Elk Valley Water Quality Plan

Annex O

Management of Uncertainty in the Selenium Ecological Affects Assessment for the Elk Valley Water Quality Plan

Teck

TECHNICAL MEMORANDUM

DATE July 8, 2014 **REFERENCE No.** 1313490006/M27

TO Chris Stroich
Teck Coal Limited

CC Carl Schwarz (Simon Fraser University), Andrew Forbes

FROM Adrian deBruyn, J.P. Bechtold **EMAIL** adebruyn@golder.com

MANAGEMENT OF UNCERTAINTY IN THE SELENIUM ECOLOGICAL EFFECTS ASSESSMENT FOR THE ELK VALLEY WATER QUALITY PLAN

The purpose of this memorandum is to summarize how uncertainty was managed in the selenium ecological effects assessment for the Elk Valley Water Quality Plan (the Plan). The following discussion of uncertainties and actions undertaken to evaluate and manage those uncertainties derives from the working document "*Summary of Uncertainties and Assumptions in the Selenium Ecological Effects Assessment for the Elk Valley Water Quality Plan*" provided by the Toxicology Working Group (ToxWG) on June 18, 2014, and updated June 27, 2014, (Attachment A). Per that working document, the discussion below focuses on uncertainty associated with bioaccumulation modelling, toxicity data and the calculation of integrated reproductive effects. This memorandum was prepared per Action Item No. 1 at ToxWG Meeting No. 6 (held in Victoria, BC on June 9, 2014), and was developed in collaboration with Dr. Carl Schwarz, Statistician, of Simon Fraser University.

Approach to Uncertainty Management

Uncertainty in the selenium ecological effects assessment was managed in several ways:

- **Relevant and Reliable Information**. Where possible, site- and species-specific data and models were preferred over extrapolating information from other sites and species. Furthermore, both site and literature data were evaluated prior to inclusion in the analysis to avoid uncertainty related to unreliable information.
- **Conservative Choices**. Where alternative data or models were supported by the available information, the more conservative alternative was adopted.
- **Use of Upper Confidence and Prediction Limits**. Where residual uncertainty existed that was not addressed by the use of reliable site-specific information and conservative choices, upper confidence or prediction limits were used in the analysis.
- **Sensitivity Analysis**. In addition to the strategies described above to reduce or account for uncertainty, sensitivity analyses were undertaken to assess the magnitude and potential implications of uncertainty.

The following subsection summarizes elements of uncertainty in the selenium ecological effects assessment and discusses how the strategies described above were applied to manage that uncertainty.

Uncertainty Management in the Ecological Effects Assessment for Selenium

Table 1 provides a collated summary of the information in Attachment A related to identified uncertainties in the selenium ecological effects assessment. Entries in Table 1 are cross-referenced to Attachment A by row number; further detail on the identified uncertainties can be found in the referenced rows in Attachment A. Rows 35 and 36 of Attachment A do not identify uncertainties and are not addressed in Table 1. Following each indicated uncertainty in Table 1, a description is provided of steps that have been taken to manage that uncertainty, and of the degree of residual uncertainty remaining in consideration of the steps that were taken.

Table 1: Summary of Uncertainty Management in the Selenium Ecological Effects Assessment

Source of Uncertainty	Steps Taken to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
Bioaccumulation – Modelling Inputs		
Variable reliability of data (Rows 3, 17, 19, 27, 28, and 33)	All input data were evaluated by reviewing source reports, visual inspection of plots, and statistical identification of outliers. Outliers and potentially anomalous values were discussed at ToxWG Meeting No. 3 and further examined with sensitivity analyses. Modelling was conducted with relevant and reliable data only (Category 'A', per the *Selenium Benchmark Derivation Report*, Appendix C: Bioaccumulation Modelling).	The majority of input data were collected recently, using consistent and accepted methods. Unreliable data were identified and excluded.
Temporal matching of data pairs (Row 4)	Where possible, synoptic data were paired for model derivation. Non-synoptic data pairs were ranked according to how closely they approximated a synoptic pair. A sensitivity analysis was conducted for each model to evaluate the effect of including non-synoptic data pairs (for further detail please refer to Section 4.2.3.1 of *Selenium Benchmark Derivation Report*, Appendix C: Bioaccumulation Modelling).	The majority of data pairs were synoptic. Inclusion of non-synoptic pairs had little or no influence on models.
Bioaccumulation – Derivation of Models		
Synoptic aqueous selenium data may not accurately represent the integrated exposure of organisms to selenium; could underestimate model slopes due to attenuation (Row 7)	A sensitivity analysis was conducted for each model to evaluate potential attenuation by comparing slopes estimated by ordinary least squares and major axis regression (for further detail please refer to Section 4.2.3.2 of Selenium Benchmark Derivation Report, Appendix C: Bioaccumulation Modelling). Regression slopes were similar between methods and not statistically different. Uncertainty in model slopes was further addressed by deriving three model structures, including a one-step model with limited potential for slope attenuation (for further detail please refer to Section 4.2.3.3 of Selenium Benchmark Derivation Report, Appendix C: Bioaccumulation Modelling). As discussed at ToxWG Meeting No. 3, the most restrictive of these three models was adopted to calculate benchmarks. An additional level of conservatism is achieved by implementing long-term targets for selenium as maximum monthly average concentrations. This measure accounts for uncertainty in the temporal matching of tissue and aqueous selenium concentrations by constraining all other months to be lower than the target, and thus reducing the chance that bioaccumulation will be understated.	Little evidence for attenuation was observed. Adoption of the most restrictive model further addressed uncertainty in model slopes. Application of targets as maximum monthly average concentrations imparts a further level of conservatism.
Potential effect of fish size on bioaccumulation (Row 16)	An evaluation was conducted of the strength of evidence for an effect of fish size on bioaccumulation. Results indicated 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 ToxWG Meeting No. 3 that a size effect was not supported and would not be modelled.	A possible size effect cannot be ruled out, but implications for the selenium ecological effects assessment are minimal. Follow-up analysis may be warranted as a more balanced dataset becomes available.
Uncertainty in the breakpoint of the invertebrate-WCT model (Row 18)	A bootstrap analysis to evaluate uncertainty in the location of the breakpoint identified two high-leverage points. As discussed at ToxWG Meeting No. 3, bioaccumulation models were derived with and without these points. The more restrictive alternative (i.e., the model that produced higher WCT egg selenium concentrations) was carried forward into subsequent analyses.	Uncertainty has been addressed by adopting the more conservative alternative.

Table 1: Summary of Uncertainty Management in the Selenium Ecological Effects Assessment (continued)

Source of Uncertainty	Steps Taken to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
Timing of collection of invertebrate samples relative to selenium uptake by WCT (Row 20)	An analysis was conducted to evaluate potential seasonality in invertebrate selenium concentrations. Compiled invertebrate selenium data from mine-influenced locations exhibited little evidence of seasonal variability, with similar median selenium concentrations in May, June, August and September (all within approximately 1 mg/kg dry weight). Fewer data were available for July and October, but these were generally consistent with a conclusion that invertebrate selenium concentrations vary little across seasons. No data were available for November to April.	Available data indicate that invertebrates sampled in fall provide a reasonable estimate of dietary selenium concentrations for WCT. Follow-up studies may be warranted to better characterize the relevant exposure period for WCT.
Uncertainty in the amphibian model (Row 30)	It was decided at ToxWG Meeting No. 3 that uncertainty in invertebrate-amphibian egg data pairs was elevated due to the pre-spawning migratory behaviour of resident amphibian species. Preliminary models indicated that amphibians do not bioaccumulate selenium to a greater extent than fish, and available toxicity data indicate that amphibians are not more sensitive than fish. Therefore, an amphibian bioaccumulation model was not developed.	Available data indicate that benchmarks protective of fish will also be protective of amphibians. Follow-up studies may be warranted to increase confidence in amphibian models.
Selection of log-linear or piecewise form for the periphyton model (Row 32)	A log-linear form was evaluated for all models; alternative forms were considered only if warranted by residual structure or other uncertainty related to the log-linear form. Evaluation of diagnostic plots for the periphyton model indicated that a piecewise form improved fit and model residuals relative to a log-linear form. Adoption of the piecewise form was recommended by the ToxWG at Meeting No. 3. Comparison of the two forms indicated that the piecewise model produced similar (within 1 mg/kg dry weight) periphyton selenium concentrations below 20 µg/L and higher periphyton selenium concentrations above 20 µg/L. Therefore, the piecewise model was retained as the more conservative alternative. (Note that a portion of the discussion in row 32 is incorrect; the breakpoint model for periphyton is not an artifact of combining lentic and lotic data.)	Uncertainty has been addressed by adopting the more conservative alternative.
Bioaccumulation – Application of Models		
Alternative models give different results (Rows 2, 14, and 24)	Three different models (1-step, 2-step, and 3-step) were derived to evaluate uncertainty in model structure. All were carried through subsequent analyses and the most restrictive of the three in each analysis was adopted to calculate benchmarks.	Uncertainty has been addressed by adopting the most conservative alternative.
Error propagation through multi-step models (Row 5)	Uncertainty in how variability propagates through the multi-step models was discussed at ToxWG Meetings No. 1 and No. 3 and it was agreed that consideration of the 1-step model accounted for this uncertainty. Propagated variability was further addressed by calculating the root mean square deviation (RMSD) for each model (for further detail please refer to *Selenium Benchmark Derivation Report*, Appendix C: Bioaccumulation Modelling). RMSD was calculated from differences between measured and modelled values, and therefore, is an appropriate way to express overall propagated variability in each model. Uncertainty in the modelled mean was accounted for by adopting the most restrictive (i.e., highest) result from the three alternative models.	Uncertainty in propagated variability has been addressed by considering a 1-step model and by calculating RMSD for each model. Uncertainty in modelled means has been addressed by adopting the most conservative alternative.
Variability in K_d (Row 34)	Variability in periphyton selenium concentrations was considered in fitting the periphyton model. Sensitivity analyses recommended by the ToxWG indicated no effect of seasonality or sampling location, suggesting that observed scatter around the periphyton model (referred to in Row 34 as variability in K_d) represents real variability in selenium uptake. Uncertainty in model fit related to this variability was accounted for by deriving alternative models (1-step and 2-step) that did not rely on periphyton data. All were carried through subsequent analyses and the most restrictive of the three was adopted to calculate benchmarks.	Variability in K_d exists, but implications for the selenium ecological effects assessment are minimal. Uncertainty has been addressed by adopting the most conservative alternative.
Statistical models should not be generalized to other systems (Row 1)	All bioaccumulation models used in the selenium ecological effects assessment were derived from site-specific or site-relevant data. No spatial extrapolation was required.	No spatial extrapolation.

