

Appendix 6.3-D

Derivation of Protective Water Quality Benchmarks

AJAX PROJECT

**Environmental Assessment Certificate Application / Environmental Impact Statement
for a Comprehensive Study**

KGMH Ajax Mining Project

Derivation of Protective Water
Quality Benchmarks



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May 8, 2015

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Abbreviations

ACR	Acute-to-Chronic Ratio
As	Arsenic
BC	British Columbia
BCMOE	British Columbia Ministry of Environment
BLM	Biotic Ligand Model
CaCl ₂	Calcium Chloride
CaCO ₃	Calcium Carbonate
CCME	Canadian Council of Ministers of the Environment
Cl	Chloride
Cr	Chromium
Cu	Copper
DOC	Dissolved Organic Carbon
EA	Environmental Assessment
EC	Effective Concentration
IC	Inhibitory Concentration
KAM	KGHM Ajax Mining Inc.
KP	Knight Piésold
LOEC	Lowest Observed Effect Concentration
MATC	Maximum Allowable Toxicant Concentration
Mo	Molybdenum
NaCl	Sodium Chloride

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NOEC	No Observed Effects Concentration
SSD	Species Sensitivity Distribution
TDS	Total Dissolved Solids
TNRD	Thompson-Nicola Regional District
TOC	Total Organic Carbon
US EPA	United States Environmental Protection Agency
WQB	Water Quality Benchmark
WQG	Water Quality Guideline

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Introduction
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1.0 INTRODUCTION

The company KGHM Ajax Mining Inc. (KAM), is proposing to develop the Ajax Project (the Project), which is an open pit copper and gold mine south-west of the City of Kamloops, British Columbia (BC). The Project is located on traditional Shuswap (Secwépemc) territory within the Thompson-Nicola Regional District (TNRD) and is in close proximity to the historic Ajax-Afton mine sites. Resources exploration and extraction have previously occurred in this area, from small-scale mine operations to the development of an open-pit operation under Teck Resources Ltd. and the Afton Operating Corporation between 1989 and 1997.

The Ajax Project will interact with the aquatic environment through the seepage of mine influenced water into receiving aquatic environments. Available baseline water quality was compared to BC water quality guidelines (WQGs) for the protection of aquatic life (KP 2013). Reported guideline exceedances included chloride, arsenic, trivalent and hexavalent chromium, copper, molybdenum, and selenium (KP 2013). Current BC WQGs are designed to be protective across a wide range of conditions and are thus conservative. The intended broad-spectrum application of these WQGs means that they do not adequately account for site-specific factors that can alter the toxicity of metals and other inorganic compounds, meaning these WQGs can be overly protective. Site-specific water quality parameters (e.g., hardness, dissolved organic carbon [DOC]) can decrease the toxicity and/or minimize the effects of some metals and other inorganic chemicals, suggesting the BC guidelines may be overprotective under certain conditions. Water quality benchmarks (WQBs) can be developed for metals and other inorganic compounds to reflect local environmental conditions. These WQBs are expected to be protective of aquatic biota.

Stantec was retained by KAM to derive WQBs for parameters exceeding WQGs including chloride, arsenic, trivalent and hexavalent chromium, copper, molybdenum, and selenium. The WQB derivations followed the lower threshold method as described by Canadian Council of Ministers of the Environment (CCME) 2007 and were derived to be protective of receiving aquatic environments located within the Ajax Project area. This report describes the methods and results for the derivation of applicable WQBs for parameters of concern.

2.0 BASELINE SURFACE WATER QUALITY AND AQUATIC BIOTA

The receiving aquatic environment for the project included Peterson Creek, Jacko Lake, Jacko Creek, and Humphrey Creek. Baseline conditions for these waterbodies are fully described in KP 2013. Baseline data collected from 2007 to 2014 are briefly summarized below.



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2.1 WATER AND SEDIMENTS

Collected surface water had relatively neutral to slightly basic pH (field pH 6.5 to 9.2), was moderately hard to very hard (157 to 1,040 mg/L as calcium carbonate [CaCO₃]), and had a wide range of conductivity (laboratory specific conductivity 367 to 2,230 µS/cm). Sulphate and chloride were the dominant anions measured at all sampled locations. Total phosphorous concentrations were highly variable (0.0069 to 0.965 mg/L), indicating that the trophic categories in sampling sites ranged from oligotrophic to hyper-eutrophic. Total dissolved solids (TDS) concentrations were highly variable and ranged from 131 (Peterson Creek) to 1,476 mg/L (Peterson Creek). Total organic carbon (TOC) and DOC varied seasonally (5.9 to 28.8 mg/L for TOC and 5.9 to 25.4 mg/L for DOC), with higher concentrations recorded during freshet. Concentrations of some metals including aluminum, copper, cadmium, and selenium exceeded BC WQGs in at least one collected sample (KP 2013).

