Nyrstar Myra Falls Operation
Science-Based Environmental Benchmarks

Development Plan: Myra Creek

Final Report

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Submitted to: **Nyrstar Myra Falls**
Campbell River, BC

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EXECUTIVE SUMMARY

Nyrstar Myra Falls Operations (MFO) is undertaking development of Science-Based Environmental Benchmarks (SBEBs) for water quality parameters identified as exceeding Provincial water quality guidelines (WQGs) in Myra Creek. This document provides background and justification for the undertaking, as well as a description of the procedures to be followed. Candidate constituents of concern were identified based on data collected from 5-in-30 sampling programs conducted during low and high-flow periods, supported by a review of monthly water quality data collected over a 5-year period. Relatively frequent exceedances of WQGs downstream of mine operations were observed for cadmium, copper and zinc, with rare exceedances also noted for nitrite, aluminum and silver. Of note, exceedances related to copper and zinc under high-flow conditions were related to upstream sources, whereas exceedances during low-flow conditions were associated with mine operations. Lead exceeded WQGs only upstream of the mine, and only under high-flow conditions

In contrast to the observed exceedances of WQGs, five cycles of Environmental Effects Monitoring conducted under the federal Metal and Diamond Mining Effluent Regulations (MDMER) have detected no adverse effects on benthic invertebrate or fish populations. Thus, the WQGs overestimate the potential for adverse effects at this site. Potential explanations for this apparent paradox include (1) local water chemistry reduces the bioavailability of the constituents of concern, and (2) local organisms have acclimated to higher concentrations due to periodic exposures to naturally elevated concentrations of metals in the creek. Based on these results, this document describes a process for deriving SBEBs for constituents of concern that will be consistent with available data and protective of aquatic life in the receiving environment.

1.0 SITE CHARACTERIZATION

1.1 Site Profile

Nyrstar Myra Falls Operation (MFO) is a zinc-copper-lead-gold-silver mine located centrally on Vancouver Island, British Columbia. Its legal mining holdings are designated as Strathcona-Westmin (Class B) Provincial Park, which is surrounded by Strathcona (Class A) Provincial Park (Figure 1). The mine produces metal concentrates that are trucked to Campbell River and then loaded onto ships for transport to various refining facilities. Discharges from the mine and mill operations, along with runoff from various areas of the site, are collected and treated in a series of ponds that drain through a single discharge point into Myra Creek which flows into Buttle Lake approximately 2.5 km downstream of the discharge point.

Buttle Lake is the head of the Campbell River watershed, and is located at an elevation of approximately 220 m, with a surrounding drainage basin of approximately 1400 km^2. The basin is within the Leeward Island Mountain (LIM) ecoregion and the Coastal Western Hemlock biogeoclimatic zone. Local waters typically exhibit low hardness and oligotrophic conditions, which largely reflect a surrounding geology composed of shallow glacial alluvium and exposed bedrock. These conditions result in rapid run-off with low concentrations of dissolved solids.

Most of Vancouver Island is underlain by rocks of the Insular Belt of the Canadian Cordillera. The lower portion of this sequence has now been documented as having moved northwards under the influence of plate tectonics. At the base of this sequence is the Sicker Group, considered to be the oldest stratigraphic unit on Vancouver Island. It outcrops along the central spine of the island where it has been faulted upwards through younger rock sequences. It is within the Sicker Group, in a volcanic assemblage of rocks called the Myra Formation, that the ore deposits of Myra Falls are located.

These ore deposits occur in two stratigraphic horizons, termed the Lynx-Myra-Price horizon and the HW horizon. Both horizons are associated with volcanic rhyolite rocks and their derivatives. The ore deposits formed during a period of crustal rifting and volcanism and are genetically described as volcanogenic massive sulphide deposits. These deposits often exhibit complex metal zonation. Individual ore lenses vary significantly in metal content and zonation, lens shape and overall size. The principal sulphide minerals are: pyrite, sphalerite, chalcopyrite and galena, with minor amounts of tennantite and bornite. Secondary copper minerals may be locally significant.

Bedrock in the Myra Valley is overlain by a variety of glacial deposits laid down during and after the Fraser glaciation, which occurred from 29,000 to 13,000 B.P. At the height of this glaciation, a continuous ice sheet covered the area to a minimum elevation of 1300 m above sea level. Basal till, deposited in Myra Valley by the advancing glacier front, is uniform, and characterized as a massive, unsorted deposit composed of volcanic clasts within a silty sand to sand matrix. In the early stages of deglaciation, a lake formed on the valley floor, and glaciolacustrine clay, silt and fine sand were deposited over the basal till. These sediments have been intersected in drill holes - the thickest intersections at mid-valley - in the middle and downstream half of the tailings disposal facility. As melt water volumes increased, coarser glaciofluvial sand and gravel was deposited over the lake sediments. The thickest glaciofluvial deposits, up to 35 m thick, are found at the upstream end of the TDF.

The most recent post-glacial deposits have resulted from the weathering and/or mass wasting of glacial deposits and bedrock. A significant deposit, composed of silty sand and angular rock fragments, is found in the Lynx Mine area. This deposit may be the result of a landslide or may be a late glacial terminal moraine. Other recent mass wasting processes include rock slides, rock falls, debris flows and avalanches. These processes have produced numerous colluvial fans at the base of the valley slopes.

1.2 Hydrology and Precipitation

The climate station in closest proximity to the watershed for which climate normal data were available is located at the Campbell River Airport (elevation 105.5 m) (Environment Canada Climate Station 1021267). Average daily temperatures from 1971 through 2000 ranged from 1.3°C in January to 16.9°C in July and August. Average total annual precipitation between 1971 and 2000 was 1,452 mm, with 109 mm (water equivalent) (i.e., 8%) falling as snow (Barlak and Phippen, 2012). Most precipitation (1,091 mm, or 75%) fell between October and March. Notably, this station is located at a lower elevation than Myra Creek, and the watershed surrounding Myra Creek contains mountains that reach elevations in excess of 2000 m. As a result of these differences in topography, annual precipitation levels at Myra Creek tend to be higher than measured at Campbell River and winter temperatures tend to be lower (Nordin *et al.,* 1985).

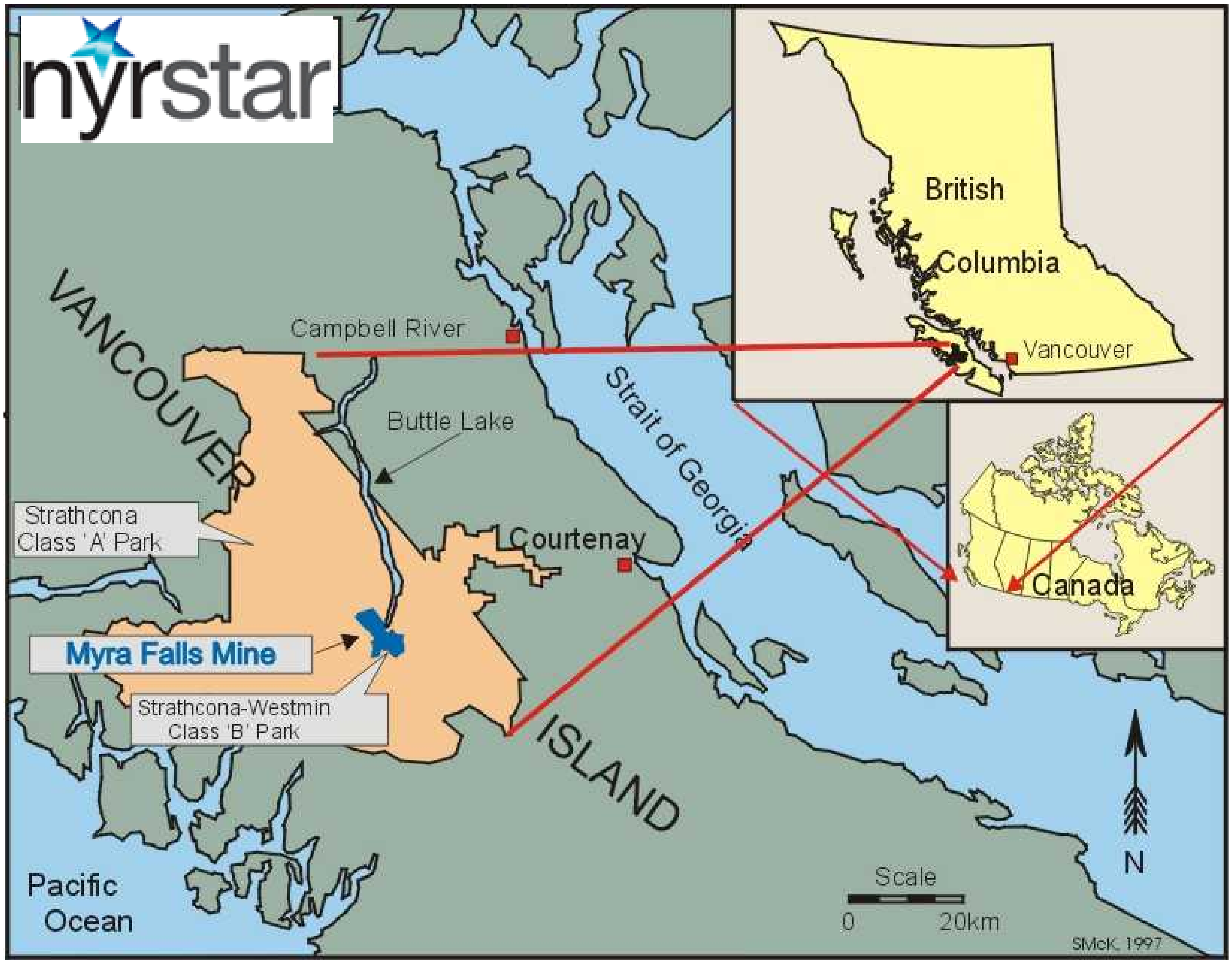


Figure 1. Location of Nyrstar Myra Falls, Vancouver Island, British Columbia.

1.3 Stream Characteristics

Myra Creek is a second-order stream with a watershed of approximately 72 square kilometers located in the mountainous terrain of Strathcona Park. The Creek is approximately 13 km in length and is largely unimpacted by anthropogenic influences above the mine operation. However, upstream of the mine, Myra Creek receives tail race water from the Tennant Lake hydro-electric facilities that help provide MFO's power needs. Flow in the creek fluctuates substantially as a result of seasonal variations in rainfall and snowmelt, but is continuous throughout the year. The creek has low productivity as a result of its short length, relatively steep gradient, low alkalinity and cold temperatures.

Substantial waterfalls are present in Myra Creek, both above and below the mine site. Upper Myra Falls is approximately 4.5 km above the discharge point and drops approximately 20 m in elevation. Lower Myra Falls is at the point of entry of Myra Creek into Buttle Lake, approximately

2.5 km below the discharge point. This cascading waterfall has a height of approximately 60 m and encompasses a tiered series of drops. These waterfalls are barriers to upstream migration of fish and result in a discrete population of fish within Myra Creek

In 1983, a section of the creek was diverted from its historical channel into a 1.4-km engineered channel that flows through the mine site. The banks of the creek in this section are comprised of rip-rap and are largely free from vegetation. Beginning in 1999, the creek bed in this section was narrowed from 20 to 10 m, and improvements to the creek bed (completed in 2002), including insertion of a deeper channel, riffle crests and boulder clusters, were made to enhance habitat for aquatic life.

According to "Classification of Wetlands and Deepwater Habitats of the United States" (Cowardin *et al.*, 1979), Myra Creek would be classified as an upper perennial riverine system with a primarily unconsolidated bottom dominated by cobble and gravel. Myra Creek has been classified into four distinct reaches, which were summarized by Hallam Knight Piesold (1999) as follows:

> "*The present day Reach 2, which includes the channelized section, has an average gradient of 1%. It extends from where the Lynx Diversion channel intercepts Myra Creek to the paved road bridge upstream, a stream distance of 1.6 km. Reach 1, situated between Buttle Lake and the Lynx Diversion, has an approximate length of 1.8 km and an average slope of 3.9%. Above Myra Falls, Reach 1 has an average slope of only 0.6%. Reach 3, situated between the paved road bridge over Myra Creek and the confluence with Arnica Creek, has a length of 0.6 km and an average slope of 3%. Reach 4 extends from Arnica Creek to the confluence with Tennant Creek, a stream distance of approximately 1.6 km. The average gradient of Reach 4 is 1.2%*"

Hallam Knight Piesold (1999) surveyed habitat types present within Reaches 1 through 4. Habitat maps were created for each of the four reaches using a scale of 1:4000 following methods described in Watershed Restoration Technical Circular No. 8, Fish Habitat Assessment Procedures, Level 1 Field Assessment (Johnson and Slaney, 1996). Maps for Reaches 1, 3 and 4 were updated from a prior study conducted in 1982, whereas a new habitat map was created for Reach 2 because this reach had been diverted since the prior study. These maps showed habitat units distinguished as riffles, pools, glides and cascades according to the dominant habitat within each unit. Large woody debris, dominant bed materials, instream cover and other significant features of the creek were also recorded. Depositional areas within the creek are limited and tend to be associated with pools and deeper sections of glides. Although large flood events (e.g., November 2006) have altered many of the habitat features over time, the general pool/riffle characteristics remain, and are summarized in Table 1.

Table 1. Characteristics of Myra Creek; Reaches 1 through 4 (summarized from Hallam Knight Piesold, 1999). Reaches are shown from upstream to downstream; note that the gradient of Reach 1 upstream of the falls is only 0.6%.

	Reach 4	Reach 3	Reach 2	Reach 1
Length	1.6 km	0.6 km	1.6 km	1.8 km
Gradient	1.2%	3.0%	1.0%	3.9%
Substrate	Cobble-gravel	Cobble-gravel	Cobble-gravel	Cobble-gravel
Habitat type				
Pool	16%	0%	5%	26%
Glide	36%	48%	40%	51%
Riffle	43%	48%	55%	23%
Cascade	5%	5%	0%	0%

1.4 Flora and Fauna

The Myra Creek watershed lies within the Coastal Western Hemlock biogeoclimatic zone; vegetation typical of this zone includes Douglas fir (*Pseudotsuga mensiesii*), western hemlock (*Tsuga heterophylla*) and red cedar (*Thuja plicata*), along with associated ground flora. However, the relatively wide ranges in elevation also reach into sub-alpine regions, where characteristic flora tend to be dominated by sub-alpine fir (*Abies lasiocarpa*), mountain hemlock (*Tsuga mertensiana*) and creeping juniper (*Juniperus horizontalis*). The watershed and surrounding Strathcona Park provide habitat to a wide variety of fauna, including blacktail deer (*Odocoileus hemionus columbianus*), Roosevelt elk (*Cervus Canadensis roosevelti*), black bear (*Ursus americanus*), wolf (*Canis lupus*), cougar (*Puma concolor*), and numerous smaller mammals. Birds observed in the vicinity include various waterbirds (e.g., trumpeter swans (*Cygnus buccinator*), Canada geese (*Branta canadensis*), common loon (*Gavia immer*), harlequin ducks (*Histrionicus histrionicus*), teal (*Anas* sp.), kingfishers (*Megaceryle* sp.), dippers (*Cinclus* sp.), raptors (bald and golden eagles (*Haliaeetus leucocephalus* and *Aquila chrysaetos*), Cooper's hawk (*Accipiter cooperii*), merlin (*Falco columbarius*), screech, horned and pygmy owls), and songbirds (e.g., swallows, warblers, finches, thrushes). The BC Conservation Data Centre reports the potential presence of two blue-listed plant species (the pointed rush, *Juncus oxymeris*, considered fairly secure; and the snow bramble, *Rubus nivalis*). The Northern Red-legged Frog, *Rana aurora*, and the Western Screech-Owl, *Megascops kennicottii kennicottii,* both blue-listed species, are likely present in the upper Campbell River watershed, as is the red-listed Northern goshawk (*Accipiter gentilis*) and wolverine (*Gulo gulo*) (BCCDC, 2017). Vancouver Island marmot (*Marmota vancouverensis*) were potentially present historically.

1.5 Water Uses

Designated water uses are those identified for protection in a specific watershed or waterbody; Table 2 summarizes the applicable designated uses in the Buttle Lake watershed.

Table 2. Applicability of designated beneficial uses to the Buttle Lake watershed.

Beneficial Uses	Applies
Aquatic Life (freshwater)	X
Aquatic Life (sediments)	X
Aquatic Life (tissue)	X
Drinking water	X
Recreation	X
Wildlife	X

1.6 Aquatic Life Receptors

Coastal cutthroat trout (*Oncorhynchus clarkii*) are the only species of fish in Myra Creek. An impassable waterfall prevents fish from entering Myra Creek from Buttle Lake and, therefore, the population of trout in Myra Creek is discrete from other trout populations. Studies conducted prior to 1999 indicated that cutthroat trout were restricted to Reach 4, upstream of the mine site (Hallam Knight Piesold, 1999). However, more recent surveys have found fish both upstream and downstream of the mine site (Nautilus Environmental, 2006; 2009). Both Hallam Knight Piesold (1999) and Nautilus Environmental (2006 and 2009) concluded that the cutthroat trout population density is low, and is subject to large fluctuations due to periodic flooding events. Overwintering habitat is available upstream and downstream of the mine, but spawning habitat and off-channel high-water refugia are largely restricted to upstream areas (i.e., Reach 4).

Myra Creek contains a relatively rich (i.e., diverse) benthic macroinvertebrate community, with strong representation of Ephemeroptera, Plecoptera and Tricoptera taxa (Sartori Environmental Services, 2017). However, due to the oligotrophic conditions and cold water, abundance is relatively low. Taxa present in the creek are listed in Table 3; of relevance to water quality are abundant EPT and pollution-intolerant taxa.

