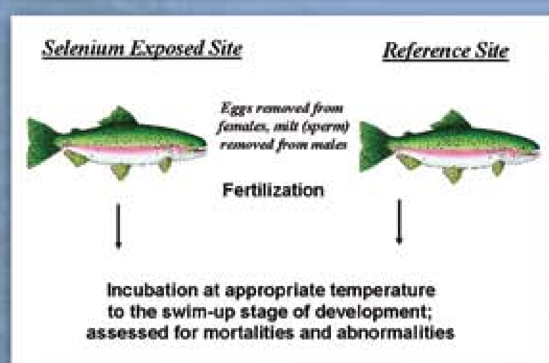
Selenium Status Report 2005/2006

ELK RIVER VALLEY, BC









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

Final Draft: MAY 2007

EXECUTIVE SUMMARY

The *Selenium Status Report 2004* summarized studies conducted through March 2005 regarding elevated selenium concentrations in the Elk River Valley in southeastern British Columbia. The present *Selenium Status Report 2005/2006*, also produced under the direction of the multi-stakeholder Elk Valley Selenium Task Force (EVSTF), summarizes further studies conducted through January 2007, as well as studies in progress, and outlines what further studies are needed and why.

Selenium is a natural element, which is released naturally from selenium-containing rocks by weathering. Coal strata in the Elk River Valley contain selenium, whose release into the environment is accelerated by coal mining. Selenium, although essential for life, can be toxic at higher concentrations and can affect the reproduction of fish, water birds and possibly amphibians feeding in waterbodies containing high levels of selenium.

Four categories of investigations have been and are being conducted in the Elk River Valley related to selenium released from coal mining: management, effects, monitoring, and other studies.

Management investigations are focused on selenium source / release studies and water quality predictions, a selenium cycling assessment, and a management decision framework. The overall goals of the management investigations are both predictive and protective. Source studies are attempting to predict future selenium releases under different mining scenarios and management approaches. Selenium cycling studies will attempt to determine controls on the cycling and conversion of inorganic selenium once it enters the aquatic environment. The management decision framework provides a means to integrate present and future information to effectively manage selenium releases from the coal mines to ensure environmental protection.

Effects studies (an effect is simply a change in status) have focused on determining whether or not fish, water bird and amphibian reproduction is being affected by the selenium released from coal mining (in other words, whether impacts have occurred; impacts are adverse effects to populations of organisms). The goals of these effects studies are two-fold: to determine a selenium effects threshold, and to provide data to assist in ensuring that adverse impacts do not occur to fish, water birds or amphibian populations living in the Elk River Valley. Studies conducted to date have determined an absence of impacts to fish (cutthroat trout) and water birds (American dipper and spotted sandpiper) living in the predominantly lotic (flowing water) areas of the Elk River Valley although effects were noted for the spotted sandpiper. In the less common but more at risk lentic (still water) areas of the Valley, an absence of selenium-related impacts has been determined for red-winged blackbirds, eight species of waterfowl, longnose sucker and Columbia spotted frog. An effects study on cutthroat trout living in a lentic environment partially confirmed the findings of the previous lotic study with this same species, specifically that cutthroat trout have a relatively high tolerance to selenium. However, the two cutthroat trout effects studies also resulted in some contradictory findings. As a result, although there are no indications of impacts from selenium to cutthroat trout living in lotic or lentic areas of the Elk River Valley, a further effects study will be conducted with this species to resolve the contradictions. Specific study findings are summarized in Table 3 at the end of this report.

Monitoring studies indicate significant long-term increases in selenium in water downstream of the mines, at the Highway 93 federal-provincial water quality monitoring station located more than 80 km downstream of the nearest coal mine. Selenium concentrations are increasing about 6% per year, while loadings are increasing about 7% per year. The preliminary results of regional monitoring indicate that selenium levels in fish (cutthroat trout and mountain whitefish) muscle have not increased between 1996 and 2006. Fish continue to reproduce and apparently thrive in areas with elevated selenium concentrations. However, increasing water selenium levels indicate that, if this trend continues, selenium may eventually reach levels that could adversely impact fish, water birds and possibly amphibians living in the Elk River Valley. Hence there is an increased focus on selenium management to prevent this occurring.

Increasing concentrations of selenium in water are not expected to adversely affect the terrestrial environment. Herds of ungulates (bighorn sheep and elk) grazing on reclaimed mine lands are thriving and show no signs of selenium poisoning. Such poisoning could occur through consumption of selenium hyperaccumulating plants. However, efforts continue to ensure that such plants are not seeded in reclaimed areas.

Additional studies being conducted or planned include:

- Mapping of aquatic lentic and lotic habitats to ensure that representative areas have been assessed 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.
- Continued monitoring of biota and water in the Elk River Valley; the former will provide early warning of any increased selenium tissue concentrations that could be detrimental while the latter will provide information on the efficacy of management actions.
- Preliminary investigations of selenium concentrations in water and biota in Lake Koocanusa, which receives all the selenium inputs from the Elk River Valley as well as from other sources.
- Research into the viability of bacterial treatments to reduce selenium concentrations in the aquatic environment.
- A summary and assessment of all available information on selenium fate and effects in the Elk River Valley to provide the EVSTF with an overall summary of available data, identify data gaps, and provide recommendations for further work.
- A website for information dissemination and exchange.
- Coordination with the recently formed Canadian Industry Selenium Working Group (CISWG) and North American Industry Selenium Working Group (NAISWG), which will be conducting research and studies on issues that, while they concern the Elk River Valley, also have national or international relevance.

The overall goal of the EVSTF and of this work is to prevent any adverse impacts of selenium from coal mining in the Elk River Valley. It is expected that the next *Selenium Status Report* will be released in 2008.

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ACKNOWLEDGEMENTS

This report was written by Dr. Peter M. Chapman, Golder Associates, North Vancouver, BC. Lee Harding (SciWrite), Patti Orr and Cynthia Russel (Minnow Environmental), Barri-Lynn Rudolph (Simon Fraser University) and Jeff Berdusco (Interior Reforestation) reviewed sections relevant to studies they conducted and provided useful comments along with photographs and some figures and tables used in this report. Additional tables and figures were provided by Golder Associates. Formatting of the document was done initially by Tricia Kersey (Golder Associates) as a Word document for review by the EVSTF and subsequently by George Gorczynski (Golder Associates) in final format. Useful review comments were provided by members of the Elk Valley Selenium Task Force (EVSTF).

I. INTRODUCTION

I.I BACKGROUND

Selenium is an essential element. Humans and other life on this planet need it for their continued health. But, like all things, selenium in excess can be harmful. Selenium can be particularly harmful to egg-laying animals that feed in or from water bodies containing elevated levels of selenium: fish, water birds and possibly amphibians. Inorganic selenium released naturally by weathering of selenium-containing rocks or whose natural release is accelerated by mining, can be changed 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. When eggs are laid 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 selenium is present in the eggs.

In October 2003 the Elk Valley Mines Environmental Management Committee (EVMEMC), comprised of representatives of the five coal mines in the Elk Valley, published the *Selenium Status Report 2003*. The purpose of that document was to provide a synthesis of information up to that date relating to investigations of selenium fate and effects in the Elk River Valley and to indicate future research priorities.

The subsequent *Selenium Status Report 2004* was published in May 2005 and provided similar information for the period October 2003 to March 2005. The 2004 *Report* was published by a larger stakeholder group: the Elk Valley Selenium Task Force (EVSTF – see Section 1.2).

The objective of the present *Selenium Status Report* 2005-2006 is to summarize information on selenium in the Elk River Valley for the period March 2005 through January 2007. *Status Reports* are provided on an approximately yearly basis and / or as significant new information becomes available. The present *Report* was completed following finalization of key environmental effects studies begun in 2005 and finalized between November 2006 and January 2007.

We hope that readers find this *Report* useful. Comments and feedback are appreciated and will be used to improve the next *Report*.

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I.2 ELK VALLEY SELENIUM TASK FORCE (EVSTF)

Membership of the EVSTF includes Elk Valley Coal, Teck Cominco, the BC Ministry of the Environment, the BC Ministry of Energy, Mines and Petroleum Resources, and Environment Canada. The overall goal of the EVSTF is to determine if any adverse ecological effects are occurring or could occur due to elevated selenium concentrations in water, sediment and biota in the Elk River Valley. The EVSTF has four specific objectives:

1. Determine if effects are occurring at present;
2. Determine if effects could occur in the future;
3. Provide input to the review of provincial or national guidelines;
4. Determine site-specific environmental objectives where possible or necessary.

The EVSTF conducts its business via face-to-face meetings (about three per year), teleconferences, and e-mail. Subcommittees are formed as necessary. All work done for the EVSTF is conducted under the direct supervision of a Project Manager appointed by the EVSTF, and such work is approved for publication following review and approval by all members of the EVSTF. The present *Report* has been approved for publication and release by the EVSTF.

2. SELENIUM STATUS TO MARCH 2005

The *Selenium Status Report 2003* provides background information on the Elk River Valley, the coal mines, and selenium and its toxicity. That *Report* and the *Selenium Status Report 2004* provide information regarding past studies. Key findings from those studies are briefly outlined below. A map showing key features of the Valley referred to in the present *Report* is provided in Figure 1. A visual summary of studies conducted through 2005 and planned through 2010 is provided in Figure 2 and forms the basis for subsequent discussion in this *Report*.

2.1 SELENIUM RELEASES

Previous studies have determined that, although selenium is released naturally by processes such as weathering, coal mining accelerates the natural release of selenium to the aquatic environment by leaching from waste rock and other coal wastes. Lentic (non-flowing water) areas tend to have the highest water column selenium concentrations. The most recent information on selenium water concentrations downstream of the mines is provided in Section 3.3.1.

2.2 MANAGEMENT

Initial studies focused on the fate and effects of selenium including biological effects studies (Section 2.3) and monitoring studies (Section 2.4), determining trends and assessing whether or not selenium releases were adversely affecting resident biota or humans. Management efforts assumed greater importance beginning in early 2006 when studies completed to that date indicated that selenium was not adversely impacting either humans or resident biota with the possible exception of cutthroat trout living in an artificial settling pond. In other words, it was determined that there were no imminent catastrophic impacts that would need to be dealt with. However, the possibility of more subtle adverse effects could not be discounted and it was recognized that, if effective management measures were not taken to manage selenium inputs and cycling in the environment, impacts could occur at some point in the future. Current management efforts are described in Section 3.1.

Goddard Marsh, above; Clode Pond, below – effects studies included these two lentic areas which had the highest measured water selenium concentrations

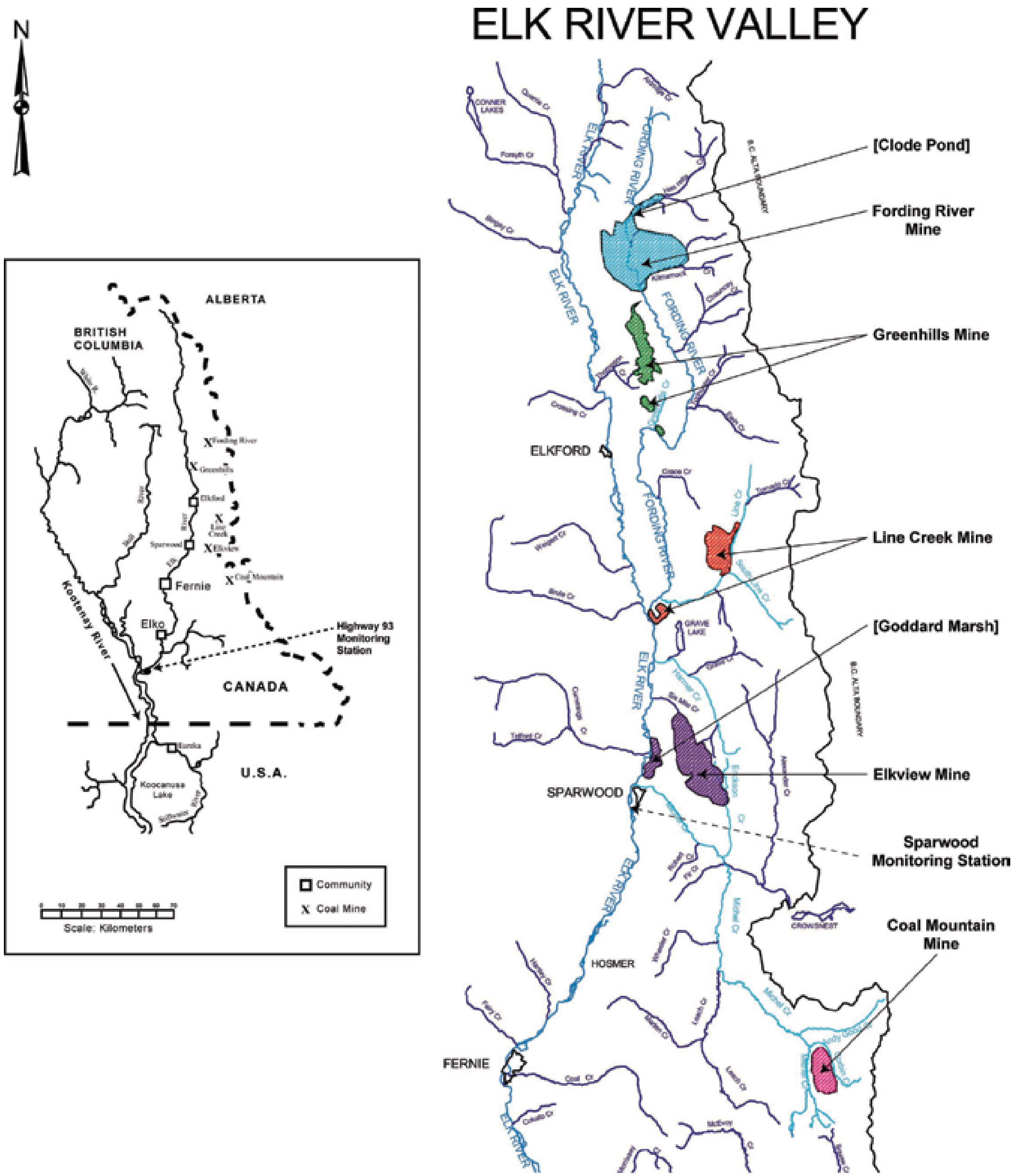


FIGURE I. The Elk River Valley, showing the locations of the five coal mines, the federal-provincial water quality monitoring stations at Sparwood and at the Highway 93 Bridge, Goddard Marsh and Clode Pond.