Sediment samples exceeded the BC sediment quality guidelines for copper, chromium, arsenic, nickel, cadmium, iron, mercury, manganese, and nickel in one or more sites within Peterson Creek and Jacko Lake. Sediments in Peterson Creek were typically sandy gravel, while Jacko Lake sediments were silt and clay.

2.2 BENTHIC INVERTEBRATE COMMUNITIES

An aquatic ecology baseline study in Peterson Creek and Jacko Lake found that the biological communities were normal for freshwater ecosystems within the BC interior. Peterson Creek and Jacko Lake had healthy populations of phytoplankton, although low numbers of zooplankton taxa in Jacko Lake may be indicative of biological stressors.

Benthic invertebrate density ranged from 131 to 76,587 organisms/m² in Peterson Creek with the highest densities at sites immediately downstream of Jacko Lake and from 0 to 36,709 organisms/m² in Jacko Lake. Benthic macroinvertebrate communities in lower Peterson Creek were dominated by the insect orders Diptera and Ephemeroptera. The order Ephemeroptera is considered to be the second most sensitive to environmental stress after Plecoptera. Trichoptera, Chironomidae, Platyhelminthes, Cladocera, Amphipoda, Copepoda, and Hydracarina were also observed in Peterson Creek. In Jacko Lake, invertebrate taxonomic composition was variable between sites, with dominant taxa including Diptera, Bivalva, and Copepoda. Hydracarina and Platyhelminths were also observed in Jacko Lake. Few toxicant sensitive organisms were found in Peterson Creek and none were found in Jacko Lake (KP 2012a).

2.3 FISH AND FISH HABITAT

Juvenile coho salmon (n = 12) and rainbow trout (n = 49) were captured in the lower reaches of Peterson Creek downstream of Bridal Veil Falls, which acts as a barrier to upstream fish passage. The distribution of coho salmon is limited to lower Peterson Creek near the confluence with the Thompson River. Lower Peterson Creek stream morphology is mainly riffles-pool with gravel and



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fine substrates. Rainbow trout ($n = 18$) have also been captured within middle Peterson creek, which is predominantly riffle pool with gravel substrate. In upper Peterson Creek, which forms the inlet to Jacko Lake, rainbow trout have been historically observed but a large beaver dam restricts downstream fish movement and these fish may have accessed this region of Peterson Creek during freshet when flows temporarily supersede the outlet spillway from Jacko Lake. No fish were captured during the fish surveys in upper Peterson Creek. Jacko Lake was historically stocked with rainbow trout and trout of all age classes have been observed in the lake. Thirty-two rainbow trout were captured in Jacko Lake during the sampling surveys (KP 2012b).

3.0 SELECTION OF PARAMETERS OF CONCERN

The WQB derivation started by screening the full list of parameters analyzed in the Baseline Water Quality Report (KP 2013) and the water quality predictions, against provincial WQGs (BCMOE 2015). Water quality guidelines are intended 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” (CCME 1999). Therefore, parameters that were consistently below WQGs were not considered to be parameters of concern and were not carried forward in the development of WQBs.

All parameters that exceeded WQGs at baseline concentrations or are predicted to exceed WQGs, were considered parameters of concern and included the following elements; chloride, arsenic, trivalent and hexavalent chromium, copper, molybdenum, and selenium.

4.0 METHODS

The preferred CCME approach for developing WQBs is the species sensitivity distribution (SSD) which amalgamates concentration-based toxicological thresholds for each aquatic species from the lowest to highest concentrations (CCME 2007). The SSD method establishes an acceptable response (effect) size, fits suitable endpoint data to a specified model, and calculates an exposure concentration that protects a specified percentage of species (e.g., 95%). Water quality benchmarks based on the SSD curve are referred to as “Type A” WQBs.

Alternatively, the CCME (2007) recommends the lower threshold approach, which generates “Type B” WQGs. If baseline data is insufficient to model an SSD curve, then a second- or third-tier guideline may be developed considering the lowest toxicity value from a high quality study (and applying an uncertainty or safety factor). This approach is based on the original federal guideline development protocol (CCME 1991).

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Both approaches require a defined minimum amount of environmental and toxicological data (CCME 2007). The minimum toxicity dataset required for the generation of long-term WQGs using the Type A method based on a SSD curve (CCME 2007) includes:

- Three studies on three different species of fish, including one salmonid and one non-salmonid
- Three studies on three different invertebrate species, including one planktonic crustacean
- At least one freshwater vascular plant or algal species

Insufficient data were available to meet the minimum toxicity dataset required for deriving Type A WQBs (SSD curve); therefore the lower threshold method was adopted to derive Type B WQBs for each of the parameters of concern.

