# Appendix 13.5-E Cobalt SPO Recommendation Memo

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# Technical Memorandum

**To:** Dan Farmer, Chief Operating Officer) (Allegiance Coal)

**From:** Aaron Edgington (Windward),[1] David DeForest (Windward), and Guy Gilron (Borealis)

**Subject:** Review of Cobalt Toxicity Data from Field and Mesocosm Studies to Support the Development of a Site Performance Objective for the Tenas Mine

**Date:** February 16, 2022

## Introduction

In support of the aquatic effects assessment for the Tenas Mine's environmental assessment (EA) application, surface water concentrations of cobalt in some receiving waters downstream of the proposed Tenas Mine have been predicted to exceed the current British Columbia (BC) aquatic life guideline (ALG) of 4 µg/L (Nagpal 2004) and the Environment Canada (2017) hardness-based WQG of 1.2 µg/L, calculated based on a hardness of 157 mg/L calcium carbonate (Borealis and Windward 2020).

The BC cobalt ALG of 4 µg/L is based on a geometric mean lowest-observed-effect concentration (LOEC) of 8.2 µg/L for the two zooplankton species, *Daphnia magna* and *Ceriodaphnia dubia*, multiplied by an arbitrary safety factor of 0.5. The Environment Canada cobalt WQG is based on a species sensitivity distribution (SSD), in which a benthic amphipod (*Hyalella azteca*) is the most sensitive species (Figure 1). Toxicity data for resident (or closely related) species, in the Tenas Mine study area (ERM 2019) are limited to *Chironomus tentans*[2] and rainbow trout (*Oncorhynchus mykiss*). Both species are relatively insensitive to cobalt, with chronic toxicity thresholds exceeding 100 µg/L (Figure 1). Data relating to the sensitivity to cobalt of the more abundant mayflies and

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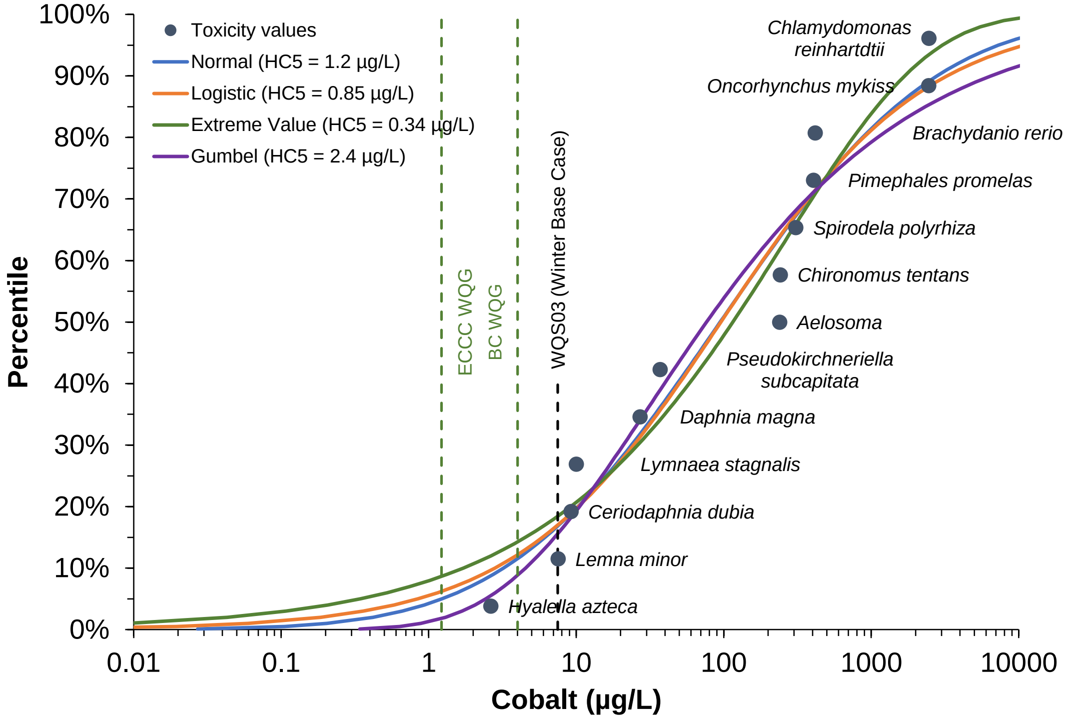
[2] Chironomids tend to be the third most abundant benthic insect at most sampling locations in the study area.

stoneflies in the study area were not available at the time that the WQGs were developed.