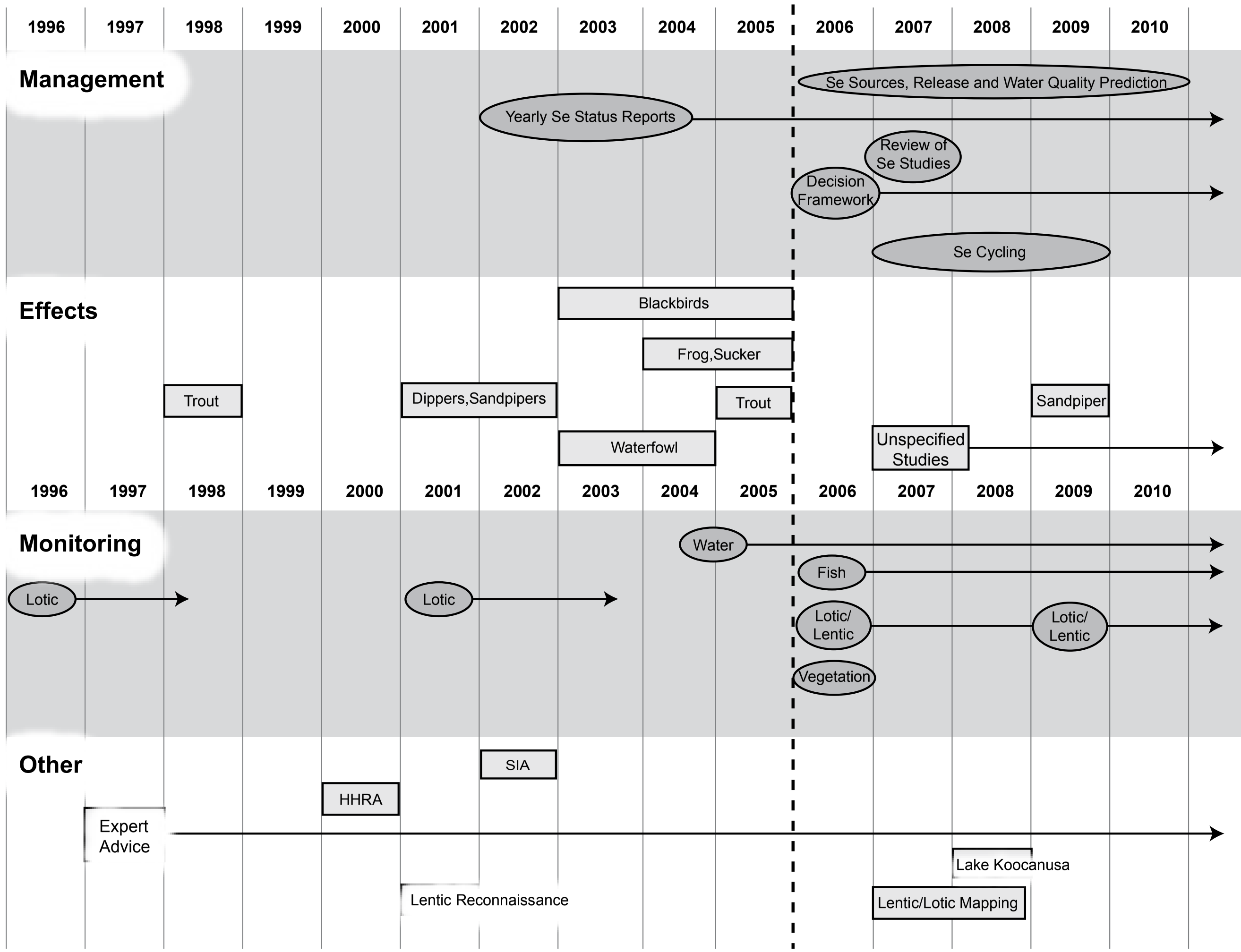


FIGURE 2. Selenium studies conducted 1996 through 2005 and recommended through 2010.

An effect is a change to individual organisms (plants and/or animals including humans) due to human activities. An effect may be positive (for instance, selenium is an essential element required for the health of all animals including humans), negative (for example, see Section 2.3.2 regarding sandpiper effects studies), or neutral.

An impact is an effect on a population of organisms other than humans that adversely affects the utility or viability of that population. An example is toxicity due to selenium that reduces the function and/or productivity of fish or water bird populations. In the case of humans or endangered species an impact would occur not at the population but rather at the individual level because individuals are protected, not populations.

2.3 EFFECTS STUDIES

A major focus of work conducted between 1998 and 2005 was effects studies (Figure 2). In the case of fish (cutthroat trout, longnose sucker) and frogs (Columbia spotted frogs), these studies typically involved following the development of fertilized eggs either in the field or in the laboratory and determining end points such as percent hatch, survival following hatching, and levels of deformities compared to reference populations. In the case of water birds (American dippers, spotted sand pipers, red-winged blackbirds) including waterfowl, field studies were conducted to determine any effects of selenium on the productivity of resident bird populations in exposed and reference areas including any mortalities or deformities associated with hatched eggs.

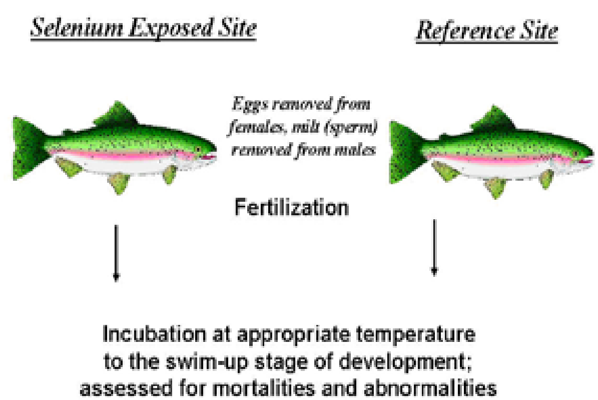
EFFECTS STUDIES are either laboratory or field studies that assess whether or not reproduction of fish, amphibians or water birds has been impaired in areas with elevated selenium concentrations compared to reference areas.

LOTIC is a term used to describe a flowing water body such as a stream or a river.

LENTIC is a term used to describe a non-flowing water body such as a marsh, pond or lake.

2.3.1 1998 Trout Lotic Effects Study

Because cutthroat trout are a key component of the recreational fishery in the Elk River (Heidt 2002), the first selenium effects study was conducted in 1998 using this fish species collected from lotic (flowing) waters. This study, commissioned directly by the BC Ministry of Environment, involved laboratory rearing of fertilized fish eggs with different selenium concentrations to the swim-up fry stage. This study found that, despite levels of selenium in mature fish and their eggs above concentrations shown to be toxic in other areas with other fish species, there were no mortalities or deformities of fry characteristic of selenium poisoning. The study results were published in the peer reviewed scientific literature (Kennedy et al. 2000) and generally allayed immediate concerns regarding impacts to the fishery in the lotic areas that comprise the majority of the Elk River Valley. The focus for the next set of effects studies remained on lotic areas, but shifted to water birds.



Example Effects Study Design – Trout

2.3.2 2001-2002 Water Bird Lotic Effects Study

A water bird lotic effects study was conducted with American dippers and spotted sandpipers over two years (2001-2002). These two species were chosen for study because they are reasonably representative of water birds in lotic areas of the Elk River, and they are sufficiently abundant that a reasonable number of eggs could be collected without adversely affecting populations. Selenium concentrations in the eggs of dippers were not statistically different between reference and exposed areas, and there were no discernable adverse effects attributable to selenium. Specifically, there were no abnormalities in chicks or embryos and no differences in hatchability or fledgling survival. In the case of sandpipers, egg selenium concentrations were higher in exposed than in reference areas and there was slightly reduced hatchability in the exposed areas compared to the reference areas. However, there was no evidence of any other selenium-related effects. Reduced hatchability could not be conclusively attributed to selenium compared to other stressors such as predation, floods or human activities that disturbed nesting pairs. As well, overall productivity (number of young produced per mating pair) was higher than the regional norm.

This study was also published in the peer-reviewed scientific literature (Harding et al. 2005) and generally allayed immediate concerns regarding impacts to water birds in the lotic areas that comprise the majority of the Elk River Valley.

The adverse effects of selenium resulting from the conversion of the inorganic form of selenium to the more toxic organic form are greater in lentic (still water) than in lotic environments (Simmons and Wallschläger 2005). Consequently, because effects studies had not determined impacts in lotic environments, effects studies now focused on lentic environments in the Elk River Valley as originally recommended in the *Selenium Status Report 2003.*

WATER BIRDS are birds that frequent water.

WATERFOWL are swimming / diving water birds such as ducks, geese, and coots. Wading birds such as sandpipers, or songbirds such as dippers and red-winged blackbirds are water birds, but they are not waterfowl.

2.3.3 2003-2004 Waterfowl Lentic Effects Studies

Waterfowl effects studies were conducted in 2003 and 2004 to determine any differences in reproductive success between a variety of waterfowl nesting around ponds and marshes with elevated selenium concentrations (exposed marshes) compared to similar environments with background selenium concentrations (reference marshes). Unfortunately this work was only moderately successful because few waterfowl reside in these areas, the nests were difficult to find, and only one egg could be removed from a nest to avoid adverse effects from sampling. Also, young waterfowl leave their nests right after hatching, which means that it was not possible to link them to a specific nest from which an egg was taken for selenium analysis.

Although information was gathered on eight species of waterfowl (American coot, hooded merganser, mallard, blue- and green-winged teal, ring-necked duck, Canada goose, Barrow's goldeneye, and bufflehead), only 29 eggs were collected, the majority from reference areas or moderately exposed areas. As expected, selenium egg concentrations were generally highest in the lentic areas with the highest water selenium concentrations. Surprisingly, this was not true for Goddard Marsh adjacent to the Elkview Operations mine (location shown in Figure 1), which had the highest water selenium concentrations.

Although egg selenium concentrations in many exposed areas were high enough that toxicity might have been expected, based on threshold levels reported in the scientific literature for different species in other areas, there was no evidence of adverse effects due to selenium. There were no apparent mortalities, no abnormalities, or differences in productivity between exposed and reference areas. However, the previously noted problems with this study, in particular the small sample sizes, mean that this result was not conclusive.

These studies also determined that the potential breeding population of waterfowl at both reference and exposed lentic areas was comprised only six or seven successful pairs. In order to get a sufficiently large sample size for a definitive study, most of these nests would have had to be found, sampled, and the hatchlings linked to specific nests. This kind of study was not realistically possible, plus it would have adversely impacted these small breeding populations. Consequently, subsequent work in these lentic areas focused on red-winged blackbirds, a more common and more easily sampled water bird.

2.3.4 2003-2004 Water Bird Lentic Effects Studies

Although they are not waterfowl, red-winged blackbirds nest around marshes and their food is associated with the marshes (insects, caterpillars, and dragonflies). Thus, they are exposed to selenium via their food in areas where selenium concentrations are elevated.

Male red-winged blackbird

Blackbird studies were conducted over three years – from 2003 to 2005. Studies conducted 2003-2004 are briefly summarized here and detailed in the *Selenium Status Report 2004*. The 2005 studies are detailed in Section 3.2.1 of this *Report*.

