# Appendix 13.5-G Selenium SPO Recommendation Memo

TELKWA COAL
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# TECHNICAL MEMORANDUM

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

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

**Subject:** Development of a Site Performance Objective (SPO) for Selenium in Tenas Mine Receiving Waters

**Date:** February 16, 2022

## INTRODUCTION

Allegiance Coal (Allegiance) is currently in the process of developing the Tenas Metallurgical Coal Mine Project (the Project) near Telkwa, BC. The aquatic effects assessment is a key component of the mine's comprehensive Environmental Assessment (EA), and includes the establishment of a site-wide water balance and various water management plans and supports effluent permitting efforts, and is based on initial water quality modelling results (developed by SRK Consulting). These modelling results indicate that effluents (i.e., end-of-pipe discharges) from the mining operation, and several post-closure scenarios, may result in downstream concentrations of selenium that could have the potential to exceed aquatic life guidelines.

The objective of the current work is to develop a site-specific selenium bioaccumulation model for the Project area. In addition to complementing the aquatic effects assessment for the Tenas Project EA, this work supports the development of site-specific water quality objectives for provincial surface water permitting (i.e., Site Performance Objectives (SPO); the latter can be used in the development of both final discharge point (FDP) limits and in-stream environmental compliance point (ECP) monitoring benchmarks for selenium.

Of all aquatic organisms, fish are the most sensitive to selenium toxicity. They are predominantly exposed to organic selenium via the diet, which may then be maternally transferred to the ovaries and eggs (Janz et al. 2010). At sufficiently high egg selenium

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concentrations, development and survival of larvae may be adversely affected. Thus, selenium exposure by fish, and potential toxicity, is driven by selenium bioaccumulation in the food web (see Figure 1), which is highly site-specific (Stewart et al. 2010). In general, surface waters with more reducing conditions (e.g., lakes) have a greater selenium bioaccumulation potential than waters with oxic conditions (e.g., streams) (Lillebo et al. 1988; Brix et al. 2005; Orr et al. 2006). For this reason, surface water selenium concentrations alone are a poor indicator of potential selenium toxicity and risk to fish. However, measurement of selenium concentrations in fish tissue, and especially in the eggs or ovaries, is a much stronger indicator of potential toxicity. The British Columbia Ministry of the Environment (Beatty and Russo 2014) and the U.S. Environmental Protection Agency (USEPA 2016) have both recently developed selenium guidelines and criteria, respectively, based on selenium concentration in fish tissue. Understanding whether modelled surface water selenium concentrations could result in effects on aquatic life and impacts on fish populations in the receiving aquatic environment (i.e., selenium risk) can be addressed through development of a selenium bioaccumulation model that is reflective of anticipated site conditions.

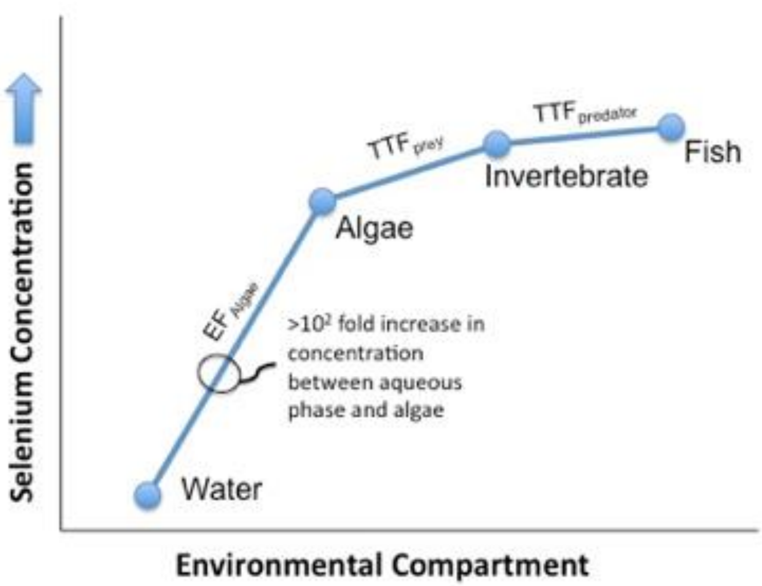


**Figure 1. Selenium bioaccumulation in an aquatic food chain (Stewart et al., 2010).**

The current aquatic life guideline for BC is 2 μg/L (Beatty and Russo 2014). This guideline is based on a weight-of-evidence evaluation that considered both food web modelling and reported relationships between effects and selenium concentrations in water. The studies evaluated included a mixture of field studies and laboratory studies, with field studies including lentic water bodies (e.g., reservoirs) that favor a higher selenium bioaccumulation potential. The observation from the weight-of-evidence evaluation was that effects converge around a water selenium concentration of 10 µg/L. An uncertainty factor of 5 was then applied to derive the guideline of 2 µg/L.

