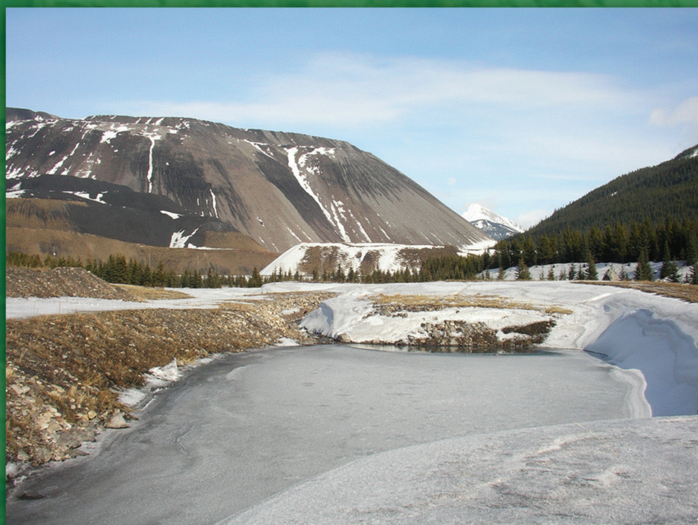
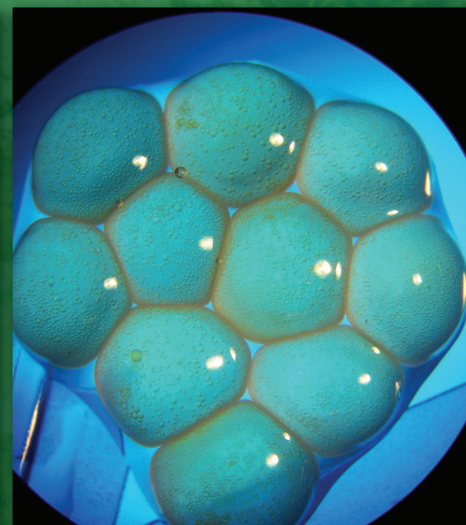
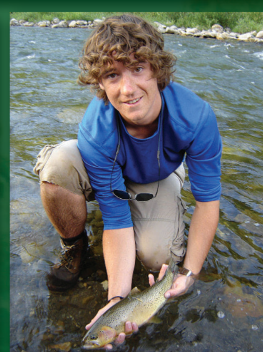
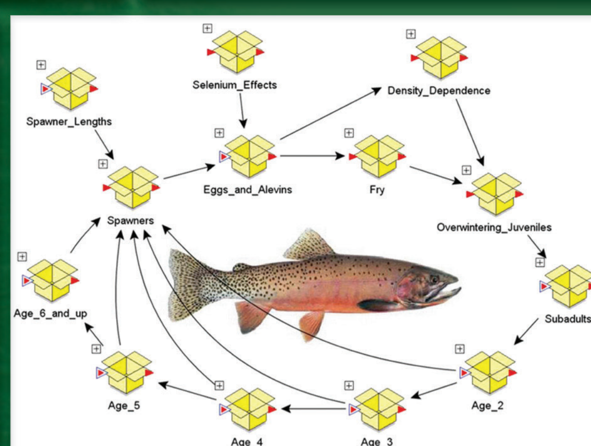
Selenium Status Report 2008/2009

ELK RIVER VALLEY, BC









Prepared by Golder Associates Ltd., for the Elk Valley Selenium Task Force (EVSTF)
SEPTEMBER 2010

EXECUTIVE SUMMARY

Previous *Selenium Status Reports* summarized studies conducted through February 2008 addressing elevated selenium concentrations in the Elk River Valley in south-eastern British Columbia. The present *Selenium Status Report 2008/2009*, produced under the direction of the multi-stakeholder Elk Valley Selenium Task Force (EVSTF), summarizes studies presented to the EVSTF through April 2010, and provides information on studies currently in progress.

Selenium (Se) is a natural element, which is released from Se-containing rocks by weathering. Coal strata in the Elk River Valley contain Se, whose release into the environment is accelerated by coal mining because Se leaches from waste rock and other coal waste materials. Although essential for life, Se can be toxic at higher concentrations and can affect the reproduction of egg-laying vertebrates (fish, water birds, amphibians) that feed in water bodies containing elevated Se concentrations.

This report provides the Executive Summary, Abstract or (in the absence of either of these) Conclusions from the following studies, completed between February 2008 and April 2010 and presented to the EVSTF:

- Mapping of lotic and lentic waters of the Elk River Valley;
- Selenium in water, sediments and aquatic biota of Lake Koocanusa;
- Quality assurance/quality control guidance for larval fish deformity assessments;
- Cutthroat trout threshold effects;
- Selenium bioaccumulation factors;
- Treatment R&D literature review;
- Geochemistry of Se in local water bodies;
- Selenium Expert Panel;
- Elk Valley sport fisheries;
- Aquatic benthic invertebrates;
- Line Creek aquatic health; and,
- Historic fish distributions.

This report also provides relevant information regarding the following ongoing studies presented to the EVSTF:

- Regional monitoring of Se in water, sediments and aquatic biota in the Elk River Valley;
- Effects studies: resolving issues related to the cutthroat trout effects study and developing a population model of Se effects to cutthroat trout;
- Various Se management and treatment R&D projects and activities; and,
- Other activities including continued Line Creek aquatic health studies, and a Strategic Advisory Panel on Selenium Management.

The overall goal of the EVSTF is to support, implement and communicate Se research for the purpose of protecting water quality and aquatic ecological resources in the Elk River Valley from adverse effects of Se. One of the specific goals of the EVSTF is to provide information on Se-related issues in the Elk River Basin to the public; such information includes the current and previous *Selenium Status Reports.*

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ACKNOWLEDGEMENTS

This report was prepared by Dr. Peter M. Chapman, Golder Associates Ltd (Golder), Burnaby, BC on behalf of the Elk Valley Selenium Task Force. Figures 1, 2, 9, 11 and 16 were prepared by Golder; Figures 3-5 and 15 are provided courtesy of Interior Reforestation Ltd; Figures 6 and 7 are provided courtesy of Spirogyra Scientific Consulting; Figure 8 is courtesy of Nautilus Environmental; Figures 10 and 17 are courtesy of Lorax Environmental Services Ltd; Figure 12 is courtesy of MacDonald Environmental Sciences Ltd; Figure 13 is courtesy of Jody Frenette. Photographs in this report were provided by (in alphabetical order): Stephane Brienne (ART); Stephen Day (SRK); James Elphick (Nautilus Environmental); Alan Martin (Lorax Environmental Services); Les McDonald (Spirogyra Scientific Consulting); Mike Robertson (Interior Reforestation); and, Chad Wilkinson (University of British Columbia, currently with Ecosystems Consulting LLP). Final formatting of the document was done by George Gorczynski (Golder). Useful review comments were provided by members of the Elk Valley Selenium Task Force (membership list provided in Appendix A).

I. INTRODUCTION

I.I BACKGROUND

Selenium (Se) is a non-metal discovered in 1818 by the Swedish chemist Berzelius, and named after Selene, the Greek goddess of the moon. It is a naturally-occurring substance, and an essential element required for the health of humans, other animals and some plants.

However, in excess, Se can be harmful. Selenium can be particularly harmful to egg-laying animals, specifically fish, water birds and amphibians that feed in or from water bodies containing elevated Se concentrations. Inorganic Se released naturally through the weathering of Se-containing rocks or whose natural release is accelerated by mining, can be modified by bacteria and microalgae in lakes, ponds or wetlands into an organic form that can be accumulated by the adults of these egg-laying animals through their diet. Selenium is transferred to the eggs where, during the development of the embryo, it can substitute for sulphur in the production of amino acids and ultimately proteins, resulting in deformities or even death of the embryos, depending on the amount of Se present in the eggs (Chapman et al. 2009a, 2010).

The *Selenium Status Reports* date back to 2003. The first such *Report* was published by the five coal mines in the Elk Valley, and was intended to provide a synthesis of information up to that date relating to investigations of Se fate and effects in the Elk River Valley and to indicate future research priorities. Subsequent *Selenium Status Reports (2004, 2005/6, 2007)* were published by a multi-stakeholder group, the Elk Valley Selenium Task Force (EVSTF – see **Section 1.2**).

The objective of the present *Selenium Status Report 2008/2009* is to summarize new information on Se in the Elk River Valley that has become available since the last Report, i.e., for the period February 2008 through April 2010, and which has been presented to the EVSTF.

For copies of this or previous Status Reports, or to provide feedback, you can contact:

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Elk River

I.2 ELK VALLEY SELENIUM TASK FORCE (EVSTF)

The EVSTF was established in 1998 to investigate the potential environmental effects of Se in the Elk River watershed. The Task Force is a joint industry-government steering committee consisting of representatives from: the BC Ministry of Environment (MoE); the BC Ministry of Energy, Mines and Petroleum Resources (MEMPR); Environment Canada; each of the five Teck Coal Ltd mines in the Elk River Valley; the corporate Environment, Health and Safety Departments of Teck and Teck Coal; and, a Secretary and Technical Advisor **(Appendix A)**.

High pit wall at Line Creek Operations showing coal-bearing strata

The EVSTF's Mission Statement (revised 2009) is "To support, implement and communicate selenium research for the purpose of protecting water quality and aquatic ecological resources in the Elk River Valley from adverse effects of selenium." The EVSTF's current objectives are to:

1. "Support the research and development of selenium reduction and control technologies for use in the Elk River Basin;
2. Support research and monitoring to develop and refine selenium management triggers for water, sediment and biota and effects thresholds appropriate for local ecological receptors in the Elk River Basin;
3. Provide scientific input to regulatory agencies for the development of site-specific environmental quality objectives for selenium in the Elk River Basin;
4. Provide a scientific forum for input into selenium management in the Elk River Basin; and,
5. Provide information on selenium-related issues in the Elk River Basin to the public."

The EVSTF's Terms of Reference (revised as of November 16, 2009) are available on request. The EVSTF conducts its business via face-to-face meetings (two to three per year), teleconferences, and e-mail correspondence. Subcommittees are formed to address specific issues; these subcommittees report back to the Task Force as required. Meeting Notes from previous EVSTF meetings are available on request. All work conducted on behalf of the EVSTF is: done under the direct supervision of a Project Manager appointed by the EVSTF; generally awarded on a competitive bid basis; and, when complete and of appropriate quality, approved for publication in the primary scientific literature following review and approval by all members of the EVSTF. The present *Selenium Status Report* was developed to provide information to the public, and has been approved for publication and release by the EVSTF. Additional information is provided via presentations at scientific conferences, and publications in peer-reviewed scientific journals as detailed herein and in previous *Selenium Status Reports*.

Westslope cutthroat trout

2. SELENIUM STATUS TO APRIL 2010

A map showing the location of the five coal mines in the Elk River Valley is provided in **Figure 1**. Selenium concentrations continue to increase in the Elk River (**Figure 2**).

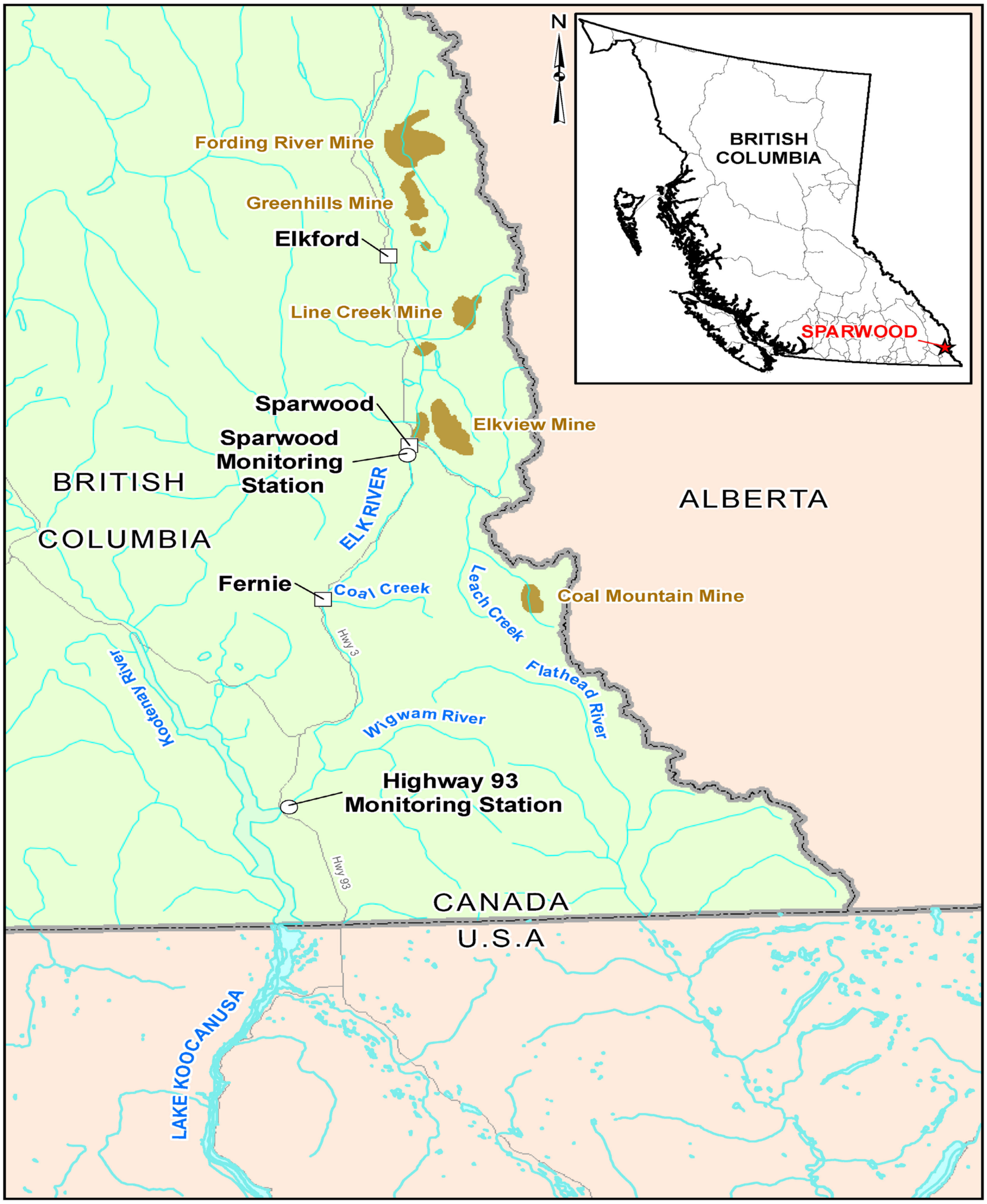


FIGURE 1. The Elk River Valley, showing the locations of the five coal mines, two Federal-Provincial water quality monitoring stations (Sparwood and Highway 93) and Lake Koocanusa.

