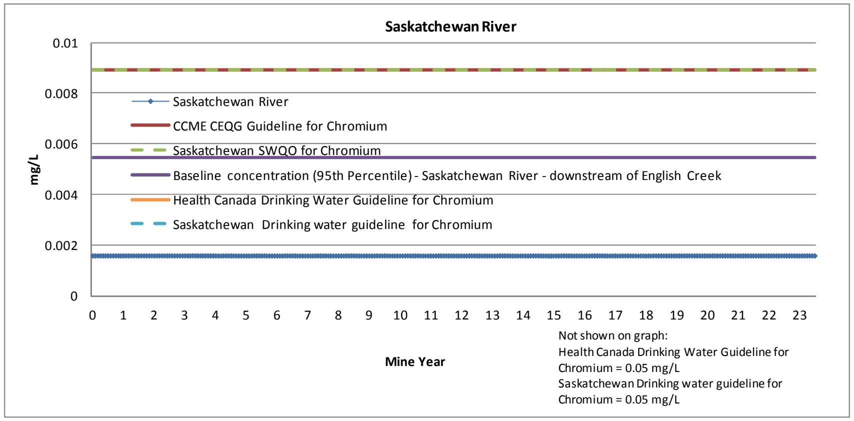


Figure 3-33 Predicted Selenium concentrations during construction and operation

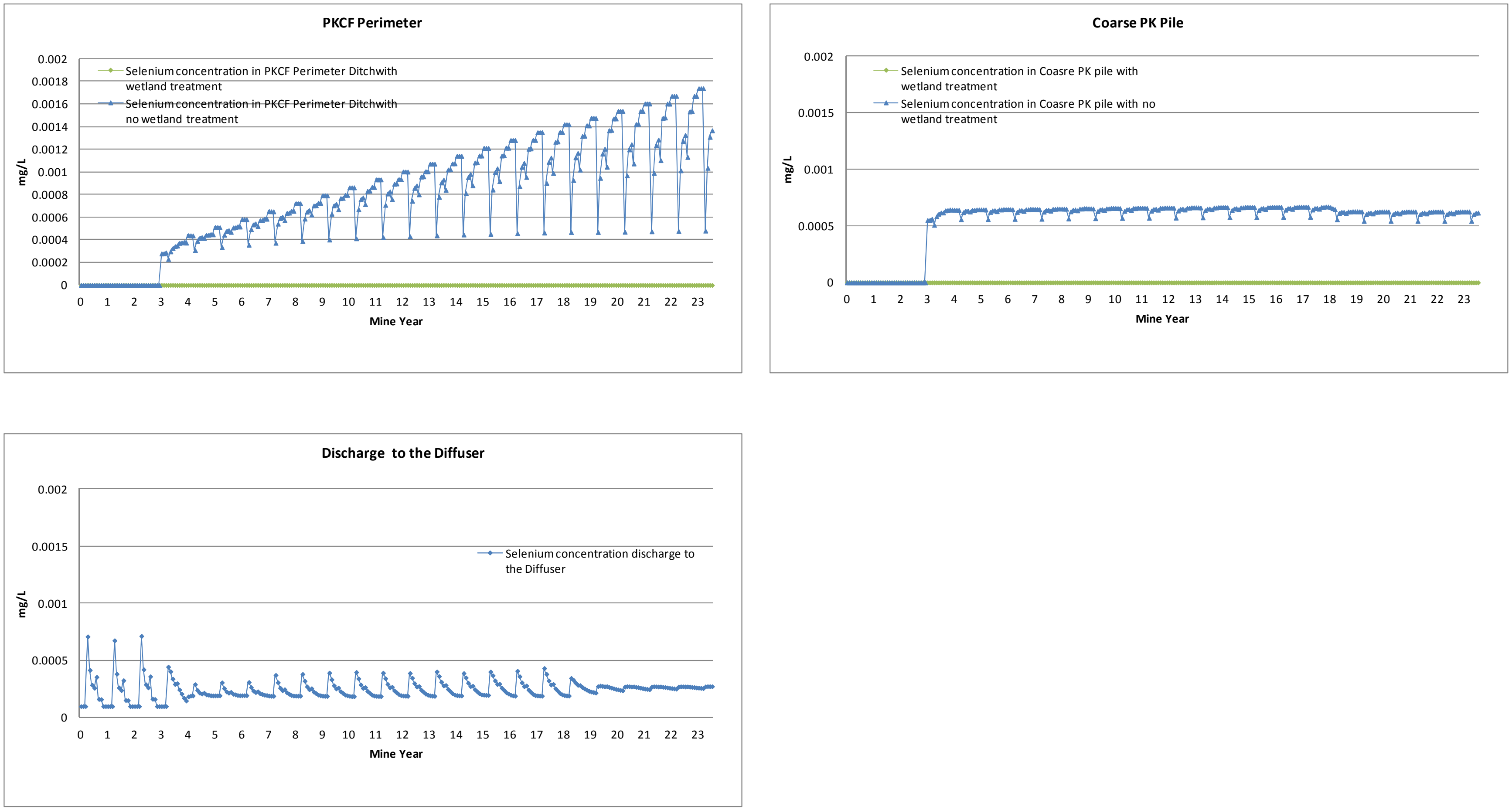
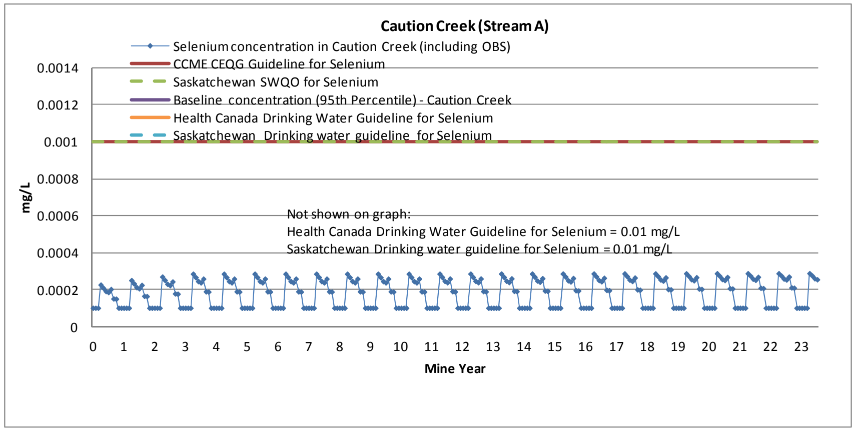
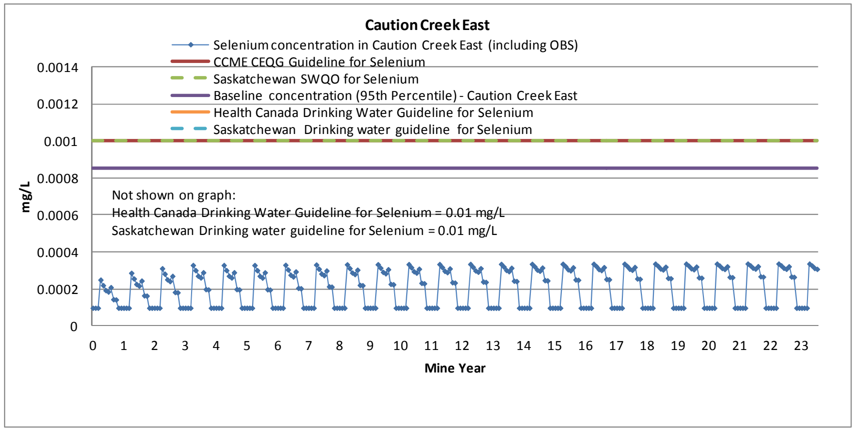
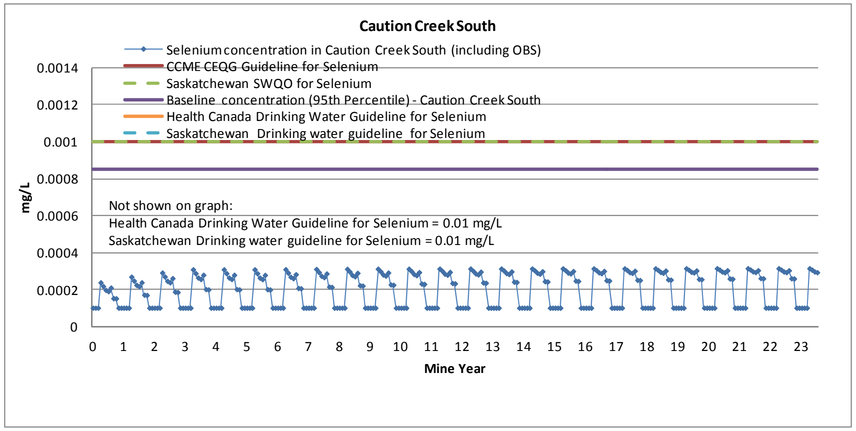


