SELENIUM INVESTIGATIONS IN THE ELK RIVER VALLEY, BC – 2008 UPDATE

Peter M. Chapman [1]
Roger Berdusco [2]
Ron Jones [2]

[1] Golder Associates Ltd., 195 Pemberton Avenue
North Vancouver, BC V7P 2R4
Tel 604-904-4005
pmchapman@golder.com

[2] Elk Valley Coal Corporation, #1000 205 - 9th Avenue SE
Calgary, AB T2G 0R4
roger_berdusco@elkvalleycoal.ca; ron_jones@elkvalleycoal.ca

ABSTRACT

Regional monitoring of water and biota indicates that there continue to be long-term increases in selenium (Se) in water downstream of the Elk Valley River coal mines, operated by the Elk Valley Coal Corporation. However, monitoring also indicates that Se concentrations in benthic invertebrates, fish muscle and bird eggs, although elevated, have not increased over the last few years. Previous studies have indicated that the viability and productivity of fish and water bird populations do not appear to be adversely impacted by Se. Nor does it appear that human health or terrestrial wildlife (*i.e.*, ungulates) are presently being adversely affected. Current efforts are focused on monitoring and management, in addition to a study attempting to establish a definitive adverse effects threshold for Westslope cutthroat trout in the Elk River Valley. Management investigations include efforts to: predict future Se releases under different mining scenarios and management approaches; determine factors affecting the cycling and conversion of inorganic Se once it enters the aquatic environment; and integrate present and future information to effectively manage Se releases from the coal mines. Research is also being conducted into treatment alternatives to reduce Se loadings to the aquatic environment. Lentic and lotic areas of the Elk River Valley are being mapped to determine the relative proportions of these habitat types both related to future Se studies, and to provide the basis for evaluating the significance of any localized impacts that may occur to the overall health of the Elk River Valley aquatic ecosystem. Selected Se studies conducted through 2007 in the Elk River Valley are being integrated into monitoring and management plans, including a Standard Operating Procedure for fish deformity analysis, and predictive modeling of fish populations.

INTRODUCTION

Selenium (Se) is a metal-like element (a metalloid) 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, Se in excess can be harmful, particularly to egg-laying animals, specifically fish, water birds and possibly amphibians that feed in or from water bodies containing elevated Se concentrations. Inorganic Se released naturally by weathering of Se-containing rocks or whose natural release is

accelerated by mining, can be modified by bacteria in lakes, ponds, marshes or wetlands into an organic form that can be accumulated by adults of these egg-laying animals from their diet. Selenium is transferred to the eggs where, during the development of the embryo, it can substitute for sulphur in the production of proteins, resulting in deformities or even death of the embryos, depending on how much Se is present in the eggs.

This paper updates Chapman et al. (2007). Previous studies summarized in Chapman (2005) and EVSTF (2005, 2007) indicated that current levels of Se in the Elk River Valley did not appear to be having large-scale negative effects or impacts. An effect is simply a change; it becomes an impact when it adversely affects the utility or viability of a valued ecosystem component (a VEC, i.e., population-level adverse effects occur). However, there were indications of some negative effects occurring on a more localized level in two lentic areas, one a settling pond, the other a marsh, both of which have been impacted directly by mining activities for over three decades. More recent management initiatives, monitoring, effects and other studies are summarized herein.

SELENIUM MANAGEMENT

When rain water and snow melt contact rocks disturbed by mining, Se from minerals leaches into the runoff, which then enters adjacent water bodies. The actual concentration of Se in the rock is low (generally only a few parts per million), but mining processes break rocks down and make the minerals more available for leaching than would occur under undisturbed conditions (i.e., prior to mining). Some of the Se minerals only require contact with water to dissolve, while other minerals require oxygen to convert them into a form that dissolves.

