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Technical Report Overview

Report: Selenium Bioaccumulation Model 2017 Update Report

Overview: This report provides an update to the selenium bioaccumulation model that was developed for the Elk Valley Water Quality Plan and recommended next steps to update the model.

This report was prepared for Teck by Golder Associates.

For More Information

If you have questions regarding this report, please:

• Phone toll-free to 1.855.806.6854

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Future studies will be made available at **teck.com/elkvalley**

TECHNICAL MEMORANDUM

DATE 30 January 2018 **PROJECT No.** 1523293/1321

TO Carla Fraser
Teck Coal Limited

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ELK VALLEY SELENIUM BIOACCUMULATION MODEL UPDATE

Golder Associates Ltd. (Golder) is pleased to provide Teck Coal Limited (Teck) with the following memorandum reporting on tasks undertaken and recommended next steps to update the selenium bioaccumulation model (hereafter, 'the model') developed for the Elk Valley Water Quality Plan (EVWQP).

1.0 INTRODUCTION

1.1 EVWQP Selenium Bioaccumulation Model

The underlying theory, modelling framework, dataset, statistical derivation, supporting analyses, and evaluation of the model are described in detail in Annex E of the EVWQP. A summary is provided here for convenience.

In brief, the model was derived to describe the uptake of aqueous selenium into periphyton and subsequent trophic transfer to benthic invertebrates, fish, and aquatic-feeding birds. These processes were modelled as a series of regression equations derived from a large dataset of selenium concentrations in water and biota measured at dozens of sites throughout the Elk Valley over several decades of studies and monitoring. Statistical techniques used to derive and evaluate these equations included ordinary least-squares linear regression, piecewise regression, linear mixed-effects models, and analysis of covariance. A range of model forms was evaluated for each uptake and trophic transfer step, and a range of overall model structures was evaluated to identify a final set of model equations that would provide statistically reliable predictions of selenium bioaccumulation with inherent conservatism to account for uncertainty. Model equations were derived to predict both the mean and the expected distribution of selenium concentrations at each level in the aquatic food web.

The final set of model equations selected for the EVWQP was a two-step model. The first step described the combined uptake of aqueous selenium into periphyton and trophic transfer from periphyton to benthic invertebrates in a single model equation. Combining these two processes into a single equation resulted in improved model performance relative to modelling the processes separately. The second step described trophic transfer of bioaccumulated selenium from benthic invertebrate prey to fish or aquatic-feeding birds. Amphibian selenium data were reviewed during development of the model, but an amphibian model was not developed because: i) insufficient amphibian toxicity data existed at the time to support applying such a model to develop selenium benchmarks; and ii) pairing of amphibian egg mass selenium concentrations with dietary or aqueous selenium concentrations was concluded to be inherently uncertain due to pre-spawning migration behaviour of resident aquatic-feeding amphibian species.

Because the model was derived by statistically describing patterns in site-specific data, an inherent assumption is that these patterns, observed under current and historical conditions, will also describe future conditions. This is a reasonable assumption as long as the underlying ecological and physiological processes of bioaccumulation reflected in the model dataset continue to operate, such that they result in the same overall patterns of bioaccumulation. Relevant processes could include seasonality in water quality and biological activity, food-web structure and dynamics, and the physiology of resident biota. Model performance could be affected if these underlying processes change in a material way sufficient to affect overall patterns of bioaccumulation.

Residual uncertainty in the final model was evaluated in Annex O of the EVWQP, and elements of the model were identified that represented opportunity for ongoing improvement. These opportunities, subsequently adopted as regulatory requirements and commitments by Teck, are discussed in the following section.

The final bioaccumulation model equations developed for the EVWQP are provided in Table 1. As discussed in Annex E of the EVWQP, the two-step model form was selected to calculate long-term selenium targets for Teck's operations in the Elk Valley.

Table 1: Final EVWQP Bioaccumulation Model Equations

Model Component	Model Equations	RMSD
Three-Step Models		
Water to Periphyton	$log_{10}[Se]_{peri} = 0.220 + 0.125 \times log_{10}[Se]_{aq}$ for $[Se]_{aq}$ < 10.5 µg/L $log_{10}[Se]_{peri} = -0.163 + 0.501 \times log_{10}[Se]_{aq}$ for $[Se]_{aq}$ ≥ 10.5 µg/L	0.276
Periphyton to Invertebrates	$log_{10}[Se]_{inv} = 0.658 + 0.456 \times log_{10}[Se]_{peri}$	0.236
Invertebrates to Fish Eggs	$log_{10}[Se]_{egg} = 1.02 + 0.026 \times log_{10}[Se]_{inv}$ for $[Se]_{inv}$ < 6.8 mg/kg dw $log_{10}[Se]_{egg} = 0.126 + 1.10 \times log_{10}[Se]_{inv}$ for $[Se]_{inv}$ ≥ 6.8 mg/kg dw	0.176
Invertebrates to Bird Eggs	$log_{10}[Se]_{egg} = 0.414 + 0.523 \times log_{10}[Se]_{inv}$	0.187
Two-Step Models		
Water to Invertebrates	$log_{10}[Se]_{inv} = 0.696 + 0.184 \times log_{10}[Se]_{aq}$	0.220
Invertebrates to Fish Eggs	$log_{10}[Se]_{egg} = 1.02 + 0.026 \times log_{10}[Se]_{inv}$ for $[Se]_{inv}$ < 6.8 mg/kg dw $log_{10}[Se]_{egg} = 0.126 + 1.10 \times log_{10}[Se]_{inv}$ for $[Se]_{inv}$ ≥ 6.8 mg/kg dw	0.172
Invertebrates to Bird Eggs	$log_{10}[Se]_{egg} = 0.414 + 0.523 \times log_{10}[Se]_{inv}$	0.162
One-Step Models		
Water to Invertebrates	$log_{10}[Se]_{inv} = 0.696 + 0.184 \times log_{10}[Se]_{aq}$	0.220
Water to Fish Eggs	$log_{10}[Se]_{egg} = 0.986 + 0.108 \times log_{10}[Se]_{aq}$	0.174
Water to Bird Eggs	$log_{10}[Se]_{egg} = 0.683 + 0.103 \times log_{10}[Se]_{aq}$	0.130

Notes: $[Se]_{aq}$ = aqueous selenium concentration (µg/L); $[Se]_{peri}$ = periphyton selenium concentration (mg/kg dw); $[Se]_{inv}$ = invertebrate selenium concentration (mg/kg dw); $[Se]_{egg}$ = egg selenium concentration (mg/kg dw); RMSD = root mean square deviation calculated from residuals of the indicated model.

1.2 Summary of Permit Requirements and Commitments

A requirement to periodically update the model is specified in Permit 107517, issued by BC Ministry of Environment and Climate Change Strategy (ENV) under the provisions of the *Environmental Management Act* on 19 November 2015 and most recently amended 5 June 2017. Section 10.6 of Permit 107517 states:

> *The RAEMP* <Regional Aquatic Effects Monitoring Program> *report for the first approved cycle under the ABMP* <Area-based Management Plan> *must be submitted to the Director by September 30, 2017 and by September 30 of the final year of each subsequent three year monitoring cycle.* […] *Each report will, on a three year cycle, verify and calibrate the selenium bioaccumulation model using the most recent three years of water quality, aquatic effects and other data from any special studies undertaken.*

Expectations of ENV for special studies to inform this update are further described in a 14 November 2014 letter (ENV Reference 211557):

> *Additional studies to address uncertainties and support validation of the selenium bioaccumulation model, including evaluating:*
>
> *a) The feasibility of using field collected amphibian egg masses for toxicity testing and refining selenium thresholds for representative species;*
> *b) Seasonal variability in selenium bioaccumulation;*
> *c) The frequency and timing of sampling needed to characterize selenium concentrations in water for modelling bioaccumulation and determining the temporal lag between selenium accumulation in water and fish eggs;*
> *d) The effect of fish size on bioaccumulation; and*
> *e) The assumption that the species used to model selenium bioaccumulation represent the most sensitive fish and bird species in the Elk Valley.*

To comply with Section 10.6 of Permit 107517, and following expectations laid out in the 14 November 2014 letter from ENV, Section 3.2.4 of Teck's *Water Quality Adaptive Management Plan for Teck Coal Operations in the Elk Valley* states:

> *The uncertainty* [in science-based environmental benchmarks for selenium] *will be reduced in part through* […] *bioaccumulation studies.*
>
> - *Selenium bioaccumulation model study to address uncertainties and support model validation or updating* […] *Further evaluation of selenium bioaccumulation may include characterizing seasonal variability, understanding time lags involved in accumulation from water to fish eggs, assessing the effect of fish size on bioaccumulation, and confirmation that the most sensitive fish and birds have been targeted (ENV 2014b).*
> - *Study of selenium speciation resulting from AWTF* <Active Water Treatment Facility> *operation is a condition of Line Creek Operations Phase II approval that is being addressed by monitoring of selenium speciation in water and the implementation of the Line Creek LAEMP* <Local Aquatic Effects Monitoring Program>*.* […] *Should these studies show changes in selenium speciation resulting from AWTF operation, and associated changes in selenium bioaccumulation in biota downstream of the AWTF, additional evaluation will be undertaken to assess the applicability of the selenium bioaccumulation model in areas receiving AWTF discharge. If warranted, the selenium bioaccumulation model would be refined to reflect these changes.*

On 19 April 2017, Golder issued the “Work Plan for Selenium Bioaccumulation Model Update”. The tasks listed in the work plan reflected the regulatory requirements and commitments summarized above.

1.3 Feedback from the Environmental Monitoring Committee

Tasks undertaken to support the 2017 model update were developed and reviewed through ongoing consultation with the EMC. Feedback provided by EMC members on the work plan and subsequent discussions during the 31 August 2017 conference call were incorporated into the this memorandum. For reference, the topics addressed by priority advice on the work plan are summarized below:

- P1. Share results of Task 4 with the Koocanusa Reservoir Monitoring and Research Group
- P2. Submit revised work plan to the Director for approval
- P3. Submit special studies to the Director
- P4. Provide scoping and timeline for supporting studies
- P5. Consider an approach to formally testing that lack of fit for the new data is greater than for the original data that were used to calibrate the models
- P6. Develop and test an approach to deriving benthos-to-amphibian egg models
- P7. Develop toxicity thresholds for selenium in amphibian eggs
- P8. Present data on seasonal variability in selenium bioaccumulation to the EMC
- P9. Document the approach to address the frequency and timing of water sampling to characterize selenium concentrations
- P10. Present data on the effect of fish size on bioaccumulation to the EMC
- P11. Document the sensitivity and bioaccumulation of selenium in various receptors
- P12. Provide more supporting information to the EMC to support an open discussion on the path forward

Priority advice P1, P2, and P7 are being addressed by Teck elsewhere. Priority advice P3 and P4 are addressed by submission of this memorandum and subsequent studies described herein. Priority advice P5, P6, P8, P9, P10, P11, and P12 are addressed by provision of this memorandum to the EMC and discussion at the October 2017 EMC meeting.

Changes made in response to feedback on the work plan were:

- Per priority advice P5, an analysis was presented at the October 2017 EMC meeting comparing lack of fit between new data and the original data that were used to calibrate the models
- Per priority advice P6, an analysis is provided in Section 2.0 to derive benthos-to-amphibian egg selenium bioaccumulation models
- Per priority advice P8, an updated analysis is provided in Section 3.0 of seasonal variability in selenium concentrations in invertebrates

- Per priority advice P9 and discussions during the 31 August 2017 conference call, an analysis is provided in Section 4.0 to assess the frequency and timing of water sampling needed to characterize temporal lag and averaging period for selenium accumulation in biota
- Per priority advice P10, a summary is provided in Section 5.0 of the analysis of selenium bioaccumulation in relation to fish size reported in Appendix B of Minnow (2016a)
- Per priority advice P11, an evaluation is provided of the performance of the model relative to data for a range of fish and bird species sampled in the Elk Valley (Section 6.0) and Koocanusa Reservoir (Section 8.0)
- Per discussions during the 31 August 2017 conference call, a piecewise model form for invertebrates is evaluated in Section 7.2.2
- Per discussions during the 31 August 2017 conference call, data not included in model development are compared both to the EVWQP model and to a lentic bioaccumulation model to identify sites exhibiting a distinct pattern of elevated selenium bioaccumulation (Sections 6.0, 7.0, 8.0, and 9.0)
- Per discussions during the 31 August 2017 conference call, box-and-whisker plots are presented in Section 8.0 to summarize selenium concentrations in fish species sampled in Koocanusa Reservoir

1.4 Document Layout

The remaining sections of this memorandum are organized as follows:

- Section 2: Draft amphibian bioaccumulation model (Task 2a from the work plan)
- Section 3: Analysis of seasonality in selenium bioaccumulation (Task 2b)
- Section 4: Evaluation of the frequency and timing of water sampling to characterize selenium bioaccumulation (Task 2c)
- Section 5: Evaluation of bioaccumulation in relation to fish size (Task 2d)
- Section 6: Comparison of the model to data for fish and bird species other than those used in model derivation (Task 2e)
- Section 7: Model validation and updates to dataset (Task 3)
- Section 8: Evaluation of application of the model to Koocanusa Reservoir (Task 4)
- Section 9: Evaluation of application of the model to Line Creek (Task 5)

2.0 TASK 2A: DRAFT AMPHIBIAN BIOACCUMULATION MODEL

Special study (a) identified in the 14 November 2014 letter from ENV was to evaluate the feasibility of using field-collected amphibian egg masses for toxicity testing and refining selenium thresholds for representative species (ENV Reference 211557). As discussed in the work plan, this special study refers to toxicity testing with amphibians, and does not relate to the bioaccumulation model update presented herein.

Priority advice P6 from the EMC identified the need for an invertebrate-amphibian selenium bioaccumulation model: “*Amphibians are key receptors that need to be addressed in the Se Bioaccumulation Model. Therefore, an approach to deriving benthos-to-amphibian egg models needs to be developed and tested*.” In response to this advice, an amphibian bioaccumulation model was developed according to methods described in the following sections.

2.1 Overview of Approach

A bioaccumulation model characterizing the trophic transfer of selenium from invertebrates to amphibian eggs was derived using methods described in Annex E of the EVWQP. In brief, model derivation was conducted as follows:

- **Data compilation and quality assessment**. Reported selenium concentrations in invertebrates and amphibian eggs were compiled from studies conducted in the Elk Valley. Data were evaluated for reliability and relevance for use in deriving selenium bioaccumulation models. Amphibian egg selenium concentrations were paired with concurrent and co-located invertebrate selenium concentrations. All data were $\log_{10}$-transformed prior to analysis to stabilize variance and linearize relationships.
- **Model derivation and selection**. Model equations were derived by regression analysis of paired datasets. Regression models were fit initially as a log-linear form (i.e., a linear fit to $\log_{10}$-transformed data, which results in a power function). Model residuals were inspected to evaluate whether an alternative model form was warranted. In cases where an alternative form was determined to be warranted, the preferred alternative was a piecewise model.
- **Model evaluation**. Derived models were evaluated to assess their sensitivity to decisions made during data preparation and selection of modelling techniques and model forms. Based on this evaluation, a final model equation was selected.

The variability of individual observations around the final models was characterized as the root mean square deviation (RMSD). RMSD is the square root of the mean squared error, which is the sum of squared residuals (i.e., squared differences between modelled and observed values), divided by the number of observations. RMSD quantifies the variability of model residuals and thus characterizes the degree of residual scatter around a fitted model.

As in the EVWQP, RMSD was calculated to characterize scatter around the overall model, including all uptake and trophic transfer steps for the predicted value. For the present analysis, this entailed combining the invertebrate-to-amphibian egg model derived herein with an existing model relating invertebrate selenium concentrations to aqueous selenium concentrations. For most sample locations, the invertebrate bioaccumulation model from Annex E of the EVWQP was used for this calculation. For sampling events in lentic locations that have been identified as having a distinct pattern of enhanced selenium bioaccumulation (i.e., Goddard Marsh, Fording River Oxbow, Elk River Wetland), the lentic bioaccumulation model developed by Orr et al. (2012) was used.

The lentic model exhibited similar residuals to the EVWQP model at aqueous selenium concentrations greater than the breakpoint of the piecewise models, indicating that the two models perform similarly well at relatively high aqueous selenium concentrations. However, the lentic model exhibited a high proportion of large positive residuals (i.e., under-prediction of observed invertebrate and amphibian egg selenium concentrations) at lower aqueous selenium concentrations. Distinct lentic sites with amphibian data in the low portion of the modelled range had aqueous selenium concentrations less than 2 µg/L, and therefore performance of the lentic model in mine-influenced areas was considered to be better represented by model residuals in the high portion of the modelled range. For sites modelled using the lentic model, RMSD was calculated from residuals in the high portion of the modelled range only. For all other sites, RMSD was calculated from residuals across the entire modelled range.