As for the waterfowl, studies were conducted in both exposed and reference lentic environments. Similarly, selenium egg concentrations were high enough at the high exposure sites that toxicity might have been expected, based on thresholds reported in the scientific literature for other species in other locations.

There was no difference in the number of eggs laid nor in hatchability between exposed and reference sites. However, at Goddard Marsh, which had the highest water selenium concentrations, investigators found 2 unhatched embryos with visible abnormalities, which were not seen at any other site. But Goddard Marsh also had 100% nestling survival, whereas some other exposed areas had lower nestling survival than reference areas. One of the other exposed sites also had a deformed nestling.

Six nestlings were discovered dead in their nests just prior to fledging at the high selenium Clode Pond, and their livers were found to contain high levels of selenium. Unfortunately the investigators had no permit to collect and sacrifice live nestlings to determine their liver selenium concentrations for comparison. The dead nestlings were over a week old and appeared healthy but had no food in their digestive tracts. The mystery as to why these nestlings died around Clode Pond but not around Goddard Marsh where selenium concentrations were higher, was solved when additional studies were conducted in 2005 as detailed in Section 3.2.1, indicating these deaths were not selenium-related but were due to natural causes.

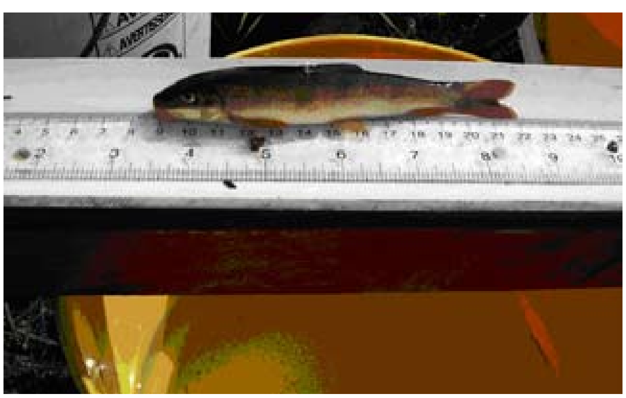
2.3.5 2004 Fish Lentic Effects Study

To the end of 2003, effects studies had been conducted in lotic areas with fish and water birds, and in lentic areas with waterfowl and water birds, but there had been no effects studies conducted in lentic areas with fish. This data gap was rectified in 2004 with new studies.

Based on previous assessments of fish communities in lentic areas (see Section 2.5), the most appropriate fish species for effects studies in lentic areas appeared to be longnose sucker. This fish species was present in sufficient numbers and could be found in both Goddard Marsh, which had the highest selenium water concentrations of any exposed lentic environment, and in a suitable reference area.

As for the lotic trout studies (Section 2.3.1), eggs were collected and fertilized. However, rather than conducting rearing of the fertilized eggs in the laboratory, rearing was conducted using incubation boxes in both Goddard Marsh and the reference area.

Unfortunately, problems developed with this study. The suckers were found to be a dwarf variety with different spawning times and smaller eggs than non-dwarf suckers. As a result, it was difficult to collect and fertilize eggs, and the eggs and hatched larvae were so small that they could have passed through the mesh of the incubation containers (the mesh had been designed to accommodate full-size sucker eggs and larvae). Further, fungus growth and sedimentation in the marshes killed many eggs. Of 6,687 fertilized eggs, only 94 fry were recovered from the incubation containers – 56 from 5 females from the reference area and 38 from 1 female from Goddard Marsh.



Adult longnose sucker

Higher selenium concentrations were recorded, as expected, in the sucker eggs from Goddard Marsh, and the data were suggestive of more deformities in those eggs than in the eggs from the reference area. But definitive conclusions were not possible, thus this effects study was repeated in 2005 (see Section 3.2.2 for details).

2.3.6 2004 Frog Lentic Effects Study

Although the scientific literature focuses on potential effects of selenium to fish and water birds, the possibility exists of similar effects to amphibians (which, like fish and water birds, also produce external eggs that may suffer from selenium poisoning as the embryos develop). To investigate this possibility, and also to provide additional information regarding possible selenium effects to aquatic organisms in lentic areas with elevated selenium concentrations, an effects study was conducted with Columbia spotted frogs.

This study was conducted in parallel with the previously discussed longnose sucker study (Section 2.3.5) at both Goddard Marsh and its reference area. Incubation of frog egg masses also occurred in their native marsh rather than in the laboratory.

However, despite numerous searches and ongoing monitoring throughout the Spring, no frog egg masses were found in the reference area, and only 3 egg masses were found in Goddard Marsh. The sample size was thus limited and there were no comparative reference data. As a result, although frog deformities occurred in Goddard Marsh and there was a positive correlation with selenium concentrations, the cause(s) of these deformities could not be established. Consequently, this study was also repeated in 2005 (see Section 3.2.3 for details).

Adult columbia spotted frog and egg mass

2.4 MONITORING

The first lotic monitoring study evaluated levels of selenium in water, sediment, and aquatic biota (animals and plants) in 1996, and was conducted by the BC Ministry of Environment (McDonald and Strosher 1998). The findings of this study, which found elevated concentrations of selenium downstream of the mines, provided the impetus for all subsequent studies.

Additional lotic monitoring was conducted between 2001 and 2003 on behalf of the mines, and served to update the 1996 monitoring studies conducted by the BC Ministry of Environment. This region-wide monitoring (EVS Environment Consultants 2005) supplemented independent, mine-specific water quality monitoring undertaken separately by the five coal mines. Although water selenium concentrations showed increases, tissue selenium concentrations did not show increases compared to 1996 **(Figure 3).**

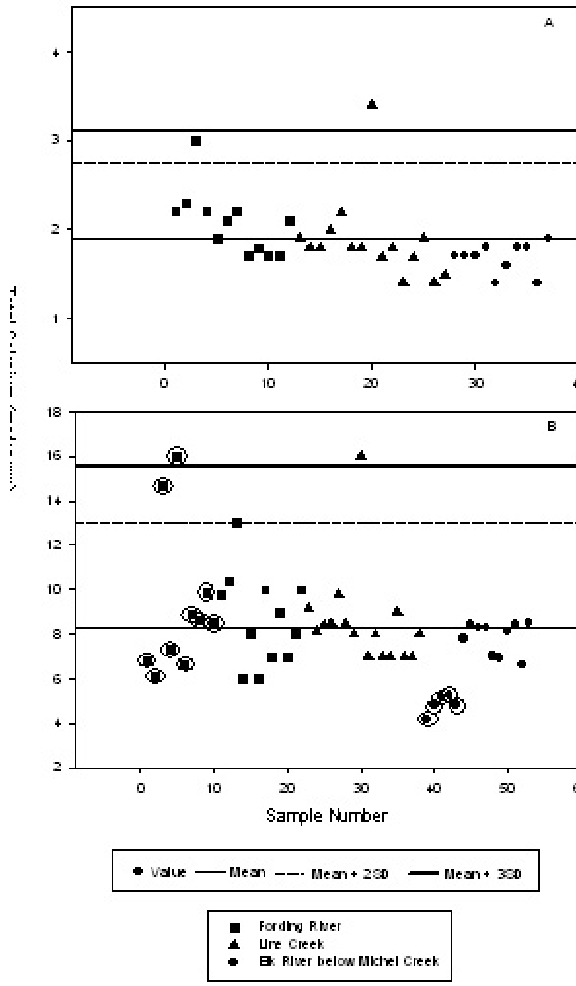


FIGURE 3: Cutthroat trout muscle selenium concentrations from selenium-exposed areas in the Elk River Valley 1996-2002. 2 standard deviations (SD) from the mean (average) enclose 95% of all values; 3 SD enclose 99.7% of all values. (A) Wet weight muscle selenium concentrations measured in 2001 and 2002. There are no wet weight data for 1996. (B) Dry weight selenium muscle concentrations measured in 1996, 2001, and 2002. Circled values are from 1996. mg/kg = parts per million.

In 2004 independent monitoring conducted separately by each mine was rationalized and standardized such that, when sufficient data became available, trends could be determined not only for selenium inputs from each mine but between different mines. This revised water quality monitoring includes all active permitted discharges. Sampling stations are shown and additional details of this program, currently into its second year, are provided in the *Selenium Status Report 2004*. Further details are provided in Section 3.3.1.

2.5 OTHER STUDIES

In 2000 a conservative human health risk assessment (HHRA) was conducted (EVS Environment Consultants 2000). This study found that there was negligible risk to humans eating fish from the Elk River Valley that contained selenium. In fact, it was found that "moderate quantities of fish consumed from the Elk River Basin (i.e., 2-3 meals per week) would actually have a net positive benefit on human health." The EVSTF, in a review of this and other previous studies during a meeting in December 2006, suggested that the HHRA be updated and prepared for peer-reviewed journal publication. Accordingly, a manuscript has been accepted for publication by the journal Human and Ecological Risk Assessment (Lawrence and Chapman in press).

During 2001 and 2002, reconnaissance surveys were undertaken of selenium concentrations in water, sediment and biota in Elk River Valley lentic environments (Minnow Environmental 2003). These reconnaissance surveys found no obvious indications of selenium-related effects in any of the lentic areas examined. All areas contained multi-trophic level food webs. However, the possibility of selenium effects could not be excluded since these reconnaissance surveys were not intended to definitively determine the presence or absence of selenium-related effects. In addition, not all species were found in all lentic areas. There are other possible reasons than selenium for species differences between areas such as habitat differences, but elevated selenium concentrations can also eliminate sensitive species. These reconnaissance surveys laid the groundwork for the more detailed effects studies conducted in 2003-2004 (Sections 2.3.3 to 2.3.6), and in 2005 (Sections 3.2.1 to 3.2.4).

In 2002 a technique called 'Stable Isotope Analysis' (SIA, described in detail in the *Selenium Status Report 2003*) was used to determine how selenium cycles through food webs in the Elk River Valley. This research, which was published in the peer-reviewed scientific literature (Orr et al. 2006), provided an improved understanding of selenium accumulation in both lentic and lotic aquatic food chains. This work assisted in the design of subsequent effects and monitoring studies.

3.0 SELENIUM STUDIES MARCH 2004 TO JANUARY 2007

Several presentations regarding the status of selenium studies in the Elk River Valley during the time period after March 2004 have been made at a provincial mining symposium (Chapman 2005a,b) and at an international scientific meeting (Chapman 2006).

3.1 MANAGEMENT

Three major management efforts were undertaken beginning in 2006: determination of selenium sources including release and water quality predictions; investigations into selenium cycling; and development of a decision framework (see Figure 2).

3.1.1 Selenium Source / Release Studies and Water Quality Predictions

Selenium source studies are focusing on understanding selenium sources and release and developing a model to predict future selenium releases under different mining scenarios and management approaches. The ultimate goal is to determine the best means to reduce selenium releases from coal mining. This work will be conducted in two phases. The first phase will build on earlier work including that reported in previous *Selenium Status Reports* (e.g., Ryan and Dittrick 2000; Lussier 2001) as well as more recent studies of selenium leaching from waste rock piles at different coal mines. The end product will be a summary of the current state of knowledge including key uncertainties and corresponding data gaps that need to be addressed in order to be able to generate mine-specific and cumulative watershed water quality predictions.

The second phase of the project will undertake a program to address these key uncertainties and data gaps. Once the data are collected, water quality models and predictions will be made to assess future water quality under current mining and various future mining scenarios.

The largest source of selenium discharged from coal mining operations is from waste rock piles due to their large volumes, hence these will be the initial focus of selenium source studies. Selenium is released primarily through chemical (oxidation) processes, but there is also a smaller physical (dissolution) release dependent on the hydrologic cycle (i.e., water cycling, in particular precipitation). Both release mechanisms need to be better understood before accurate predictive modeling can be done.

3.1.2 Selenium Cycling

The EVSTF is currently reviewing a proposal from Lorax Environmental to study the biochemical cycling of selenium in lentic environments. Selenium is released from coal mining in an inorganic form but can be converted into the more toxic organic form in lentic (still water) areas. This toxic organic form can then accumulate via the food chain in fish, water birds and amphibians and adversely affect their reproduction.

The ultimate goal of this proposed work is to determine what controls the cycling and conversion of inorganic and organic selenium. This understanding will assist in predicting selenium-induced toxicity in the aquatic environment of the Elk River Valley. It may also assist in determining opportunities for management intervention to disrupt the selenium cycle and reduce the amount of organic selenium in the system.

3.1.3 Decision Framework

A decision framework has been developed for managing selenium released from the Elk Valley Coal Corporation (EVCC) coal mines located in British Columbia (BC) and Alberta (AB) and for assessing knowledge gaps and priority issues. This decision framework **(Figure 4)**, which has been presented to the EVSTF and at two international scientific meetings (Chapman et al. 2006a,b), is currently being finalized. EVCC intends to use this decision-making framework for determining the basis for future studies and monitoring at all their mines where selenium is a contaminant of potential concern.