Figure 3-33 Continued







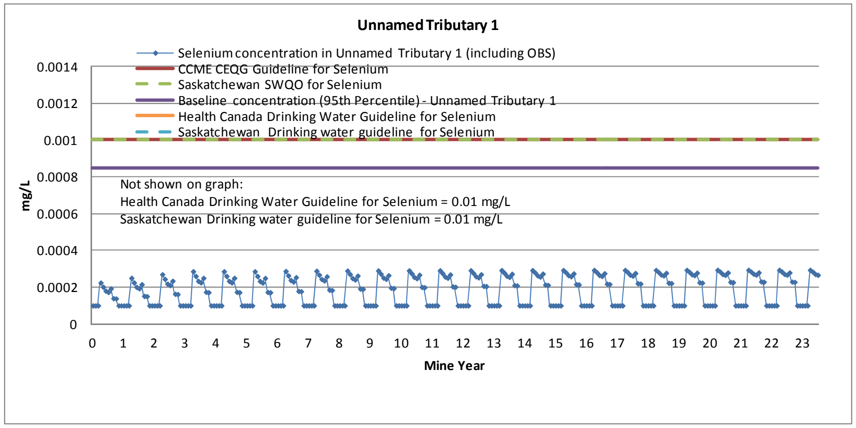
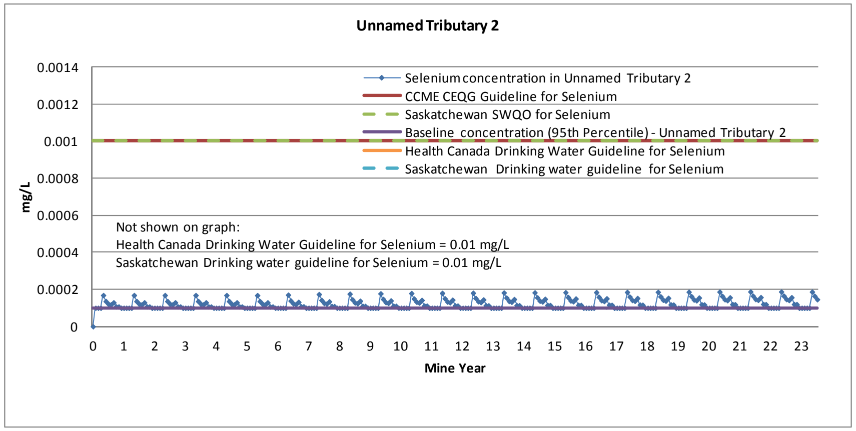
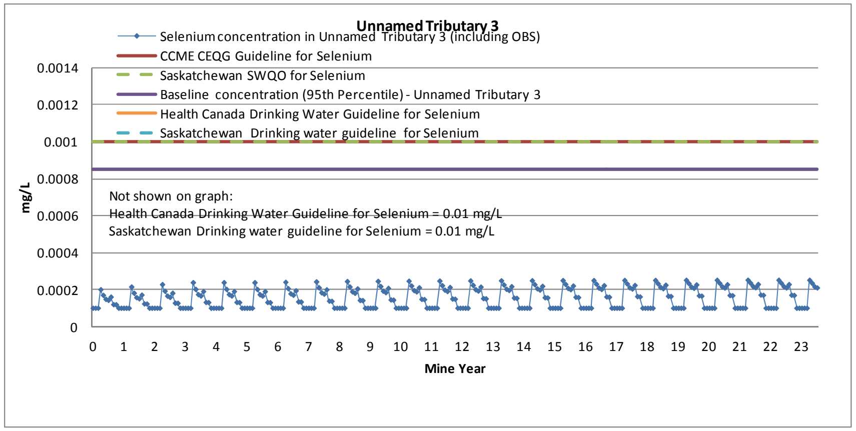
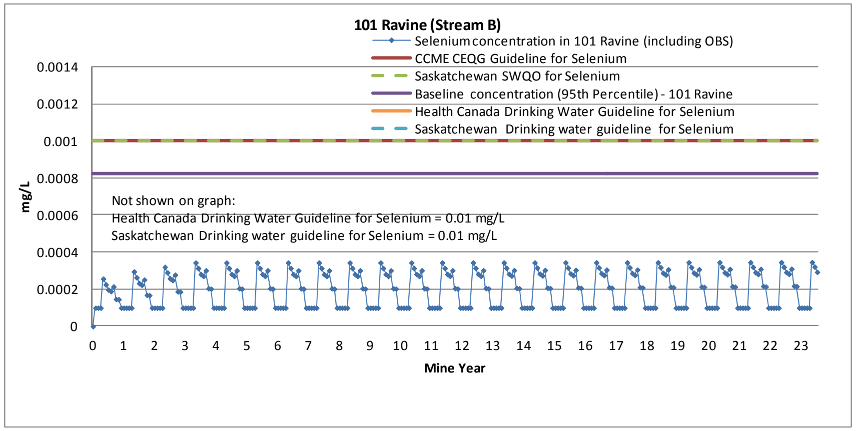