2.2 Data Compilation and Quality Assessment

Amphibian egg selenium concentrations were obtained from regional biomonitoring (Minnow 2004, 2006, 2013; Minnow et al. 2007, 2011) and baseline sampling programs undertaken by Golder in support of permit applications for Teck's operations (Teck 2013, 2014a,b). Amphibian egg selenium concentrations were available for Columbia spotted frog (*Rana luteiventris*; $n = 89$), western toad (*Bufo boreas*; $n = 31$), and long-toed salamander (*Ambystoma macrodactylum*; $n = 2$).

Data for each sampling event were used to calculate a geometric mean amphibian egg selenium concentration for each species sampled at a particular location on a particular date. Data were combined in this way because each sampling event was associated with a single invertebrate selenium concentration. Including multiple amphibian egg data associated with the same invertebrate datum would constitute pseudoreplication, and would decrease the reliability of the resulting model. An alternative would have been to use mixed-effects modelling to nest replicate egg selenium concentrations within each sampling event. However, the complexity associated with fitting a piecewise form as a mixed-effects model was judged not to be warranted for the present analysis, which was focused on deriving a model to predict the mean amphibian egg selenium concentration associated with a given invertebrate selenium concentration. The variability of individual amphibian egg selenium concentrations around this predicted mean was characterized by calculating the RMSD for each model from individual reported egg selenium concentrations.

Amphibian egg samples collected in 2012 from Grave Lake Marsh (one geometric mean concentration for Columbia spotted frog and one for western toad) were paired with a reported invertebrate selenium concentration of 0.78 mg/kg dw (Minnow 2013). Consistent with decisions made in consultation with the Toxicology Working Group to the EVWQP, this invertebrate selenium concentration was considered to be anomalously low and potentially inaccurate. The two geometric mean egg selenium concentrations from this sampling event were therefore excluded from model derivation.

The sample size included in model derivation for all amphibian species combined represented 36 sampling events with invertebrate selenium concentrations ranging from 2.3 to 41.8 mg/kg dw. The majority of these data were for Columbia spotted frog, representing 27 sampling events with invertebrate selenium concentrations ranging from 2.3 to 21.2 mg/kg dw.

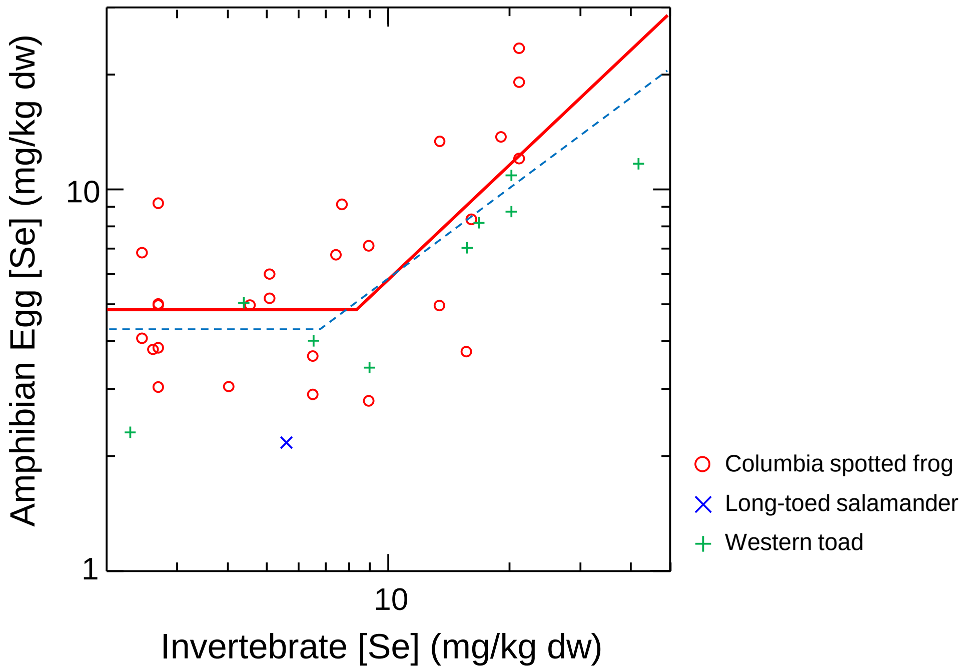
2.3 Model Derivation and Evaluation

Ordinary least-squares (OLS) regression was initially used to fit a log-linear model to the amphibian egg selenium data for all species combined, and to Columbia spotted frog data only. Both log-linear models exhibited residual structure, apparent as a tendency to overestimate observed data in the middle of the range of sampled invertebrate selenium concentrations and underestimate observed data at lower or higher values.

To address residual structure in the log-linear model forms, piecewise models were fit to the data. An initial, unconstrained piecewise fit resulted in a slope less than zero over the low portion of the modelled range for both models, and a slope greater than 1 over the high portion of the modelled range for Columbia spotted frog data. Slopes less than zero or greater than 1 are biologically unrealistic, as they would indicate that amphibian egg selenium concentrations either decline with increasing dietary concentration or increase disproportionately as dietary selenium concentration increases. Neither of these outcomes is consistent with the prevailing understanding of dose-dependent trophic transfer of selenium in vertebrates. Constraining slopes in each portion of the piecewise model to biologically realistic values between zero and 1 resulted in similar residuals and model fit, with an r^2 value of approximately 0.50 for unconstrained and constrained piecewise models. For both models, this constraint resulted in a slope of zero (i.e., constant mean amphibian egg selenium concentrations) over the low portion of the modelled range.

The breakpoint of the piecewise model for all amphibian species combined was 0.81 as a log value, or 6.5 mg/kg dw. The breakpoint of the piecewise model for Columbia spotted frog was 0.92 as a log value, or 8.3 mg/kg dw. The Columbia spotted frog model had a higher selenium concentration in the low portion of the modelled range, a higher breakpoint, and a steeper slope in the high portion of the modelled range compared to the combined-species model (Figure 1).

Figure 1: Amphibian Bioaccumulation Data and Fitted Models



Notes: Blue dashed line is piecewise fit to data for all species combined. Red solid line is piecewise fit to Columbia spotted frog data.

2.4 Final Models

The fitted model relating amphibian egg selenium concentration ($[Se]_{egg}$; mg/kg dw) to invertebrate selenium concentration ($[Se]_{inv}$; mg/kg dw) for all amphibian species combined was:

$log_{10}[Se]_{egg} = 0.625$ for $[Se]_{inv} < 6.5$ mg/kg dw (Equation 1a)

$log_{10}[Se]_{egg} = -0.00923 + 0.783 \times log_{10}[Se]_{inv}$ for $[Se]_{inv} \geq 6.5$ mg/kg dw (Equation 1b)

RMSD of the overall model (i.e., Equation 1 combined with existing water-to-invertebrate bioaccumulation models) was 0.221 log units.

The fitted model relating amphibian egg selenium concentration to invertebrate selenium concentration for Columbia spotted frog data only was:

$log_{10}[Se]_{egg} = 0.682$ for $[Se]_{inv} < 8.3$ mg/kg dw (Equation 2a)

$log_{10}[Se]_{egg} = -0.238 + 1 \times log_{10}[Se]_{inv}$ for $[Se]_{inv} \geq 8.3$ mg/kg dw (Equation 2b)

RMSD of the overall model (i.e., Equation 2 combined with existing water-to-invertebrate bioaccumulation models) was 0.219 log units.

The models derived above are intended be applied in the same manner as the EVWQP models for fish and birds in Table 1. Equation 1 or Equation 2 would be used to translate measured or predicted invertebrate selenium concentrations into predicted mean egg selenium concentrations in amphibians. The associated RMSD could then be used to characterize the expected distribution of individual amphibian selenium concentrations around that predicted mean.

2.5 Conclusions and Next Steps

The bioaccumulation models presented above are expected to provide reasonable predictions of selenium exposure for amphibians in the Elk Valley. In consultation with the EMC, Teck is developing a plan to sample amphibian eggs in spring 2018. These data should be used to evaluate the performance of the models presented above.

3.0 TASK 2B: ANALYSIS OF SEASONALITY OF BIOACCUMULATION

Seasonal variability in selenium concentrations in invertebrates was evaluated during initial development of the model (Action Item A-135 from Toxicology Working Group Meeting #4, provided in a memo to the working group on 8 July 2014). Further analysis of seasonality data was requested by ENV as special study (b) identified in the 14 November 2014 letter (ENV Reference 211557) and was requested by the EMC in priority advice P8.

3.1 Methods

The analysis conducted in Action Item A-135 was updated with invertebrate tissue data from recent monitoring in the Elk Valley (Minnow 2017a,b). Consistent with the approach used for Action Item A-135, the updated analysis only included data from mine-influenced sites because reference sites have lower selenium concentrations and show less variability in water quality, and thus may obscure an overall seasonal trend at mine-influenced sites. Data collected prior to 2006 were excluded for the same reason. The analysis focused on invertebrate selenium concentrations because of the relative abundance of such data from sites throughout the Elk Valley and the key role of invertebrates as a dietary source of selenium to fish, amphibians, and aquatic-feeding birds.

Seasonality in invertebrate selenium concentrations was evaluated using the following approaches:

- **Monthly Box-and-Whisker Plot**. Data were grouped by month of collection and summarized in box-and-whisker plots to visually evaluate variation across months in the distribution of invertebrate tissue selenium concentrations at mine-influenced sites. Box-and-whisker plots show the median (center horizontal line), upper and lower quartiles (limits of box), and 5th and 95th percentiles (whiskers) of the data. Boxes were plotted for months with more than four reported values. Individual values were plotted over the boxes to show the number and general distribution of values for each month.
- **Site-specific Line Plot**. For sites that were sampled in at least two months in the same year, invertebrate selenium concentrations were plotted in a line plot. This approach shows variability across months within each site, enabling a comparison of this between-month variability across all sites with sufficient data.

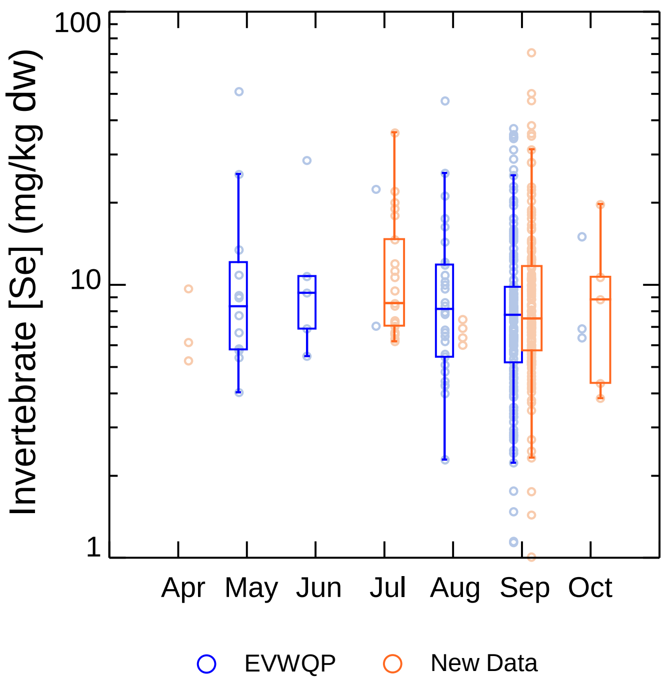
3.2 Results

3.2.1 Monthly Box-and-Whisker Plot

Data included in Action Item A-135 for the EVWQP were available for samples collected between 2006 and 2013 in May (n = 12), June (n = 5), July (n = 2), August (n = 30), September (n = 146) and October (n = 3). Data collected subsequently (between 2014 and 2016) were available for samples collected in April (n = 3), July (n = 21), August (n = 4), September (n = 137) and October (n = 5).

The box-and-whisker plot (Figure 2) showed little evidence of seasonal variation for invertebrate tissue selenium concentrations in either the EVWQP data or newer data. Median concentrations were approximately 7.5 to 9.5 mg/kg dw for all months between April and October. For both the EVWQP and newer data, too few data were available for April to calculate meaningful summary statistics, but reported values were generally consistent with other sampled months. The lack of sufficient data from November to March precluded an evaluation of potential changes in tissue selenium concentrations over winter.

Figure 2: Summary of invertebrate selenium data by month from mine-exposed sites in the Elk Valley



Notes: Concentration is in milligrams per kilogram dry weight (mg/kg dw). Data included in the EVWQP analysis (2006 – 2013) shown as blue symbols; newer data (2014 – 2016) shown as orange symbols.

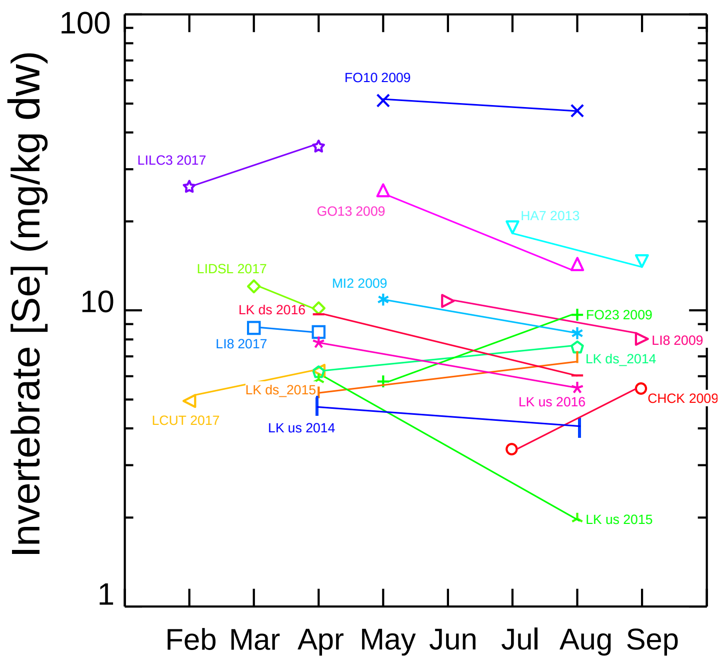
3.2.2 Site-specific Line Plot

A total of seventeen pairs of data were identified for inclusion in line plots, representing samples taken at the same site in more than one month between February and September (Figure 3). Data from LILC3 in 2017 are shown on Figure 3 but should not be interpreted to reflect normal patterns of seasonality in the Elk Valley because they are influenced by operation of the West Line Creek active water treatment facility (AWTF) (discussed further in Section 9).

Adjusted for the length of the interval between sampling events (i.e., expressed as a change in concentration per month), reported changes in invertebrate selenium concentrations at sampled sites (LILC3 excluded) ranged from -2.2 mg/kg dw per month between July and September in Harmer Sediment Pond to +1.0 mg/kg dw per month between July and September in Chauncey Creek. The mean change across all sites (LILC3 excluded) was -0.5 mg/kg dw per month.

The compiled data show no consistent pattern of seasonal variation in invertebrate selenium concentrations. For approximately half of the station/year combinations (7 of 16), there was an increasing trend (FO23 2009, CHCK 2013, LK ds 2014, LK ds 2015, LCUT 2017) or no discernable trend (LI8 2017, FO10 2009) from winter/spring sampling to summer/fall sampling. For the remaining station/year combinations (9 of 16), there was a decreasing trend from the earlier sampling month to the later sampling month (GO13 2009, LI8 2009, MI2 2009, HA7 2013, LK us 2014/2015/2016, LK ds 2016, LIDSL 2017). Site-specific seasonality could be assessed across years at three stations: LI8 (2009 and 2017), LK ds (2014 to 2016), and LK us (2014 to 2016). Of these three stations, LK us was the only station to exhibit a decreasing trend in tissue selenium concentrations in all three years. Seasonal trends in invertebrate selenium concentrations were variable at LI8 (no trend in 2017 and decreasing trend in 2009) and LK ds (increasing trend in 2014 and 2015; decreasing trend in 2016). Overall, the available data indicate that seasonal variation in invertebrate selenium concentrations is neither large nor consistent across sites or years.