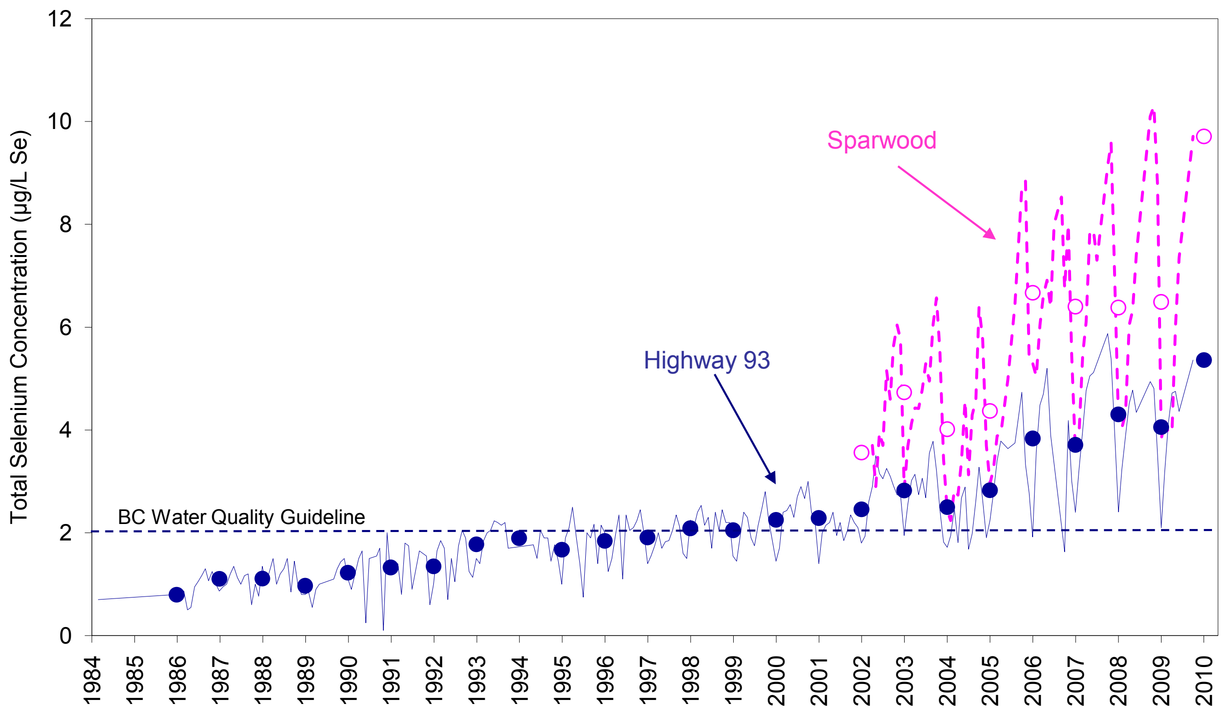


FIGURE 2. Selenium concentrations downstream of the mines at the Highway 93 Federal-Provincial water quality monitoring station (filled diamonds = annual means, solid line = individual measurements) and at Sparwood, upstream (open circles = annual means, dashed line = individual measurements). Dashed horizontal line is the BC water quality guideline for total Se (2 µg/L).

2.1 REGIONAL MONITORING

2.1.1 Selenium in Water, Sediments and Biota in the Elk River Valley

The previous *Selenium Status Report 2007* provides details of regional monitoring of Se in water, sediments and biota in the Elk River Valley conducted in 2006 (Minnow Environmental et al. 2007). This monitoring program has been conducted on a three year cycle. The report on the 2009 monitoring had not been finalized as of April 2010. The Executive Summary from that report is thus not provided herein but will be included in the next *Selenium Status Report.*

2.1.2 Mapping of Lotic and Lentic Waters of the Elk River Valley

A study was conducted to determine the relative proportions of lotic (moving water) and lentic (still water) areas in the Elk River Valley, especially within and below the mines (Polzin et al. 2008). Lentic areas are of more concern for possible adverse Se effects than lotic areas (Chapman et al. 2010). Thus, this study is expected to assist in focusing future Se research and assessments. The Executive Summary and three figures from that study (**Figures 3-5** herein), are provided in the following pages.

EXECUTIVE SUMMARY

"The Elk Valley Selenium Task Force (EVSTF) through the Elk Valley Coal Corporation (EVCC [now Teck Coal Ltd]) retained Interior Reforestation Co Ltd (Interior) to complete watershed mapping to determine the relative proportion of lentic (standing) and lotic (moving) waters in the Elk River Valley downstream of the mines. Understanding the extent of lentic areas is of particular importance because these areas (e.g., wetlands, marshes, backwater areas) have a greater potential to convert inorganic selenium to its organic form, which has been identified as a concern for animals. This work was intended to assist in understanding the overall relative distribution of each type of area downstream of the mines and will assist in focusing future selenium research and assessments.

Mainstem and tributary areas downstream of the coal mines and within the mines' boundaries were videotaped from a helicopter using the Red Hen geo-spatial video product in September and October of 2007. The video was analysed and following field reconnaissance of priority areas, lentic and lotic areas were delineated on Terrain Resources Inventory Mapping (TRIM) orthophoto base maps using Geographic Information System (GIS) applications. Lotic areas were defined as the active channel where water has a relatively short retention time (seconds to minutes), while lentic areas had a longer retention time (hours to weeks). Lentic areas were distinguished as either:

> Lentic 1 Areas - Standing water area (i.e., pond, backwater, relict channel or wetland area) apparent at base stream flow conditions; or
>
> Lentic 2 Areas - Wetlands that were not wetted at base stream flows, but that are expected to be wetted during mid to high flow periods for a significant portion of the year. The outlying boundary for these lentic areas was defined by vegetation, soils and topography visible in the aerial images, from ground-truthing and, where appropriate and possible, from earlier vintage air photos and other historic information.

Lentic 1a areas or standing water areas that were surrounded by lentic 2 wetlands were uniquely identified to avoid duplication of area calculations. Anthropogenic pools were also identified separately from the lentic 1 and 2 wetlands and were not included in the lentic area calculations.

This study area includes the following subbasins (or portions thereof): Elk River, Erickson Creek, Fording River, Henretta Creek, Line Creek and Michel Creek. Findings have been presented in attribute tables by subbasin, on a 1:175,000 scale overview map and on detailed 1:10,000 scale geo-referenced maps. The data reveals that the project area is comprised of approximately 139 ha lentic and 976 ha lotic habitat, respectively representing 12% and 84% of the aquatic area assessed. The Elk River subbasin had the greatest total extent of aquatic habitat assessed (838 ha) and subsequently the greatest extent of lentic area (93 ha). The Fording River had the second largest area of total aquatic habitat assessed (180 ha), and lentic habitat (33 ha). The results also revealed that anthropogenic pools made up a large percentage of the aquatic area in the Fording River (17%), Henretta Creek (38%) and Line Creek (30%) subbasins.

In the study area, 31 of the lentic areas were large enough to be classified under the Forest Practices Code (FPC). Most of these (28) were classified as W3 wetlands since they were between 1 and 5 ha in size. There were two W1 wetlands (greater than 5 ha) and one W5 wetland complex. The majority of these FPC classified wetlands were located in the Elk River subbasin. There was variation amongst wetlands in terms of potential fall and spring accessibility for fish. Video interpretation suggested that many of the wetlands would not be accessible to fish in the fall, under low flow conditions. However, in the spring under higher flows, the fish accessibility to most of the wetlands was expected to improve."

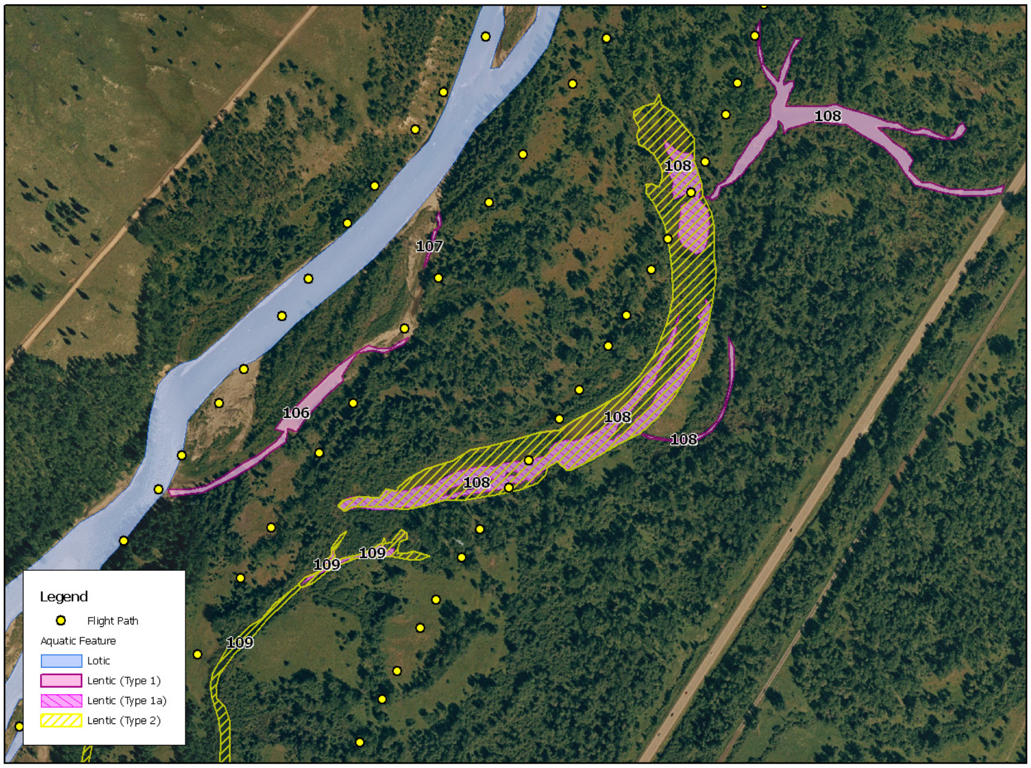


FIGURE 3. Representative site along the Elk River showing delineation of discrete wetted ponds (lentic1), embedded wetted ponds (lentic 1a), and lentic 2 areas (the whole wetland complex) [Figure 3 from Polzin et al. (2008)]**.**

FIGURE 4. Lentic 1 and lentic 2 areas associated with a beaver dam on Michel Creek [Figure 4 from Polzin et al. (2008)].

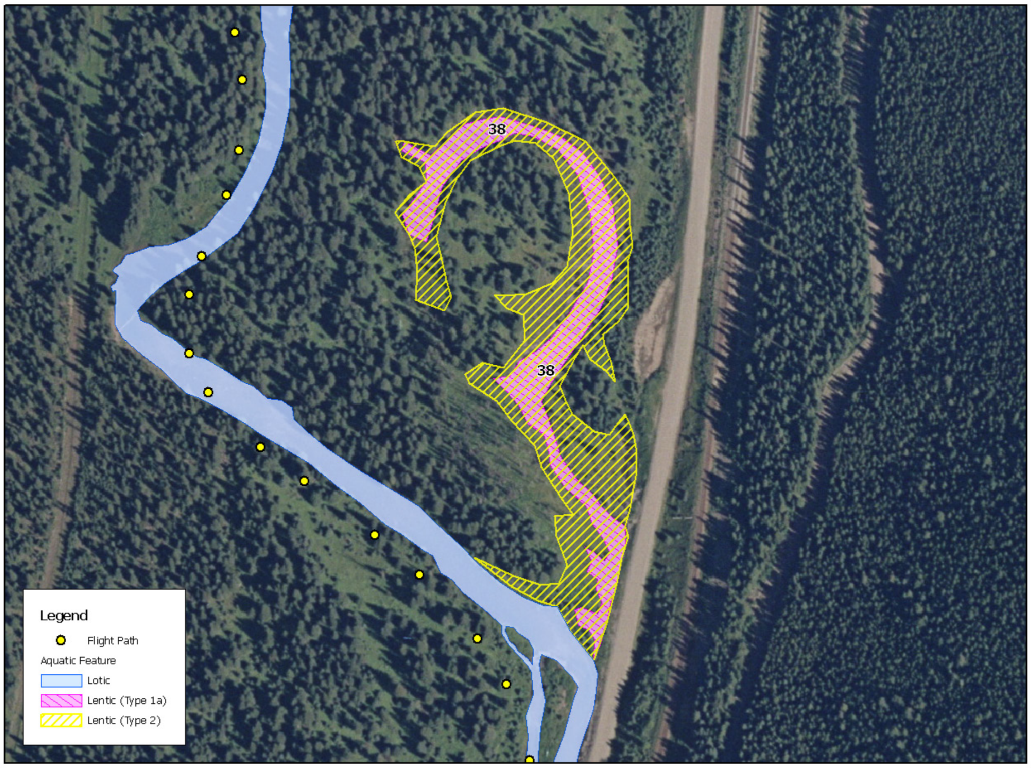


FIGURE 5. Forest Practices Code - W3 wetland on the Upper Fording River at Site 38 [Figure 6 from Polzin et al. (2008)].

2.1.3 Selenium in Water, Sediments and Biota in Lake Koocanusa

A 2008 study examined Se concentrations in water, zooplankton and fish from Lake Koocanusa, which receives water from the Elk River (**Figure 2**). The Executive Summary from that study (McDonald 2009) is provided below together with two figures from that report (**Figures 6** and **7**, herein).

EXECUTIVE SUMMARY

"In August of 2008, a survey of selenium (Se) in water, zooplankton and fish (with a focus on kokanee) in Lake Koocanusa, upstream and downstream of the Elk River confluence, was conducted by Kootenay Region, Environmental Protection staff. Selenium is elevated in the Elk River as a result of coal mining within the basin, averaging 4.26 µg/L in 2008, compared to 0.09 µg/L in the Kootenay River. The goal of this study was to determine metals concentration, specifically Se, above and below inputs from the Elk River, to answer the following questions: 1) Are there risks to the aquatic environment, based on a comparison with current aquatic life water quality guidelines and tissue-based thresholds; 2) Do these data corroborate historical data for Lake Koocanusa, where available; and 3) Are there significant differences in concentrations among the sites?

Historic flow gauging and water quality monitoring indicate that while the Elk River supplies approximately 26% of the water flowing into Lake Koocanusa, in 2008 it was responsible for 95% of the total Se loading. The Se loading from the Elk River in 2008 was estimated to be 10 t/yr, a 5-fold increase from 1.9 t/yr in 1986.

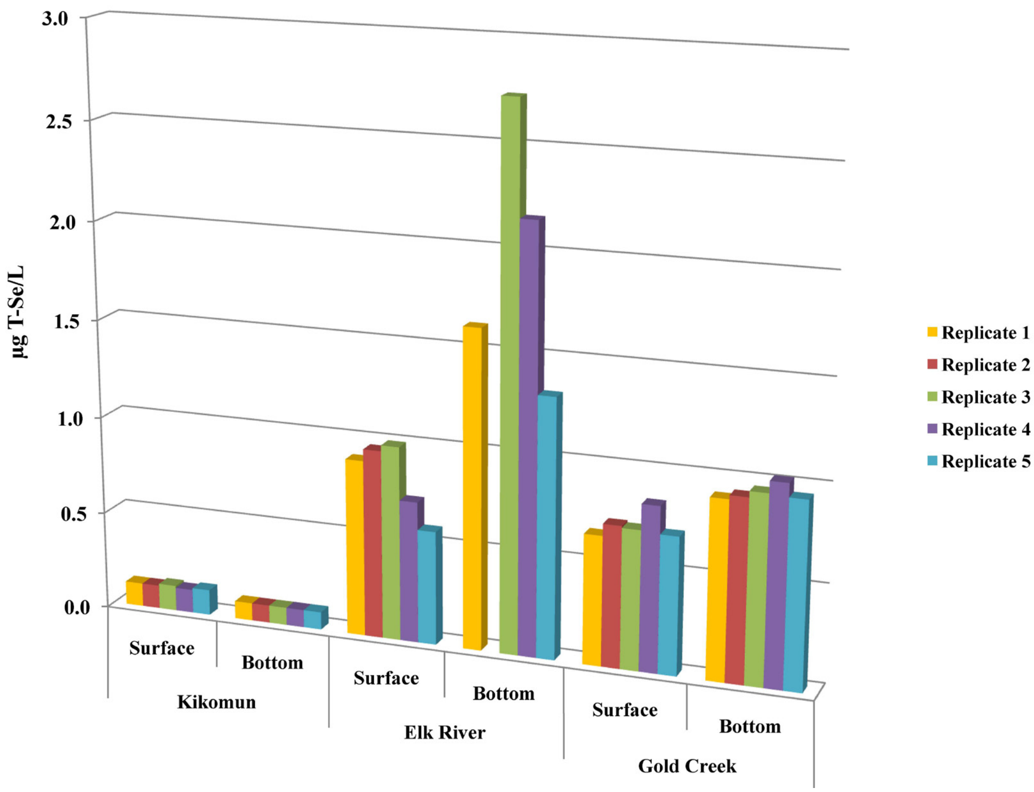


FIGURE 6. Selenium concentrations in water, Lake Koocanusa [Figure 9 from McDonald (2009)].

