APPENDIX D

MEMO

Date: May 11, 2011 **HCP Ref No.:** CZN1682

From: John Wilcockson and Martin Davies

To: David Harpley, CZN

Subject: Prairie Creek Mine – Water Quality Objectives (Memo 1)

1.0 INTRODUCTION

1.1 BACKGROUND

This memo follows a series of documents produced previously (i.e., Dubé and Harwood 2010, Harwood 2010a,b, Hatfield 2010, 2011) related to the prediction and recommended management of potential aquatic effects of discharges from Canadian Zinc Corp. (CZN)'s Prairie Creek Mine. Specifically, the contents of this document represent the update and expansion of the contents of these previous assessments, stemming from technical discussions between regulators and CZN at Yellowknife on April 12, 2011.

The purpose of the effects assessment is to:

1. Derive protective site-specific water quality objectives for Prairie Creek (SSWQO);
2. Assess potential aquatic effects (to all trophic levels) of discharges from the Prairie Creek mine by:
   - Comparing predicted downstream concentrations of analytes of concern against SSWQO and, where appropriate, other indicators of environmental effect, under a range of operating and environmental conditions;
   - Assessing risks to aquatic biota of bioaccumulative substances (i.e., mercury and selenium);
   - Assessing whole-effluent toxicity and sources of any observed toxicity in effluent; and
   - Assessing potential enrichment effects related to nutrient discharges; and
3. Derive effluent quality criteria (EQCs), and assess downstream concentrations of analytes of concern with EQCs against derived SSWQOs.

In this memo, updated site-specific water quality objectives (SSWQO) for Prairie Creek are derived and evaluated. These SSWQOs are then compared against modelled concentrations of analytes of concern downstream from the mine under various mine-discharge and creek-flow scenarios.

This memo also discusses the potential physical effects of the mine discharge on fish and fish habitat, including the passage of migrating fish past the exfiltration trench.

2.0 SITE-SPECIFIC WATER QUALTIY OBJECTIVES

2.1 INTRODUCTION

Proposed SSWQO derived for the Prairie Creek Mine using the Canadian Council of Ministers of the Environment (CCME) Reference-Condition Approach (RCA) (CCME 1991) were previously reported by the Saskatchewan Research Council in the following documents:

- The report, *Development of Site-Specific Water Quality Guidelines for Prairie Creek, NWT, March 2010* (Dubé and Harwood 2010), which provided a full rationale for the derivation process and proposed objectives for chloride, total cadmium, total copper, total lead, total mercury, total selenium and total zinc;
- The memo, *Site-Specific Water Quality Objectives for Prairie Creek, NWT, September 2010* (Harwood 2010a), which proposed SSWQO for some additional analytes of concern requested by regulators in Information Requests, namely total iron, arsenic, silver, and antimony, dissolved sulphate, total ammonia-N, nitrate-N, nitrite-N, total phosphorus and total dissolved solids (TDS); and
- The memo, *Site-Specific Water Quality Objective for Zinc in Prairie Creek, NWT, September 2010* (Harwood 2010b), which proposed a revised SSWQO for zinc.

In this document we refer to these proposed SSWQOs as "RCA-derived benchmarks". The RCA-derived benchmarks represent the upper limit of natural background concentrations of various analytes of concern (AOC).

Subsequently, Hatfield Consultants outlined an iterative SSWQO derivation approach (Attachment 1, Hatfield 2010). In this iterative approach, the use of RCA-based benchmarks was proposed as a first step, paired with consideration of other published guidelines and direct toxicity testing. Other guidelines were considered because the RCA-derived values are based only on upstream conditions, rather than toxicological information, and therefore do not necessarily provide realistic thresholds for potential effects in the aquatic receiving environment. Guidelines published by the CCME are based on toxicity testing data and provide a more scientifically defensible threshold for assessing the potential for toxic effects, although they are considered by some to be insufficiently protective for northern lakes and rivers, particularly for nutrients (i.e., nitrogen and phosphorus), which may naturally be present in very low concentrations, and dissolved metals in Northern water bodies that may have low natural hardness.

Hatfield (2010) outlined a scientific approach for evaluating and possibly adopting published guidelines as SSWQOs, which also considered the results of whole-effluent toxicity testing. Conceptually, this approach first assessed whether Prairie Creek water quality downstream of the mine would not change measurably from upstream conditions (i.e., would remain within the natural range of upstream variability, defined using the RCA approach) during mine operations. If this was predicted to be the case, then the RCA-based benchmarks would be adopted as water quality objectives for Prairie Creek downstream of the mine. However, if water quality modelling predicted a measurable change in specific water quality variable(s) downstream of the mine relative to upstream, then a second-tier assessment of potential effect would be undertaken to determine whether predicted changes in water quality would cause negative (acutely or chronically toxic) effects downstream. This second-tier assessment would be done using the CCME guideline (or equivalent provincial guidelines, where CCME guidelines do not exist).

2.2 CALCULATION OF RCA-BASED WQO

During the April 12, 2011 technical meeting, a reviewer raised the concern that the method used for calculating RCA-derived concentrations of various analytes of concern may have been confounded by the presence of numerous non-detectable concentrations for some variables. These RCA-derived benchmarks were derived statistically, as two standard deviations (SDs) above the mean upstream concentration (Dubé and Harwood 2010, Hatfield 2011). In order to calculate the mean+2SD, Dubé and Harwood (2010) assumed the non-detectable concentrations were equal to equal half of the method detection limit. A small number of non-detectable values in a large data set are unlikely to have a large influence on the calculated mean+2SD; however, a higher proportion can generate an inaccurate estimate of the reference condition, particularly where detection limits change within the dataset, as is the case for analytes such as mercury in the historical Prairie Creek dataset. Therefore, in cases where a dataset contains a large proportion of non-detects, a 90th percentile concentration provides a better upper estimate of reference condition. Unlike the mean+2SD estimate, the 90th percentile is not quantitatively affected by specific values of lower concentrations (often reported as not-detect) in calculations.

Consequently, RCA-based benchmarks were re-calculated using the 90th percentile for analytes of concern where numerous non-detectable values appeared in the dataset (Table 1).

If the proportion of non-detectable (or suspected non-detectable) concentrations was less than 5% of the total number of measurements, then the Mean+2SD concentrations were maintained as the background concentration. In these cases, the concentration of the sample below the detection limit was assumed to be equal to the detection limit.

If non-detectable values were reported for more than 5% of measurements, then the 90th-percentile approach was used for calculating the RCA benchmark. If the 90th percentile concentration was less than any non-detected measurements (or suspected non-detects), these specific measurements were eliminated from the calculation of the 90th percentile.

The revised reference-condition concentrations were often lower than the previously calculated RCA concentrations based on the Mean+2SD. This supports the assertion that detection limits may have been artificially elevating the calculated background concentrations.

Shaded concentrations in (Table 1) indicate 90th percentiles calculated from datasets consisting primarily of non-detectable values. One of the following conditions were met:

- The concentrations immediately below the calculated 90th percentile were reported as not-detected; or

- There were some reported non-detectable concentrations greater than the calculated 90th percentile (these concentrations were excluded from the calculation).

The RCA-derived Benchmark for these analytes of concern should not be considered to be precise representations of upstream concentrations.

For mercury and silver, specifically, all measured upstream concentrations were non-detectable values. Therefore, no representative RCA-derived benchmark could be derived using either method, making use of a published guideline for benchmarking a necessary and appropriate approach.

Table 1 Considered site-specific water quality objectives for Prairie Creek downstream of the Prairie Creek Mine, including those derived using Reference-Condition Approach, and published benchmarks from CCME and other sources.