Four major Se management efforts have been initiated by Elk Valley Coal Corporation (EVCC): determination of specific Se sources including release and water quality predictions; research and development into management options including treatment (with the goal of minimizing Se releases to water bodies); investigations into Se cycling; and development of a Se management decision framework.

Selenium Source / Release Studies and Water Quality Predictions

In 2007, EVCC initiated a project that is being undertaken by SRK Engineers to further investigate Se sources and the mechanisms that control its release. This information will be used to develop a model to predict future Se releases under different mining scenarios and management approaches, with the ultimate goal of finding the most effective means of reducing Se releases from coal mining. Based on the results of this work, it is possible that different types of mine wastes may be amenable to different forms of source control or management approaches.

This project involves field and laboratory programs using rock and water samples from the mines in the Elk River Valley. Phase 1 of the project, which has already been completed, involved collecting existing information from each of EVCC's five operating mines to identify data gaps and those sites suitable for further study. Phase 2 will involve the design of specific studies to determine mine waste mineralogy and

geochemistry over time and at different scales, as well as additions and enhancements to water quality monitoring programs. This work will be implemented (Phase 3) at selected sites in 2008.

Management Options Including Treatment R&D

Several approaches can be used to reduce the amount of a substance, like Se, in waters from a mine site. One way is to treat the mine water to remove the substance to an acceptable level. Possible approaches to treatment research and development are currently being investigated; however, treatment has disadvantages which include the difficulty of collecting water, and the need to operate a treatment plant and dispose of solid and liquid waste by-products. Alternative approaches, known together as "source controls", aim to reduce the amount of substances such as Se entering waters discharged to the environment. These approaches may be the best means to reduce Se loadings to the environment. Such approaches can include applying engineering technologies such as: structures to divert water, backfilling of pits and flooding to submerge waste rock to reduce air and oxygen content; and truck compaction of the top layer of spoils during construction coupled with positive drainage to reduce water and/or oxygen contact. The main advantage of these approaches is that, if successful, they may reduce or possibly even eliminate the need for water treatment.

In addition to source control, EVCC has concluded that biologically-based treatment technologies may have potential under certain site-specific conditions. R&D testing is underway at both BC and Alberta coal mines to determine the feasibility of using local microbes and nutrients for Se treatment, particularly at naturally occurring low-oxygen locations (i.e., where there are anoxic conditions in the bottom layers of end pit lakes) or areas with subsurface discharges. Golder Associates are presently conducting research for EVCC into the applicability of passive bioreactor systems. Research into treatment is also being conducted at TeckCominco's Trail (BC) facility.

Selenium Cycling

A project conducted by Lorax Environmental in cooperation with various University researchers and nearing completion, has assessed biogeochemical cycling of Se in lentic environments. The ultimate goal of this work is to determine the controls for the cycling and conversion of inorganic and organic forms of Se. This determination will assist in understanding Se mobility in the environment and its bioavailability to plants and animals, and ultimately may help to predict and prevent potential Se-induced aquatic toxicity in the Elk River Valley. It may also assist in determining opportunities for management intervention to disrupt Se cycling, and reduce the amount of potentially toxic organic Se in the aquatic ecosystem.

Various state-of-the-art techniques are being used to measure the proportions of various inorganic and organic Se species in both sediments and their pore waters. The data obtained are being used to: 1) determine the biogeochemical controls governing the remobilization and fixation of Se in lentic sediments; 2) determine the dominant "sinks" (accumulation pathways) for Se in sediment; 3) quantify the direction and magnitude of Se exchanges across the sediment-water interface; 4) help explain temporal and spatial differences in Se accumulation and toxicity in biological receptors; and 5) develop

seasonal and longer-term predictions for both Se mobility and bioavailability, considering current and future mining scenarios.