Figure 3-33 Continued







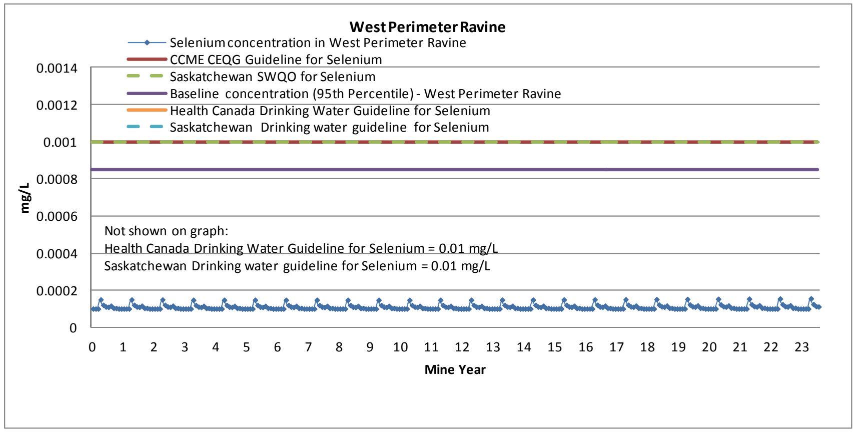
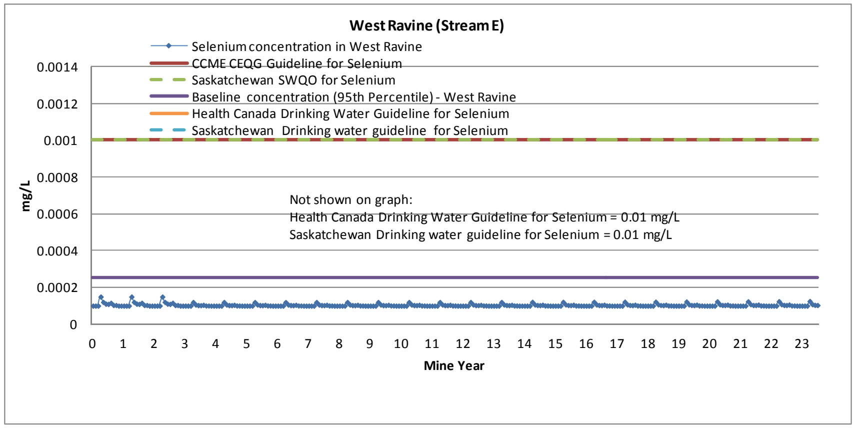
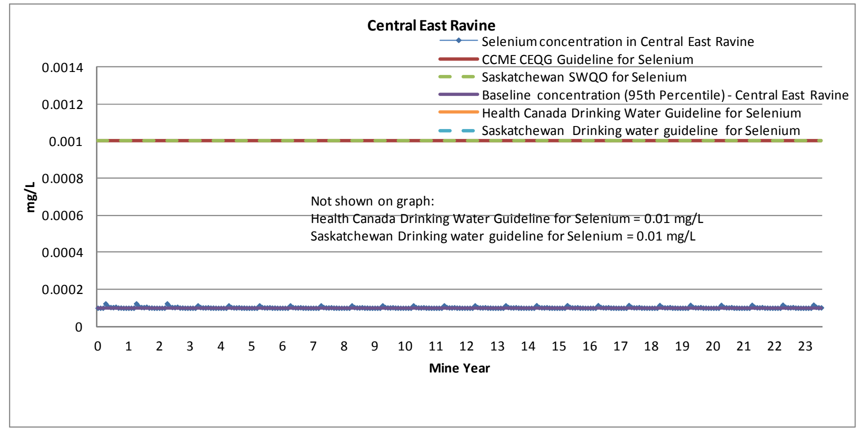
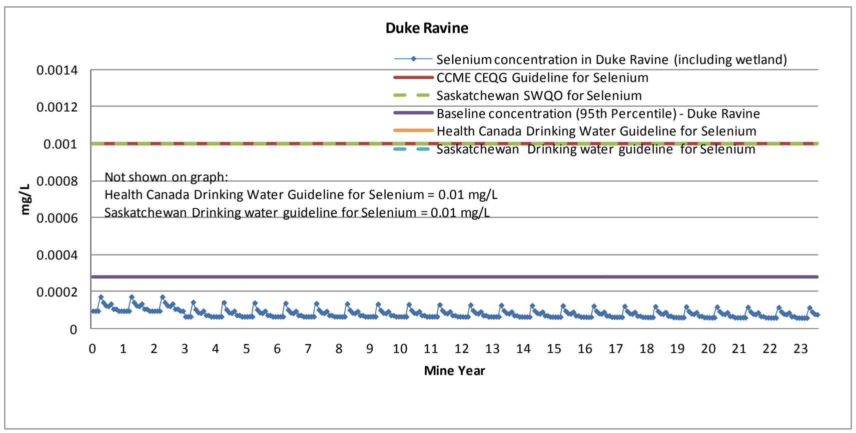