		RCA-derived Benchmarks		CCME		
	units	Mean + 2SD	90th percentile	Current	Proposed	Alternative
Cd	µg/L	NA	0.05	0.017	**0.38**[3]	-
Cu	µg/L	NA	0.74	5.17	-	-
Pb	µg/L	NA	0.3	7	-	-
Se	µg/L	2.22	NC	1	-	-
Zn	µg/L	19.3	NC	30	**35**[4]	-
Sb	µg/L	NA	0.15	-	-	20[5]
As	µg/L	NA	0.14	5	-	-
Fe	µg/L	242	NC	300	-	-
Hg	µg/L	NA	NA	0.026	-	-
Ag	µg/L	NA	NA	0.1	-	-
NH_3-N	mg/L	NA	0.007	0.409[1]	-	-
NO_3-N	mg/L	0.83	NC	2.900	-	-
NO_2-N	mg/L	NA	0.01	0.060	-	-
Total P	mg/L	NA	0.0034	0.004 / <50%[2]	-	-
SO_4	mg/L	121	NC	-	-	100[6] / 200[7]
TDS	mg/L	413.0	NC	-	-	-

Shaded concentrations: see text above table.

1 Calculated from the un-ionized ammonia guideline of 19 µg/L (see discussion on ammonia below). Objective may have to be revised downwards if winter mine water flows greater than "High K" are encountered.

2 Value of 4 µg/L CCME Total Phosphorus "trigger range" in ultra-oligotrophic waters for further investigations (not a toxicological threshold). CCME guideline also recommends <50% increase from background conditions to be environmentally acceptable.

3 Revised, hardness-based Cd guideline (Roe 2009), assuming a hardness of 210 mg/L.

4 Revised, hardness-based Zn guideline is hardness-based (Roe 2009) assuming a hardness of 200 mg/L.

5 Ontario Working Guideline for antimony (Fletcher *et al*. 1996).

6 British Columbia Interim Guideline for sulphate (BCMoE 2000).

7 Proposed objective for sulphate, based on recent research (Elphick *et al*. 2010). Hardness of 200 mg/L was assumed.

NA = indicated that an RCA-derived benchmark could not be calculated. This was due to a paucity of quantifiable data.

NC = not calculated 90th percentiles were only used when the original approach (mean+2SD) could not be used due to NDs.

2.3 ADOPTION OF TOXICITY-BASED BENCHMARKS AS WQOS

Because the reference-condition approach does not consider toxicity information, it is not a good predictor of potential effects of water quality on stream biota. As such, exceedance of an RCA-derived benchmark does not indicate on its own that there is any potential for effects on aquatic biota. However, some reviewers were concerned that reliance only on published national guidelines may not be sufficiently protective of aquatic species resident in northern waters.

It should be noted that "northern waters" encompasses an immense region of vastly different climatic and ecological regions. The Prairie Creek mine sits at the edge of the Boreal ecoclimatic region, which also encompasses the bulk of "southern" Canada, from Newfoundland to northern British Columbia (Environment Canada 1989).

To assess the applicability of relevant CCME or other published guidelines to Prairie Creek (Table 1), the following approach was followed:

1. Acute and sublethal toxicity testing was undertaken on samples of simulated whole effluent. An indication of a threshold of toxicity for individual contaminants of whole effluent may be made through identification of concentrations of individual analytes of concern in the most concentrated sample *not* exhibiting toxicity. Testing a simulated effluent containing a mixture of contaminants also effectively tested for additive or synergistic effects of individual analytes of concern. If the concentration of an individual analyte of concern in the highest concentration of effluent not resulting in an effect was greater than both the RCA-derived benchmark and the CCME guideline, that provided evidence supporting the adoption of the CCME guideline. *Toxicity testing results are discussed further in an accompanying memo.*

2. Comparison of CCME guidelines with published toxicity data describing northern species or taxanomic groups representative of those found in cold oligotrophic streams, including those identified in Prairie Creek by Spencer *et al.* (2008) and others. Hatfield conducted a literature review to obtain available toxicity test information for northern species exposed to each of the analytes of concern. Toxicity results were either compared directly with CCME water quality guidelines, or the toxicity test results were plotted on the species sensitivity curve that was used in the derivation of the original CCME water quality guideline.

Each analyte of concern is discussed separately below.

2.3.1 Antimony

There is little available aquatic toxicity data for antimony. A search of available literature yielded only toxicity tests with standard toxicity test species. The results indicated that the Ontario guideline of 20 µg/L (proposed for Prairie Creek) is over twenty times lower than the lowest toxicity threshold concentration found. Therefore, we do not anticipate any effects of antimony on aquatic organisms at this concentration.

Figure 1 Available toxicity measurements for antimony relative to the Ontario guideline.

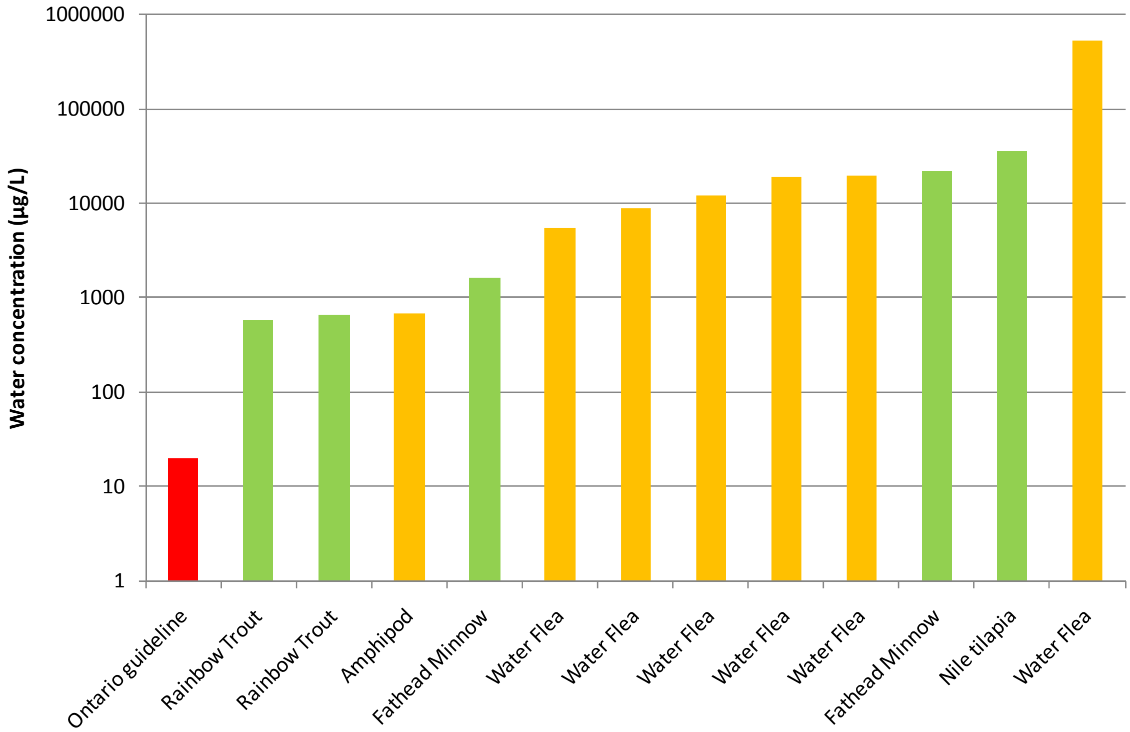


Table 2 Available toxicity measurements for antimony relative to the Ontario guideline.