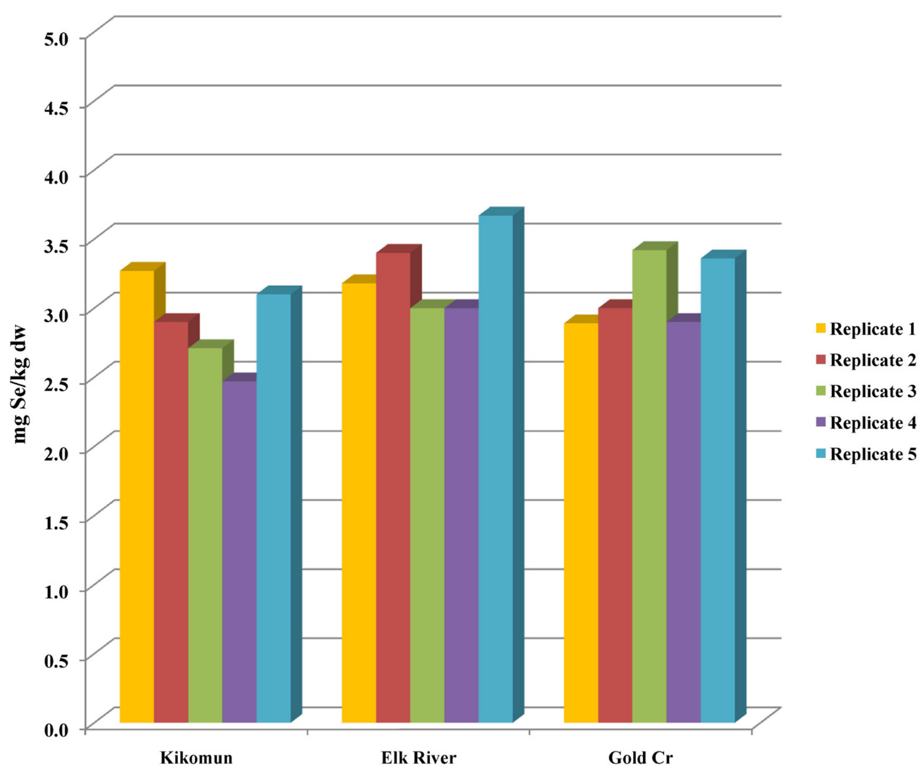


FIGURE 7. Selenium concentrations in zooplankton, Lake Koocanusa [Figure 10 from McDonald (2009)].

In this survey the influence of Se loadings from the Elk River on water column concentrations in Lake Koocanusa was apparent, with an average of 0.11 µg/L upstream, 1.33 µg/L in the Elk River forebay, and 0.84 µg/L at a location 17 km below the confluence [**Figure 6**], all differences being statistically significant. At all three locations, surface water Se concentrations were higher near the bottom of the reservoir compared to the surface, probably as a result of uptake by bacteria and phytoplankton in surface waters and subsequent downward transport due to settling.

The 8 to 12 fold increases in water-column Se at the downstream sites were not reflected in zooplankton uptake from the same locations, where respective averages were 2.89, 3.25, and 3.11 µg Se/g dw [**Figure 7**], and these differences were not statistically significant.

Research has found that the major pathway of Se bioaccumulation in fish is food-chain transfer rather than direct uptake from water, thus Se concentrations in kokanee should more resemble those of the zooplankton than the water-column. This was indeed found to be the case in this survey, with mean kokanee whole body Se of 2.11, 2.49, and 2.61 µg/g dw from the same water and zooplankton sampling locations, respectively. Only the difference between the Kikomun (2.11) and Rexford (2.61) site means were found to be statistically significant. As was the case for zooplankton, kokanee whole-body Se did not exhibit the 8 to 12 fold increases at the downstream sites observed in the water-column. Based on recent research in the scientific literature, the reason for the lack of Se bioaccumulation in zooplankton, despite large increases in water concentrations, is hypothesized to be due to limited uptake by the phytoplankton on which they feed, caused by local water chemistry. The dominant form of Se entering the reservoir from the Elk River is believed to be selenate, the least bioavailable form, and its uptake by phytoplankton, is further inhibited by elevated sulphate concentrations, which enter the reservoir from both the Elk and Kootenay Rivers. Selenate uptake by phytoplankton and transfer to upper tropic levels has been reported in the literature to take over a week in laboratory studies and thus may not occur in Lake Koocanusa until nearer the Libby Dam, 70 km downstream. These hypotheses need to be confirmed through additional sampling.

Lake Koocanusa looking south (above) and looking north (below)

A similar, though less extensive survey was carried out in 2002, in which sampling was only conducted at the upstream site. Zooplankton Se concentrations in 2002 at this site were similar to 2008 (i.e., 2 to 3 µg Se/g dw), while concentrations in kokanee were higher in 2002. Kokanee muscle tissue averaged 2.4 µg Se/g dw in 2002 versus 1.82 µg Se/g dw in 2008, while ovary tissue averaged 6.6 µg Se/g dw in 2002 versus 3.43 µg Se/g dw in 2008. Whether these differences are a reflection of annual variation (i.e., fish movement and feeding patterns), differences in sampling and analytical methods, or a real decrease in tissue Se is unknown. Over this 6-year period, the average annual total Se concentration in the Elk River just upstream of the reservoir has risen from 2.4 to 4.26 µg/L.

Peamouth chub were also sampled in 2008, but only at a downstream site near Rexford, Montana. This species was found to contain significantly more Se than kokanee from the same location. Both species were sampled in pre-spawning condition to allow analysis of egg Se, but because peamouth spawn in the spring, kokanee in the fall, samples were taken in May and September respectively. Whether the higher Se in peamouth was due to the time of year, species differences in Se bioaccumulation or differences in diet is not known. The benthic invertebrates which, in addition to zooplankton, form a part of the peamouth diet, were not sampled in this survey and, based on research conducted in other ecosystems, may bioaccumulate greater quantities of Se than zooplankton from the same waters.

None of the data generated from this survey were found to exceed British Columbia Se guidelines for the protection of aquatic life for water (i.e., 2.0 µg/L as a mean of at least 5 samples over a 30 day period) or fish tissue (i.e., (interim) whole body concentration of 1.0 µg Se/g ww as a mean of 5 independent samples). Though the guideline for water could not be properly evaluated because sampling was only carried out over a two day period in August, only 2 of 29 sample results exceeded 2.0 µg/L by a small amount (i.e., the highest result was 2.73 µg/L).

Data were also evaluated using the recently-developed Elk Valley Selenium Monitoring and Management Framework and its step-wise water/biota monitoring triggers, which, if exceeded, prompt certain additional monitoring and management efforts [**Section 2.4, Figure 12**] None of these triggers were exceeded in Lake Koocanusa in 2008 suggesting that no additional ramp-up efforts in terms of monitoring or management need be taken at this time. The Framework does recommend the maintenance of a basic monitoring program even when triggers are not exceeded.

Recommendations were made to repeat this survey in approximately three years, with a number of changes. Some of the more important of these recommended changes include:

- Analysis of water samples for Se speciation (i.e., selenate, selenite, organoselenide);
- Sampling benthic invertebrates, fed on by certain species of fish, that may bioaccumulate Se at greater rates than zooplankton from the same site;
- Sampling additional fish species, prioritized on the basis of the potential exposure to Se through food-chain relationships. Future surveys should eventually sample the Se content of all species present in the reservoir;
- The inclusion of additional sample sites farther down the reservoir, including at least one at Forebay, just upstream of the Libby Dam; and
- The inclusion of stable isotope ratio techniques, that have been employed successfully in the upper Elk River watershed, to identify Se uptake by various primary producers (phytoplankton, detrital microbial flora living on the bottom sediments) and confirm trophic transfer relationships."

2.2 EFFECTS STUDIES

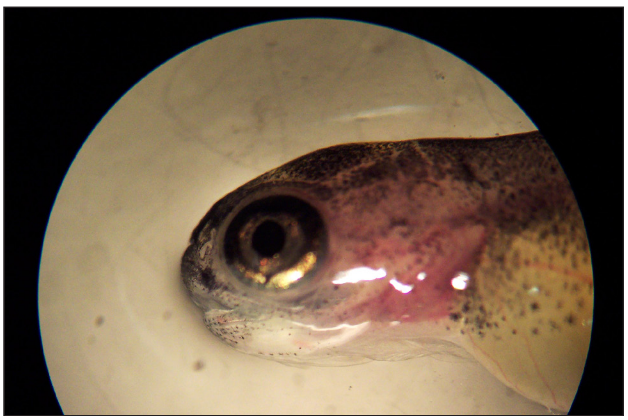
2.2.1 Quality Assurance / Quality Control Guidance for Larval Fish Deformity Assessments

A study was commissioned to assess the environmental implications of larval deformities determined in laboratory effects studies and to recommend quality assurance/quality control guidance for reducing uncertainties associated with this important laboratory test endpoint (Golder 2008). Two presentations at scientific meetings (McDonald et al. 2008a,b) and a peer reviewed journal publication (McDonald and Chapman 2009) resulted from this work. Findings from this study were incorporated into the Nautilus Environmental (2009) cutthroat trout effects study (**Section 2.2.2**). The Executive Summary is provided below.

EXECUTIVE SUMMARY

"Selenium (Se) tissue residue guidelines (TRGs) for fish are based on residue-response relationships between egg Se concentrations and the frequency or severity of larval fish deformities. This report provides an overview of the quality assurance/quality control (QA/QC) aspects of larval deformity data and provides recommendations for improvement of future study designs to reduce the inherent uncertainty in these data. Explicit evaluation of this source of uncertainty on a TRG is clearly warranted given its importance for Se management planning.

Larval westslope cutthroat trout with deformities



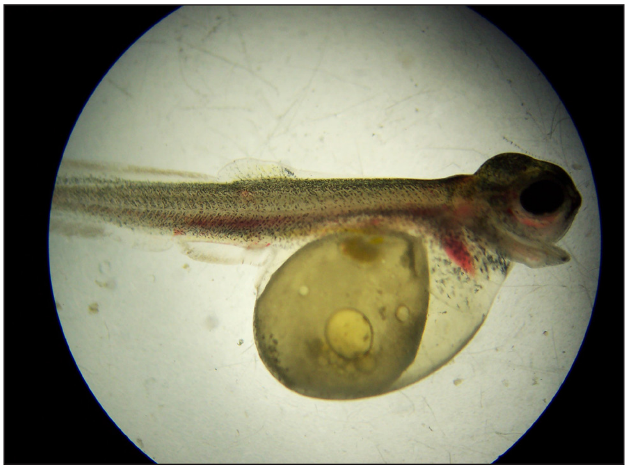
An additional objective of this report was to determine whether the available information supported a differential weighting system for deformity data instead of the common practice of assuming that all deformities are equal irrespective of their type or severity. Three key factors for the development of a differential weighting system were identified: 1) ecological relevance of the deformity in terms of changes in individual fish fitness; 2) reproducibility and overall quality of larval deformity data; and 3) strength of the relationship between egg Se concentrations and the frequency or severity of the deformity. The first two factors were examined in this report.

A literature review was completed to assess the current level of knowledge regarding the ecological relevance of larval fish deformity. Data were highly limited; to our knowledge, ecological relevance has not been directly evaluated for larval fish deformities or edema. This is a significant data gap that prevents the development of a differential weighting system. However, the data were adequate to determine that mild edema was likely reversible and thus unlikely to lead to inevitable mortality of larval fish (as is a common assumption). Data from Rudolph et al. (2006) were evaluated to determine the overall reproducibility of the larval deformity between two observers. To our knowledge, this is the only study with relevant QA/QC information for deformity data: it included a duplicate larval deformity assessment conducted on the same fish by an external observer. There was poor reproducibility between the two observers for nearly all types and magnitude of deformity; however, there were particularly large differences in how mild deformities were assessed. The reproducibility of the edema endpoint was the poorest of the four types of deformity evaluated.

Recommendations for the improvement of future Se reproductive toxicity tests are provided in light of the findings of the literature and data review. These recommendations focus on guiding principles (with suggested actions that can be modified in the context of a given study design) to quantify (and to the extent possible, reduce) the uncertainty in larval deformity data. Data quality objectives for larval deformity data are proposed, along with examples of how the proposed QA/QC actions should be applied."

2.2.2 Cutthroat Trout Effects Study

A westslope cutthroat trout Se effects study was conducted (Nautilus Environmental 2009, building on two previous effects studies with the same species (Kennedy et al. 2000; Rudolph et al. 2008). Two presentations were made at scientific meetings (Elphick et al. 2009a,b). The Executive Summary and one figure (**Figure 8**, herein) from the final report on that study are provided below. Additional work is being conducted to resolve several issues related to chemical laboratory analytical variability that could influence the final effects threshold (**Section 3.2**). Once these issues are resolved, a paper will be prepared and submitted for publication in a peer-reviewed scientific journal.



Larval westslope cutthroat trout with attached yolk sac

Westslope cutthroat trout were held in a stream section then spawned

EXECUTIVE SUMMARY

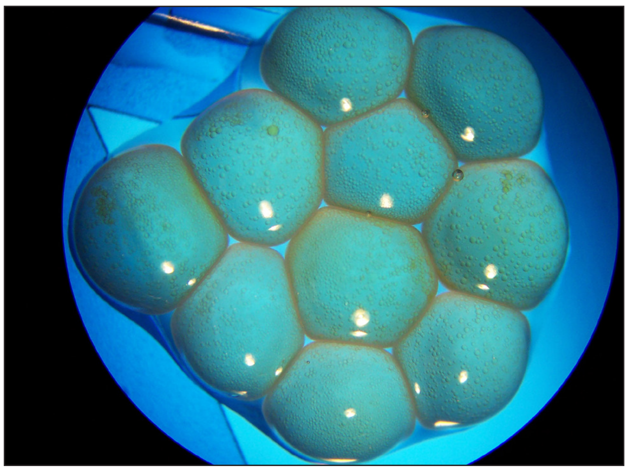
"Selenium concentrations in parts of the Elk River basin have become elevated as a result of mobilization of this metalloid from seleniferous rock. Selenium mobilization has been accelerated by coal mining activities, which disturbs the rock and increases its surface area, thereby facilitating leaching. The selenium enters the aquatic environment, where organisms such as fish, water birds, invertebrates and plants become exposed.

Selenium causes adverse effects in egg-laying vertebrate species as a result of accumulation of selenium in the egg, where it occurs primarily as selenium-containing amino acids (i.e., selenomethionine, selenocysteine and selenocystine). Adverse effects occur in the developing offspring as these seleno-amino acids are used to build proteins during embryonic or larval development. Thus, effects associated with selenium can occur without apparent adverse effects on the exposed adults.

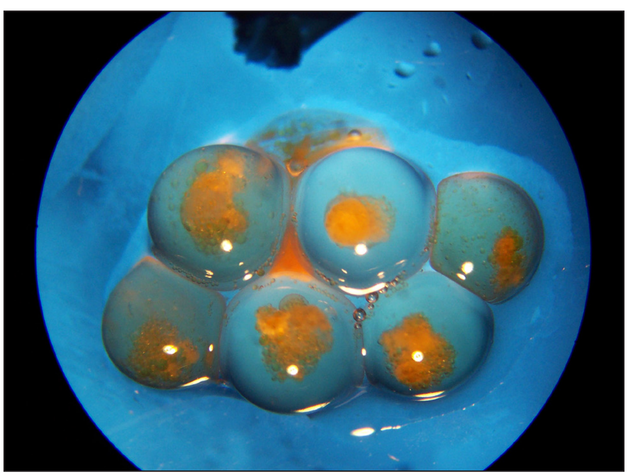
Westslope cutthroat trout is an important ecological and recreational species in the Elk River watershed. Two previous investigations have attempted to establish threshold effect levels for selenium for this species on the basis of tissue concentrations in adult fish. Kennedy et al. (2000) reported no relationship between selenium and larval deformities or mortalities, and a high rate of survival (i.e., >80%) of swim-up fry from two fish that contained the highest egg selenium

concentrations of those tested (approximately 60 and 80 µg/g Se dry weight [dw]). Conversely, Rudolph et al. (2006; 2008) reported adverse effects on embryos before hatching in eggs that exceeded 46.8 µg/g dw Se, and eggs that were not viable in cases where they contained more than 86 µg/g dw Se. The results of both studies were constrained by small sample sizes, which prevented definitive establishment of an effects threshold for selenium for this species. Furthermore, the results raised questions whether the fish used in the Kennedy et al. (2000) study, which were collected from lotic (i.e., flowing water) environments, might have differed ecologically from those used in the Rudolph et al. (2006; 2008) study, which were collected from lentic (i.e., still water) environments.