Table 1: Summary of Uncertainty Management in the Selenium Ecological Effects Assessment (continued)

Source of Uncertainty	Steps Taken to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
Not all areas in the Elk Valley are included in models (Row 8)	Differences in selenium bioaccumulation among areas were explicitly considered in the derivation of models. Certain areas (e.g., the Fording Oxbow) are hypothesized to exhibit distinct underlying mechanisms of bioaccumulation, and therefore, were included in a separate bioaccumulation model. The 'lentic' model presented in Orr et al. (2012) and Minnow (2014) was used in the selenium ecological effects assessment to model bioaccumulation in these areas.	Uncertainty has been addressed by adopting the more conservative alternative.
WCT and red-winged blackbird models were used for all species (Rows 9, 15, and 25)	All fish and bird species with sufficient site-specific tissue selenium data were considered for model derivation. Analysis of covariance indicated significant differences in the slope of the bioaccumulation relationship between species for both fish (WCT 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. Models were derived for the species that tended to exhibit higher tissue selenium concentrations. 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 will have similar or lower exposure to selenium compared to the modelled species.	Uncertainty has been addressed by adopting the more conservative alternative. Follow-up studies are warranted to confirm that other species are adequately represented by the models.
Limited dataset for the 1-step red-winged blackbird model (Row 26)	Uncertainty related to the limited range of data available to derive the 1-step bird model was discussed at TAC Meeting No. 5. Uncertainty was addressed by relying preferentially on the 2-step and 3-step models at aqueous selenium concentrations beyond the 1-step model's data range.	The 1-step model was not extrapolated beyond its data range.
Toxicity Data		
Representativeness of dose-response curves for all sensitive species (Rows 10 and 21)	Toxicity data were compiled for all fish and bird species with information relevant and reliable to the Elk Valley. From this compilation, the most sensitive species, life stages, and effects endpoints were adopted for the selenium ecological effects assessment (for further detail please refer to *Selenium Benchmark Derivation Report*, Appendix D: Toxicity Literature Review). Brown trout (which do not occur in the Elk Valley) are the most sensitive of 14 fish species for which relevant and reliable reproductive toxicity data were available. Mallard are the most sensitive of 37 bird species for which relevant and reliable reproductive toxicity data were available.	Uncertainty has been addressed by adopting the most conservative alternative.
Uncertainty in dose-response curves (Rows 11 and 29)	Best-fit dose-response curves were adopted for the selenium ecological effects assessment, representing the interpretation best supported by the data and recommended by the authors of the toxicity studies and in subsequent re-analyses by other authors. Uncertainty in the fitted dose-response curves was evaluated with a bootstrap analysis, which was used to calculate an upper prediction limit for integrated reproductive effects. This upper prediction limit was taken into consideration in the selection of benchmarks.	Uncertainty has been addressed by using the best scientific estimates of the most sensitive dose-response curves for fish and birds . Residual uncertainty in the parameters of those curves has been characterized as an upper prediction limit for potential integrated reproductive effects.
Reliability of laboratory and field toxicity studies (Row 12)	Toxicity data were compiled from both laboratory and field studies relevant and reliable to the Elk Valley, and the most sensitive species, life stage and effects endpoint was adopted for the selenium ecological effects assessment. For fish, the most sensitive dose-response curve derived from a study of field-collected brown trout exposed to selenium in Idaho streams. For birds, the most sensitive dose-response curve derived from several studies of mallard exposed to experimentally-dosed dietary selenium in a laboratory. In both cases, studies with other species in both laboratory and field indicated lesser sensitivity.	Uncertainty has been addressed by using the most sensitive dose-response curves for fish and birds, irrespective of whether the curve was derived from a laboratory or field study.

Table 1: Summary of Uncertainty Management in the Selenium Ecological Effects Assessment (continued)

Source of Uncertainty	Steps Taken to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
Limited toxicity data for amphibians (Row 31)	It was decided at ToxWG Meeting No. 3 that amphibian toxicity data were insufficient to support tissue effects benchmarks. Available toxicity data indicate that amphibians are not more sensitive than fish and monitoring data indicate that amphibians do not bioaccumulate selenium to a greater extent than fish.	Available data indicate that benchmarks protective of fish will also be protective of amphibians. Follow-up studies are warranted, potentially including amphibian toxicity testing.
Integrated Effects Calculation		
Appropriate standard deviation to calculate integrated effect (Row 6)	Variability in modelled egg selenium concentrations was characterized using the root mean square deviation (RMSD) for each model . RMSD was calculated from differences between measured and modelled values, and therefore, is an appropriate way to express overall variability for each model. RMSD was calculated using relevant and reliable (category 'A') data only, reducing potential uncertainty related to anomalous values. Following discussion at ToxWG Meeting No. 4, Connor Lake data were excluded from the RMSD calculation to correct an artificial inflation of the RMSD related to model over-estimation of low WCT egg selenium concentrations in a headwater lake outside the Designated Area (aqueous selenium in Connor Lake is <0.1 µg/L). It was agreed with the ToxWG that the corrected RMSD for WCT accurately characterized variability in egg selenium concentrations across the range of exposures relevant to the derivation of selenium benchmarks. A sensitivity analysis was presented at ToxWG Meeting No. 4 to show how alternative values for the standard deviation would affect the calculation of integrated effects.	An appropriate method was used to calculate standard deviation. Increasing the standard deviation from the best-fit estimate of 0.175 to 0.200, or decreasing it to 0.150, changed the integrated reproductive effect by approximately 2%.
Appropriate critical effect size for WCT (Row 22)	The selenium ecological effects assessment made reference to critical effect sizes (CES) of 10% to 20%, consistent with findings that effects <20% are not expected to result in meaningful and measureable changes to populations (Suter et al. 1995; USEPA 1999, 2013; Mebane 2010). Mebane (2010) recommended a CES of 10% for growth or mortality of fish when multiple stressors are present, although an equivalent CES for WCT reproduction may be higher because of density-dependent compensation mechanisms in WCT populations (Hilborn and Walters 2001; Van Kirk and Hill 2007). Following this rationale, selenium benchmarks for the upper Fording River were derived to try to meet three criteria: 1) an integrated effect size of <10% for the Management Unit; 2) an effect size of <10% for all mainstem sections of the upper Fording River; and 3) upper prediction limit of integrated effect size <20%.	Uncertainty was addressed by using a conservative CES of 10% as the primary criterion for WCT, even for reproductive effects.
Interactive effects on multiple endpoints and from multiple stressors (Row 13)	Potential interactive effects of selenium on multiple endpoints were characterized in the Evaluation Tables prepared to support benchmark derivation (see the Plan Document). Interactive effects on multiple endpoints were considered for invertebrates to differentiate between potential effects to only the most sensitive species and potential effects to a broader range of species that could result in community level changes. Interactive effects on multiple endpoints were considered for fish and birds in terms of the potential for direct effects on the most sensitive endpoint (either reproduction or juvenile growth) to interact with indirect effects via potential changes to their invertebrate food supply. Uncertainty related to potential interactive effects was addressed by adopting low CES values (10% as the primary criterion) and toxicity data from the most sensitive species as conservative indicators of the potential for ecologically meaningful change. Potential interactive effects of multiple stressors were evaluated in Section 7.2.4 of the Plan by qualitatively considering the potential for future conditions to result in changes to current environmental quality. Uncertainty in the assessment of multiple stressors was addressed by adopting low CES values (10% as the primary criterion) and toxicity data from the most sensitive species as conservative indicators of the potential for ecologically meaningful change.	The current state of the science precludes definitive conclusions regarding interactive effects, but uncertainty was addressed by use of sensitive species data and a conservative CES. Follow-up studies are warranted, potentially including development of population models.