Figure 3-33 Continued







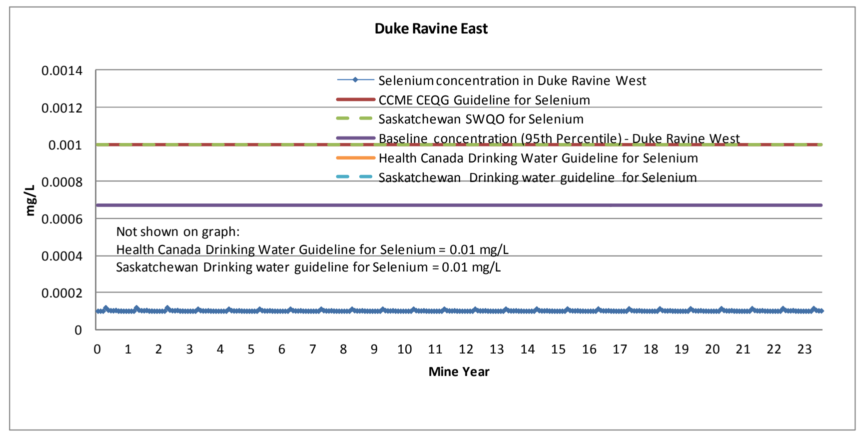
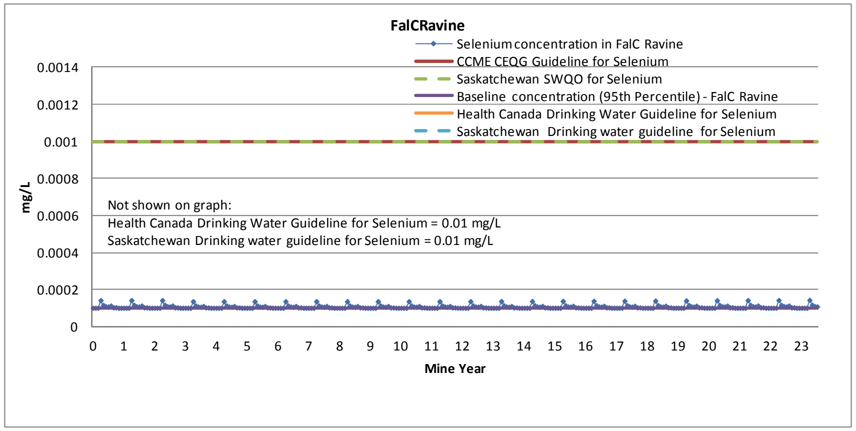
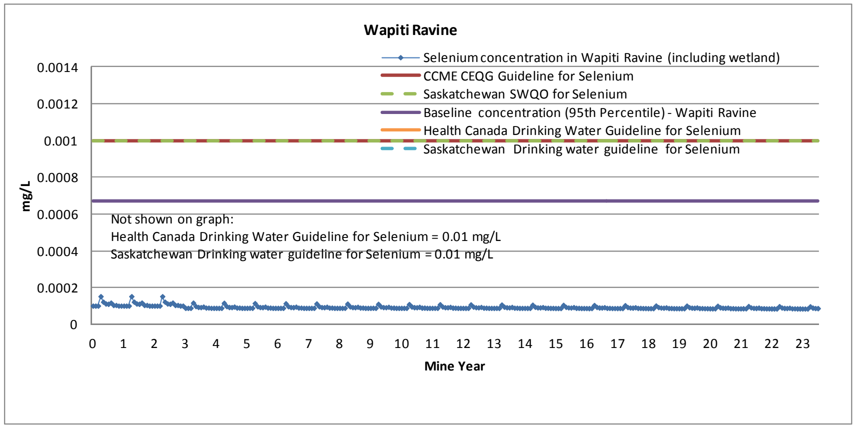
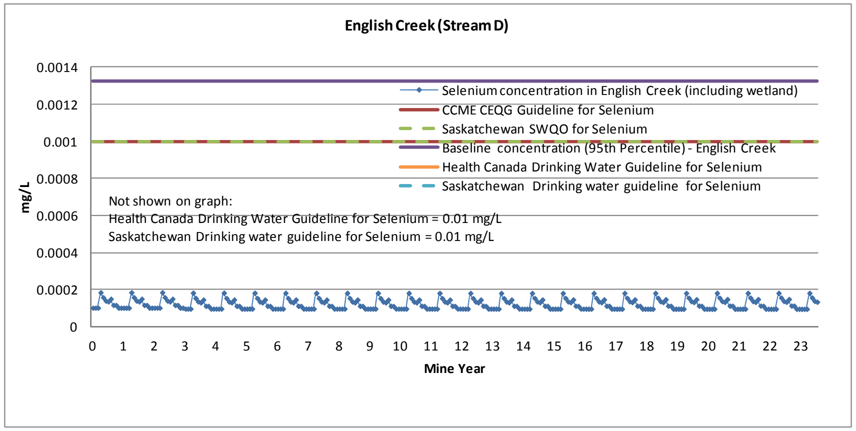