Table 3. Benthic macro-invertebrate taxa found in Myra Creek.

Order	Family	Genus/Species
Haplotaxida	Enchytraeidae	
Lumbriculida	Lumbriculidae	
Prostigmata	Hygrobatidae	*Hygrobates sp.*
	Lebertiidae	*Lebertia sp.*
	Sperchontidae	*Sperchon sp.*
Ephemeroptera	Ameletidae	*Ameletus sp.*
	Baetidae	*Baetis sp.*
	Ephemerellidae	*Drunella coloradensis sp.*
		Drunella doddsii sp.
	Heptageniidae	*Cinygmula sp.*
		Epeorus sp.
		Epeorus longimannus sp.
		Ironodes sp.
		Rhithrogena sp.
	Leptophlebiidae	*Paraleptophlebia sp.*
Plecoptera	Capniidae	*Mesocapnia sp.*
		Eucapnopsis brevicauda sp.
	Chloroperlidae	*Sweltsa sp.*
	Leuctridae	*Paraleuctra sp.*
	Nemouridae	*Visoka cataractae sp.*
		Zapada cinctipes sp.
		Zapada columbiana sp.
	Perlodidae	*Megarcys sp.*
	Taeniopterygidae	(Early instar)
Trichoptera	Apataniidae	*Apatania sp.*
	Glossosomatidae	*Glossosoma sp.*
	Hydropsychidae	*Parapsyche sp.*
	Hydroptilidae	Agraylea sp.
	Limnephilidae	*Ecclisomyia sp.*
	Polycentropodidae	*Polycentropus sp.*
	Rhyacophilidae	*Rhyacophila sp.*
Coleoptera	Elmidae	*Narpus sp.*
Diptera	Ceratopogonidae	*Probezzia sp.*
	Chironomidae	Orthocladiinae (early instar)
		Tanypodinae (early instar)
		Brillia sp.
		Cardiocladius sp.

		Corynoneura sp.
		Eukiefferiella sp.
		Cricotopus/Orthocladius sp.
		Pagastia sp.
		Parametriocnemus sp.
		Tanytarsus sp.
		Thienemannimyia sp.
	Empididae	*Oreogeton sp.*
	Simuliidae	*Simulium sp.*
	Tipulidae	*Dicranota sp.*
		Hexatoma sp.

2.0 MINING OPERATIONS

The approximate 3300 hectare area of Strathcona-Westmin Provincial Park is held as legal crown grants and leases issued under the Mines Act by the Ministry of Energy and Mines (MEM). Consequently, MFO is required to adhere to the *Health, Safety and Reclamation Code for Mines in British Columbia*, issued by MEM in 2003. The mining operation itself occupies a footprint of less than 200 hectares within the 220,000 hectare Strathcona (Class A) Park (i.e., <0.1% of the park area). As noted in the 1995 Strathcona-Westmin Park Master Plan, the mine operates under use permits issued by BC Parks under authority of the Ministry of Water, Land and Air Protection, and the Park Act. The permitted area includes portions of both Strathcona and Strathcona-Westmin Provincial Parks, and allows the use of Park lands for mining, roads and power generation and transmission.

During regular operations, the mine processes approximately 500,000 tonnes of ore annually in a modern milling facility that separates the ore into precious metal concentrates. The milling process consists of four stages: crushing, grinding, flotation and filtration, and the concentrates are trucked to Campbell River and loaded onto ships. Daily average processing rates were 1,696, 1,194 and 1,700 tonnes of ore in 2011, 2012 and 2013, respectively (S. Skagford, MFO, *pers. comm,* 2015).

The mine operates a water treatment system that collects and treats contaminated groundwater and surface runoff (partially consisting of acid rock drainage), mill effluent, tailings area decant water, mine water and sewage treatment plant effluent. Sewage (i.e., conventional sewage and grey water) is biologically treated, and comprises approximately 1% of the total final effluent flow. Most of the surface water, including mine drainage, mill thickener overflows and tailings area decant water, is pumped to the Superpond where lime slurry is added to facilitate precipitation of metal hydroxides. The Superpond effluent discharges into the Myra Pond system, which consists of 6 "polishing" ponds that settle out any remaining suspended particles. The treated water is then discharged into Myra Creek through a Parshall flume. This discharge, designated "11A-Runoff", is monitored under MDMER for potential effects on the receiving environment of Myra Creek. Mean daily discharge was approximately 0.35 m^3/sec (with a range of 0.21 to 1.28 m^3/sec) for the period of January 1 to October 31, 2016.

The effluent discharge enters Myra Creek through a culvert on the south bank of the creek. At the point of discharge, Myra Creek is fast flowing and somewhat turbulent, resulting in rapid mixing in the creek. Based on data collected from 2010 to 2015, effluent flow averaged approximately 6.1 ± 0.5% of the total flow in Myra Creek, with minimum and maximum values of 3.6 and 11.6%, respectively (S. Skagford, MFO, *pers. comm*., Dec 2015). It should be noted that estimates of effluent concentrations in the creek reported in previous documents (as much as 75% of total creek flow; Nautilus 2006 and 2009) were based on manual methods that were not very accurate (S. Henderson, MFO, *pers. comm*. Jan 2010); flow meters installed in 2006 corrected this issue.

As an example of seasonal flow relationships, effluent and creek flows from 2015 are plotted in Figure 2. Of note, flows vary seasonally in the creek, as well as the discharge, with the least opportunity for dilution occurring during low-flow periods in the creek, typically in late summer under prolonged dry weather conditions.

Other surface inflows of water into Myra Creek downstream are limited, although groundwater inputs may be significant depending on hydrological conditions. A small tributary, Webster Creek, enters the creek 50 m downstream of the outfall; flows are seasonally variable, and are estimated to be less than that of the effluent discharge during high flows. The Lynx diversion ditch that directs surface water flows away from waste rock surrounding the old Lynx mine and the decommissioned tailings pond enters Myra Creek downstream of the engineered channel just below the road bridge in proximity to the MC-TP4 sampling location; flows are estimated to be approximately equal to the effluent during run-off conditions. Upstream inputs include Arnica Creek and several small seasonal tributaries located between Arnica Creek and the Tennant Lake tail race water. These small tributaries are particularly important for spawning and off-channel refugia for the resident cutthroat trout.

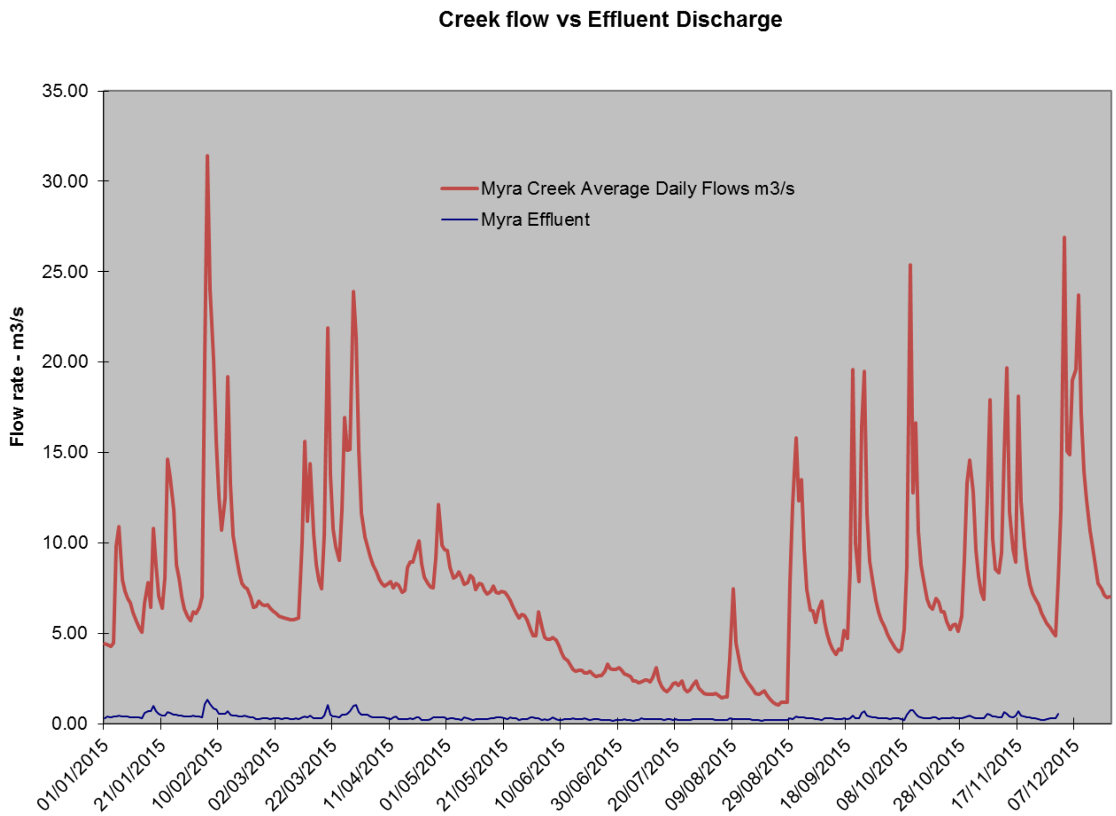


Figure 2. Flow rates of Myra Creek relative to Nyrstar Myra Falls mine's effluent discharge in 2015.

2.1 Contaminant Sources and Closure Plans

At some point, the mine will permanently close. The overall objective of MFO's reclamation program is to return the mine site to a condition similar to its natural, pre-mining state – consistent with "Class A" park status. To help attain this future state, the company has posted security bonding and is engaged in ongoing research, specifically supporting research carried out by others to determine the most effective reclamation methods available that will minimize any long-term effects from rock piles and tailings deposits. This research is being conducted in cooperation with industry and government agencies, and has been recognized at several international forums. Nyrstar is following a progressive reclamation plan for the Myra Falls site, with yearly updates that track progress and describe the evolution of the Long-term Closure Plan. It is anticipated that reclamation activities will continue for several years after operations cease.

Of note, an updated conceptual decommissioning and mine closure plan was submitted to government agencies on July 31, 2014 by Robertson GeoConsultants on behalf of MFO (Robertson

GeoConsultants, 2014); an addendum to this plan was submitted December 31, 2016 (Nyrstar Myra Falls, 2016). The report included updated information and current plans for closure of the operation, proposed closure timelines, and cost estimates for implementation of the closure and post-closure monitoring and treatment systems. The 2016 addendum included an update to the site-wide contaminant load balance model for current and future conditions (Robertson GeoConsultants, 2016). This load balance was used to model several closure scenarios and the dry cover options put forth in the addendum report were chosen based on the model results. The closure works slated for the five-year progressive closure plan include relocation of potentially acid generating (PAG) waste rock from the slopes to a new location in the Lynx Tailings Dam Facility (Lynx TDF), and dry covers for the old Tailings Dam Facility and the Lynx TDF outer berm. A ground water recovery system was recommended based on the modelling; stages one and two of the Lynx Seepage Interception System (Lynx SIS) have been installed in 2017 and 2018 respectively.

With respect to concentrations and loads, EEM studies under MDMER have typically focused on the effluent discharge as the primary source of metals in the receiving environment. While MFO's treatment system is generally effective at maintaining concentrations of metals of concern well-below permitted levels (e.g., Table 12), recent studies have shown that contaminated groundwater contributes significantly greater loadings of metals to Myra Creek. Thus, efforts to develop effective closure plans have been largely directed at groundwater seepages associated with waste rock deposits and the Old and Lynx TDFs (Robertson GeoConsultants, 2016).

However, control of the different groundwater discharges has presented multiple challenges in terms of identifying sources and associated flow patterns, as well as designing appropriate systems to intercept contaminated water and direct it to the treatment facility. Based on data from an extensive system of monitoring wells, some of the sources have already been identified and directed into the treatment system, and a more complete picture of all sources and associated flows and concentrations has emerged. These data have been used to design additional collection systems, as well as model the overall system so that a comprehensive plan for source control and/or treatment can be developed and associated metals concentrations estimated (Robertson GeoConsultants, 2016).

Efforts to intercept contaminated groundwater and direct it to the treatment plant have already resulted in significant improvements in water quality. Using zinc as an example, it was recently estimated that over 80% of the zinc in contaminated groundwater was removed by current interception systems and directed to the treatment facility (Robertson GeoConsultants, 2016). However, even under these conditions, a mass balance assessment of zinc loadings to the creek suggested that the effluent contributed less than 20% of the total loadings to the creek (Figure 3; from Robertson GeoConsultants 2016).

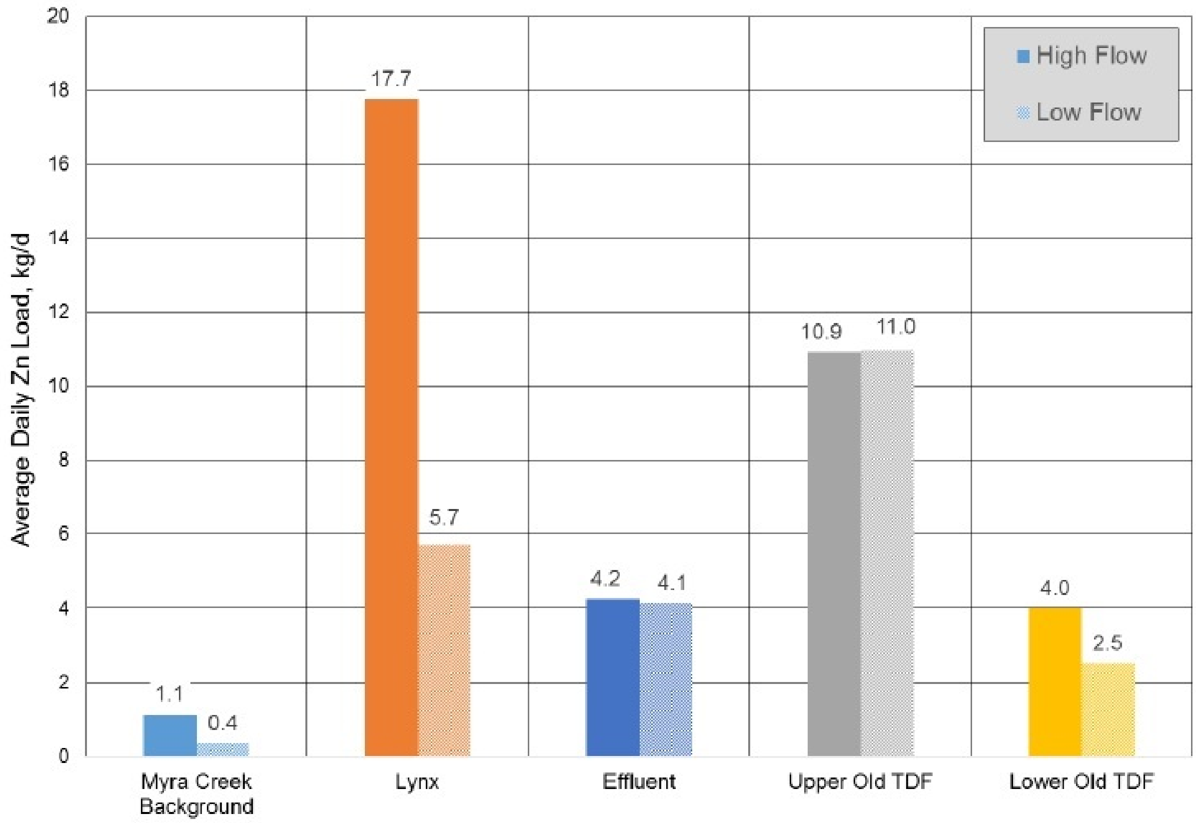


Figure 3. Average Daily Zinc Loads in Myra Creek During High Flow and Low Flow Conditions (From Robertson GeoConsultants, 2016).

Consequently, as part of MFO's efforts to further improve water quality, the modeling results have been used to identify a tiered series of collection systems and cover options for the site that would further reduce metals concentrations reaching Myra Creek (Robertson GeoConsultants 2016). These options are shown in Table 4 (from Robertson GeoConsultants 2016). Assuming full implementation of all of the options, average concentrations of zinc at MC-M2 are expected to decrease by approximately 40% (i.e., from 71 to 40 µg/L), corresponding to an overall removal of approximately 90% of the zinc that could potentially enter the creek from contaminated groundwater. Of note, these estimates are largely based on the results of modeling, and will continue to be refined as interception systems are installed and monitoring results become available (e.g., Robertson GeoConsultants 2018).

Table 4. Predicted Loads and Zn Concentrations in Myra Creek, Future Conditions.