Table 1: Summary of Uncertainty Management in the Selenium Ecological Effects Assessment (continued)

Source of Uncertainty	Steps Taken to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
Habitat use by fish within Management Units (Row 23)	Potential fish use of different habitat types and areas within each Management Unit was characterized by calculating the area of fish-accessible habitat within mainstem reaches, tributaries, and off-channel areas. The Evaluation Tables for selenium present these calculated areas, along with predicted selenium concentrations and an associated ecological effects assessment for each of the habitat sub-units. For the calculation of an overall, integrated effect across each Management Unit, it was assumed that all fish-accessible habitat is potentially used for feeding during critical exposure periods (e.g., during egg provisioning for reproductive effects, during sensitive early life stages for juvenile growth).	The majority of fish-accessible habitat is in the mainstem of each Management Unit, and benchmarks were set to meet critical effect sizes in all mainstem reaches as well as for the whole Management Unit. Follow-up analyses are warranted as telemetry data become available.

Note: Indicated row numbers refer to the table in Attachment A.

Summary of Residual Uncertainty

As summarized in Table 1, steps were taken in consultation with the ToxWG to evaluate and manage uncertainty throughout the selenium ecological effects assessment. As a result, the associated selenium benchmarks represent a best scientific estimate of concentrations associated with a defined level of protection, with inherent conservatism to account for uncertainty.

In most cases, uncertainties were related to particular elements of the technical analysis; and therefore, could be addressed directly within the technical analysis. For example, uncertainty in model structure and parameters was addressed by selecting conservative predictions from multiple models and by considering upper confidence or prediction limits. In general, elements of conservatism were adopted so that the selenium benchmarks would achieve the defined level of protection for populations and communities of aquatic life in the Elk Valley. As discussed in Table 1, all identified sources of uncertainty in the selenium ecological effects assessment were addressed in a manner such that further analyses would not be expected to indicate more restrictive outcomes. Some uncertainties were identified for which it may be possible to resolve the uncertainty via follow-up studies during implementation of the Plan, including:

- effect of fish size on selenium bioaccumulation;
- seasonality of invertebrate selenium concentrations relative to the period of uptake by WCT;
- frequency and timing of sampling that is needed to characterize selenium concentrations in water for the purposes of modelling selenium bioaccumulation;
- habitat use by fish;
- representativeness of WCT and red-winged blackbird bioaccumulation models for other species;
- sensitivity of amphibians to selenium and bioaccumulation of selenium by amphibians; and
- potential interactive effects of selenium on multiple endpoints and with other stressors.

Clear resolution of uncertainties concerning potential interactive effects of selenium on multiple endpoints and potential interactive effects of multiple stressors is not possible at this time, as they are beyond the current state of the science in selenium ecological effects assessment. Elements of conservatism were adopted to account for these uncertainties. However, it is possible that residual uncertainty remains, which cannot be resolved with further analysis of the current data (e.g., with different models or using different statistical methods).

Instead, residual uncertainty is best addressed through follow-up studies (as indicated above), regional monitoring, and adaptive management, all of which are components of the Plan.

Closure

We trust the above meets your present requirements. If you have any questions or require additional details, please contact the undersigned.

GOLDER ASSOCIATES LTD.

On behalf of
Adrian deBruyn, Ph.D., R.P.Bio.
Associate, Senior Environmental Scientist

JP Bechtold, M.A., P.Biol
Principal, Senior Water Quality Specialist

References

Hilborn R and Walters CJ (Eds). 2001. *Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty.* Kluwer Academic Publishers, Boston, MA.

Mebane CA. 2006 (2010 rev). *Cadmium Risks to Freshwater Life: Derivation and Validation of Low-Effect Criteria Values using Laboratory and Field Studies (v1.2).* USGS Scientific Investigations Report 2006-5245.

Minnow Environmental Ltd. 2014. *2012 Biological Monitoring Program for Coal Mines in the Elk River Valley, BC.* Prepared for Teck Coal Limited.

Orr PL, Wiramanaden CI, Paine MD, Franklin W, Fraser C. 2012. Food chain model based on field data to predict westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) ovary selenium concentrations from water selenium concentrations in the Elk Valley, British Columbia. *Environmental Toxicology and Chemistry* 31: 672-680.

Suter GW II, Cornaby BW, Hadden CT, Hull RN, Stack M. Zafran FA. 1995. An approach for balancing health and ecological risks at hazardous waste sites. *Risk Analysis* 15: 221-231.

USEPA (United States Environmental Protection Agency). 1999. *1999 Update of Ambient Water Quality Criteria for Ammonia*. EPA-822-R-99-014. National Technical Information Service, Springfield, VA.

USEPA. 2013. *Aquatic Life Ambient Water Quality Criteria for Ammonia – Freshwater*. EPA-822-R-13-001.

Van Kirk RW, Hill SL. 2007. Demographic model predicts trout population response to selenium based on individual-level toxicity. *Ecological Modelling* 206: 407-420.

ATTACHMENT A

Toxicology Working Group Selenium Uncertainties Table

Summary of Uncertainties and Assumptions in the Selenium Ecological Effects Assessment for the Elk Valley Water Quality Plan

Purpose of Document: This is a working document to facilitate discussion within the TAC and the Toxicology Working Group (Tox WG) for the Elk Valley Water Quality Plan (EVWQP) on the uncertainties and assumptions in the selenium ecological effects assessment.

Process for Development and Updating: The first version of this document was created by the Ministry of Environment (MOE) with assistance from Compass Resource Management (facilitator for the TAC and the Tox WG). Input from other Tox WG members has since been integrated into subsequent versions of the document. In the June 23, 2014 version of the document, Teck added two columns: (1) *"Steps Taken to Evaluate and Manage Uncertainty" and "Residual Uncertainty in the Selenium Ecological Effects Assessment"* based on *interpretation provided in "Management of Uncertainty in the Selenium Ecological Effects Assessment for the Elk Valley Water Quality Plan" (Memo from Golder and C. Schwarz dated June 23, 2014).*

Document Structure:

The document is composed of summary tables with the following five pieces of information:

1. A list of the uncertainties/assumptions with respect to estimating the effects of a given selenium water quality concentration [Se water];
2. A summary of any completed or suggested analyses of these uncertainties/assumptions;
3. A summary of comments/discussion during the TAC or Tox WG process on the implications of these uncertainties/assumptions for estimating the effects of selenium water quality concentrations;
4. A summary of the steps Teck has taken to evaluate and manage uncertainty; and,
5. Comments on the residual uncertainties in the Selenium Ecological Effects Assessment and suggestions for follow-up studies.

The first table in the document includes uncertainties/assumptions that are relevant to all receptors in the selenium effects assessment. The subsequent tables contain uncertainties/assumptions that are specific to the effects assessment for fish, birds, and amphibians. The last table includes uncertainties/assumptions related to the periphyton bioaccumulation model.