While 2 µg/L is the provincial guideline for BC, which would apply to the receiving environment downstream of the Tenas Mine, it is important, for context, to note that the USEPA lotic criterion (which would apply to this ecosystem) is 3.1 µg/L (USEPA 2016). Moreover, a recent study which investigated the development of an aqueous selenium guideline based on a selenium bioaccumulation model, recommended a lotic criterion of 6.5 µg/L (DeForest et al. 2017). As such, the BC guideline of 2 µg/L is considered to be conservative for lotic systems. In addition, because sulphate mitigates the uptake of selenate by primary producers such as algae and aquatic plants (Williams et al. 1994; Lo et al. 2015), generic water selenium guidelines are also likely to be overly conservative in waters with moderate to high sulphate concentrations.[2]

As indicated above, water quality modelling results indicate that effluents from the mining operation may result in downstream concentrations of selenium that could have the potential to exceed aquatic life guidelines/thresholds (i.e., BC Environment guideline of 2 µg/L; USEPA lotic criterion of 3.1 µg/L; and, lotic screening guideline of 6.5 µg/L, as recommended in DeForest et al. (2017).

## SITE INFORMATION

The proposed Tenas Mine site is located in north-west British Columbia, 7 km southwest of the village of Telkwa. There are four streams potentially affected by the proposed Project: Tenas Creek, Four Creek, Goathorn Creek, and Helps Creek. Four Creek lies to the east of the main project site and flows northward into Goathorn Creek. Tenas Creek lies to the west of the project site and joins Goathorn downstream from where Four and Goathorn meet, and just over 1 km from where Goathorn then flows into Telkwa River. The Telkwa River is a tributary of the Bulkley River; Helps Creek – over which the proposed Tenas by-pass road crosses – flows into the Bulkley River, downstream of its confluence with Telkwa River. The Bulkley River is a tributary of the Skeena River, which flows into the Pacific Ocean.

A comprehensive baseline monitoring effort was conducted between 2017 and 2019 around the proposed Tenas Mine site. Sampling was undertaken in all four creeks, and the Telkwa and Bulkley rivers. Sampling data were also supported by historic, publicly-available data, where available and relevant.

### Receiving Surface Water Quality Conditions

Temperatures recorded in the water bodies downstream of the proposed mine site during baseline monitoring ranged from -0.2 °C to 16.7 °C; dissolved organic carbon

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[2] Selenate is the expected selenium species in oxic receiving streams for the Tenas Mine. However, if any mine-related operations can result in reducing conditions and reduced selenium forms, such as selenite or organic selenium species, the mitigating influence of sulphate would be reduced.

(DOC) concentrations ranged from below the detection limit of 0.5 mg/L to 20.5 mg/L (ERM 2019). Other water quality parameters in receiving waters vary seasonally; the seasonal patterns are driven largely by changes to stream flow associated with rains occurring during the May/June freshet and early autumn: hardness (ranging from 22.8 to 203 mg $CaCO_3$/L); pH (ranging from 6.9 to 8.5), and sulphate (ranging from <0.30 to 59.1 mg/L) are generally high during periods of low flow in the summer and winter, and low during the freshet and autumn rains; the opposite relationship occurs for TSS and turbidity (ERM 2019).

### Resident Aquatic Biota

Periphyton communities in receiving waters downstream of the proposed mine site are dominated either by diatoms (Bacillariophyceae) or blue-green algae (Cyanophyceae). Frequently-sampled genera include Achnanthidium, Chamaesiphon, Fragilaria, Heteroleibeinia, and Leptolyngbya. Less frequently-observed genera are Phormidium, Pseudanabaena, and Tapinothrix (ERM, 2019).