Figure 3-33 Continued







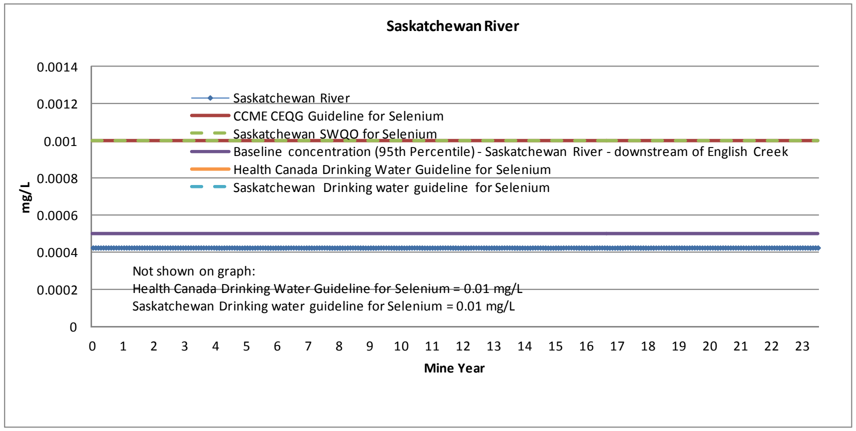
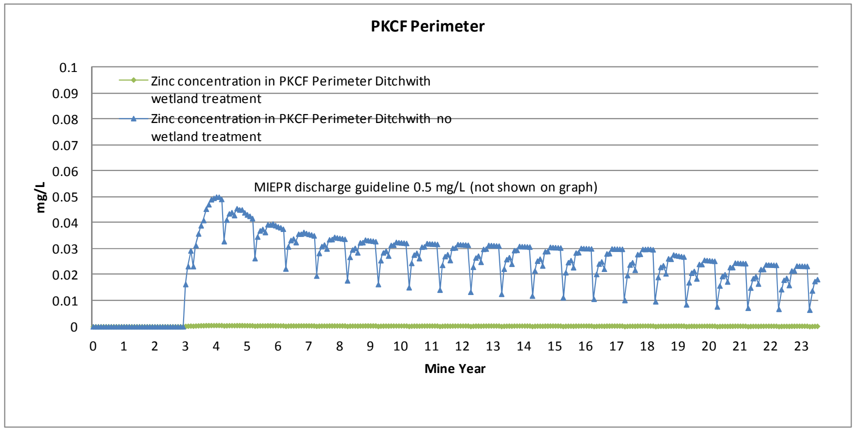
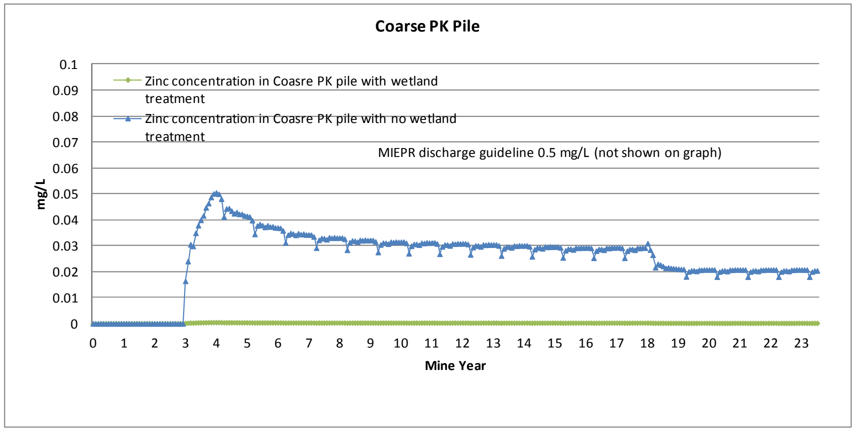
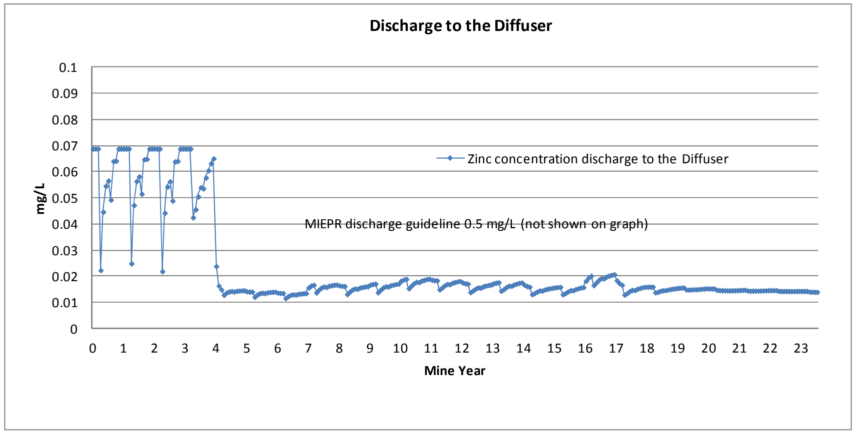