Figure 3: Variation in invertebrate selenium concentration between months at mine-influenced sites in the Elk Valley



Notes: Concentrations are in milligrams per kilogram dry weight (mg/kg dw). Annotation shows site code and sampling year. Site codes are LILC3 (Line Creek downstream of West Line Creek and AWTF outfall), FO10 (Fording River Oxbow), GO13 (Goddard Marsh), HA7 (Harmer Sediment Pond), LIDSL (Line Creek downstream of South Line Creek), MI2 (Michel Creek upstream of Coal Mountain Operation), FO23 (Fording River downstream of Line Creek), LI8 (Line Creek near the mouth), LK ds (Koocanusa Reservoir downstream of the Elk River), LK us (Koocanusa Reservoir upstream of the Elk River), LCUT (Line Creek upstream of the AWTF), and CHCK (Chauncey Creek).

3.3 Conclusions and Next Steps

The analysis presented above indicates little evidence for large or consistent seasonal changes in selenium concentrations in invertebrates in Elk Valley waters between February and October. No data were found to characterize selenium concentrations in invertebrates in November through January. However, it is expected that there is little potential for uptake and trophic transfer of aqueous selenium in winter due to expected low growth of periphyton (related to short days, low temperatures, and ice cover), reduced or negligible feeding by invertebrates (due to low temperatures, low periphyton growth, and overwinter resting stages for many species), and reduced feeding by fish (due to low temperatures, reduced activity of invertebrates, and congregation of fish in overwintering areas). This expectation could be confirmed by sampling invertebrates in mid-winter from selected locations that had also been sampled in the previous summer and/or spring. In consultation with the EMC, Teck will consider the potential value of including winter sampling of invertebrates in the next cycle of the RAEMP.

4.0 TASK 2C: FREQUENCY AND TIMING OF SAMPLING TO CHARACTERIZE SELENIUM BIOACCUMULATION

Special study (c) requested by ENV in the 14 November 2014 letter (ENV Reference 211557) was an analysis of the frequency and timing of sampling needed to characterize selenium concentrations in water for modelling bioaccumulation and determining the temporal lag between selenium accumulation in water and fish eggs. This request relates to the understanding that aqueous selenium concentrations are not instantaneously reflected in fish egg selenium concentrations. Biota at all levels of the aquatic food web continuously accumulate and eliminate selenium, integrating variability in their aqueous or dietary exposure concentrations over an averaging period and with an inherent degree of ‘lag’ that reflects the kinetics of uptake and accumulation relative to the rate of change of aqueous or dietary concentrations. The goal of this task would be to evaluate whether consideration of temporal dynamics could improve model performance.

4.1 Methods

As recommended by the EMC during the 31 August 2017 conference call, the approach was a statistical analysis of the relationship between aqueous and invertebrate selenium concentrations, which is the first step of the EVWQP selenium bioaccumulation model. Invertebrates are well suited to this analysis because they have low mobility and therefore are expected to provide good spatial pairing with aqueous selenium concentrations.

As in the EVWQP model, invertebrate selenium concentrations were paired with co-located aqueous selenium concentrations. However, whereas derivation of the model paired concurrent concentrations, the present analysis used a range of pairing permutations to evaluate lag times from zero to six months and averaging periods for aqueous selenium concentrations from one to three months (Table 2). A total of 82 invertebrate tissue selenium concentrations were identified for which sufficient aqueous selenium data were available to test the selected permutations. Invertebrate selenium concentrations in this dataset ranged from approximately 2 to 22 mg/kg dw and aqueous selenium concentrations ranged from 0.2 to 700 µg/L.

Table 2: Permutations for Aqueous Selenium Data Paired with Invertebrate Data Collected in September

Lag (Months)	Aqueous Selenium Concentration Averaging Period (Months)		
	1	2	3
0	Sep	Aug - Sep	Jul - Sep
1	Aug	Jul - Aug	Jun - Aug
2	Jul	Jun - Jul	May - Jul
3	Jun	May - Jun	Apr - Jun
4	May	Apr - May	Mar - May
5	Apr	Mar - Apr	Feb - Apr
6	Mar	Feb - Mar	Jan - Mar

Note: The aqueous selenium concentration to be paired with an invertebrate selenium concentration collected in September would be the average of concentrations measured in the indicated months.

For each evaluated permutation, an OLS regression analysis was conducted to relate log invertebrate selenium concentration to the calculated log aqueous exposure concentration. Both log-linear and piecewise models were tested. Fitted models were characterized in terms of slope and goodness of fit (r^2). Models were then evaluated as a function of lag and averaging period to evaluate whether any permutation(s) resulted in an improvement in model fit relative to the existing model based on concurrent pairing (i.e., zero lag and one month averaging period).

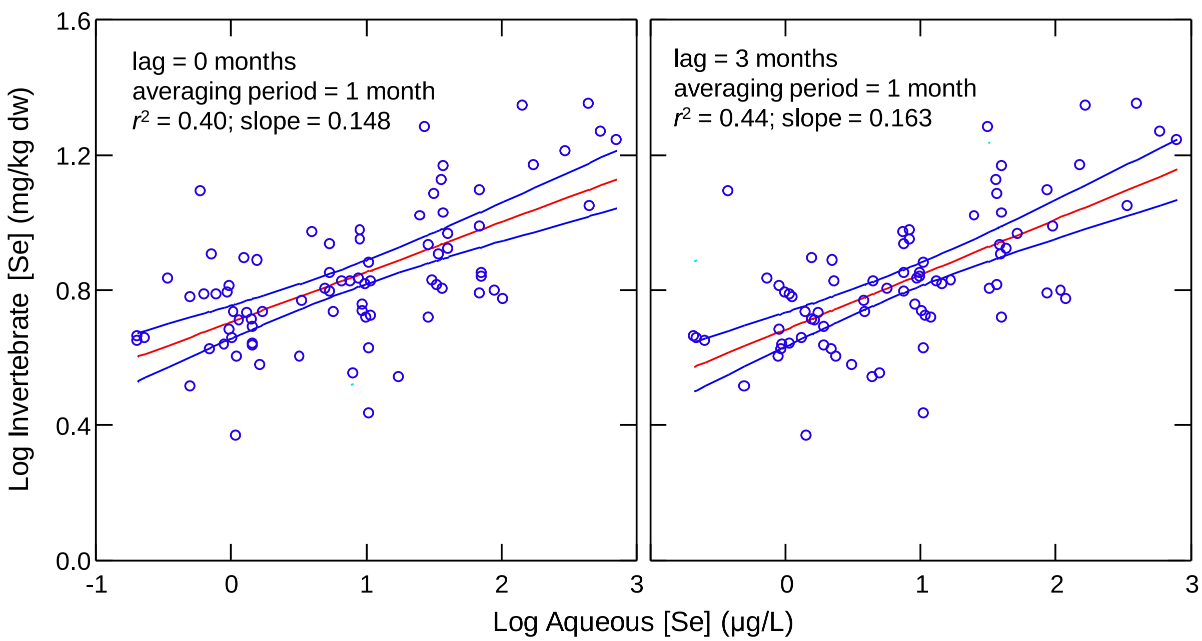
4.2 Results

Significant (p < 0.0001) log-linear regression fits were obtained for all 21 tested permutations. Example regression results are shown in Figure 4 for two of the tested permutations. Piecewise model results are not shown because of the 21 permutations tested, all but 4 had a fitted breakpoint outside the range of data (i.e., the best fit model was a linear regression within the range of data) and of these, 3 had a negative slope below the breakpoint (i.e., the model was not biologically realistic) and none exhibited a better fit than log-linear regression.

The dependence of model fit (expressed as r^2) and model slope on lag and averaging period is shown in Figure 5. Overall, there was little difference among permutations in model fit and no compelling indication that including lag or averaging into the bioaccumulation model would improve model performance relative to the more parsimonious form derived for the EVWQP (Figure 5, left panel).

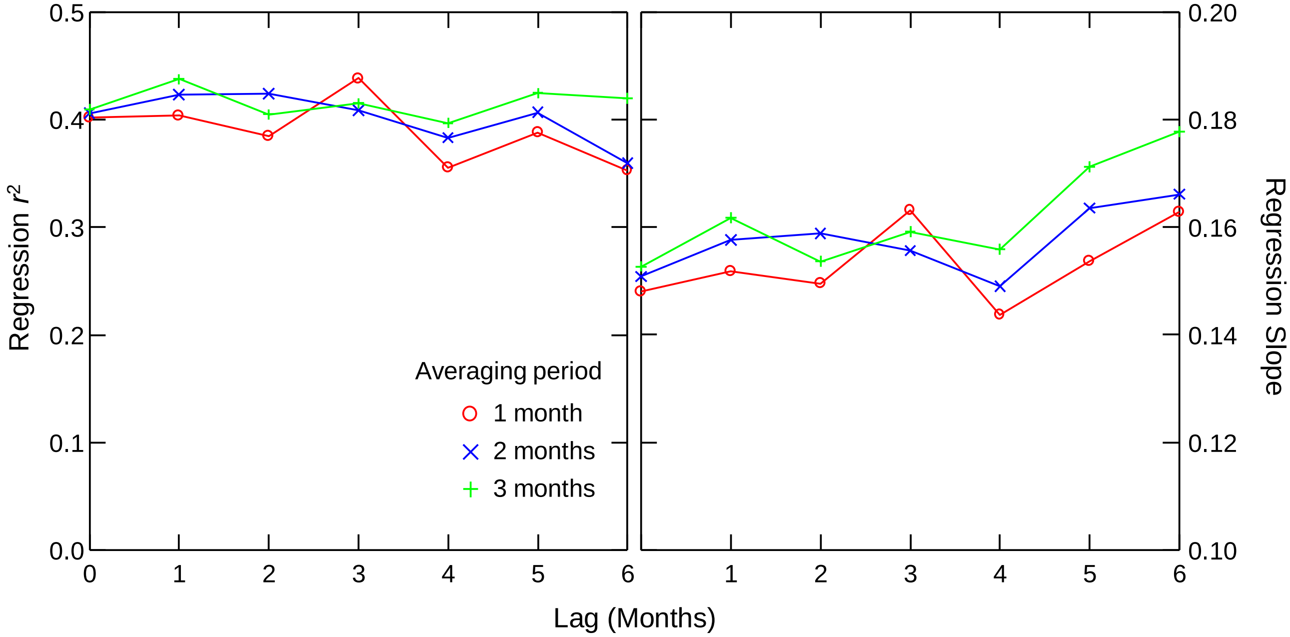
Slightly higher slopes were observed for permutations with lags of 5 to 6 months and averaging periods of 2 to 3 months (Figure 5, right panel). This pattern likely reflects the effect of freshet on calculated aqueous selenium exposure concentrations at the most mine-affected sites. Mine-affected sites exhibit relatively large seasonal variability in aqueous selenium concentrations due to the diluting effect of high flows of unaffected water in spring. Inclusion of early spring high-flow, low-concentration months in the calculated aqueous exposure concentration has the effect of moving the highest points in the regression to the left, which results in a steeper model slope. Because most invertebrate samples were collected in September, the effect of spring high flows occurs in permutations with the highest lag and averaging period.

Figure 4: Example log-linear regression results for the EVWQP permutation (left panel: zero lag and one month averaging period) and the permutation that gave the highest r^2 (right panel: three month lag and one month averaging period)



Notes: Red line is linear best-fit regression. Blue curved lines are 95% confidence interval.

Figure 5: Effect of averaging period and lag on fit (left panel) and slope (right panel) of log-linear regression of invertebrate and aqueous selenium concentrations



4.3 Conclusions and Next Steps

The analysis outlined above was presented to the EMC for discussion at the October 2017 EMC meeting. The conclusion presented at that time was that lag and averaging period have little effect on the performance of the bioaccumulation model. It was recommended that the approach taken for the EVWQP of pairing concurrent tissue and aqueous selenium concentrations be retained in future modelling.

5.0 TASK 2D: BIOACCUMULATION IN RELATION TO FISH SIZE

Special study (d) requested by ENV in the 14 November 2014 letter (ENV Reference 211557) was an analysis of the effect of fish size on selenium bioaccumulation. The effect of fish size was evaluated during development of the model (discussed at Toxicology Working Group Meeting #3, held 28 March 2014) and the conclusion at that time was that a statistical effect was present, but could be attributed to an artifact of an unbalanced distribution of sampled fish sizes between high-selenium and low-selenium areas in the underlying dataset. It was agreed at the working group meeting that a size effect was not supported and would not be modelled.

A follow-up analysis was presented in Appendix B of the tissue selenium data package to support the RAEMP provided to the EMC in December 2016 (Minnow 2016a) that reached a similar conclusion. In response to priority advice P10 from the EMC, an overview of the methods and results from Minnow (2016a) is presented below.

5.1 Methods

Minnow (2016a) evaluated the relationship between fish tissue selenium concentration and fish length. The effect of fish size on selenium bioaccumulation was evaluated for each sampling location and year separately, to control for spatial and temporal differences in exposure. Data were plotted separately for each species and tissue type, including westslope cutthroat trout (*Oncorhynchus clarki lewisi*) muscle, mountain whitefish (*Prosopium williamsoni*) muscle and ovary, and longnose sucker (*Catostomus catostomus*) muscle, ovary, and whole body. Scatterplots and linear regressions were plotted. For each species and tissue type, analysis of covariance was conducted to test for consistency in a potential effect of size on selenium concentration across sampling locations.

5.2 Results

Scatterplots and linear regressions were provided by species and tissue type in Appendix B of Minnow (2016a). No consistent effect of fish size on selenium bioaccumulation was apparent in any of the species or tissue types evaluated. Analysis of covariance did not indicate a consistent effect of size on fish tissue selenium concentrations.

5.3 Conclusions and Next Steps

The two analyses summarized above indicated no consistent effect of size on fish tissue selenium concentrations. No further work is proposed at this time.

6.0 TASK 2E: COMPARISON OF THE MODEL TO DATA FOR FISH AND BIRD SPECIES OTHER THAN THOSE USED TO DERIVE THE MODEL

Special study (e) requested by ENV in the 14 November 2014 letter (ENV Reference 211557) was an analysis of the assumption that the species used to model selenium bioaccumulation represent the most sensitive fish and bird species in the Elk Valley. Toxicological sensitivity is not a component of the bioaccumulation model, but was considered in the EVWQP by adopting tissue-based effects benchmarks for the most sensitive species and life stages relevant to the Elk Valley.

The term 'sensitive' in the present context was interpreted to refer to the magnitude of bioaccumulation, reflecting sensitivity to aqueous selenium concentrations in terms of potential exposure. Sensitivity to bioaccumulation of aqueous selenium was considered in the EVWQP by focusing on species with relatively high exposure to dietary selenium and by basing the model on those species that exhibited the highest magnitude of bioaccumulation. In addition, where alternative model forms were equally supported by the data, the analysis conservatively selected model forms that gave higher predictions of bioaccumulation.

During model derivation, data were reviewed from all sampled fish and bird species in all sampled habitats in the Elk Valley. This sampling has intentionally focused on widespread, abundant species that occur in locations with relatively high exposure to selenium:

- For birds, sampling has focused on species that represent worst-case exposure to dietary selenium because of their high degree of territoriality, their breeding-season diet of predominantly aquatic invertebrates, and their occurrence throughout the Elk Valley, including breeding in close proximity to mines. Red-winged blackbird (*Agelaius phoeniceus*) breed in lentic habitats, and therefore have potential exposure to relatively high dietary selenium concentrations in areas like Goddard Marsh that exhibit enhanced selenium bioaccumulation. Spotted sandpiper (*Actitis macularius*) breed on gravel bars adjacent to a range of aquatic habitat types, and therefore have potential exposure to relatively high dietary selenium concentrations in mine settling ponds and small tributaries that receive mine-influenced water.

- For fish, sampling has focused on species that represent worst-case exposure to dietary selenium because of their aquatic invertebrate diet and their occurrence in a range of aquatic habitat types in close proximity to mines. Westslope cutthroat trout inhabit the upper Fording River, historically including areas with elevated selenium bioaccumulation like Clode Settling Pond, as well as tributaries and mainstem rivers throughout the Elk Valley. Longnose sucker tend to occur in lentic areas, and therefore have potential exposure to relatively high dietary selenium concentrations in areas like Goddard Marsh. Mountain whitefish have also been a focus of monitoring, although patterns of bioaccumulation for this species are confounded by pre-spawning migration behaviour that precludes a reliable pairing of fish tissue and dietary selenium concentrations (discussed in Annex E of the EVWQP).

Following the review of data and identification of species with sufficient reliable data to characterize patterns of bioaccumulation, an evaluation was performed to select species for modelling. Analysis of covariance indicated significant differences in the slope of the bioaccumulation relationship between species for both fish (westslope cutthroat trout and longnose sucker) and birds (red-winged blackbird and spotted sandpiper), although a large degree of overlap in egg selenium concentrations was apparent between species. The model was derived using data from the species that tended to exhibit higher tissue selenium concentrations (i.e., red-winged blackbird and westslope cutthroat trout). These species are expected to provide a reasonable representation of bioaccumulation in other species, including piscivores, because trophic transfer factors for fish (i.e., ratios of selenium concentrations in predators to prey) tend to be near 1 and are often less than 1. Thus, higher trophic level species would be expected to have similar or lower exposure to selenium compared to the modelled species.