4.1 GENERAL APPROACH

The general procedure for the development of the WQBs followed a three step process. These steps included:

- Establishing site-specific conditions such as species present and current water quality conditions in the Project area
- Creation of a toxicological database for each of the parameters of concern
- Establishing the lowest reported chronic toxicity threshold set to protect the most sensitive species present in the Project area

A water quality benchmark was required for any element that was carried through the initial screening procedure described in Section 3.0.

Site-specific WQBs reflect local water quality conditions (e.g., hardness) and are protective of the aquatic biota present in the receiving waterbodies at the Project site. Consequently, the WQBs are considered to be conservative thresholds by which potential effects to aquatic health can be assessed.

4.2 PROCEDURE

The following subsections outline the technical procedures for the three-step derivation process.

4.2.1 Toxicity Data Compilation

Available chronic toxicological data for each parameter of concern were summarized, with a focus on data for algae, invertebrates and fish (following the recommendations of CCME 2007). The development of each toxicity database began with an examination of primary chronic toxicity data from fact sheets used to derive relevant BC, Canadian and US Water Quality Guidelines (CCREM 1987; CCME 1999; US EPA 2007a; BC MOE 2015). The toxicity database was then expanded by querying the ECOTOX databases (US EPA 2007a), and by searching for other available peer-reviewed scientific literature from journal databases (e.g., Cambridge Scientific



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Abstracts, PubMed). This review was focused on the time period subsequent to the previous guideline derivations. The resulting database contained data with various test endpoints, such as mortality, reduced survival, growth, or reproduction, derived from sub-chronic and chronic studies.

The toxicity database was created according to the requirements of United States Environmental Protection Agency (US EPA) and CCME guideline development protocols (Stephan et al. 1985; CCME 2003; CCME 2007; US EPA 2015). Once potential data were identified from the sources described previously (e.g., fact sheets, ECOTOX), the data were screened against the criteria discussed in Section 4.2.2 to determine if they should be included in the toxicity database.

4.2.2 Data Inclusion or Exclusion

Available studies were screened for inclusion or exclusion based on rules specified by CCME (2003, 2007) for developing WQBs. Confirmation of test acceptability was conducted by consulting the original publication or report, reviewing the test methodology and checking for good laboratory practice. Rules for data exclusion and inclusion were as follows:

- Toxicity data on species that are known to occur in Canadian waters or may occur at the site were included, whereas toxicity data on species that are not known to occur in Canada were excluded.
- All life stages were included in the toxicity database; however, for aquatic invertebrates and amphibians with terrestrial adult stages (e.g., non-biting midge), only the aquatic phases were included in the analyses.
- Endpoints included data for growth, mortality and reproduction. Non-traditional endpoints with uncertain biological relevance (e.g., biochemical endpoints) were excluded.
- Tests using field-collected organisms or tests performed in the field were excluded due to uncontrolled sources of variability (e.g., life history of organisms unknown, exposure conditions not controlled, chemical mixtures present).
- Only studies with freshwater exposure to the substance in question were included. Experiments in which test organisms exposure occurred through injections or diet were excluded.
- Studies were also excluded if exposure concentrations (e.g., nominal concentrations, extrapolated concentrations) or test duration were not reported.
- Studies evaluating synergistic, or antagonistic effects of chemicals or compensatory responses of organisms (such as tolerance [acclimation, adaptation], or reduced density-dependent mortality among juveniles) were excluded.
- Included studies must have followed good laboratory practices (e.g., presence of control group), a defensible experimental design, and accepted statistical procedures for data analysis.
- If a member of a family of freshwater fish may occur at the site, then toxicity data from any fish species within that family were maintained in the database.
- If a member of a family of amphibians may occur at the site, then toxicity data from any amphibian species within that family were maintained in the database.



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- If a member of a class of freshwater invertebrates may occur at the site, then toxicity data from that invertebrate class were retained in the toxicity database.
- If a member of a phylum of freshwater algae may occur at the site, then toxicity data from that phylum were retained in the database.
- Tests greater than 96 hours in duration were considered to be chronic for most species.

4.2.2.1 Endpoint Selection

For statistical endpoints, the preference ranking (i.e., the most preferred acceptable to the least preferred acceptable endpoint) was conducted following guidance from CCME (2007):

- Effective concentration (EC_x)/Inhibitory concentration (IC_x) representing a no-effects threshold
- EC_{10}/IC_{10}
- EC_{11-25}/IC_{11-25}
- Maximum allowable toxicant concentration (MATC), which was estimated using the geometric mean of the no observed effects concentration (NOEC) and the lowest observed effects concentration (LOEC) reported for a given test
- NOEC
- LOEC
- IC_{26-49} or EC_{26-49}
- IC_{50}/EC_{50}

Regression-based endpoints, such as IC, EC or LC values, were given preference over hypothesis-based endpoints, such as LOEC and NOEC values. They are also the endpoints favored by CCME (2007) and US EPA (2007a). The IC_{10}/EC_{10} results were given first priority because these represent a conservative threshold for no negative effect, and are derived by regression analysis.