General (applies to all receptors)

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
	Selenium Bioaccumulation Models General				
1	**Bioaccumulation statistical models**	Regression models on the log-log scales are used to find a "statistical relationship". K.Brix input (June 24): I agree this is a statistical relationship, but there is an understanding (though incomplete) of the general mechanisms underlying observed relationships.	Results are specific to the Elk River watershed and should not be generalized to other systems. (MOE input, June 4 & K. Brix, June 18).	All bioaccumulation models used in the selenium ecological effects assessment were derived from site-specific or site-relevant data. No spatial extrapolation was required.	Nil. No spatial extrapolation.
2	**Choosing between 1/2/3/ step models**	The models give different results with 3 step models flatter than 2 step models which are flatter than 1 step models. Not possible to use AIC or other statistical models to choose between models with current analysis methods because data set is not the same among the different stepped models (MOE input, June 4).	The choice of model will result in different values of [Se water] that are associated with a 10% integrated effect (MOE input, June 4, 2014).	Three different models (1-step, 2-step, and 3-step) were derived to evaluate uncertainty in model structure. All were carried through subsequent analyses and the most restrictive of the three in each analysis was adopted to calculate benchmarks.	Uncertainty has been addressed by adopting the most conservative alternative.
3	**Reliability of data**	C. Schwarz notes: • Some data appear to be outliers. • Some data are anomalous	Type A/B/C/D data classification. Only Type A data used. Outliers removed. Anomalous points removed. All of these tend to change the fitted lines and the final SD. (MOE input, June 4, 2014)	All input data were evaluated by reviewing source reports, visual inspection of plots, and statistical identification of outliers. Outliers and potentially anomalous values were discussed at ToxWG Meeting #3 and further examined with sensitivity analyses. Modelling was conducted with relevant and reliable data only (category 'A', per the *Selenium Benchmark Derivation Report*, Appendix C: Bioaccumulation Modelling).	The majority of input data were collected recently, using consistent and accepted methods. Unreliable data were identified and excluded.
4	**Reliability of data II (related to #7)**	Some data pairs are not synoptic. D. MacDonald identifies uncertainties in the data pairings for the bioaccumulation models (for e.g. some data pairings are not synoptic) in his TAC Advice Submission of Feb. 18, 2014 (Advice #4B-26). D. MacDonald suggests an analysis of the uncertainty in data pairings (Advice #4B-26). Such an analysis has not yet been presented to the TAC.	The input [Se] may not match the measured [Se] when pairs taken. This will cause problems related to the error-in-variables problem noted below (MOE input, June 4, 2014).	Where possible, synoptic data were paired for model derivation. Non-synoptic data pairs were ranked according to how closely they approximated a synoptic pair. A sensitivity analysis was conducted for each model to evaluate the effect of including non-synoptic data pairs (for further detail please refer to Section 4.2.3.1 of *Selenium Benchmark Derivation Report*, Appendix C: Bioaccumulation Modelling).	The majority of data pairs were synoptic. Inclusion of non-synoptic pairs had little or no influence on models.

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
5	**Error propagation through the multi-step models.** Teck is using only the uncertainty around the mean response (the SD) in the last step in the calculation of the integrated total reproductive effect. The uncertainty in the SD is not accounted for. The uncertainty in the mean response is not used in the integration process.	*Suggested Analysis:* Only the uncertainty in the predictions at the final step of the 1/2/3 step models is used. For example, in the 3 step models, the [Se water] -> [Se peri] ignores uncertainty in the prediction when taking the [Se peri] -> [Se inv] and the uncertainty in this prediction is again ignored in the [Se inv] -> [Se fish tissue]. The uncertainty in the lower steps is assumed to be captured by the uncertainty in the final step. This seems like a reasonable approach because of the "averaging" that takes place as Se moves up the tropic levels. Only the uncertainty in this final step is used to derive the SD. The uncertainty in this SD is likely to be small because of the large number of data points typically found in the highest step. Some combination of uncertainty in the mean and the variation of individuals in the integrated response should be done. Using the UCL for the mean with the SD is one approach (MOE input, June 4, 2014). Comment from K. Brix: Most of these concerns are addressed by comparing 1-step vs. multi-step models. Important to recognize that the 1-step model incorporates all the uncertainty (June 24).	Critical that good data be collected at the final step so that both the function form of the relationship and the SD are estimated well. Need to carefully check for outliers and be cautious in just deleting points that don't fit without good rationale as this tends to reduce the estimated SD and increase the [Se water] for an estimated effects level (MOE input, June 4, 2014). Because the uncertainty in the mean at the final step is not used, the actual integrated reproductive effect could be more variable than predicted (MOE input, June 4, 2014).	Uncertainty in how variability propagates through the multi-step models was discussed at ToxWG Meetings #1 and #3 and it was agreed that consideration of the 1-step model accounted for this uncertainty. Propagated variability was further addressed by calculating the root mean square deviation (RMSD) for each model (for further detail please refer to *Selenium Benchmark Derivation Report*, Appendix C: Bioaccumulation Modelling). RMSD was calculated from differences between measured and modelled values, and therefore is an appropriate way to express overall propagated variability in each model. A sensitivity analysis of uncertainty in SD was presented at TAC Meeting #6 (see row 6). Uncertainty in the modelled mean was accounted for by adopting the most restrictive (i.e., highest) result from the three alternative models.	Uncertainty in propagated variability has been addressed by considering a 1-step model and by calculating RMSD for each model. Uncertainty in modelled means has been addressed by adopting the most conservative alternative.

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
6	**What is the appropriate value for the Standard Deviation used for the integrated reproductive effect?**	Various values of SD have been proposed ranging from an "upper bound" of around 0.20 and lower. Current values around 0.175 were established by removing various sets of data (e.g. Conner Lake) or the Type B/C/D set.	A smaller SD results in an increase in the mean [Se tissue] that gives rise to the 10% integrated reproductive effect which then increase the [Se water] associated with the mean [Se tissue] (MOE input, June 4, 2014).	Variability in modelled egg selenium concentrations was characterized using the root mean square deviation (RMSD) for each model. RMSD was calculated from differences between measured and modelled values, and therefore is an appropriate way to express overall variability for each model. RMSD was calculated using relevant and reliable (category 'A') data only, reducing potential uncertainty related to anomalous values. Following discussion at ToxWG Meeting #4, Connor Lake data were excluded from the RMSD calculation to correct an artificial inflation of the RMSD related to model over-estimation of low WCT egg selenium concentrations in a headwater lake outside the Designated Area (aqueous selenium in Connor Lake is < 0.1 µg/L). It was agreed with the ToxWG that the corrected RMSD for WCT accurately characterized variability in egg selenium concentrations across the range of exposures relevant to the derivation of selenium benchmarks. A sensitivity analysis was presented at ToxWG Meeting #4 to show how alternative values for the standard deviation would affect the calculation of integrated effects.	An appropriate method was used to calculate standard deviation. Increasing the standard deviation from the best-fit estimate of 0.175 to 0.200, or decreasing it to 0.150, changed the integrated reproductive effect by approximately 2%.

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
7	**Seasonal variation in [Se Water] and attenuation:** The variation of [Se Water] across seasons creates an "error-in-variables" problem that can lead to attenuation of the model slopes. For example, if all samples are taken during the highest [Se water] in a year, then the bioaccumulation will be understated. (C. Schwarz, April 29, 2014). Another way to describe this uncertainty is that the measured [Se Water] may not accurately represent the integrated exposure of an organism to [Se Water] (KNC input, June 24).	**Completed Analysis:** Teck assessed the potential for model bias and found that some slope attenuation was apparent in the Ordinary-Least Squares (OLS) models (i.e. error in the x variable had some influence on the estimated relationships), but the OLS slopes could be considered as reasonable estimates of the Major Axis (MA) slopes and the decision was made to use OLS rather than MA regression (Selenium Report – Appendix C, pg. 13).	A. DeBruyn stated at Tox WG Meeting #4 that attenuation was slight and is only a small source of uncertainty in the model results. A. DeBruyn mentioned that these results will be clearly presented in the updated report and can be reviewed when the report is available.	A sensitivity analysis was conducted for each model to evaluate potential attenuation by comparing slopes estimated by ordinary least squares and major axis regression (for further detail please refer to Section 4.2.3.2 of *Selenium Benchmark Derivation Report*, Appendix C: Bioaccumulation Modelling). Regression slopes were generally similar between methods and not statistically different. Uncertainty in model slopes was further addressed by deriving three model structures, including a one-step model with limited potential for slope attenuation (for further detail please refer to Section 4.2.3.3 of *Selenium Benchmark Derivation Report*, Appendix C: Bioaccumulation Modelling). As discussed at ToxWG Meeting #3, the most restrictive of these three models was adopted to calculate benchmarks. An additional margin of safety is achieved by implementing long-term targets for selenium as maximum monthly average concentrations. This measure accounts for uncertainty in the temporal matching of tissue and aqueous selenium concentrations by constraining all other months to be lower than the target, and thus reducing the chance that bioaccumulation will be understated.	Little evidence for attenuation was observed. Adoption of the most restrictive model further addressed uncertainty in model slopes. Application of targets as maximum monthly average concentrations imparts a further margin of safety.