Decision Framework

A decision framework has been developed by EVCC for managing Se released from the EVCC coal mines located in British Columbia (BC) and Alberta (AB), and for assessing knowledge gaps and priority issues. The decision framework (Chapman et al. 2007, 2008; EVSTF 2007) will be regularly updated as new site-specific and other relevant knowledge becomes available. The framework is currently being used by EVCC as a guide for determining the basis for future studies, management actions, and monitoring at EVCC coal mines where Se is a chemical of concern.

EFFECTS STUDY – WESTSLOPE CUTTHROAT TROUT

Two Westslope cutthroat trout (WCT) effects studies have been conducted to date, one in lentic waters (Rudolph et al. 2008), the other in lotic waters (Kennedy et al. 2000). Both studies indicated that WCT in the Elk River Valley were not adversely affected by relatively elevated Se concentrations. However, Kennedy et al. (2000) did not determine a Se effects threshold for WCT; only three of the female trout they tested had egg Se concentrations above levels shown to be toxic in other studies with warm water fish and no toxicity was observed.

The Rudolph et al. (2008) study was intended to determine such a threshold. However, although this lotic study generally used the same methodology as the previous lentic study, some of the results appeared to be contradictory. Kennedy et al. (2000) demonstrated that eggs with up to 81.3 mg/kg dry weight Se produced normal fry with no evidence of Se-related deformities or mortalities. In contrast, in the lentic study when egg Se concentrations were greater than 46.8 but less than 88.3 mg/kg dry weight (4 females), no viable fry were produced. And when egg Se concentrations were between 88.3 and 140.0 mg/kg dry weight (4 females), the eggs died before reaching the laboratory.

Because of these apparent contradictions, a further WCT effects study is underway. It is hypothesized that the different results between the two previous studies may be due to differences in partitioning and/or speciation of Se found in trout tissue from lentic vs. lotic waters related to differences in prey and food chain dynamics/structure. The current study is designed to test this possibility by collecting, analyzing, and rearing trout from both lentic and lotic habitats to:

(1) establish a definitive adverse effects tissue threshold for Se in WCT in the Elk River Valley; and

(2) explain the contradictions in the results of the two previous studies.

REGIONAL MONITORING OF WATER AND BIOTA

Regional monitoring and spatial and temporal analyses of Se data in water and aquatic biota have been conducted in the Elk River Valley. For the most part, trend assessment was based on three separate years of data collection, 1996, 2001, and 2006 (Minnow Environmental et al. 2007). The purpose of this work

was to: evaluate any temporal and spatial trends in Se concentrations based on routine water quality and flow monitoring data collected by the coal mines (cf. Chapman 2005; EVSTF 2005); and determine trends in Se concentrations in sediment and biota.

The following summarize the results of these monitoring studies:

- Selenium was elevated in water, sediment, and biota downstream of the mines compared to upstream reference areas;

- Increased water Se concentrations at near-field monitoring stations downstream of the mines can be attributed directly to coal mining activities;

- Surface water Se concentrations are increasing at a rate of about 8% per year at near-field monitoring stations downstream of the coal mines; this equates to a doubling about every 10 years. Changes of this magnitude or greater have already occurred. Increases are smaller downstream due to dilution effects, but demonstrate the same trend;

- Selenium concentrations in sediment, fish and their prey are elevated both downstream of the mines and in reference areas unaffected by coal mining activities (e.g., upstream concentrations occasionally exceed BC water and sediment guidelines); in other words, natural Se concentrations are elevated in some areas, and mining activities are further increasing natural Se concentrations;

- Sediment Se concentrations have increased in some areas but not in others; the current data are insufficient at present to determine trends;

- Benthic invertebrates had higher Se concentrations near the mine than further away; however, concentrations have not increased over the last ten years;

- Selenium in fish tissues is elevated in some, but not at all, areas downstream of the mines, and Se concentrations have also not increased over the last ten years; and

- Similarly, Se in bird eggs has not increased over the last few years.

Both tissue and water quality monitoring will continue, on a 3-5 year cycle, depending on any changes in measured water or tissue Se concentrations.