Toxicity data and hardness slope of 0.414 from Environment Canada (2017). SSD models were developed from the SSD Master software (Version 3.0).

**Figure 1. Chronic cobalt SSD normalized to a hardness of 157 mg/L (WQS03 winter base case)**

It does not appear that *H. azteca*, the most sensitive species in the SSD, is present in study area, but it could potentially be considered a surrogate for other resident species (e.g., other freshwater amphipods). However, the sensitivity of *H. azteca* may have been confounded by the test design in the key study, Norwood et al. (2007) and Heijerick et al. (2007). *H. azteca* is the most sensitive species in the cobalt toxicity dataset, with an 10% effect concentration (EC10) (i.e., 2.2 µg/L) that is about 65% less than the second most sensitive species (i.e., *Lemna minor* [duckweed]) (Figure 1). Recently, the US Environmental Protection Agency (USEPA), US Geological Survey (USGS), Illinois Natural History Survey, and Environment and Climate Change Canada (ECCC) have all conducted significant research on chronic toxicity test methods for *H. azteca*. This research was designed to improve test performance, as inappropriate diets and water conditions have been found to stress the test organisms. The previous *H. azteca* study designs used in the cobalt toxicity tests upon which the guidelines are based are not consistent with the recently-recommended feeding regimes for chronic tests with *H. azteca*; therefore, the cobalt toxicity threshold in the SSD may be biased low. However, this can only be identified as an uncertainty in applying these guidelines, unless and until additional cobalt testing is conducted.

Given that the predicted worst-case cobalt concentration exceeds only the EC10 for *H. azteca*, the purpose of this technical memorandum is to determine:

1. whether there are mesocosm or field studies on the effects of cobalt that are relevant to the aquatic species composition in the study area (e.g., aquatic insects, salmonids); and,
2. if so, whether the above-mentioned studies could be used to support the development of a Site Performance Objective (SPO) for cobalt.

## LITERATURE SEARCH

Google and Google Scholar were used to search for peer-reviewed literature on cobalt toxicity to aquatic organisms in mesocosm and field studies. In addition, a targeted search of all published papers in the journal, *Environmental Toxicology and Chemistry* was conducted. Researchers at Oregon State University (Oregon, USA) with known experience conducting cobalt toxicity studies were also contacted for input on potentially-relevant data.

Key words used for the peer-reviewed literature search included:

- Aquatic toxicity of cobalt
- Aquatic toxicity of cobalt to freshwater organisms
- Aquatic toxicity of cobalt in mesocosm studies
- Field studies to determine toxicity of cobalt

The literature search yielded two useful studies:

- Mebane CA, Eakins RJ, Fraser BG, Adams WJ. 2015. Recovery of a mining-damaged stream ecosystem. *Elementa: Science of the Anthropocene*. 3:000042.
- Balistrieri LS, Mebane CA, Schmidt TS. 2020. Time-dependent accumulation of Cd, Co, Cu, Ni, and Zn in natural communities of mayfly and caddisfly larvae: Metal sensitivity, uptake pathways, and mixture toxicity. *Science of the Total Environment.* 732:139011.

Summaries of these two studies, and their implications on the development of an SPO for cobalt for the Tenas Mine, are provided below.

## MEBANE ET AL. (2015)

Mebane et al. (2015) presented a 30+-year record of data from examining changes in stream communities associated with declines in metals contamination from Blackbird Mine, an inactive hard-rock mine in Idaho, USA.

The authors' objectives were to:

1. Assess the effectiveness of water quality restoration efforts in reducing contamination in different stream media (i.e., water, sediment, periphyton, and macroinvertebrates tissues).
2. Examine different recovery trajectories for stream invertebrate and fish communities in response to improving water quality.
3. Identify apparent field thresholds for recovery of different taxa.
4. Consider whether the "recovering" stream ecosystems had "recovered."

### Study Location

The Blackbird Mine in Idaho was a cobalt and copper mine that operated from 1948 to 1967. The mine is on a high divide that flows south and north to Blackbird Creek and Big Deer Creek, respectively. The southern mine drainage enters Blackbird Creek, a steep second-order stream that flows for about 10 km before reaching Panther Creek, a fourth-order stream. The northern mine drainage enters South Fork Big Deer Creek and Big Deer Creek, before entering Panther Creek. Panther Creek is a tributary of the Salmon River.