4.2.3 Identification of Water Quality Benchmarks

In general, toxicity data were available for up to five species for each parameter of concern. The derivation of the WQBs was based on the lowest chronic toxicity result present in the parameter-specific toxicity database.

5.0 WATER QUALITY BENCHMARK RESULTS

5.1 ARSENIC

Arsenic (As) is widely distributed in the natural environment. This element has four oxidation states: As^{3-} , As^0 , As^{3+} , and As^{5+} ; however, in aquatic systems, inorganic arsenic occurs primarily as As^{3+} and As^{5+} . Both forms generally exist together, although As^{3+} predominates under reducing conditions and As^{5+} predominates under oxidizing conditions. The arsenic toxicity depends on its chemical form, with inorganic forms being more toxic than organic ones and arsenate (As^{5+}) less toxic than arsenite (As^{3+}) (Sharma and Sohn 2009).

The BC working WQG for arsenic of 5 µg/L is based on the CCME (2001) WQG which was derived by multiplying the 14-d EC_{50} (growth) of 50 µg/L for the alga *Scenedesmus obliquus* (Vocke et al. 1980) by a safety factor of 0.1. This species was not recorded as present in any of the receiving waterbodies at the Project site. The most sensitive species listed in CCME (2001) that was recorded in at least one receiving aquatic environment at the Project site, was *Cyclops vernalis* (recorded at genus level in Jacko Lake) (Borgmann et al. 1980). The lowest estimate of toxicity for *C. vernalis* was a 14-d EC_{20} (sublethal concentration causing 20% reduction in growth) of 320 µg/L (Borgmann et al. 1980).

No studies were found on the effects of water hardness on arsenic toxicity to crustaceans; however a study was carried out by Inglis and Davis (1972) on the effects of water hardness on the toxicity of trivalent inorganic arsenic to freshwater blue fish. This study found no significant difference between soft, medium and hard water (50, 200, and 370 mg/L as $CaCO_3$), to indicate that hardness had any effect on arsenic toxicity. Therefore, hardness was not considered any further in the derivation of a benchmark for arsenic and the study performed by Borgmann et al. (1980) was used to derive the arsenic WQB of 32 µg/L, based on the reported 14-d EC_{20} of 320 µg/L with an applied safety factor of 0.1.

5.2 CHLORIDE

The chloride (Cl) ion typically exists as a salt (e.g., sodium chloride [NaCl], calcium chloride [$CaCl_2$]), although it is highly soluble so these salts tend to dissociate into their ionic forms (e.g., Na^+ and Cl^-) in water (Elphick et al. 2011). The chloride ion is mobile, does not biodegrade, and does not bioaccumulate (Nagpal et al. 2003; CCME 2011).

The BC ambient WQG for the protection of aquatic life for chloride is 150 mg/L as a 30-day average (five weekly measurements over a 30-day period) and 600 mg/L as a maximum concentration (Nagpal et al. 2003). The BC 30-day criteria for chloride was calculated using chronic toxicity data from 8 species, with *Ceriodaphnia dubia* identified as the most sensitive species to chloride with a 7-d Lowest Observed Effect Concentration (LOEC) (50% reduction in reproduction) of 735 mg/L (Nagpal et al. 2003). A safety factor of five was used to derive the guideline of 150 mg/L for chloride, based on previously published acute-to-chronic ratios (ACRs)

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ranging from 1.0 to 6.9 (Nagpal et al. 2003). *Ceriodaphnia dubia* have been recorded in the receiving aquatic environment (Jacko Lake) at the Project site.

Elphick et al. (2011) conducted chronic toxicity tests for chloride using nine freshwater species (*Ceriodaphnia dubia*, *Daphnia magna*, *Oncorhynchus mykiss*, *Pimephales promelas*, *Lumbriculus variegatus*, *Tubifex tubifex*, *Chironomus dilutes*, *Hyallela azteca*, and *Bracionus calyciflorus*) and 6 other species from previous studies, for a total of 15 species. Data from the toxicity tests were used to propose a WQG for long-term exposure to chloride using the SSD approach. Endpoints used in the study included reproduction, biomass, and survival. The sixth percentile from the SSD was calculated as 307 mg/L and proposed as the WQG. Cladocerans were the most sensitive species in the dataset.