Scenario	MC+50		MC+800		MC-TP4		MC-M2	
	Load, t/year	[Zn], mg/L	Load, t/year	[Zn], mg/L	Load, t/year	[Zn], mg/L	Load, t/year	[Zn], mg/L
Current Conditions	3.45	0.027	7.37	0.051	9.97	0.071	10.53	0.071
Lynx SIS	1.76	0.012	5.28	0.035	7.16	0.049	7.59	0.049
Old TDF closure	1.76	0.012	5.07	0.033	6.42	0.044	6.73	0.043
Final Lynx TDF at closure	1.74	0.011	5.05	0.033	6.40	0.044	6.72	0.043
Covered Lynx TDF Berm								
Final Lynx TDF (till cover)	1.71	0.011	4.98	0.033	6.27	0.042	6.57	0.042
Final Lynx TDF (geomembrane)	1.66	0.011	4.85	0.032	6.01	0.041	6.28	0.040
Additional SIS (assuming rock and till cover)								
Additional SIS (Zone IV only)	1.71	0.011	4.50	0.029	5.78	0.039	6.08	0.039
Additional SIS (Zone I only)	1.39	0.008	4.82	0.031	6.11	0.041	6.41	0.041
Additional SIS (Zones I and IV)	1.39	0.008	4.29	0.027	5.58	0.037	5.88	0.037

3.0 ENVIRONMENTAL MONITORING STUDIES

3.1 Metal Mining Effects Studies

Under the *Metal and Diamond Mining Effluent Regulations* (MDMER), MFO has been required to conduct environmental effects monitoring (EEM) studies to evaluate whether mine operations are having adverse effects on the receiving environment. These studies are typically repeated over 3-year cycles to identify the presence of adverse effects and are designed to provide data that are scientifically defensible using approaches that can be adapted to site-specific conditions, while remaining consistent with standard guidance that is implemented nationally. Each cycle consists of two key components:

1) Effluent characterization and water quality monitoring – effluent chemistry, toxicity (acute and chronic) and water quality in the receiving environment are evaluated by the mine at various times (e.g., daily, weekly, monthly, quarterly or biannually) throughout the year; and,
2) Biological monitoring – potential effects of mine effluent on benthic invertebrates (representing fish habitat) and fish populations are assessed through field surveys.

MFO first became subject to the MDMER on December 6, 2002. Because historical biological monitoring data were available for the mine, largely from an evaluation of fish and fish habitat conducted in 1999 by Hallam Knight Piesold (1999), the first EEM study was not required until 2005. The results of Cycle 1 suggested that there was moderate enrichment of the benthic macro-invertebrate (BMI) community downstream of the discharge, but no effects on fish (Nautilus Environmental 2006). Cycle 2 was completed in 2008, and again showed an effect on the BMI community downstream of the mine (Nautilus Environmental 2009). Although BMI community metrics exhibited a reduction in enrichment between Cycles 1 and 2, the presence of effects across both Cycles triggered an Investigation of Magnitude and Extent in Cycle 3 (2011). This Cycle involved a more thorough review of the BMI community data, as well as analyses of the results of the laboratory toxicity tests and concentrations of various analytes found in the effluent to determine if there were any relationships with the effects observed. In addition, because the discharge ultimately enters Buttle Lake, which is part of the Class A Strathcona Provincial Park, Cycle 3 included an evaluation of data collected in Buttle Lake to determine if any impacts observed in Myra Creek extended downstream into the lake.

The detailed Investigation of Magnitude and Extent revealed three important findings (Nautilus Environmental 2011):

1. Conditions in the benthic community were substantially improved in Cycle 2 relative to Cycle 1;
2. Impacts were limited to a relatively short section of Myra Creek, with no adverse effects apparent downstream in Buttle Lake;
3. The reduced level of effects observed in Cycle 2 relative to Cycle 1 coincided with marked reductions in phosphate concentrations in the discharge; thus, elevated phosphate concentrations were the most likely explanation (i.e., cause) of the enrichment observed in the BMI community downstream of the mine in Cycle 1.

The Investigation of Magnitude and Extent is typically followed by an Investigation of Cause (IOC) to determine what components of the effluent (or other factors) are responsible for the observed effects. However, because the most likely cause of the alterations in the BMI community downstream of the discharge (i.e., elevated phosphate concentrations) was already determined during Cycle 3, a follow-up field investigation of the BMI communities upstream and downstream of the discharge was conducted in Cycle 4 to provide empirical data with which to evaluate the Cycle 3 findings.

The results of Cycle 4 indicated that the enrichment effects observed in Cycles 1 and 2 were no longer evident, suggesting that the mine`s efforts to control phosphate concentrations in the discharge eliminated the effects on BMI community structure (Nautilus Environmental and Sartori Environmental Services 2014). Nevertheless, BMI community structure downstream of the discharge still exhibited significant differences in some metrics compared to upstream. Further investigation of the data revealed that the differences in community structure were related to habitat, primarily substrate size, with smaller substrate dominating downstream reaches of the creek. This effect on community structure was most apparent in the *Simuliidae*, which varied in abundance between sites by over 3 orders of magnitude. Notably, *Simuliidae* taxa are known to be among the most sensitive species to metal contamination. The fact that these organisms were well represented at downstream sites suggests that MFOs effluent was not eliciting adverse effects related to metal toxicity. In addition, numbers and abundance of *Ephemeroptera*, *Plecoptera* and *Tricoptera* (EPT) taxa did not differ between upstream and downstream reaches, indicating no impacts on these important indicator taxa. Of particular interest, the BMI community attributes for the three exposure sites located closest to MFO's discharge into Myra Creek were consistent with similar sites located in the same Eco-region of Vancouver Island, providing further confirmation of lack of effects associated with the discharge. Conversely, the two exposure sites located furthest downstream of the discharge exhibited highly divergent community attributes, suggesting a localized condition, rather than an effect of the mine's discharge (Nautilus Environmental and Sartori Environmental 2014).

Since Cycle 4 of the EEM program concluded that there were no impacts on the BMI community related to the mine's effluent discharge, Cycle 5 was designed as a "re-set" of the EEM program and included the full suite of monitoring components that were evaluated in Cycles 1 and 2 to obtain an update on environmental conditions upstream and downstream of the discharge. Specifically, Cycle 5 generated data related to chemistry, biology and toxicology to characterize environmental conditions and evaluate the potential for adverse effects due to the discharge of mine effluent. Ultimately, the study found no evidence of adverse effects that could be attributed to the discharge. Importantly, no differences were observed in cutthroat trout early life stages exposed at fixed locations upstream and downstream of the discharge, or between adult fish metrics from upstream and downstream reaches. Differences were observed between benthic macroinvertebrate community metrics upstream and downstream of the discharge, but these again appeared to be related to differences in habitat rather than proximity to the discharge. Notably, sensitive indicator groups (i.e., EPT and other pollutant-intolerant taxa) were well-represented downstream of the discharge point. As with previous cycles, exceedances of BC water quality guidelines (e.g., cadmium, aluminum, zinc and copper) were detected in Myra Creek (Nautilus Environmental, 2017), but were not associated with impacts to biota downstream of the discharge. These observations were consistent with results of acute and sublethal toxicity tests conducted on effluent samples which generally suggested that no adverse effects should be present outside of the initial mixing zone based on estimates of available dilution (i.e., differences in stream and effluent flows).

3.2 Water Quality Monitoring Studies

In addition to the EEM investigations, two recent studies have evaluated water quality in Myra Creek. In 2013, Nautilus Environmental completed a comprehensive evaluation of monthly concentrations of a wide range of water quality parameters measured between 2007 and 2012 at various locations in Myra Creek, as well as other locations in the Buttle Lake watershed (Nautilus Environmental 2013). More recently, MFO completed a “5-in-30” sampling program focused on key times of the year (i.e., low [Aug – Sept 2014] and high [Nov – Dec 2015] flow conditions) to obtain additional water quality data consistent with BC Ministry requirements for identifying the need for site-specific objectives (Nautilus Environmental 2016). The resulting data were reviewed and evaluated by Nautilus Environmental (2017) to identify parameters that were elevated above applicable BC WQGs. Water quality parameters evaluated in each of the studies are shown in Table 5, and sampling sites are shown in Figures 4 and 5. In addition, a conceptual model of the site showing the constituents of concern and receptors of interest is provided in Figure 6.

Table 5. Water quality parameters in Myra Creek analyzed in the historical data evaluation and the 5-in-30 sampling program.

Parameter	Historical analysis	5-in-30 Program
Temperature	X	--
pH	X	--
Specific conductivity	X	--
Total suspended solids	X	X
Turbidity	--	X
True colour	--	X
Total phosphorus	X	X
Nitrate	X	X
Nitrite	X	X
Ammonia	X	X
DOC	X	X
TOC	X	X
Dissolved Sulphate	X	X
Total and Dissolved Metals	X	X
Hardness	X	X
Dissolved oxygen	X	--

There was general agreement between the two studies regarding parameter exceedances. Specifically, in the 5-year historical dataset (Nautilus 2013), exceedances of BC water quality guidelines (WQGs) were observed for aluminum, zinc, cadmium and copper in Myra Creek. In the 5-in-30 sampling program, exceedances of BC WQGs were identified for aluminum, zinc, cadmium and copper at all Myra Creek sampling locations under high-flow conditions (Nautilus 2017); of note, the highest concentrations of aluminum, zinc, copper and lead were measured *upstream* of the mine during high-flow conditions, indicating that background stream chemistry can exceed downstream concentrations at certain times of the year. However, during low-flow conditions, exceedances were observed for aluminum, zinc, cadmium, copper, nitrite and silver in Myra Creek downstream of the mine, with no exceedances at upstream reference locations [note that relatively small exceedances of sulphate were observed downstream of the mine if upstream hardness concentrations (i.e., soft water) were used for the comparison, but did not exceed the guideline for soft to moderately soft water]. Parameters with exceedances are described in greater detail in the following sections, with particular emphasis on the 5-in-30 sampling results; the results of the historical data analysis are also included for comparison. Of note, sampling site MC-M1 is located well-above the discharge point and tailings disposal facility (TDF), whereas MC-TP4 and MC-M2 are located downstream of the discharge and TDF (Figures 4 and 5).

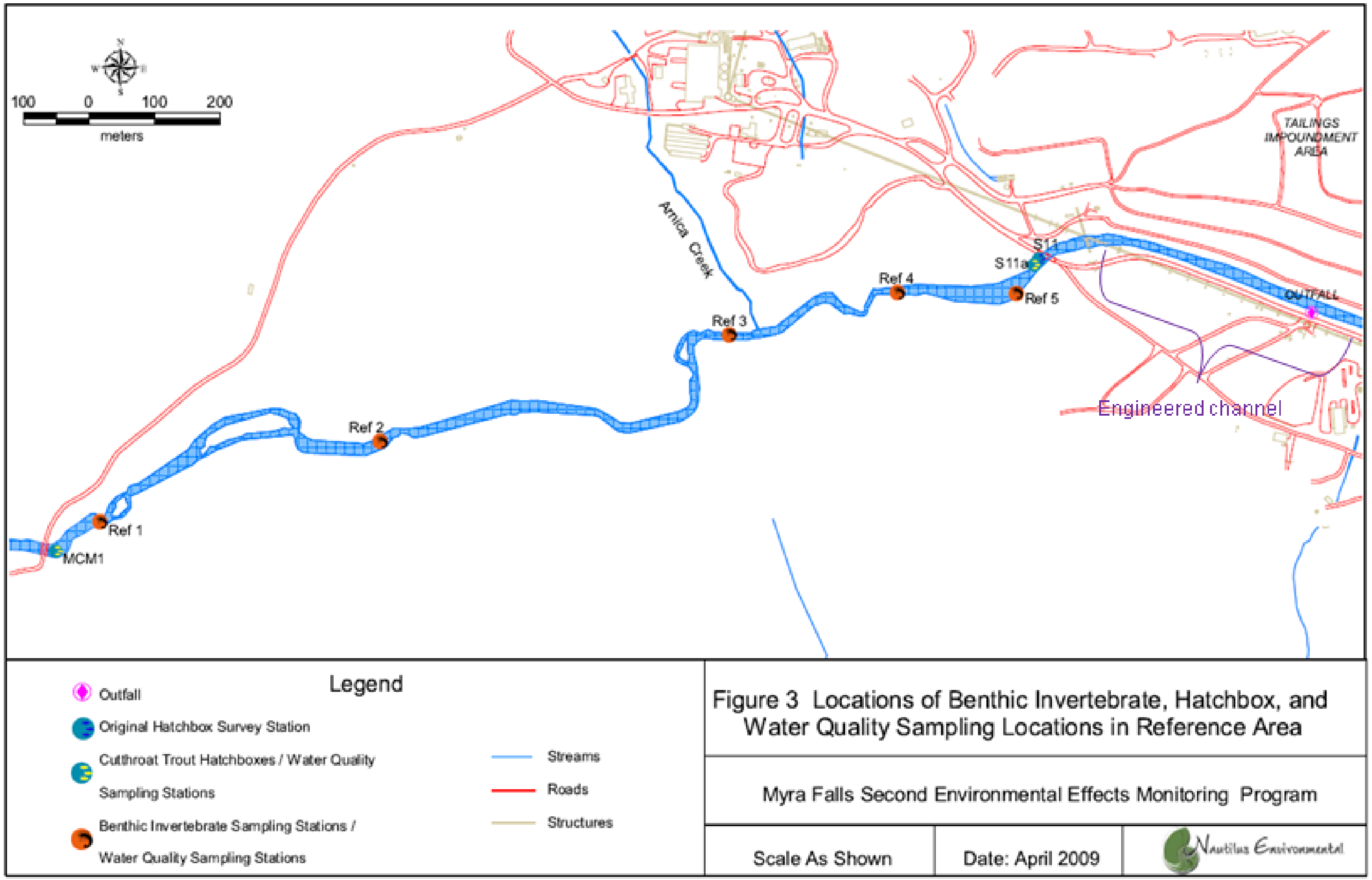


Figure 4. **Hatchbox, benthic invertebrate, and water sampling stations, Myra Falls EEM Programs: Reference sites.**

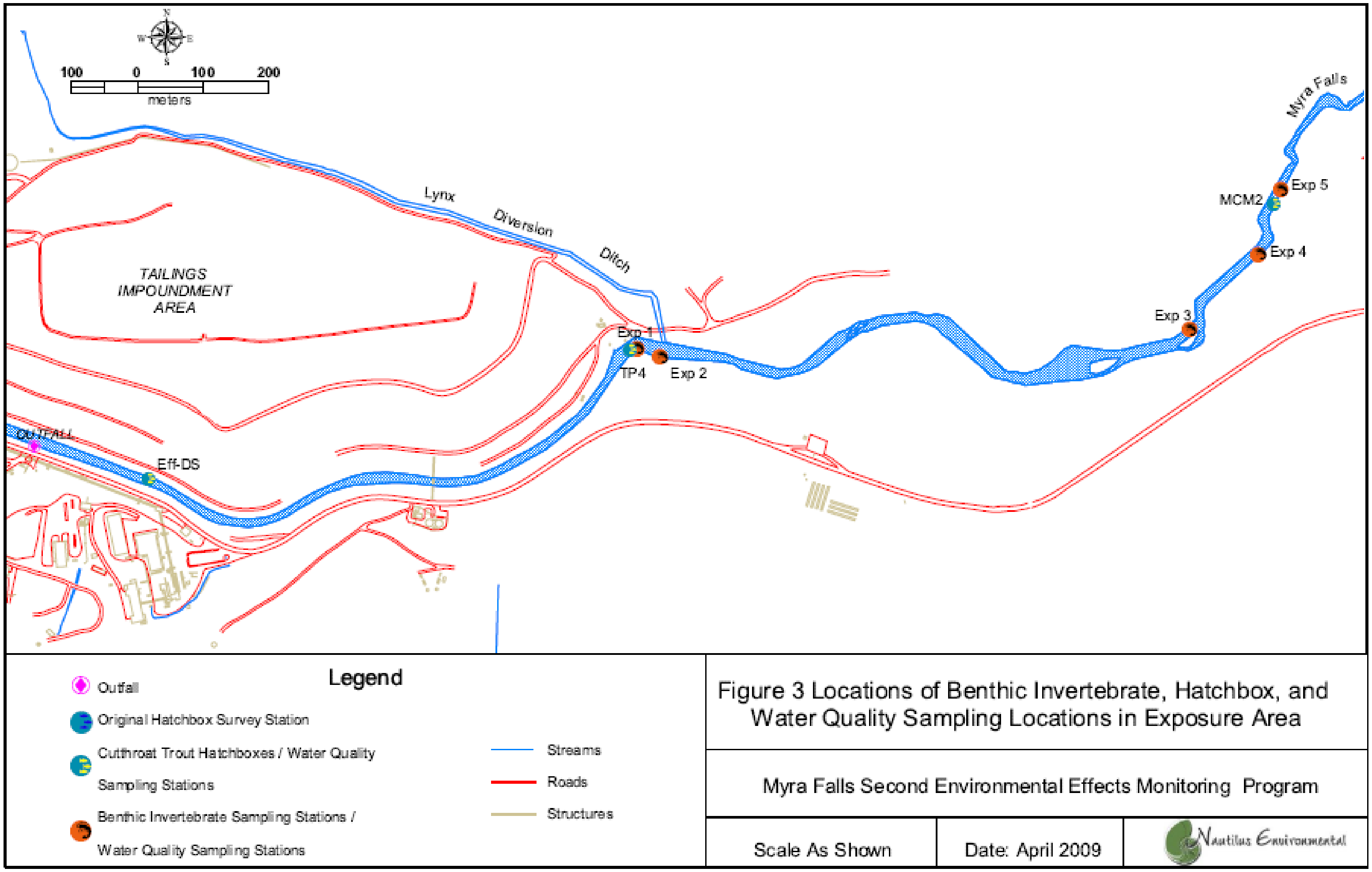


Figure 5. **Hatchbox, benthic invertebrate, and water sampling stations, Myra Falls EEM Programs: Exposure sites.**