Figure 3-41 Predicted Zinc concentrations during construction and operation







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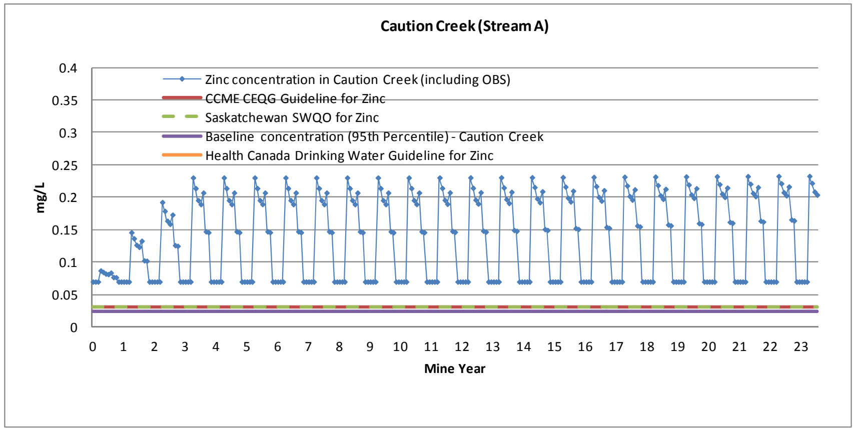
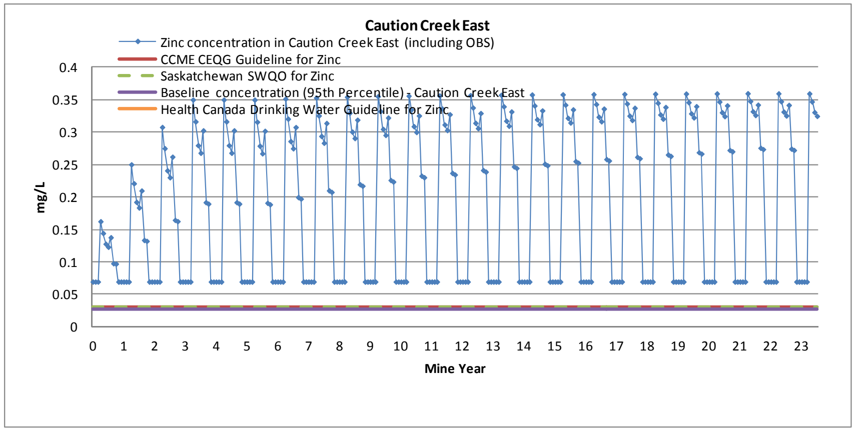
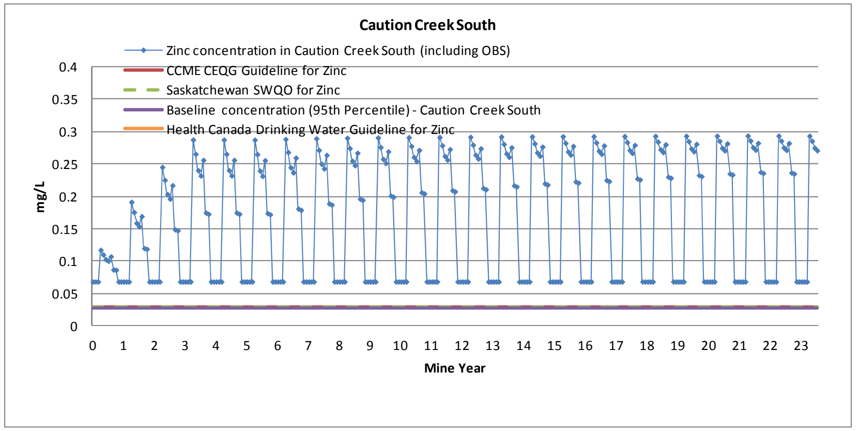