RESIDENT FISH COMMUNITIES

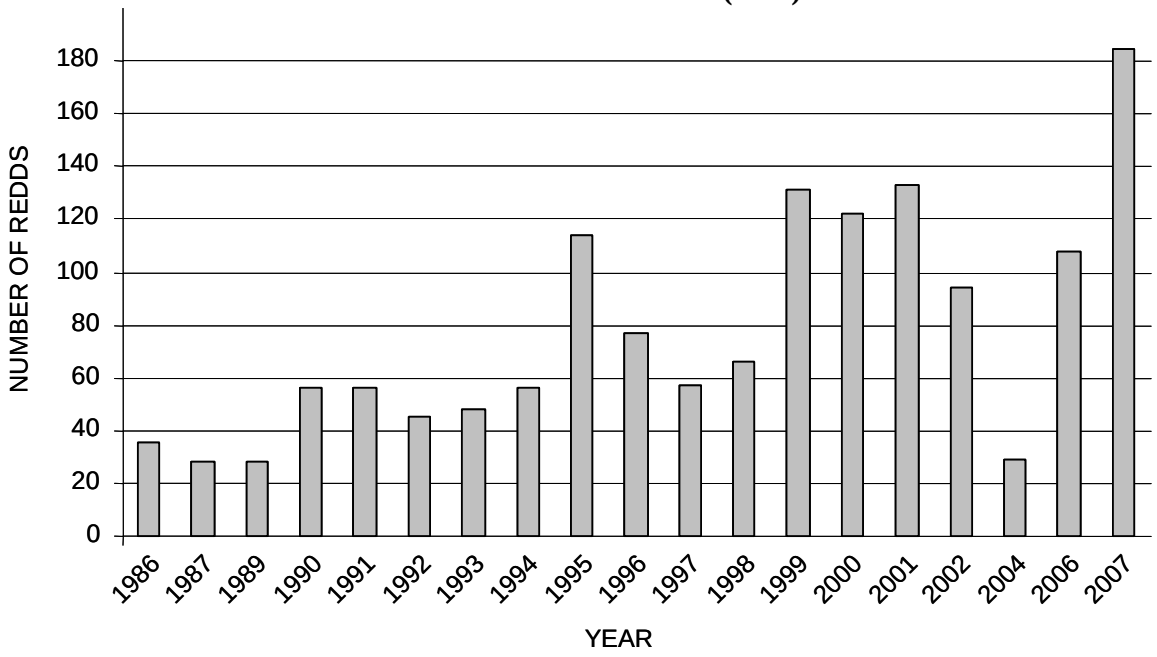
Line Creek Fisheries

Line Creek, which contains elevated Se concentrations from coal mining activities (in the range of 20 µg/L) continues to support a resident population of WCT, a migratory adult spawning bull trout

population, a resident juvenile bull trout population that rears in the creek, and a migratory mountain whitefish population that uses the lower portion of the creek for summer feeding.

The results of monitoring conducted in 2007 for EVCC (Berdusco and Arnett 2008) indicate that resident WCT and juvenile bull trout populations have not changed significantly over the last 20 years. Bull trout fry enumeration in three reaches of Line Creek indicates that fry are found throughout the creek, with the highest density in the lowest reach. This is what one would expect given observations of bull trout spawning activity (based on redd [nest] counts) in the lower portion of Line Creek, near its confluence with the Fording River. The bull trout fry population of Line Creek appears to be responding to environmental variables in a similar fashion to a reference stream, the Wigwam River (Berdusco and Arnett 2008). There is no evidence of a decreasing trend in spawning activity; in fact, the number of redds observed in the creek in 2007 was at an all-time high (Figure 1).