### Methods

Data were extracted from chemical and biological surveys conducted over a 30+-year period. Mebane et al. (2015) focused their analysis on the period between 2002 to 2013, since monitoring during that time period occurred at the same sampling locations and same time of year (i.e., mid-September), using identical protocols and field crews. The authors also presented data from other sampling dates.

Water sampling efforts varied among sampling years; however, sampling was biased toward the spring to capture the more variable conditions observed during spring runoff. For our review the full dataset for dissolved (i.e., < 0.45-µm filtered) cobalt and copper reported by Mebane et al. (2015) was considered (it was necessary to include copper in the present evaluation because this metal was also of concern in this field study; see further discussion below). Locally estimated scatterplot smoothing (LOESS) regression was used to smooth and visualize patterns in time series graphs of aqueous metals concentrations (example illustrated in Figure 2). All metals data reported herein are from the LOESS regressions.[3]

[3] as used to determine metals concentrations from the locally-weighted regression line.

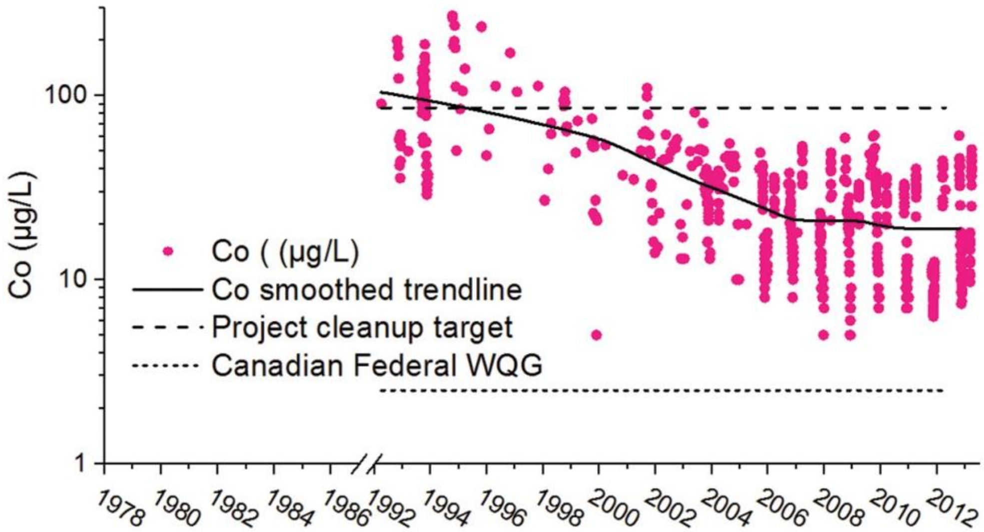



**Figure 2. Example of the locally-weighted regression (cobalt-smoothed trendline) presented in Figure 3 of Mebane et al. (2015) for cobalt data collected from Panther Creek**

The authors compared cobalt concentrations to the Environment Canada (2013) guideline of 2.5 µg/L, and a site-specific cobalt target (i.e., Project Cleanup Target in Figure 2), of 86 µg/L (Figure 2). The site-specific cobalt target was derived using data from chronic toxicity testing with rainbow trout and the midge, *Chironomus dilutus*, and acute testing with mottle sculpin (*Cottus bairdii*), rainbow trout, and resident invertebrates (*Brachycentrus americanus* [caddisfly], *Centroptilum conturbatum* [mayfly], and *Serratella tibialis* [mayfly]). However, Mebane et al. (2015) did not provide details of how they derived the site-specific value using these data.

In addition to the cobalt guidelines reported by Mebane et al. (2015), the updated Environment Canada (2017) hardness-based cobalt WQG was considered as part of the literature review. Hardness-based WQGs were derived using sampling location hardness data reported by Mebane et al. (2015) for each sampling year. However, the hardness reported at each sampling location indicates that the hardness was < 52 mg/L as $CaCO_3$, the minimum hardness value recommended by Environment Canada (2017) guidance. Therefore, both cobalt WQGs derived from site water hardness and the minimum hardness of 52 mg/L as $CaCO_3$ (i.e., 0.78 µg/L cobalt WQG) were used in the present evaluation.