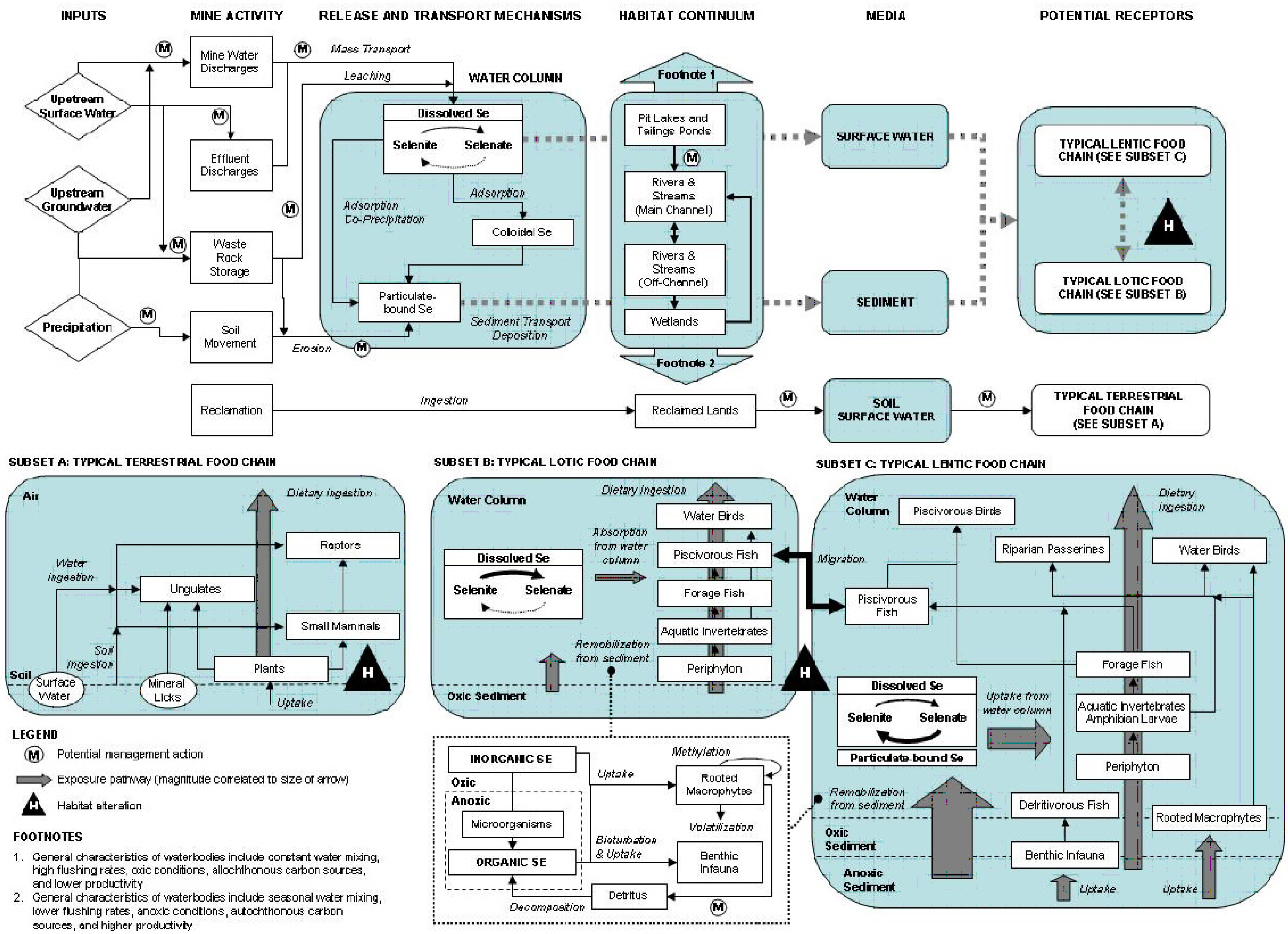


FIGURE 4: Selenium management decision framework.

3.2 EFFECTS STUDIES

3.2.1 2005 Red-Winged Blackbird Lentic Effects Study

The 2005 blackbird effects studies (SciWrite Environmental Sciences 2007) built on the 2003-2004 studies (Section 2.3.4). Productivity and development were determined for red-winged blackbirds nesting in marshes with elevated selenium concentrations (exposed marshes) compared to those with background levels of selenium (reference marshes). A key objective of the 2005 studies was to determine whether or not nestling mortalities observed in 2004 could have been due to selenium.

Predation effects on red-winged blackbird eggs

In 2005, as in previous studies, egg selenium concentrations were significantly elevated in the two highest exposure sites (Clode Pond and Goddard Marsh) in comparison to the reference sites. However, any effects of selenium appeared to be modest or absent. No level of selenium in eggs was consistently associated with higher numbers of egg failures, lower hatchability or lower nestling survival. Similarly, no level of selenium in livers of nestlings was consistently associated with higher nestling mortalities.

As previously noted (Section 2.3.4), 6 nestlings were found dead at Clode Pond following a period of cold wet weather in the 2004 study. Elevated selenium concentrations in their livers originally prompted a hypothesis of selenium poisoning despite the fact that there were no other observations consistent with that diagnosis. In 2005 live, apparently healthy fledglings were caught, sacrificed, and their livers found to contain similar or higher levels of selenium as the fledglings that died in 2004. A re-evaluation of the condition of the 2004 dead nestlings (apparently healthy, but empty digestive tracts) indicated that their deaths probably resulted from exposure and / or starvation, which can occur during prolonged rain storms such as occurred in 2004. In fact, in 2005 dead nestlings were found at both reference and exposed sites during unusually bad weather conditions (rain and snow).

Egg temperatures measured with a non-invasive infrared sensor, and observations at the nest sites, indicated that the cold, wet weather was likely responsible for the majority of egg failures in both selenium exposed and reference areas. Necropsies of dead nestlings conducted by a veterinarian wildlife pathologist, together with observations at the nest sites, confirmed that effects of exposure and drowning (resulting from high winds tipping over nests) were the most common causes of death.

Embryonic abnormalities that could have been due to selenium were only observed in 2 embryos from a low selenium area (Otto Pond). No developmental abnormalities in nestlings were observed despite thorough examinations of dead and sacrificed birds and superficial (to avoid excessive handling) examinations of all live nestlings.

Record rainfall and snow in early June 2005 resulted in overall lower productivity across all sites including the previously noted nestling mortalities. However, despite this, red-winged blackbird productivity in 2005 was above levels reported in the rest of British Columbia, which indicates that selenium was not having impacts on red-winged blackbird populations in selenium-enriched lentic areas of the Elk River Valley. Additional details are provided in **Text Box 1**.

TEXT BOX I: 2005 RED-WINGED BLACKBIRD EFFECTS STUDY

The 2005 study consisted of four reference marshes with levels of selenium below the federal water quality guideline for the protection of aquatic life (<1.0 µg/L [= parts per billion]), an intermediate exposure marsh (1.0 to 10 µg/L selenium), and three high selenium (>10 µg/L selenium) exposure marshes. A total of 133 blackbird nests were monitored; 63 eggs were collected from active nests and 55 eggs were salvaged after they failed to hatch, for a total of 118 eggs analyzed for selenium.

Mean egg selenium (MES) concentrations per nest ranged from 0.16 to 6.99 mg/kg wet weight (0.89 to 39.94 mg/kg dry weight [= parts per million]). Concentrations in the highest exposure sites (Clode Pond and Goddard Marsh) were significantly elevated in comparison to the reference sites. Interestingly, two of the reference sites (Elkford Marsh and Michel Creek) had MES concentrations that were higher than two of the exposed sites (Line Creek Marsh and Otto Creek).

Selenium concentrations in livers of nestlings were highest in Clode Pond; live nestlings with levels of selenium in their livers consistent with generic (i.e., not specific to red-winged blackbirds) selenium concentrations associated with adverse effects (up to 72.0 mg/kg dry weight) were found alive and apparently in good condition.

Typical effects of selenium poisoning were not found in any embryos or nestlings in the most highly selenium-contaminated marshes (e.g., see **Figures 5 and 6**, below), and there was no consistent elevation in glutathione peroxide (a selenium-dependent enzyme that can indicate selenium exposure) in contaminated marshes (e.g., Clode Pond) compared to reference marshes, where this enzyme was assessed.

Table 1 compares thresholds from the Alberta and BC studies with widely-quoted thresholds proposed by Lemly (1993) for freshwater fish species including trout. All trout species appear to have higher thresholds than those proposed by Lemly (1993).

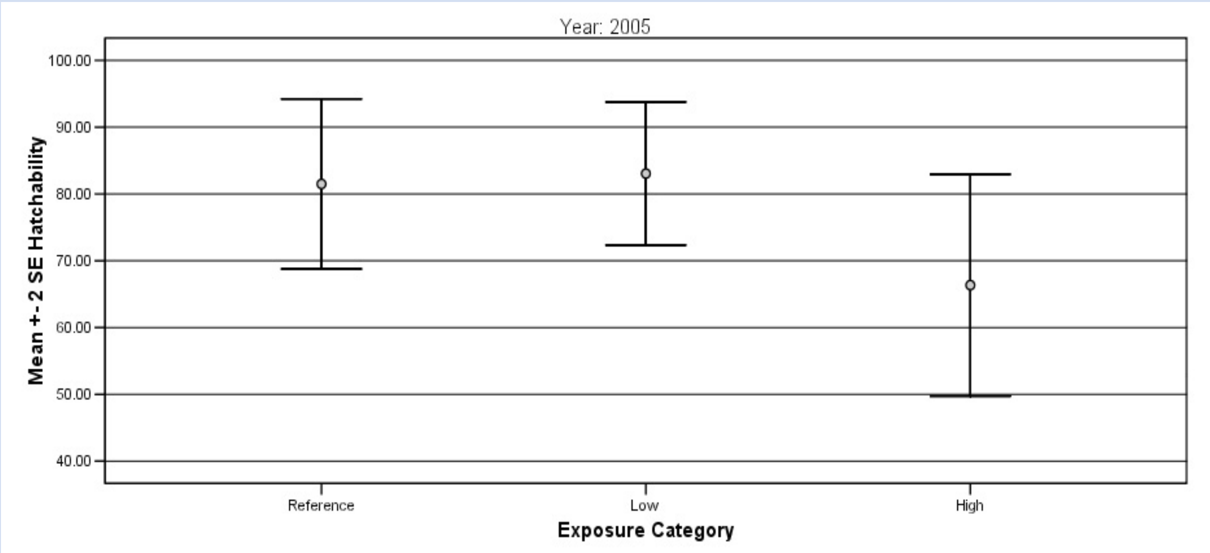


FIGURE 5: Hatchability (mean plus or minus two standard errors of the mean – percent of eggs incubated to full term that hatched) at the reference, low and high exposure marshes.

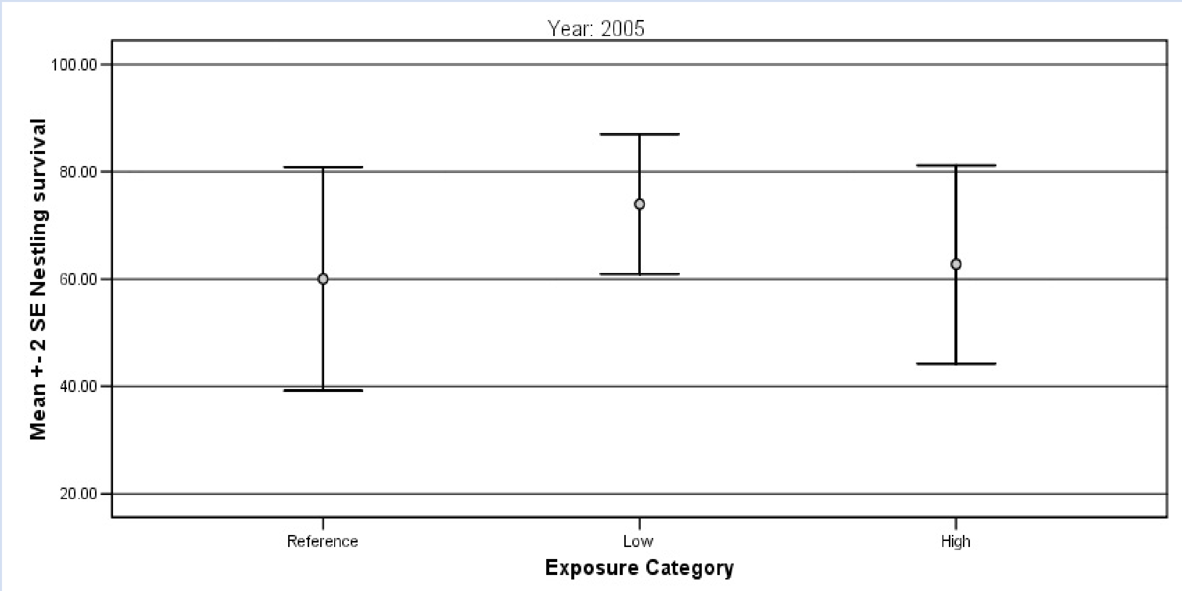


FIGURE 6: Nestling survival (mean plus or minus two standard errors of the mean – percent of nestlings that survived to fledge) at the reference, low and high exposure marshes.