FIGURE 1: Bull Trout Redd Counts in Line Creek Data from Allan (2003) and Berdusco and Arnett (2008)



Large-Scale Fisheries Assessment

As noted in Chapman et al. (2007), a larger-scale assessment of the status of fisheries in the Elk River Valley is being conducted by a graduate student from the University of British Columbia with funding assistance from EVCC. This research is investigating the population dynamics of bull and cutthroat trout in the Elk River Valley. This study is specifically investigating two factors that influence the distributions of these two fish species in the Elk River Valley: recreational fishing activities that predominate in the Elk River mainstem (both catch-and-keep and catch-and-release), and coal mining operations in tributary streams. In the mainstem, drift boat activity is the dominant form of angling activity. Tagging of adult WCT and other studies were conducted to evaluate the influence of drift fishing

in the mainstem on those fish populations, compared to fish populations in the lower section of Michel Creek, where drift boat activity is absent.

Although the results have not been finalized, the data (Figure 2) indicate that adult WCT densities are higher in catch-and-keep fishing areas, as opposed to catch-and-release areas. The results are less clear for bull trout.

A comparison of WCT densities with fishing effort for all sections in the lower mainstem, where drift fishing takes place, indicates that trout densities are unaffected by drift fishing (Figure 2). The positive relationship between fishing effort and fish density is likely due to angler familiarity of where the fish are located. For bull trout the same sort of positive relationship is evident, but it is weaker than for WCT.