As noted above, copper was also a metal of concern in Panther Creek and so it was necessary to consider concentrations of this metal in evaluating the biological effects metrics. Copper criteria concentrations were based on the USEPA (2007) biotic ligand model (BLM). Some time periods did not have sufficient BLM parameter data, so the authors made conservative seasonal estimates of the BLM-based copper criteria: 5.3 and 2.3 µg/L for spring and near-base flow conditions, respectively. Spring runoff tends to have greater concentrations of dissolved organic carbon (DOC), which alleviates the toxicity of copper, hence the higher criteria value for this season.

Biological data from mine-influenced sampling locations were compared to reference sampling location conditions. Data from mine-influenced sampling locations were considered "similar" to reference sampling location conditions when a biological measurement from a mine-influenced sampling location was within the 95% confidence interval of the mean of the concurrent reference condition value.

The biological data used for this assessment were:

- Benthic macroinvertebrate community data
  - Species richness
  - Biomass
  - Mayfly and stonefly abundance
- Fish population data
  - Species richness
  - Population size
  - Age structure
  - Condition factor

Dissolved cobalt (and copper) concentrations were determined from LOESS regressions for the years in which biological data for each site had returned to reference sampling location conditions.

## Table 1. Concentrations of cobalt and copper as various biological metrics reached reference sampling location conditions and comparison to Environment Canada (2017) hardness-based cobalt WQG

| Location | Year(s) | Cobalt (µg/L) | Copper (µg/L) | Endpoint Similar to Reference | Environment Canada (2017) WQG* |
|---|---|---|---|---|---|
| Panther Creek (PA-km 37) | 1999–2013 | 65→19 | 17→9 | taxa richness (60–90% of reference) | 0.51-0.69 |
| | 2002 | 43 | 6 | stonefly abundance, rainbow trout abundance | 0.68 |
| | 2003 | 37 | 4 | rainbow trout balanced age class | 0.68 |
| | 2005 | 27 | 4 | shorthead sculpin abundance | 0.66 |
| | 2006 | 24 | 4 | Chinook salmon condition factor | 0.69 |
| | 2007 | 21 | 4 | rainbow trout condition factor | 0.66 |
| | 2009 | 20 | 3 | mayfly abundance | 0.64 |
| Panther Creek (PA-km17) | 2001 | 20 | 8 | taxa richness (63–90% of reference) | 0.59[a] |
| | 2002 | 17 | 6 | stonefly abundance | 0.59[a] |
| | 2003 | 13 | 4 | rainbow trout balanced age class and abundance | 0.59[a] |
| | 2006 | 11 | 3 | Chinook salmon condition factor | 0.59[a] |
| | 2007 | 10 | 3 | mayfly abundance, rainbow trout condition factor | 0.59[a] |
| | 2008 | 10 | 3 | shorthead sculpin abundance | 0.57 |
| Big Deer Creek (BD-km 5.3) | 2005 | 8 | 6 | taxa richness | 0.56[a] |
| | 2007 | 5 | 4 | stonefly abundance, rainbow trout abundance | 0.56[a] |
| | 2008-2013 | 2-3 | 2-4 | mayfly abundance (45–113% of reference) | 0.56[a] |
| | 2009 | 3 | 3 | rainbow trout age class | 0.56[a] |
| Big Deer Creek (BD-km 0.1) | 2003 | 12 | 15 | rainbow trout abundance | 0.58[a] |
| | 2007 | 6 | 8 | stonefly abundance | 0.58[a] |
| | 2008-2013 | 2-4 | 4-6 | mayfly abundance (45–113% of reference) | 0.58[a] |
| | 2009 | 4 | 6 | rainbow trout age class | 0.58[a] |
| | 2012 | 2 | 5 | taxa richness | 0.58[a] |

[a] Hardness values were not reported for these study years. As a result, hardness-based cobalt WQGs were calculated using the geometric mean of all hardness values reported for all years at the sampling location.

* WQG – water quality guideline.

### Results

The various biological metrics reached reference conditions at varying points in time (Table 1). At each site, stonefly and rainbow trout abundances were the least sensitive metrics (i.e., recovered more quickly) and mayfly abundance was the most sensitive metric (i.e., took longer to recover).