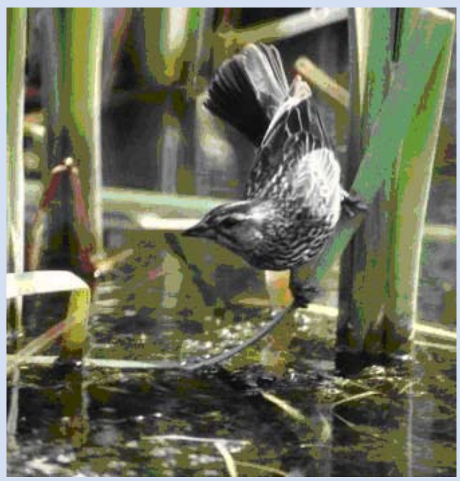
The two highest selenium-contaminated marshes, Clode Pond and Goddard Marsh, showed some interesting differences. Prey-items fed to Clode Pond nestlings had nearly 5 times higher levels of selenium than Goddard Marsh prey-items, which may be due to differences in selenium species at the two marshes. This finding explains the high levels of selenium in livers of fledglings from nests around Clode Pond. Selenate, the more bioavailable form of inorganic selenium, was present in higher concentrations and in higher ratios in Clode Pond sediments compared to Goddard Marsh sediments than the less bioavailable selenite inorganic form of selenium. Higher levels of sulfate were found in Goddard Marsh, which may have reduced selenium uptake and toxicity. Lower aqueous selenium concentrations were measured in Goddard Marsh than in previous years.

MES concentrations in two of the reference marshes (Elkford Marsh and Michel Creek) were higher than in two of the exposed marshes (Line Creek Marsh and Otto Creek). Of particular interest was a prey-item sample (a composite of 2 samples) from Elkford Marsh (a reference site) that had the second highest level of selenium in a prey-item sample (second only to Clode Pond). This measurement is consistent with higher mean red-winged blackbird egg selenium concentrations at this reference site and extends the range of naturally elevated selenium in the region.

By analyzing all 2003, 2004 and 2005 data using a quadratic model – a type of statistical analysis that can detect both beneficial and adverse effects at different scales – the investigators found a slight but statistically significant increase in productivity at low MES concentrations and an equally slight, statistically significant decrease in productivity at high MES concentrations. The beneficial effect is consistent with selenium's well-known role as an essential nutrient. Both beneficial and adverse effects were far smaller than weather-related effects.

An intriguing finding was a non-linear relationship between selenium concentrations in water and mean egg selenium (MES) concentrations, indicating that these water birds have a declining ability to accumulate selenium in their eggs. The point where further increases in MES were almost negligible was around 24 mg/kg dry weight, similar to the site average estimated effects threshold for red-winged blackbirds of 22.6 mg/kg dry weight (individual eggs had up to 39.9 mg/kg dry weight). This finding is in accord with Vasterling's (2003) independent conclusion related to selenium released from phosphate mining in Idaho. She found that adverse effects of selenium on the reproductive success of red-winged blackbirds do not occur when egg selenium concentrations are at or below 20 mg/kg dry weight.

These birds seem to have a built-in ability to limit selenium accumulation to levels that are just barely into the potentially toxic range, regardless of water selenium concentrations. As a result, the beneficial effect on productivity at low selenium concentrations balances the potentially adverse effects at higher concentrations. This finding is in accord with Ratti and co-workers (2006), who found increasing reproductive success of red-winged blackbirds at low selenium concentrations in Idaho phosphate mining areas, and no clear adverse effects at the highest selenium concentration recorded in their study: 31.2 mg/kg dry weight.



Red-winged blackbird photos clockwise from top left: female with a damselfly in her beak; female hunting at the water surface; taking a blood sample from a juvenile; juvenile with neck ligature to prevent swallowing during feeding studies; about 2-day old nestlings.

3.2.2 2005 Longnose Sucker Lentic Effects Study

The 2005 longnose sucker effects study (Minnow Environmental and Paine, Ledge and Associates 2006) built on the 2003-2004 studies (Section 2.3.5). A number of measures were taken to maximize the possibility of obtaining a sufficient number of larval fish to fully assess the relationship between egg selenium concentrations and any larval deformities.

Spawning development was monitored so that ripe adults could be procured in sufficient numbers for egg and sperm collection. As in the 2004 study, spawning longnose suckers were collected at Goddard Marsh (the exposed marsh) and at a low selenium reference area. Embryos and larvae were cultured not in the marshes as in previous studies but rather in incubation units like those used in fish hatcheries, which were placed adjacent to and received water from the Elk River. The incubation trays were modified to ensure no loss of eggs or larvae as happened previously. Longnose dace, a different fish species, were also collected, spawned and the embryos cultured to attempt to provide additional data on any selenium-related effects to lentic fish. However, all of the embryos from both the exposed and the reference area died and this study had to be terminated. Fertilized eggs of both species were also sent to Simon Fraser University for rearing in the laboratory as a back-up to the field incubations, but few viable larvae were produced from either exposed or reference eggs.

A total of 14 and 10 ripe longnose sucker females were captured, respectively, from Goddard Marsh and the reference area (Upper Elk River Oxbow). Ripe males from the reference area were generally used for sperm to fertilize these eggs. Selenium concentrations were measured in sub-samples of the exposed and reference area eggs.

Despite all precautions some embryos went missing during incubation, either due to miscounting or because embryos became caught and died in tiny crevices in the incubation units. The remaining embryos had variable mortality, in some cases as high as 100%.

A total of 20,398 embryos began incubation; 6,353 fry were retrieved and analyzed for any deformities (Text Box 2). Most surviving larvae had one or more deformities regardless of collection location (exposed or reference) or egg selenium concentration. There were no significant correlations between egg selenium concentrations and embryo-fry mortalities or deformities (Figure 7). Although selenium could not be excluded as a possible contributing factor, the observed mortalities and deformities could also have been due to stress from other factors including handling, exposure conditions (e.g., low dissolved oxygen concentrations, temperature extremes), radiation, or parasites. The results of this study were presented at an international scientific meeting (Orr et al. 2006).

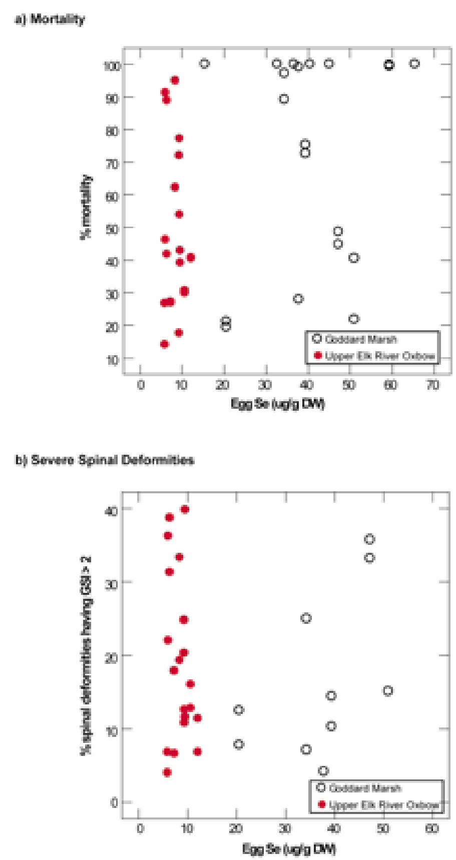
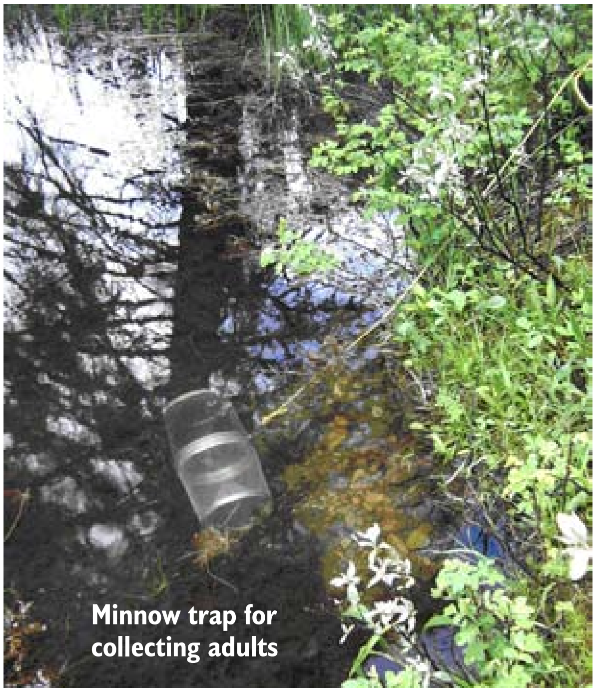


FIGURE 7: Lack of significant correlations between egg selenium concentrations and (a) fry mortalities or (b) severe spinal deformities for longnose sucker.

LONGNOSE SUCKER PHOTOGRAPHS

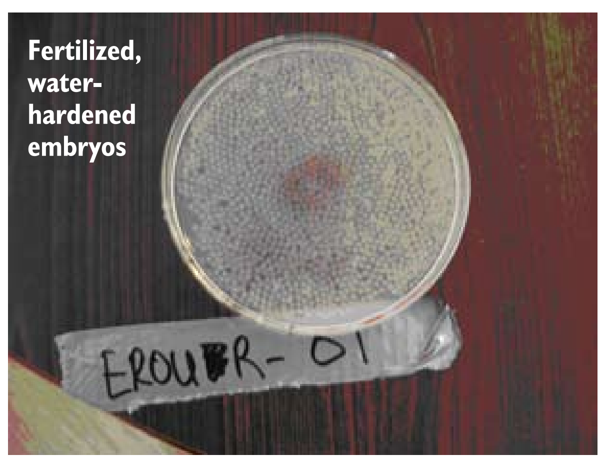

Minnow trap for collecting adults


Egg incubation trays


Stripping eggs from females


Adding milt (sperm) from male fish


Mixing the sperm and eggs in water


Fertilized, water-hardened embryos

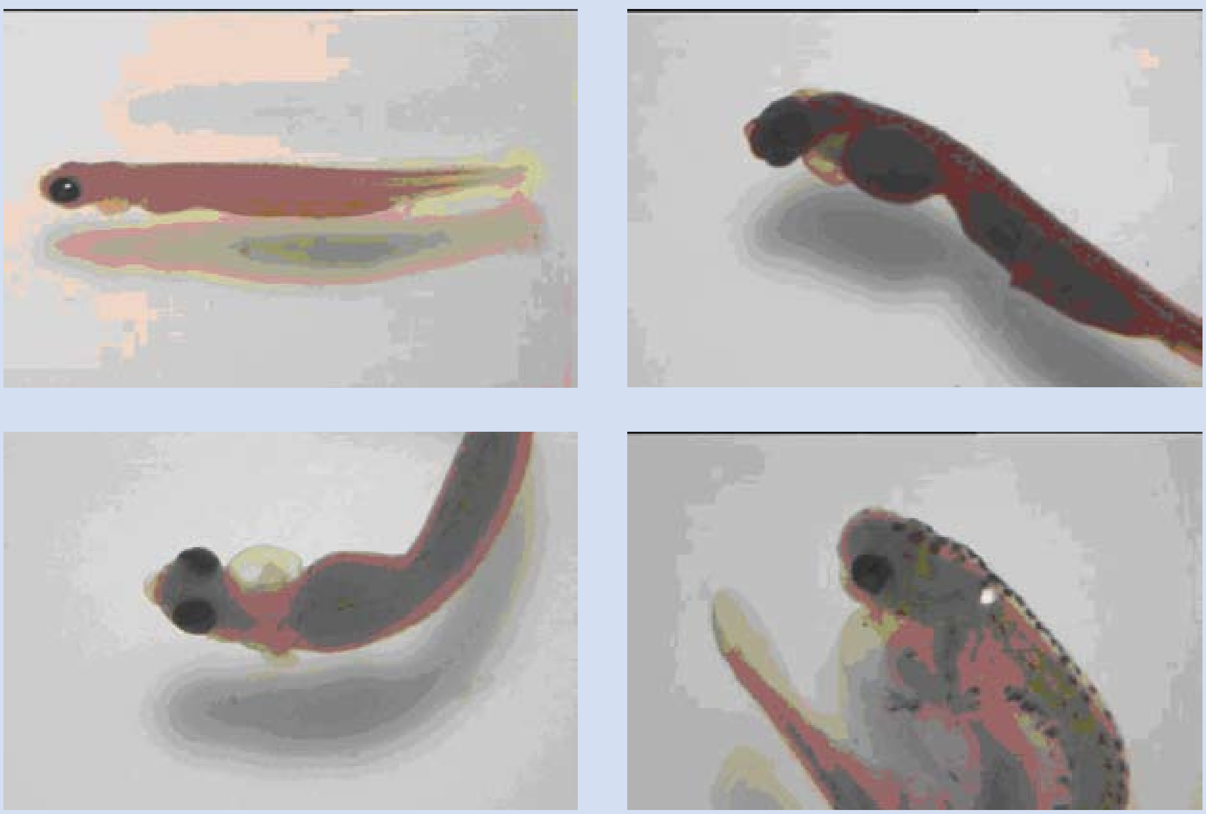
TEXT BOX 2: 2005 Longnose Sucker Effects Study Deformity Assessment

Deformities were assessed by Department of Fisheries and Oceans (DFO) personnel at the Freshwater Institute in Winnipeg. Fry were examined for the presence or absence of nine types of deformities: edema (fluid in tissue), craniofacial (skull and face), finfold (fold of larval skin from which the fins develop), kyphosis (outward curvature of the spine – humpback), lordosis (inward curvature of the spine - swayback), scoliosis (abnormal sideways curvature of the spine), lateral bend, other spinal deformity, or other uncharacterized deformity.