The steps outlined above mitigated the potential for bioaccumulation of unstudied species to be underestimated. Combined with margins of safety inherent in the selection of tissue-based effects benchmarks, these steps addressed uncertainty related to the protection of potentially sensitive species resident in the Elk Valley. There is residual uncertainty in how accurately the model represents bioaccumulation in all species, but this uncertainty is not expected to result in underestimation of exposure or under-protectiveness of water quality benchmarks.

6.1 Methods

Existing data for species of fish and birds not included in model development were compiled, paired with aqueous selenium concentrations, and plotted in comparison to the EVWQP model and its underlying datasets. The EVWQP model for fish and underlying westslope cutthroat trout data were compared to egg selenium data for eastern brook trout (*Salvelinus fontinalis*; *n* = 5), longnose dace (*Rhinichthys cataractae*; *n* = 3), and dwarf longnose sucker (*n* = 17) reported in Teck (2014a, 2015) and Minnow (2017a). Comparison to additional fish species collected in Koocanusa Reservoir is presented in Section 9. For birds, the EVWQP model and underlying red-winged blackbird data were compared to egg selenium data collected for American dipper (*Cinclus mexicanus*; *n* = 16), common merganser (*Mergus merganser*; *n* = 6), killdeer (*Charadrius vociferous*; *n* = 3), mallard (*Anas platyrhynchos*; *n* = 7), and spotted sandpiper (*n* = 248) reported in Harding and Paton (2003), Teck (2013, 2015), Minnow et al. (2007), and Minnow (2013, 2016b, 2017a).

Some of the data included in the present analysis were collected in lentic areas that had previously been identified as exhibiting a distinct pattern of enhanced selenium bioaccumulation (e.g., Goddard Marsh). Therefore, data were also compared to the lentic models developed by Orr et al. (2012). Fish egg selenium data were compared to the lentic model for westslope cutthroat trout. Bird egg selenium data were compared to a model combining the lentic model for invertebrates with the EVWQP invertebrate-bird egg model.

Model residuals were inspected to evaluate performance of the EVWQP and lentic models for describing patterns of bioaccumulation exhibited by the sampled fish or bird species, relative to the data used to derive the models.

6.2 Results

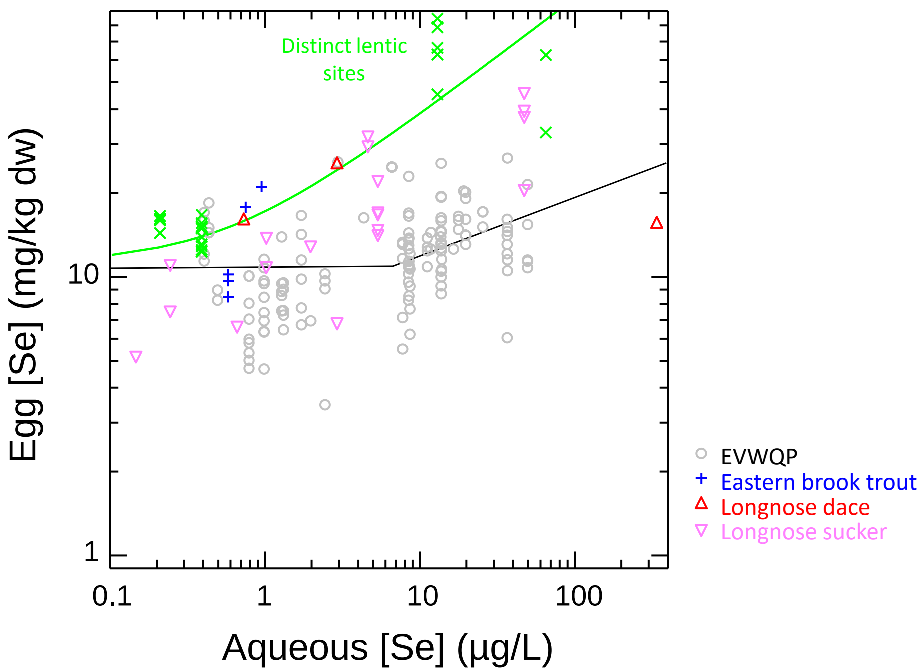
The following elements are shown on the plots provided below:

- EVWQP model (solid black line)
- lentic and lotic data that were combined to derive the EVWQP model (grey ○ symbols)
- data from distinct lentic sites identified during development of the EVWQP (green × symbols)
- lentic bioaccumulation model (solid green line)
- data for fish and bird species not included in the model (various symbols, see legend)

6.2.1 Fish

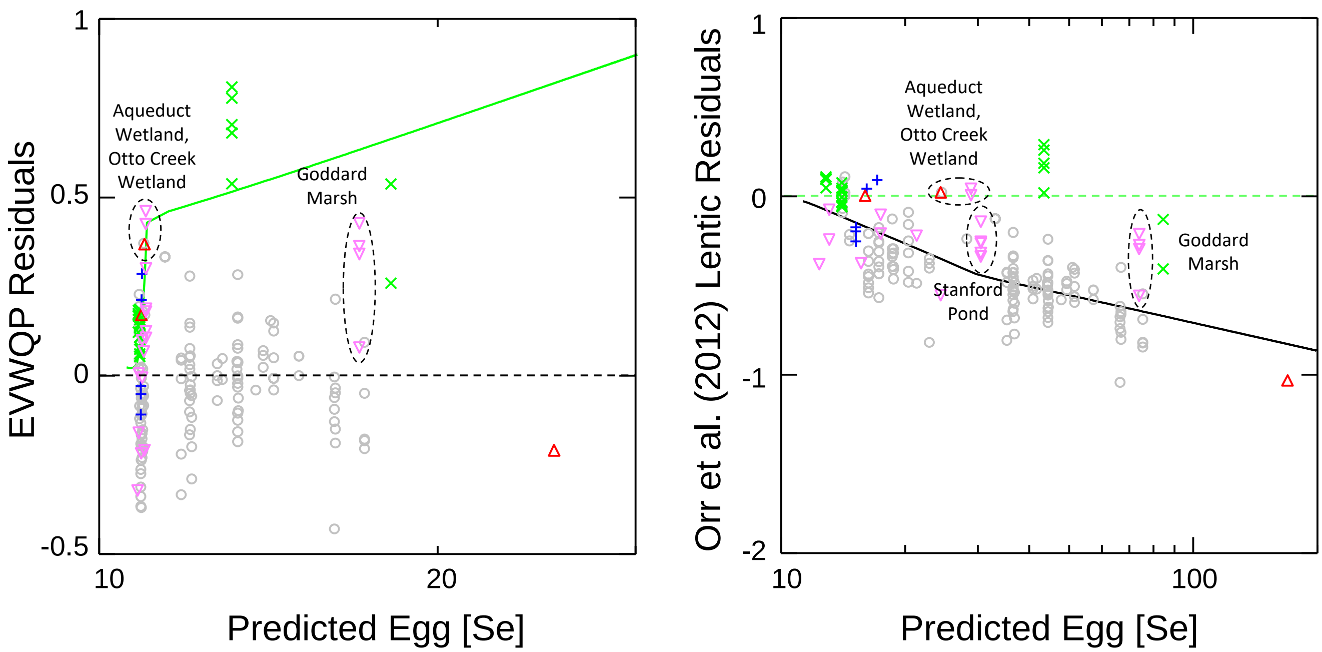
Data are plotted in comparison to the EVWQP model and lentic model in Figure 6. Residuals relative to each model are plotted on Figure 7.

Figure 6: Comparison of selenium bioaccumulation in fish sampled in the Elk Valley to bioaccumulation model predictions made by the EVWQP model (black line) and lentic model (green line)



Notes: Grey circles are westslope cutthroat trout data used to derive the EVWQP model. Green × symbols are westslope cutthroat trout data from lentic sites with a distinct pattern of enhanced selenium bioaccumulation that were not included in the EVWQP model.

Figure 7: Model residuals for fish sampled in the Elk Valley compared to bioaccumulation model predictions made by the EVWQP model (left panel) and lentic model (right panel)



Notes: Symbols and lines as denoted in Figure 6. Annotated data are discussed in text.

Most of the data for fish species not included in the EVWQP model fell within the range of the westslope cutthroat trout data underlying the model (Figure 6) and had residuals similar to those of the underlying data (Figure 7). Exceptions were samples collected in lentic areas with a distinct pattern of selenium bioaccumulation, which were more consistent with the lentic model. Observations for each species were as follows:

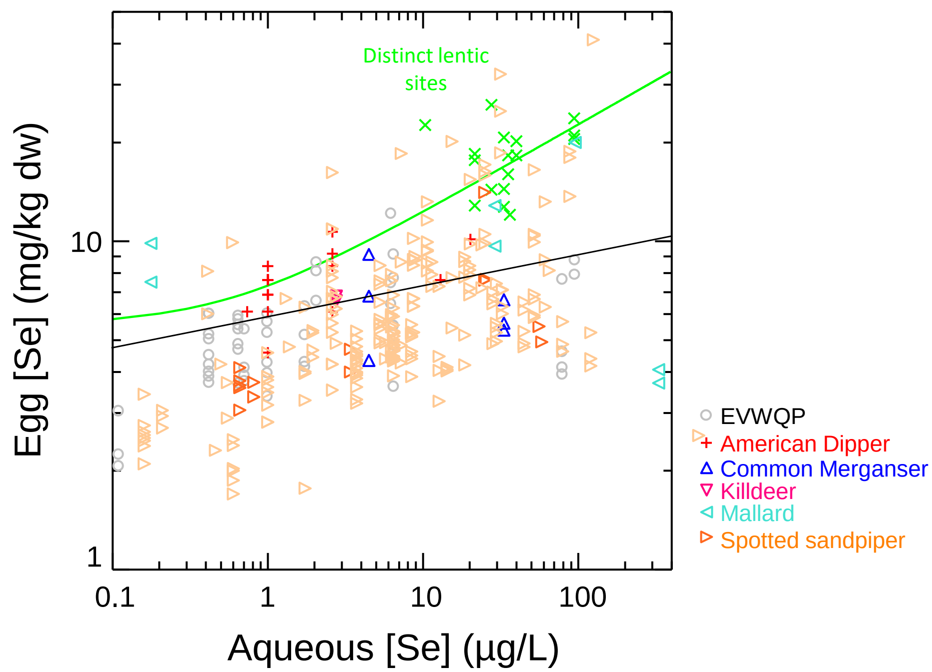
- Three eastern brook trout data had negative residuals and two had positive residuals. These five fish were collected in areas of Michel Creek Wetland and Mine Creek unaffected by mining, with aqueous selenium concentrations less than 1 µg/L. It is possible that some of these fish, although collected in unaffected areas, had previously been exposed to higher dietary selenium concentrations, for example in the adjacent mine-affected portions of Michel Creek and the Elk River. Therefore, the positive residuals observed for two of the fish likely reflect inaccurate pairing of fish tissue and aqueous concentrations due to fish movement, rather than a tendency for the model to underestimate bioaccumulation in eastern brook trout.
- Two longnose dace data had positive residuals and one had negative residuals. The fish with the larger positive residual was collected in Otto Creek wetland, which has previously been identified as having lentic conditions with a distinct pattern of elevated selenium bioaccumulation (Teck 2015). The other, which was collected in Six Mile Creek, had a positive residual similar in magnitude to the negative residual of the third fish and within the scatter of westslope cutthroat trout data.
- A statistical comparison of longnose sucker and westslope cutthroat trout data was presented in Annex E of the EVWQP. The conclusion of that analysis was that westslope cutthroat trout tend to exhibit higher selenium bioaccumulation than longnose sucker. Newer longnose sucker data shown on Figure 6 tended to be approximately evenly distributed around the EVWQP model, with the exception of samples collected in Aqueduct Wetland and Goddard Marsh that conformed better to the lentic model. Both of these locations

have previously been identified as having a distinct pattern of selenium bioaccumulation (Teck 2014, 2015). Five longnose sucker collected in Stanford Pond had egg selenium concentrations intermediate between the EVWQP model and the lentic model. However, the invertebrate sample collected in Stanford Pond had a selenium concentration consistent with the lentic model (Figure 12). Taken together, these data suggest that Stanford Pond also has distinct lentic conditions.

6.2.2 Birds

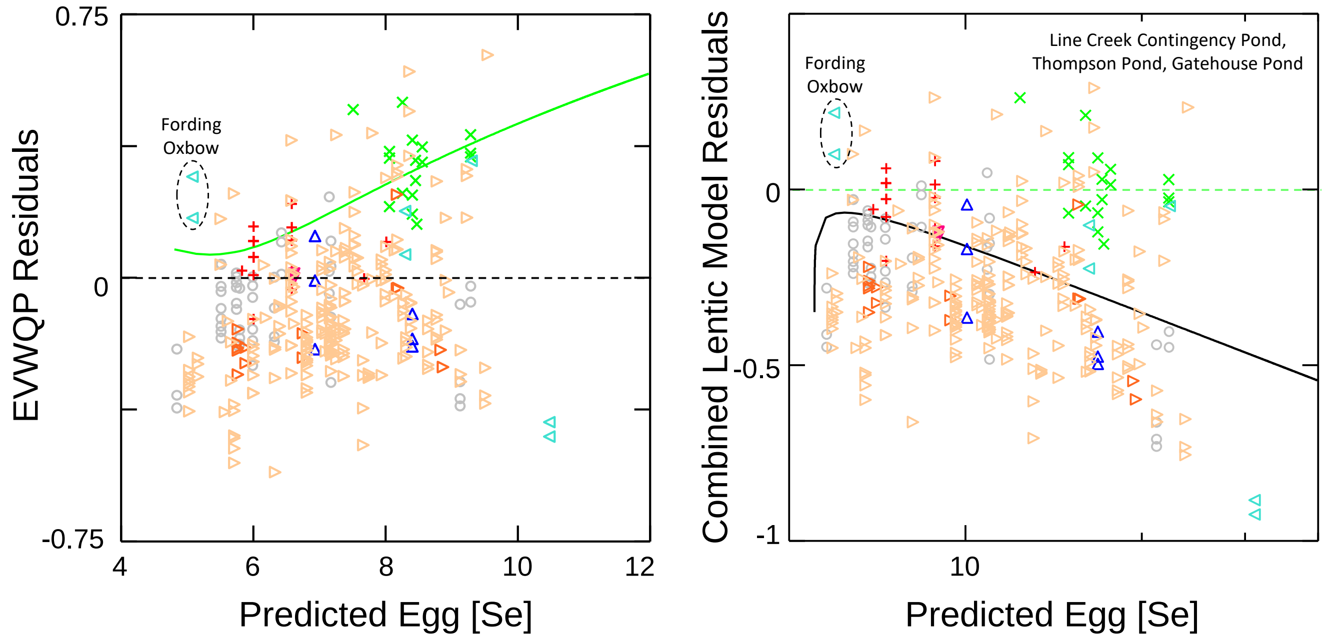
Data are plotted on Figure 8 in comparison to the EVWQP model and a lentic model that combines the lentic equations for invertebrates with the invertebrate-bird egg equation from the EVWQP (Table 1). Residuals relative to each model are plotted on Figure 9.

Figure 8: Comparison of selenium bioaccumulation in bird eggs sampled in the Elk Valley to bioaccumulation model predictions made by the EVWQP model (black line) and a combined Orr et al. (2012)-EVWQP lentic model (green line)



Notes: Grey circles are red-winged blackbird data used to derive the EVWQP model. Green × symbols are data from lentic sites with a distinct pattern of enhanced selenium bioaccumulation that were not included in the EVWQP model.

Figure 9: Model residuals for bird eggs sampled in the Elk Valley compared to bioaccumulation model predictions made by the EVWQP model (left panel) and a combined Orr et al. (2012)-EVWQP lentic model (right panel)



Notes: Symbols and lines as denoted in Figure 8. Annotated data are discussed in text.