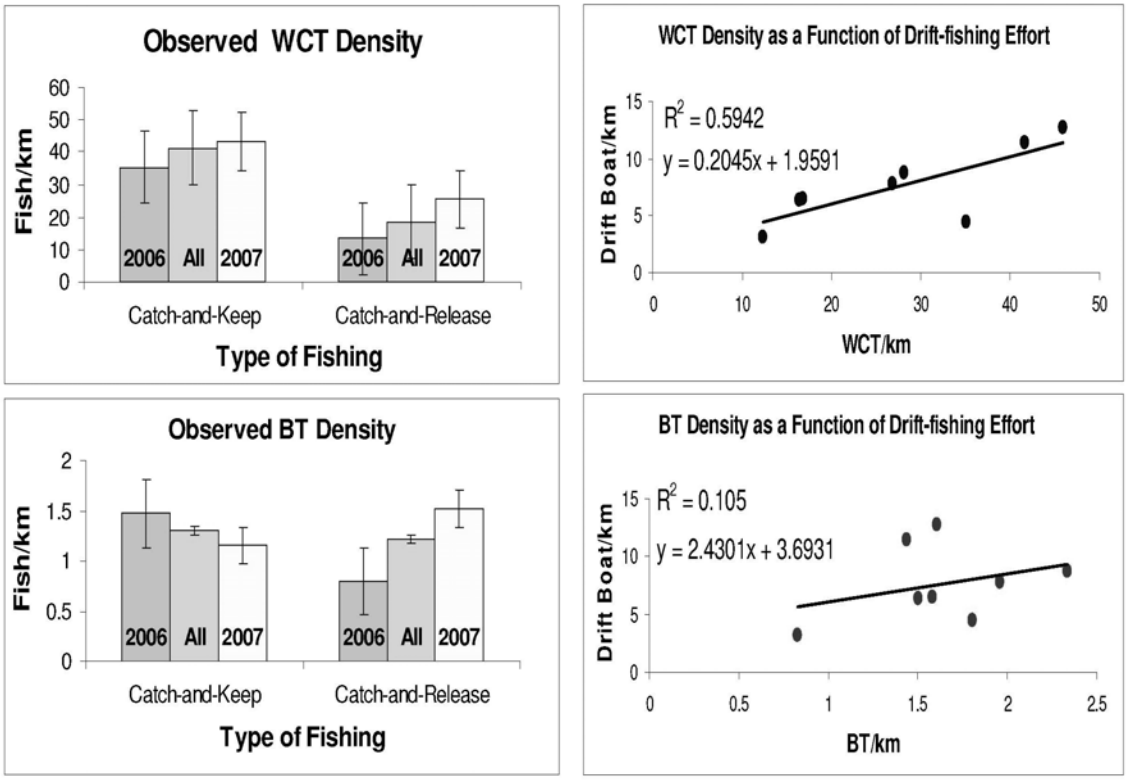


FIGURE 2: (left). Fish densities observed during snorkel counts for Westslope cutthroat trout (WCT) and bull trout (BT) in the catch-and-keep and catch-and-release fishing zones over the summers of 2006 and 2007. Figure 2 (right). The relationship between WCT density and mean observed drift boat activity during 2006 and 2007 including both catch-and-keep and catch-and-release fisheries. Figures provided by Chad Wilkinson (UBC).

In the tributaries, electrofishing and trapping methods were used to determine relative abundances of juvenile fish in streams upstream and downstream of the coal mines, as well as in reference streams. Although Se concentrations in fish tissues were not measured, the relative abundance of fish in streams downstream of the coal mines compared to reference streams provides useful information. In this regard,

there is no clear relationship between fish densities above and below mine-affected streams and in reference streams. Both the lowest and highest densities are found in streams downstream of mining operations (i.e., Elkview and Coal Mountain, respectively). The major determinant of fish abundance may be a combination of abiotic factors, including: stream temperature, water flow rate, and nitrogen (present as a nutrient). Further analyses will attempt to investigate the relationship between fish abundance and these abiotic factors, including tributary-specific levels of Se and nitrogen.

MAPPING OF LENTIC AND LOTIC HABITATS

Watershed mapping conducted to determine all lentic areas potentially at risk from Se (e.g., wetlands, marshes, backwater areas) and the relative proportion of lentic vs. lotic areas in the Elk River Valley is in progress. This work is intended to assist in understanding the overall relative distribution/importance of each type of area downstream of the mines, and will assist in focusing future Se research and assessments. Mainstem and tributary areas downstream of the coal mines and within the mines' boundaries were videotaped from a helicopter. Lentic areas are being distinguished as either:

- Standing water areas (i.e., pond, backwater, relict channel or wetland areas) apparent at base stream flow conditions; or

- Wetlands not wetted at base stream flows, but that were expected to be wetted during mid- to high-flow periods for a significant portion of the year. The outlying boundary for these lentic areas is defined by vegetation, soils and topography visible in the aerial images, from ground-truthing (see below) and, where appropriate and possible, from earlier vintage air photos and other historical information.

FUTURE STUDIES

Management

Future management studies in addition to those already underway will be undertaken based on results from current management and monitoring studies, federal and provincial government requirements, and discussions within the EVSTF. Selected Se studies conducted through 2007 in the Elk River Valley are being integrated into monitoring and management plans, including a Standard Operating Procedure for fish deformity analysis, and predictive modeling of fish populations.

Effects

The need for additional effects studies will be determined partly based on the results of on-going monitoring studies, as well as on the findings of the WCT effects study currently in progress.

Monitoring

Site-specific monitoring of Se and other relevant parameters in discharge water will continue to be undertaken at the five mines (EVSTF 2005; Chapman et al. 2005). The next cycle of regional monitoring

of water and biota will occur in 2009. Monitoring of fish populations and reproduction in Line Creek by EVCC will continue on an annual basis.

OTHER STUDIES

The Terrestrial Environment

As reported previously (Chapman et al. 2007; EVSTF 2007), there is currently no reason to believe that Se from the mines is adversely affecting resident ungulate populations (e.g., elk, sheep). Routine wildlife monitoring undertaken by EVCC, including annual wildlife surveys, indicates that these populations are thriving. Accordingly, the only terrestrial studies planned are continued monitoring of the health of the ungulate herds and vegetation analysis every 5 years (next cycle in 2011) of Se concentrations in vegetation.