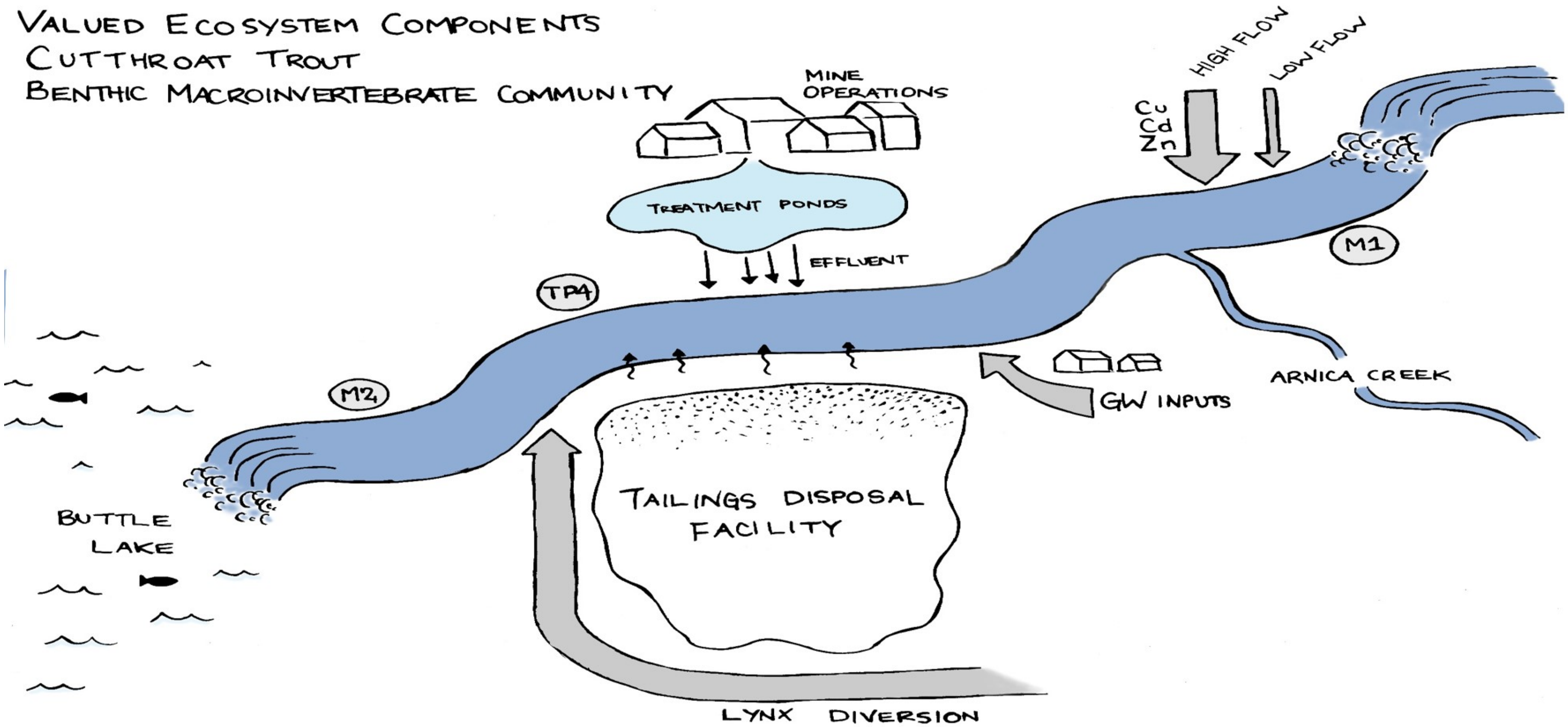


Figure 6. Conceptual Site Model Showing Sampling Sites, Constituents of Concern, Potential Sources and Receptors of Concern.

3.2.1 Zinc

WQGs for zinc are a function of hardness. Hardness concentrations ranged from 6.91 to 21.3 mg/L upstream of the mine's discharge at MC-M1, whereas downstream of the discharge at sites MC-TP4 and MC-M2, hardness concentrations ranged between 12.4 and 191 mg/L; all hardness measurements were <90 mg/L during high-flow conditions, but hardness was >90 mg/L in four out of 5 samples collected from both MC-TP4 and MC-M2 during low-flow conditions. Regardless, since the lowest hardness concentration measured during low-flow conditions was <90 mg/L, maximum and average guidelines of 33 µg/L and 7.5 µg/L were applied at all locations in Myra Creek during both sampling events. Upstream of the effluent discharge (i.e., at MC-M1) zinc concentrations were below the maximum and average guidelines during low-flow conditions, but exhibited dramatic exceedances of both guidelines during high-flow conditions. Conversely, both guidelines were exceeded during low and high-flow conditions downstream of the mine discharge at MC-TP4 and MC-M2. Zinc concentrations in Myra Creek are summarized in Table 6, with general agreement in distributions between historical data and data from the 5-in-30 sampling program.

Table 6. Summary statistics for total zinc concentrations (µg/L) in Myra Creek.

Parameter	Historical Values (2007-2012)	MC-M1		MC-TP4		MC-M2	
		Low flow	High flow	Low flow	High flow	Low flow	High flow
Minimum	18.0	0.1	0.6	80.1	22.7	93.3	67.9
Maximum	320.0	1.1	**2670.0**	**151.0**	**129.0**	**144.0**	**107.0**
95th Percentile	221.6	1.0	2177.2	147.2	118.0	141.8	105.2
Mean	92.5	0.3	**582.8**	**117.0**	**71.2**	**117.7**	**90.0**
Std. Dev.	70.2	0.5	1169.8	27.0	38.1	21.2	15.4
n	69	5	5	5	5	5	5

Bolded values represent an exceedance of either the short- or long-term guideline for the maximum or mean values, respectively.

Historical values represent downstream sites in Myra Creek (i.e., MC-TP4 and MC-M2).

3.2.2 Aluminum

No exceedances of the average and maximum aluminum guidelines (i.e., 0.05 and 0.10 mg/L, respectively) were observed at MC-M1 or MC-M2 under low-flow conditions, although the average guideline was exceeded at MC-TP4. Under high-flow conditions, the average guideline was also exceeded at all three stations, and the maximum guideline was also exceeded at MC-M1.

Thus, these data suggest that elevated upstream background aluminum concentrations may be influencing the exceedances observed downstream under high-flow conditions. Notably, no exceedances were apparent from the historical dataset at the downstream sites, and the low-flow downstream exceedances were marginal and limited to only one site. Summary statistics for aluminum are presented in Table 7.

Table 7. Summary statistics for dissolved aluminum concentrations (mg/L) in Myra Creek.

Parameter	Historical Values (2007-2012)	MC-M1		MC-TP4		MC-M2	
		Low flow	High flow	Low flow	High flow	Low flow	High flow
Minimum	0.020	0.017	0.029	0.043	0.025	0.031	0.022
Maximum	0.064	0.027	**0.158**	0.082	0.096	0.058	0.099
95th Percentile	0.056	0.026	0.145	0.077	0.090	0.056	0.092
Mean	0.041	0.020	**0.076**	**0.055**	**0.053**	0.043	**0.052**
Std. Dev.	0.009	0.004	0.053	0.016	0.028	0.010	0.030
n	64	5	5	5	5	5	5

Bolded values represent an exceedance of either the short- or long-term guideline for the maximum or mean values, respectively.

Historical values represent downstream sites in Myra Creek (i.e., MC-TP4 and MC-M2).

3.2.3 Cadmium

There were no measured exceedances of guidelines at MC-M1 during low-flow conditions and, during high-flow conditions, the maximum guideline was exceeded only once. This suggests that upstream concentrations of cadmium in this watershed are generally below WQGs, although events can lead to periods where maximum guidelines are exceeded. Conversely, maximum and average guidelines were exceeded at MC-TP4 and MC-M2 during both low and high-flow conditions. The maximum and average guidelines calculated using the lowest measured hardness at Myra Creek were 0.07 and 0.05 µg/L, respectively, during high-flow conditions (12.4 mg/L hardness), and 0.5 and 0.2 µg/L under low-flow conditions (87.1 mg/L hardness). The elevated concentrations observed at the two sampling sites downstream of the mine's discharge suggests that the mine's discharge is likely influencing the cadmium concentrations observed in lower Myra Creek. The cadmium data from Myra Creek are summarized in Table 8.

Table 8. Summary statistics for dissolved cadmium concentrations (µg/L) in Myra Creek (historical values are provided as total cadmium which are not directly comparable).

Parameter	Historical Values (2007-2012)	MC-M1		MC-TP4		MC-M2	
		Low flow	High flow	Low flow	High flow	Low flow	High flow
Minimum	0.05	<0.005	<0.005	0.256	0.049	0.288	0.078
Maximum	0.71	<0.005	**0.078**	**0.633**	**0.294**	**0.598**	**0.264**
95th Percentile	0.52	<0.005	0.067	0.626	0.278	0.587	0.257
Mean	0.24	<0.005	0.025	**0.473**	**0.172**	**0.453**	**0.179**
Std. Dev.	0.16	0	0.031	0.170	0.093	0.140	0.076
n	62	5	5	5	5	5	5

Bolded values represent an exceedance of either the short- or long-term guideline for the maximum or mean values, respectively.

Historical values represent downstream sites in Myra Creek (i.e., MC-TP4 and MC-M2).

3.2.4 Copper

In general, copper concentrations at MC-M1 were below guidelines during low-flow conditions, but exhibited appreciable exceedances of both the maximum and average guidelines (i.e., 3.2 and 0.2 µg/L, respectively, at a hardness of 12.8 mg/L) under high-flow conditions. Specifically, the average concentration at high flow was approximately 200 times higher than the low-flow average (i.e., 40.1 µg/L compared to 0.2 µg/L), and the maximum concentration measured at high-flow was 184 µg/L, compared to 0.6 µg/L at low flow (Table 9). Conversely, copper concentrations were elevated above maximum and average guidelines at MC-TP4 and MC-M2 during both low and high-flow conditions.

Interestingly, the maximum concentrations observed at MC-M1 and MC-TP-4 appeared to be "pulse" events that occurred on two separate sampling dates and elevated concentrations were not observed concurrently at downstream sampling locations. Furthermore, only 39% of the total copper measured was in the dissolved form during the pulse event at MC-M1 and only 4% of the total copper was in the dissolved phase at MC-TP-4. These limited data suggest that periodically high total copper concentrations that occur in Myra Creek during high flow events are due to the presence of particulates eroding from the surrounding watershed. These particulates likely settle out quickly and, therefore, appear as localized and transient observations. Notably, the mine diverts surface water flow away from the tailings impoundments to the Lower Lynx Diversion Ditch (LLDD), which discharges in close proximity to MC-TP4. Consequently, input of this surface water may be contributing to the concentration spikes observed at MC-TP4 relative to MC-M2; however, additional work would be required to characterize this influence. Regardless, it appears that copper concentrations are a potential concern in Myra Creek, with background (upstream) concentrations during high-flow conditions being higher than concentrations at sites downstream of the mine's effluent, and the opposite being true during low-flow conditions. Summary statistics associated with copper concentrations in Myra Creek are presented in Table 9.

Table 9. Summary statistics for total copper concentrations (µg/L) in Myra Creek

Parameter	Historical Values (2007-2012)	MC-M1		MC-TP4		MC-M2	
		Low flow	High flow	Low flow	High flow	Low flow	High flow
Minimum	0.9	0.1	0.3	4.0	2.6	3.8	4.5
Maximum	14.0	0.6	**184.0**	**17.3**	**131.0**	**13.0**	**13.5**
95^{th} Percentile	10.1	0.6	149.5	16.5	105.8	12.4	12.1
Mean	4.4	0.2	**40.1**	**9.7**	**29.4**	**7.7**	**7.1**
Std. Dev.	3.0	0.2	80.6	5.8	56.8	4.0	3.6
n	65	5	5	5	5	5	5

Bolded values represent an exceedance of either the short- or long-term guideline for the maximum or mean values, respectively.

Historical values represent downstream sites in Myra Creek (i.e., MC-TP4 and MC-M2).

3.2.5 Silver

The maximum guideline for total silver is 0.1 µg/L at a water hardness of <100 mg/L (as $CaCO_3$). This value was marginally exceeded on only one occasion, which occurred at MC-TP4 under low-flow conditions (September 2, 2014) when the total silver concentration reached 0.11 µg/L. Therefore, despite a measured exceedance of the WQG for silver at MC-TP4, the aquatic risk was likely minimal.

The long-term average guideline for total silver is 0.050 µg/L at a water hardness of <100 mg/L; this value was exceeded during low flow conditions only at MC-M2, which exhibited an average silver concentration of 0.067 µg/L. Given the small and localized levels of the exceedances, these data also suggest that the risk of adverse effects due to silver in Myra Creek were minimal. Of note, no exceedances of the WQG for silver were observed in the long-term dataset.

3.2.6 Lead

During high-flow conditions, MC-M1 exhibited an average hardness concentration of 12.8 mg/L, which would result in a 6.0 µg/L maximum guideline and a 3.5 µg/L average guideline, based on total lead. The maximum and average concentrations of lead measured at MC-M1 during high-flow conditions were 75.2 µg/L and 16.0 µg/L, respectively, well over the guideline values. However, during low-flow conditions there were no exceedances of either the maximum (i.e., 8.2) or average (i.e., 3.6 µg/L) guidelines at MC-M1. Interestingly, there were no exceedances of the average or maximum guidelines for lead at sites downstream of the mine's discharge (i.e., MC-TP4 or MC-M2) under low or high-flow conditions. In addition, historical lead concentrations at sites downstream of the discharge were all below guideline values. Overall, these data suggest that lead concentrations in Myra Creek are not a major concern downstream of the mine's discharge. Lead concentrations in Myra Creek are summarized in Table 10.

Table 10. Summary statistics for total lead concentrations (µg/L) in Myra Creek.

Parameter	Historical Values (2007-2012)	MC-M1		MC-TP4		MC-M2	
		Low flow	High flow	Low flow	High flow	Low flow	High flow
Minimum	0.03	<0.005	0.04	0.35	0.31	0.30	0.34
Maximum	1.50	0.07	**75.20**	1.02	5.37	0.87	1.50
95th Percentile	0.68	0.07	61.01	1.02	4.46	0.85	1.46
Mean	0.23	0.03	**16.00**	0.64	1.44	0.51	0.82
Std. Dev.	0.25	0.03	33.14	0.34	2.20	0.28	0.54
n	63	5	5	5	5	5	5

Bolded values represent an exceedance of either the short- or long-term guideline for the maximum or mean values, respectively.

Historical values represent downstream sites in Myra Creek (i.e., MC-TP4 and MC-M2).

3.2.7 Nitrite

The nitrite guideline is a function of chloride; given that no chloride data were available during the analysis of the 5-in-30 data, the potential for exceedances was based on a worst-case screening-level assessment at the lowest chloride level; i.e., <2 mg/L, which results in an average guideline of 0.02 mg/L, with a maximum of 0.06 mg/L. There were no exceedances of the nitrite WQG during high-flow conditions at any sites measured in Myra Creek. However, under low-flow conditions, exceedances of the average WQG were observed downstream of the mine's discharge at MC-TP4 and MC-M2, with average nitrite concentrations of 0.030 and 0.025 mg/L, respectively. Given that the exceedances of the nitrite WQG were small in magnitude, the aquatic risk posed by nitrite in Myra Creek is likely to be low. Notably, no exceedances were observed in the historical dataset. Data for total nitrite measured in Myra Creek are reported in Table 11.

Table 11. Summary statistics for total nitrite concentrations (mg/L) in Myra Creek

Parameter	Historical Value (2007-2012)	MC-M1		MC-TP4		MC-M2	
		Low flow	High flow	Low flow	High flow	Low flow	High flow
Minimum	0.0005	<0.002	<0.002	0.019	<0.002	0.016	<0.002
Maximum	0.015	<0.002	<0.002	0.038	<0.002	0.035	<0.002
95th Percentile	0.010	<0.002	<0.002	0.038	<0.002	0.034	<0.002
Mean	0.004	<0.002	<0.002	**0.030**	<0.002	**0.025**	<0.002
Std. Dev.	0.003	n/a	n/a	0.008	n/a	0.007	n/a
n	70	5	5	5	5	5	5

Bolded values represent an exceedance of either the short- or long-term guideline for the maximum or mean values, respectively.

Historical values represent downstream sites in Myra Creek (i.e., MC-TP4 and MC-M2).

3.3 Additional Water Chemistry and Toxicity Data

Additional monitoring data were collected during the Cycle 5 EEM program (i.e., between January 1 and October 31, 2016) to provide points of comparisons against which to evaluate the results of in-stream fish and benthic macroinvertebrate studies. These data included water chemistry collected at different sites and frequencies, as well as effluent toxicity studies.

3.3.1 Water Chemistry Data

As part of MFOs environmental monitoring requirements, mine staff collect daily, weekly, monthly and quarterly grab samples to measure a variety of analytical parameters in surface waters. Daily and weekly samples were collected from the 11-A Run-off (i.e., treated effluent) and MC-TP4 locations. Daily samples from 11-A Run-off were measured for total copper and zinc concentrations, and daily measurements of total zinc concentrations were also performed at MC-TP4. Weekly monitoring included measurements at both locations for total and dissolved copper, as well as total lead concentrations at the 11-A Run-off location, exclusively. These sample were analyzed on site at the MFO analytical laboratory using ICP-MS.

Monthly sampling was also performed at 11-A Run-off, MC-TP4 and MC-M2, and included measurements of total and dissolved aluminum, cadmium, calcium, copper, iron, lead, manganese, phosphorus and zinc. Measurements of non-metals included total suspended solids (TSS), sulphate, water hardness, ammonia, nitrate, nitrite, total nitrogen, alkalinity and temperature. These same parameters were measured quarterly at the upstream MC-M1 location. All parameters were measured by Maxxam Analytics (Courtenay, BC).