Elphick et al. (2011) also developed a hardness-specific WQG equation using the results of the SSD model and *C. dubia* chronic IC₂₅ reproductive toxicity tests:

$$\text{Water quality guideline} = [116.63 * \ln(\text{Hardness})] - 204.09$$

They found a strong positive relationship between hardness and LC₅₀, IC₅₀, and IC₂₅ values for toxicity in *C. dubia*, indicating that as hardness increases, chloride toxicity decreases. Using this equation, at a water hardness of 160 mg/L, which is representative of the minimum hardness for receiving waters (157 mg/L) within the Project area, the derived WQB is 388 mg/L. These results suggest that the current BC long-term WQG for chloride (150 mg/L) may be unnecessarily conservative in the moderate to high hardness waters found in the Project area. Furthermore, the derived 388 mg/L chloride WQB is below the chloride toxicity threshold for non-cladoceran species (e.g., rainbow trout) and is expected to be protective of the majority of aquatic biota (Elphick et al. 2011). Thus, 388 mg/L was adopted as the WQB for chloride.

5.3 CHROMIUM

Elemental chromium (Cr) does not occur naturally on earth, instead chromium exists in nine oxidation states (-II to VI) which form halides, oxides and sulfides with other compounds. The most common chromium species include Cr(II), Cr(III), and Cr(IV). Dichromate (Cr(II)) rapidly decomposes in air and water to form trivalent chromium (Cr(III)). The valence state of chromium is dependent on the redox potential and pH of the aquatic system. Hexavalent chromium (Cr(VI)) is most prevalent in high oxidation environments such as surface waters, and trivalent chromium is most prevalent in reducing environments such as wetlands and soils. In waters of intermediate pH values, the trivalent chromium/hexavalent chromium ratio is largely dependent on the concentration of oxygen (Stanin and Pirnie 2004).

In the Project area creeks, groundwater is the significant source of flow (KP 2013). It has been shown that hexavalent chromium will disappear from the aqueous phase in the anaerobic part of an aquifer due to reduction to the less soluble trivalent form (Stanin and Pirnie 2004).

Therefore, it is expected that trivalent chromium will be the dominant form of chromium present in the receiving waters in the Project area. However, as mentioned the distribution between



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trivalent chromium and hexavalent chromium in the environment, including aquatic environments such as groundwater, will be regulated by redox reactions and redox conditions as well as the presence of iron and manganese ions (Stanin and Pirnie 2004).

5.3.1 Hexavalent Chromium

Hexavalent chromium is considered to be the more toxic form of chromium because it can permeate biological membranes and has high solubility and oxidation potential. The working BC WQG for the protection of freshwater aquatic life for hexavalent chromium is 1.0 µg/L and is the same as the CCME (1999) WQG for the protection of freshwater aquatic life.

Invertebrates are the most sensitive organism to this element, with the guideline based on the most sensitive invertebrate species, *Ceriodaphnia dubia*. The guideline was derived from the 14-d LOEC of 10 µg/L for *C. dubia* with an applied safety factor of 0.1.

Insufficient chronic toxicity data were available to develop a WQB for hexavalent chromium; therefore the current WQG was adopted as the WQB.

5.3.2 Trivalent Chromium

Trivalent chromium is an acid that forms with organic compounds to produce chromic hydroxide species. The formation of these highly insoluble hydroxide species limit the solubility of trivalent chromium and provide a high tendency to absorb to surfaces that can be suspended in the water column (e.g., clay and organic material). The working BC WQG for the protection of freshwater aquatic life is the same as the CCME (1999) WQG (8.9 µg/L). The guideline was based on the most sensitive species to trivalent chromium, rainbow trout (*Oncorhynchus mykiss*), which is present in Jacko Creek, Jacko Lake and Peterson Creek. The guideline was derived from the 102-d LOEC (mortality) of 89 µg/L for rainbow trout (Stevens and Chapman 1984) with an applied safety factor of 0.1.

Insufficient chronic toxicity data were available to develop a WQB for trivalent chromium; therefore, the current WQG of 8.9 µg/L was adopted as the WQB.

5.4 COPPER

In oxygenated waters, copper exists primarily as part of complexes with ligands such as dissolved organic compounds, hydroxides, and carbonates, while a small percentage of copper exists as Cu(II) (US EPA 2007b). Copper bioavailability, and subsequent toxicity to aquatic organisms is reduced when copper complexes with organic compounds (e.g., dissolved organic compounds) and inorganic ligands (e.g., Ca⁺) (Santore et al. 2001, Hyne et al. 2005).