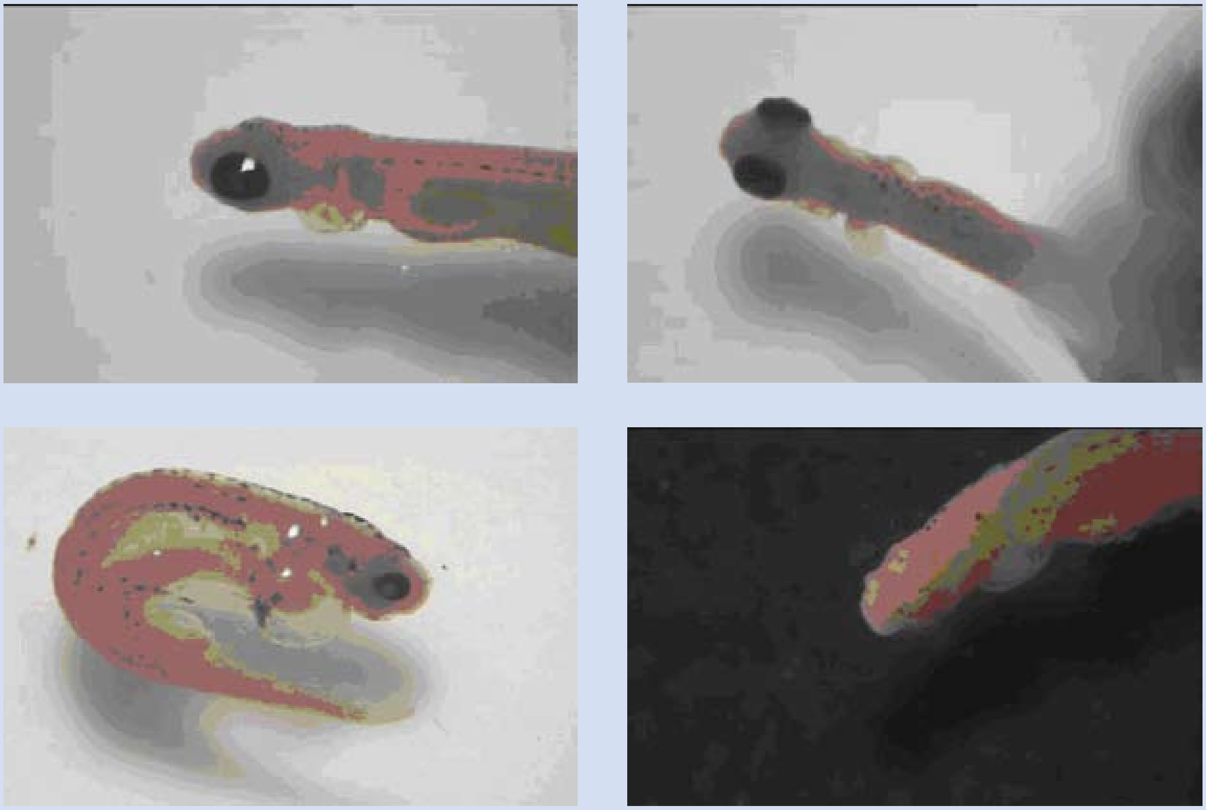
The relative severity of any deformities was assessed using a Graduated Severity Index (GSI) where 0 = normal, 1 = a slight defect in structure or size, 2 = a moderate defect, and 3 = a severe defect. All samples were double-checked to ensure that no deformities were overlooked or misidentified, and were archived to enable other researchers to validate the findings in future if so desired. Examples of different severities of deformities are shown below.

For each fry, GSI scores were summed for the 9 types of deformities to derive an overall GSI score. Mean GSI scores were calculated for each batch of fry and related back to egg selenium concentrations.

Examples of Longnose Sucker Fry Deformities: Edema (clockwise from upper left GSI scores of 0 [normal], 1 [slight fluid accumulation around eyes], 2 [more distinct edema including spreading of eyes] and 3 [swimming inhibited])

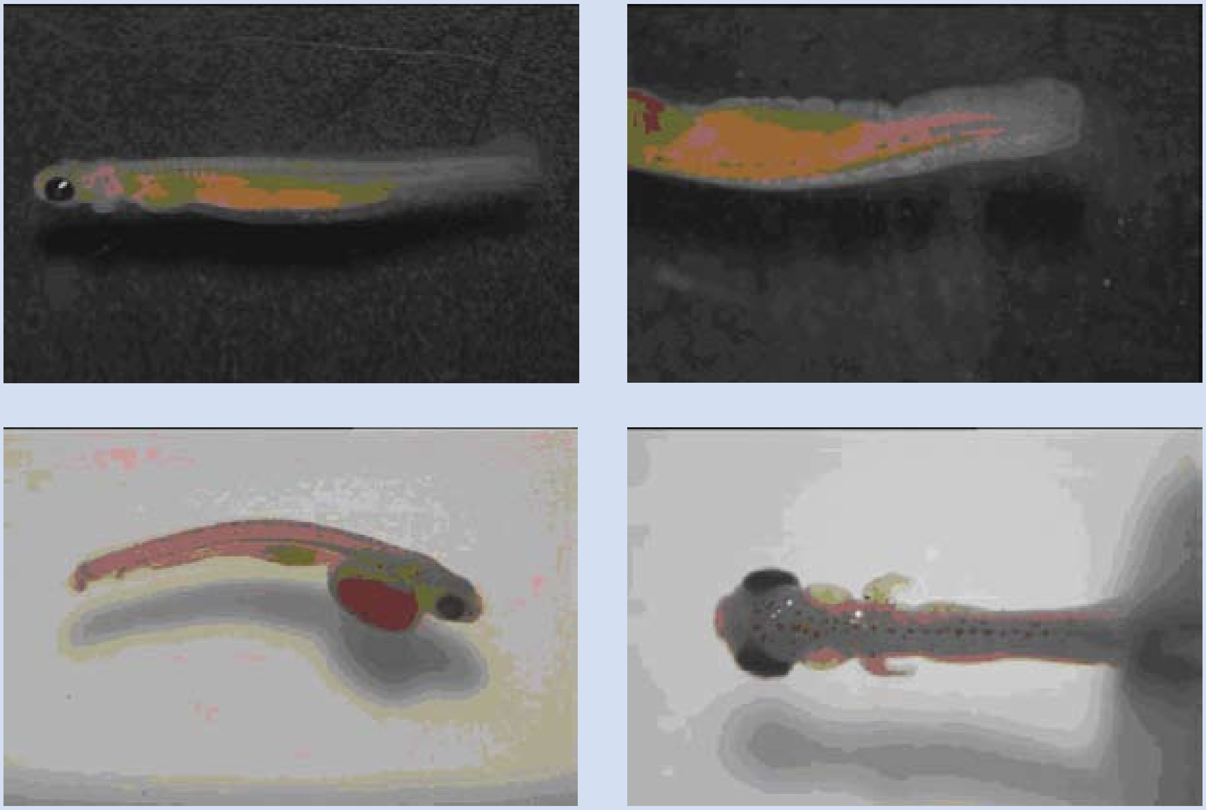


Examples of Longnose Sucker Fry Deformities: Craniofacial (clockwise from upper left GSI scores of 0 [normal], 1 [bump on head], 2 [more obvious craniofacial deformities including small eyes], and 3 [small head, missing eyes])



Examples of Longnose Sucker Fry Deformities: Spinal Deformities (clockwise from lower left GSI scores of 2 [affecting swimming], and 3 [swimming almost impossible]

Examples of Longnose Sucker Fry Deformities: Fins (clockwise from upper left GSI scores of 0 [normal], 1 [slight curvature or folding at tips of fins], 2 [more distinctly misshapen fins], and 3 [entire fin missing])



3.2.3 2005 Frog Lentic Effects Study

The 2005 Columbia spotted frog effects study (Minnow Environmental 2006) built on the 2003-2004 studies (Section 2.3.6). More wild egg masses were found than in the previous (2004) effects study, and these egg masses encompassed a wider range of selenium concentrations than had been previously assessed.

In total, 28 egg masses were collected from 7 lentic areas in the Elk River Valley. Selenium water concentrations during collection ranged from <0.5 to 50 µg/L (= parts per billion) or up to 25 times the BC water quality guideline of 2 µg/L. Approximately 200 embryos from each egg mass were separated into mesh bags, then replaced where they had been found to allow incubation to occur under natural field conditions. Developing embryos were assessed every 3-5 days. A subsample of the embryos was analyzed for selenium.

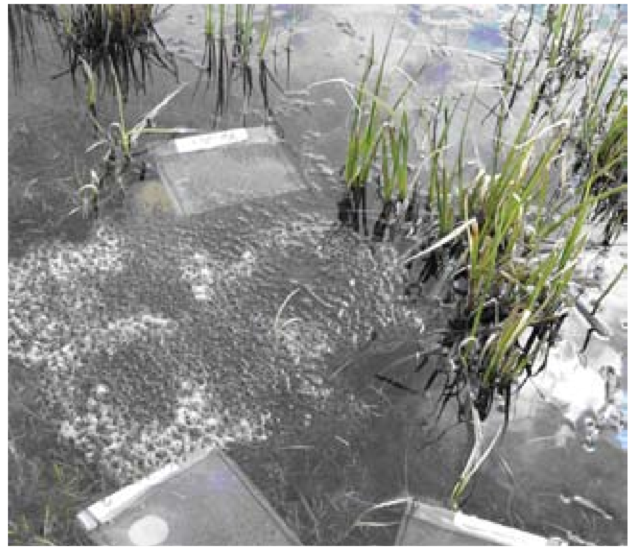
In total 2,324 tadpoles were collected at the end of the study and sent to the DFO Freshwater Institute in Winnipeg, as was done for the longnose suckers, to determine any deformities. The Graduated Severity Index (GSI) was also used to rate the severity of any deformities (see **Text Box 2** for general details and **Text Box 3** for specific details).

Low tadpole survival was observed in lentic areas with elevated selenium concentrations but also in some of the lentic areas with low selenium concentrations. There was no statistically significant relationship between selenium concentrations and mortalities, suggesting that other contributing factors were at least partly responsible for the mortalities that occurred. Based on other frog studies reported in the scientific literature, some of the variability in mortalities and deformities observed among frogs in this study can be considered "normal".

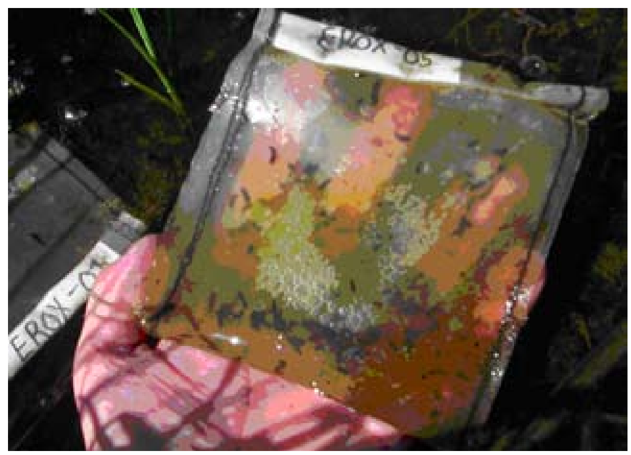
There was evidence that some types of spinal deformities increased among tadpoles as tissue selenium concentrations increased. However, there was high variability in mortalities and deformities of tadpoles with low selenium concentrations. In addition, there was not a wide range in tissue selenium concentrations, and the dose-response relationship was shallow. A threshold selenium tissue effect concentration could not be determined.