The concentrations of various parameters were compared to applicable BC water quality guidelines (Myra Creek sites), whereas parameters measured in the effluent were compared to discharge limits detailed in MFO’s discharge permit PE 06858 (Table 12). Exceedances of either discharge limits or WQGs were flagged for additional investigation into their potential to cause adverse effects on biota during the 2016 field season.

Total zinc and copper concentrations measured from daily composite samples collected from the discharge were below permit discharge limits of 1 mg/L zinc and 0.6 mg/L copper in all 305 samples collected between January 1 and October 31, 2016. Zinc concentrations reached a maximum of 0.22 mg/L and averaged 0.11 mg/L. Copper concentrations reached as high as 0.02 mg/L and averaged 0.01 mg/L. Daily composite samples collected from MC-TP4 exhibited maximum and average total zinc concentrations of 0.21 and 0.09 mg/L, respectively. Both of these values exceeded the BC average and maximum water quality guideline for zinc of 0.0075 and 0.033 mg/L, respectively.

Weekly dissolved copper concentrations collected from the discharge were below the 0.20 mg/L discharge limit for dissolved copper, as the maximum concentration was 0.004 mg/L, over the 43 sampling events. Maximum and average total weekly lead concentrations measured in the effluent were 0.005 and 0.001 mg/L, respectively (n = 34). Both of these values fell below the dissolved lead limit of 0.05 mg/L in MDMER Schedule 4, and also below the limit for dissolved lead of 0.05 mg/L in the mine’s discharge permit (there is no limit for total lead specified in the permit).

Weekly sampling at the MC-TP4 location resulted in a maximum total copper concentration of 0.018 mg/L and an average concentration of 0.005 mg/L. During the same period, the maximum dissolved concentration was 0.006 mg/L and the average dissolved concentration was 0.003 mg/L. The BC water quality average guideline for total copper when water hardness is less than 50 mg/L is 0.002 mg/L. Of the 43 weekly sampling events conducted between January 1 and October 31, 2016, the average WQG was exceeded on 28 occasions.

MFO’s average monthly (quarterly for MC-M1) water quality monitoring data for Myra Creek stations are shown in Table 13. Notably, exceedances of WQGs were observed for total copper and zinc at the upstream MC-M1 location, as well as at both sampling locations located downstream of the effluent discharge (i.e., MC-TP4 and MC-M2). Additionally, exceedances of the dissolved cadmium WQG were also observed at the downstream sampling locations. Interestingly, dissolved concentrations of copper and zinc were substantially lower than their respective total concentrations at MC-M1, and were also below their respective guidelines. Since dissolved concentrations of metals are typically more relevant with respect to their potential for eliciting adverse effects, the elevated total concentrations measured at MC-M1 were likely not a major concern from an ecological risk perspective. Conversely, dissolved concentrations represented a much larger percentage of the total metals measured downstream of the discharge, and exceedances of WQGs were observed for cadmium, copper and zinc at MC-TP4 and MC-M2. Interestingly, none of the values for aluminum in samples from Myra Creek analyzed in this sampling program exceeded the BC average WQG of 0.05 mg/L for dissolved aluminum.

Table 12. 2016 monthly (January through October) water quality parameter measurements for the effluent relative to the mine's discharge limits.

Parameters	Effluent (mg/L)					Discharge limit
	Average	Standard deviation	Maximum	Minimum	95th percentile	
pH (pH unit)	8.6	0.1	8.7	8.3	8.7	6.5-10.0
Total aluminum	0.249	0.063	0.314	0.137	0.310	n/a
Dissolved aluminum	0.201	0.062	0.297	0.084	0.288	n/a
Total cadmium (µg/L)	0.369	0.225	0.850	0.169	0.778	n/a
Dissolved cadmium (µg/L)	0.177	0.082	0.380	0.100	0.320	5.0
Total calcium	103	12	122	88	122	n/a
Total copper	0.011	0.006	0.022	0.006	0.021	0.6
Dissolved copper	0.002	0.001	0.004	0.001	0.004	0.2
Total iron	0.062	0.058	0.173	0.019	0.164	n/a
Dissolved lead	0.001	0.002	0.005	0.0002	0.005	0.05
Total manganese	0.095	0.039	0.156	0.033	0.148	n/a
Total zinc	0.107	0.060	0.223	0.053	0.216	1.0
Dissolved zinc	0.039	0.017	0.073	0.019	0.067	0.5
TSS	5.65	1.20	6.50	4.80	6.42	25.0
Total phosphorus	0.003	0.003	0.008	0.002	0.007	n/a
Sulphate	272	37	312	215	310	n/a
Hardness	330	35.6	373	282	372	n/a
Total nitrogen	0.29	0.06	0.36	0.23	0.35	n/a
Total alkalinity	9.0	3.8	12.4	3.0	12.4	n/a

SD = standard deviation; all concentrations are reported in mg/L, unless otherwise indicated.

Table 13. 2016 monthly (January through October) water quality parameter measurements at locations within Myra Creek relative to applicable BC water quality average guidelines.

Parameters	Stations Upstream MC-M1	Downstream MC-TP4	Downstream MC-M2	BC WQG
pH (pH unit)	6.7 ± 0.9	7.5 ± 0.4	7.6 ± 0.4	>6.5 and <9
Total aluminum	0.05 ± 0.01	0.06 ± 0.02	0.05 ± 0.01	n/a
Dissolved aluminum	0.04 ± 0.02	0.04 ± 0.01	0.04 ± 0.01	0.05
Total cadmium (ug/L)	0.01 ± 0.01	**0.20 ± 0.12**	**0.18 ± 0.10**	
Dissolved cadmium (ug/L)	0.01 ± 0.00	**0.21 ± 0.11**	**0.19 ± 0.11**	0.07
Total calcium	4.1 ± 1.2	20.2 ± 12.8	19.8 ± 11.7	n/a
Total copper	**0.007 ± 0.011**	**0.005 ± 0.005**	**0.006 ± 0.010**	0.002
Dissolved copper	0.001 ± 0.001	**0.003 ± 0.002**	**0.006 ± 0.009**	
Total iron	0.006 ± 0.003	0.011 ± 0.005	0.009 ± 0.005	1.0
Total lead	0.0007 ± 0.0011	0.0005 ± 0.0008	0.0007 ± 0.0017	0.0035
Total manganese	0.00028 ± 0.00003	0.017 ± 0.012	0.001 ± 0.002	--
Total zinc	**0.052 ± 0.086**	**0.092 ± 0.061**	**0.099 ± 0.084**	0.0075
Dissolved zinc	0.0041 ± 0.006	**0.085 ± 0.052**	**0.103 ± 0.076**	
Total phosphorus	n/a	n/a	0.003 ± 0.001	n/a
Dissolved phosphorus	n/a	n/a	<0.002	
Sulphate	n/a	45.1 ± 36.1	42.4 ± 32.0	128
Hardness	11.0 ± 4.5	60.4 ± 39.9	58.4 ± 38.5	n/a
Ammonia (as N)	n/a	n/a	0.11 ± 0.21	0.50
Nitrate (as N)	n/a	n/a	0.050 ± 0.043	3
Nitrite (as N)	n/a	n/a	≤0.002	0.02
Total alkalinity	n/a	n/a	17.6 ± 5.4	n/a

SD = standard deviation; all concentrations are reported in mg/L, unless otherwise indicated; Bolded values represent an exceedance of BC WQGs

Despite the observed exceedances of WQGs observed in Myra Creek for copper, cadmium and zinc, data from the biological health metrics collected in the EEM study found no evidence of adverse effects on fish health or benthic macro-invertebrate communities within Myra Creek. Notably, WQGs represent conservative screening-level benchmarks for identifying the potential for risk of adverse effects to biota across a wide range of ecosystems; thus, exceedances of the guidelines do not necessarily mean that concentrations have reached effect levels for a given system, only that additional investigations are required to ensure that the measured exceedances are below site-specific effects thresholds.

3.3.2 Toxicity Test Data

MFO is required to perform sublethal toxicity tests on its effluent on an annual basis using a freshwater fish, invertebrate, plant and algal species. Specifically, the testing program includes: 7-d rainbow trout (*Oncorhynchus mykiss*) embryo viability test, 7-d water flea (*Ceriodaphnia dubia*) survival and reproduction test, 7-d duckweed (*Lemna minor*) growth inhibition test, and a 72-h green alga (*Pseudokirchneriella subcapitata*) growth inhibition test. Additionally, MFO is required to perform acute toxicity testing on its effluent on a quarterly basis, which involves 96-h rainbow trout fry and 48-h water flea (*Daphnia magna*) survival tests. A key factor to consider when interpreting the toxicity test data is that the results provide an assessment of worst-case effects associated with the effluent; because the effluent is diluted once released into the receiving environment, the effect levels need to be evaluated in the context of anticipated dilution levels.

3.3.2.1 Historical Data (2004 – 2011)

Cycle 3 provided the last update on the historical acute toxicity testing program, which summarized a total of 60 acute rainbow trout survival tests conducted between 2004 and the first quarter of 2011. Of these tests, all but one (i.e., >98% of the tests) exhibited an LC50 of >100% effluent.

Over the same time period, a total of 64 acute *D. magna* survival tests were performed, 60 of which were performed as a series of dilutions (LC50), and 4 of which were performed only on the full-strength undiluted sample. Of the 60 LC50 tests, 24 samples showed acute toxicity. In general, LC50 values were ≥70%. Interestingly, the majority of acutely toxic samples occurred prior to 2007; of a total of 31 samples tested from 2004 through 2006, 18 exhibited acute toxicity.

MFO was required to conduct sub-lethal toxicity testing on their effluent using *Ceriodaphnia dubia*, rainbow trout embryos, *Pseudokircneriella subcapitata*, and *Lemna minor* on a twice annual basis up until 2005 (Cycle 1), after which the frequency was reduced to annual testing beginning in 2006 (Cycle 2). The sub-lethal toxicity data was last summarized in the Cycle 3 report, which integrated the toxicity testing data collected over Cycles 1 and 2. There was substantial variability in organism response over this period; however, the degree and frequency of responses did not appear to differ appreciably between cycles.

Historically, *Ceriodaphnia dubia* appeared to be the most sensitive species to MFO's effluent, as the IC25 for reproductive effects ranged from 1.5% to >100% effluent. Rainbow trout were the least sensitive, with effect levels (IC25) for embryo viability ranging between 51% and >100%, with 67% of the tests showing no adverse effects at 100% effluent. *P. subcapitata* exhibited effect levels for growth that ranged from 30.8% to >97% effluent, and *L. minor* exhibited effect levels for frond growth and weight that ranged between 20% and >97%, and between 15% and >97%, respectively.

3.3.2.2 Recent Data (2011 – 2016)

Since Cycle 3 of the EEM program, MFO has conducted twenty-seven 96-h rainbow trout survival tests and twenty-six 48-h *D. magna* survival tests. With one exception, these toxicity tests resulted in LC50 values of >100% effluent; the 48-h *D. magna* test performed in August 2013 resulted in an LC50 value of 100% effluent. These results indicate that MFO's effluent has generally not been acutely toxic even at full strength during quarterly testing conducted over the past six years. These data further suggest that the mine`s effluent quality has improved substantially over the years, as acute toxicity to *D. magna* was observed on six occasions between 2007 and 2011, and on 18 occasions between 2004 and 2006. Toxicity to rainbow trout on the other hand has never been a major issue, with only one toxic sample identified in over 14 years of monitoring.

Since 2008, sub-lethal toxicity testing has been conducted annually for a total of 8 events, and the results are presented in Table 14. The results suggest that the most sensitive species has been *C. dubia*, as the average IC25 for reproduction was 40% effluent. On average, the next most sensitive species was duckweed, with an average IC25 for frond growth of 53% effluent; however, some IC25 values obtained with this species were below 10% effluent. The remaining species were relatively insensitive to MFO's effluent, as average IC25s for *P. subcapitata* growth and rainbow trout embryo viability were 89% and 100% effluent, respectively. Variability among test results makes it problematic to definitively identify differences between cycles, but it appears that the *C. dubia* survival endpoint, *P. subcapitata* growth and trout embryo viability responses have all improved since Cycle 1 (Nautilus Environmental, 2017).

In summary, monitoring of acute toxicity to rainbow trout and *Daphnia magna* in MFO's effluent has generally shown the effluent to be non-toxic during quarterly tests conducted over the past six years. Similarly, annual sub-lethal toxicity tests of MFOs effluent conducted since 2008 exhibited relatively little toxicity in rainbow trout embryo development tests and *P. subcapitata* growth tests. Sub-lethal toxicity testing over the same period with *C. dubia* and duckweed showed that these species were more sensitive to MFO's effluent, as IC25 values for *C. dubia* reproduction and duckweed frond growth averaged 40% and 53% effluent, respectively. However, it should be noted that IC25 values as low as 5% have been observed with duckweed on an occasional basis. Regardless, given that the effluent generally accounts for less than 12% of the flows in Myra Creek downstream of the discharge, these results suggest that MFO's effluent would typically not result in acute or sub-lethal effects if mixing (i.e., dilution) is taken into consideration. Of note, this observation is also consistent with the lack of effects observed during EEM sampling programs, in spite of the fact that a number of metals have consistently been observed at concentrations exceeding WQGs downstream of the discharge point.

Table 14. A comparison of mean endpoints collected from sub-lethal toxicity tests on MFO's effluent since 2008 (n = 8).

	Ceriodaphnia dubia		**Rainbow trout**	**Green alga**	**Duckweed**	
Test date	**Survival (LC50)**	**Reproduction (EC25)**	**Embryo viability (EC25)**	**Growth (EC25)**	**Frond growth (EC25)**	**Dry weight (EC25)**
May 2009	>100	14	>100	46	6	>97
May 2010	>100	44	>100	>95	>97	9
Nov. 2011	>100	25	>100	>95	42	>97
May 2012	>100	60	>100	>95	>97	>97
May 2013	>100	24	>100	>95	49	>97
May 2014	>100	54	>100	>95	68	>97
Apr. 2015	>100	30	>100	>95	5	>97
Jun. 2016	>100	65	>100	>95	62	>97
Average (± SD)	>100	40 ± 19	>100	89 ± 17	53 ± 36	86 ± 31

All values are listed as % volume/volume effluent; SD = standard deviation; Average and SD calculations were performed by assigning >values as the highest concentration tested (i.e., >100% = 100%, >97% = 97%, etc.).

4.0 COMPARISONS TO BACKGROUND AND CANDIDATES FOR THE DEVELOPMENT OF SBEBS

Parameters that exceeded WQGs in Myra Creek in the 5-in-30 sampling program are summarized in Table 13; note that upper Myra Creek (i.e., MC-M1) represents water conditions in Myra Creek that are upstream of the mine's discharge and, therefore, can be assumed to represent background conditions. During high-flow conditions, exceedances of WQGs for zinc, aluminum and copper were observed in upper Myra Creek that could also account for elevated concentrations in the downstream reaches. Thus, exceedances of these constituents observed at the downstream sites during high-flow events could be explained on the basis of background concentrations associated with upper Myra Creek.

Upstream concentrations of zinc and copper did not account for exceedances observed during low-flow conditions. Thus, elevated concentrations of zinc and copper in lower Myra Creek appeared to be related to the effluent discharge and, therefore, warrant the development of SBEBs. The magnitude and frequency of exceedances for zinc and copper were substantial, suggesting that development of SBEBs for these constituents in lower Myra Creek is appropriate to reflect local conditions and ensure that water quality (i.e., aquatic life) is protected.

Similarly, cadmium concentrations were also elevated above the maximum guideline in upper Myra Creek during high-flow conditions, but the magnitude and frequency of exceedances were lower than observed at the downstream Myra Creek sites, suggesting that the effluent discharge was primarily responsible for cadmium concentrations downstream of the discharge. This observation was even more apparent during low flows when upstream concentrations were below WQGs, and both maximum and average guidelines were routinely exceeded at MC-TP4 and MC-M2. Collectively, these data suggest that development of SBEBs for cadmium were warranted for lower Myra Creek to ensure that water quality (i.e., aquatic life) is protected.

The remaining parameters in Table 15 (lead, aluminum, silver and nitrite) exhibited low frequency and magnitude of exceedances (aluminum, silver and nitrite), or were limited to the upstream site only (lead). Of note, no exceedances of WQGs were observed for aluminum, silver and nitrite at the downstream sites in the historical dataset.

Table 15. Summary of parameters and exceedances of WQGs in Myra Creek under different flow conditions during the 5-in-30 sampling program; guideline exceedances are denoted by (+). Shaded cells identify parameters measured downstream at M2 that may exceed upstream conditions at M1.

Parameter	Myra Creek	
	Low Flow	High Flow
Zinc	+	+
Aluminum	+	+
Cadmium	+	+
Copper	+	+
Silver	+	-
Lead	-	+
Nitrite	+	-

Based on this analysis, parameters with identified exceedances in the 5-in-30 sampling program can be broken down into different categories:

- Exceedances only occurred at the upstream site: this was observed for lead under high flow conditions, indicating a background condition.
- Exceedances occurred at downstream sites, but were low in magnitude (i.e., within analytical variation of guideline value) and infrequent, and were not observed in the historical dataset: this was the case for aluminum, silver and nitrite.
- Exceedances occurred at downstream sites on a consistent basis that were appreciably greater than the WQGs and could not always be explained by background conditions: this was observed for copper, cadmium and zinc.

Thus, constituents of concern that merit development of SBEBs include copper, cadmium and zinc. Conversely, potential COCs that exhibited minor exceedances of WQGs and can continue to be evaluated on the basis of existing WQGs include nitrite, silver and aluminum. Given the presence of exceedances in Myra Creek upstream of the mine, it may be desirable to consider a site-specific water quality objective for lead in this reach.