The present study was conducted to assist in resolving the apparent discrepancies between the two prior investigations. This study was designed to provide sufficient data to establish an effects threshold for westslope cutthroat trout on the basis of tissue concentrations of selenium, as well as to test whether fish collected from lentic and lotic habitats differ with respect to their sensitivity to selenium. In order to establish a mechanism that might explain any observed differences in sensitivity between fish from representative lentic and lotic sites, the selenium species were measured in eggs from a subset of fish used in the study. Differences in speciation of selenium was considered a plausible mechanism that could result in eggs from fish derived from lentic and lotic sites having differing sensitivities to this metalloid.



Normal westslope cutthroat trout eggs (above) and eggs with aggregated lipid vesicles (below)



The study design involved collecting and spawning approximately 30 adult female fish from lentic and lotic environments in areas that would be considered high selenium-exposure sites proximate to Teck Coal's Fording River Operations. Eggs from four female fish collected from Connor Lake were also tested, in order to provide a methodological control; Connor Lake reflects a "reference" site within the Elk Valley watershed that is not exposed to mine discharges. A sufficient number of male fish were spawned and used to fertilize the eggs from each of the female fish once the gametes arrived at the laboratory. The eggs were reared in the laboratory until they reached the swim-up fry stage, at which point, the number, types and severity of deformities were assessed. In cases where sufficient surviving fish remained, only half of the fish from each replicate were used for the deformity assessment, with the remainder being reared for an additional 28 days in order to evaluate the potential for latent adverse effects and to provide a measure of the ecological significance of any deformities observed at swim-up. The results of the study yielded the following major conclusions:

- There was no evidence of significant differences in sensitivity to selenium in offspring from fish collected from lentic and lotic environments with respect to survival or rates of deformity. Consistent with this finding, measurements of speciation of selenium in the eggs also provided no evidence of difference in the forms of selenium present between eggs from adults collected from lentic and lotic sites, although the methods used were unable to distinguish between relative contributions of individual seleno-amino acids.
- The general pattern of effects observed in this study was similar to that described in Rudolph et al. (2006; 2008). In particular, there was a low incidence of adverse effects on survival in eggs containing up to 22.1 µg/g dw Se, with substantial adverse effects (i.e., >40% mortality) observed in eggs containing 31.5 µg/g dw Se, and higher; no eggs were tested that had egg selenium concentrations falling between these values. The EC10, EC20 and EC50 (with 95% confidence intervals) for larval survival at the swim-up stage were 19.0 (6.8 – 22.7), 22.8 (16.3 – 26.6) and 29.9 (26.1 – 33.6) µg/g dw Se in eggs.
- In eggs containing greater than 75 µg/g dw Se, a significant proportion of the eggs broke immediately upon water-hardening. Breakage of eggs during water-hardening, and mortalities of developing embryos were often associated with eggs

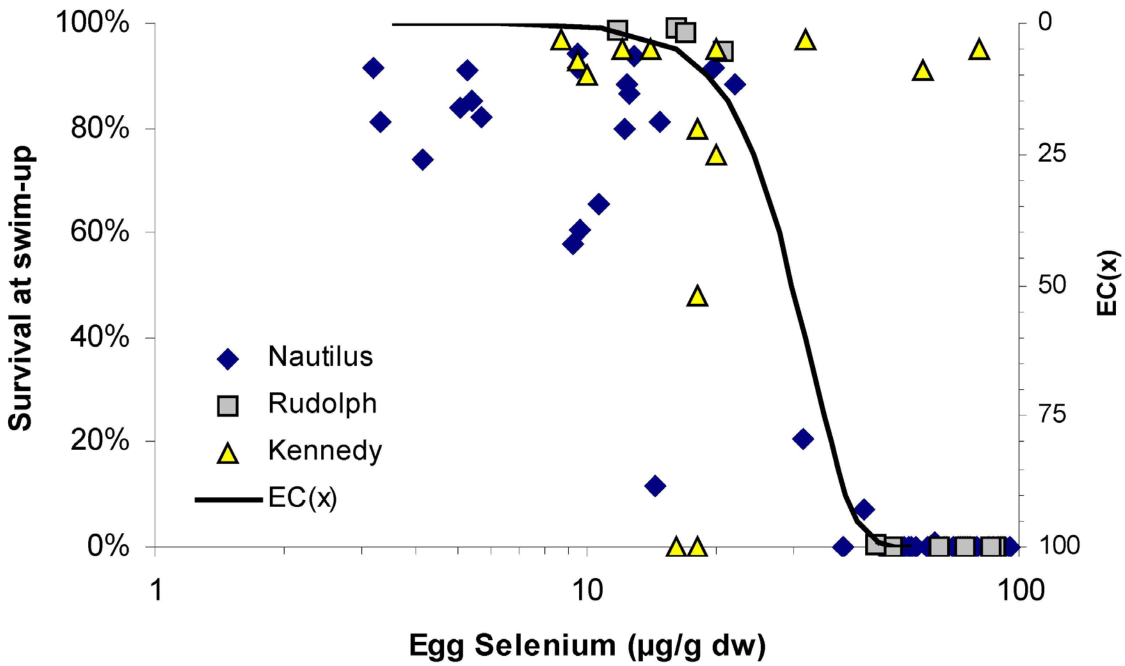


FIGURE 8. Comparison of results of westslope cutthroat trout rearing studies conducted using Elk Valley fish. The non-linear regression line illustrates the point estimate (ECx) data from the Nautilus Environmental (2009) study [Figure 14 from Nautilus Environmental (2009)]**.**

in which lipid vesicles had partially or entirely aggregated. This phenomenon was also related to elevated selenium concentrations, indicating the potential for a secondary mechanism-of-action for selenium toxicosis.

- There was no evidence of selenium-related deformities in fry that produced good survival (i.e., >60%) to the point of swim-up, and containing up to 22.1 µg/g dw Se. After rearing for an additional 28 days, these fry had good survival (i.e., >90%) and growth rates, and a very low frequency of deformities (i.e., <5%), supporting the conclusion that there were no latent adverse effects due to selenium exposure.

This study provides suitable data to establish a tissue-based effects threshold for selenium exposed westslope cutthroat trout from the Elk Valley that would be applicable to fish from both lentic and lotic habitats. These data are supported by those from Rudolph et al. (2006; 2008), whose findings are largely consistent with those presented here. In addition, the results are also consistent with data from Holm et al. (2005), whose data suggest an effect level of between 21 and 26 µg/g dw Se for rainbow trout. The results also compare favourably to the threshold proposed by DeForest et al. (1999) of 17 µg/g dw Se based on ovary concentrations in warmwater fish."

Winter in the Elk Valley

2.2.3 Selenium Bioaccumulation Factors

The development of site-specific water quality objectives requires determination of relationships between tissue Se concentrations (from dietary sources) and water Se concentrations. A study was conducted attempting to determine such relationships for three resident fish species, using data collected over many years. The Executive Summary of this study (Golder 2010) is provided below along with an explanatory figure from a presentation to the EVSTF (**Figure 9**, herein).

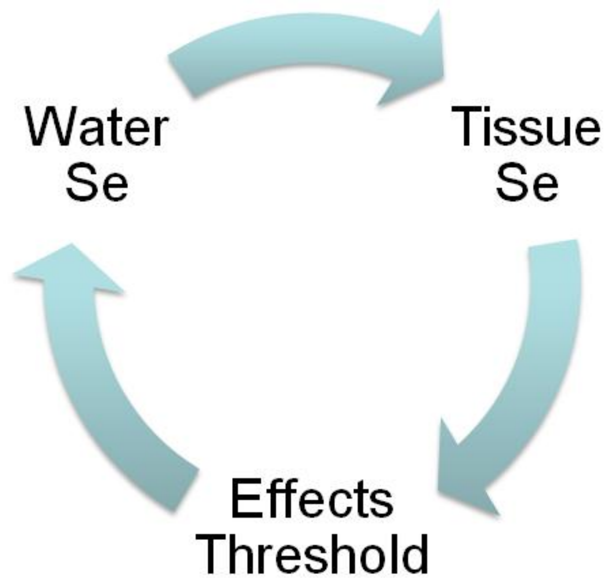


FIGURE 9. The BAF model can be used to estimate tissue Se concentrations from measured or predicted water Se concentrations. From this, it is possible to estimate a water Se concentration associated with a protective tissue Se level [Figure from a presentation given to the EVSTF].

EXECUTIVE SUMMARY

"This report summarizes a study undertaken to develop bioaccumulation factor (BAF) relationships between fish tissue and water selenium (Se) concentrations, with the overall objective of supporting the development of site-specific water quality objectives for Se. A review was conducted of previous studies in the Elk Valley to compile measurements of water, fish tissue (egg or ovary, whole body, muscle) and fish diet Se concentrations. Fish species included in the analysis were westslope cutthroat trout (WCT), mountain whitefish (MWF) and longnose sucker (LNS).

The statistical tools employed were General Linear Models (GLM) and Linear Mixed-effects Models (LMM). GLM was used in preliminary analyses, to investigate differences among species and between lentic and lotic ecosystems. GLM (not LMM) analysis was also used to derive BAF relationships for benthos tissue because there were only single observations per site (i.e., no uncharacterized process error and no pseudoreplication) and only a single tissue (i.e., no repeated measures). LMM analysis was used in the development of BAF relationships for fish, providing an improved characterization of process error (by explicitly recognizing among-site differences), improved power to detect relationships (by simultaneously considering all three tissue types) and reduced incidence of Type 1 errors (i.e., false positive results arising from pseudoreplication).

Each combination of species and ecosystem type (lentic, lotic) was analyzed separately. Each GLM was run as a backward stepwise analysis (i.e., initially specifying a regression model including all predictors in the given subset, then progressively removing the least-significant predictors from the model until only significant predictors remained). Each LMM was specified manually to test selected subsets of the predictor variables. All LMMs included water Se concentration and tissue type (and a water Se × tissue interaction, if significant) as fixed factors, with the multiple tissues within each individual fish treated as repeated measures. All LMMs also included site as a random factor, allowing the model to fit a different intercept for each sampling location. Additional predictor variables were then added as fixed factors to this base model. Tested models included a base model including water Se concentration alone as a predictor variable, and various combinations of additional predictor variables including fish characteristics (e.g., length, weight), habitat characteristics (water quality parameters or stream metrics), and dietary Se concentrations (benthos Se and periphyton Se). The results of these analyses provided a set of candidate BAF models based on various subsets and combinations of potential predictors. Evaluation of the relative predictive power of the candidate BAF models was then based on a consideration of model fit (i.e., coefficient of determination, Akaike Information Criterion), sample size, model residuals, and parsimony (i.e., number of predictors required).

The compiled data supported the derivation of a variety of statistical relationships that enable the prediction of fish Se concentration from water Se concentration and relevant modifying factors. In several cases, inclusion of additional predictor variables provided a substantial improvement in model fit over water Se alone, suggesting that these variables represent important modifying factors in the bioaccumulation of Se. In other cases, however, no model could be identified that was substantially better than the simplest model based on water Se alone. In several GLM relationships, benthos Se was a significant predictor of fish tissue Se. However, benthos-water BAF relationships were either poor (lotic) or based on very limited data (lentic). No satisfactory LMM relationships were identified with benthos Se as a predictor. In general, the potential for predicting fish tissue Se from benthos-to-water and fish-to-benthos relationships appears to be low with the existing data.

The likely predictive power of the BAF relationships varied from low to high. Inspection of plots of LMM-predicted vs. observed tissue Se indicate good fit for lentic WCT, with no apparent bias among tissues and with most predicted values falling within a factor of 2 of observed values across nearly two orders of magnitude. Model fit for lotic WCT was weaker and there was some indication of bias among tissues; the much smaller range of tissue Se in the lotic dataset may have contributed to the reduced model fit. Datasets for LNS and MWF were too small to reliably assess predictive power. The MWF dataset in particular encompassed a very narrow range of Se concentrations within any given tissue. GLM model fit was also generally better for lentic WCT and LNS than for lotic WCT and MWF. The potential for the derived BAF relationships to support development of a WQO appears to be relatively high for WCT, especially in lentic systems, and relatively low for MWF."

2.3 SELENIUM MANAGEMENT AND TREATMENT R&D

Kilmarnock Spoil from Kilmarnock Creek near the Fording River

2.3.1 Literature Review

To support Teck Coal's management R&D program, and to evaluate and prioritize available treatment technologies, Golder (2009) completed a literature review of processes for the removal of Se from mining-influenced water. The Executive Summary from that report is provided below.

EXECUTIVE SUMMARY

"Elevated aqueous selenium concentrations have been detected at multiple mine sites in Alberta and British Columbia. The waterbodies containing elevated concentrations, which exceed the Canadian Council of Ministers of the Environment (CCME) guideline for total selenium of 1 µg/L, range from creeks and rivers to large endpit lakes. The purpose of this paper is to provide a review of the literature for advances in the treatment of selenium in mining influenced water (MIW) and other waters containing selenium derived from non-mining sources. This review focuses on the types of technologies available, discusses the advantages and disadvantages of various treatment options, and identifies the stage of development of each technology, i.e., laboratory studies, pilot scale tests, or full scale treatment facilities. This review is limited to water treatment, which is one of three selenium management tools (Chapman et al. 2009[b]). The other two management tools, prevention of selenium release and control of selenium in the environment, are not reviewed.

Significant research and development of selenium treatment technologies has occurred over the past two decades. The challenge of treating selenium to meet the stringent applicable standards of a few micrograms per liter has led to testing of multiple physical, chemical, and biological treatment methods. Among these methods, proven full-scale treatment is currently being conducted by reverse osmosis, reduction by iron, active and passive microbial reduction, in situ microbial reduction, and wetlands. These methods are capable of meeting applicable standards, and provide a suite of tools to tackle the increasingly important issue of selenium in the environment. Some Canadian mine site discharge flow rates pose a significant design challenge. These rates can be on the order of 250,000 m^3/day (45,863 US gallons per minute), significantly greater than the highest selenium treatment plant flow rate of 7,630 m^3/day (1,400 US gallons per minute). Although full-scale treatment of selenium is proven, it has not been demonstrated for flow rates typical of the Canadian mine sites.

In the past five years, biological treatment has emerged as a leading technology for selenium treatment. Biological treatment offers a low cost alternative to more expensive physical and chemical treatment methods and is effective in cold climates. Additionally, it has the proven ability to meet regulatory selenium limits. Several different types of active microbial reduction biological systems are currently in operation, including Upflow Anaerobic Sludge Blanket Reactors and Anaerobic Fixed Film Bioreactors. Passive and in situ microbial reduction biological treatment systems have the lowest operating costs but have not been developed at full-scale to the same extent as active microbial systems."

2.3.2 Geochemistry of Selenium in Lentic Environments in the Elk River Valley

Lorax Environmental Services (2009) investigated the biogeochemical behavior of Se in two lentic environments in the Elk River Valley. The Executive Summary and one figure from that study (**Figure 10**, herein) are provided below. A presentation was made at a scientific meeting (Martin et al. 2008) and a manuscript is being prepared for submission to a peer-reviewed scientific journal (Martin et al. in preparation). A follow-up study is also underway (see **Section 3.3**).

West Line Creek (above) and West Line Creek Settling Ponds (below)

EXECUTIVE SUMMARY

"Field studies were conducted in two lentic environments in the Elk River Valley between August and September 2007, to expand our current understanding of selenium (Se) behaviour in mine-influenced lentic systems. The study approach focused on the collection of high-resolution vertical profiles of Se species in sediments, bottom water and porewater, with the primary objective being to delineate the biogeochemical processes governing the post-depositional behaviour of Se.

Goddard Marsh (GM) is located immediately downstream of a sediment pond discharge from Elkview Mine and comprises a dense cattail marsh (~4 ha in area) with limited areas of open water. Fording River Oxbow (FRO) is located adjacent to the Fording River approximately 6 km downstream of the Fording Mine. The oxbow feature extends for approximately 350 m and comprises a series of narrow channels and open ponds which are in permanent and/or seasonal exchange with the Fording River. Both GM and FRO are depositional in nature, host fine-grained, organic-rich sediments, and receive Se-rich drainages associated with the leaching of Se from mine-related geologic materials. Total Se concentrations in surface waters at the time of study at GM and FRO were 24 and 21 µg/L, respectively.