Most of the data for bird species not included in the EVWQP model fell within the range of the red-winged blackbird data underlying the model (Figure 8) and had residuals similar to those of the underlying data (Figure 9). Observations for each species were as follows:

- American dipper egg selenium concentrations were on average approximately 1 mg/kg dw higher than the mean concentration predicted by the EVWQP model, but all observed values fell within the range of red-winged blackbird data underlying the model.
- Common merganser and killdeer egg selenium concentrations were consistent with or slightly lower than the EVWQP model.
- Mallard egg selenium concentrations were on average 2 to 3 mg/kg dw higher than the mean concentration predicted by the EVWQP model and some values fell outside the range of red-winged blackbird data underlying the model. The highest positive residuals were observed for mallard eggs collected at the Fording River Oxbow, which has previously been identified as having a distinct pattern of selenium bioaccumulation (discussed in Annex E of the EVWQP). Smaller positive residuals were observed for mallard eggs collected adjacent to Bodie Sediment Pond and Greenhills Creek Sediment Pond. It is likely that these positive residuals result from exposure to relatively high dietary selenium concentrations associated with some sediment ponds (discussed further in Section 7.2.2), rather than a tendency for the model to underestimate bioaccumulation in mallard.

- A statistical comparison of spotted sandpiper and red-winged blackbird data was presented in Annex E of the EVWQP. The conclusion of that analysis was that red-winged blackbird tend to exhibit higher selenium bioaccumulation than spotted sandpiper. The data plotted on Figures 8 and 9 also show that spotted sandpiper egg selenium concentrations are generally within the range of red-winged blackbird data underlying the model and most fall below the mean model prediction. The relatively high positive residuals that occur at relatively high aqueous selenium concentrations represent egg samples collected adjacent to several mine sedimentation ponds. These data suggest that sites such as the Line Creek Contingency Pond, Thompson Sediment Pond, and Bodie Sediment Pond exhibit relatively high selenium concentrations in invertebrates (discussed further in Section 7.2.2).

6.3 Conclusions and Next Steps

Overall, the analysis presented above indicates that the EVWQP model provides reasonable predictions of selenium bioaccumulation in a range of fish and bird species sampled at most locations in the Elk Valley. For those lentic locations with a distinct pattern of selenium bioaccumulation, a separate model is warranted. Ongoing review and validation of the model should continue to evaluate where these distinct lentic conditions occur, and should inform future refinement of models to predict selenium bioaccumulation under those distinct conditions. However, the data summarized above do not indicate a need to develop species-specific models.

7.0 TASK 3: MODEL VALIDATION AND UPDATES TO DATASET

Section 10.6 of Permit 107517 requires that Teck periodically verify and calibrate the selenium bioaccumulation model using the most recent three years of water quality, aquatic effects and other data from any special studies undertaken.

7.1 Methods

The analysis presented herein verifies performance of the model by comparing the mean model prediction and underlying data to newer data collected subsequent to model development. The potential need for calibration of the model (i.e., recalculation of model equations) was evaluated by considering whether the addition of newer data indicated a different pattern relative to that characterized by the existing model. As was done during development of the model for the EVWQP, model residuals were inspected to evaluate whether an alternative model form would better characterize the observed pattern in the data.

Sample sites included in the present analysis were referred to in the original reports as lotic or lentic based on habitat observations at the time of sampling. As discussed in Annex E of the EVWQP, some sites with lentic habitat characteristics exhibit selenium bioaccumulation similar to that observed at lotic sites, whereas others exhibit a distinct pattern of enhanced selenium bioaccumulation. The site characteristics underlying this distinction are not fully understood, but may be related to water residence time, depth, sediment type, and vegetation cover (de Bruyn et al. 2014).

At this time, objective criteria do not exist for distinguishing between these two types of lentic sites. Therefore, sites are plotted below as lentic or lotic based on how they were referred to in the original data source. Bioaccumulation conditions at each site are then inferred by comparing observed selenium concentrations in biota to predictions of the EVWQP model (reflecting lotic and semi-lentic conditions) and the lentic models developed to reflect conditions of enhanced selenium bioaccumulation (Orr et al. 2012). Fish egg data were compared to the EVWQP model and the lentic model for westslope cutthroat trout. Bird egg data were compared to the EVWQP model and a model combining the lentic model for invertebrates with the EVWQP invertebrate-bird egg model.

Separate analyses were conducted for data collected Koocanusa Reservoir (Section 8.0) and at locations in Line Creek potentially affected by operation of the West Line Creek AWTF (Section 9.0).

Model residuals were inspected to evaluate performance of the EVWQP and lentic models for describing patterns of bioaccumulation exhibited by newer data, relative to the data used to derive the models.

7.2 Results

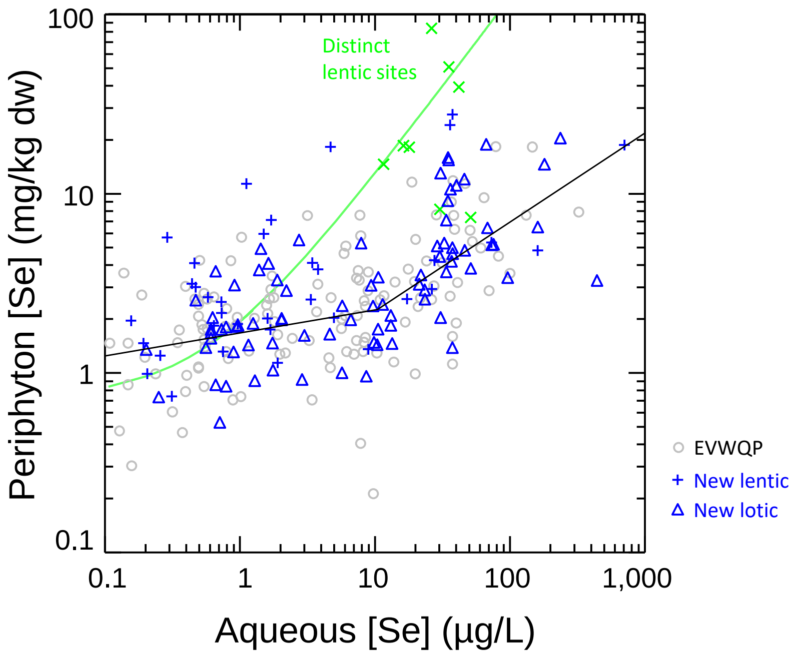
The following elements are shown on the plots provided below:

- EVWQP model (solid black line)
- lentic and lotic data that were combined to derive the EVWQP model (grey ○ symbols)
- data from distinct lentic sites identified during development of the EVWQP (green × symbols)
- lentic bioaccumulation model (solid green line)
- newer data from lentic sites (blue + symbols, denoted ‘new lentic data’)
- newer data from lotic sites (blue Δ symbols, denoted ‘new lotic data’)

7.2.1 Periphyton

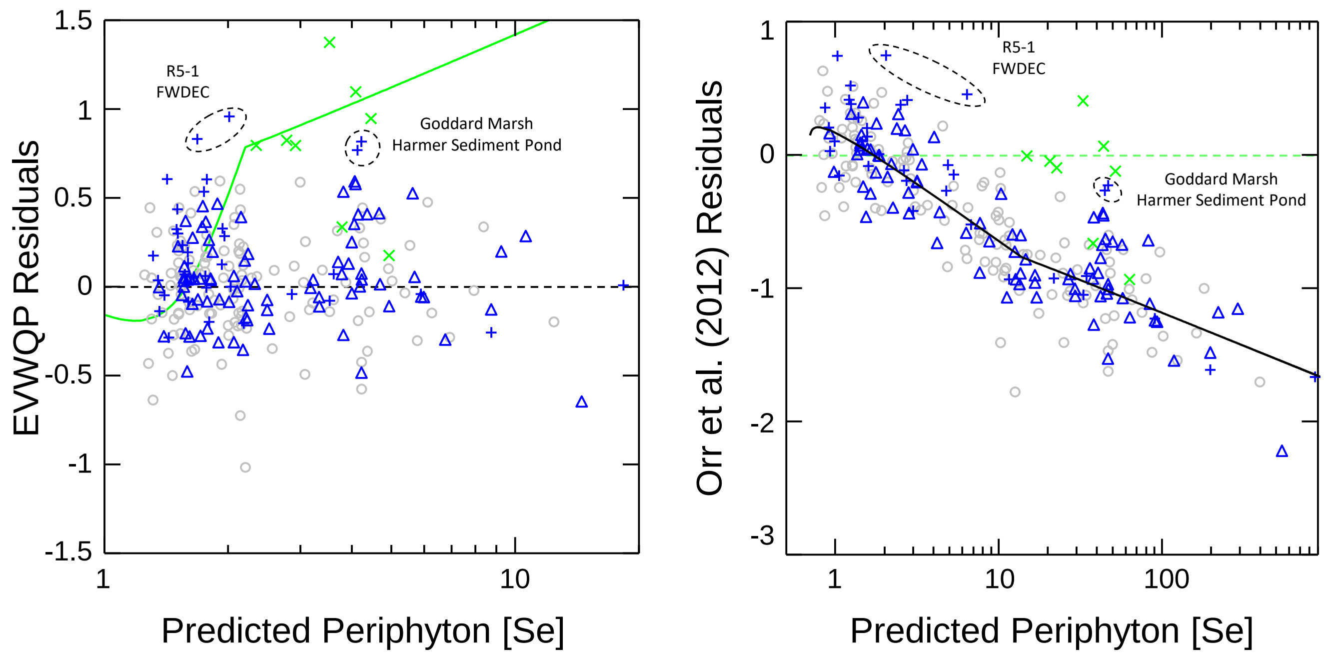
Periphyton data collected subsequent to the EVWQP at lentic (n = 35) and lotic (n = 85) sites are plotted in comparison to the EVWQP model and lentic model on Figure 10. Residuals relative to each model are plotted on Figure 11.

Figure 10: Comparison of selenium bioaccumulation in periphyton sampled in the Elk Valley to bioaccumulation model predictions made by the EVWQP model (black line) and the lentic model (green line)



Notes: Grey circles are periphyton data used to derive the EVWQP model. Green × symbols are data from lentic sites with a distinct pattern of enhanced selenium bioaccumulation that were not included in the EVWQP model.

Figure 11: Model residuals for periphyton sampled in the Elk Valley compared to bioaccumulation model predictions made by the EVWQP model (left panel) and the lentic model (right panel)



Notes: Symbols and lines as denoted in Figure 10. Annotated data are discussed in text.

New periphyton data from lotic sites were evenly distributed within the range of data underlying the model (Figure 10) and had residuals similar to those of the underlying data (Figure 11). Most new periphyton data from lentic sites were also within the range of data underlying the model, although sites with low aqueous selenium concentrations (between 0.1 and 4 µg/L) tended to exhibit relatively more positive than negative residuals relative to both the EVWQP and lentic models. At most sampled locations, these positive residuals were relatively small and within the range of residuals for data underlying the EVWQP model (i.e., between -0.5 and +0.5). However, a few lentic sites with low aqueous selenium concentrations exhibited relatively larger positive residuals (annotated on Figure 11).

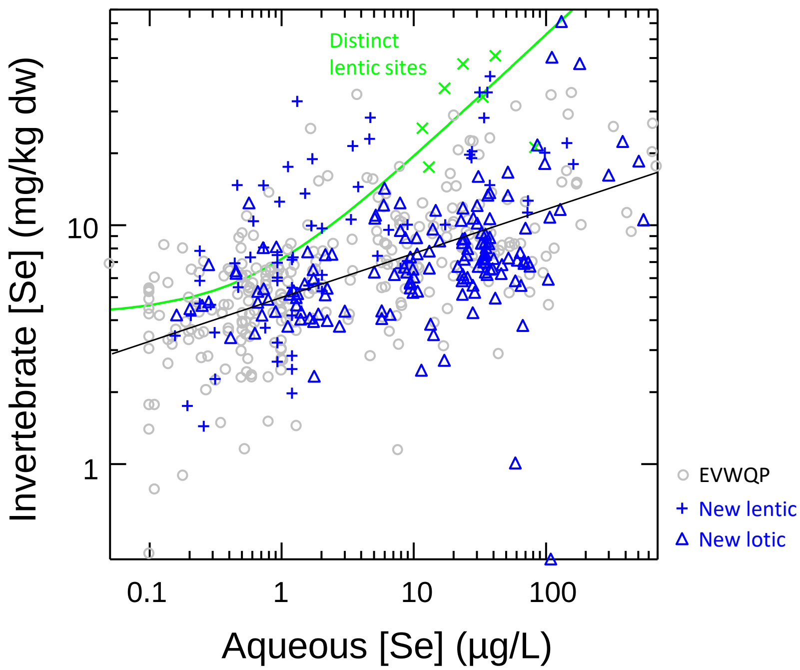
Observations for samples with relatively large positive residuals were as follows:

- R5-1 is an off-channel wetland adjacent to the Fording River downstream of Greenhills Creek that was sampled during the 2013 lentic study reported in Annex E of the EVWQP. FWDEC is a wetland adjacent to the Fording River downstream of Ewin Creek that was sampled in the 2015 RAEMP. Aqueous selenium concentrations at these sites were less than 2 µg/L, indicating little exposure to mine-influenced water. Periphyton selenium concentrations at these sites were consistent with the lentic model.
- Goddard Marsh and Harmer Sediment Pond have previously been identified as having a distinct pattern of selenium bioaccumulation at multiple trophic levels (Teck 2014b, 2015).

7.2.2 Invertebrates

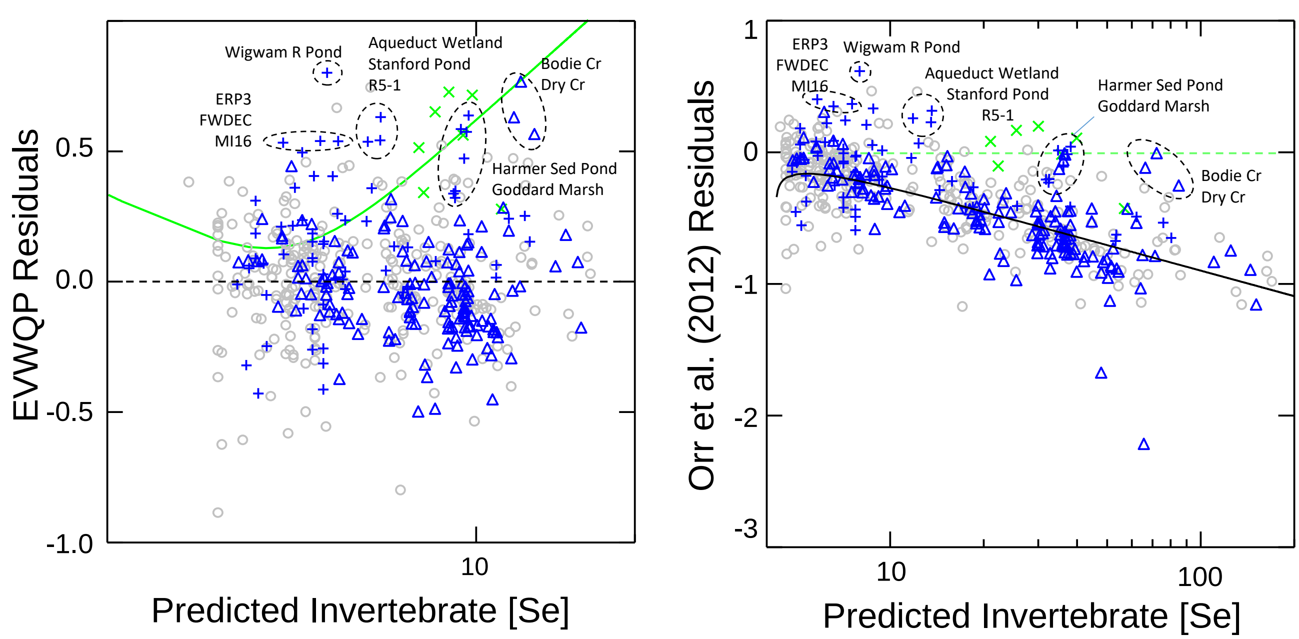
Invertebrate data collected subsequent to the EVWQP at lentic (n = 67) and lotic (n = 153) sites between July 2013 and April 2017 are plotted in comparison to the EVWQP model and lentic model on Figure 12. Residuals relative to each model are plotted on Figure 13.

Figure 12: Comparison of selenium bioaccumulation in invertebrates sampled in the Elk Valley to bioaccumulation model predictions made by the EVWQP model (black line) and the lentic model (green line)



Notes: Grey circles are invertebrate data used to derive the EVWQP model. Green × symbols are data from lentic sites with a distinct pattern of enhanced selenium bioaccumulation that were not included in the EVWQP model.

Figure 13: Model residuals for invertebrates sampled in the Elk Valley compared to bioaccumulation model predictions made by the EVWQP model (left panel) and the lentic model (right panel)



Notes: Symbols and lines as denoted in Figure 12. Annotated data are discussed in text.