Up to 75% of benthic macroinvertebrates found in receiving waters downstream of the proposed mine site are: mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera) (also known as "EPT" groups). Representative mayfly genera include Baetis, Rithrogena, and Drinella; Plecoptera genera included Zapada and Taenionema. True flies (Diptera) – particularly non-biting midges (family Chironomidae) – are dominant at some sites.

Fish communities in receiving waters downstream of the proposed mine site mainly comprise rainbow trout (*Oncorhynchus mykiss*) and Dolly Varden trout (*Salvelinus malma*). Other fish sampled include: coho salmon (*Oncorhynchus kisutch*), chinook salmon (*Oncorhynchus tshawytscha*), lampreys (*Lampetra* spp.), suckers (*Catostomus* spp.), minnows (Cyprinidae), and mountain whitefish (*Prosopium williamsoni*) (ERM 2019).

### Baseline Selenium and Sulphate in Water and Aquatic Biota

Waterborne selenium concentrations sampled and analyzed during baseline monitoring ranged from below the detection limit of 0.05 µg/L to a maximum of 0.153 µg/L; supplemental historical data indicate that selenium concentrations can reach as high as 0.5 µg/L in receiving waters (ERM 2019). Exceedances of the CCME (i.e., 1.0 µg/L) or BC (i.e., 2.0 µg/L) aquatic life guidelines for selenium have neither been recorded in baseline monitoring efforts, nor historically, in receiving waters. Waterborne sulphate concentrations sampled and analyzed during baseline monitoring ranged from below the detection limit of 0.30 mg/L to a maximum of 59.1 mg/L; supplemental historical data for sulphate did not exceed this range (ERM 2019).

Selenium concentrations in individual rainbow trout muscle tissue collected during baseline monitoring ranged from 0.176 mg/kg wet weight (ww) to 0.99 mg/kg ww (or from 0.800 to 4.5 mg/kg dry weight [dw] based on a mean moisture concentration of 78%). Two muscle samples from Tenas Creek had selenium concentrations in excess of BC's interim tissue-based guideline (i.e., 4 mg/kg dw), but none of the site means exceeded the interim guideline, which applies to the mean of at least 8 samples (ERM 2019).

## METHODS

For this evaluation, an SPO for selenium was developed using statistical bioaccumulation models, which relate fish tissue-based selenium benchmarks to selenium concentrations in surface waters. Of the fish species occurring in site receiving waters (see above), rainbow trout are the most sensitive of those species with a known sensitivity to selenium. Rainbow trout are also one of two species (along with westslope cutthroat trout [*Oncorhynchus clarki lewisi*]) that were used to develop BC's egg-based selenium guideline. Accordingly, rainbow trout was selected as a sensitive model species for the present analysis.

The statistical bioaccumulation models developed herein are based on selenium partitioning between steps in the food web. This type of an approach was also used to develop water quality benchmarks for selenium in support of the Elk Valley Water Quality Plan (EVWQP) (Golder 2014).

Statistical models for describing selenium uptake from water and trophic transfer to fish are typically based on one of the following types of approaches:

1. One-step model: Water → fish tissue
2. Two-step model: Water → invertebrate → fish tissue
3. Three-step model: Water → periphyton → invertebrate → fish tissue

The present study was based on a two-step model approach for the following primary reasons:

- A one-step model was not developed because publicly-available data for co-locating rainbow trout and water selenium data are limited.
- A three-step model was not evaluated because there is generally high variability in periphyton selenium concentrations due to particulates entrained in the periphyton matrix, which also contributes to uncertainty in the true exposure potential of benthic invertebrates to selenium in the periphyton.

### Data Compilation

To develop the two-step model, it was necessary to compile datasets for each step, as summarized below.

#### *Paired Benthic Invertebrate and Water Selenium Data*

Selenium surface water and benthic invertebrate monitoring data from three regions with coal mining effluent discharges (in British Columbia and Alberta) were compiled. Monitoring data from lotic (i.e., streams) sampling locations were compiled based on their similar characteristics to Tenas Mine study area surface waters. Surface water selenium concentrations were paired with benthic invertebrate tissue concentrations according to data pairing rules outlined in Golder (2014). When possible, the geometric mean[3] of monthly surface water grab samples were paired with individual, or composited, benthic invertebrate samples that were collected from the same sampling location. Paired data are provided in Table A-1 (Attachment A).