The BC water quality criteria for copper for the protection of freshwater aquatic life in water are calculated using hardness-based equations (BC MOE 1987). When average water hardness as

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CaCO₃ is greater than 50 mg/L the chronic (30-day average) copper water quality criterion is calculated using the following equation:

$$\text{BC water quality criterion (copper)} = 0.04 * \text{mean hardness } \mu\text{g/L} \\ \text{(measured over 5 weekly samples in 30 days)}$$

The median water hardness for receiving waters in the Project area (Peterson Creek, Humphrey Creek, Jacko Creek, and Jacko Lake) was 381 mg/L (mean 440.6, range 157 to 1,040 mg/L). The median value was chosen because of the wide range in hardness values measured for the site and because it is more conservative. Additionally, the mean hardness does not represent 5 weekly samples in 30 days. For a water hardness of 381 mg/L, the calculated 30-day hardness-based BC copper guideline is 15.2 µg/L. This guideline, however, is based on laboratory toxicity tests that are typically done in water with low complexing capacities (e.g., low DOC) (BC MOE 1987). The hardness-based equation does not address the effects of water chemistry parameters on copper toxicity. Copper toxicity is predicted to decrease with increasing pH and DOC due to lower copper bioavailability, meaning the BC hardness-based criterion is likely overprotective for waterbodies with comparatively elevated hardness, DOC, and pH (BC MOE 1987, US EPA 2007b).

The Biotic Ligand Model (BLM) accounts for the effects of water chemistry (e.g., pH, DOC, hardness) on metal bioavailability and toxicity. The US EPA (2007b) used the BLM to develop freshwater benchmarks for copper and has provided a simplified version of the BLM for copper for which water quality criteria can be estimated using pH, hardness, and DOC. Table 1 shows output from the simplified BLM, which assumes alkalinity and pH are proportional to hardness (US EPA 2007b, Appendix G). The hardness equation based water quality criteria for copper shown in Table 1 were calculated using a hardness-based equation, similar to the method used for BC MOE (1987).

Table 1 Water Quality Criteria using the Biotic Ligand Model (BLM) and the Hardness Equation

pH	Hardness	DOC ¹	Hardness Equation Based Water Quality Criterion for Copper ²	BLM Based Instantaneous Water Quality Criterion for Copper ³
8	40	2	5.9	13.8
		4	5.9	27.6
		8	5.9	55.8
		16	5.9	115
	80	2	11.3	15.5
		4	11.3	30.6
		8	11.3	61.4
		16	11.3	125.1
	159	2	21.7	18



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Table 1 Water Quality Criteria using the Biotic Ligand Model (BLM) and the Hardness Equation

pH	Hardness	DOC ¹	Hardness Equation Based Water Quality Criterion for Copper ²	BLM Based Instantaneous Water Quality Criterion for Copper ³
		4	21.7	35.3
		8	21.7	70.3
		16	21.7	142
	317	2	41.5	21.5
		4	41.5	41.6
		8	41.5	82.3
		16	41.5	165.1
	NOTES:			
¹ DOC = Dissolved organic carbon (mg/L)				
² Hardness equation = $e^{(0.9422[\ln(H)]-1.7)}$ where H = water hardness (mg/L CaCO ₃)				
³ BLM = Biotic Ligand Model				
SOURCE: from US EPA 2007b				

The summary statistics for pH (measured in situ), hardness, and DOC are provided in Table 2. Water quality samples were collected at sites within the receiving waters from 2008 to 2014. The median values were chosen as input for the BLM model because they were similar (pH, DOC) or lower (hardness) to the mean values and are in general representative of the receiving waterbodies.

Table 2 Summary Statistics for Water Chemistry Parameters for Receiving Waters (Peterson Creek, Humphrey Creek, Jacko Lake, and Jacko Creek)

	n	Minimum	Maximum	Mean	Median
pH	396	6.5	9.2	8.1	8.1
Hardness	401	157	1,040	441	381
DOC ¹	399	5.9	25.4	13.2	13.4
NOTE:					
¹ DOC = dissolved organic carbon					

Using the median values for pH, hardness, and DOC (Table 2), the most applicable BLM instantaneous water quality criterion for copper is 82.3 µg/L (2). The BLM copper criterion is approximately five times greater than the BC WQG calculated using the BC MOE (1987) hardness-based equation (15.2 µg/L) and twice the value calculated using the US EPA (2007b) hardness-based equation (41.5 µg/L), illustrating the effect of water chemistry on copper toxicity.



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A chronic water quality criterion for copper was calculated from the BLM-based instantaneous water quality criteria using an ACR provided by the US EPA (2007b) as a conservative measure to protect freshwater aquatic life. The final ACR for copper (3.22) was calculated using the geometric mean of ACRs for five sensitive freshwater species including water fleas (*Ceriodaphnia dubia*, *Daphnia magna*, and *Daphnia pulex*), Chinook salmon (*Oncorhynchus tshawytscha*), and rainbow trout (*Oncorhynchus mykiss*) in addition to the saltwater sheepshead minnow (*Cyprinodon variagatus*). The BLM-based instantaneous water quality criterion (82.3 µg/L) was divided by the final ACR from US EPA (3.22) to calculate a WQB for copper of 25.6 µg/L for receiving waters within the Project area.