5.0 TOXICITY MODIFYING FACTORS

Through five cycles of EEM monitoring, the fish and invertebrate communities in Myra Creek have exhibited no evidence of adverse effects, in spite of the fact that a number of parameters exceed WQGs. Thus, from a site-specific perspective, it is clear that the WQGs over-estimate the potential for adverse effects. To be fair, the exceedances associated with parameters such as aluminum, silver and nitrite were small and likely well within the variability that might be expected in terms of analytical chemistry. Conversely, exceedances associated with copper, zinc and cadmium were larger and potentially of concern. Although it is not immediately apparent what actual site-specific factors mitigate the potential toxicity associated with these exceedances, potential possibilities include some aspect of local water chemistry or acclimation on the part of local organisms. The latter possibility is especially attractive given the pulses of metals concentrations that occur during high-flow events. Thus, local organisms are challenged by pulses of metals on a regular basis that would likely result in biochemical responses (i.e., induction of metallothionein, for example) that would mitigate the effects of exposure (e.g., Buckley *et al.*, 1982; Benson and Birge, 1985; Mebane, 2003; Brinkman and Hansen, 2007). Since this is a background condition, it would be expected that this would provide some level of protection at the watershed level.

6.0 LITERATURE REVIEW

Exceedances of effects levels associated with copper, zinc and cadmium are an area of concern to freshwater aquatic organisms, resulting in a substantial body of literature spanning over 60 years. While a comprehensive review of each metal is beyond the scope of this document, there are many resources available to the interested reader. Of note, results from numerous controlled laboratory and field studies have been compiled over the years to derive regulatory guidelines for all of these metals, including efforts in British Columbia, Canada and the United States:

- Copper
  - BC (1987)
  - CCME (1999)
  - USEPA (2007)
- Cadmium
  - BC (2015)
  - CCME (2014)
  - USEPA (2016)
- Zinc
  - BC (1999)
  - CCME (1987)
  - USEPA (1995)

These reviews collect and compile data and associated water quality conditions from studies around the world in order to derive applicable water quality guidelines. Of note, they may arrive at different numbers depending on assumptions, methodology and intended application. Academia and industry have also collaborated to provide better understanding of copper (Flemming and Trevors, 1988; Ashish *et al*., 2013; Gaetke *et al*., 2014), cadmium (Taylor, 1983; Wright and Welbourn, 1994; Zaki *et al*., 2016), and zinc toxicity (Skidmore, 1964; Luoma, 1983; Rainbow and Luoma, 2011).

6.1 Role of Water Chemistry in Toxicity

Metals toxicity can vary substantially from exposure to exposure, either in field or laboratory testing (Campbell, 1995; Allen and Hansen, 1996; Paquin *et al*., 2002). Water chemistry plays a large role on toxicity, and numerous models have been created over the years to try and encompass these modifying factors. The biotic ligand model (BLM) is a well-recognized metal bioavailability model that uses receiving water characteristics to aid in developing site-specific water quality guidelines. For example, it allows for input of ten parameters to calculate a site-specific copper criterion: pH, temperature, dissolved organic carbon (DOC), calcium, magnesium, sodium, potassium, sulfate, chloride and alkalinity to estimate speciation, bioavailability and associated toxicity (MacRae *et al*., 1999). Alternatively, a simpler hardness-based guideline can be applied.

It is widely known and extensively documented that metals such as copper, cadmium and zinc are less toxic in harder water (Mount, 1966; Pickering and Henderson, 1966; Brown *et al*., 1974; Zitko and Carson, 1976; Chapman and McCardy, 1977; Howarth and Sprague, 1978). These metals are often more toxic in soft water as they are more soluble and, therefore, in their dissolved (bioavailable) form (Waiwood and Beamish, 1978; Lauren *et al*., 1986; Taylor *et al*., 2000; Rathore and Khangarot, 2003). In addition, the greater abundance of divalent cations in harder waters may compete for binding sites at the fish gill (Playle *et al*., 1993; Hollis *et al*., 1997; Niyogi *et al*., 2008).

The pH of the receiving environment is also an important factor affecting the toxicity of metals to freshwater organisms, as it can affect speciation (Flemming and Trevors, 1988). For example, numerous fish and invertebrate studies have shown increases in copper toxicity with decreasing pH due to the predominance of the free metal ion at low pH (Starodub *et al.* 1987; Rai *et al.* 1993). Conversely, while the toxicity of copper to *C. dubia* has been shown to decrease five-fold with increasing pH, the toxicity of zinc increased five-fold with increasing pH (Hyne *et al*., 2009).

Temperature also plays a pivotal role in heavy metal toxicity. With increasing water temperature, the toxicity of metals generally increases a result of both increased chemical activity and increased metabolic rates of aquatic organisms (Davies, 1976).

Another pivotal covariate involved in metal toxicity is dissolved organic carbon. As an example, copper bioavailability is strongly influenced by DOC. Dissolved copper, being the most toxic bioavailable form, can complex with the negatively charged dissolved organic matter, thus reducing the amount of free Cu in solution and thereby reducing its bioavailability and toxicity (Santore *et al*., 2001; Gillis *et al*., 2010; Wang *et al*., 2010). This complexation and subsequent reduction in toxicity has been demonstrated in a range of species from microinvertebrates to fish (Giesy *et al*., 1983; Arnold, 2005).

6.2 Toxicity Mitigating Factors

Using copper as an example, it is evident that toxicity can vary substantially (USEPA 2007). For example, reviewing 17 chronic toxicity exposures in invertebrates, LC50s ranged from 2.83 (*D. pulex*) (Winner, 1985) to 34.6 µg/ L (*C. dubia*) (Oris *et al*., 1991); and 12 chronic values for fish species ranged from <5 (brook trout) (Sauter *et al*., 1976) to 60.4 µg/L (northern pike) (McKim *et al*., 1978).

Of note, copper concentrations observed in Myra Creek overlap with these literature values and sometimes are quite a bit higher; however, no adverse effects have been observed. A potential explanation for apparent paradox, in addition to possible site-specific physicochemical differences in water chemistry discussed previously, could be potential acclimation of local species to copper. Given that pulses of metals concentrations occur during high-flow events, local organisms are being challenged by metals on a regular basis which could result in attenuating responses. For example, the induction of metallothionein mitigates the effects of exposure (Brinkman and Hansen, 2007), resulting in enhanced tolerance to copper (Dixon and Sprague, 1981), zinc (Bradley *et al*., 1985) and cadmium (Chowdhury *et al*., 2004). Metallothionein induction plays a pivotal role in acclimation and acquired tolerance by binding and subsequently preventing toxic metals from causing cellular damage (Roch and McCarter, 1984; Wu and Hwang 2003). Thus, binding of toxic metals to metallothionein represents a sequestration function that renders metals unable to interact with other proteins, and thereby produces protection against metal toxicity at the cellular level.

There is also evidence for modifications at the cellular and genetic level that could provide generational protection to species. Thus, acclimated or resistant populations could arise, and pass on "acquired" adaptations to subsequent generations (Klerks and Weis, 1987). Of note, the level of tolerance exhibited by acclimated organisms is significant; for example, rainbow trout pre-acclimated to zinc exhibited an LC50 more than ten times greater than non-acclimated trout (Bailey and Saltes, 1982). On a population scale, selection against individuals with low tolerances to pollutants can result in genetic adaptation (Ownby *et al*., 2002). This process of natural selection has been documented in a range of species including plants (Antonivics, 1971; Baker, 1989), where exposed seedlings had greater survival and germination compared to non-tolerant seedlings on contaminated soil; second-generation arthropods (Posthuma, 1990) who descended from highly contaminated sites showed no growth reduction in the presence of cadmium, while reference site offspring exhibited significant reduction, and fish (Chambers and Yarbrough, 1979; Wise *et al*., 1986) for both organic and metal contaminants.

7.0 PROPOSED SCIENTIFIC APPROACH

The proposed approach for developing the SBEBs is relatively straightforward. At its simplest, for each constituent of concern (i.e., copper, zinc and cadmium), there is a range of concentrations that are associated with lack of effects in the receiving environment. Thus, it will be necessary to quantify that range and express it in the form of average and maximum values, similar to the approach taken with the BCWQGs for each of the metals. To achieve this objective, it will be necessary to identify underlying concentration distributions that provide the most robust estimates of values protective of acute and chronic exposure endpoints, and ensure that different sets of data provide convergent information for the same constituent. In addition, given the influence of hardness on toxicity, work will also need to be directed towards determining the relationships between concentration and hardness for the different metals. Therefore, the associated SBEBs will need to be expressed as a continuous function of hardness and will be developed on the basis of actual paired concentration and hardness data.

In order to illustrate the proposed methodology, copper is presented as an example; cadmium and zinc will follow a similar approach with appropriate modifications applied as necessary consistent with providing a science-based level of protection to the receptors of concern. First, concentration data will be compiled, along with corresponding hardness values, and evaluated for congruence and any outliers. Focus will be placed on the downstream M2 sampling site, as it reflects mine influences, as well as other inputs. This site also contains concentrations that are very similar to the TP-4 downstream site, is well mixed and has a large historical dataset. Furthermore, metals data will be expressed as the dissolved fraction based on the fact that the dissolved fraction is widely recognized as the bioavailable (i.e., toxic) fraction, and the data available suggest that the ratio of total to dissolved varies widely in Myra Creek, depending on sampling time and location. Thus, use of the dissolved fraction should provide a more consistent indication of the potential for adverse effects across all sampling locations.

There are five datasets of interest for this approach:

- Analytical data associated with acute toxicity tests (daphnia and trout) over the past EEM Cycle 5 monitoring program: Jan – Oct 2016
- Analytical data associated with sublethal toxicity tests (trout embryo, duckweed, algae, *Ceriodaphnia*) over the past EEM Cycle 5 monitoring program: Jan – Oct 2016
- Historical analytical data previously compiled for a 5-year period (2007-2012)
- 5-in-30 analytical data for low and high flow periods: Aug – Sept 2014 (low flow) and Nov – Dec 2015 (high flow)
- Supplemental analytical data related to the *in situ* cutthroat trout ELS exposures and the invertebrate surveys.

The historical 5-year analytical dataset was the primary basis for implementing this procedure as it encompasses a large dataset of at least 60 individual samples with paired hardness data, and can be broken down into seasonal or monthly categories to facilitate comparisons with the short-term (i.e., 5-in-30) data sets. Moreover, given that the concentrations were determined within the temporal boundaries of the EEM monitoring program, the concentrations should represent a non-toxic dataset from which transparent and defensible endpoints can be calculated.

The basic process of endpoint derivation is relatively straightforward. A preliminary “average” value (pSBEB Average) will be derived as a best-fit model of the historical dataset, and a preliminary maximum value (pSBEB Max) will be determined by re-fitting the appropriate BCWQG maximum model such that only 5% (i.e., 3 datapoints) of the collective datapoints exceed the upper boundary or maximum exposure value; thus, the maximum value is nominally the 95th percentile of the historical dataset. As part of the process, it will be necessary to make sure that the derived values are not biased by a few appreciably higher outlier values. Validations steps will include comparisons of pSBEBs to USEPA water quality criteria, the range of concentrations associated with the 5-in-30 sampling program and the range of concentrations associated with the *in situ* test. The specifics of the process are described below using copper as an example.

7.1 Endpoint Derivation (Copper)

Figure 7 shows the baseline case of total copper and hardness in comparison to the BCWQGs, providing visual evidence of the magnitude and frequency of the exceedances. As noted previously, nearly all of the values exceed the average guideline and several exceed the maximum guideline. Figure 8 shows first step of the process, wherein the same data are shown on the basis of the *dissolved* copper concentration and corresponding hardness. Exceedances are still present, but to a lesser degree. Figure 9 shows recalculated lines for maximum and average values (i.e., the pSBEBs); comparison of the equations associated with the WQGs in Figures 8 and the calculated pSBEBs in Figure 9 shows the relatively small mathematical differences from the guideline equations relative to the calculated SBEBs.

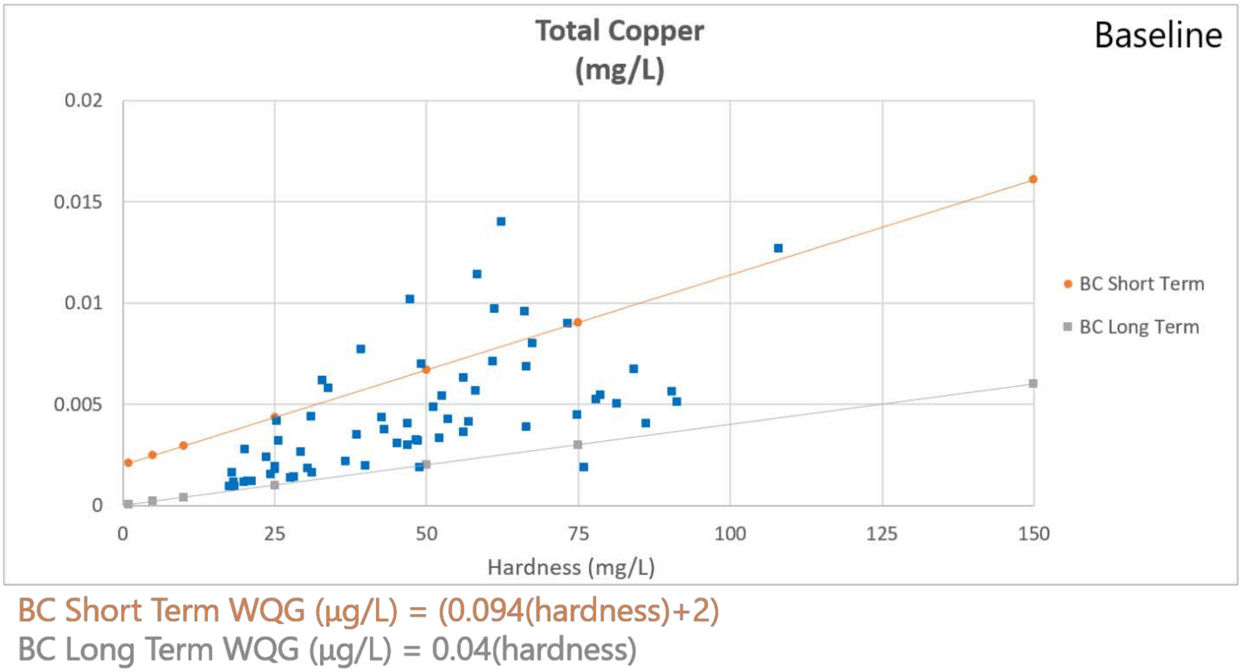
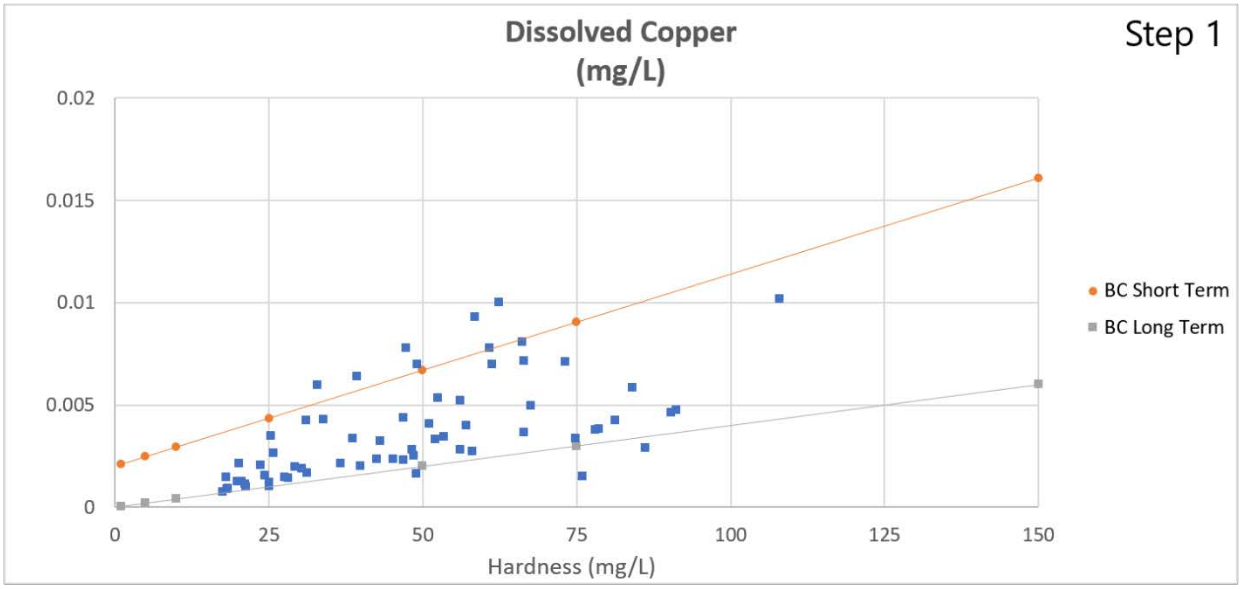
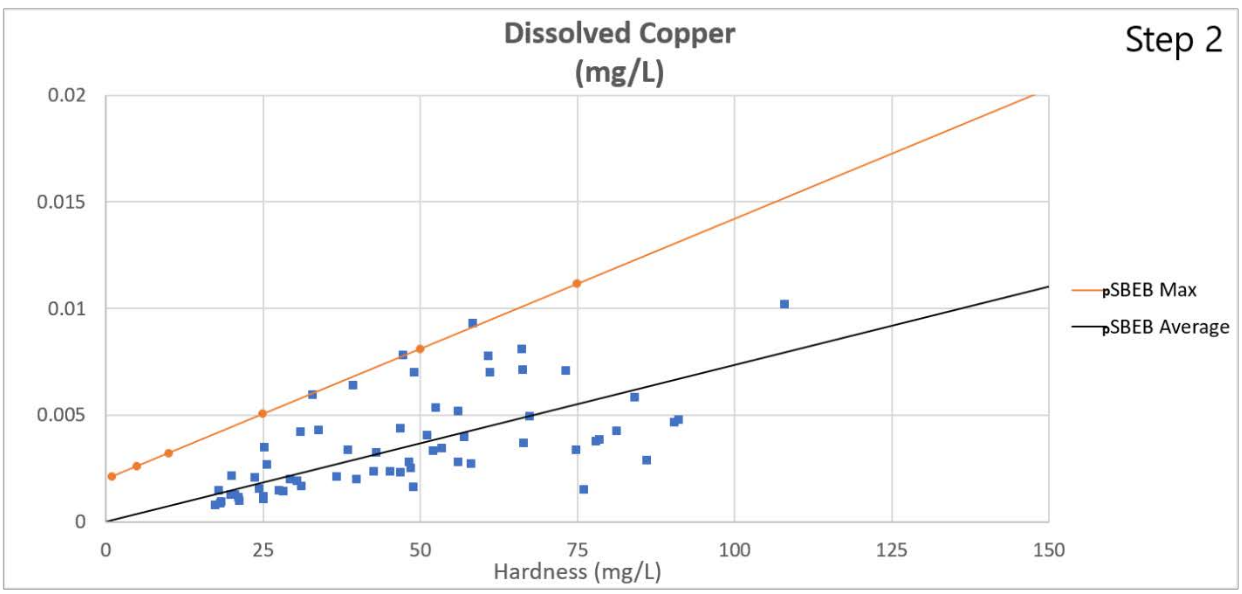