### *Paired Rainbow Trout and Benthic Invertebrate Selenium Data*

The second step of the two-step model is selenium transfer from invertebrates to rainbow trout eggs. Trophic transfer of selenium from food items into fish is generally not highly variable among sites and, on a whole-body basis, is typically not highly variable among fish species. Unlike organic forms of mercury, for example, organic selenium in fish does not biomagnify with increasing trophic position and fish size. Rather, selenium TTFs for fish tend to decrease with increasing dietary concentrations (DeForest et al. 2007) and selenium concentrations may decrease with increasing fish size (i.e., biodilution) (May et al. 2001; 2008). Presser and Luoma (2010) recommended a default mean trophic transfer factor (TTF) of 1.1 for whole body fish (i.e., the selenium concentration in whole body fish is 1.1-times greater than in its diet). However, because, as noted, TTFs generally decrease with increasing selenium concentrations in the diet, preference was given to defining the concentration-dependent relationship between selenium concentrations in rainbow trout and its diet.

In developing its ambient water quality criteria for selenium, the USEPA compiled selenium TTFs for several fish species and their diets (USEPA 2016). This rainbow trout dataset compiled by the USEPA, which was based on whole body selenium concentrations, was used in the present evaluation. An underlying assumption was that rainbow trout sampled fed exclusively from aquatic benthic invertebrates. These whole body selenium concentrations were used to estimate egg selenium concentrations using a whole body-to-egg selenium factor of 2.44 (USEPA 2016). The paired invertebrate and rainbow trout data are provided in Table A-2 (Attachment A).

### *Fish Tissue Selenium Benchmarks*

As noted, rainbow trout was selected as the model fish species for the present evaluation. Concentration-response relationships for selenium in eggs and effects on larval offspring are available for rainbow trout, with the relationships based on a long-term study conducted in the Upper McLeod and Upper Gregg river watersheds in west-central Alberta (Holm 2002; Holm et al. 2003; Holm et al. 2005). Concentration-response data from this study were compiled in USEPA (2016). Edema in larvae was identified as the most sensitive endpoint measured and it was used as the basis for the concentration-response data used in the present evaluation. It should be noted that the

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[3]The geometric mean of surface water grab samples provides a more realistic exposure concentration as opposed to a single grab sample.

concentration-response relationship is very steep, which results in an egg selenium EC10 of 24.5 µg/g dw, which is just 11% less than the EC50 of 27.4 µg/g dw (Figure 2).[4]

### *Model Development*

Quantile regression modelling was used to back-calculate water selenium concentrations from fish egg selenium toxicity benchmarks (e.g., the EC10). This approach was also recently used to develop water selenium screening values (DeForest et al. 2017). One benefit of quantile regression in comparison to linear regression is that the method is robust, even when assumptions of normality and homogeneity of variance are not met.

Quantile regression analyses were conducted using the quantile regression package ("quantreg") in the software program R (R Core Team 2013; Koenker 2013). The regression analyses were conducted on ln-transformed data. Paired invertebrate and water selenium concentrations indicated that there is a "hockey stick" relationship, in which selenium concentrations in invertebrate tissue do not increase until an inflection point in water selenium concentrations is reached. This hockey stick relationship has been observed in other selenium bioaccumulation models (Brix et al. 2005; Golder 2014). Hockey stick models were evaluated using the non-linear quantile regression function (nlrq) in the quantreg library in R.