Cobalt and copper concentrations in Panther Creek were both several-fold greater than in reference streams prior to restoration efforts initiated in the mid-1990s; concentrations of both metals subsequently and concurrently declined throughout the study period (Table 1). Accordingly, it is difficult to identify the relative influence of the declining concentrations of each of these metals on the improvement in biological metrics. Conservatively, the cobalt and copper concentrations measured in receiving waters, at time points when abundance metrics had reached reference conditions, may be considered field-based, no-observed-effect-concentrations (NOECs) for each metric.

In Panther Creek, mayfly abundance returned to reference conditions after cobalt and copper concentrations had reached 20 and 3 µg/L, respectively, at sampling location PA-km 37 and 10 and 3 µg/L, respectively, at sampling location PA-km 17 (Table 1). At both locations in Big Deer Creek, mayfly abundance remained variable between 2008 and 2013, ranging from 45 to 113% of reference conditions; cobalt concentrations ranged from 2 to 4 µg/L and copper concentrations ranged from 4 to 6 µg/L (Table 1). Despite reference conditions being met, aqueous cobalt concentrations exceeded the Environment Canada (2013) cobalt WQG (i.e., 2.5 µg/L) and updated Environment Canada (2017) hardness-based WQGs, as well as the WQG 'capped' at the minimum hardness value of 52 mg/L as $CaCO_3$ (i.e., 0.78 µg/L cobalt) (Table 1).

### Discussion

At sampling location PA-km 17 in Panther Creek, shorthead sculpin (*Cottus confusus*) abundance appears to be a biological metric for recovery, with sensitivity similar to that of the mayfly abundance metric (Table 1). However, Mebane et al. (2015) reported that shorthead sculpin abundance at this sampling location was most likely influenced by the distance from a colonizing source, rather than metals concentrations. In fact, distance from a colonizing source may also play a role in benthic invertebrate metrics. Distance from a colonizing source influences recovery, because macroinvertebrates recolonize via drift or egg deposit from adults. These two modes of recolonization occur over very short distances. Big Deer Creek BD-km 0.1 is the sampling location furthest downstream, so it is furthest away from possible colonizers. This (rather than metals exposure) may explain why taxa richness took the longest to recover (slow recruitment) at this sampling location.

While mayfly abundance remained the most sensitive biological metric at both sites (Panther Creek and Big Deer Creek) and all sampling locations, there were apparent differences in the sensitivities of mayfly taxa. For instance, at the Big Deer Creek sampling location BD-km 5.3, *Baetis* and *Drunella* mayflies returned to reference conditions in 2004, when cobalt and copper concentrations were both 7 µg/L. In the Big

Deer Creek sampling location BD-km 0.1 *Baetis*, mayflies returned to reference conditions in 2001, when cobalt and copper concentrations were 17 and 3 µg/L, respectively, and *Esperorus* mayflies returned to reference conditions in 2004, when cobalt and copper concentrations were both 11 µg/L. These differences indicate that the sensitivity of the mayfly abundance biological metric is strongly influenced by the mayfly taxa present in the water body.

### Summary

The concurrent declines in cobalt and copper concentrations in Panther and Big Deer Creeks, and the corresponding attainment of biological metric scores comparable to reference conditions, were associated with cobalt concentrations ranging from approximately 2 to 20 µg/L and copper concentrations ranging from approximately 3 to 6 µg/L. This range of cobalt concentrations spans an order of magnitude—the lower end of this range was for Big Deer Creek (i.e., BD-km 5.3), which, as noted, was the furthest downstream from a source of potential colonizers. This likely contributed to the temporal delay in recovery of biological metrics after cobalt and copper concentrations had declined at this location. Other sampling locations with evidence of mayfly recovery to reference conditions were associated with cobalt concentrations ranging from 10 to 20 µg/L.

## BALISTRIERI ET AL. (2020)

Balistrieri et al. (2020) conducted four experimental stream studies that examined the effects of single and multiple metal mixtures of cobalt, copper, cadmium, nickel, and zinc on abundances of natural benthic macroinvertebrate communities. The study was designed to address metal mixture toxicity to aquatic insect communities, more fully explain differences in metal sensitivity among aquatic insect taxa, assess the relative roles of dissolved and dietary uptake on metal bioaccumulation by aquatic insects, and act as a bridge between the results of short-term laboratory toxicity tests and field population/community studies. The Balistrieri et al. (2020) data analysis focused on developing linked equilibrium, biodynamic, and dose-response models that quantitatively described processes in the experimental streams to provide insight into modes of metal accumulations and the relative toxicities of these metals. The review herein focuses on the tests that were conducted individually for cobalt.