With the exception of three samples collected downstream of sediment ponds on Bodie Creek and EVO Dry Creek, new invertebrate data from lotic sites were evenly distributed within the range of data underlying the model (Figure 12) and had residuals similar to those of the underlying data (Figure 13). Most new invertebrate data from lentic sites were also within the range of data underlying the model, with the exception of several sites that had previously been identified as having a distinct pattern of selenium bioaccumulation (Harmer Sediment Pond, Goddard Marsh, Aqueduct Wetland) and several new lentic sites with low aqueous selenium concentrations (between 0.4 and 4 µg/L) that exhibited positive residuals relative to both the EVWQP and lentic models (annotated on Figure 13). Observations for samples with relatively large positive residuals were as follows:

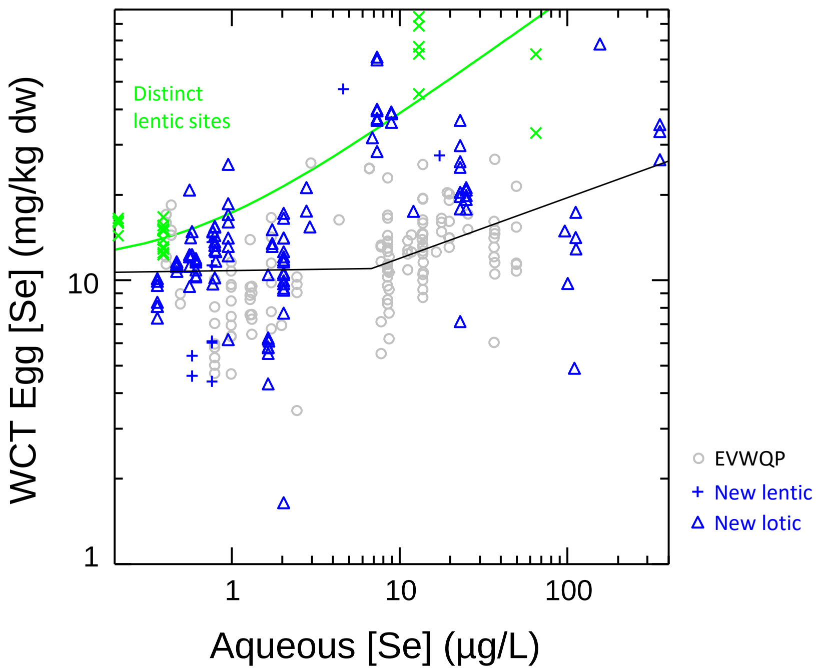
- The largest positive residual from both models was observed for a reference location sample collected in a beaver pond on the Wigwam River during the 2013 spotted sandpiper study (Minnow 2016b).
- As discussed in Section 7.2.1 for periphyton, relatively large positive residuals were observed for invertebrates collected in two off-channel wetlands adjacent to the Fording River with aqueous selenium concentrations less than 2 µg/L (R5-1 and FWDEC) and in Stanford Pond.
- Goddard Marsh, Harmer Sediment Pond, and Aqueduct Wetland have previously been identified as having a distinct pattern of selenium bioaccumulation at multiple trophic levels (2014b, 2015).
- Additional large positive residuals were observed for samples collected in a sediment pond on Erickson Creek (ERP3) and a reference wetland on Michel Creek (MI16) in 2015 (Minnow 2017a). Samples collected at MI16 in 2006 and 2012 were near the mean prediction of the EVWQP model, suggesting that conditions in this reference wetland may be heterogeneous, with some portions conforming to the EVWQP model and others conforming better to the lentic model.
- Three samples collected in lotic habitat downstream of sediment ponds on Bodie Creek and EVO Dry Creek exhibited relatively large positive residuals. It is unknown whether these samples reflect drift of invertebrates from lentic conditions in the sediment ponds, altered invertebrate communities due to exposure to mine-influenced water downstream of the sediment ponds, or some other factor related to proximity to the point of discharge. Locations close to sediment ponds also have a greater potential influence of mine water management practices (e.g., pit dewatering) that could expose these locations to mine-influenced water from a range of sources.

The model residuals depicted on the left panel of Figure 13 exhibited evidence of slight residual structure, characterized by a relatively large proportion of negative residuals associated with aqueous selenium concentrations between 20 µg/L and 100 µg/L. These residuals may indicate that a piecewise model form would better describe the pattern of bioaccumulation. However, attempts to fit a piecewise model resulted in a breakpoint lower than the lowest aqueous selenium concentration in the dataset (i.e., a log-linear model through the data range). Restricting the model fit to less than 100 µg/L (to remove the potential leverage of relatively high invertebrate selenium concentrations and the unknown factors discussed above that appear to result in elevated invertebrate tissue selenium concentrations near sediment ponds) resulted in the same breakpoint.

7.2.3 Westslope Cutthroat Trout

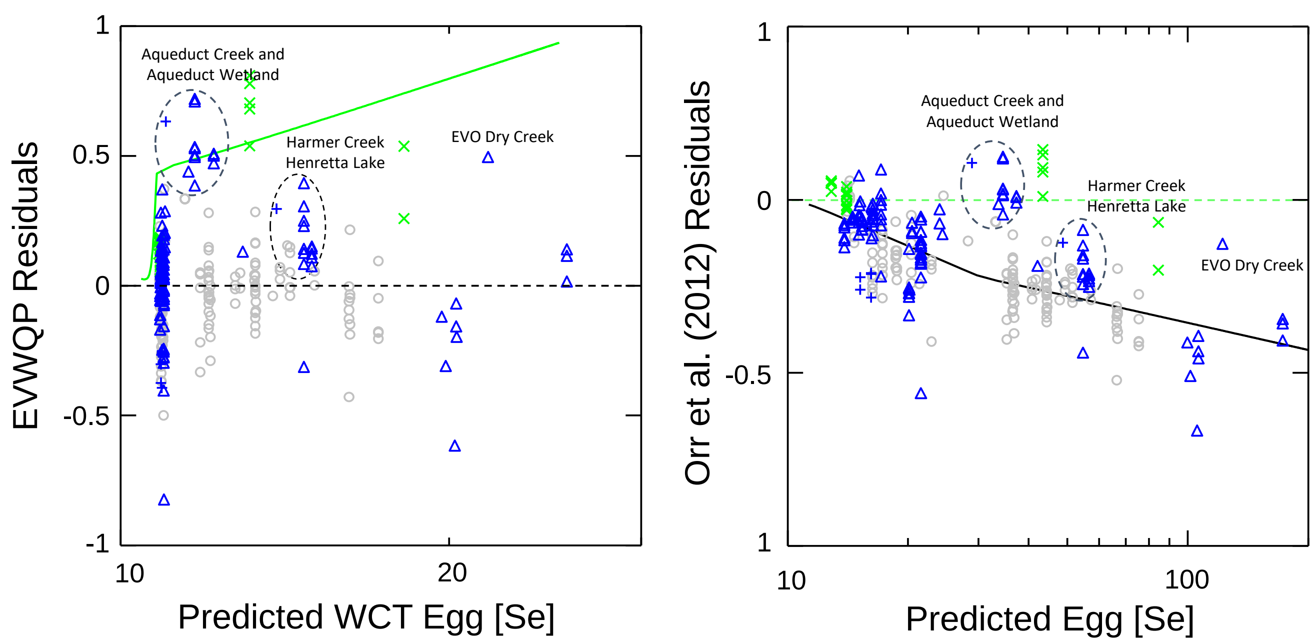
Westslope cutthroat trout egg data collected subsequent to the EVWQP at lentic (n = 10) and lotic (n = 113) sites in the Elk Valley are plotted in comparison to the EVWQP model and lentic model on Figure 14. Additional westslope cutthroat trout collected in Koocanusa Reservoir are presented in Section 8. Residuals relative to each model are plotted on Figure 15.

Figure 14: Comparison of selenium bioaccumulation in westslope cutthroat trout eggs sampled in the Elk Valley to bioaccumulation model predictions made by the EVWQP model (black line) and the lentic model (green line)



Notes: Grey circles are westslope cutthroat data used to derive the EVWQP model. Green × symbols are data from lentic sites with a distinct pattern of enhanced selenium bioaccumulation that were not included in the EVWQP model.

Figure 15: Model residuals for westslope cutthroat trout eggs sampled in the Elk Valley compared to bioaccumulation model predictions made by the EVWQP model (left panel) and the lentic model (right panel)



Notes: Symbols and lines as denoted in Figure 14. Annotated data are discussed in text.

The majority of new westslope cutthroat trout egg selenium data were collected at sites with aqueous selenium concentrations less than 5 µg/L. New data were generally consistent with the EVWQP model and its underlying data within this range. At higher aqueous selenium concentrations, the largest positive residuals were observed for samples collected from Aqueduct Wetland and the adjacent creek, and a single sample from EVO Dry Creek downstream of the sediment pond (Figure 14). Smaller positive residuals were observed for samples from Henretta Lake and Harmer Creek.

Observations for samples with relatively large positive residuals were as follows:

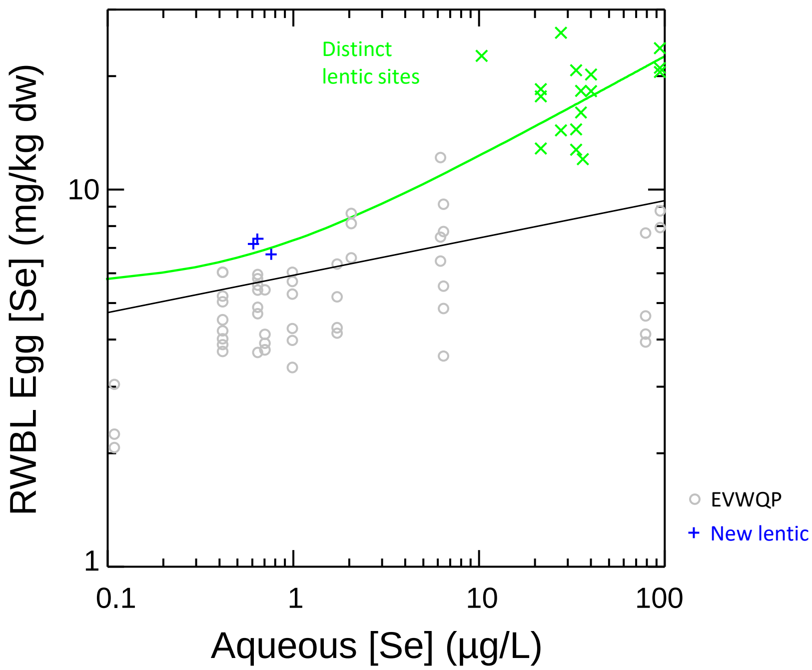
- The largest positive residuals from the EVWQP model were observed for samples from Aqueduct Wetland and the adjacent Aqueduct Creek. These samples conformed to the lentic model. As was discussed in Teck (2015), these data, combined with the invertebrate data on Figure 12, suggest that at least some portions of the Aqueduct watershed have distinct lentic conditions that result in elevated selenium bioaccumulation.
- A similarly large residual was observed for a westslope cutthroat trout sample collected in EVO Dry Creek downstream of the sediment pond. The invertebrate sample from this location also exhibited a relatively large positive residual (Figure 13). Potential explanations for these observations are discussed in Section 7.2.2.
- Smaller positive residuals were observed for samples collected in Harmer Creek. Most samples from this location were within the range of data underlying the EVWQP model, but four samples exhibited larger positive residuals and were intermediate between the EVWQP and lentic models. As was discussed in Teck (2015), these data may indicate some use by fish of lentic habitat in Harmer Sediment Pond.
- A single sample from Henretta Lake also exhibited an egg selenium concentration intermediate between the EVWQP and lentic models. Invertebrate samples collected in Henretta Lake in 2009, 2012, and 2015 exhibited selenium concentrations near the mean prediction of the EVWQP model. Further evaluation is recommended when additional data are available to evaluate selenium bioaccumulation in Henretta Lake.

The new westslope cutthroat trout egg data plotted on Figure 14 exhibited more variability than the dataset used to validate the model during development of the EVWQP (the grey circles on Figure 14). As discussed above, much of this variability may reflect distinct lentic conditions in the Aqueduct Creek watershed, the Harmer Creek watershed, and potentially in Henretta Lake.

7.2.4 Red Winged Blackbird

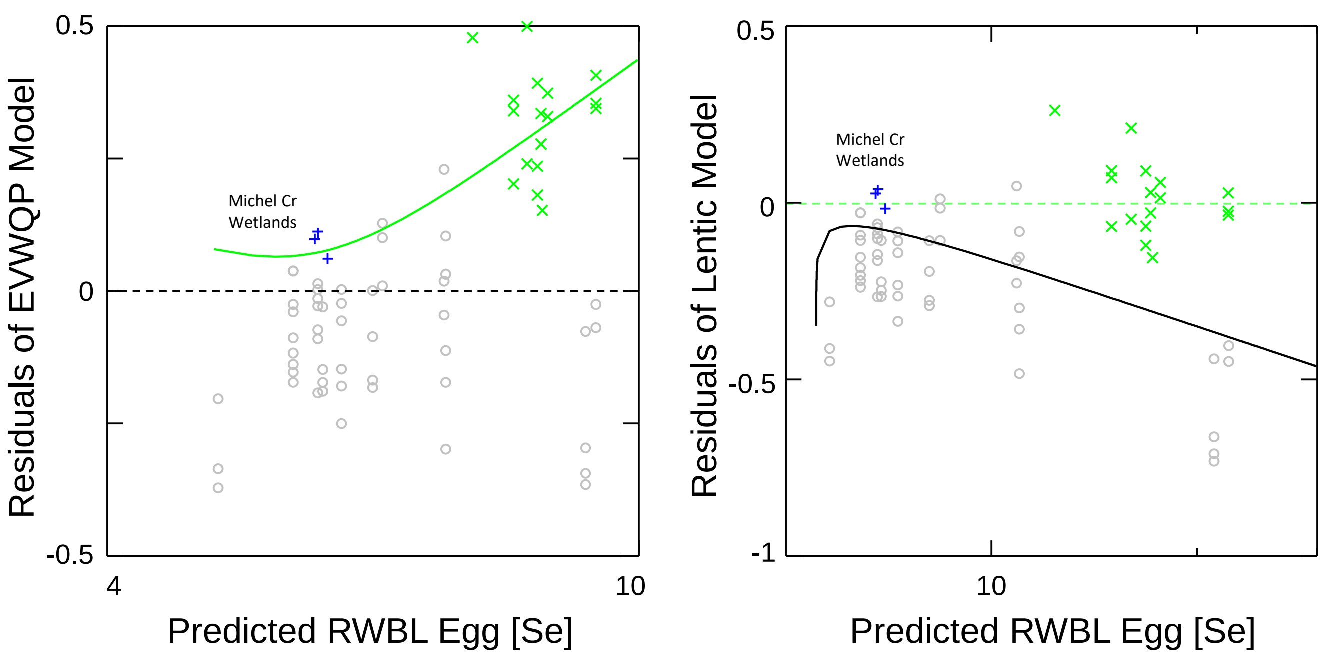
Red-winged blackbird egg data collected subsequent to the EVWQP at lentic sites (n = 3) in the Elk Valley are plotted in comparison to the EVWQP model and lentic model on Figure 16. Residuals relative to each model are plotted on Figure 17.

Figure 16: Comparison of selenium bioaccumulation in red-winged blackbird eggs sampled in the Elk Valley to bioaccumulation model predictions made by the EVWQP model (black line) and the lentic model (green line)



Notes: Grey circles are red-winged blackbird data used to derive the EVWQP model. Green × symbols are data from lentic sites with a distinct pattern of enhanced selenium bioaccumulation that were not included in the EVWQP model.

Figure 17: Model residuals for red-winged blackbird eggs sampled in the Elk Valley compared to bioaccumulation model predictions made by the EVWQP model (left panel) and the lentic model (right panel)



Notes: Symbols and lines as denoted in Figure 16. Annotated data are discussed in text.

The three new red-winged blackbird data were collected from off-channel reference wetlands on Michel Creek with aqueous selenium concentrations less than 1 µg/L. As discussed in Section 7.2.2 for invertebrate data, at least some portions of these wetlands exhibit selenium concentrations consistent with the lentic model.

7.3 Conclusions and Next Steps

Overall, the majority of newer periphyton, invertebrate, and fish egg selenium data conformed to the EVWQP model. As was acknowledged during development of the EVWQP, the model does not (and was not intended to) perform well for those lentic sites that have conditions resulting in a distinct pattern of selenium bioaccumulation, including several sites previously identified as distinct and several new sites discussed above that appear to also fall into this category. The derivation of long-term selenium targets for the EVWQP addressed this limitation by applying the lentic model to predict selenium bioaccumulation at these distinct sites.