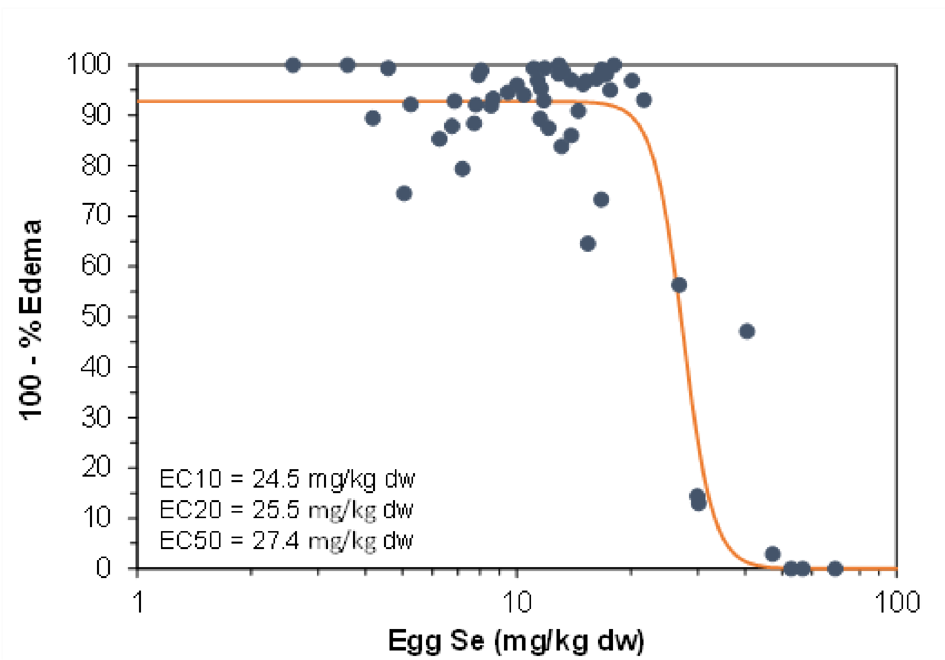


**Figure 2. Concentration-response curve for egg selenium concentrations and edema in larval offspring. Data sources: Holm (2002), Holm et al. (2003), and Holm et al. (2005), as compiled in USEPA (2016).**

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[4]The EC10 and EC50 are 10% and 50% effect concentrations, respectively.

Quantile regression was used to estimate the median (50th) and 75th quantiles of the response variables (i.e., selenium concentration in benthic invertebrates and rainbow trout eggs) as conditional linear functions of the independent variables. The 75th quantile was selected to represent a reasonable upper bound of the model. Previous application of this approach, such as DeForest et al. (2017), reported that the use of a more conservative quantile, such as the 90th, resulted in compounded conservatism, such that the model was unreasonable (e.g., reference site water selenium concentrations that could result in exceedance of toxicity thresholds for fish).

## RESULTS

### Water-to-Invertebrates

There was high variability in the paired water and invertebrate selenium data compiled, which is not unusual given the various site-specific factors that influence selenium bioaccumulation potential. The inflection point in the hockey stick regression can vary depending on the starting values provided to the model. The raw data indicated that the inflection point occurs between 3 and 4 µg/L, which encompasses the USEPA's lotic criterion of 3.1 µg/L. Accordingly, the inflection point was defined as 3.5 µg/L, above which selenium concentrations in invertebrates begin to increase with increasing water selenium concentrations (Figure 3). The model statistics for water-to-invertebrate selenium models are provided in Table 1.