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
8	**Not all areas in the Elk Valley are included in the bioaccumulation models.** – Not all lentic areas are represented in the EVWQP modelling work (e.g. Fording River Oxbow, Clode Pond, Goddard Marsh etc.). – A bioaccumulation model for Lake Koocanusa has not been developed.	***Suggested analysis:*** Present results of the bioaccumulation model developed for these areas (MOE input, June 4, 2014). K. Brix input: Agreed, there needs to be an explicit incorporation of the "bioaccumulative" sites into the effects assessment (June 18).	Since some lentic areas in the Elk Valley watershed are not represented by the EVWQP bioaccumulation models and these areas are known to have higher bioaccumulation rates, than the effects calculated using the EVWQP bioaccumulation models may underestimate the actual effects (MOE input, June 4, 2014)	Differences in selenium bioaccumulation among areas were explicitly considered in the derivation of models. Certain areas (e.g., the Fording Oxbow) are hypothesized to exhibit distinct underlying mechanisms of bioaccumulation, and therefore were included in a separate bioaccumulation model. The 'lentic' model presented in Orr et al. (2012) and Minnow (2014) was used in the selenium ecological effects assessment to model bioaccumulation in these areas.	Uncertainty has been addressed by adopting the more conservative alternative.
9	**Representativeness of bioaccumulation models for all sensitive species:** Data is not available to make bioaccumulation models for all sensitive species. A Westslope Cutthroat Trout (WCT) bioaccumulation model is being used to estimate bioaccumulation for all fish species. A red-winged blackbird model (RWBL) is being used to estimate bioaccumulation for all bird species (MOE input, June 4, 2014).			All fish and bird species with sufficient site-specific tissue selenium data were considered for model derivation. Analysis of covariance indicated significant differences in the slope of the bioaccumulation relationship between species for both fish (WCT 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. Models were derived for the species that tended to exhibit higher tissue selenium concentrations. 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 will have similar or lower exposure to selenium compared to the modelled species.	Uncertainty has been addressed by adopting the more conservative alternative. **Follow-up studies are warranted to confirm that other species are adequately represented by the models.**

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
	Toxicity Benchmarks / Dose-Response Curve				
10	**Representativeness of dose-response curves for all sensitive species:** Dose-response curves are not available for all sensitive species. Dose-response curves for mallards and Brown Trout are integrated with bioaccumulation models for red-winged blackbirds and WCT to determine the 10% integrated effect as Brown Trout and mallards are assumed to be the most sensitive bird and fish species. There are over 100 different species of birds in the Elk Valley (Minnow avian bird census June 2012). Every bird species likely has its own dose-response curve (MOE input, June 4, 2014).		If mallards, and Brown Trout are the most sensitive species, then using these dose-response curves may overestimate the total reproductive effects. However, if they are not the most sensitive species, then using these dose-response curves may underestimate the total reproductive effects. In general, the actual total integrated effect will differ from that estimated using these dose-response curves (MOE input, June 4, 2014). K. Brix input (June 24): I agree, but this is always an issue for every assessment. There is a considerable amount of both field and laboratory data available for Se toxicity to fish and birds. It is worth noting that the effect level (EC10) for the most sensitive bird and fish species hasn't changed in the past ~15 years despite numerous additional studies. This does not rule out the possibility of that there are more sensitive species, but I do not think the uncertainty is particularly high.	Toxicity data were compiled for all fish and bird species with information relevant and reliable to the Elk Valley. From this compilation, the most sensitive species, life stages, and effects endpoints were adopted for the selenium ecological effects assessment (for further detail please refer to *Selenium Benchmark Derivation Report*, Appendix D: Toxicity Literature Review). Brown trout (which do not occur in the Elk Valley) are the most sensitive of 14 fish species for which relevant and reliable reproductive toxicity data were available. Mallard are the most sensitive of 37 bird species for which relevant and reliable reproductive toxicity data were available.	Uncertainty has been addressed by adopting the most conservative dose-response curve for all species that have been tested.

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
11	**Uncertainty in dose-response curve.**	The single best-fit estimated dose-response curve is used to estimate the integrated effects. The Sensitivity Analysis (conducted by Dr. C. Schwarz and presented on May 28th to the toxicology working group) demonstrated that there is uncertainty in the integration of the dose-response curves for Brown trout, WCT, and Birds when the uncertainty in the dose-response curve is factored in.	Uncertainty in the dose-response relationship has been ignored. The uncertainty in the dose-response relationship results in uncertainty in the estimated integrated effects. The sensitivity analysis demonstrates that there is a very large range of Se water concentrations that would be associated with a 10 % total reproductive effect to brown trout, WCT and birds. A conservative approach would be to select the lower end of this range as a level 1 benchmark (MOE input, June 4, 2014).	Best-fit dose-response curves were adopted for the selenium ecological effects assessment, representing the interpretation best supported by the data and recommended by the authors of the toxicity studies and in subsequent re-analyses by other authors. Uncertainty in the fitted dose-response curves was evaluated with a bootstrap analysis, which was used to calculate an upper prediction limit for integrated reproductive effects. This upper prediction limit was taken into consideration in the selection of benchmarks.	Uncertainty has been addressed by using the best scientific estimates of the most sensitive dose-response curves for fish and birds. Residual uncertainty in the parameters of those curves has been characterized as an upper prediction limit for potential integrated reproductive effects.

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
12	**The accuracy of laboratory studies in measuring the effects of a given [Se fish egg] under field conditions:** Most of the dose-response studies are laboratory based with attempts to control any confounding variables and conditions held relatively constant over the course of the study. Field conditions are less controlled and other uncontrolled factors may interact with the effect of [Se] to either heighten or lessen impacts. Overdispersion was seen in some of the laboratory studies even under controlled conditions (C. Schwarz, April 29, 2014, pg. 9).	C. Schwarz advises that no statistical analyses will estimate the difference between laboratory and field studies, and recommends a literature review (MOE input, June 4, 2014).	To allow for uncertainty in the total reproductive effect, the mean [Se fish tissue] should be shifted left by some amount which shifts allowable [Se water] also to the left (MOE input, June 4, 2014). K. Brix input (June 24): I disagree with the above proposed approach if it is presented as a "scientific" correction for uncertainty. It acceptable to lower the water Se benchmark by some amount due to uncertainty, but this is a policy decision, not a scientific decision. Its very misleading to arbitrarily apply some "correction" in the middle of the calculation. It may be misconstrued that the resulting value was scientifically derived, which is not the case Rather, it should be made transparent that there was a scientifically derived benchmark and then remaining uncertainty was addressed lowering that benchmark based on risk aversion policy. For example, explicitly state: 1. X is the best scientific estimate 2. A,B,C and D are the uncertainties the science couldn't deal with objectively 3. Y is the final number considering number 1 and 2 and the agencies policy on risk aversion.	Toxicity data were compiled from both laboratory and field studies relevant and reliable to the Elk Valley, and the most sensitive species, life stage, and effects endpoint was adopted for the selenium ecological effects assessment. For fish, the most sensitive dose-response curve derived from a study of field-collected brown trout exposed to selenium in Idaho streams. For birds, the most sensitive dose-response curve derived from several studies of mallard exposed to experimentally-dosed dietary selenium in a laboratory. In both cases, studies with other species in both laboratory and field indicated lesser sensitivity.	Uncertainty has been addressed by using the most sensitive dose-response curves for fish and birds, irrespective of whether the curve was derived from a laboratory or field study.

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
	Population-level Effects at a given [Se Water]				
13	**Uncertainty in the combined effects of multiple endpoints and multiple stressors on a population.**	The interactive effects from multiple stressors on multiple endpoints have not been assessed yet. MOE advises that population modelling work is needed which includes effects from multiple stressors and endpoints for fish species in the Elk Valley (MOE input, June 4, 2014).	The combined effects from multiple stressors on multiple endpoints may be higher than those predicted from individual stressors. K. Brix input (June 18): Agreed. There needs to be very carefully planned studies on this in the future. KNC Input (June 24): Need to consider the other stressors that are not included in the evaluation tables. For example, changes in stream-bed substrate composition suggests “high” uncertainty in this area.	Potential interactive effects of selenium on multiple endpoints were characterized in the Evaluation Tables prepared to support benchmark derivation (see the Plan Document). Interactive effects on multiple endpoints were considered for invertebrates to differentiate between potential effects to only the most sensitive species and potential effects to a broader range of species that could result in community-level changes. Interactive effects on multiple endpoints were considered for fish and birds in terms of the potential for direct effects on the most sensitive endpoint (either reproduction or juvenile growth) to interact with indirect effects via potential changes to their invertebrate food supply. Uncertainty related to potential interactive effects was addressed by adopting low critical effect size (CES) values (10% as the primary criterion) and toxicity data from the most sensitive species as conservative indicators of the potential for ecologically meaningful change. Potential interactive effects of multiple stressors were evaluated in Section 7.2.4 of the EVWQP by qualitatively considering the potential for future conditions to result in changes to current environmental quality. Uncertainty in the assessment of multiple stressors was addressed by adopting low CES values (10% as the primary criterion) and toxicity data from the most sensitive species as conservative indicators of the potential for ecologically meaningful change.	The current state of the science precludes definitive conclusions regarding interactive effects, but uncertainty was addressed by use of sensitive species data and a conservative CES. **Follow-up studies are warranted, potentially including development of population models.**