Common Name	Species	Conc (µg/L)	Reference	Notes
Ontario guideline	**-**	***20***	**-**	**-**
Rainbow trout	*O. mykiss*	580	1	28-day LC50
Rainbow trout	*O. mykiss*	660	2	28-day LC50
Amphipod	H. azteca	687	3	7-day LC50
Fathead minnow	*P. promelas*	1,600	4	28-day CV (larval)
Water flea	*D. magna*	5,400	5	Life cycle test
Water flea	*D. magna*	9,000	6	2-day LC50
Water flea	*D. magna*	12,100	7	2-day LC50 (fed)
Water flea	*D. magna*	18,800	8	2-day LC50 (unfed)
Water flea	*D. magna*	19,800	9	3-day LC50
Fathead minnow	*P. promelas*	21,900	10	4-day LC50 (larval)
Nile tilapia	*O. mossambicus*	35,500	11	4-day LC50 (larval)
Water flea	*D. magna*	530,000	12	2-day LC50

1 Birge 1978.
2 Birge *et al.* 1980.
3 Borgmann *et al.* 2005.
4 Kimball, unpublished (as cited in Beak 2002).
5 Kimball, unpublished (as cited in Beak 2002).
6 Bringman and Kuhn 1959.
7 Kimball, unpublished (as cited in Beak 2002).
8 Kimball, unpublished (as cited in Beak 2002).
9 Anderson 2002.
10 Kimball, unpublished (as cited in Beak 2002).
11 Lin and Hwang 1998.
12 LeBlanc 1980.

2.3.2 Arsenic

The CCME factsheet for arsenic provides a species-sensitivity curve. We adopted this curve and added available toxicity data for northern species, shown as red data points in Figure 2. These data points are for 96-hour mortality tests using a sensitive life stage of arctic grayling and coho salmon (Table 3). The data indicate that the adoption of the CCME guideline of 5 µg/L should be adequately protective.

Figure 2 CCME species sensitivity curve for arsenic with northern species added.

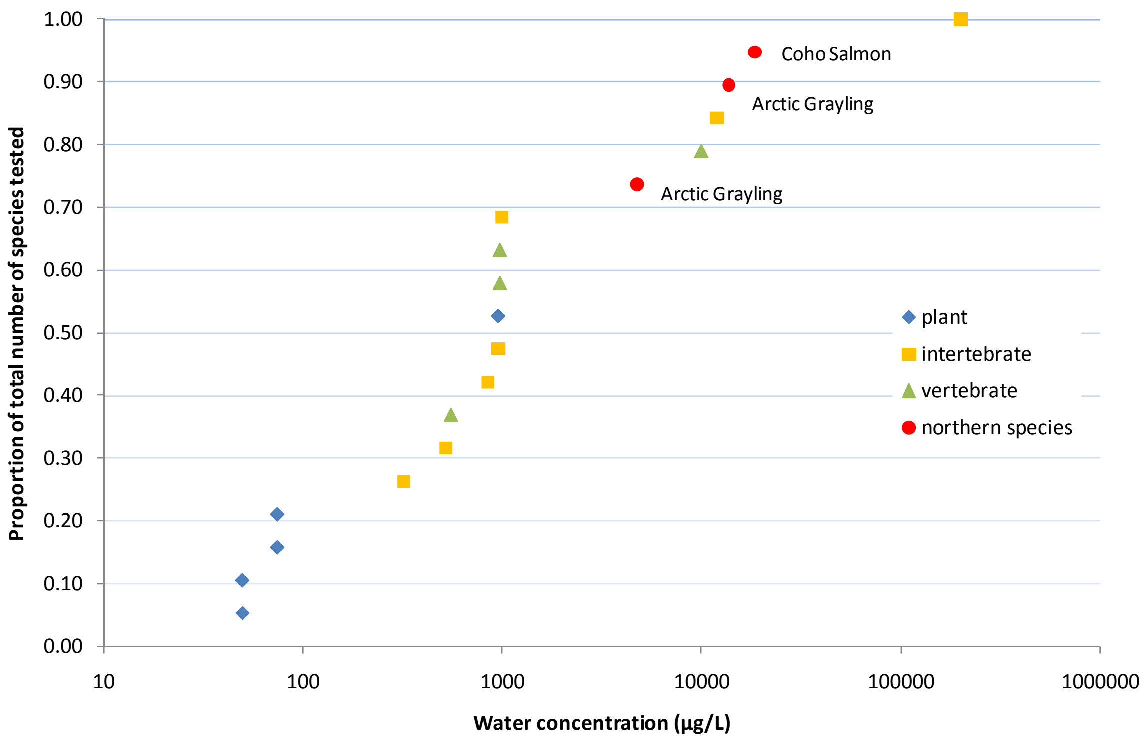


Table 3 CCME species sensitivity curve for arsenic with northern species added.

Contaminant	Species	Conc (µg/L)	Hardness (mg/L)	Notes
Aquatic plant	*S. obliquus*	50		
Aquatic plant	*S. obliquus*	50		
Aquatic plant	*M. granulata*	75		
Aquatic plant	*O. vallesiaca*	75		
Copepod	*C. vernalis*	320		
Water flea	*D. magna*	520		
Rainbow trout	*O. mykiss*	550		
Copepod	*B. longirostris*	850		
Crustacean	*G. pseudoimnaeus*	960		
Aquatic plant	*S. quadricus*	960		
Climbing perch	*A. testudineus*	970		
Crayfish	*C. batrachus*	970		
Water flea	*C. dubia*	1000		

Table 3 (Cont'd.)

Contaminant	Species	Conc (µg/L)	Hardness (mg/L)	Notes
Arctic grayling	*T. arcticus*	4760	40-43	1
Tusk fish	*C. fasciatus*	10000		
Water flea	*S. serrulatus*	12000		
Arctic grayling	*T. arcticus*	13700	41	2
Coho salmon	*O. kisutch*	18500	42	3
Rotifer	*P. roseola*	200000		

Shaded species represent added northern species.

1. Juvenile 96hr-LC50, Buhl *et al* 1991.
2. Juvenile 96hr-LC50, Buhl *et al* 1990.
3. Juvenile 96hr-LC50, Buhl *et al* 1991.

2.3.3 Cadmium

The CCME factsheet for cadmium provides a species-sensitivity curve. We adopted this curve and added available toxicity data for northern species shown as red data points in Figure 3, including sublethal endpoints for bull trout and developmental endpoints for chironomids. Chironomids, commonly known as midges, have been documented in Prairie Creek water. Cadmium toxicity is greatest in low-hardness water. The bull trout toxicity test was conducted with moderately hard water (30-82 mg/L), not the very hard water of Prairie Creek (250 mg/L). The data indicate that the adoption of the proposed CCME guideline (0.38 µg/L) should be adequately protective of Prairie Creek.

Figure 3 CCME species sensitivity curve for cadmium with northern species added.