At relatively high aqueous selenium concentrations, the lentic model performed well for the distinct lentic sites. At relatively low aqueous selenium concentrations (< 5 µg/L), however, both models under-predicted selenium bioaccumulation in periphyton and invertebrates at distinct lentic sites. An update to the lentic model may be warranted to better characterize selenium bioaccumulation across the entire modelled range. As data become available to characterize sites with distinct lentic conditions (i.e., following analyses such as those presented above), effort should be made to develop criteria to discriminate between sites that exhibit the typical pattern of bioaccumulation reflected in the EVWQP model and those that exhibit the distinct pattern associated with certain lentic conditions.

The lotic sites at which the EVWQP model did not perform well were downstream of sediment ponds on Bodie Creek and EVO Dry Creek (discussed in the subsections above). Conditions at these locations appear to be different from the majority of Elk Valley waters. Selenium assessment and management at these sites should rely on monitoring data rather than predictions of the model. However, calibration of the model to perform better for these sites would result in an overall decrease in model performance across the Elk Valley, and is not recommended.

8.0 TASK 4: EVALUATION OF APPLICATION OF THE MODEL TO KOOCANUSA RESERVOIR

8.1 Methods

The analysis presented below evaluates application of the model to Koocanusa Reservoir by comparing the mean model prediction and underlying data to invertebrate and fish tissue selenium data collected in the reservoir (Minnow 2017b). The potential need for a separate model to describe conditions in the reservoir was evaluated by considering whether data from the reservoir exhibited a different pattern of bioaccumulation relative to that characterized by the EVWQP model. As in previous sections, data were also compared to the lentic models developed by Orr et al. (2012). Model residuals were inspected to evaluate performance of the models.

8.2 Results

The following elements are shown on the plots provided below:

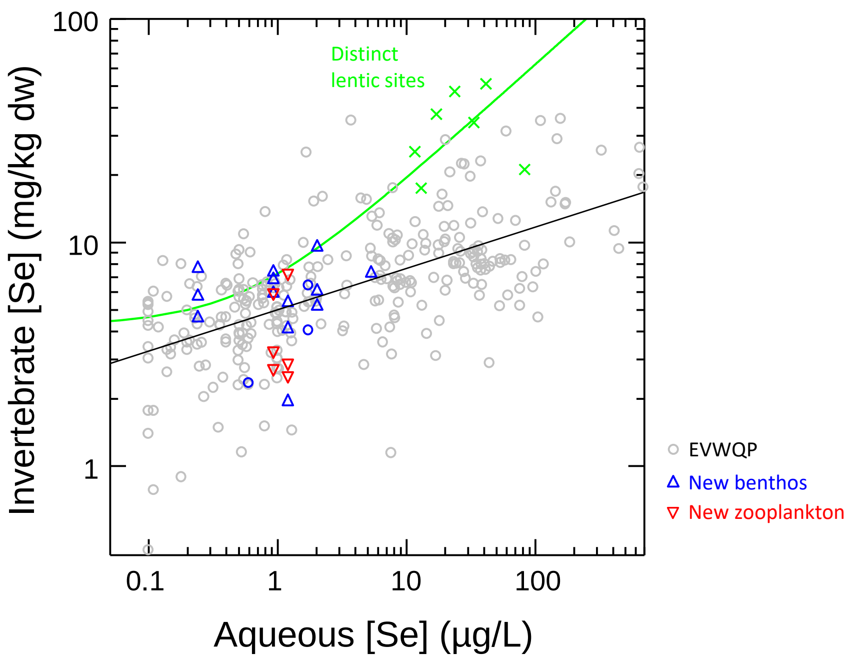
- EVWQP model (solid black line)
- lentic and lotic data that were combined to derive the EVWQP model (grey ○ symbols)
- data from distinct lentic sites identified during development of the EVWQP (green × symbols)

- lentic bioaccumulation model (solid green line)
- data from Koocanusa Reservoir for benthic invertebrates (red Δ symbols), zooplankton (purple ∇ symbols), and fish eggs (various symbols, see legend)

8.2.1 Invertebrates

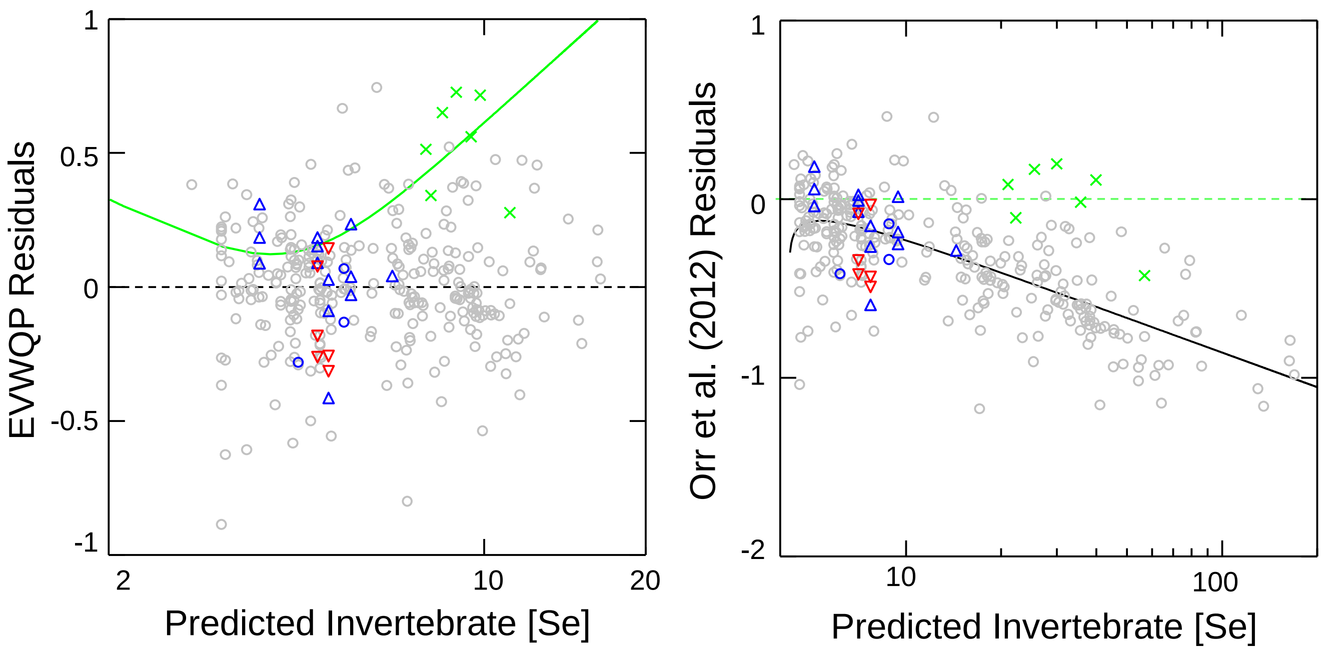
Selenium concentrations in benthic invertebrates (n = 13) and zooplankton (n = 6) collected from Koocanusa Reservoir between 2013 and 2016 are plotted in comparison to the EVWQP model and lentic model on Figure 18. Residuals relative to each model are plotted on Figure 19.

Figure 18: Comparison of selenium bioaccumulation in invertebrates sampled in Koocanusa Reservoir to bioaccumulation model predictions made by the EVWQP model (black line) and the lentic model (green line)



Notes: Grey circles are invertebrate data used to derive the EVWQP model. Green × symbols are data from lentic sites with a distinct pattern of enhanced selenium bioaccumulation that were not included in the EVWQP model.

Figure 19: Model residuals for invertebrates sampled in Koocanusa Reservoir compared to bioaccumulation model predictions made by the EVWQP model (left panel) and the lentic model (right panel)



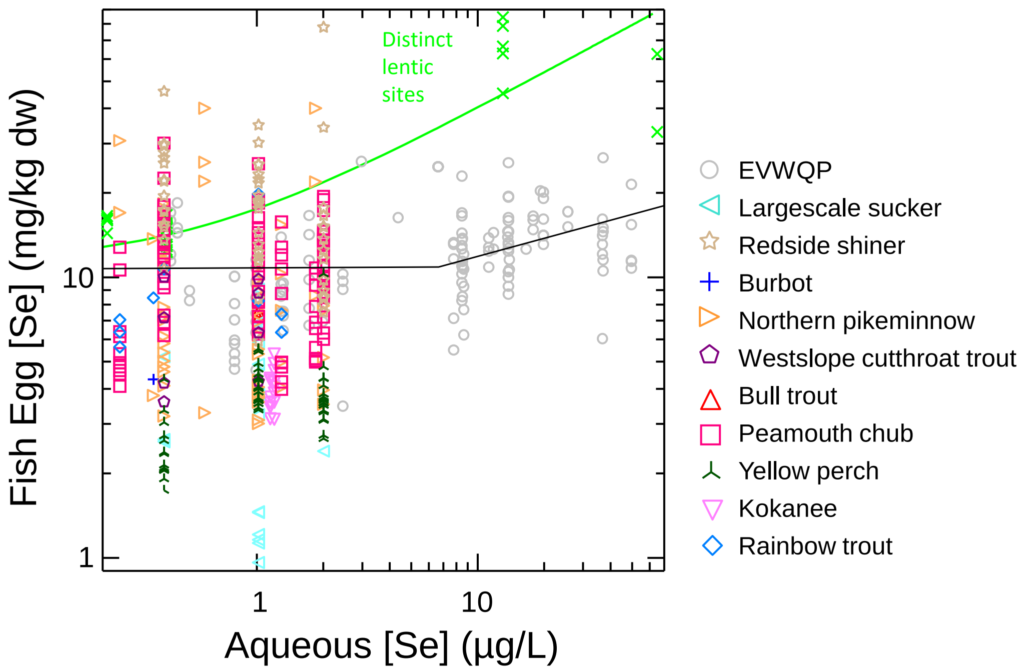
Notes: Symbols and lines as denoted in Figure 18.

Both benthic invertebrate and zooplankton data collected in Koocanusa Reservoir were consistent with the EVWQP model and its underlying data.

8.2.2 Fish

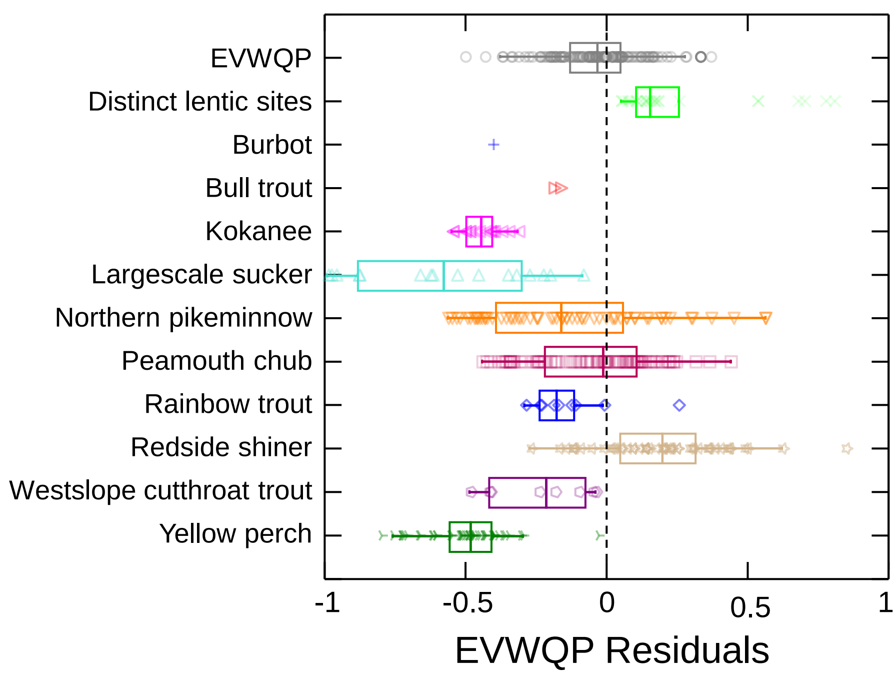
Selenium concentrations in eggs of fish collected in Koocanusa Reservoir (total *n* = 312) are plotted in comparison to the EVWQP model and lentic model on Figure 20. Data are shown for burbot (*Lota lota*), bull trout (*Salvelinus confluentus*), northern pikeminnow (*Ptychocheilus oregonensis*), peamouth chub (*Mylocheilus caurinus*), redside shiner (*Richardsonius balteatus*), yellow perch (*Perca flavescens*), kokanee (*Oncorhynchus nerka*), largscale sucker (*Catostomus macrocheilus*), and rainbow trout (*Oncorhynchus mykiss*). Westslope cutthroat trout muscle selenium data were used to estimate egg selenium concentrations by assuming an egg/muscle selenium concentration ratio of 2 (Orr et al. 2012). Residuals relative to the EVWQP model are plotted on Figure 21. Based on visual inspection of Figure 21, evaluation of residuals relative to the lentic model was not considered necessary.

Figure 20: Comparison of selenium bioaccumulation in fish eggs sampled in Koocanusa Reservoir to bioaccumulation model predictions made by the EVWQP model (black line) and the lentic model (green line)



Notes: Grey circles are westslope cutthroat trout egg data used to derive the EVWQP model. Green × symbols are data from lentic sites with a distinct pattern of enhanced selenium bioaccumulation that were not included in the EVWQP model.

Figure 21: Model residuals for fish eggs sampled in Koocanusa Reservoir compared to bioaccumulation model predictions made by the EVWQP model



Notes: Symbols as denoted in Figure 20.

Northern pikeminnow and peamouth chub exhibited residuals similar in magnitude to the westslope cutthroat trout data underlying the EVWQP model, although the median egg selenium concentration in northern pikeminnow was approximately 2 mg/kg dw lower than the mean model prediction. Burbot, bull trout, kokanee, largscale sucker, rainbow trout, and yellow perch exhibited consistently negative residuals and median concentrations less than the mean model prediction, indicating that the model over-predicts selenium bioaccumulation in these species in Koocanusa Reservoir. Westslope cutthroat trout egg selenium concentrations estimated from muscle data also exhibited consistently negative residuals, but were within the range of data underlying the model. Redside shiner was the only species that exhibited a median egg selenium concentration slightly (approximately 2 mg/kg dw) greater than the mean model prediction, reflecting a higher egg/muscle selenium concentration ratio for this species than for westslope cutthroat trout and other species sampled in Koocanusa Reservoir.

8.3 Conclusions and Next Steps

The analysis presented above indicates that Koocanusa Reservoir does not exhibit the pattern of elevated selenium bioaccumulation that occurs in some lentic environments. The EVWQP model provides reasonable predictions of selenium bioaccumulation in biota in Koocanusa Reservoir. Redside shiner tended to exhibit slightly higher egg selenium concentrations than predicted by the EVWQP model, reflecting a relatively high egg/muscle selenium concentration ratio. Application of the model to predict selenium bioaccumulation in redside shiner or other fish species could be refined by considering these differences in egg/muscle ratios. However, the data presented above do not indicate a need to develop a separate model for Koocanusa Reservoir or for specific fish species such as redside shiner.

9.0 TASK 5: EVALUATION OF APPLICATION OF THE MODEL TO LINE CREEK

Section 3.2.4 of Teck's *Water Quality Adaptive Management Plan for Teck Coal Operations in the Elk Valley* commits to undertaking a study of changes to selenium speciation resulting from the West Line Creek AWTF and associated changes in selenium bioaccumulation in biota downstream of the AWTF. The adaptive management plan further commits to evaluating the applicability of the EVWQP model in areas receiving AWTF discharge and, if warranted, refining the selenium bioaccumulation model to reflect these changes.

9.1 Methods

The analysis presented below evaluates application of the model to Line Creek downstream of the AWTF by comparing the mean model prediction and underlying data to periphyton and invertebrate selenium data collected in Line Creek. The potential need for refinement of the model to reflect conditions in Line Creek was evaluated by considering whether data from sites downstream of the AWTF exhibited a different pattern of bioaccumulation relative to that characterized by the EVWQP model. As in previous sections, data were also compared to the lentic models developed by Orr et al. (2012). Model residuals were inspected to evaluate performance of the models.