At both GM and FRO, the speciation and behaviour of Se are strongly linked to sedimentary redox (reduction-oxidation) conditions. However, subtle differences exist between the depositional environments at GM and FRO that have marked influences on redox conditions and thus Se behaviour. GM is characterized by significantly higher concentrations of organic-carbon (25 to 30% dry wt) in sediments compared to FRO (5 to 7% dry wt). Sedimentary C-Org:N ratios suggest that the organic matter at GM is composed largely of decomposing wetland vascular plants (cattails), while that at FRO reflects primarily non-vascular aquatic plants (algae). High-resolution profiles of redox-sensitive parameters (dissolved oxygen, nitrate, iron, manganese, sulphate and hydrogen sulphide) across the sediment-water interface at FRO show the presence of aerobic (oxic) conditions at the sediment-water interface. In contrast, profiles of these parameters at GM show that suboxic conditions extend into the water column. The more reducing sedimentary conditions at GM can be linked to the presence of emergent vegetation at this site. Emergent vegetation provides an abundant source of organic matter and affords a low-energy environment conducive to the development of chemical stratification in the lower water column.

Lentic areas in the Elk River Valley

Total Se concentrations in sediments at GM (mean = 37 mg/kg dry wt) and FRO (mean = 10 mg/kg dry wt) are significantly greater than concentrations reported for various lithologies of coal-bearing strata in the Elk Valley region, and suggest that the deposition of particulates (fines) exported from the mine sites do not contribute significantly to the sediment Se burden. Porewater and solid-phase speciation data suggest that the enriched levels of Se in sediments at GM and FRO relate primarily to: 1) in situ precipitation of elemental Se; and 2) accumulation of organic Se. The higher total Se content at GM indicates that the emergent-rich setting at this site is more favourable for the accumulation of solid-phase Se, reflecting greater accumulations of both organic and elemental Se as revealed by x-ray absorption near-edge structure (XANES).

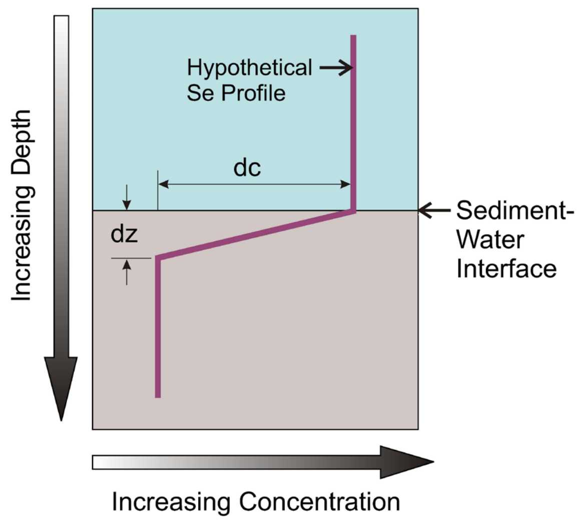


FIGURE 10. Hypothetical concentration profile of dissolved Se across the sediment-water interface showing change in concentration (dc) over the depth of the concentration gradient (dz) [Figure 3-18 from Lorax Environmental Services (2009)].

At both GM and FRO, dissolved Se values decrease across or below the sediment-water interface, demonstrating that the sediments at both sites are serving as diffusive sinks for dissolved Se, where Se is being removed from solution as reduced Se forms. Undetectable levels of selenate (SeVI) in sediments by XANES suggest that the removal of selenate from solution involves a commensurate reduction step to selenite (SeIV), elemental Se (Se0), and/or selenide (Se-II). Peaks of dissolved selenite and organo-Se observed near the sediment-water interface at both GM and FRO demonstrate that these species are recycled back into the water column. The emergent-rich setting at GM is more favourable for the recycling of dissolved Se species into bottom waters. The more anaerobic redox zonation at GM favours the recycling of reduced species in two ways: 1) selenite and organo Se are re-mobilized closer to the sediment-water interface which translates to a shorter diffusive path length and larger flux to the water column; and 2) the suboxic conditions in the lower water column at GM limit the attenuating effects of oxidation/re-precipitation. In this regard, the conditions at GM are predicted to be more favourable for the accumulation of Se in sediment-detrital food chains. This conclusion is consistent with the results of another study that examined Se food chain transfer at these lentic sites, and which showed higher Se contents in the tissues of benthic invertebrates at GM in comparison to FRO.

With regards to environmental management, the results demonstrate that those conditions that are more favourable for Se bioremediation in wetland systems (via Se removal to sediments) are also more conducive to the food chain transfer of Se. Therefore, environmental strategies may differ depending on objectives. Nutrient control and vegetation control are discussed from the perspective of minimizing the food chain transfer of Se. The potential for Se removal from wastewaters through bioremediation using pond/wetland environments, end-pit lakes and permeable reactive barriers is also discussed. Cost-effective indicators that can be used to assess the relative-risks of Se exposure to faunal assemblages in lentic zones are provided. Recommendations for future work are focused on better understanding the merits of bioremediation as they relate to pond/wetland environments and end pit lakes. Specific recommendations include: 1) quantify existing removal rates of dissolved Se at GM through the generation of a seasonal mass balance; 2) quantify Se levels in plant tissues (leaves, stem, rhizomes and fine roots) at GM to better explain Se removal mechanisms; and 3) assess the suitability of pit lakes for bioremediation through seasonal characterization of pit lake vertical structure, thereby delineating the timing, duration and frequency of vertical mixing events."

Upper Erickson Stream – Evaluated as a candidate site for Se removal R&D (see Section 3.3)

2.4 SELENIUM EXPERT PANEL WORKSHOP AND REPORT

A workshop was held in Vancouver on February 5-6, 2008 to enable an independent, high-level review of all Se studies conducted to that date in the Elk River Valley, including identifying key uncertainties and the path forward. Recommendations arising from that workshop have been prioritized and refined by the EVSTF; most of them have been implemented. The final report from that expert review (Canton et al. 2008) has no Abstract or Executive Summary; thus, the Summary and Conclusions are provided below together with two figures from that report (**Figures 11** and **12**, herein).

SUMMARY AND CONCLUSIONS

"A workshop was convened in Vancouver on February 5 and 6, 2008 to provide four selenium experts with an opportunity to share their perspectives on a variety of issues related to the sources and releases, transport and fate, and effects of selenium in the Elk Valley and to develop specific recommendations for addressing these issues. The workshop was attended by over 30 individuals with an interest in selenium-related issues in British Columbia.

This workshop was intended to support the development of strategies for management of selenium in the province, including the determination of regulatory limits for selenium in the Elk Valley. Accordingly, the selenium experts reviewed the existing Elk Valley selenium studies and evaluated the overall conclusions that have been drawn from these studies. In addition, the selenium experts identified major data gaps about the potential impacts of selenium and determined if it is possible to establish regulatory limits for selenium with the available data and information. Furthermore, the selenium experts recommended studies that would support the further identification of toxicity thresholds for selenium. The selenium experts also identified future monitoring priorities for selenium originating from the coal mines, based on their reviews of the available data and information on selenium in the Elk Valley. The six questions that were posed by the EVSTF were explicitly addressed in the technical reports that were prepared and the technical presentations that were delivered by the selenium experts.

In the second half of the workshop, the selenium experts identified four key undertakings that would substantially contribute to the assessment and management of selenium in the Elk Valley. First, the selenium experts determined that development of a conceptual site model (CSM) would facilitate an enhanced understanding of issues and concerns related to selenium releases into the environment. Accordingly, the selenium experts reviewed the existing CSM that was developed by Golder Associates Ltd. (2007: termed a selenium decision framework in that document) and identified a number of refinements that were needed to establish a detailed conceptual model of the selenium problem in the Elk Valley. The resultant CSM effectively links coal mining activities to potential ecological receptors by defining the sources and releases of selenium, describing transport and fate mechanisms, evaluating the ecological effects of selenium, identifying potentially complete exposure pathways, and determining the ecological receptors potentially at risk (See Figure 1 for more information). [Note added: the CSM revised based on the Expert Panel's input has been published in the peer-reviewed literature (Chapman et al. 2009b); Figure 1 from this report is reproduced here as **Figure 11**] Assessment and measurement endpoints were identified based on the refined CSM that was developed and the experts' experience in this field.

The selenium experts identified the need for an effective framework for monitoring and managing selenium in the Elk Valley. Accordingly, the selenium experts developed a monitoring and management framework (i.e., decision tree with feedback loops) that identifies the management actions that should be taken if critical selenium concentrations (i.e., triggers) are exceeded in environmental media. Application of the framework requires data and information on the concentrations of selenium in water, in tissues of invertebrates that represent prey organisms, and in the tissues of fish, amphibians, and/or birds that utilize habitats within the Elk Valley (see Figure 2 for more information [Note added: Figure 2 from this report is reproduced on page 24 as **Figure 12**]).

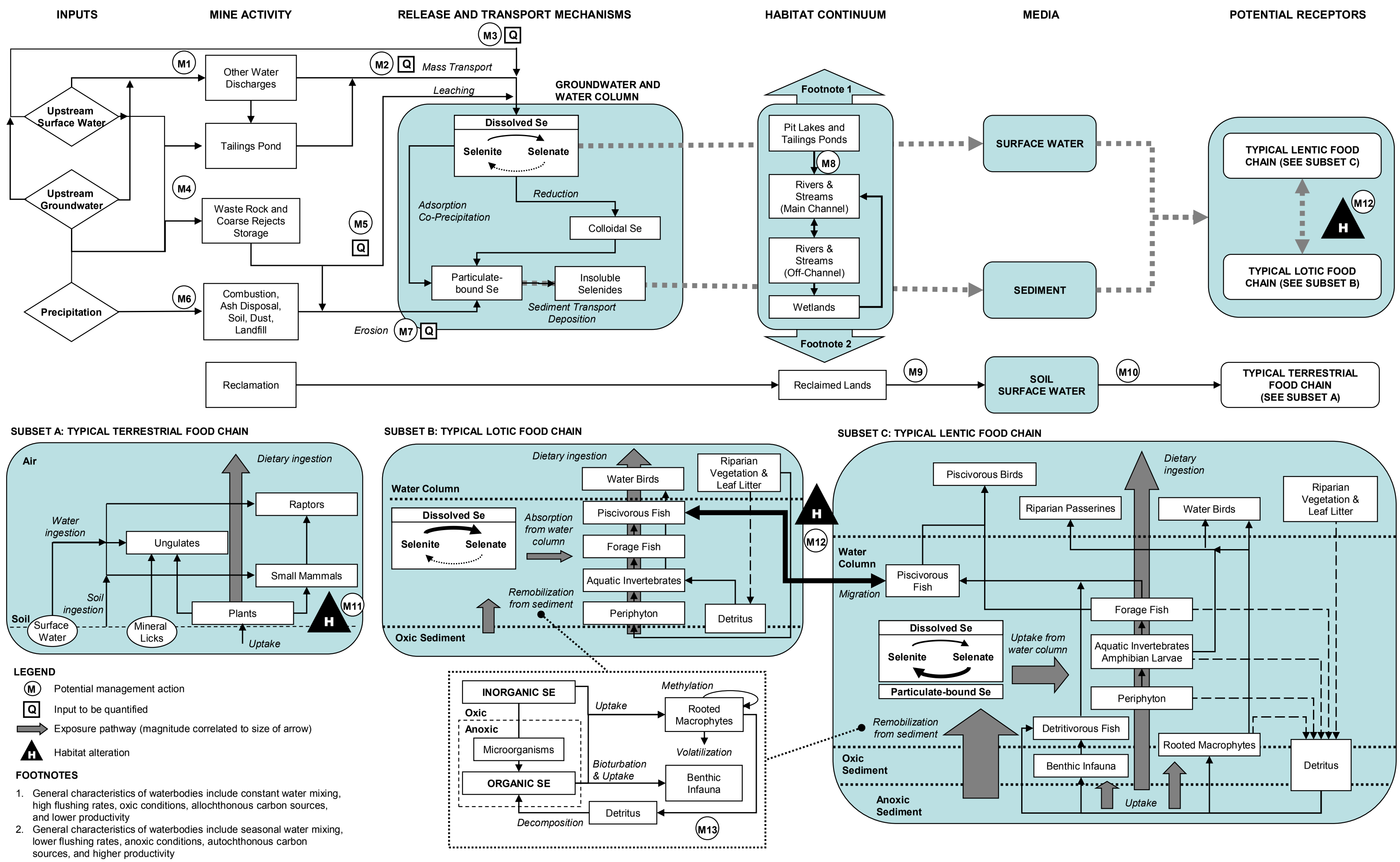
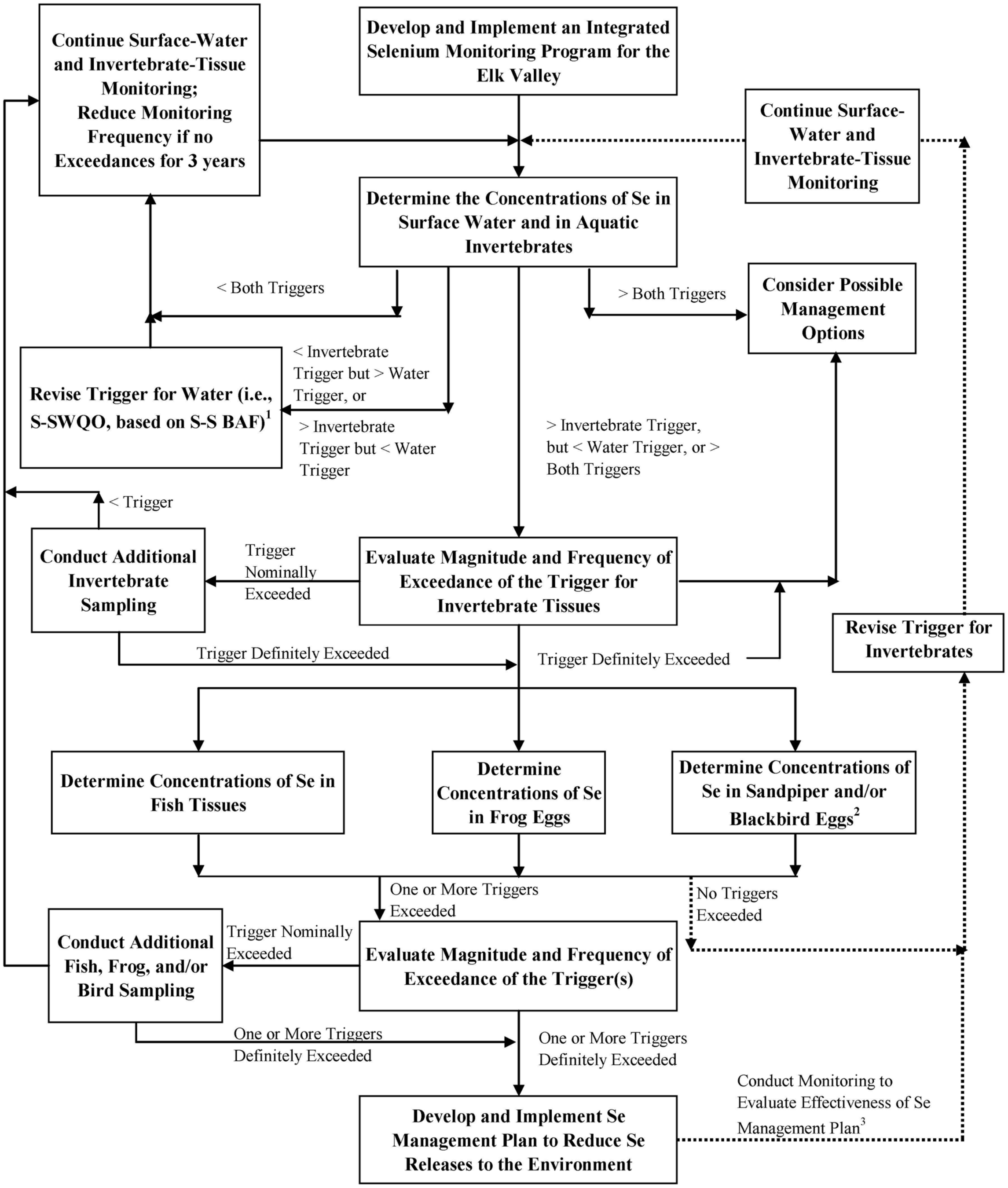


FIGURE 11. Conceptual site model (CSM) for Se in the Elk Valley [Figure 1 from Canton et al. (2008); also Figure 1 from Chapman et al. 2009b)].