Hardness-based copper water quality criteria equations do not account for the effects of other water quality parameters including pH and DOC on copper toxicity. The BLM method accounts for these effects and provides a more appropriate criterion because it considers site-specific water chemistry. The copper benchmark calculated using the BLM approach is considered conservative because the input DOC (8.0 mg/L) and hardness for the model (317 mg/L) were lower than the median values for DOC (13.4 mg/L) and hardness in the receiving waters (381 mg/L).

5.5 MOLYBDENUM

Molybdenum occurs naturally in the environment and is an essential nutrient. The maximum BC WQG for molybdenum for the protection of aquatic life is 2 mg/L (Swain 1986). The receiving waters within the Project area are not expected to exceed 2 mg/L molybdenum. However, they are expected to exceed 0.05 mg/L, which may be a concern for livestock and wildlife.

Two BC WQGs for livestock watering were developed for cattle: 0.05 mg/L for drinking water and 0.08 mg/L for drinking water when forage crops are irrigated (Swain 1986). The BC WQG to protect wildlife from excess molybdenum is 0.05 mg/L, which is based on the livestock guideline, although wildlife are likely less susceptible to molybdenum toxicity than domesticated animals because they can forage over a wider area (Swain 1986). The maximum BC WQG for molybdenum for the protection of aquatic life is 2 mg/L (Swain 1986). The receiving waters within the Project area are not expected to exceed 2 mg/L molybdenum; therefore the main concern for molybdenum is toxicity to livestock and wildlife through drinking water.

When excess quantities of molybdenum are consumed, toxicity (molybdenosis) can occur particularly in ruminants (e.g., cattle, moose, and sheep). The unique biochemical environment in the rumen means that cattle and other ruminants are more sensitive to molybdenosis, which is caused by copper deficiency and is exacerbated by sulfate in ruminants (US EPA 1998). Molybdenum sensitivity can differ between ruminants. For example, female mule deer were fed 200 mg/kg/d of molybdenum and had no visible symptoms of molybdenosis (Nagy et al. 1975 as cited by Swain 1986), whereas lactating cattle showed toxicity at 40 mg/kg dietary molybdenum, indicating that cattle are among the most sensitive ruminant animals to molybdenum toxicity (Wittenberg and Devlin 1987). In general, non-ruminant mammals are less sensitive to molybdenum toxicity, which is prevented in monogastric mammals by sulfate (US

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EPA 1998). Mice showed decreased survival in the second and third generations at 10 mg/L molybdenum exposure in drinking water (Earl and Vish 1979 as cited in US EPA 1998).

The livestock watering guideline was developed based on the premise that the largest dose of molybdenum would be through dietary exposure (Swain 1986). The guideline states that forage with 5 µg/g molybdenum causes copper deficiency, and assumes normal values of molybdenum in plants range up to 4 µg/g (Reid and Horvath 1980 as cited in Swain 1986), leaving 1 µg/g molybdenum for consumption in drinking water to bring the total maximum molybdenum dose to 5 µg/g (Swain 1986). The livestock water guideline was calculated using a maximum daily water consumption rate for dairy cows of 205 L and a food intake rate of 16 kg/d.

However, the cattle expected to be in the Project area are beef cattle, which are anticipated to consume up to 91 L/d of water in summer (temperatures above 25°C) (Brown 2006). A 1,200 lb beef cow feeding at 3% body weight per day would consume approximately 16 kg of food per day. Using the methods described by Swain (1986) to develop the BC WQG, the maximum amount of molybdenum which could safely be consumed by watering for beef cows is 16 mg (16 kg/d x 1 µg/g). Based on the water consumption rate of 91 L/d, a WQB for molybdenum for beef cattle was calculated to be 0.18 mg/L (16 kg/91 L).

The derived WQB for molybdenum of 0.18 mg/L is considered conservative because it assumes that the beef cattle will obtain all drinking water and vegetation from receiving waterbodies within the Project area. This WQB is also considered protective of other mammals (e.g., deer, moose) because wildlife migrates and can feed over large areas.