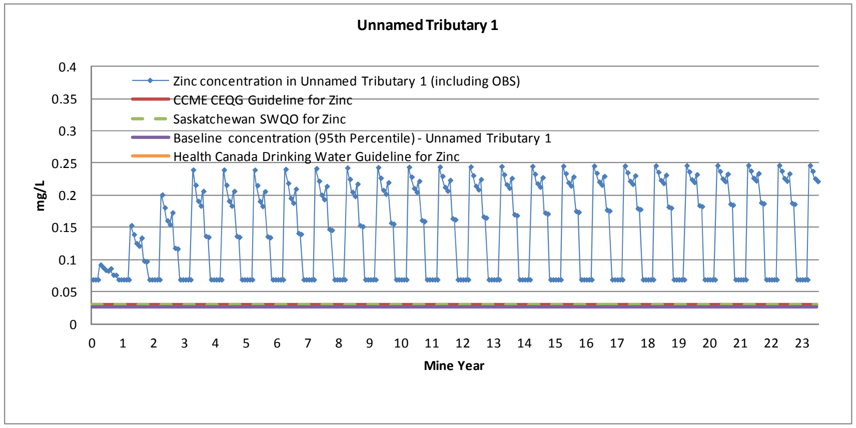
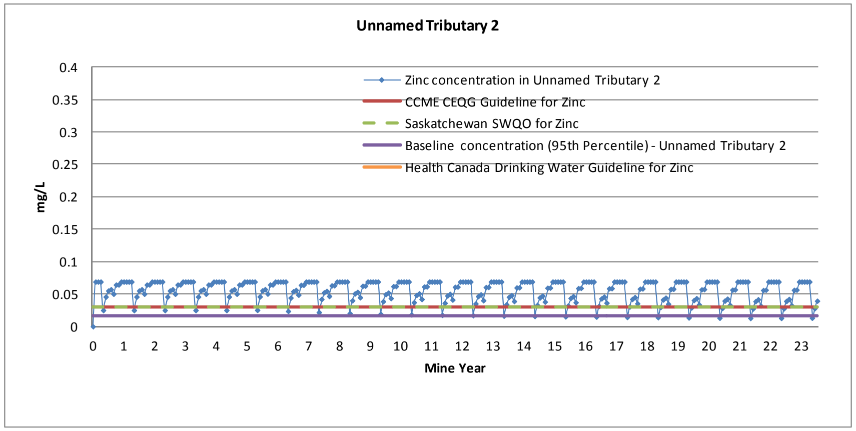
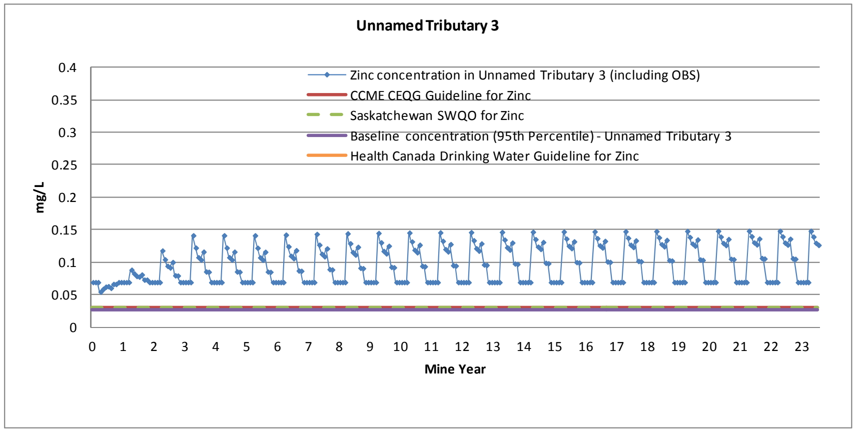
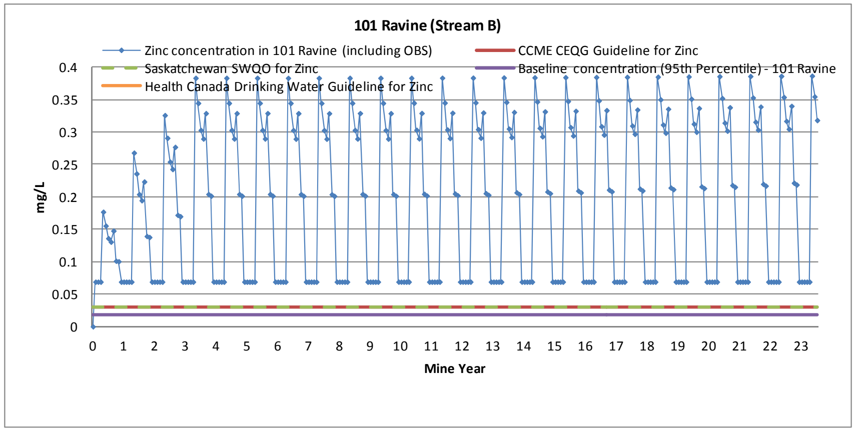