[1] S-SWQO = site-specific water quality objectives; S-SBAF = site-specific bioaccumulation function.

[2] Depending on whether lotic or lentic ecosystesm had exceedances of the invertebrate trigger.

[3] Triggers for fish, amphibians, and birds may be refined periodically, based on site-specific investigation results.

FIGURE 12. Recommended assessment and management framework for Se in the Elk Valley [Figure 2 from Canton et al. (2008)].

The selenium experts established triggers that could be applied to the selenium monitoring and management framework. In this context, the term trigger is defined as the concentration of selenium in an environmental medium (e.g., water, invertebrate tissues, fish tissues, amphibian tissues, and/or bird eggs) that, if exceeded, would prompt a specific management response. Such responses could range from continued environmental monitoring to development and implementation of a management plan to reduce inputs of selenium into aquatic ecosystems. The proposed management framework also allows modification of these triggers, based on the findings of site-specific and/or other investigations.

Following the technical presentations and the facilitated discussions, a question and answer session was convened to address any questions that had been raised by the workshop participants.

Finally, the selenium experts developed a series of recommendations based on the results of their technical reviews of the Elk Valley studies. These recommendations were evaluated and ranked to identify the highest-priority initiatives for the next 3 to 5 years. The selenium experts anticipate that these recommendations will assist the EVSTF in defining near-term and long-term priorities relative to selenium monitoring and management in the Elk Valley."

2.5 OTHER STUDIES

2.5.1 Elk Valley Sport Fisheries

A University of British Columbia graduate (Master of Science) student completed his studies on the population dynamics of sportfish in the Elk River Valley. He gave presentations at two international conferences (Wilkinson 2008, 2009a); the thesis is in press as a BC Ministry of Environment Management Report (Wilkinson 2010); and, two manuscripts are in preparation for submission to peer reviewed journals. The Abstract from his MSc Thesis (Wilkinson 2009b) is provided below.

ABSTRACT

"The Elk River valley is intensively utilized by various resource industries including a recreational fishery that predominates in the river section between Sparwood and Elko. Most angling comes from fly-fishers in drift boats who mainly target westslope cutthroat trout (WCT) *Onchorhyncus clarkii lewisi* in the summer, but also secondarily catch bull trout (BT) *Salvelinus confluentus*. Non-native rainbow trout (RB) *Onchorhyncus mykiss* and Eastern brook trout (EB) *Salvelinus fontinalis* have also been introduced to the system. The river's trout and char populations have never been directly examined in response to fishing regulations. In 2006 and 2007, I used ecological survey methods to determine WCT growth, mortality, and abundance in a series of catch-and-release and catch-and-keep regulation zones of the lower mainstem Elk River. I assessed the angling effort response to WCT and BT densities in the lower mainstem and systematically determined the relative recruitment capability of the two drainage basins in the tributary system.

Angler surveys on Michel Creek (above), electrofishing on Alexander Creek (below)

I estimated 10,050 WCT inhabited the lower mainstem in 2006 with 16,200 WCT in 2007, indicating an annual recruitment of 5,753 fish into the mainstem. Growth was inversely related to fish density, particularly in the first fractal plane of the tributary system. Effects on mortality due to fishing pressure could not be directly determined from effort, but mortality rates were slightly higher in the harvest zones in 2007, especially in the first fractal division of tributaries. Angling effort showed a linear increase with WCT densities. In the tributary system, the highest WCT densities were found in the Michel drainage, whereas BT recruitment appeared largely restricted to the Upper Elk drainage. A strong EB presence in the upper Michel drainage coupled by an absence of BT suggests that EB have displaced BT in warmer streams in this river system, which may even lead to improved WCT densities. This initial investigation indicates that active monitoring of the Elk River sportfish populations can feasibly be integrated into a systemwide adaptive management strategy."

2.5.2 Aquatic Benthic Invertebrates

Benthic (bottom-dwelling) invertebrates (animals without backbones) are an important part of the food web in water bodies in the Elk River Valley. The Abstract and one figure (**Figure 13**, herein) from a Masters Thesis regarding benthic invertebrate communities below active coal mines in the Elk River Valley is provided below (Frenette 2008).

Benthic invertebrates from Line Creek

ABSTRACT

"The objective of this research was to determine whether the benthic invertebrate community structure is impacted by coal mining within the Elk River Basin, where open pit coal mining has occurred for more than 30 years.

Benthic invertebrate communities assessed within Michel Creek below active coal mining were found to be within the natural variability as determined by the reference sites sampled, except for a decrease in sensitive species. The abundance and proportion of EPT and Ephemeroptera significantly decreased below coal mining, while Dipterans, particularly Chironomidae, increased. The changes in benthic communities suggest an impact to the aquatic health.

Obvious changes in water quality below the coal mines included increased selenium, sulphate, nitrate and nitrite concentrations. Selenium concentration was the only water quality variable that showed a relatively strong negative correlation with changes in benthic community structure, while depth and predominant substrate were also strongly correlated."

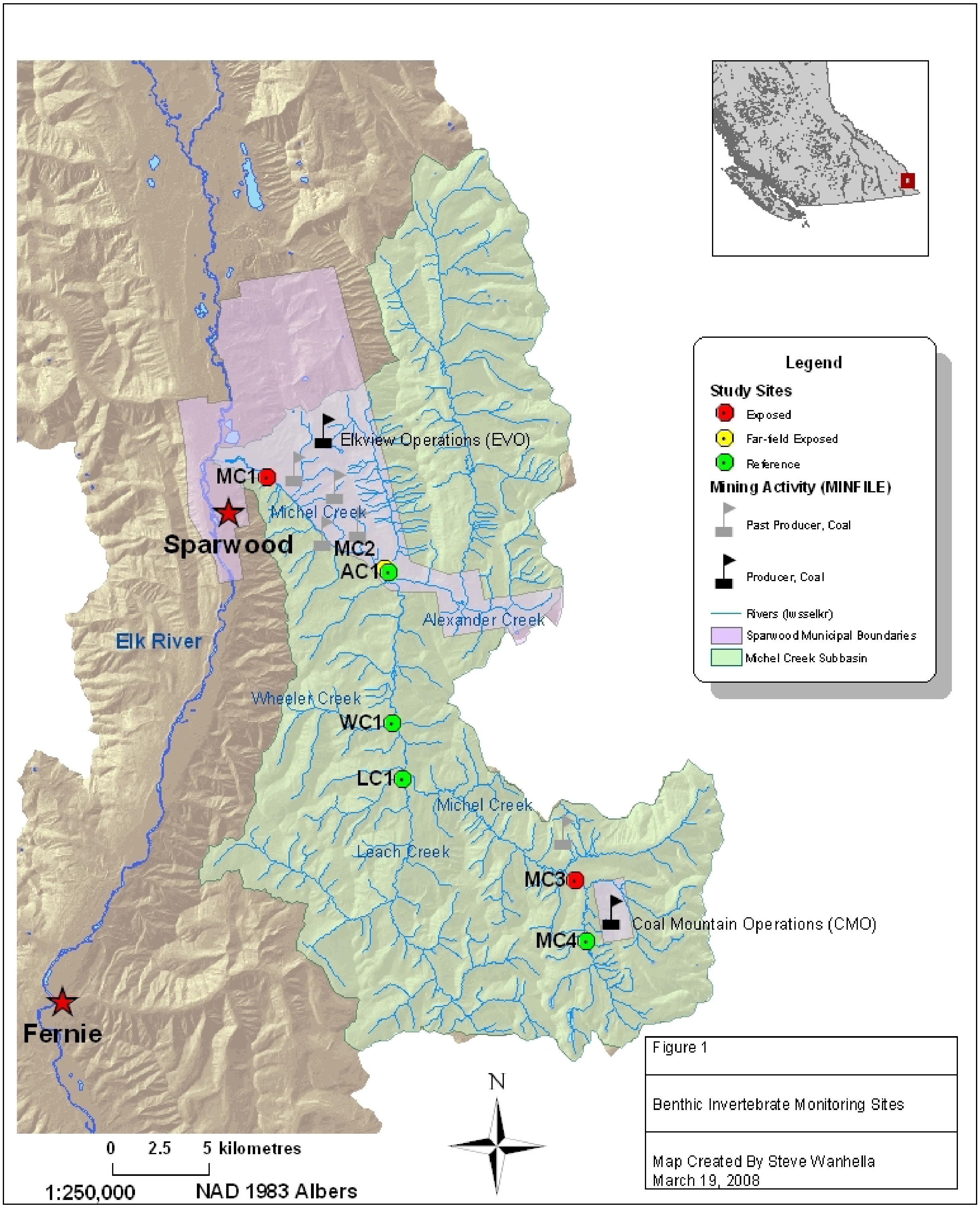


FIGURE 13. Map of Michel Creek basin and monitoring sites [Figure 1 from Frenette (2008)].

2.5.3 Line Creek Aquatic Health

A five-year study of the aquatic health of Line Creek, which receives Se inputs from coal mining, is on-going. The Executive Summary from the most recent report on this on-going study (Arnett and Berdusco 2009) is provided below along with an illustration of one of their samplers (**Figure 14**) and a figure from their report (**Figure 15**, herein).

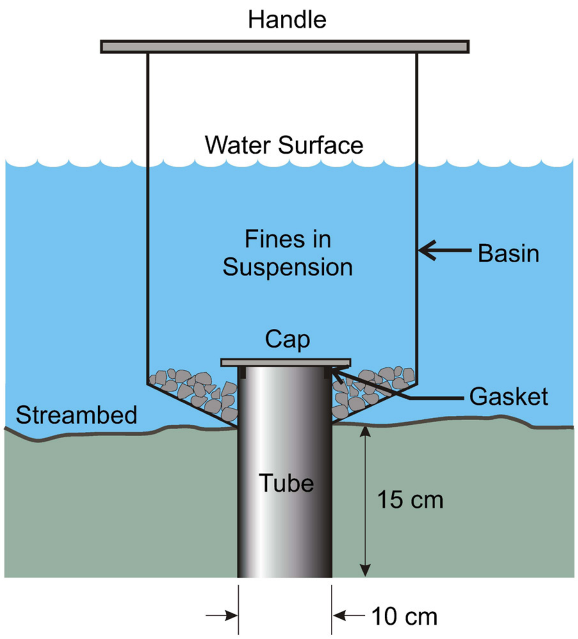


FIGURE 14. McNeil core sampler [Redrawn from http://www.rickly.com/ss/coresamplers.htm]

EXECUTIVE SUMMARY

"Teck Coal Ltd., Line Creek Operations 2008 Aquatic Health Monitoring Program is the second year of a larger, 5-year study of Line Creek's aquatic ecosystem. The objectives of this program are a continuation of work performed in 2007 to assess and quantify how the potential impacts of mining, specifically, the rock drain across the mainstem, have affected the overall health and function of this ecosystem.

Bedload sampling was repeated in 2008 to add the second year of sampling data to the current Line Creek Aquatic Monitoring Program. McNeil core data was collected at nine historical bedload sites upstream and downstream of the rock drain and in South Line Creek. Sites upstream of the rock drain and in South Line Creek represented reference areas while sites below the rock drain were considered exposed areas. The intent was to determine the particle size distribution of total fines (coarse gravel to silt) characteristic of the sub-pavement material. Statistical analyses of nine years (1989, 1991-1996, 2007 and 2008) of McNeil core data was used to assess any potential changes in substrate downstream of the rock drain. Linear regression determined that variation in substrate composition downstream of the rock drain is significantly related to the variation observed at both reference sites (i.e. upstream and South Line Creek). Furthermore, ANOVA analyses showed no significant difference in the mean percentage of fines (i.e. percent < 2.00 mm and < 6.35 mm fractions) found between sites (< 2.00 mm had $p = 0.400$ and the fraction < 6.35 mm had $p = 0.681$). Overall, statistical analyses indicated that any fining and/or coarsening trends observed in bedload composition were occurring at the downstream site and reference sites simultaneously. Due to the fact that this study design is restricted by the location of past sample sites it is not possible to assess any potential moderating effect that South Line Creek may have on sediment transport downstream of the rock drain.

Invertebrate recolonization plate

Periphyton sampling occurred at four historical sites sampled pre and post mining. Qualitative assessment of pollution tolerance indices (PTI), trophic state indicator values and percent motile diatoms suggested that the Toe site has been impacted. This was supported by statistical analyses of phyla, genera and chlorophyll a all of which indicated significant changes only at the Toe site. These results indicated that the site directly downstream of the rock drain (the Toe site) had significantly changed since rock drain construction and was most impacted by mining, but also that these impacts decreased closer to reference site levels at the downstream site. Chlorophyll a concentrations at the Toe exceeded BC water quality standards for the protection of aquatic life (maximum allowable concentration is equal to 100 mg/m^2) for both 2007 and 2008 (113 mg/m^2 and 119 mg/m^2, respectively).

Water quality results indicated high concentrations of total nitrogen (in comparison to reference location concentrations) downstream of the rock drain. Total nitrogen concentrations at the mining impacted sites were 7.45 mg/L to 18.84 mg/L higher than the reference locations. Elevated total nitrogen concentrations are a result of explosive residues left on the waste rock from rock drain construction, which ultimately leached into Line Creek. Other contributing environmental factors, specifically increased daily solar radiation due to riparian vegetation removal, may also affect the periphyton community at the Toe site. Benthic invertebrate sampling also occurred at four historical sites sampled pre and post mining. Comparing 2007 and 2008 data to past results showed that invertebrate and periphyton communities were experiencing community shifts. These changes were most noticeable downstream of the rock drain where both communities were colonized by more organisms tolerant to pollution. Since rock drain construction, benthic invertebrate diversity, evenness and the percent Ephemeroptera, Plecoptera and Trichoptera (%EPT) has decreased at both sites downstream of the rock drain but not at either reference site. The benthic invertebrate assemblage at the Toe site appeared to be the most affected by the rock drain, as it had the highest percentage of tolerant organisms, the lowest %EPT, the lowest diversity and the highest pollution tolerance index. The D/S site (located in Reach 2 of the canyon) was comparable to these observations, however, to a lesser extent. Based on percent composition it appeared that chironomids are increasing within all four sites and causing an uneven distribution within the benthic invertebrate communities, most notably at the two sites downstream of the rock drain.

Sampling occurs under all weather conditions

Taxa richness, Shannon Diversity, Shannon Equitability and %EPT were the only benthic invertebrate metrics available to compare past Line Creek studies to recent data. Analyses for diversity, evenness and %EPT indicated no significant difference between sites and the interaction of site and year. However, diversity, evenness and %EPT were all found to significantly decrease with year. Linear regression detected a significant decrease in diversity at the D/S and Toe sites. Both reference sites indicated no significant change in diversity over time.

Significant changes in biota community shifts were found downstream of the rock drain, but not at the reference locations. While effects to the invertebrate community were observed at both downstream sites, the influence of the rock drain on periphyton was not significant at the downstream site. These results indicate that the rock drain has significantly affected downstream benthic invertebrate and periphyton communities.

Fish collected from Line Creek

The fish habitat assessment conducted in the first three reaches of Line Creek was used primarily to compare and contrast fish-habitat relationships between reaches. Identification of key habitat features can then be used to indicate what habitat conditions may need attention to enhance local conditions or provide future mitigation. Upon analysis of summarized fish habitat assessment data, minor changes in habitat features observed were not expected to be of an extent high enough to affect local fish population levels. However, it is important to continue monitoring these habitat parameters to ensure major changes are captured, explained and managed accordingly.