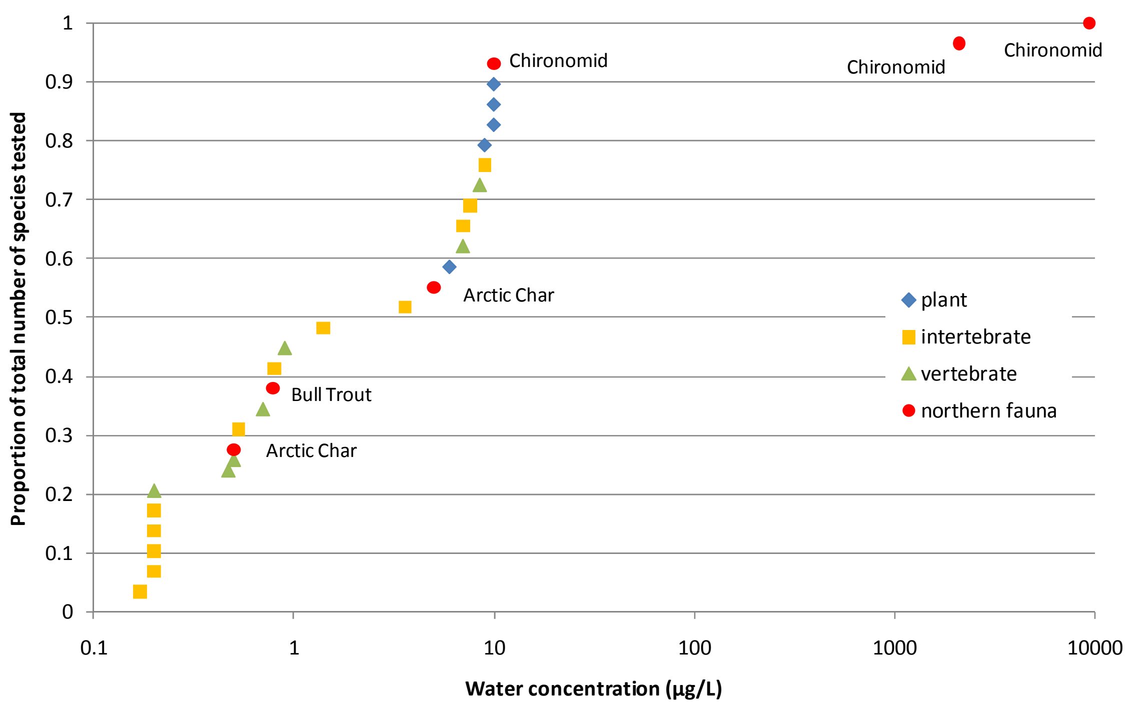


Table 4 CCME species sensitivity curve for cadmium with northern species added.

Contaminant	Species	Conc (µg/L)	Hardness (mg/L)	Notes
	D. magna	0.17		
	C. reticulata	0.2		
	D. pulex	0.2		
	D. galeata mendotae	0.2		
	H. gibberum	0.2		
	S. salar	0.47		
	M. saxatilis	0.5		
Char	*S. alpinus*	0.5	81.2	1
	H. azteca	0.53		
	O. mykiss	0.7		
Bull Trout	*S. confluentus*	0.786	30	2
	O. tshawytscha	0.8		
	O. mykiss	0.9		
	O. kisutch	1.4		
	D. magna	3.6		
Char	*S. alpinus*	5	81.2	3
	S. capricornutum	6		
	O. latipes	7		
	S. serrulatus	7		
	G. fossarum	7.6		
	J. floridae	8.5		
	A. imbecilis	9		
	L. minor	9		
	N. linckia	10		
	S. platensis	10		
	T. flocculosa	10		
Chironomid	*P. nubifer*	10	68	4
Chironomid	*C. riparius*	2100	100-110	5
Chironomid	*C. riparius*	9,380	8	6

Shaded species represent added northern species.

1. fish ability to capture prey decreased, Kislalioglu *et al* 1996.
2. significantly reduced growth and survival, Hanson 2002.
3. fewer attacks on prey, Kislalioglu *et al* 1996.
4. 70% emergence success, Hatakeyama 1987.
5. mortality to first instar, Williams 1986.
6. mortality to first instar, Béchard 2007.

2.3.4 Copper

CCME does not provide a factsheet for copper. We compared available toxicity data for northern species shown as green and yellow bars (Figure 4), including sublethal endpoints for Arctic char and bull trout, and developmental and lethality endpoints for a chironomid, mayfly and caddisfly. All of these aquatic insects have been documented in Prairie Creek water. Mayflies and caddisflies are known to be particularly sensitive to metal exposure. Similar to cadmium, copper toxicity is dependent on water hardness, with highest toxicity in low hardness water. With the exception of the caddisfly, mayfly and bull trout data, all tests were conducted using low to moderate hardness water, rather than very hard water as found in Prairie Creek.

One study (Buhl and Hamilton 1990) found acute toxicity of copper to juvenile arctic grayling at LC50 concentrations as low as 2.58 µg/L Cu. However, this same study found LC50 concentrations of 30.0 and 49.3 µg/L for copper to juvenile arctic grayling collected from a different location. The first test appears to be an anomaly, given other related fish species exhibited toxicity endpoints more than ten-times higher for similar endpoints. However, it is not possible with this single test result to assign cause to artifacts of the test or to a unique sensitivity of the first population tested; no QA/QC information regarding the test were provided in this study for review. This test was performed in low to moderate hardness water (40-43 mg/L). The CCME guideline adjusts upward from 2 µg/L, depending on hardness. A hardness of 250 mg/L yields a hardness-adjusted guideline of 5.17 µg/L (CCME 2011). For comparison, the British Columbia hardness-adjusted water quality guideline for very hard water (250mg/L) is 8 µg/L (British Columbia 1989). Given the high hardness of Prairie Creek and the overall weight-of-evidence of toxicity data, the proposed guideline of 4 µg/L should be protective of aquatic life.

Figure 4 Northern species toxicity measurements for copper relative to current CCME guideline.

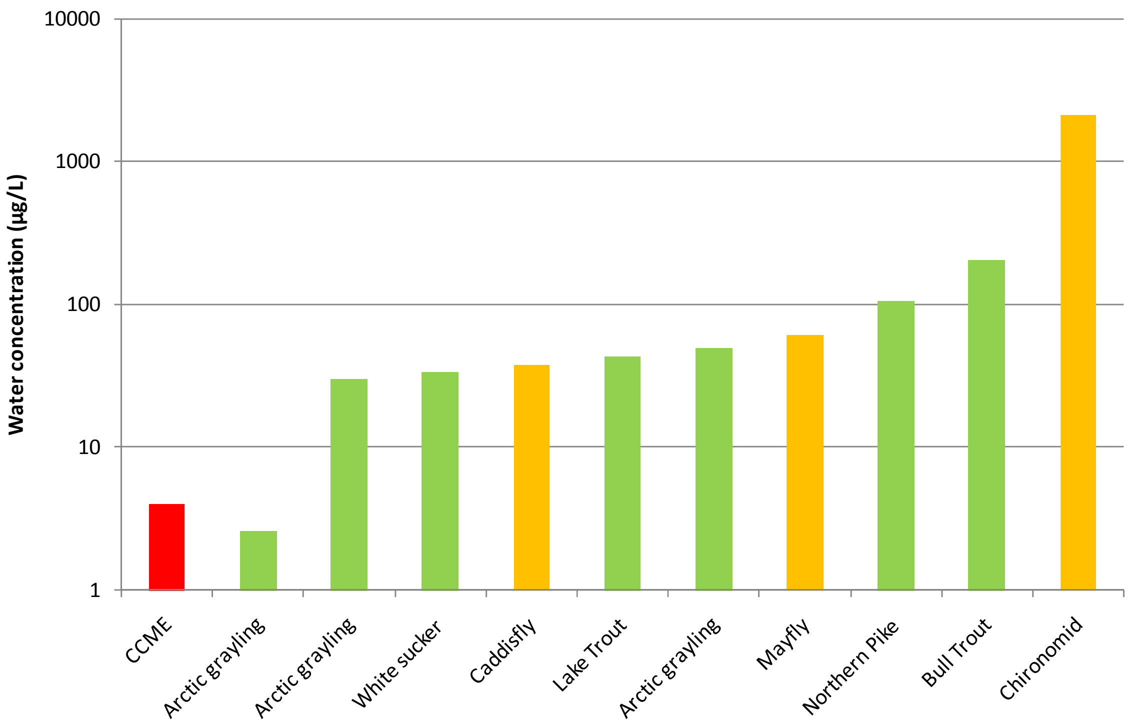


Table 5 Northern species toxicity measurements for copper relative to current CCME guideline.