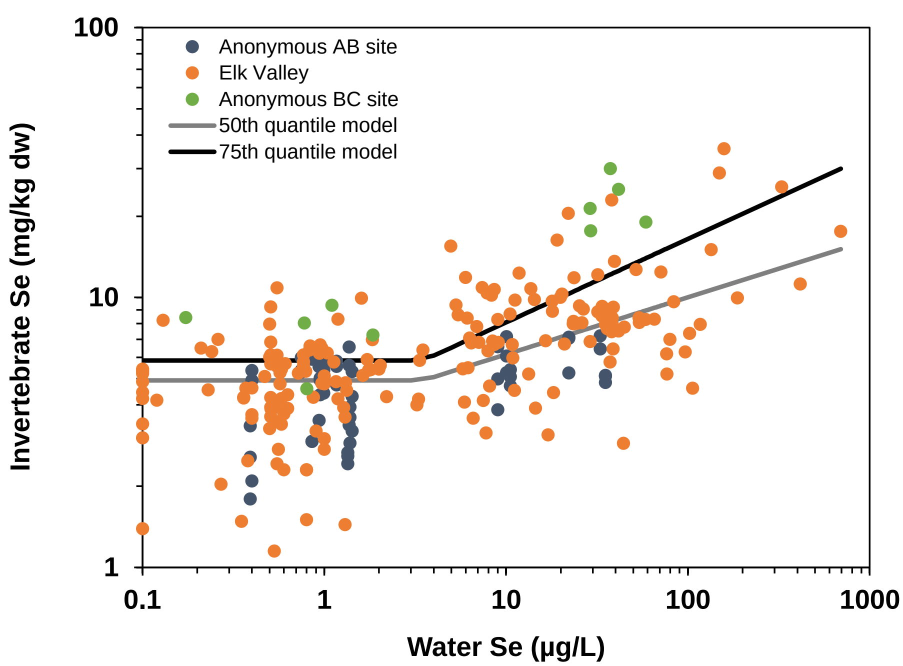



**Figure 3. Relationship between invertebrate and water selenium concentrations.**

**Table 1. Summary of statistics for the water-to-invertebrate selenium models.**

| Dataset Source | n | Quantile | Intercept | ln(Se) Slope | tau | Slope p-value |
|---|---|---|---|---|---|---|
| Present study (three regions; AB and BC) | 256 | 50th | 1.595 | 0.211 | 1.253 | <0.001 |
| | | 75th | 1.765 | 0.309 | 1.253 | <0.001 |

### Invertebrates-to-Rainbow Trout Eggs

A hockey stick relationship between paired rainbow trout egg and invertebrate selenium concentrations was not observed, so linear quantile models were fit to the data (Figure 4). In general, selenium concentrations in rainbow trout eggs tend to be about two-times greater than selenium concentrations in their diet. The model statistics for the invertebrate-to-rainbow trout egg selenium models are provided in Table 2.

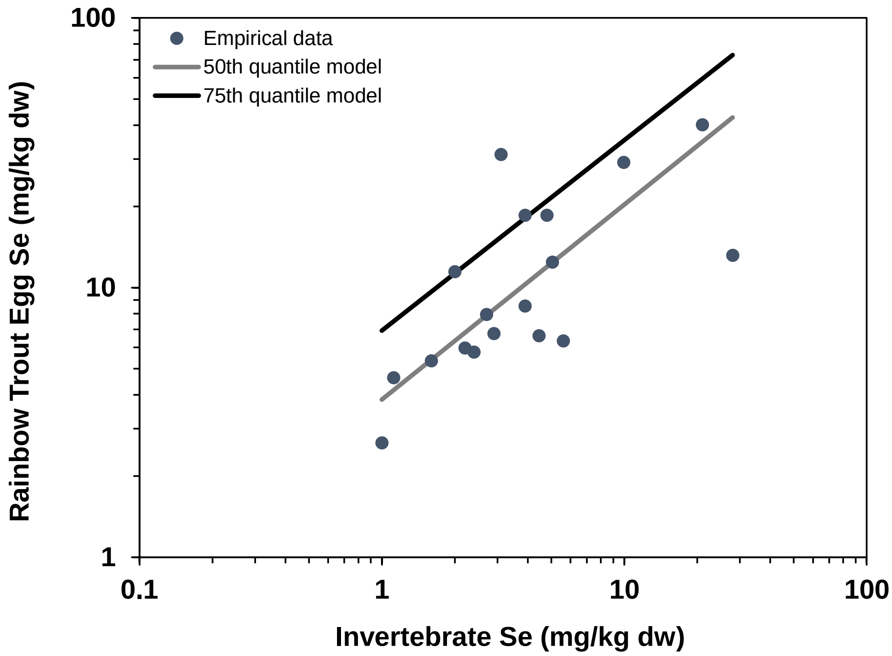



**Figure 4. Relationship between rainbow trout egg and invertebrate selenium concentrations.**

**Table 2. Summary of statistics for the invertebrate-to-rainbow trout egg selenium models.**

| Dataset Source | n | Quantile | Intercept | ln(Se) Slope | Slope p-value |
|---|---|---|---|---|---|
| USEPA (2016) | 18 | 50th | 1.346 | 0.723 | 0.015 |
| | | 75th | 1.936 | 0.626 | 0.018 |

### Back-calculation from Rainbow Trout Selenium Benchmark to Water Selenium

The water-to-invertebrate and invertebrate-to-rainbow trout egg selenium models were combined into a two-step model to estimate the water selenium concentration that may result in the rainbow trout egg selenium EC10 of 24.5 mg/kg dw. Based on the 75th quantile of the invertebrate-to-rainbow trout egg selenium model, the invertebrate Se concentration predicted to result in the rainbow trout egg selenium EC10 is 7.5 mg/kg dw (Figure 5). Then, based on the water-to-invertebrate selenium model, a water selenium concentration of 8 µg/L is predicted to result in the invertebrate selenium concentration of 7.5 mg/kg dw (Figure 5). Integrating the two model steps results in a water selenium concentration of 8 µg/L that is back-calculated from the rainbow trout egg selenium EC10 of 24.5 mg/kg dw (Figure 5).