Population density estimates for both bull trout (BT-*Salvelinus confluentus*) and westslope cutthroat trout

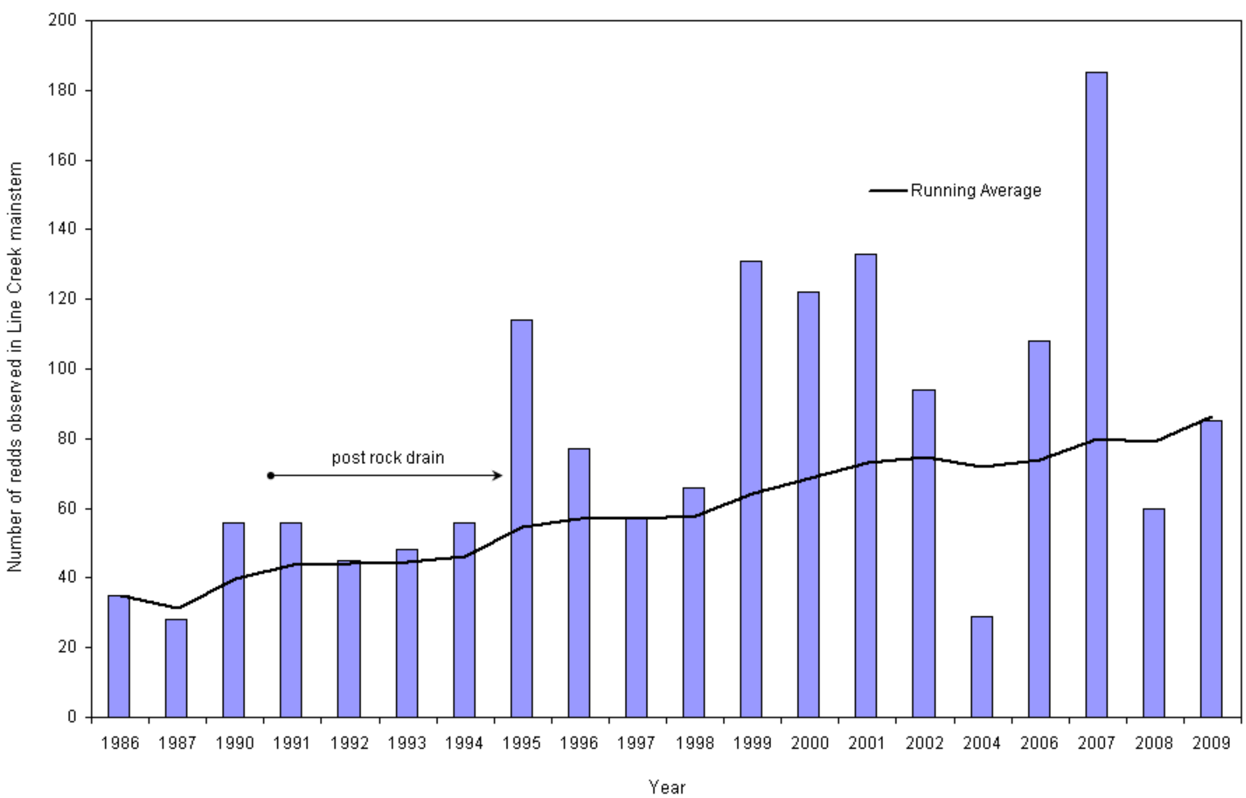


FIGURE 15. Bull trout redd counts gathered from the Line Creek main stem from 1986–2009
[Figure 22 from Arnett and Berdusco (2009) updated by Interior Reforestation to include 2009 data].

(WCT-*Oncorhynchus clarki lewisi*) were determined using the closed, single-pass mark recapture method at the lower and upper index sites (PES 1 in Reach 2 and PES 2 in Reach 3, respectively). Relative abundances for PES 1 were 4.70/100 m^2 (WCT) and 3.09/100 m^2 (juvenile BT), while 4.63/100 m^2 (WCT) and 10.31/100 m^2 (juvenile BT) were calculated in PES 2. Again in 2008 modest increases through the sample sites were observed when compared to past data. However, this increase was only significant for WCT in PES 1 and BT in PES 2, the remaining sample sites' relative densities were not significantly higher (p=0.0013, p=0.0002, respectively).

The 2008 survey was the second consecutive year that we tested the effect of the rock drain on BT and WCT densities. Sampling in 1987 (n=1) was the only year that fish density data was gathered prior to rock drain construction. The 1987 data was compared with the mean of all years' data (1989-2008, n=14). The mean relative densities for both BT and WCT from 1989-2008 in the upper index site were found to be statistically higher than density estimates from 1987 (p=0.007 and p=0.021, respectively). Although we cannot statistically derive significance of pre and post rock drain fish densities due to sample size issues, we can state that, monitoring conducted following the construction of the rock drain indicates stable to increasing population estimates for both species in Line Creek. Using a dataset incorporating 2008 results, mean June discharge was statistically correlated to fluctuations in relative densities for both species including BT fry. This result continues to suggest the status of Line Creek's fishery downstream of the rock drain is functioning independent of mining activities.

An average stream flow discharge observed in August allowed for successful bull trout fry enumeration in 2008. Closed, three-pass removals were performed for 250 m^2 of channel margin habitat (consisting of a combination of riffle, glide and cascade) for the first three reaches. Similar to results in 2007, calculated relative fish densities showed an upstream decreasing gradient (Reach 1 = 6.70/100m^2; Reach 2 = 1.99/100 m^2; Reach 3 = 1.59/100 m^2). These densities were higher in magnitude than 2007; however, with only two years of data, no strong conclusions can be drawn from this growing dataset.

Bull trout escapement was estimated by conducting three redd surveys. Reach 1 was initially assessed on September 17, 2008 with the entire length of Line Creek (Reaches 1-3) and Reach 1 of South Line Creek fully surveyed from September 30 – October 1, 2008. Low water levels allowed field crews to navigate and assess all habitat units with enough confidence that a third survey, which would have included underwater observation, was not warranted. In total, 60 confirmed redds were counted in Line Creek downstream of the contingency ponds and no redds were observed in South Line Creek. This number of confirmed redds (60) was not statistically lower than the mean of all years data (76.4, p=0.105, n=20). Comparison of the number of redds between pre (n=2) and post-rock drain construction (n=18), found a statistically significant difference between the means of these two time periods. Therefore, the number of redds surveyed post construction was higher than the pre-construction assessment mean. However, the limited pre rock drain data set must be considered.

Young fly fisher in the making

We attempted to explain interannual BT redd variation by testing for correlation between different factors affecting BT redds counts. However, due to "gaps" in the data from several years where no work was completed in Line Creek (1988, 2003 and 2005), we did not have the benefit of a complete dataset gathered since 1986. The first test explored if the strength of a particular cohort could affect the number of redds in future surveys. We tested anywhere from three to six years separation working off the assumption that bull trout become mature and therefore are capable of returning to their natal stream to spawn as early as 3 years of age. This analysis was adversely impacted by the noted data gaps.

The second test examined the relationship of September discharge on the number of redds counted that particular year. The test results, at this time, provided no statistically valid correlation between any of the tested years. The second analysis looked at the effect that discharge in the month of September had on the number of redds counted that particular year. The assumption is that high or low discharge affects the number of redds constructed during that spawning period and/or redd observability. This test failed to detect a significant relationship between the two variables ($p=0.179$, $df=19$). There are many different factors which combine to form a particular escapement, and are therefore very difficult to explain or predict the strength of one particular bull trout spawning survey. This null result further enforces the need to monitor natural systems in order to provide background for comparison and explain short-term results.

Results from the 2008 program suggested certain indicators, such as benthic invertebrates and periphyton, are capable of detecting changes influenced by the effects of the rock drain. Bedload sampling did not detect changes between reference and exposed areas. We can state that, at this time, bedload composition appears to be fluctuating naturally as seen by the comparison of the reference site locations to the site downstream of the rock drain. Pre mining information on historical fish populations was not available and therefore it is difficult to predict how the rock drain is affecting those populations. However, considering the 2008 program results, and subsequent statistical analyses, we can state that fish populations within Line Creek, downstream of the rock drain appear to be functioning naturally during the period of record."

2.5.4 Historic Fish Distributions in the Elk River Watershed

In response to a question from the 2008 Expert Panel (**Section 2.4**) regarding possible loss of fish species in the Elk River watershed due to historic Se inputs, Teck Coal commissioned a desk-top study of available historic data. That report (Interior Reforestation 2010) has no Executive Summary, thus the Conclusions are reproduced below.

CONCLUSIONS

"The results of this study suggest that the Elk River (lower) sub-basin had the highest species diversity. This site was shown to be unique when averaged over the entire data record, but did not vary over time any differently than Wigwam sub-basin in a paired comparison.

In two of three cases, species diversity was higher in the exposed sub-basins than in the reference areas. This is likely due to the selection of basin pairs. Our ability to select pairs with similar habitat and accessibility to other tributaries was limited by the availability of data, in that the sub-basins selected needed to contain a sufficient number of sampling events. As noted, the higher Species Richness in the exposed areas of sub-basin pairs 1 and 2 was likely due to habitat variables predicted by stream order. In both cases, the exposed areas had higher order mainstem streams, which would produce more diverse habitat.

Goddard Marsh

In sub-basin pair 3, the exposed site (Fording River) showed lower diversity than the reference site, the upper Elk River. Again, this was likely in part due to habitat variability. However, a major migratory barrier exists on the Fording River making accessibility the more likely explanation of these results. Approximately 17 km upstream from the mouth of the Fording River is Josephine Falls. This feature is likely a historic barrier that precluded any upstream recolonization following glaciation. Supporting evidence of this is that only westslope cutthroat trout inhabit waters above Josephine Falls and these are locally reported to be the result of unauthorized stocking. Approximately two-thirds of the Fording River watershed exists upstream of Josephine Falls, greatly reducing overall species diversity of the watershed. The downstream third is primarily made up of the Line Creek drainage. Line Creek has been repeatedly sampled and only reports cutthroat, bull trout and occasionally mountain whitefish. We had hoped that more records would have come from the mainstem Fording River, downstream of Line Creek to make this sub-basin more comparable to the Elk River (upper) that it flows into. However, most of the Fording River records come either from upstream of Josephine Falls or Line Creek. This explains the low Species Richness estimate of three species (with negligible error) for the Fording River.

A final component presented in this proposed project was the use of cumulative upstream mining footprint to predict any changes in species diversity over time. The lack of significant trends precluded this analysis. With the available data, no evidence was found to suspect that mining has changed the fish community composition or overall species diversity. Again, this report makes no inferences on proportional fish abundance or overall aquatic health.

The results of this study suggest overall fish community structure and spatial variability within the Elk River upstream of Elko is likely a combination of Hypotheses 1 and 2, habitat preference and limited recolonization post-glaciation."

3. FUTURE STUDIES

The following on-going studies, when completed, will be summarized in a future *Selenium Status Report*.

3.1 REGIONAL MONITORING

As noted previously (**Section 2.1.1**), regional monitoring of Se concentrations in water, sediment and biota is ongoing and the findings of 2009 monitoring will be reported in the next *Selenium Status Report.*

3.2 EFFECTS STUDIES

As noted previously (**Section 2.2.2**), additional work is being conducted to resolve issues related to chemical laboratory analytical variability that could influence the final effects endpoint from the Nautilus Environmental (2009) report. The findings of this additional work will be reported in the next *Selenium Status Report.*

Golder Associates Ltd are developing a population model of Se effects to westslope cutthroat trout in the Elk Valley. The purpose of this model, which is based on Van Kirk and Hill (2007) is to extrapolate from laboratory effects studies with individual cutthroat trout to predict the Se effects threshold for populations of cutthroat trout in the Elk Valley, taking into account density-dependent survival of early life stages, which can compensate for Se-induced mortality of those life-stages (**Figure 16**).

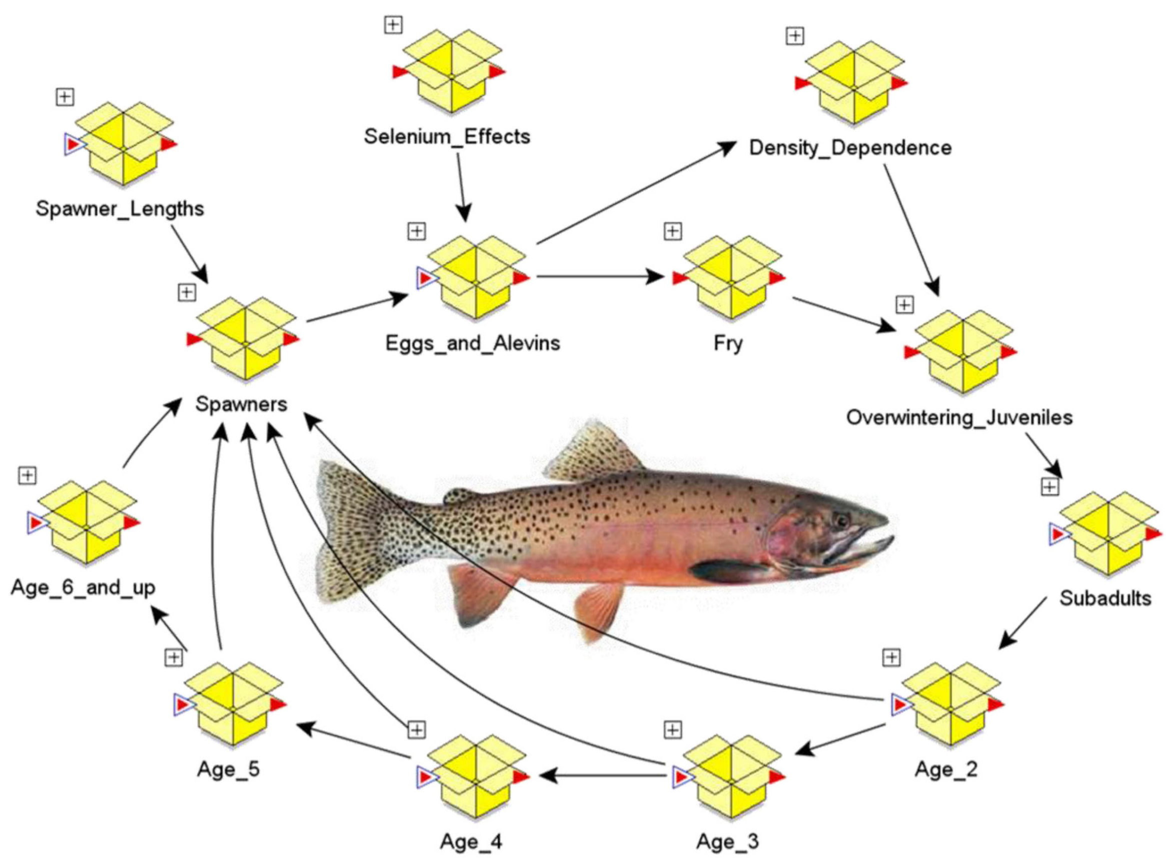


FIGURE 16. Structure of the westslope cutthroat trout population model, which is under development [From a presentation to the EVSTF].

3.3 MANAGEMENT AND TREATMENT R&D

Pyrite in coal host rock

A Selenium Release Model is being developed by SRK Consulting to understand and quantify the mechanisms by which Se is mobilized from coal mining wastes. This model is expected to provide a basis for predicting future release trends including water quality, and is intended for use in the design of mitigation strategies under various mining scenarios. The first phase of this work involved a data knowledge / gap review to identify mines suitable to develop the model (SRK Consulting 2008a). The second phase involved the design of further characterization studies for candidate mines (SRK Consulting 2008b). The final phase, currently in progress, is the implementation of those further characterization studies.

Teck Coal is funding a Se R&D project being conducted by Golder Associates Ltd for the five Elk Valley coal mines and for Cardinal River Operations in Alberta. The objective of this project is to develop multiple Se treatment technologies to provide Teck Coal with the flexibility to implement sustainable, site-specific Se water treatment systems. The project includes biological and physical / chemical treatment methods assessment by laboratory, pilot and demonstration scale testing.

Field selenium removal R&D

Teck Coal has developed an integrated laboratory-based treatment testing program with Applied Research and Technology (ART) in Trail, BC, to evaluate Se removal methods at Elk Valley coal mines. This work, which is ongoing and which may result in patented technology, is intended to be integrated into potential future on-site pilot testing and implementation.

Laboratory selenium removal R&D

Scanning electron microscope photograph of elemental sulphur in test samples

A follow-up study to Lorax Environmental Services (2009) (**Section 2.3.2**) is underway. The primary goal of this study is to develop information specific to Se removal (i.e., through vegetation, sediment and other pathways – e.g., **Figure 17)**, using Goddard Marsh as a case study. Depending on the results of this study, a wetland Se removal pilot test may be conducted at one of Teck Coal's mine sites.