Common Name	Species	Conc (µg/L)	Hardness (mg/L)	Reference	Notes
CCME		***5.17***			
Arctic grayling	*T. arcticus*	2.58	40-43	1	96-hr Survival (juvenile)
Arctic grayling	*T. arcticus*	30.0	40-43	1	96-hr Survival (alevin)
White sucker	*C. commersonii*	33.8	45.4	2	juveniles significantly reduced
Caddisfly	*H. angustipennis*	38	211	3	LC10
Lake trout	*S. namaycush*	43.5	45.4	2	juveniles significantly reduced
Arctic grayling	*T. arcticus*	49.3	40-43	1	96-hr Survival (juvenile)
Mayfly	*E. virgo*	61	210	3	LC10
Northern pike	*E. lucius*	104.4	45.4	2	juveniles significantly reduced
Bull trout	*S. confluentus*	205	220	4	LC50- 120-hr
Chironomid	*C. riparius*	2090	8	5	instar survival

1. Buhl and Hamilton 1990.
2. McKim *et al*. 1978.
3. van der Geest *et al*. 2001.
4. Hansen *et al*. 2002.
5. Béchard *et al*. 2008.

2.3.5 Lead

CCME does not provide a factsheet for lead. We compared available toxicity data for northern species shown as green and yellow bars (Figure 4), including data for sensitive life-stages of arctic grayling and coho salmon, and growth and developmental endpoints for chironomids, a mayfly and an amphipod. All these aquatic invertebrates have been observed in cold temperature streams. Mayflies are generally known to be particularly sensitive to metal exposure. Similar to cadmium and copper, lead toxicity decreases with increasing water hardness. All tests were conducted using low to moderate hardness water, compared to Prairie Creek's water has a high hardness of 250 mg/L. The data indicate that the adoption of the CCME guideline (7 µg/L) should be adequately protective.

Figure 5 Northern species toxicity measurements for lead relative to current CCME guideline.

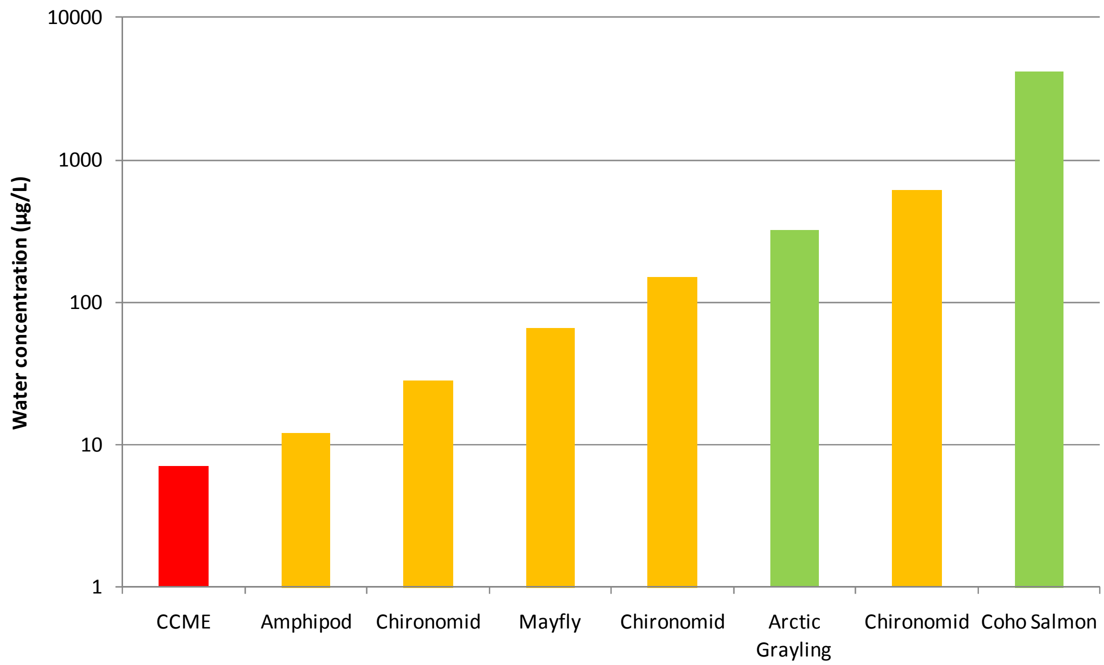


Table 6 Northern species toxicity measurements for lead relative to current CCME guideline.

Contaminant	Species	Conc (µg/L)	Hardnes s (mg/L)	Reference	Notes
CCME		***7***			
Amphipod	*H. azteca*	12	138	1	EC20 life cycle test
Chironomid	*C. dilutus*	28	32	1	EC20 life cycle test -growth
Mayfly	*B. tricaudatus*	66	20	1	EC20 early instar development/survival
Chironomid	*C. dilutus*	149	48	1	EC20 early instar development/survival
Arctic grayling	*T. arcticus*	<320	41.3	2	Juvenile 96-hour LC50
Chironomid	*C. riparius*	610	8	3	1st instar survival
Coho salmon	*O. kisutch*	4180	41	4	Juvenile 96-hour LC50

1. Mebane *et al*. 2008.
2. Buhl *et al*. 1990.
3. Béchard *et al*. 2008.
4. Buhl *et al*. 1991.

2.3.6 Zinc

CCME does not provide a factsheet for zinc. We compared available toxicity data for northern species shown as green and yellow bars (Figure 4), including data for sensitive life-stages for bull trout, arctic grayling, cutthroat trout and chinook salmon, and growth and developmental end points for chironomid. Mayfiles are generally known to be particularly sensitive to metal exposure. Similar to cadmium and copper, zinc toxicity is dependent on water hardness. All tests were conducted using low to moderate hardness water compared to Prairie Creek's high hardness of 250 mg/L. The data indicate that the adoption of the proposed CCME guideline (35 µg/L) should be adequately protective.

Figure 6 Northern species toxicity measurements for zinc relative to current CCME guideline.

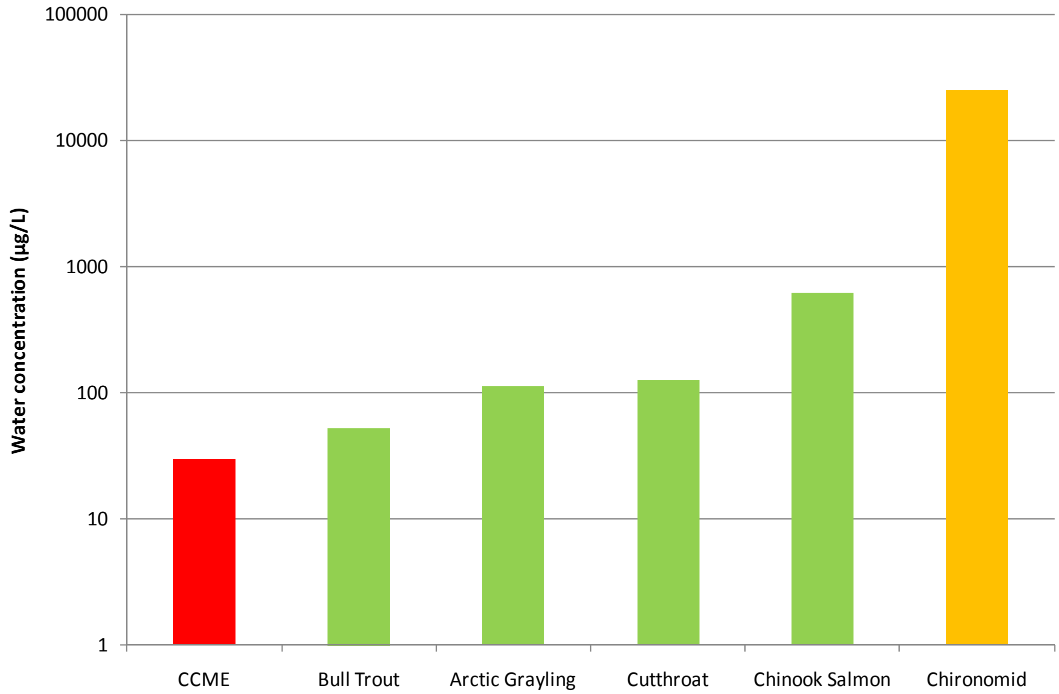


Table 7 Northern species toxicity measurements for zinc relative to current CCME guideline.