### Methods

The experimental stream study was designed to:

1. Consider simultaneous exposures to individual metals and metal mixtures over a range of dissolved metal concentrations.
2. Examine the toxicities of metal mixture ratios observed in drainage from mineralized ecosystems.
3. Chronically expose (i.e., 32 days) natural aquatic insect communities to metals, including during critical life stage events, such as emergence.

To initiate the stream studies, trays of landscape gravel were deployed in the Cache La Poudre River in Colorado (USA) for approximately 45 days in the late summer/early fall to allow for colonization by natural benthic communities. The authors considered the river pristine, with headwaters in Rocky Mountain National Park, and easily accessible from the Aquatic Experimental laboratory (AEL) at the USGS Fort Collins Science Center. After colonization, trays were transported back to the AEL and distributed among 36 study streams; site water was used during the course of the experiment (at hardness of 17 mg/L as $CaCO_3$). In each study stream, there was a 19-L plastic bucket with a 13-cm standpipe to maintain volume, temperature controlled to match conditions in the Cache La Poudre River, with a flow of approximately 3 cm/s and covered with a 1-mm emergent net.

Dissolved concentrations of major and minor ions were determined over time for all streams. Macroinvertebrates were enumerated (to determine abundances) on day 32 for all streams. Macroinvertebrate abundance included three orders (i.e., Ephemeroptera [mayflies], Plecoptera [stoneflies], and Trichoptera [caddisflies]) and two families in each of the Ephemeroptera and Trichoptera orders (i.e., Ephemerellidae, Heptageniidae, Hydropsychidae, and Brachycentridae). Cobalt-only exposures included four control streams and six nominal cobalt concentrations: 1.5, 7, 15, 30, 80, and 150 µg/L. The cobalt-only exposures were the only data considered for the purpose of this review.

### Results

Dissolved metals concentrations in almost all individual streams increased as a function of time. Balistrieri et al. (2020) fit a model to dissolved metals concentrations to obtain consistent daily concentrations during the experiments (i.e., 0 to 32 days) (Table 2). Abundance data were determined for orders Ephemeroptera, Plecoptera, and Trichoptera (EPT), as well as families Ephemerellidae (order Ephemeroptera), Heptageniidae (order Ephemeroptera), Hydropsychidae (order Trichoptera), and Brachycentridae (order Trichoptera). These families were specifically chosen due to their known sensitivity to dissolved metals concentrations.

Ephemeroptera was the most sensitive order present in the study streams and was the only order with a concentration-response relationship between abundance and cobalt exposure (Table 2). However, the two lowest cobalt concentrations had anomalously low abundances that the study authors attributed to low initial numbers of mayflies (USGS 2020). The methods used to initiate the study streams with substrates colonized with benthic invertebrates from the field, precluded the investigators from determining the abundance of benthic invertebrates at test initiation. Therefore, it was not possible to determine whether each test substrate was colonized with comparable numbers of benthic invertebrates within each taxon. It was suggested that the data associated with the two lowest cobalt concentrations be removed from consideration, and that the focus be on abundance data for the following concentrations: 0.03 (four controls), 6.04, 15.23, 53.97, and 134.22 µg/L cobalt.

### Table 2. Benthic macroinvertebrate abundance data from study streams following 32-day exposure to cobalt (after Balistrieri et al. (2020))

| Co Conc. (µg/L) | Ephemer-optera Abundance | Plecoptera Abundance | Trichoptera Abundance | Ephemer-ellidae Abundance | Hepta-geniidae Abundance | Hydro-psychidae Abundance | Brachy-centridae Abundance |
|---|---|---|---|---|---|---|---|
| 0.03 (control) | 97 | 3 | 21 | 56 | 38 | 10 | 7 |
| 0.03 (control) | 96 | 6 | 25 | 23 | 65 | 11 | 7 |
| 0.03 (control) | 149 | 4 | 36 | 78 | 61 | 8 | 2 |
| 0.03 (control) | 63 | 7 | 20 | 29 | 26 | 13 | 5 |
| 0.28 | 31 | 3 | 29 | 8 | 11 | 10 | 3 |
| 1.88 | 68 | 8 | 21 | 23 | 34 | 10 | 8 |
| 6.04 | 112 | 0 | 32 | 43 | 59 | 6 | 23 |
| 15.23 | 56 | 7 | 28 | 28 | 21 | 12 | 10 |
| 53.97 | 9 | 6 | 23 | 3 | 2 | 12 | 6 |
| 134.22 | 6 | 2 | 21 | 5 | 0 | 10 | 5 |