CONCLUSIONS

Based on studies conducted to date, current Se concentrations in the Elk River Valley do not appear to be having large-scale adverse effects or impacts (Chapman et al. 2007; EVSTF 2007). Although Se water column concentrations are increasing, Se concentrations in benthic invertebrates, fish muscle and water bird eggs have not increased over the last few years. Red-winged blackbirds appear to have an inherent ability to limit Se accumulation in their eggs to levels that are just barely into the potentially toxic range, not related to increasing water Se concentrations (Harding 2007). Terrestrial (i.e., ungulate) or human health effects from Se are not occurring and are not expected to occur in future.

Increasing Se surface water concentrations are a potential concern in the aquatic environment downstream of the Elk Valley coal mines. A step-wise approach has been taken to identifying the extent and significance of any effects or impacts, followed by increased emphasis on monitoring and management (cf Chapman et al. 2007; EVSTF 2007) Efforts are presently focused on managing/minimizing Se inputs and understanding how to intervene in the Se cycle once Se is in the environment (to reduce production of the more toxic organic form of Se).

ACKNOWLEDGMENTS – Useful review comments were provided by members of the multi-stakeholder Elk Valley Selenium Task Force (EVSTF). However, the summary information provided herein is the sole responsibility of the authors and does not necessarily reflect the views of all members of the EVSTF.

REFERENCES

Allan JH. 2003. Fisheries investigations in Line Creek in 2001. Report prepared by Pisces Environmental for Line Creek Mine, Sparwood, BC, Canada.

Berdusco J, Arnett T. 2008. Line Creek Operations 2007 aquatic health monitoring report-year 1 of the 5-year aquatic health monitoring program. Report prepared for Elk Valley Coal Corporation - Line Creek Operations, Sparwood, BC by Interior Reforestation Co. Ltd., Cranbrook, BC.

Chapman PM. 2005. Selenium status – Elk River Valley, BC. In: Price W, Hart B, Dixon B, Jarman P, Riordan B, Freberg M, Howell C, Proceedings of the Twenty-Ninth Annual British Columbia Mining Reclamation Symposium – "The Many Facets of Mine Reclamation". British Columbia Technical and Research Committee on Reclamation, Abbottsford, BC, September 19-22, 2005.

Chapman PM, Berdusco R, Jones R. 2007. Update on the status of selenium investigations in the Elk River Valley, BC. In: Proceedings of the 31st Annual British Columbia Mining Reclamation Symposium – "Rejuvenation Through Reclamation, and Operating for Closure", British Columbia Technical and Research Committee on Reclamation, Squamish, BC, September 17-20, 2007.

Chapman PM, McDonald B, Ohlendorf H. 2008. Selenium management model. Draft Technical Memorandum to EVCC, July 2, 2008.

EVSTF (Elk Valley Selenium Task Force). 2005. Selenium Status Report 2004 – Elk River Valley, BC. Prepared by Golder Associates, North Vancouver, BC, Canada.

EVSTF. 2007. Selenium Status Report 2005/2006 – Elk River Valley, BC. Prepared by Golder Associates, North Vancouver, BC, Canada.

Harding LE. 2007. Non-linear uptake and hormesis effects of selenium in red-winged blackbirds (*Agelaius phoeniceus*). Sci Total Environ 389; 350-366.

Kennedy CJ, McDonald LE, Loveridge R, Strosher MM. 2000. The effect of bioaccumulated selenium on mortalities and deformities in the eggs, larvae and fry of a wild population of cutthroat trout (*Oncorhynchus clarki lewisi*). Arch Environ Contam Toxicol 39: 46-53.

Minnow Environmental, Interior Reforestation, Paine Ledge and Associates. 2007. Selenium monitoring in the Elk River watershed, BC – 2006. Report prepared for the EVSTF.

Rudolph B-L, Andreller I, Kennedy CJ. 2008. Reproductive success, early life stage development and survival of westslope cutthroat trout (*Oncorhynchus clarki lewisi*) exposed to elevated selenium in an area of active coal mining. Environ Sci Technol 42: 3109-3114.