Fish

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
	Selenium Bioaccumulation Models for Fish – General				
14	**Model choice:** Should a 1-, 2-, or 3-step bioaccumulation model be used to estimate the [Se fish tissue] from a given [Se Water]?	1-, 2- and 3- step bioaccumulation models have been carried forward in the analysis. As well, different approaches for calculating standard deviation in the bioaccumulation models have ben carried forward. This results in six bioaccumulation models each for WCT.	See the rows below for uncertainties/assumptions related to the specific 1-, 2-, or 3-step bioaccumulation models. For [Se WCT eggs], the "3step-3stepSD" model estimated the highest bioaccumulation rates of the various models considered (TAC 5 – Se Presentation, Slide 19).	Three different models (1-step, 2-step, and 3-step) were derived to evaluate uncertainty in model structure. All were carried through subsequent analyses and the most restrictive of the three in each analysis was adopted to calculate benchmarks.	Uncertainty has been addressed by adopting the most conservative alternative.
15	**Representativeness of bioaccumulation models for all sensitive fish species:** Sufficient egg selenium concentration data were available to develop bioaccumulation models for Westslope Cutthroat Trout (WCT) and Longnose Sucker (LNS). However, bioaccumulation models have not been developed for other fish species in the Elk Valley.		K. Brix input: Agreed, a wider range of species should be sampled in the future (June 18).	All fish and bird species with sufficient site-specific tissue selenium data were considered for model derivation. Analysis of covariance indicated significant differences in the slope of the bioaccumulation relationship between species for both fish (WCT 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. Models were derived for the species that tended to exhibit higher tissue selenium concentrations.	Uncertainty has been addressed by adopting the more conservative alternative. Follow-up studies are warranted to confirm that other species are adequately represented by the models.

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
16	**Fish Size:** Are separate bioaccumulation models needed for different ages/sizes of fish? (TAC Mtg 4 Notes, Appendix A, A4-9)	**Tox WG #1 Recommendation #6:** Check whether there are differences in fish tissue concentrations as a function of fish size. • At Tox WG #3, Adrian de Bruyn presented the results of this analysis. **Tox WG #3, Recommendation #2:** Recommend not differentiating WCT size effects into the bioaccumulation model, given uncertainty with the unbalanced datasets. (Slide 11 – Tox WG 3 meeting March 28th suggested that egg Se in 200 mm fish was 20% higher than 300 mm fish, but A. De Bruyn stated that this was likely due to unbalanced sampling).	MOE recommends additional sampling to review fish size as part of the adaptive management program (MOE input, June 4, 2014).	An evaluation was conducted of the strength of evidence for an effect of fish size on bioaccumulation. Results indicated 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 ToxWG Meeting #3 that a size effect was not supported and would not be modelled.	A possible size effect cannot be ruled out, but implications for the selenium ecological effects assessment are minimal. **Follow-up analysis may be warranted as a more balanced dataset becomes available.**
	1- step Bioaccumulation Model: Water to Fish Eggs				
17	Inclusion of dataset "A" vs. all data in the 1-step water to fish eggs model.	C. Schwarz calculated the results using the "A" dataset and all data for this model. C. Schwarz concluded that the impact of the excluded points results in an almost parallel downward shift in the fitted lines by about 0.07 units on the log-scale or about a 20% reduction in the predicted mean [Se WCT] at a given [Se Water] (C. Schwarz, April 29, 2014, pg. 4).	Currently, Teck is using the "A" dataset for this model. Consequently, Teck's predicted mean [Se WCT] at a given [Se water] using the 1-step model will be lower than if all of the data points were included.	All input data were evaluated by reviewing source reports, visual inspection of plots, and statistical identification of outliers. Outliers and potentially anomalous values were discussed at ToxWG Meeting #3 and further examined with sensitivity analyses. Modelling was conducted with relevant and reliable data only (category 'A', per the *Selenium Benchmark Derivation Report*, Appendix C: Bioaccumulation Modelling).	The majority of input data were collected recently, using consistent and accepted methods. Unreliable data were identified and excluded.

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
	Invertebrate to WCT egg Se bioaccumulation model				
18	**Linear vs. Breakpoint:** Whether a linear or breakpoint fit is most appropriate to characterize the paired-sample data of [Se Invertebrates] and [Se WCT egg].	C. Schwarz compared the linear and breakpoint fit for the paired invertebrate and WCT data. C. Schwarz concluded that fitting a break point model gives quite different predictions for the [Se WCT] when the [Se Invertebrates] is around log(10 mg/kg/dw) = 1. This difference is notable because the location of the breakpoint is not well defined because of the gap in data between log([Se invert]=1.0 and log({Se invert])=1.5 (C. Schwarz, April 29, 2014, pg. 2). C. Schwarz recommended that a conservative approach is to push the location of the breakpoint to the left (i.e. to a lower selenium tissue concentration of invertebrates).		A bootstrap analysis to evaluate uncertainty in the location of the breakpoint identified two high-leverage points. As discussed at ToxWG Meeting #3, bioaccumulation models were derived with and without these points. The more restrictive alternative (i.e., the model that produced higher WCT egg selenium concentrations) was carried forward into subsequent analyses.	Uncertainty has been addressed by adopting the more conservative alternative.
		The uncertainty around the location of breakpoints was discussed at Tox Working Group #2. As a result, Teck did a bootstrapping analysis for the INV-WCT model. The bootstrapping analysis identified two data points in the invertebrate-WCT egg relationship as having high leverage on the fitted piecewise model. Models were run with these data included and with them excluded. (TAC 5 Se Presentation, Slide 6).	Tox WG agreed to carry forward two breakpoint models (with the two data points included and excluded) and use the most conservative breakpoint model to estimate [Se water] associated with a 10% integrated effect.		
19	Inclusion of dataset “A” vs. all data in the INV-WCT eggs model.	C. Schwarz calculated the results using the “A” dataset and all data for this model. C. Schwarz concluded that the results are not significantly different between the “A” dataset and all data. (C. Schwarz, April 29, 2014)	No implications for the use of the “A” dataset in this model.	All input data were evaluated by reviewing source reports, visual inspection of plots, and statistical identification of outliers. Outliers and potentially anomalous values were discussed at ToxWG Meeting #3 and further examined with sensitivity analyses. Modelling was conducted with relevant and reliable data only (category ‘A’, per the *Selenium Benchmark Derivation Report*, Appendix C: Bioaccumulation Modelling).	The majority of input data were collected recently, using consistent and accepted methods. Unreliable data were identified and excluded.

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
20	Are the [Se Inv] at the time of measurement representative of the [Se] exposure and uptake for WCT over the entire year? (C. Schwarz, April 29, 2014; Tox WG 4 Notes)	**Tox WG #4 – Action #1:** Provide a comparison of invertebrate Se concentrations at the same stations between spring and fall. K. Brix input: I agree this should be done. (June 18).	K. Brix input: Future studies should characterize the pharmaco-kinetics of Se transfer from the diet, to the fish and then to the eggs. This is best accomplished by doing a radio-isotopic study (June 18).	An analysis was conducted to evaluate potential seasonality in invertebrate selenium concentrations. Compiled invertebrate selenium data from mine-influenced locations exhibited little evidence of seasonal variability, with similar median selenium concentrations in May, June, August, and September (all within approximately 1 mg/kg dry weight). Fewer data were available for July and October, but these were generally consistent with a conclusion that invertebrate selenium concentrations vary little across seasons. No data were available for November to April.	Available data indicate that invertebrates sampled in fall provide a reasonable estimate of dietary selenium concentrations for WCT. **Follow-up studies are warranted to better characterize the relevant exposure period for WCT.**
	Toxicity Benchmarks / Dose-Response Curve				
21	**Assumption:** A dose-response relationship for Brown Trout reproduction is used to represent the effects of the most sensitive fish species in the Elk River, Lower Fording River, and in tributaries to these rivers.	In a letter to the TAC Chair, K. Brix recommended the use of the selenium dose-response relationship for Brown Trout developed by Formation Environmental to ensure protection of all fish species that have been tested to date for selenium, on the assumption that this represents the range in sensitivities of fish species resident to the Elk River Valley for which no toxicity data are available. Further, he recommended using all of the data from the study in estimating the dose-response relationship, which results in an EC10 value of 17.7 mg/kg dw egg Se (Brix, March 5, 2014).	Teck adopted the use of the brown trout dose-response curve (EC10 = 17.7 mg/kg dw) to represent potentially sensitive fish species (TAC 5 – Se Presentation, Slide 8).	Toxicity data were compiled for all fish and bird species with information relevant and reliable to the Elk Valley. From this compilation, the most sensitive species, life stages, and effects endpoints were adopted for the selenium ecological effects assessment (for further detail please refer to *Selenium Benchmark Derivation Report*, Appendix D: Toxicity Literature Review). Brown trout (which do not occur in the Elk Valley) are the most sensitive of 14 fish species for which relevant and reliable reproductive toxicity data were available. Mallard are the most sensitive of 37 bird species for which relevant and reliable reproductive toxicity data were available.	Uncertainty has been addressed by adopting the most conservative alternative.