This effects study indicated that selenium may contribute to tadpole mortalities and deformities. However, it also indicated that factors other than selenium can have an equal or greater influence, particularly at tissue selenium concentrations less than 10 mg/kg dry weight (= parts per million). The results of this study were presented at an international scientific meeting (Orr et al. 2006).

COLUMBIA SPOTTED FROG PHOTOGRAPHS



Frog embryos ready for testing and later exposed in mesh bags in a marsh



Checking the status of embryo development at two different locations

Hatched embryos, and anaesthetized prior to preservation and deformity analysis

TEXT BOX 3: 2005 Columbia Spotted Frog Effects Study

The Columbia spotted frog is deemed vulnerable under the British Columbia Wildlife Act to disturbance both because it takes 4 to 6 years to mature sexually, and because the size of Columbia spotted frog populations in BC is not well known. This frog over-winters in water bodies that are deep enough not to freeze to the bottom. Adults spawn in Spring after the ice melts, but individuals may not breed every year, particularly at higher altitudes (James 1998).

Eggs are laid in vegetated shallow water at water depths of 3-30 cm. The eggs are contained in spherical clusters of jelly that float freely in the water. These clusters are about 15 cm in diameter, with up to 1,500 eggs each.

Hatched tadpoles from the field study (Section 3.2.3) were measured and examined for three types of deformities: craniofacial (skull and face), spinal, and other (for example, a shorter than usual tail). The severity of each deformity was assessed using the Graduated Severity Index (GSI) detailed in **Textbox 2**.

Craniofacial, spinal, tail and fin deformities were found. Greater than 50% of some egg masses had some type of deformity; the most common deformities were spinal. Initial plots of all deformities and selenium concentrations in the tadpoles (embryos) showed no relationship. A relationship (albeit one that was statistically very weak) did appear when data analyses focused on specific groups of deformities (**Figure 8**). Use of specific individual deformities and weighted mean (rather than individual) selenium concentration in embryos resulted in the best relationships (**Figure 9**), but these relationships did not indicate that selenium was the factor primarily responsible for the observed deformities.

There is a paucity of scientific information regarding the toxicity of selenium to amphibians. There are no established selenium threshold effects values for any amphibians for comparison with the present study. Selenium effects thresholds, as noted in Section 3.2.3, could not be established in the present study.

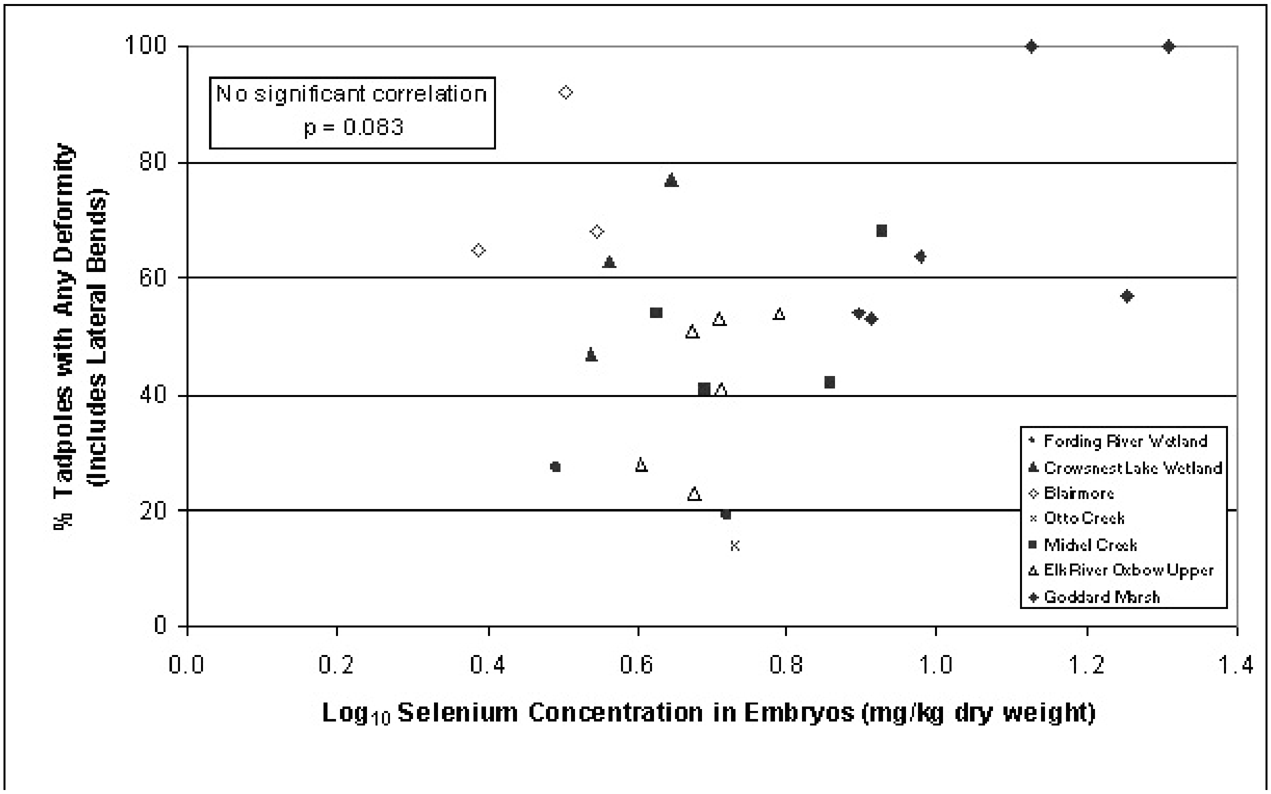
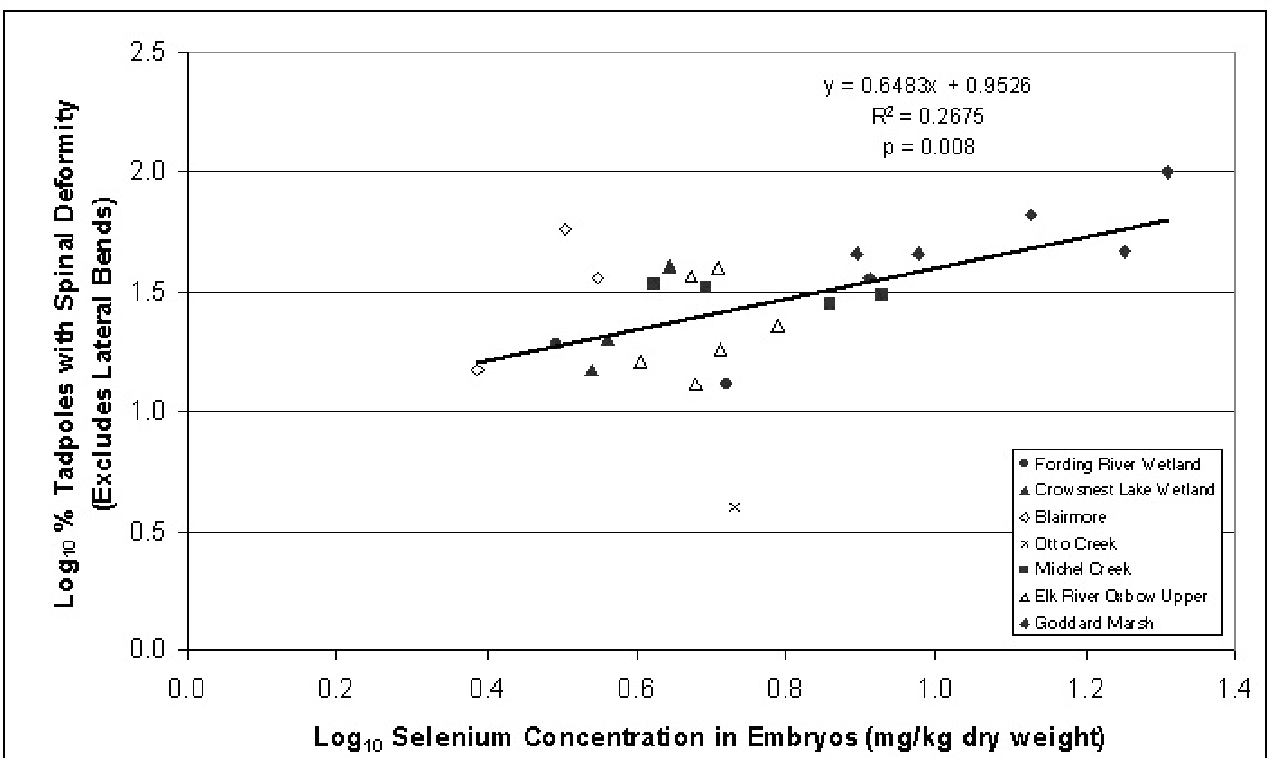


FIGURE 8: Columbia spotted frog embryo selenium concentrations relative to (above) percentage of tadpoles with any deformity and (below) percentage of tadpoles with a spinal deformity.



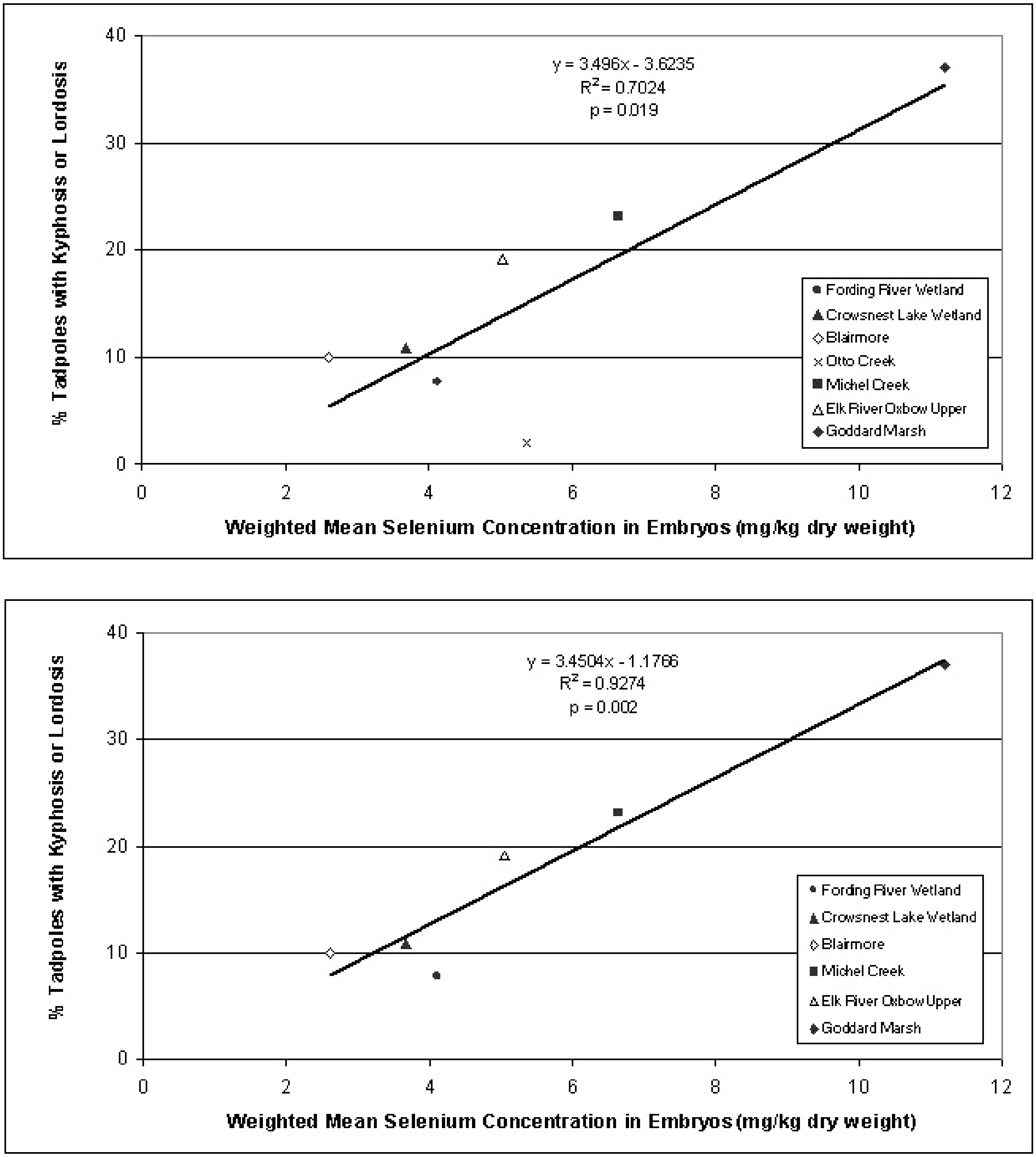


FIGURE 9: Weighted mean Columbia spotted frog embryo selenium concentration relative to the percentage of tadpoles with kyphosis or lordosis in each area: including (above) and excluding (below) Otto Creek.