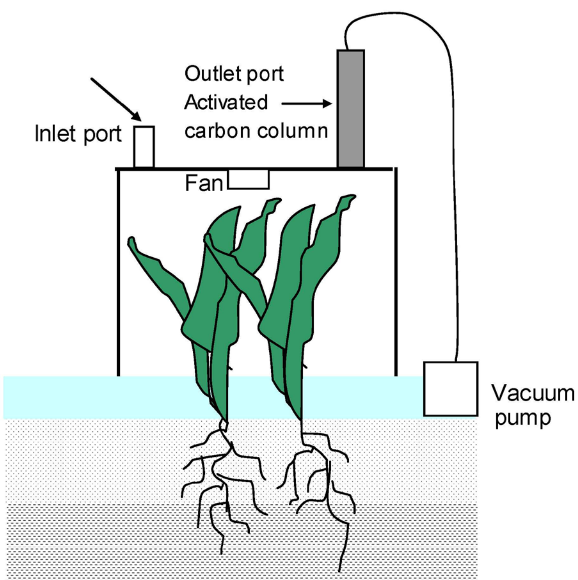


FIGURE 17. Simplified example of apparatus for collecting volatile Se from wetland components [From a proposal to the EVSTF].

Wetland vascular plant test plot

Selenium release R&D test cells

3.4 OTHER STUDIES

The Line Creek aquatic health studies are continuing for three more years (cf. **Section 2.5.3**). The findings of those studies will be reported in subsequent *Selenium Status Reports*.

Teck Coal has established an independent Strategic Advisory Panel on Selenium Management. The Panel will produce, in summer 2010, a Strategic Selenium Management Plan for the sustainable management of Se at Teck Coal Operations.

BCMoE will be attempting to collect sculpin in the Elk River Valley in spring 2010. This work follows a recommendation from the Historic Fish Distribution work regarding determining whether these fish are found in the Elk River Valley (**Section 2.5.4**).

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APPENDIX A

EVSTF MEMBERSHIP AS OF APRIL 2010

EVSTF MEMBERSHIP AS OF APRIL 2010
(In alphabetical order by last name)

Kim Bellefontaine	BCMEMPR
Peter Chapman	Golder Associates Ltd (Secretary and Technical Advisor)
Warn Franklin	Teck Coal Ltd
Carla Fraser	Teck Coal Ltd
Jody Frenette	BCMoE
Guy Gilron	Teck Resources Ltd
Ron Jones	Teck Coal Ltd
Marc Meyer	Teck Coal Ltd
Kevin Podrasky	Teck Coal Ltd
John Pumphrey	Teck Coal (EVSTF Chair)
Patrick Shaw	Environment Canada
Chris Stroich	BCMoE
Mark Strosher	BCMoE
Greg Sword	Teck Coal Ltd

APPENDIX B

LIST OF ACRONYMS/SYMBOLS AND GLOSSARY

LIST OF ACRONYMS/SYMBOLS

AB	Alberta
ANOVA	Analysis of variance
ART	Applied Research and Technology
BAF	Bioaccumulation factor
BC	British Columbia
BT	bull trout
CCME	Canadian Council of Ministers of the Environment
CSM	conceptual site model
D/S	downstream
dw	dry weight
EA	Environmental Assessment
EB	Eastern brook trout
EC10	effects concentration affecting 10% of the organisms tested
EC20	effects concentration affecting 20% of the organisms tested
EC50	effects concentration affecting 50% of the organisms tested
EPT	Ephemeroptera, Plecoptera and Trichoptera
EVCC	Elk Valley Coal Corporation
EVSTF	Elk Valley Selenium Task Force
FPC	Forest Practices Code
FRO	Fording River Oxbow
GIS	Geographic Information System
GLM	General Linear Models
GM	Goddard Marsh
LMM	Linear Mixed-effects Models
LNS	longnose sucker
MEMPR	Ministry of Energy, Mines and Petroleum Resources
MIW	mining-influenced water
mm	millimetres
MoE	Ministry of Environment
m^2	square metres
m^3/d	cubic metres per day
mg/L	milligrams per litre
mg/m^2	milligrams per square metre

MWF	mountain whitefish
p	probability
PTI	pollution tolerance indices
QA/QC	quality assurance / quality control
RB	rainbow trout
R&D	research and development
SD	standard deviation
Se	selenium
Se-0	elemental selenium
Se-II	selenide
SeIV	selenite
SeVI	selenate
TRG	tissue residue guideline
TRIM	Terrain Resources Inventory Mapping
t/yr	tons per year
µg/g	micro-grams per gram
µg/L	micro-grams per liter
WCT	westslope cutthroat trout
WQO	Water Quality Objective
ww	wet weight
XANES	X-ray absorption near-edge structure
<	less than

GLOSSARY

Aerobic
Depending on oxygen or air.

Akaike Information Criterion
A measure of the goodness of fit of an estimated statistical model.

Amino acids
The building blocks of proteins.

ANOVA
A mathematical process for separating the variability of a group of observations into assignable causes and setting up various significance tests.

Assessment endpoint
In ecological risk assessment, an explicit expression of the environmental value to be protected; includes both an ecological entity and specific attributed thereof (e.g., trout are a valued ecological entity; reproduction and population maintenance--the attribute--form an assessment endpoint).

Bedload
Sediment that is carried along the bottom of a river or stream, rather than in the current.

Benthic
Pertaining to the bottom region of a water body, such as a lake or wetland.

Bioaccumulation
Uptake by living tissue of a substance found in the environment. Not necessarily harmful if the substance is essential and is not taken up in forms and quantities that can be toxic.

Bioaccumulation factor
The relationship between the concentration of a substance taken up by biological tissues and the concentration of that substance in the surrounding water.

Biogeochemical
Of or relating to the partitioning and cycling of chemical elements and compounds between the living and nonliving parts of an ecosystem.

Bioreactor
Container in which a biological reaction occurs.

Bioremediation
The branch of biotechnology that uses biological processes to overcome environmental problems.

Cascade
A small waterfall or series of small waterfalls.

Chironomidae
Non-biting insects resembling mosquitoes.

Cohort
Age-group.

Conceptual model
A simplified representation of the system being examined.

Confidence intervals
A range of values centred on the sample estimate that is known to contain the true value with a given degree of confidence (usually 95%).

Confluence
Location where things merge or flow together (e.g., two rivers).

Correlation
A measure of the relationship between two mathematical variables or measured data values.

Density dependence
Describes a factor that influences individuals in a population to a degree that varies in response to how crowded (dense) the population is.

Detritus
Non-living particles of disintegrating biological material (inorganic, dead and decaying organic material) that can be suspended in the water column or that can settle on the bottom of water bodies such as lakes.

Diatoms
Microscopic, single-cell algae having cell walls made out of silicon.

Dipterans
Flies with only one pair of wings.

Diversity
The number of species in a given habitat.

Edema
Swelling of soft tissues as a result of excess water accumulation.

Effect
A change due to human activities. An effect is not necessarily a negative impact; an effect may be neutral or even positive.

Emergent vegetation
Erect plants rooted underwater that grow above (emerge from) the surface of the water (e.g., cattails).

Endpit lake
A mining pit which, following the cessation of mining activities, is meant to function like a natural pond or lake.

Ephemeroptera
Mayflies.

Escapement
That portion of a fish run that is not harvested and escapes to natural or artificial spawning areas.

Evenness
A measure of how similar the abundances of different species are in a community.

Extrapolate
To generalize from one case or situation to another.

Food chain
The transfer of nutrients and energy from one group of organisms to another, linked together in a series resembling a "chain".

Food web
Food chains interconnecting at various levels.

Fractal
Repetitive pattern. A self-similar structure whose geometrical and topographical features are recapitulated in miniature on finer and finer scales, for example rivers drained into by streams which in turn are drained into by creeks.

Gamete
Egg or sperm.

Genera
Taxonomic categories ranking below families and above species; a genus generally consists of a group of species exhibiting similar characteristics.

Geo-reference
To establish a feature's location in terms of map projections or coordinate systems.

Geo-spatial
A term widely used to describe the combination of spatial software and analytical methods with terrestrial or geographic datasets.

Glide
Portion of a stream where the water flows smoothly.

Ground truthing
The use of a ground survey to confirm the findings of an aerial survey or to calibrate quantitative aerial observations.

Guideline
Numerical concentration limit, in an environmental medium (e.g., water, biota tissue) recommended to support and maintain a designated water use. A site-specific guideline is a generic guideline adjusted to local conditions.

Hatchability
For animals that lay eggs, such as birds, the proportion of eggs incubated to full term that hatch.

Hypothesis
A proposed explanation for an observation.

Invertebrates
A collective term for all animals without a backbone or spinal column (e.g., insects, worms, clams, snails).

Kokanee
Landlocked population of sockeye salmon (*Oncorhynchus nerka kennerlyi*) found in some lakes in western North America.

Lentic
Non-flowing (static) water bodies such as lakes, ponds and wetlands.

Lipid
Fat, or fat-like substance.

Lithology
Gross physical character of a rock or rock formation.

Lotic
Flowing water bodies such as creeks, streams and rivers.

Mainstem
The main part of river, its principal waterway excluding its tributaries.

Mark recapture
The tagging and releasing of fish to be recaptured later in their life cycles.

McNeil Core sampler
Consists of a cylinder that defines the portion of the streambed to be sampled and an attached basin that is used to store the collected sediments and trap the suspended fines (see **Figure 14** in main text).

Mean
The arithmetic average of a collection of numbers, computed by adding them up and dividing by their number.

Measurement endpoint
A change in an attribute of an assessment endpoint or its surrogate in response to a stressor.

Metalloid
An element whose chemical behaviour can include both metallic and non-metallic aspects, depending on the particular chemical forms in which they exist.

Mitigation
To moderate or lessen the severity of a condition.

Natal
Pertaining to birth, usually in the context of animals that return to their place of birth to spawn or give birth themselves (e.g., many salmon).

Non-metal
A chemical element (such as selenium, boron, carbon, or nitrogen) that lacks the characteristics of a metal and that is able to form anions, acidic oxides, acids, and stable compounds with hydrogen.

Null result
An experimental outcome which does not show an otherwise expected effect. This does not imply a result of zero or nothing, simply a result that does not support the hypothesis. The term is a translation of the Latin *nullus resultarum*, roughly meaning "none as a consequence".

Organoselenium
Chemical compounds containing carbon-to-selenium chemical bonds.

Orthophoto
An aerial photograph that has been processed (via a scanning and rectification process) in such a way as to eliminate image displacement due to camera tilt and terrain relief, so that it represents every object as if viewed directly from above. An orthophoto combines the visual properties of a photograph with the geometric qualities of a map and offers a realistic visualization of the landscape.

Oxbow
A crescent-shaped lake formed when a meander of a river or stream is cut off from the main channel.

Oxidation
Addition of oxygen, removal of hydrogen, or removal of electrons from an element or compound.

Parsimony
The concept that the simplest explanation of a phenomenon is the best one.

Periphyton
Organisms that grow on underwater surfaces; periphyton include algae, bacteria, fungi, protozoa, and other organisms.

Permeable
Can be permeated or penetrated, especially by liquids or gases.

Phyla
Primary taxonomic divisions of the plant or animal kingdom, ranking next above class divisions in size.

Phytoplankton
Microscopic or small floating plants suspended in the water column of aquatic ecosystems such as lakes.

Plecoptera
Stoneflies.

Population model
A model that characterizes the response of a population to different factors; such models typically help characterize minimum viable population sizes.

Porewater
The water contained in the spaces between sediment particles.

Primary producers
Organisms (primarily green photosynthetic plants) that utilize the energy of the sun and inorganic molecules from the environment to synthesize organic molecules.

Productivity
The ability to produce life (e.g., number of offspring produced by fish, birds or amphibians).

Pseudoreplication
Exaggeration of the statistical significance of a set of measurements resulting from treating the data as independent observations when they are in fact interdependent. There are two types of pseudoreplication: temporal pseudoreplication, involving repeated measurements from the same individual; and spatial pseudoreplication, involving several measurements taken from the same location.

Reach
An individual segment of a stream that has beginning and ending points defined by identifiable features.

Redd
Fish such as trout and salmon build nests called redds for their eggs. In general, the female digs the redd in the gravel and lays her eggs, which the male then fertilizes. The eggs are then covered with gravel and left to incubate for several months until the hatched juvenile fish are ready to emerge.

Red Hen products
Red Hen Systems provides hardware and software to collect geo-referenced video and photo data in the field, and brings those data into desktops and Web-based maps.
Red Hen - Specializing Multimedia Asset and Risk Mapping - Home

Redox
Oxidation-reduction: a reversible chemical reaction in which one reaction is an oxidation and the reverse is a reduction.

Reduction
Any process in which electrons are added to an atom or ion (as by removing oxygen or adding hydrogen); always occurs accompanied by oxidation of the reducing agent.

Reference
A benchmark for comparison or context.

Regression
A model for predicting one variable from another.

Residuals
The difference between the data observed and the values expected.

Reverse osmosis
Forces water through membranes that contain holes so small that even salts cannot pass through. Reverse osmosis removes microorganisms, organic chemicals, and inorganic chemicals, producing very pure water.

Rhizome
A horizontal plant stem with shoots above and roots below serving as a reproductive structure.

Riffle
A fast-flowing, shallow part of a stream.

Riparian
Located on the banks of a water body.

Rock drain
When blast rock is disposed of in a valley bottom through which a watercourse passes, the base of the dump is referred to as a rock drain.

Selenate
An inorganic selenium species; the selenate ion is SeO_4^{2-}.

Selenite
An inorganic selenium species; the selenite ion is SeO_3^{2-}.

Shannon Diversity
A diversity index that accounts for both abundance and evenness of the species present.

Shannon Equitability
A diversity index with values that range between 0 and 1 (a value of 1 indicates complete evenness).

Source Control
The means by which the origin of a substance is controlled to reduce release of that substance.

Speciation (chemistry)
The chemical form or compound in which an element occurs in the environment, in both non-living and living systems.

Stable isotope ratio technique
A process that uses stable isotope ratios of carbon, nitrogen and sulphur to provide information about feeding relationships, food chains and food webs.

Standard deviation
A measure of the range of variation from an average or mean of a group of measurements. 68% of all measurements fall within one standard deviation of the mean. 95% of all measurements fall within two standard deviations of the mean. 99.7% of all measurements fall within three standard deviations of the mean.

Standard error
The standard deviation (positive square-root of the variation) of the errors associated with a series of measurements.

Statistically significant
Unlikely to have occurred by chance.

Swim-up fry
Fry (juvenile fish) that have absorbed their yolk sac and are ready to start feeding.

Taxa
A grouping of organisms given a formal taxonomic name such as species, genus, family.

Taxa richness
The number of distinct species or taxa that are found in an assemblage, community, or sample.

Topography
The configuration of a surface and the relations among its man-made and natural features.

Toxic
Poisonous, carcinogenic, or otherwise directly harmful to a living organism.

Toxicosis
Harm due to a toxic substance.

Trichoptera
Caddisflies.

Trigger
A change in status that would prompt a response. Such a response could involve management to reverse or halt the change and/or investigative studies to determine the significance of the change.

Trophic level
A functional classification of organisms in an ecosystem according to feeding relationships, from primary producers through herbivores (secondary producers) and carnivores (tertiary producers).

Type 1 error
A determination that a hypothesis is false when in fact it is true.

Vascular plant
A plant having specialized tissues that conduct water and synthesized foods.

Vertebrates
Animals with backbones or spinal columns.

Viable
Capable of life.

Water birds
Birds that frequent water.

Water hardening
The process by which an egg absorbs water, stores it and hardens its outer shell.

Water quality objective
Site-specific numerical concentration limit recommended to support and maintain a designated use (e.g., a generic guideline adapted to take into account site-specific conditions), which includes consideration of factors beyond environmental protection such as socio-economic factors or particularly sensitive species. Usually a negotiated number with input from affected stakeholders and, where appropriate, aboriginal peoples. Generally subject to review and revision as new information becomes available.

Water quality standard
Regulatory agency-approved concentration limit for a water body prescribing the use of the water body and establishing what must be done to protect designated uses.

Weathering
Processes that decay and break up bedrock by a combination of physical fracturing and chemical decomposition.

Wetland
A low-lying area of land that is saturated with moisture. Marshes, swamps, and bogs are examples of wetlands.

Zooplankton
Microscopic or small floating animals suspended in the water column of aquatic ecosystems such as lakes.