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
	Integrated Reproductive Effect Calculation at a given [Se Water]				
22	What Critical Effect Size[1] should be used for WCT?	Teck has stated that a CES of 10% to 20% will not result in ecologically meaningful or measurable effects to WCT populations (TAC 5 Se Presentation, Slide 14-15). Teck stated that using a CES of 10-20% is a conservative approach because effects to cutthroat trout and other salmonids have been estimated to occur when reproductive effects exceed 40-60% (TAC 5 Se Presentation references Van Kirk and Hill 2007). Mebane (2010) states: "In several scenarios when reductions occurred in fish populations that were reasonably stable, habitats were intact, and if environmental conditions were not otherwise severe, reductions of about 20% (EC20) in growth or first year survival likely would be sustainable. However, in more vulnerable populations, or in populations subject to other stressors, reductions of 10 percent or less for growth or mortality endpoints would be a better estimate of an acceptable low-effects threshold. (page 16)" MOE advises that population modelling work is needed which includes effects from multiple stressors and endpoints for fish species in the Elk Valley. (MOE input, June 4, 2014).		The selenium ecological effects assessment made reference to critical effect sizes (CES) of 10 to 20%, consistent with findings that effects <20% are not expected to result in meaningful and measureable changes to populations (Suter et al. 1995; USEPA 1999, 2013; Mebane 2010). Mebane (2010) recommended a CES of 10% for growth or mortality of fish when multiple stressors are present, although an equivalent CES for WCT reproduction may be higher because of density-dependent compensation mechanisms in WCT populations (Hilborn and Walters 2001; Van Kirk and Hill 2007). Following this rationale, selenium benchmarks for the upper Fording River were derived to try to meet three criteria: 1) an integrated effect size of <10% for the Management Unit; 2) an effect size of <10% for all mainstem sections of the upper Fording River; and 3) upper prediction limit of integrated effect size <20%.	Uncertainty has been addressed by using a conservative CES of 10% as the primary criterion for WCT, even for reproductive effects.

[1] Teck defines "Critical Effect Size (CES) as an effects size that would not be expected to have adverse effects on populations of sensitive species or communities of benthic invertebrates" (TAC 5 Presentation – Se Presentation, Slide 14).

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
	Integrated Reproductive Effect Calculation for a Management Unit				
23	**Fish Location:** Fish move between different habitats with different [Se], making it difficult to model the total [Se] exposure of a fish population in a management unit. Teck has made a simplifying assumption to assume that fish use habitat in proportion to its area (C. Schwarz input, May 26, 2014).	A telemetry study of WCT habitat use in the Upper Fording River area is underway, but the results are not yet available.	The telemetry data should be analyzed and included as part of the adaptive management framework. If the fish use assumption is not correct, integrated reproductive effects may need to be re-calculated for the management units (MOE input, June 4, 2014).	Potential fish use of different habitat types and areas within each Management Unit was characterized by calculating the area of fish-accessible habitat within mainstem reaches, tributaries, and off-channel areas. The Evaluation Tables for selenium present these calculated areas, along with predicted selenium concentrations and an associated ecological effects assessment for each of the habitat sub-units. For the calculation of an overall, integrated effect across each Management Unit, it was assumed that all fish-accessible habitat is potentially used for feeding during critical exposure periods (e.g., during egg provisioning for reproductive effects, during sensitive early life stages for juvenile growth).	The majority of fish-accessible habitat is in the mainstem of each Management Unit, and benchmarks were set to meet critical effect sizes in all mainstem reaches as well as for the whole Management Unit. **Follow-up analyses are warranted as telemetry data become available.**

Birds

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
	Selenium Bioaccumulation Models for Birds - General				
24	**Model choice:** Should a 1-, 2-, or 3-step bioaccumulation model be used to estimate the [Se Bird Eggs] from a given [Se Water]?	1-, 2- and 3- step bioaccumulation models have been carried forward in the analysis. As well, different approaches for calculating standard deviation in the bioaccumulation models have been carried forward. This results in six bioaccumulation models for red-winged black bird (RWBL) ovaries.	See the rows below for uncertainties/assumptions related to the specific 1-, 2-, or 3-step bioaccumulation models. For RWBL reproduction, the "1step-1stepSD" model estimated the highest bioaccumulation rates of the six models considered. (TAC 5 – Se Presentation, Slide 22).	Three different models (1-step, 2-step, and 3-step) were derived to evaluate uncertainty in model structure. All were carried through subsequent analyses. The 2-step and 3-step models were relied on preferably for aqueous selenium concentrations beyond the 1-step model's data range. The most restrictive of the three in each analysis was adopted to calculate benchmarks.	Uncertainty has been addressed by adopting the most conservative alternative.
25	**Representativeness of bioaccumulation models for all sensitive bird species:** Sufficient egg selenium concentration data were available to develop models for the red-winged blackbird (RWBL) and spotted sandpiper (SPSA).			All fish and bird species with sufficient site-specific tissue selenium data were considered for model derivation. Analysis of covariance indicated significant differences in the slope of the bioaccumulation relationship between species for both fish (WCT 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. Models were derived for the species that tended to exhibit higher tissue selenium concentrations.	Uncertainty has been addressed by adopting the more conservative alternative. Follow-up studies are warranted to confirm that other species are adequately represented by the models.
	1- step Bioaccumulation Model: Water to Bird Eggs model				
26	**Limited Dataset:** 1-step RWBL egg model values above 10 µg/L are extrapolations for RWBL (TAC 5 – Se Presentation)	Teck suggests that results from the 2-step and 3-step model are more reliable (TAC 5 – Se Presentation).		Uncertainty related to the limited range of data available to derive the 1-step bird model was discussed at TAC Meeting #5. Uncertainty was addressed by relying preferentially on the 2-step and 3-step models at aqueous selenium concentrations beyond the 1-step model's data range.	The 1-step model was not extrapolated beyond its data range.

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
27	Inclusion of dataset "A" vs. all data in the 1-step water to bird eggs model	C. Schwarz calculated the results using the "A" dataset and all data for this model. C. Schwarz concluded that the inclusion/exclusion of the data has little impact on the model fit with only a slight reduction in the intercept when points are excluded. (C. Schwarz, April 29, 2014, pg. 4).	No implications for the use of the "A" dataset in this model.	All input data were evaluated by reviewing source reports, visual inspection of plots, and statistical identification of outliers. Outliers and potentially anomalous values were discussed at ToxWG Meeting #3 and further examined with sensitivity analyses. Modelling was conducted with relevant and reliable data only (category 'A', per the *Selenium Benchmark Derivation Report*, Appendix C: Bioaccumulation Modelling).	The majority of input data were collected recently, using consistent and accepted methods. Unreliable data were identified and excluded.
	Invertebrate to RWBL eggs Se bioaccumulation model				
28	Inclusion of dataset "A" vs. all data in the INV-RWBL eggs model	C. Schwarz calculated the results using the "A" dataset and all data for this model. C. Schwarz concluded that the inclusion/exclusion of the data has little impact on the model fit. (C. Schwarz, April 29, 2014, pg. 4).	No implications for the use of the "A" dataset in this model.	All input data were evaluated by reviewing source reports, visual inspection of plots, and statistical identification of outliers. Outliers and potentially anomalous values were discussed at ToxWG Meeting #3 and further examined with sensitivity analyses. Modelling was conducted with relevant and reliable data only (category 'A', per the *Selenium Benchmark Derivation Report*, Appendix C: Bioaccumulation Modelling).	The majority of input data were collected recently, using consistent and accepted methods. Unreliable data were identified and excluded.

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
	Dose-Response Curve				
29	Combining multiple studies into one dose-response curve.	C. Schwarz gave a critique of the mallard dose-response curve that is being used by Teck, suggesting that a slightly different method for developing this dose-response curve may be preferable (i.e. an approach based on analyzing the raw data from Ohlendorf (2003)) (C. Schwarz, May 28, 2014, pg. 7).	Different methods of combining the data will give slightly different dose-response curves and so slightly different total integrated effect (MOE input, June 4, 2014).	Best-fit dose-response curves were adopted for the selenium ecological effects assessment, representing the interpretation best supported by the data and recommended by the authors of the toxicity studies and in subsequent re-analyses by other authors. Uncertainty in the fitted dose-response curves was evaluated with a bootstrap analysis, which was used to calculate an upper prediction limit for integrated reproductive effects. This upper prediction limit was taken into consideration in the selection of benchmarks.	Uncertainty has been addressed by using the best scientific estimates of the most sensitive dose-response curves for fish and birds. Residual uncertainty in the parameters of those curves has been characterized as an upper prediction limit for potential integrated reproductive effects.