Contaminant	Species	Conc (µg/L)	Hardness (mg/L)	Reference	Notes
CCME		***30***			
Bull trout	*S. confluentus*	52.7	30	1	120-hr LC50
Arctic grayling	*T. arcticus*	112	40-43	2	96-hr Survival
Cutthroat	*O. clarkii*	125	30	3	EC20 juvenile growth/survival
Chinook salmon	*O. tshawytscha*	623	25	3	EC20 early life stage test
Chironomid	*C. riparius*	25,000	8	3	> instar survival

1. Hansen *et al*. 2002.
2. Buhl *et al*. 1990.
3. Mebane *et al*. 2008.

2.3.7 Ammonia

In the natural environment, ammonia is commonly found in both ionized (NH_4^+) and unionized (NH_3) forms. Of the two, NH_3 has a much greater toxic potency, but fortunately is found at much lower concentrations than NH_4^+. Conversely NH_4^+ is a bioavailable nutrient; potential for nutrient-related enrichment in Prairie Creek is addressed in a separate memo, *Prairie Creek Mine – Potential Enrichment Effects (Memo 6)*. The proportion of NH_3 in water samples is highly dependent on temperature and pH. CCME provides a guideline of 19 µg/L for NH_3. Unfortunately, no test results using northern fish species were found. In Figure 7 and Table 8 below, the guideline was compared to species having some relevance to Prairie Creek; rainbow trout, sockeye salmon and emergent insects (mayflies and caddisflies). The results indicate that fish appear to be most sensitive to NH_3. The CCME NH_3 guideline appears to be sufficiently protective of the selected aquatic organisms.

The CCME fact sheet for ammonia provides an equation for calculating total ammonia (NH_3 plus NH_4^+) based on NH_3 concentration, temperature and pH. The higher the pH and temperature, the greater the proportion of ammonia in the NH_3 form. Using the formula provided by CCME for calculating total ammonia, a total ammonia water quality guideline for Prairie Creek was calculated from the NH_3 guideline in two steps:

1) First by creating a curve modeling the highest pH values observed for any given temperature. Because there is a negative relationship between temperature and pH (Figure 8Figure 8), the lowest calculated total ammonia guideline occurs in winter, especially between two and eight degrees (Figure 9).

2) Second, by calculating the influence of the effluent on downstream pH during low winter flows. Effluent pH is anticipated to range from 9 to 9.5. During lowest flows, creek temperatures were estimated to be no more than 2ºC. Two scenarios were modeled a) a normal to high treated mine water: upstream creek water flow of 1:7; and b) an extreme treated mine water:upstream creek water flow of 1.8:1. For both scenarios it was assumed that the downstream creek water temperature was 2ºC, effluent pH was 9.5 and stream pH was 8.65. For the low to high treated minewater flow scenario, (a), the estimated pH downstream of the mine was 8.7. This pH, at 2ºC, results in a site-specific guideline of 409 µg/L. For the extreme treated minewater flow scenario, (b), the estimated pH downstream of the mine was 9.0. This pH, at 2ºC, results in a site-specific guideline of 214.2 µg/L.

Figure 7 Northern species toxicity measurements for unionized-ammonia relative to current CCME guideline.

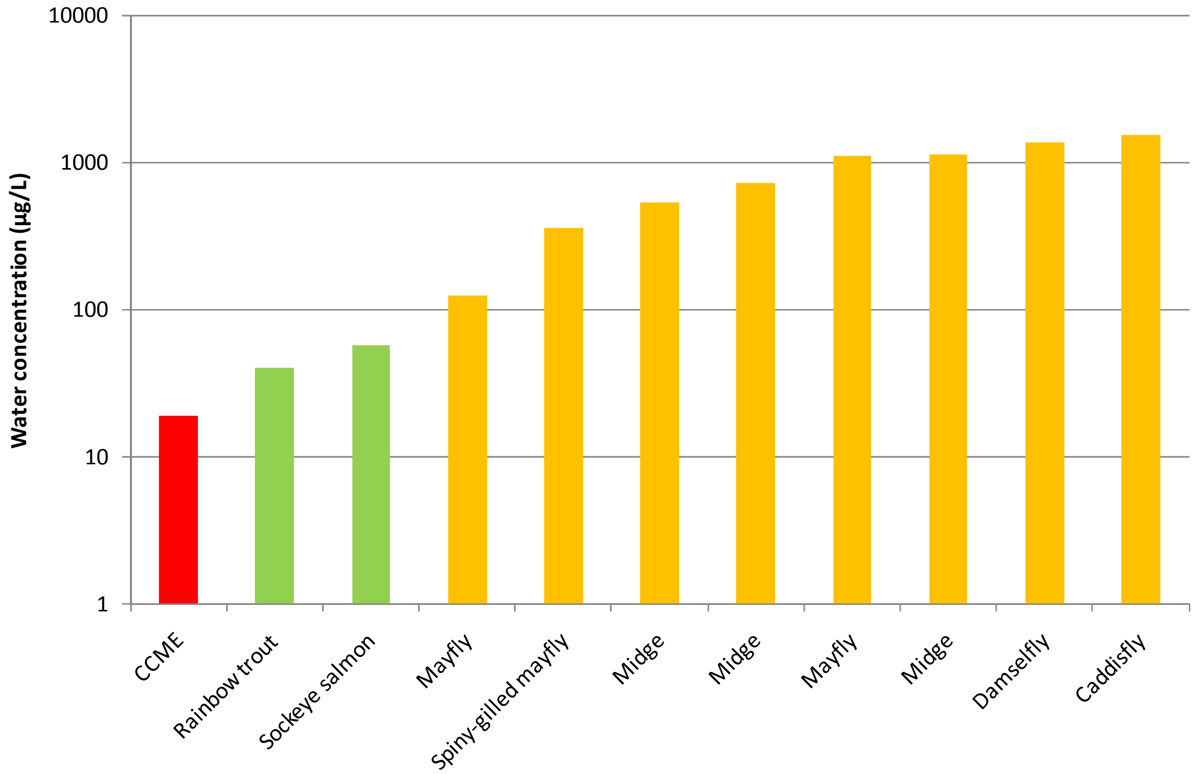


Table 8 Northern species toxicity measurements for unionized-ammonia relative to current CCME guideline.

Common Name	Species	Conc (µg/L)	Reference	Notes
CCME		19		
Rainbow trout	*O. mykiss*	40	1	4-month exposure/physiological effects
Sockeye salmon	*O. nerka*	57	2	62-day hatchability EC20
Mayfly	*Deleatidium*sp	126	3	29-day EC50
Spiny-gilled mayfly	*Coloburiscus humeralis*	357	3	29-day LOEC
Midge	*Chironomus tetans*	530	4	4-day LC50
Midge	*Chironomus tetans*	720	5	10-day LC50
Mayfly	*Baetis rhodani*	1110	6	6.25-day LC50
Midge	*Chironomus riparius*	1140	6	6.25-day LC50
Damselfly	*Enallagma* sp.	1360	6	6.25-day LC50
Caddisfly	*Hydropsyche angustipennis*	1520	6	6.25-day LC50

1. Thurston *et al*. 1984.
2. Rankin 1979.
3. Hickey *et al*. 1999.
4. Besser *et al*. 1998.
5. Schubauer-Berigan *et al*. 1995.
6. Williams *et al*. 1986.