A 90% confidence interval (CI) on the back-calculated water selenium concentration of 8 µg/L was calculated using a bootstrap technique (Efron and Tibshirani 1993). Paired water and invertebrate selenium data were randomly sampled, with replacement, from the dataset 1,000 times. Each bootstrap sample was the same size as the original dataset (n = 256). For each of the 1,000 bootstrap samples, a 75$^{th}$ quantile hockey-stick model was fit and the water concentration corresponding to an invertebrate selenium concentration of 7.5 mg/kg dw was back-calculated using the coefficients from the model fit to that sample. The quantiles of the 1,000 back-calculated water selenium concentrations were used to develop a 90% CI of 6.7 to 11.2 µg/L bracketing the back-calculated water Se concentration of 8 µg/L.

When the 50$^{th}$ quantile models are applied, a water selenium concentration of 340 µg/L is predicted to result in the rainbow trout egg selenium EC10 of 24.5 mg/kg dw (Figure 5). Combining the 50$^{th}$ quantile models, however, is inadequately protective of sites that have a higher selenium bioaccumulation potential. As illustrated in Figure 3, there is sufficient variability in paired invertebrate and water selenium data that the 50$^{th}$ quantile model may underestimate selenium concentrations in invertebrates by a factor of approximately four for some sites.

The back-calculated water selenium concentration of 8 µg/L (CI: 6.7-11.2 µg/L), based on the 75$^{th}$ quantile models, is similar in magnitude to a screening value of 6.5 µg/L for lotic waters recommended in DeForest et al. (2017). The latter evaluation was based on a synthesis of selenium data from sites throughout many regions of Canada and the U.S. Because sulphate mitigates against selenate uptake into the base of the food web, and selenate is the dominant selenium species in typical lotic waters (in the absence of an upstream source of reduced selenium species), DeForest et al. (2017) also developed sulphate-dependent water selenium guidelines for lotic waters. Waters with sulphate concentrations of 100 and 200 mg/L, for example, assuming a fish egg selenium benchmark of 24.5 mg/kg dw and a conservative 90$^{th}$ quantile model, would result in water selenium screening guidelines of 14 and 27 µg/L, respectively.

Based on the selenium bioaccumulation model described in the present study, and considering the mitigating influence of sulphate on the bioaccumulation of selenate, a two-tiered selenium SPO is proposed. The Tier 1 SPO is the back-calculated water selenium concentration of 8 µg/L (CI: 6.7-11.2 µg/L); the Tier 2 SPO is the 90$^{th}$ quantile sulphate dependent selenium guideline derived in DeForest et al. (2017). If the Tier 1 SPO is exceeded, the Tier 2 SPO may be applied to evaluate the mitigating influence of sulphate on selenium bioaccumulation, as selenium and sulphate concentrations downstream from mines are typically correlated. Further discussion of these Tier 1 and Tier 2 SPOs relative to modelled selenium and sulphate concentrations in Tenas Mine receiving waters is provided in the next section.