Concentration-response models were fit to the mayfly abundance data using USEPA's Toxicity Relationship Analysis Program (USEPA 2015). Models were fit to concentration-response data for both the order Ephemeroptera and families Ephemerellidae and Heptageniidae; EC10s, EC20s, and EC50s were calculated. The EC10s—the effects metric of primary interest for development of WQGs— for Ephemeroptera, Ephemerellidae, and Heptageniidae were 9.3, 7.0, and 8.9 µg/L, respectively (Table 3; Figure 3).

### Table 3. Effect concentrations for mayflies exposed to cobalt in a study stream (after Balistrieri et al. (2020))

| Order - Family | EC10* (µg/L) | EC20** (µg/L) | EC50*** (µg/L) |
|---|---|---|---|
| Ephemeroptera | 9.3 | 11.1 | 15.9 |
| Ephemeroptera - Ephemerellidae | 7.0 | 9.6 | 18.2 |
| Ephemeroptera- Heptageniidae | 8.9 | 10.4 | 14.2 |

*EC10 – 10% effect concentration

**EC20 – 20% effect concentration

***EC50 – 50% effect concentration

### Discussion

Mayflies were the benthic macroinvertebrate taxa most sensitive to cobalt in the study streams. The hardness of the site water used in the experiment was 17 mg/L $CaCO_3$, which resulted in an Environment Canada (2017) hardness-based cobalt WQG of 0.49 µg/L (or 0.78 µg/L, if the hardness was capped at a minimum of 52 mg/L $CaCO_3$). The range of mayfly EC10s (i.e., 7.0-9.3 µg/L) were an order of magnitude greater than these WQGs, and about twice the BC WQG of 4 µg/L.