9.2 Results

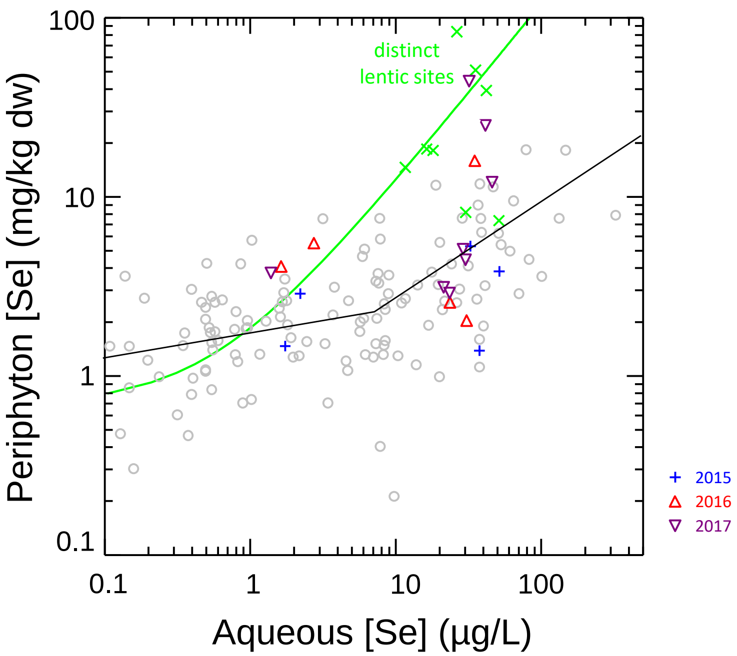
The following elements are shown on the plots provided below:

- EVWQP model (black line)
- lentic and lotic data that were combined to derive the EVWQP model (grey ○ symbols)
- data from distinct lentic sites identified during development of the EVWQP (green × symbols)
- lentic bioaccumulation model (green line)
- data collected in Line Creek (various symbols, see legend)

9.2.1 Periphyton

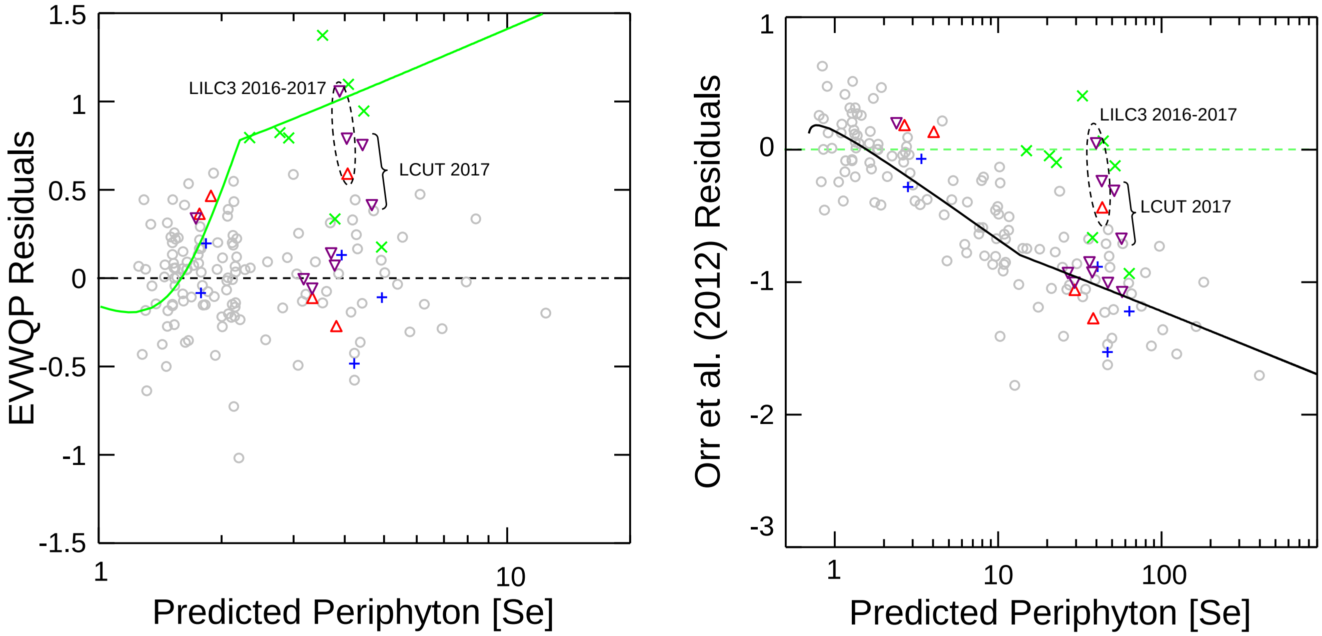
Selenium concentrations in periphyton collected in Line Creek (n = 21) between 2015 and 2017 (Minnow 2017a) are plotted in comparison to the EVWQP model and lentic model on Figure 22. Residuals relative to each model are plotted on Figure 23.

Figure 22: Comparison of selenium bioaccumulation in periphyton sampled in Line Creek to bioaccumulation model predictions made by the EVWQP model (black line) and the lentic model (green line)



Notes: Grey circles are periphyton data used to derive the EVWQP model. Green × symbols are data from lentic sites with a distinct pattern of enhanced selenium bioaccumulation that were not included in the EVWQP model.

Figure 23: Model residuals for periphyton sampled in Line Creek compared to bioaccumulation model predictions made by the EVWQP model (left panel) and the lentic model (right panel)



Notes: Symbols and lines as denoted in Figure 22.

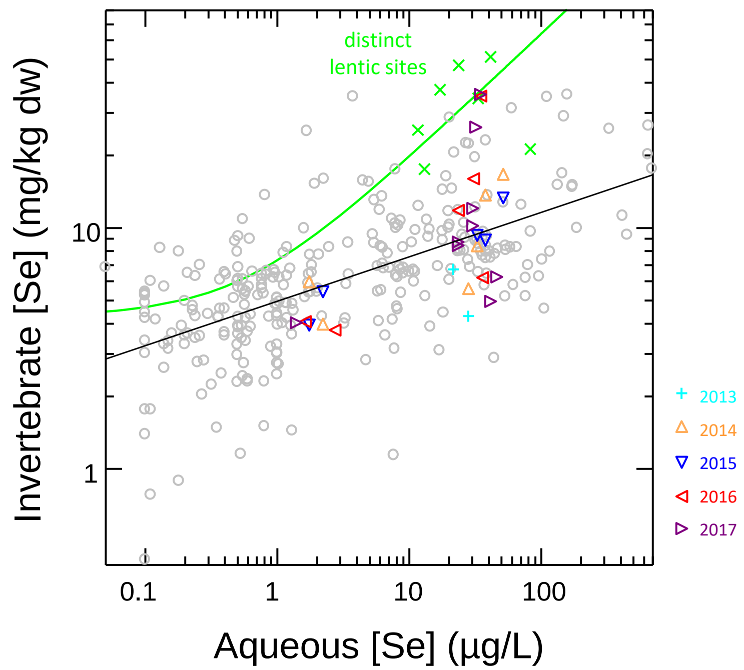
Most periphyton sampled in Line Creek exhibited selenium concentrations within the range of data underlying the EVWQP model (Figure 22) and residuals similar to those of the underlying data (Figure 23). Data collected in 2015 prior to commissioning of the AWTF and data collected during AWTF operation both upstream and downstream of the discharge point conformed to the model, with the following exceptions:

- Relatively large positive residuals were observed for periphyton at LILC3 in 2016 and 2017. LILC3 is the closest site downstream of the AWTF discharge, and therefore would be expected to show the strongest response to AWTF-related changes in selenium speciation. In 2017, LILC3 data conformed to the lentic model, indicating that selenium uptake at this site was comparable to that observed in some lentic areas.
- Relatively large positive residuals were also observed in 2017 in Line Creek immediately above the AWTF discharge (station LCUT). The cause of this deviation from the EVWQP prediction is not known, but is not related to AWTF operation. A similar deviation was not observed for invertebrates (Figures 24 and 25), suggesting that this sample may reflect normal variability inherent in periphyton selenium concentrations or some confounding factor such as entrainment of calcite particles (noted in Minnow 2017a) that affected the selenium analysis.

9.2.2 Invertebrates

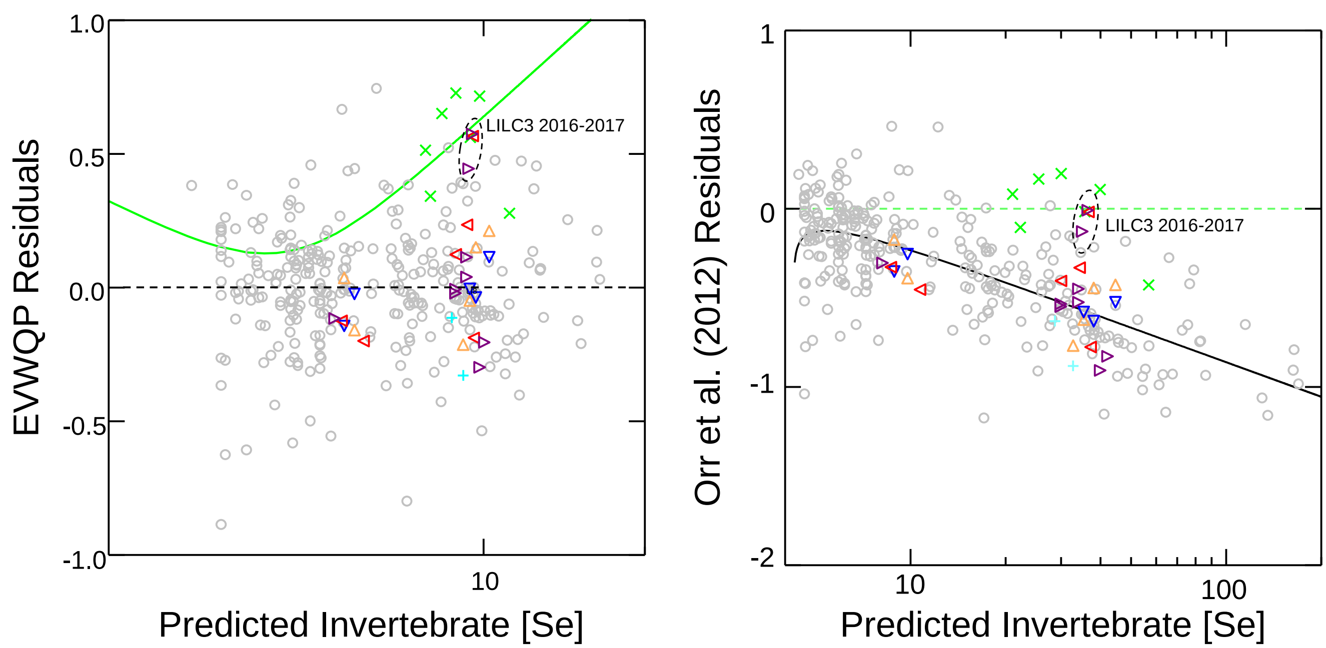
Selenium concentrations in invertebrates collected in Line Creek (*n* = 36) are plotted in comparison to the EVWQP model and lentic model on Figure 24. Residuals relative to each model are plotted on Figure 25.

Figure 24: Comparison of selenium bioaccumulation in invertebrates sampled in Line Creek to bioaccumulation model predictions made by the EVWQP model (black line) and the lentic model (green line)



Notes: Grey circles are invertebrate data used to derive the EVWQP model. Green × symbols are data from lentic sites with a distinct pattern of enhanced selenium bioaccumulation that were not included in the EVWQP model.

Figure 25: Model residuals for invertebrates sampled in Line Creek compared to bioaccumulation model predictions made by the EVWQP model (left panel) and the lentic model (right panel)



Notes: Symbols and lines as denoted in Figure 24.

Most of the data for invertebrates sampled in Line Creek fell within the range of data underlying the EVWQP model (Figure 24) and had residuals similar to those of the underlying data (Figure 25). Data collected in 2015 prior to commissioning of the AWTF and data collected during AWTF operation both upstream and downstream of the discharge point conformed to the model, with the following exceptions:

- Relatively large positive residuals were observed for invertebrates at LILC3 in 2016 and 2017. LILC3 is the closest site downstream of AWTF discharge, and therefore would be expected to show the strongest response to AWTF-related changes in selenium speciation. In 2017, LILC3 data conformed to the lentic model, indicating that selenium uptake at this site was comparable to that observed in some lentic areas.

9.3 Conclusions and Next Steps

The analysis presented above indicates that the EVWQP model provides reasonable predictions of selenium bioaccumulation in biota in Line Creek, except under conditions related to the influence of AWTF operation at LILC3. Selenium assessment and management at LILC3 should rely on monitoring data rather than predictions of the model. Calibration of the model to perform better at LILC3 would result in an overall decrease in model performance across the Elk Valley, and is not recommended. Development of a separate model to predict selenium bioaccumulation as a function of selenium speciation is not recommended because the effect of AWTF operation appears to be spatially restricted (i.e., only apparent at LILC3). In addition, Teck is undertaking work to reverse the speciation shift in AWTF effluent, which will result in selenium speciation at LILC3 dominated by selenate, resembling conditions elsewhere in the Elk Valley.

10.0 SUMMARY OF RECOMMENDATIONS

The model validation and updates to the EVWQP dataset presented in Section 7.0 support the following recommendations for ongoing refinement and updates to the Elk Valley selenium bioaccumulation models:

1) Bioaccumulation modelling for distinct lentic conditions should be updated with newer data. Lentic sites should be evaluated for inclusion in the lentic model according to objective criteria (see next bullet). An update to the lentic model should then be conducted following methods described in Annex E of the EVWQP.

2) Objective criteria should be developed to discriminate between sites that exhibit the typical pattern of bioaccumulation reflected in the EVWQP model and those that exhibit the distinct pattern associated with certain lentic conditions. These criteria could be developed from an empirical analysis of site characteristics that are predictive of the occurrence of large positive residuals from the EVWQP model, as was done by de Bruyn et al. (2014).

3) The existing EVWQP model should continue to be used to predict selenium bioaccumulation at lotic sites and “semi-lentic” sites that do not meet the criteria for inclusion in the lentic model. If any data currently included in the EVWQP model are removed to be included in the lentic model, an evaluation should be performed of whether recalculation of the EVWQP model equations and residual variance (RMSD) is warranted.

The tasks recommended above will also inform the design and interpretation of sampling conducted under the RAEMP. The criteria for classifying lentic habitats (recommendation #2) will inform the selection of monitoring sites to confirm that data collection reflects the range of lentic habitat types present in the Elk Valley. In combination with existing habitat mapping information, these criteria will allow data collected at lentic sites to be interpreted in the context of where, how abundant, and how ecologically important habitats of that type are in each management unit. Linking monitoring results more explicitly to the broader range of habitats that occur in the Elk Valley will help identify locations that may be particularly sensitive to selenium bioaccumulation, and will support developing a watershed-wide evaluation of selenium. An updated watershed-wide evaluation of selenium would also support an updated confirmation of the protectiveness of current water quality targets for selenium in the Elk Valley. In addition, refining the modelling approach for lentic and lotic sites (recommendations #1 and #3) will provide refined model prediction intervals, which would be expected to improve the ability of monitoring to detect changes in selenium concentrations in biota.

The special studies and evaluations presented in the remaining sections of this memorandum support the following additional recommendations:

4) Amphibian egg data collected as part of RAEMP or supporting studies should be used to evaluate the performance of the amphibian bioaccumulation models presented in Section 2.0.

5) Consider the potential value of including winter sampling of invertebrates in the next cycle of the RAEMP to supplement the analysis of seasonality presented in Section 3.0.

These recommendations and associated work will continue to be discussed with the EMC and input provided will be incorporated as appropriate to continue advancement of selenium bioaccumulation understanding within the Elk Valley.

As discussed in Section 5.0, no further work is recommended at this time to evaluate the effect of size on fish tissue selenium concentrations. It is also not recommended at this time to develop separate bioaccumulation models for different fish and bird species in the Elk Valley (Section 6.0), for Koocanusa Reservoir (Section 8.0), or for Line Creek downstream of the AWTF (Section 9.0).

11.0 CLOSURE

We trust the information provided in this memorandum meets your present requirements. If you have any questions or require additional information, please do not hesitate to contact the undersigned.

GOLDER ASSOCIATES LTD.

Original Signed

Liz Ashby, MSc
Environmental Scientist

Original Signed

Adrian de Bruyn, PhD, RPBio
Associate, Senior Environmental Scientist

EJA/AMD/al

https://golderassociates.sharepoint.com/sites/13124g/p3210_bmod_update/07 deliverables/b-model memo/1523293_3210_revd_tm-draft_b-model_update_18jan2018.docx

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