Amphibians

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
	Selenium Bioaccumulation Models for Amphibians - General				
30	Uncertainty in the bioaccumulation of selenium in amphibians in the Elk Valley.	A bioaccumulation model was developed for amphibians but it was decided to not carry the amphibian model forward given uncertainty in the data pairing between [Se Invertebrates] and [Se amphibians] due to pre-spawning migration (Tox WG 3, Recommendation #1, TAC 5 – Se Presentation). Teck stated that their data on [Se amphibian egg] do not indicate higher bioaccumulation than fish and birds.	K. Brix input: I agree. Additional studies on Se bioaccumulation and toxicity to amphibians is needed (June 24).	It was decided at ToxWG Meeting #3 that uncertainty in invertebrate-amphibian egg data pairs was elevated due to the pre-spawning migratory behaviour of resident amphibian species. Preliminary models indicated that amphibians do not bioaccumulate selenium to a greater extent than fish, and available toxicity data indicate that amphibians are not more sensitive than fish. Therefore, an amphibian bioaccumulation model was not developed.	Available data indicate that benchmarks protective of fish will also be protective of amphibians. **Follow-up studies are warranted to increase confidence in amphibian models.**
	Toxicity Benchmarks				
31	Limited selenium toxicity data for amphibians.	Teck summarized selenium toxicity data for amphibian reproduction at TAC 4 (Se Presentation, Slide 29). Teck highlighted that there are few primary or secondary toxicity studies identified for amphibians, but that this limited toxicity data suggests that amphibians are less sensitive to selenium than fish and birds.	Teck suggested that amphibians are less sensitive than fish and birds, so [Se Water] based on fish and birds could also apply to amphibians (Tox WG 3, Recommendation #1). MOE advises that a recently released draft Se criteria from the USEPA states that amphibians are equally sensitive as fish (MOE input, June 4, 2014).	It was decided at ToxWG Meeting #3 that amphibian toxicity data were insufficient to support tissue effects benchmarks. Available toxicity data indicate that amphibians are not more sensitive than fish, and monitoring data indicate that amphibians do not bioaccumulate selenium to a greater extent than fish.	Available data indicate that benchmarks protective of fish will also be protective of amphibians. **Follow-up studies are warranted, potentially including amphibian toxicity testing.**

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
			MOE and KNC suggested additional toxicity testing for amphibians resident to the Elk Valley (Advice# 4B-19, #5B-25). K. Brix input: I agree. These studies should be performed by researchers with expertise in amphibian testing and should include endpoints up to and including metamorphosis.(June 24).		

Periphyton Bioaccumulation Model

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
32	**Linear vs. Breakpoint:** Whether a linear or breakpoint fit is most appropriate to characterize the bioaccumulation of selenium in periphyton.	C. Schwarz compared the linear and breakpoint fit for the periphyton data (C. Schwarz, April 29, 2014). C. Schwarz concluded that the breakpoint model will tend to give lower predictions of the [Se periphyton] for a given [Se water] around the breakpoint (concentrations around log (10 µg/L)=1) compared to the models that don't have a breakpoint (C. Schwarz, April 29, 2014).	The breakpoint model is an artifact of the separation of the [Se water] in the lentic and lotic systems. The behavior of each type of system when [Se water] moves past the breakpoint is not known. Predictions around the breakpoint will tend to be higher in the no-breakpoint model than in the breakpoint model and conversely will tend to be lower at high/low values of input Se. Actual relationship around the breakpoint is unlikely to show a sharp change.	A log-linear form was evaluated for all models; alternative forms were considered only if warranted by residual structure or other uncertainty related to the log-linear form. Evaluation of diagnostic plots for the periphyton model indicated that a piecewise form improved fit and model residuals relative to a log-linear form. Adoption of the piecewise form was recommended by the ToxWG at Meeting #3. Comparison of the two forms indicated that the piecewise model produced similar (within 1 mg/kg dry weight) periphyton selenium concentrations below 20 µg/L and higher periphyton selenium concentrations above 20 µg/L. Therefore, the piecewise model was retained as the more conservative alternative. (Note that a portion of the discussion in row 32 is incorrect; the breakpoint model for periphyton is not an artifact of combining lentic and lotic data.)	Uncertainty has been addressed by adopting the more conservative alternative.
33	**Dataset:** Inclusion of dataset "A" vs. all data in the water to periphyton bioaccumulation model.	C. Schwarz calculated the results using the "A" dataset and all data for both linear and breakpoint water to periphyton models using the combined lentic and lotic dataset. C. Schwarz concluded that the inclusion/exclusion of the paired-samples not in class A makes little difference to the straight line fit, but it has a large impact on the breakpoint model. The sample points in category B pull the breakpoint up to the right and then cause the fitted line to decline after a [Se water] of around 2=log(100) (C. Schwarz, April 29, 2014, pg. 2).	Different estimates in the final estimated [Se tissue] in the multi-step models which shift the [Se water].	All input data were evaluated by reviewing source reports, visual inspection of plots, and statistical identification of outliers. Outliers and potentially anomalous values were discussed at ToxWG Meeting #3 and further examined with sensitivity analyses. Modelling was conducted with relevant and reliable data only (category 'A', per the *Selenium Benchmark Derivation Report*, Appendix C: Bioaccumulation Modelling).	The majority of input data were collected recently, using consistent and accepted methods. Unreliable data were identified and excluded.

Row	Uncertainty / Assumption	Analysis *(Completed and/or Suggested)*	Implications of Analysis / Uncertainty *(specifically for estimating effects of [Se Water] and future monitoring/studies)*	Steps Taken by Teck to Evaluate and Manage Uncertainty	Residual Uncertainty in the Selenium Ecological Effects Assessment
34	**High Variability in K_d estimates.**	KNC made suggestions for data analysis and laboratory studies to address this uncertainty (TAC Advice #4B-21, #4B-22).		Variability in periphyton selenium concentrations was considered in fitting the periphyton model. Sensitivity analyses recommended by the ToxWG indicated no effect of seasonality or sampling location, suggesting that observed scatter around the periphyton model (referred to in row 34 as variability in K_d) represents real variability in selenium uptake. Uncertainty in model fit related to this variability was accounted for by deriving alternative models (1-step and 2-step) that did not rely on periphyton data. All were carried through subsequent analyses and the most restrictive of the three was adopted to calculate benchmarks.	Variability in K_d exists, but implications for the selenium ecological effects assessment are minimal. Uncertainty has been addressed by adopting the most conservative alternative.
35	**Seasonal variation in [Se Water]:** Are the [Se water] values at the time of measurement representative of the [Se] exposure and uptake of periphyton over the entire year? Note that periphyton samples for the bioaccumulation models were collected in late summer (Aug – Sep) (Tox WG 4, Se Presentation).	C. Schwarz considered this uncertainty and concluded that if the lifespan of the periphyton is small, then the actual [Se] during the short time they are exposed may be well modelled by the single regression line (C. Schwarz, April 29, 2014, pg. 5).	No implications for identifying [Se water] associated with a 10% integrated effect.	No uncertainty identified.	Nil
36	**Lentic/Lotic:** Does selenium bioaccumulation in periphyton vary between lentic and lotic sites in the Elk Valley watershed?	Teck evaluated both lentic and lotic bioaccumulation models for periphyton. The Tox WG recommended combining the lentic and lotic periphyton data into one model (Tox WG #2, Recommendation #3).	No implications for identifying [Se water] that is associated with a 10% integrated effect.	No uncertainty identified.	Nil

REFERENCES

The following documents were used to inform these tables.

Brix, Kevin. (March 5, 2014). Letter to Lynn Kriwoken, TAC Chair. "Review of Proposed Fish Egg Se Thresholds for Elk Valley Water Quality Plan"

deBruyn, Adrian and Carl Schwarz (June 23, 2014), "Management of Uncertainty in the Selenium Ecological Effects Assessment for the Elk Valley Water Quality Plan", Golder Memorandum to Chris Stroich, Teck Coal Limited.

Mebane CA. 2006 (2010 rev). Cadmium risks to freshwater life: Derivation and validation of low-effect criteria values using laboratory and field studies (v1.2). USGS Scientific Investigations Report 2006-5245.

Schwarz, Carl. (April 29, 2014). *A Review of Current Bioaccumulation and Population Effect Modelling.*

Schwarz, Carl. (May 28, 2014). *Sensitivity Analysis of Uncertainty in the Integration of the Dose-Response Curves.*

TAC Advice Master Table.

Teck (April 3, 2014), TAC 5 Presentation, "Selenium Assessment Update"

Tox WG 1 (January 2014). *EVWQP Toxicology Working Group Meeting #1 – Final Notes.*

Tox WG 2 (March 6, 2014). *EVWQP Toxicology Working Group Meeting #2 – Final Notes.*

Tox WG 3 (March 28, 2014). *EVWQP Toxicology Working Group Meeting #3 – Final Notes.*

Tox WG 4 (March 28, 2014). *EVWQP Toxicology Working Group Meeting #3 – Final Notes.*