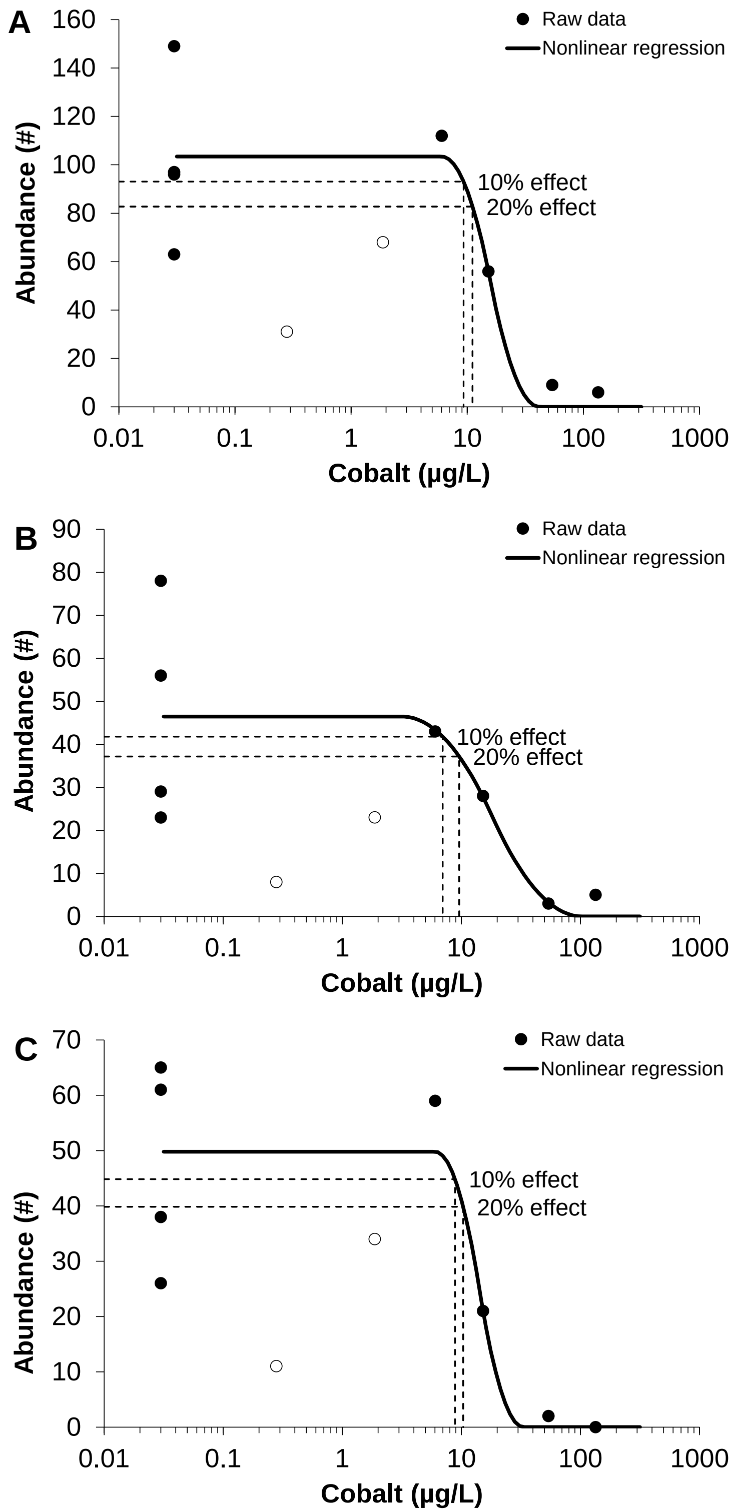
## OVERALL SUMMARY AND RECOMMENDATIONS

The results of the field study by Mebane et al. (2015) and the mesocosm stream study by Balistrieri et al. (2020) indicate that mayflies are the most sensitive taxa in cold-water mountain streams. In the field study, mayfly abundance recovered to reference conditions in some streams at cobalt concentrations in the range 10 to 20 µg/L (mean water hardness in the streams ranged from about 27 to 39 mg/L as $CaCO_3$). This concentration range was reasonably corroborated by the mesocosm/stream study by Balistrieri et al. (2020), in which cobalt EC10s for mayflies ranged from 7.0 to 9.3 µg/L and EC20s ranged from 9.6 to 11.1 µg/L (at a lower test water hardness of 17 mg/L as $CaCO_3$).

Given the influence of hardness on cobalt toxicity, the resulting toxicity thresholds suggested by observations from Mebane et al. (2015) and Balistrieri et al. (2020) are conservative for the hardness concentrations in the Tenas Mine study area (i.e., 157 mg/L).

Mayflies, particularly those in the order Ephemeroptera, are highly sensitive to metals (Clements et al. 2000). Indeed, mayfly abundance was typically the last biological metric to show evidence of recovery in the field study, reported by Mebane et al. (2015). The benthic invertebrate communities in some of the proposed Tenas Mine receiving waters are dominated by Ephemeroptera and Plecoptera (e.g., WQS02 in Tenas Creek), while others have a high abundance of Diptera (true flies) and Chironomidae (chironomids), in particular (ERM 2019). Fish species in the study area include rainbow trout and other salmonids, including Dolly Varden trout (*Salvelinus malma*) and coho salmon (*Oncorhynchus kisutch*).

The cobalt toxicity data for mayflies described in this review, along with cobalt toxicity data presented in the Environment Canada (2017) SSD that demonstrate the relative insensitivities of chironomids and rainbow trout to cobalt, support that mayfly toxicity can be used to develop a cobalt SPO for the Tenas Mine study area. The recommended cobalt SPO is 17.4 µg/L, which, as summarized above, is based on the lowest mayfly EC10 of 7.0 µg/L adjusted to a predicted site-specific hardness of 153 mg/L using the Environment Canada (2017) hardness slope.

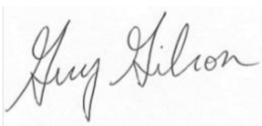



Note: Open symbols excluded because reduced abundance not attributed to cobalt (USGS 2020)

**Figure 3. Concentration-response relationships for cobalt and abundance of (A) order Ephemeroptera, (B) family Ephemerellidae, and (C) Heptageniidae (after Balistrieri et al. (2020))**

## CLOSURE

We trust that this technical memorandum meets your needs. Please do not hesitate to let either of the undersigned know if you have any questions or require additional information.

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