5.6 SELENIUM

Selenium is a contaminant of potential concern for mining operations due to its release from seleniferous waste rock that has been subject to weathering and erosional processes. The concern over this element is its propensity to accumulate in the food web of aquatic ecosystems, reaching concentrations in gametes (eggs) that have the potential to cause reproductive impairment in egg-laying vertebrates (i.e., fish, aquatic-feeding birds, amphibians) (Janz et al. 2010). Selenium typically enters the aquatic environment as selenate (Se^{6+}) or selenite (Se^{4+}). Primary producers accumulate inorganic selenium from the water and transform inorganic selenium into organic forms (e.g., selenomethionine), which accumulate in higher trophic organisms through dietary exposure (Fan et al. 2002, Lemly 1993). The BC WQG for selenium is 0.002 mg/L (BC MOE 2015).

For lotic (flowing water) systems, such as the majority of the systems encountered within the study area, there is known to be a limited increase in aquatic biota tissue concentrations from elevated water concentrations (Orr et al. 2012). This suggests there is a limited selenium uptake occurring at lower trophic levels (e.g., invertebrates) and assumes that high water selenium concentrations can occur in lotic systems without harming aquatic biota. However, selenium presents a potential risk to the development of the eggs of aquatic-feeding birds, and selenium concentrations in eggs are often strongly correlated with waterborne selenium concentrations



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greater than 0.005 mg/L (Adams et al. 1998; Lemly 1993). The only lentic (still or slow flowing water) system of concern within the project area is Jacko Lake which supports populations of rainbow trout. Based on the range of selenium toxicity thresholds for this fish (22.9 to 29.3 mg/kg [dry weight]) in eggs (Holm et al. 2005) and applying the equation derived by Orr et al. 2012, the proposed WQB for Jacko Lake ranges from 0.0025 to 0.0045 mg/L .

Selenium toxicity to birds has been reported to occur at concentrations exceeding 0.005 mg/L (Adams et al., 2003) and; therefore, the range of Se targets proposed for fish (0.0025 to 0.0045 mg/L) in lentic systems it is also anticipated to be protective of aquatic-feeding birds. Therefore, the protective WQB is set at 0.0025–0.0045 mg/L for lentic systems where only rainbow trout are present and 0.005 mg/L in lotic systems, as higher water concentrations are not expected to be protective for fish-eating birds. In cases where fish other than rainbow trout are present and where selenium toxicity thresholds have not been developed, the WQG of 0.002 mg/L should be applied.

It should be noted that the general consensus in the scientific community recommends a tissue guideline or benchmark based on concentrations of selenium in either aquatic biota eggs or in whole body fish, as the most appropriate approach to evaluate toxicological effects of this element in aquatic environments. Therefore, it is recommended that the assessment of potential effects of selenium on aquatic health be based on measured and/or predicted selenium concentrations in fish tissue. The WQB developed above can be adopted as a preventative measure until a more relevant benchmark based on selenium tissues levels can be developed for the Project area. Fish tissue concentrations could be determined using historical data or additional sampling.

6.0 SUMMARY

Site-specific WQBs for chloride, arsenic, hexavalent and trivalent chromium, copper, molybdenum, and selenium were derived for aquatic environments that may receive effluent from the Ajax Project, an open pit copper and gold mine located in Kamloops, BC (Table 3). A chronic toxicity database was created from fact sheets used to derive relevant BC, Canadian and US Water Quality Guidelines (CCREM 1987; CCME 1999; CCME 2003; US EPA 2007a; BC MOE 2015), the ECOTOX databases (US EPA 2007a), and by searching for other available peer-reviewed scientific literature from journal databases (e.g., Cambridge Scientific Abstracts, PubMed). Data were screened for suitability based on inclusion or exclusion criteria specified by CCME (2007) for developing WQBs. The lower threshold approach (CCME 2007), which considers the lowest toxicity value from a high quality study combined with an appropriate safety factor, was then used to develop WQBs for each parameter of concern based on the water quality conditions of the Project's receiving aquatic environments.

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Table 3 Water Quality Benchmarks for Receiving Aquatic Environments for the Ajax Project

Parameter	Unit	BC MOE ¹ Water Quality Guideline	Water Quality Benchmark
Arsenic	µg/L	5	32
Chloride	mg/L	150	388
Chromium	µg/L	Cr(VI) = 1.0 Cr(III) = 8.9	Cr(VI) = 1.0 Cr(III) = 8.9
Copper	µg/L	15.2	25.6
Molybdenum	mg/L	0.05	0.18
Selenium	µg/L	2.0	Lentic systems with rainbow trout = 2.5 to 4.5 Lotic systems = 5.0 Systems where fish other than rainbow trout occur ² = 2.0

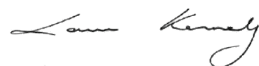
NOTES:
¹ BC MOE: British Columbia Ministry of Environment
² Selenium toxicity thresholds using fish tissue sampling may be used to develop additional WQBs for selenium

7.0 CLOSURE

We trust the information herein is sufficient for your needs at this time. Should you have any questions or require further information, please do not hesitate to contact the undersigned.

Regards,

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