Figure 8 Prairie Creek Relationship between pH and temperature.

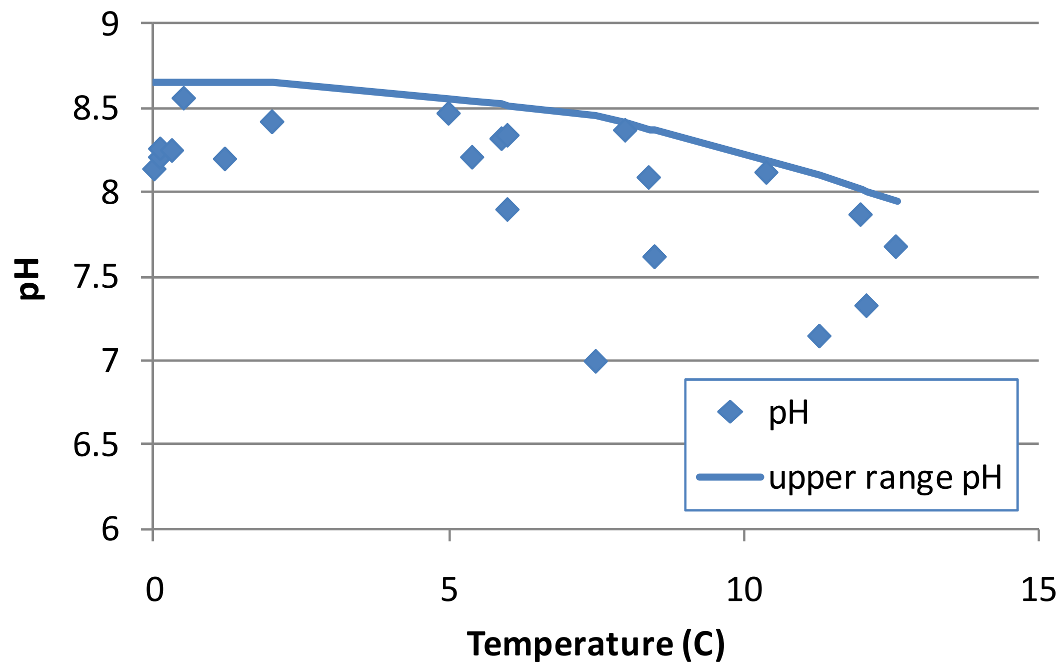
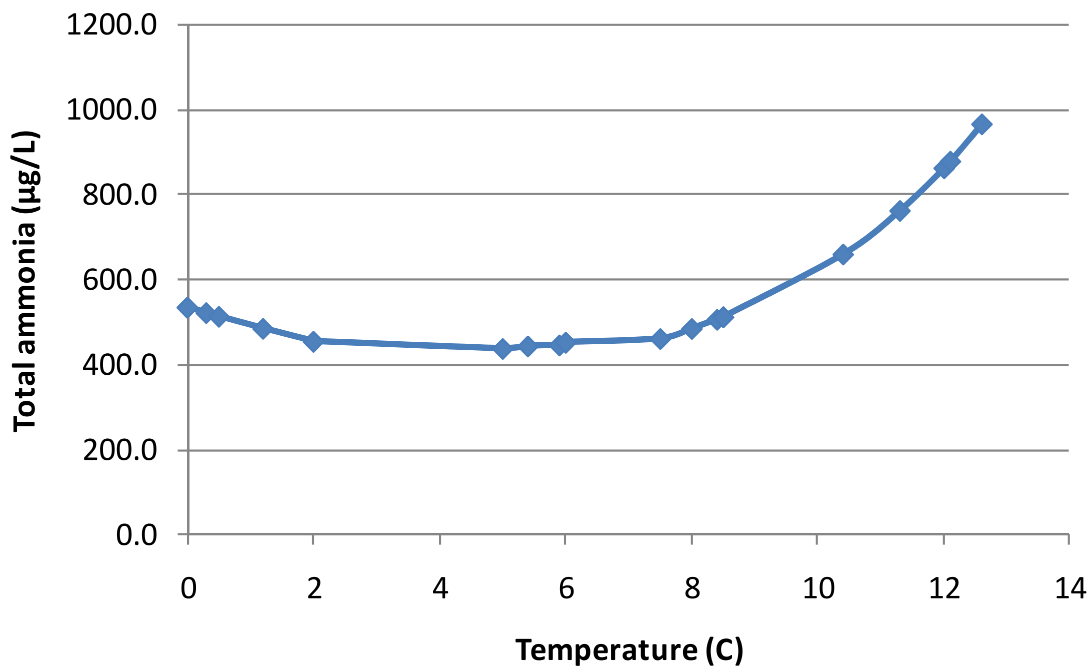


Figure 9 Guideline for total ammonia in Prairie Creek as a function of temperature.



2.3.8 Sulphate

No CCME guideline exists for sulphate. British Columbia uses a water quality guideline for sulphate of 100 mg/L, but has acknowledged that this value may be overly conservative because it does not consider the ameliorating effect of water hardness (Nagpal 2006). Recently published sulphate-toxicity data (Elphick *et al*. 2010) indicate a strong attenuating influence of hardness on sulphate toxicity. Based on hardness-dependant, species-sensitivity curves developed by Elphick *et al*. (2010) for various aquatic species, the relatively high hardness of Prairie Creek water (mean 256 mg/L) should mitigate any potential acute or sub-lethal toxicity of sulphate at concentrations predicted in the creek.

Data presented in the Elphick *et al.* (2010) paper indicate that at a hardness of 256 mg/L (i.e., mean hardness of Prairie Creek), chronic effects would not be observed to sensitive aquatic organisms (such as cladocerans) below sulphate concentrations of approximately 1,000 mg/L. The lowest mean concentration resulting in a chronic effect at a similar hardness (160 mg/L), was 678 mg/L sulphate (range 258-1,059 mg/L). Elphick *et al.* (2010) recommended a guideline of 725 mg/L for hard water (160-250 mg/L).

We have proposed a water quality objective of 200 mg/L, This value represents a conservative interpretation of the Elphick *et al.* (2010) results. Since this concentration was selected fairly arbitrarily, it may need to be revised in future.

2.3.9 TDS

The Prairie Creek mine intends to meet the RCA-derived SSWQO, therefore, an evaluation of a proposed toxicity-based protective benchmark is not necessary.

2.3.10 Iron

The toxicological concern associated with iron is generally with ferrous (Fe^{2+}) iron (BCMOE 2008). Oxygen rapidly oxidizes ferrous iron resulting in the conversion of ferrous iron to ferric iron (Fe^{3+}). If this oxidation occurs within the water column, the chemical oxygen demand associated with the reaction can deplete oxygen in the water column. Ferric iron also results in damage to respiratory surfaces such as gills. CZN anticipates that all iron in solution will be in an oxidized state (due to aeration), and therefore that concerns associated with ferrous (Fe^{2+}) iron are not founded. Toxicity testing conducted to date with simulated effluents has indicated that suppression of oxygen due to chemical oxygen demand will unlikely be an issue. Furthermore, no ferrous (Fe^{3+}) flocs have been observed in test chambers.

2.3.11 Silver

The concentration of silver in treated mine water and treated process water is low and silver is not anticipated to be an analyte of concern once the mine is operational. Modelled silver concentrations in downstream water are at least three times lower than the CCME guideline for silver. Furthermore, the predicted concentrations in water are largely reflective of the background water concentration, which has consistently been below detection limit. Consequently, estimates have been based on method detection limits and estimated downstream concentrations have been over estimated.