Figure 3-41 Continued







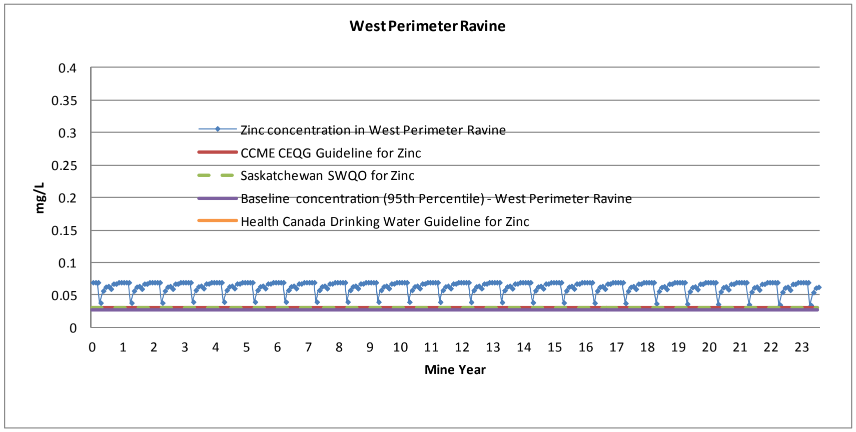
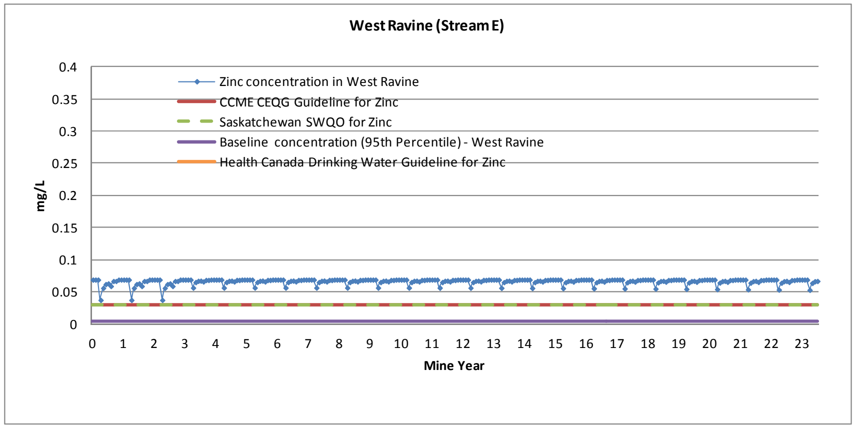
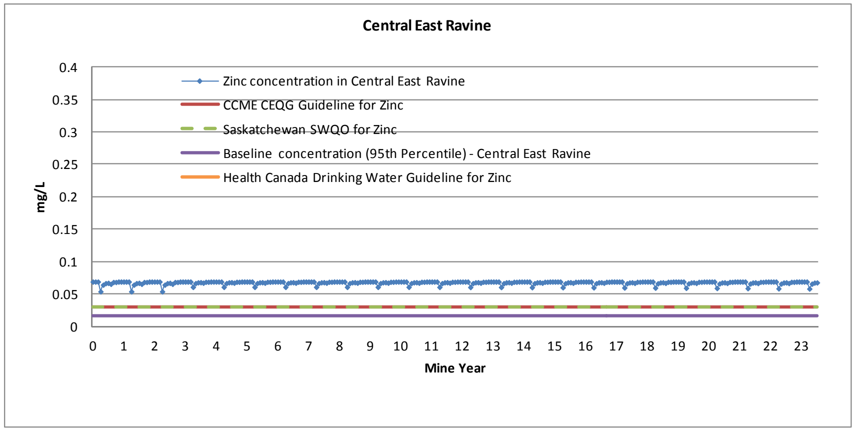
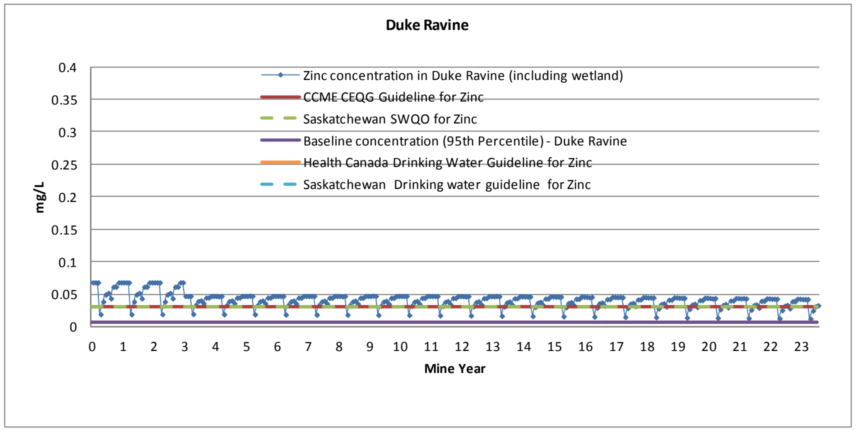


Figure 3-41 Continued







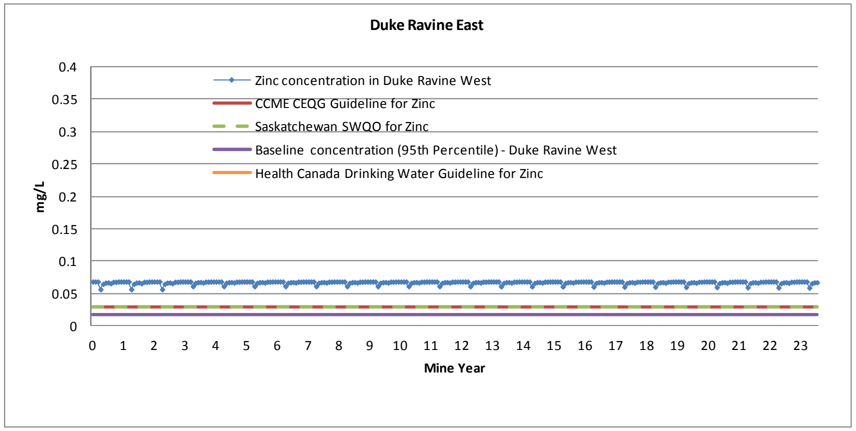


Figure 3-41 Continued