Figure 7. Total Copper and Hardness at M2 Compared to BC Water Quality Guidelines



BC Short Term WQG (µg/L) = (0.094(hardness)+2)
BC Long Term WQG (µg/L) = 0.04(hardness)

Figure 8. Dissolved Copper and Hardness at M2 Compared to BC Water Quality Guidelines

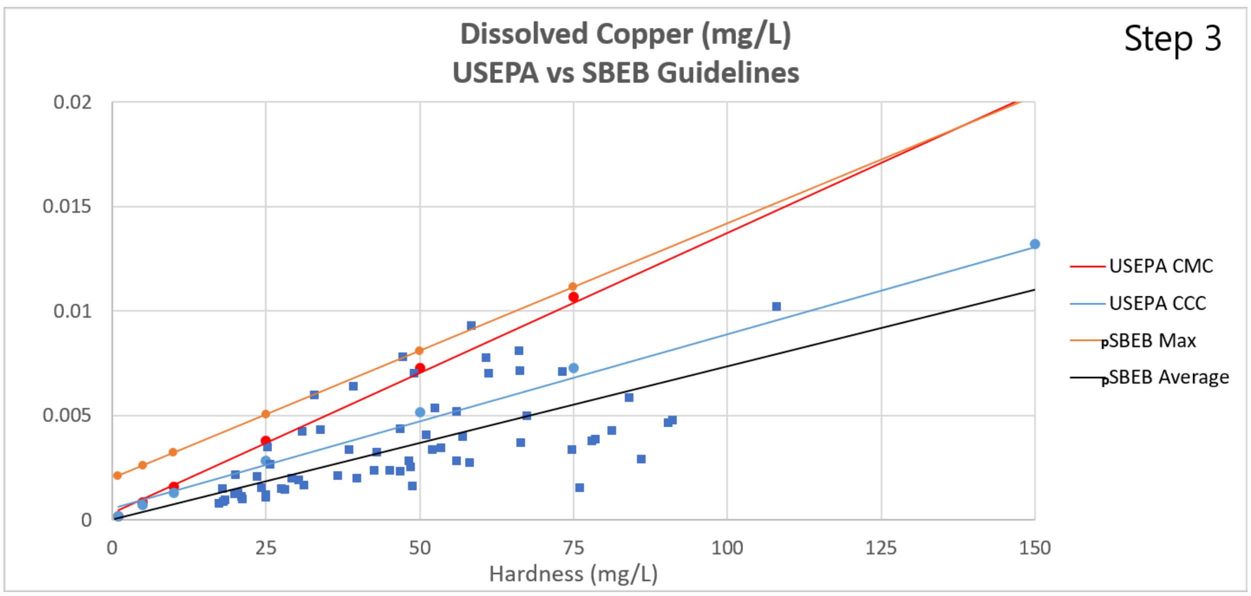


pSBEB Max (µg/L) = 0.122(hardness)+2
pSBEB Average (µg/L) = 0.07(hardness)

Figure 9. pSBEBs Derived for Dissolved Copper as a Function of Hardness at M2

7.2 Endpoint Validation

To ensure that the pSBEBs are protective, it is important to compare them to other data to provide an additional level of validation that supports their intended use. Figure 10 compares the proposed SBEBs to the USEPA copper criteria for maximum and continuous exposures. As the figure shows, the pSBEBs are in reasonably close agreement with the USEPA criteria, being slightly less and slightly more conservative than the maximum and continuous (average) values, respectively. The calculated pSBEBs were also compared to effluent copper concentrations (Figure 11) and the *in situ* cutthroat trout ELS exposures (Figure 12), which both represent non-toxic conditions. Notable, these data fall within or below the pSBEB ranges, consistent with their associated lack of toxicity. Collectively, the different lines of evidence suggest that the pSBEBs should be protective of aquatic life in Myra Creek.



CMC (µg/L) = exp(0.9422*(ln(hardness))-1.7)

CCC (µg/L) = exp(0.85452*(ln(hardness))-1.702)

pSBEB Max (µg/L) = 0.122(hardness)+2

pSBEB Average (µg/L) =0.07(hardness)

Figure 10. Dissolved Copper pSBEB Guidelines Compared to USEPA Water Quality Criteria

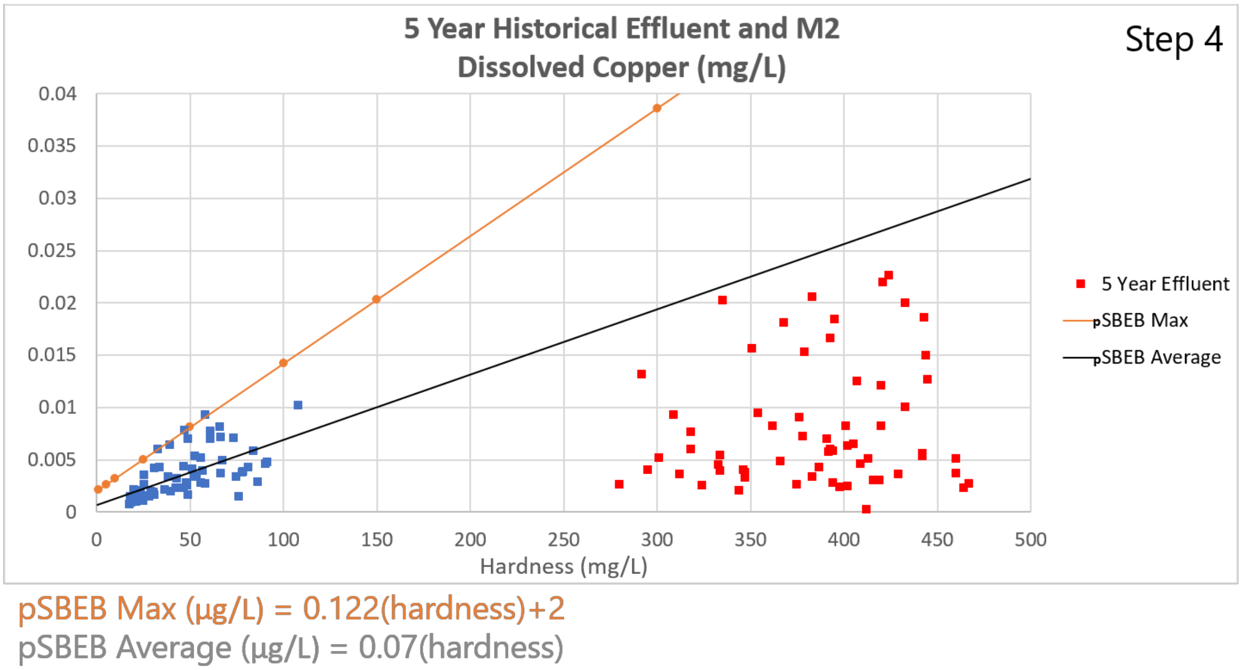


Figure 11. Dissolved Copper pSBEB Guidelines Compared to 5 Year Effluent Data

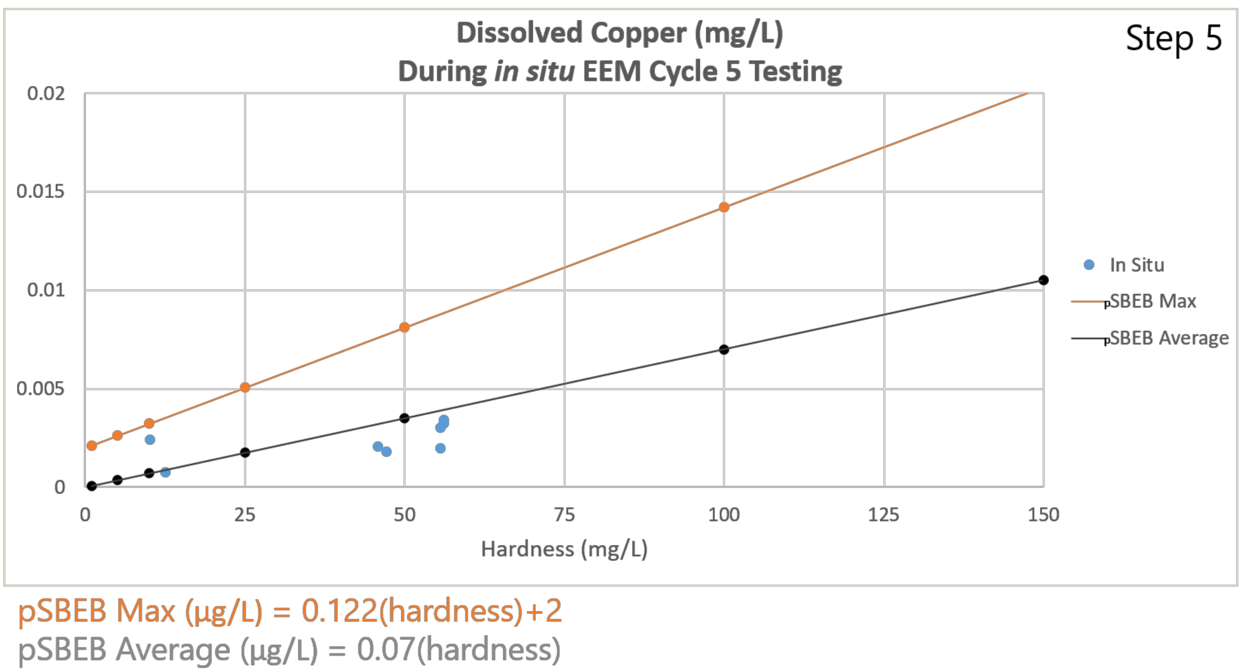


Figure 12. Dissolved Copper pSBEB Guidelines Compared to *in situ* Data

8.0 IMPLICATIONS OF BACKGROUND COPPER CONCENTRATIONS

The results of the 5-in-30 sampling at M1 and M2 are shown together with the historical data and pSBEBs in Figure 13. For the most part, the 5-in-30 sampling results at M2 fall within the range of pSBEB values. However, during the high-flow period, it is clear that higher concentrations are present at M1, which are also reflected in elevated but lower values at M2. This suggests that monitoring at M2 needs to take concentrations originating upstream of mine inputs into consideration during high-flow events.

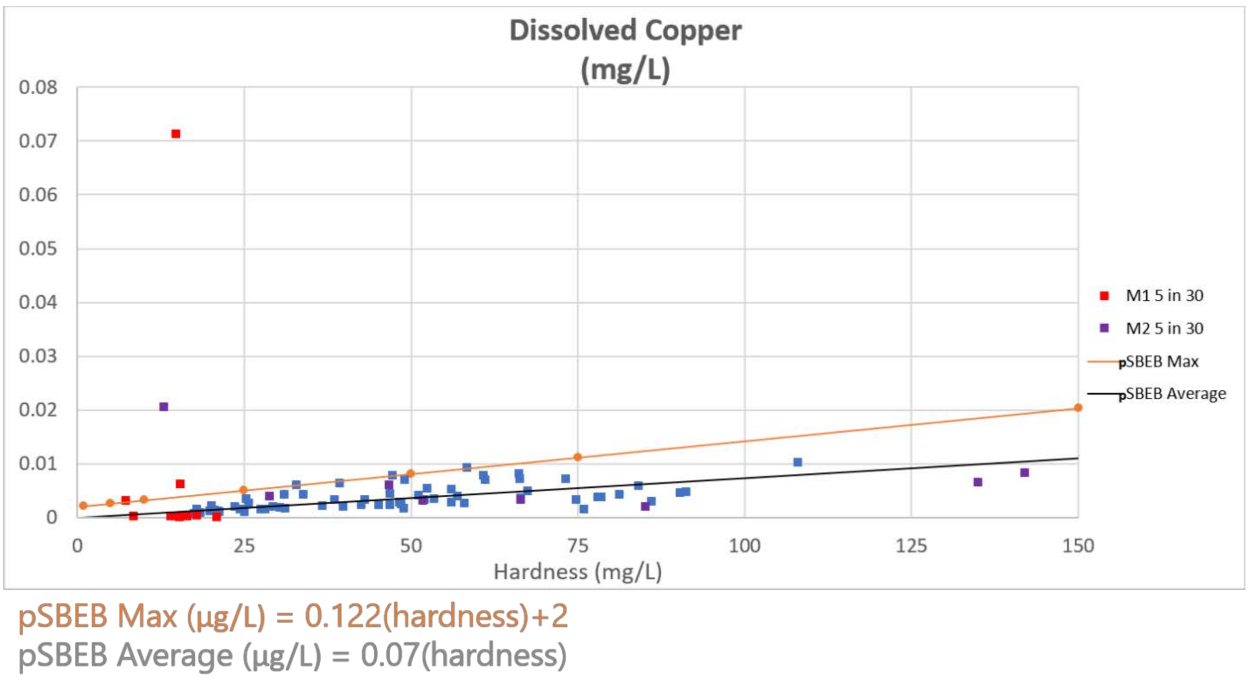


Figure 13. Dissolved Copper pSBEB Guidelines Compared to 5-in-30 Sampling Results

9.0 UNCERTAINTIES

To summarize, the proposed SBEB derivation process will involve:

- Organizing and collating data
- Identifying and assigning matching variables (i.e., total and dissolved concentrations, hardness, season)
- Identifying any outliers and data gaps
- Obtaining any missing data
- Establishing relationships between variables
- Comparing the results to validity criteria
- Identifying the most robust combination to serve as pSBEBs

However, as with all projects, there are uncertainties that may affect the outcome. Possible company-wide issues might include loss of key staff and data file corruption, and would be mitigated by best practices regarding staffing depth, data back-ups and so on. On a project level, all of the key data groups have been identified; however, the precise extent to which they overlap, or can be related to supporting ancillary information has not yet been established. Thus, for example, it is unknown if total and dissolved fractions are available for each metal measurement. Similarly, associated hardness values may not be available for all measurements. Consequently, an important aspect of the initial steps of the project will be to organize all the data in the context of desired data requirements, identify any associated gaps, and then attempt to fill them.

That being said, the data sets available are robust and we are confident they can be used to establish appropriate benchmarks that will withstand scientific scrutiny and be protective of aquatic life. Indeed, this conclusion is strongly supported by initial SBEB derivation undertaken for copper.

10.0 SCHEDULE

It is estimated that it will take approximately 16 weeks to complete the analysis and pSBEB derivation. This period includes data review and analysis, preparation of a draft report and document review and revision (Table 16). Additional time may be required to respond to Ministry review and comments. Of note, the first four items in Table 16 have largely been completed as a function of preparing the Development Plan; therefore, assuming this development plan is approved, proceeding through the final calculations and report should be fairly straightforward.

Table 16. Schedule for SBEB determination: Myra Creek

	Weeks																
Task	1	2	3	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Organize and collate data																	
Identify data gaps																	
Obtain missing data																	
Data analysis																	
Finalize SBEBs																	
Preparation of draft report																	
Review by Myra												******************					
Revise report																	
Submit to Ministry																X	

11.0 DELIVERABLES

The deliverable will be a report detailing the overall approach, methods, data analysis, and the SBEB recommendations. Specifically, the report will provide clear documentation of the process and any associated assumptions, as well as the rationale for why the recommended values are consistent with continued protection of aquatic life in Myra Creek. Appendices with the data used for the analyses will also be provided. Following acceptance of the Phase I SBEB Development Document, Nautilus Environmental will commence working on the Phase II Method Derivation Document, to be submitted within three months' time after notice to proceed has been received from Nyrstar Myra Falls.

12.0 ADDITIONAL CONSIDERATIONS

Following initial review of the draft Design Document, ENV requested that two additional items be addressed in the final SBEB report (per N. Obee email 26 April 2019), and each is discussed below. Please note that because the actual SBEB derivations have not been completed, the associated discussions are necessarily general descriptions of process, rather than detailed narratives of actual methods and findings.