2.3.12 Mercury

The concerns related to mercury are generally associated with bioaccumulation and not direct toxicity, and are therefore not sufficiently addressed by regulating water quality alone. *The bioaccumulation related effects of mercury are addressed in a separate memo (Memo 4).*

To assess the CCME guideline protective of aquatic species (from direct water exposure), we compared available toxicity data for northern species and species typically resident of fast moving streams shown as green and yellow bars (Figure 10). These include data for sensitive life-stages for arctic grayling, rainbow trout, coho salmon, and larval LC50s for chironomids and caddisflies. The data indicate that the adoption of the proposed CCME guideline (0.026 µg/L) should be adequately protective.

Figure 10 Northern species toxicity measurements for mercury relative to current CCME guideline.

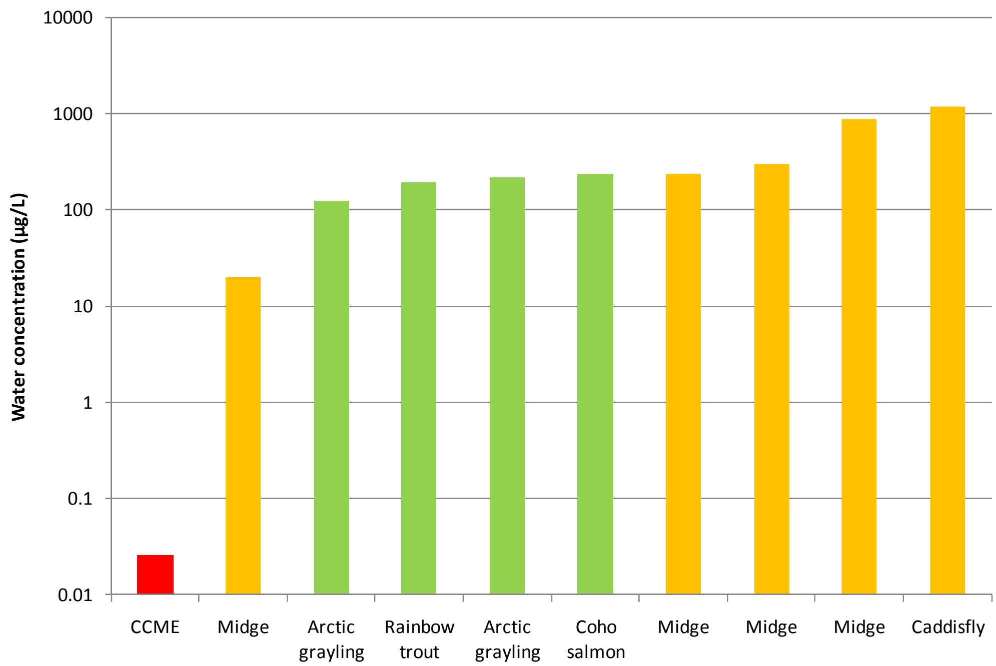


Table 9 Northern species toxicity measurements for mercury relative to current CCME guideline.

Common Name	Species	Conc (µg/L)	Reference	Notes
CCME		***0.026***		
Midge	*Chironomus sp.*	20	1	6.25-day LC50, larvae
Arctic grayling	*T. arcticus*	124	2	4-day LC50, Juvenile fish
Rainbow trout	*O. mykiss*	193	2	4-day LC50, Juvenile fish
Arctic grayling	*T. arcticus*	218	2	4-day LC50, Juvenile fish
Coho salmon	*O. kisutch*	238	2	4-day LC50, Juvenile fish
Midge	*Chironomus tentans*	240	3	6.25-day LC50, larvae
Midge	*Chironomus plumosus*	300	4	4-day LC50, larvae
Midge	*Chironomus plumosus*	880	3	3-day LC50, larvae
Caddisfly	*Trichoptera*	1200	1	4-day LC50, larvae

1 Rehwoldt 1973.
2 Buhl and Hamilton 1991.
3 Hooftman et al. 1989.
4 Vedamanikam 2008.

2.3.13 Nitrate

Nitrate is primarily an enrichment concern rather than a toxicological one. Consequently, the CCME guideline for nitrate has been adopted and enrichment will be monitored as part of the AEMP. *The environmental effects related to enrichment are addressed in a separate memo.*

2.3.14 Phosphorous

Phosphorus is primarily an enrichment concern rather than a toxicological one. The RCA-derived guideline is confounded by mainly non-detectable values in the historical dataset. Therefore, the CCME trisser level for total phosphorus of 4 µg/L for protection of ultra-oligotrophic waters has been adopted and enrichment will be monitored as part of the AEMP. *Potential environmental effects related to enrichment are addressed in a separate memo.*

2.3.15 Selenium

Similar to mercury, the concerns related to selenium are generally associated with bioaccumulation and not direct toxicity, and are therefore not sufficiently addressed by regulating water quality alone. *The bioaccumulation related effects of selenium are addressed in a separate memo (Memo 4).*

2.4 PROPOSED SSWQOS

The following list of recommended objectives, below, should be sufficiently protective of the aquatic environment downstream of the Prairie Creek Mine. Some are based on RCA benchmarks and therefore represent similarity to the upstream concentrations. Others are based on effects-based benchmarks that have been evaluated in a northern species toxicity context.

It should be noted that receiving-water objectives are targets for use in interpretation of environmental quality, rather than firm, regulatory end-points, such as Effluent Quality Criteria. However, mine environmental performance relative to these objectives should be an important factor in ongoing, adaptive management in the Prairie Creek watershed. Particularly given the high variability of flows available for dilution in Prairie Creek during some times of the year, managing downstream water quality, rather than just effluent quality, will be an important element of operational environmental management for the mine.

Table 10 Proposed site-specific water quality objectives for Prairie Creek downstream of the Prairie Creek Mine.

Analyte of Concern	Proposed SSWQO	Derivation/Rationale
Metals		
Antimony (Sb)	20 μg/L	Ontario guideline
Arsenic (As)	5 μg/L	CCME (existing guideline)
Cadmium (Cd)	0.38 μg/L	CCME (proposed guideline)
Copper (Cu)	5.17 μg/L	CCME (existing guideline)
Iron (Fe)	242 μg/L	RCA-derived benchmark
Lead (Pb)	7.0 μg/L	CCME (existing guideline)
Mercury (Hg)	0.026 μg/L	CCME (existing guideline)
Selenium (Se)	2.22 μg/L	RCA-derived benchmark
Silver (Ag)	0.1 μg/L	CCME (existing guideline)
Zinc (Zn)	35 μg/L	CCME (proposed guideline)
Nutrients[1]		
Ammonia (total)	0.409 mg/L[2]	CCME (existing guideline)
Nitrate	2.9 mg/L	CCME (existing guideline)
Total phosphorus	4 μg/L	CCME (existing guideline for protection of ultra-oligotrophic waters)
Ions		
Sulphate	200 mg/L	Based on hardness-based, dose-response relationships published in Elphick *et al*. (2010)
Total Dissolved Solids (TDS)	413 mg/L	RCA-derived benchmark

[1] See discussion below.

[2] Calculated from the un-ionized ammonia guideline of 19 μg/L (see discussion on ammonia above). Objective may have to be revised downwards if winter mine water flows greater than "High K" are encountered.

Specific Note Regarding Nutrients

Because of several factors—including the naturally low-nutrient environment of Prairie Creek, interactions and dependencies between specific nutrients with respect to their effects on primary productivity, and confounding effects of climate and ice cover on algal production—it is important to consider nutrient concentrations in Prairie Creek differently than one would assess other analytes such as metals, where more precise, toxicological thresholds exist.

Although water quality objectives for nutrients have been proposed in this section, effects of nutrient discharges on Prairie Creek will require site-specific assessment and monitoring. A separate memo (Memo 6) discusses potential for enrichment effects in Prairie Creek specifically.

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