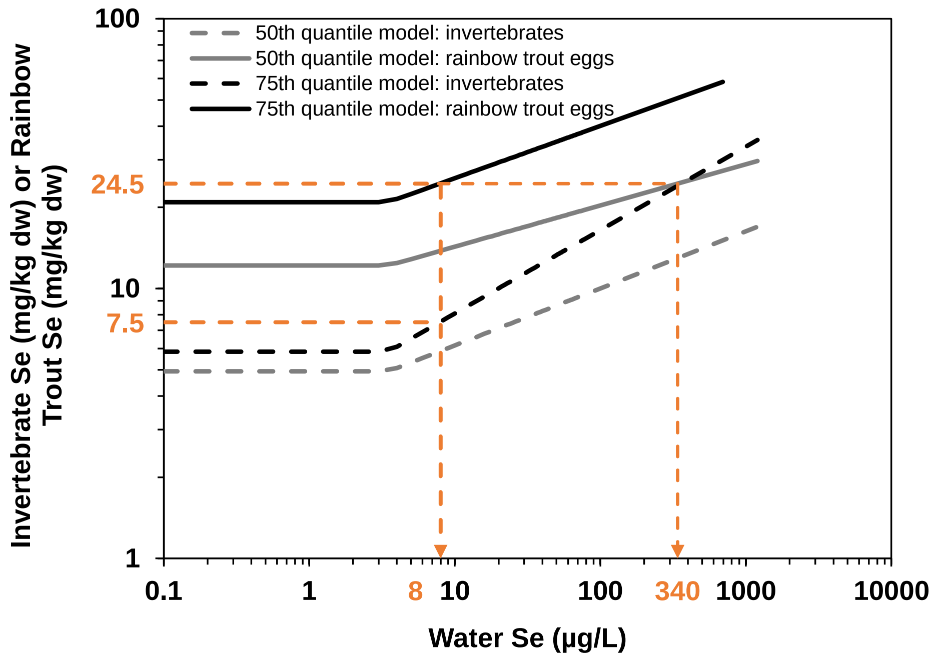



**Figure 5. Back-calculation of water selenium concentration predicted to result in rainbow trout egg selenium EC10 based on the two-step water→invertebrate→rainbow trout egg model.**

As noted earlier, it is also important to consider the sulphate concentration when evaluating the bioaccumulation potential of selenium in aquatic systems in which selenate is expected to be the dominant selenium species, which is why a sulphate-dependent Tier 2 SPO was identified.

## SUMMARY AND CONCLUSIONS

Paired water and invertebrate selenium data were compiled from receiving waters downstream from three coal mining regions in British Columbia and Alberta. A 75$^{th}$ quantile hockey stick regression model was fit to these data and coupled with a 75$^{th}$ quantile invertebrate-to-rainbow trout egg selenium model to develop a two-step relationship between selenium concentrations in water and the rainbow trout egg selenium EC10 of 24.5 mg/kg dw. The two-step 75$^{th}$ quantile model resulted in a back-calculated water selenium concentration of 8 μg/L (CI: 6.7-11.2 μg/L), which is the Tier 1 SPO selected in this study (Table 3).

The back-calculated water selenium concentration of 8 μg/L is comparable to the water selenium screening guideline of 6.5 μg/L for lotic waters, recommended by DeForest et al. (2017). In the latter study, sulphate-dependent water selenium guidelines were also recommended for lotic sites in which selenium was present as selenate. Given the similarity of the back-calculated water selenium concentration of 8 µg/L in the present analysis, compared to the lotic screening guideline of 6.5 µg/L recommended in DeForest et al. (2017), the sulphate-dependent guideline from that study was identified as the Tier 2 SPO to account for the mitigating influence of sulphate on selenium bioaccumulation (for example, use of a conservative 90$^{th}$ quantile model results in a recommended sulphate-dependent guideline of 34 µg/L when the sulphate concentration if 250 mg/L) (Table 3).

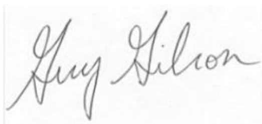
The Tier 1 and Tier 2 water selenium SPOs are both based on conservative assumptions. Modelled selenium concentrations in certain receiving waters downstream of the proposed Tenas Mine sometimes exceed the Tier 1 SPO of 8 µg/L. These exceedances, however, occur during late fall and winter, which are mostly likely to overstate potential selenium exposure during which biological productivity is at its lowest. Further, the periods with highest modelled selenium concentrations also have the highest modelled sulphate concentrations (e.g., >250 mg/L at WQS03_DS), such that no modelled selenium concentrations exceed the Tier 2 sulphate-dependent selenium SPO.

**Table 3. Recommended Tier 1 and Tier 2 selenium SPOs.**

| Selenium SPO | Basis |
|---|---|
| Tier 1: 8 µg/L | Back-calculated from two-step model described in present study (90% CI: 6.7-11.2 µg/L). |
| Tier 2: Sulphate-dependent | Based on 90$^{th}$ quantile model in DeForest et al. (2017). For example: Tier 2 SPOs are 14, 20, 27, and 34 µg/L at sulphate concentrations of 100, 150, 200, and 250 mg/L, respectively. |

## 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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