1. Action Item #1: ENV requested that the SBEB Development Plan include a way to figure out the concentration above which effects are likely, for Zn, Cd and Cu. This could be done by spiking site water with the mixture of contaminants, or other methods in Technical Guidance 8.

Response: Deriving the SBEBs will be a two-step process. Step 1 is the range-based approach described in this document that uses 5 years of historical monitoring data to determine maximum and average values consistent with non-toxic conditions based on invertebrate community monitoring and *in situ* trout early life stage testing. Of note, these data incorporate instream variability in metals concentrations over an extended period of time, with approximately 60 measurements per metal. This exercise will result in preliminary SBEBs as a function of maximum and average instream concentrations (i.e., $pSBEB_{max}$ and $pSBEB_{av}$).

Once the pSBEBs have been derived, an effort will be made to identify the threshold above or below the SBEBs that would likely be associated with adverse effects (Step 2). This process is complicated by the potential range of variability in concentration ratios among the different metals, available test species and the fact that resident organisms are likely acclimated to higher concentrations due to periodic in-stream exceedances from upstream sources. However, a reasonable and conservative approach would be to spike different levels (e.g., 0.25, 0.5, 1, 2 and 4X) of a mixture of metals at the ratio of their respective $pSBEB_{max}$ concentrations into site water, determining the associated level for acute toxicity (e.g., 96-hr rainbow trout test) and comparing that level to the $pSBEB_{max}$ values. Lack of toxicity in the mixture at $pSBEB_{max}$ concentrations would imply that the derived metrics are suitable for their intended purpose.

2. Action Item #2: ENV asked that the SBEB Document (Phase 2) include an explanation about how the SBEB numbers will be implemented; e.g. what happens in the event of an exceedance. Part of the reason for this is that it appears the SBEBs will be exceeded fairly frequently in freshet due to upstream spikes in concentrations.

Response: Once the concentration data for each of the metals under investigation have been compiled and SBEBs determined and validated, a supplemental monitoring plan will be proposed that would be triggered in the event of an exceedance. Elements of the plan would include sampling locations, frequency and duration in order to provide context for the source, magnitude and duration of the event to facilitate management decisions and impact assessment. For example, in the event of an exceedance, given the potential for occasional spikes in metals concentrations from upstream sources, the first action might be to compare the downstream concentration to a triggered upstream background result. If the upstream concentration was elevated above typical background conditions, it could be assumed that was the cause of the downstream exceedance. Triggered monitoring at the upstream location(s) would continue at the same frequency as the downstream site until concentrations returned to below the SBEB.

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APPENDIX A – Chemistry

5 year Historical Dataset (mg/L)														
M2 (Dissolved)					M1 (Total)					Effluent (Dissolved)				
Date	**Hardness**	**Copper**	**Cadmium**	**Zinc**	**Date**	**Hardness**	**Copper**	**Cadmium**	**Zinc**	**Date**	**Hardness**	**Copper**	**Cadmium**	**Zinc**
1/25/2007	39.3	0.0064	0.00047	0.223	**1/25/2007**	9.81	<0.0010	<0.000017	<0.0050	**1/25/2007**	394	0.0058	0.00141	0.249
2/22/2007	62.4	<0.010	<0.010	0.357	**2/22/2007**	14	<0.010	<0.010	<0.0050	**2/22/2007**	381	<0.010	0.00312	0.218
3/22/2007	58.4	0.0093	0.000692	0.324	**3/22/2007**	13.3	<0.0010	<0.000017	<0.0050	**3/22/2007**	445	0.0127	0.00196	0.242
4/25/2007	47.3	0.0078	0.00934	0.246	**4/25/2007**	<0.70	<0.0010	<0.000017	<0.0050	**4/25/2007**	443	0.0186	0.159	0.239
5/23/2007	29.9	<0.010	<0.010	0.141	**5/23/2007**	9.55	<0.010	<0.010	<0.0050	**5/23/2007**	425	<0.010	<0.010	0.0654
6/12/2007	31	<0.010	<0.010	0.103	**6/12/2007**	8.38	<0.010	<0.010	<0.0050	**6/12/2007**	433	0.010	<0.010	0.128
7/10/2007	18.5	<0.010	<0.010	0.0347	**7/10/2007**	5.35	<0.010	<0.010	<0.0050	**7/10/2007**	433	0.020	<0.010	0.107
8/8/2007	37.4	<0.010	<0.010	0.0764	**8/8/2007**	7.65	<0.010	<0.010	0.0146	**7/13/2007**	433	0.020	<0.010	0.107
9/6/2007	36.8	<0.010	<0.010	0.142	**9/6/2007**	8.8	<0.010	<0.010	<0.0050	**8/8/2007**	444	0.015	<0.010	0.135
10/23/2007	27	<0.010	<0.010	0.0719	**10/23/2007**	9.13	<0.010	<0.010	0.0073	**9/6/2007**	352	<0.010	<0.010	0.143
11/7/2007	53.5	0.00345	0.000311	0.0825	**11/7/2007**	12.4	0.00017	0.000008	0.0009	**10/23/2007**	412	<0.010	<0.010	0.252
12/13/2007	67.5	0.00496	0.000534	0.206	**12/13/2007**	16.7	0.00011	<0.000005	0.0003	**11/7/2007**	402	0.00636	0.00142	0.0868
1/30/2008	108	0.0102	0.0143	0.5	**4/15/2008**	14.8	<0.0010	<0.000017	<0.0050	**12/13/2007**	442	0.00533	0.000421	0.0317
2/28/2008	73.2	0.0071	0.000432	0.186	**5/21/2008**	9.24	<0.0010	<0.000017	<0.0050	**1/30/2008**	460	0.00507	0.0592	0.205
3/13/2008	61.2	0.0070	0.000496	0.233	**5/26/2008**	7.48	<0.0010	0.000029	<0.0050	**2/28/2008**	424	0.0226	0.000772	0.0653
4/16/2008	66.2	0.0081	0.000465	0.216	**7/8/2008**	6.6	0.0004	<0.00001	0.005	**3/13/2008**	401	0.0082	0.000553	0.0592
5/21/2008	25.3	0.0035	0.000283	0.0948	**8/20/2008**	4.2	0.00029	0.000104	0.0024	**4/16/2008**	393	0.0166	0.000264	0.0203
6/17/2008	25.7	0.00266	0.000133	0.0525	**10/9/2008**	12.9	0.0004	<0.00001	<0.005	**5/21/2008**	379	0.0153	0.00479	0.0967
7/8/2008	25.1	0.0012	0.00006	0.021	**10/22/2008**	14.5	0.0005	0.000011	0.0142	**6/12/2008**	395	0.0184	0.000802	0.0613
8/20/2008	33.9	0.0043	0.00013	0.032	**3/30/2009**	22	0.00052	0.000007	0.0009	**7/8/2008**	362	0.0082	0.00026	0.029
9/16/2008	84.1	0.00585	0.000311	0.082	**6/10/2009**	7.2	0.00015	<0.000005	0.0001	**8/20/2008**	368	0.0181	0.00064	0.072
10/9/2008	46.9	0.0023	0.00017	0.036	**8/19/2009**	11.8	0.00009	<0.000005	0.0003	**9/16/2008**	335	0.0202	0.000525	0.0461
11/20/2008	58.1	0.00272	0.000176	0.0543	**10/21/2009**	14.4	0.0003	0.000021	0.0008	**10/9/2008**	391	0.007	0.00104	0.102
12/4/2008	56.1	0.00282	0.000155	0.0532	**12/21/2009**	8.2	0.00034	<0.000005	0.0002	**11/20/2008**	392	0.00577	0.000134	0.022
1/21/2009	48.3	0.0028	0.000184	0.0686	**2/10/2010**	17.4	0.00022	<0.000005	0.0002	**12/4/2008**	420	0.00819	0.00012	0.0215
2/18/2009	74.8	0.00336	0.000281	0.0976	**2/17/2010**	14	0.00024	<0.000005	0.0014	**1/21/2009**	366	0.00489	0.000324	0.0666
3/30/2009	90.4	0.00464	0.000331	0.123	**5/10/2010**	11.1	0.00008	<0.000005	<0.0001	**2/18/2009**	383	0.00338	0.000139	0.0251
4/29/2009	48.6	0.00253	0.000136	0.0478	**5/19/2010**	6.7	0.00013	<0.000005	0.0001	**3/30/2009**	442	0.0056	0.000191	0.0312
5/20/2009	31.2	0.00167	0.000085	0.0322	**8/11/2010**	7.4	0.00006	<0.000005	0.0001	**4/29/2009**	334	0.00546	0.000054	0.0085
6/10/2009	21.1	0.00113	0.000082	0.0203	**8/19/2010**	7.9	<0.00005	<0.000005	0.0002	**5/20/2009**	344	0.00208	0.00007	0.0105
7/29/2009	52.1	0.00334	0.00016	0.0456	**11/10/2010**	15.7	0.00017	0.000008	0.0022	**6/10/2009**	334	0.00392	0.000307	0.0464
8/19/2009	76	0.00151	0.00022	0.0559	**2/9/2011**	13.3	0.00013	0.000011	0.0007	**7/29/2009**	383	0.0206	0.000694	0.0932
9/22/2009	57	0.00398	0.000225	0.0557	**2/9/2011**	13.5	0.00017	0.000009	0.0009	**8/19/2009**	347	0.00329	0.000189	0.0196
10/27/2009	38.6	0.00335	0.000153	0.041	**5/24/2011**	9.9	0.00008	<0.000005	0.0002	**9/22/2009**	292	0.0132	0.000679	0.093
11/27/2009	49.1	0.00699	0.000598	0.176	**8/10/2011**	6.9	0.00005	<0.000005	<0.0001	**10/21/2009**	351	0.0156	0.000632	0.0978
12/21/2009	31	0.00423	0.000238	0.079	**8/11/2011**	6.3	0.00021	<0.000005	0.0009	**11/27/2009**	538	0.00383	0.00321	0.184
1/13/2010	32.9	0.00597	0.000478	0.148	**11/8/2011**	19.2	0.00038	0.000006	0.0018	**12/21/2009**	407	0.0125	0.00144	0.123
2/17/2010	60.9	0.00777	0.00052	0.236	**11/9/2011**	14.7	0.00015	<0.000005	0.0006	**1/13/2010**	375	0.00264	0.00281	0.115
3/18/2010	52.5	0.00536	0.000358	0.158	**2/8/2012**	18.1	0.00011	<0.000005	0.0011	**2/17/2010**	421	0.022	0.000621	0.158
4/6/2010	66.4	0.00714	0.000442	0.211	**5/8/2012**	10.9	0.000091	<0.0000050	0.00011	**3/18/2010**	413	0.00511	0.000288	0.0791
5/19/2010	18	0.00148	0.000061	0.0358	**5/23/2012**	9.16	0.000318	<0.0000050	<0.00010	**4/6/2010**	420	0.0121	0.000268	0.0899
6/17/2010	24.4	0.00154	0.000077	0.032	**8/7/2012**	6.53	0.000189	<0.0000050	0.00016	**5/19/2010**	409	0.0046	0.000145	0.0272
7/14/2010	27.6	0.00148	0.000071	0.0291	**8/8/2012**	6.62	0.00073	0.000009	0.00183	**6/17/2010**	347	0.00378	0.000049	0.0085
8/19/2010	48.9	0.00163	0.000135	0.0489						**7/14/2010**	312	0.00361	0.000125	0.0205
9/16/2010	39.9	0.002	0.000156	0.0641						**8/19/2010**	324	0.00257	0.000022	0.0014
10/27/2010	43.1	0.00323	0.000205	0.0784						**9/16/2010**	333	0.00451	0.000117	0.0132
11/10/2010	66.5	0.00368	0.000298	0.119						**10/27/2010**	393	0.00604	0.000474	0.116
12/15/2010	56.1	0.0052	0.000419	0.147						**11/10/2010**	460	0.0037	0.000227	0.0528
1/19/2011	51.1	0.00407	0.000304	0.125						**12/15/2010**	429	0.00362	0.000175	0.0313
2/9/2011	46.9	0.00437	0.000307	0.144						**1/19/2011**	412	0.00027	0.000023	0.0007
3/24/2011	91.2	0.00477	0.000415	0.171						**2/9/2011**	402	0.00247	0.000194	0.0403
4/21/2011	81.3	0.00427	0.000327	0.135						**3/24/2011**	467	0.00271	0.000227	0.0562
5/13/2011	36.7	0.00213	0.000123	0.0504						**4/19/2011**	464	0.00226	0.000268	0.0673
5/18/2011	30.4	0.0019	0.000119	0.0461						**5/24/2011**	376	0.00908	0.000147	0.034
5/24/2011	28.2	0.00144	0.000083	0.0341						**6/8/2011**	378	0.00725	0.000235	0.0608
6/2/2011	20.6	0.00128	0.000066	0.0286						**7/19/2011**	318	0.00764	0.000252	0.0458
6/8/2011	19.9	0.00126	0.000071	0.03						**8/11/2011**	295	0.00402	0.00117	0.249
7/19/2011	18.4	0.00094	0.000047	0.0185						**9/22/2011**	309	0.00931	0.00262	0.137
8/11/2011	25.1	0.00106	0.000102	0.0311						**10/12/2011**	405	0.00646	0.000708	0.0531
9/22/2011	20.1	0.00216	0.000163	0.0219						**11/9/2011**	354	0.00943	0.000504	0.0791
10/12/2011	23.7	0.00206	0.000119	0.0394						**12/7/2011**	416	0.00307	0.000313	0.0376
11/9/2011	42.6	0.00234	0.000104	0.0294						**1/22/2012**	398	0.00239	0.000245	0.0677
12/7/2011	78.6	0.00384	0.000304	0.113						**2/12/2012**	394	0.00277	0.000331	0.0546
1/22/2012	86.1	0.00289	0.000276	0.105						**3/18/2012**	419	0.00308	0.000169	0.0373
2/12/2012	45.2	0.00234	0.000183	0.0607						**4/25/2012**	387	0.00426	0.000254	0.0594
3/18/2012	78	0.00378	0.000282	0.109						**5/16/2012**	346	0.004	0.000152	0.047
4/25/2012	29.3	0.00199	0.000095	0.0357						**6/13/2012**	301	0.00516	0.000314	0.0603
5/16/2012	21.3	0.000994	5.06E-05	0.0208						**7/11/2012**	318	0.00602	0.000404	0.0701
6/13/2012	18.2	0.000879	4.52E-05	0.0175						**8/7/2012**	280	0.00259	0.000127	0.0306
7/11/2012	17.5	0.000771	3.79E-05	0.0156										
8/7/2012	24.3	0.00134	0.00006	0.0261										

5 in 30 Low Flow (mg/L)											
M2 (Dissolved)				M1 (Dissolved)				TP4 (Dissolved)			
Hardness	**Copper**	**Cadmium**	**Zinc**	**Hardness**	**Copper**	**Cadmium**	**Zinc**	**Hardness**	**Copper**	**Cadmium**	**Zinc**
85.2	0.00196	0.000317	0.0881	14	0.000166	0.000005	0.00029	87	0.00216	0.000327	0.0923
135	0.00651	0.000519	0.108	15.3	0.000085	0.000005	0.00012	195	0.00872	0.000548	0.108
142	0.00832	0.000541	0.137	15.2	0.000265	0.000005	0.00005	131	0.0141	0.000599	0.138
153	0.00812	0.000598	0.132	16.5	0.000288	0.000005	0.00031	170	0.00969	0.000633	0.132
186	0.00307	0.000288	0.0944	20.9	0.000088	0.000005	0.00005	133	0.00334	0.000256	0.0816

5 in 30 High Flow (mg/L)											
M2 (Dissolved)				M1 (Dissolved)				TP4 (Dissolved)			
Hardness	**Copper**	**Cadmium**	**Zinc**	**Hardness**	**Copper**	**Cadmium**	**Zinc**	**Hardness**	**Copper**	**Cadmium**	**Zinc**
28.9	0.00394	0.000228	0.0574	8.41	0.000219	2.5E-06	0.00042	26.8	0.00395	0.000214	0.0552
46.7	0.00608	0.000126	0.0751	18	0.000426	0.000078	0.105	47.2	0.00383	0.000118	0.0626
51.8	0.0032	0.000199	0.0648	15.5	0.00615	0.000023	0.0243	50.4	0.00303	0.000187	0.0648
66.5	0.00329	0.000078	0.166	7.33	0.00319	0.000014	0.00315	12.4	0.00211	0.000049	0.0201
13	0.0206	0.000264	0.0904	14.8	0.0712	0.000006	0.983	64.8	0.0046	0.000294	0.0987

In Situ (mg/L)														
M2 (Dissolved)					M1 (Dissolved)					TP4 (Dissolved)				
Date	Hardness	Copper	Cadmium	Zinc	Date	Hardness	Copper	Cadmium	Zinc	Date	Hardness	Copper	Cadmium	Zinc
4/15/2015		0.00274			4/15/2015	12.6	0.000763	0.0000072	0.00379	4/1/2015	56.1	0.00325	0.000199	0.0714
5/12/2015	45.8	0.00208	0.000115	0.0496	5/12/2015	10.1	0.0024	0.0000053	0.0186	4/1/2015	56.1	0.00342		
										4/9/2015		0.00215		
										4/15/2015	55.6	0.00303	0.000199	0.0753
										4/15/2015	55.6	0.00196		
										4/21/2015		0.00297		
										4/29/2015		0.00364		
										5/6/2015		0.00262		
										5/12/2015	47.2	0.00181	0.000132	0.0533
										5/13/2015		0.00172		
										5/20/2015		0.0017		

End of Report