3.2.4 2005 Cutthroat Trout Lentic Effects Study

The 2005 cutthroat trout lentic effects study, conducted by Simon Fraser University (SFU; Rudolph et al. 2007) was intended to build on the previous cutthroat trout effects study. The latter study, which was conducted in lotic waters (Kennedy et al. 2000), demonstrated that cutthroat trout in the Elk River Valley were not adversely affected by relatively high selenium concentrations (see Section 2.3.1). However, Kennedy et al. (2000) did not determine a selenium effects threshold for cutthroat trout in the Elk River Valley; only three of the female trout they tested had egg selenium concentrations above levels shown to be toxic in other studies with warm water fish (but no toxicity was observed by Kennedy et al. (2000)).

The primary goal of the 2005 cutthroat trout effects study was to determine an effects threshold by assessing the reproductive success of cutthroat trout resident in a lentic area with very high selenium concentrations – Clode Pond (for location, see **Figure 1**). Eggs from 12 female fish from Clode Pond and 16 female fish from O'Rourke Lake (a reference lake) were fertilized and raised to the swim-up fry stage in the laboratory. Elevated selenium concentrations were recorded in both the exposed (16.1 to 140.0 mg/kg dw [= parts per million]) and the reference fish (12.3 to 16.7 mg/kg dw). This latter finding was unexpected as selenium water concentrations in O'Rourke Lake are less than 1 µg/L (= parts per billion), whereas they are on the order of 71 to 93 µg/L in Clode Pond.

Another interesting observation was that the reference trout from O'Rourke Lake had a greater frequency of many embryonic deformities than fry from 4 female exposed trout from Clode Pond which had higher egg selenium concentrations (up to 20.6 mg/kg dry weight). In fact, fry from these 4 Clode Pond female trout showed no significant selenium effects in terms of either fry mortalities or deformities (see **Text Box 4**).

The greatest surprise was that, although the 2005 study used the same methodology as Kennedy et al. (2000), some of the results were contradictory. Kennedy et al. (2000) demonstrated that eggs with up to 81.3 mg/kg dry weight selenium produced normal fry with no evidence of selenium-related deformities or mortalities. In contrast, in the 2005 study when egg selenium 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 selenium concentrations were between 88.3 and 140.0 mg/kg dry weight (4 females), the eggs died before reaching the laboratory.

This latter observation, of eggs failing to survive, does not fit with the current scientific understanding of the effects of selenium on fish reproduction. Specifically, adverse effects are expected to occur as high enough levels of selenium are taken up during embryonic development so that the developing fry is affected, but the egg is not directly killed. Because of the contradictions between the earlier (Kennedy et al. 2000) and the later (Rudolph et al. 2007) cutthroat trout effects study, a further cutthroat trout effects study will be conducted by an independent party chosen following a competitive bidding process (see Section 4.2). It is hoped that this third trout effects study will provide data to understand the reason(s) for the differences between the two previous studies and also provide a definitive selenium effects threshold for westslope cutthroat trout in the Elk River Valley.

The findings of the 2005 trout effects study were presented at an international scientific meeting (Rudolph 2006, Rudolph and Kennedy 2006). Scientists in the audience were intrigued by the findings but did not provide any new explanations or interpretations.

The findings of both the cutthroat trout effects studies conducted to date in the Elk River Valley (Kennedy et al. 2000, Rudolph et al. 2007) have been compared with other selenium effects studies with other cold water fish (brook and rainbow trout, white sucker and northern pike - Chapman 2007). This comparison indicates that cold-water fish including cutthroat trout from the Elk River Valley have higher tolerances to selenium taken up via dietary sources than warm-water fish species. It was concluded that the USEPA (2004) draft whole body selenium tissue criterion of 7.9 mg/kg dry weight (which is about 2-fold higher than the present BC interim selenium tissue guideline) will provide a conservative level of protection for these cold-water fish species.

Research into the recovery of several sensitive fish species from two lakes in the south-eastern United States impacted by selenium over two decades ago, indicates that the USEPA (2004) draft criterion is also overprotective of warm-water fish, by about a factor of 2-fold (Finley and Garrett 2007). However, the level of protectiveness of the USEPA (2004) draft criterion is a contentious issue, and both studies noted that site- and species-specific studies are required to set realistically protective upper guideline values. Determining the toxicity threshold is the primary focus of the 2007 cutthroat trout effects studies. Interestingly, although selenium water concentrations have increased between 1996 and 2006, preliminary data indicate that fish tissue selenium concentrations have not (Sections 3.3.1 and 3.3.2; **Figures 11 and 13**, respectively).

TEXT BOX 4: 2005 Cutthroat Trout Effects Study

Because eggs with selenium concentrations greater than 46 mg/kg dry weight did not produce viable fry, deformity analysis was only performed on fry that developed from eggs with selenium concentrations below 20.6 mg/kg dry weight. [Unfortunately, no eggs with selenium concentrations between 20.6 and 46.8 mg/kg dry weight were collected for testing by Rudolph et al. (2007).] Deformity analyses were conducted on the same samples by both the DFO Freshwater Institute in Winnipeg and by the Simon Fraser University (SFU) researchers who conducted the effects study. Deformity analyses were conducted as for longnose sucker (see **Textbox 2**). There was no relationship between selenium concentrations in eggs and the frequency or severity of deformities in fry developing from those eggs.

Fry developed from the O'Rourke Lake (reference) trout had significantly higher frequencies of skeletal deformities than trout from Clode Pond, but there were no differences in craniofacial or finfold deformities. There were very few moderate or severe deformities at either location.

Clode Pond and O'Rourke Lake are very different. Clode Pond, located at an elevation of 1670 m, comprises a series of constructed settling ponds. Until 2004 a cutthroat trout population moved freely in and out of Clode Pond. Subsequently, the fish were confined to allow for a fish salvage operation conducted to move these fish into the Elk River before mining activities physically impacted Clode Pond. Fish not captured in the initial salvage operations in 2004 and which were resident in Clode Pond for more than 8 months were used in the SFU effects study.

O'Rourke Lake is located at an elevation of 2145 m east of, and unimpacted by coal mining activities. Westslope cutthroat trout from Connor Lake (which latter served as the reference site for Kennedy et al. 2000) were stocked into the lake in 1985 (3000 fish), 1989 (2000 fish) and 1992 (2000 fish). Populations are sustained through natural spawning. However, O'Rourke Lake is also known locally as "The Icebox" because it remains frozen for a large part of the year.

In total 2,914 fry from 14 O'Rourke Lake females and 2,008 fry from 4 Clode Pond females were assessed for deformities. The results are shown in **Table 1**. There were differences between the deformity analyses conducted by DFO and by SFU, particularly for edema (higher for the SFU researchers), but relative differences between the sites were similar for both analyses.

TABLE I: Deformity analysis results (frequency and severity scores) for swim-up cutthroat trout fry from O'Rourke Lake and Clode Pond - SFU data.

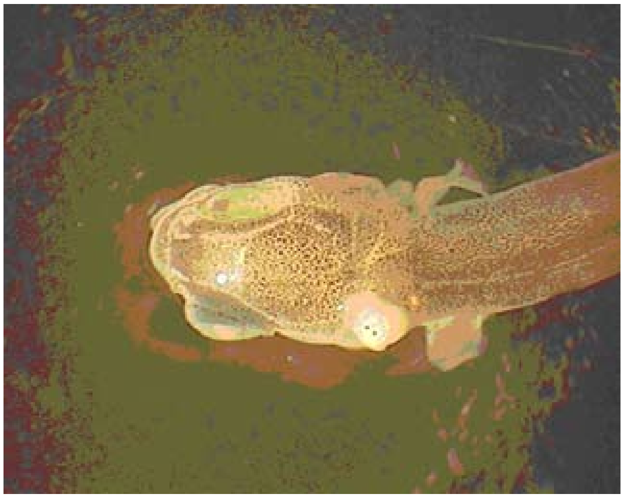
Values are presented as mean ± standard error (SE) and are based on fish with similar selenium concentrations from both reference and exposed sites; fish with higher selenium concentrations from exposed sites suffered 100% mortality of alevins or eggs.

Site	O'Rourke Lake	Clode Pond
Frequency of Deformity (%)		
Skeletal	**37.4 ± 3.6***	16.5 ± 0.02
Craniofacial	**10.2 ± 2.0**	5.7 ± 0.01
Finfold	**10.6 ± 3.1**	7.5 ± 0.04
Edema	61.2 ± 4.9	**87.7 ± 0.02***
Severity of Deformity (scored from 0 to 3)		
Skeletal	**0.47 ± 0.07***	0.18 ± 0.02
Craniofacial	**0.12 ± 0.03**	0.06 ± 0.01
Finfold	**0.15 ± 0.05**	0.09 ± 0.05
Edema	0.61 ± 0.05	**0.88 ± 0.02***

* Indicates a significant difference at the 95% confidence level between means from the two sites.
Bolded values are the highest of the two site means.

The reason(s) for higher deformities in the O'Rourke Lake fish are unknown. The SFU researchers conjectured that natural stress (e.g., lack of food, low dissolved oxygen, limited space, extended winter conditions) in O'Rourke Lake may make these fish more sensitive to selenium than fish from other areas of the Elk River Valley. However, cutthroat trout populations in O'Rourke Lake appear to be thriving, thus selenium does not appear to be impacting that population. Similarly, cutthroat trout populations in Clode Pond prior to the fish salvage appeared to be thriving (Interior Reforestation 2007).

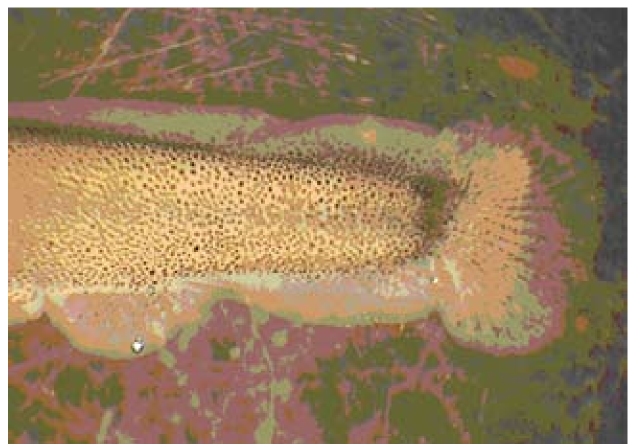
CUTTHROAT TROUT FRY DEFORMITIES



Craniofacial deformity (GSI score 3: missing eye; remaining eye turned inwards)

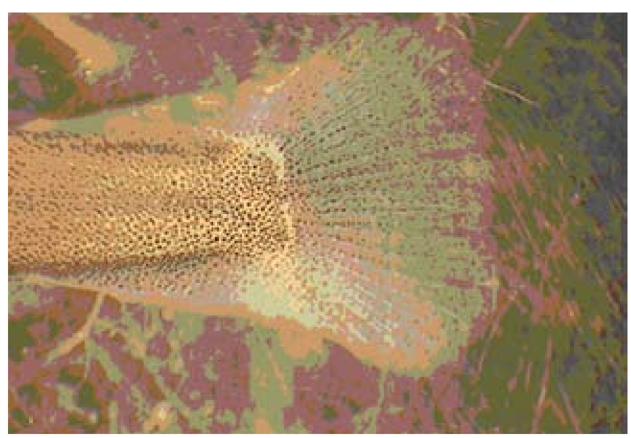
Top fry: skeletal deformities (lordosis and kyphosis, GSI score 2); bottom fry: normal (GSI score 0)

Top fry: keletal deformity (scoliosis, GSI score l); bottom fry: normal (GSI score 0)



Finfold deformity in tail fin (GSI score 2)

Top fry: skeletal deformity (kyphosis, GSI score 3); bottom fry: normal (GSI score 0)



Normal tail fin (GSI score 0)

3.3 MONITORING

3.3.1 Long-Term Water Quality Trends

The two previous *Selenium Status Reports* (2003 and 2004) summarized trends in selenium water quality concentrations downstream of the coal mines both at the Sparwood and Highway 93 federal-provincial water quality monitoring stations (FPWQMS; locations shown in **Figures 1 and 10**). In late 2005, EVCC commissioned a more detailed statistical trend analysis of all of the data available for these two water quality monitoring stations.

This detailed analysis (Golder Associates 2006) indicated a significant long-term increase in total selenium concentrations and loadings at the Highway 93 water quality monitoring station between 1984 and 2005. This increase in concentrations (the amount of selenium in a given volume of water; **Figure 11**) is about 6% per year; loadings (the total amount of selenium inputs) showed a similar long-term increasing trend of approximately 7% per year.

The data base for the Sparwood water quality monitoring station was only three years (2002-2005). Thus, although selenium water concentrations are higher than at the downstream Highway 93 station, there are currently not enough data to determine long-term trends.

The results of this study have been presented to the EVSTF. The study report, presently a draft, will be finalized following input from the EVSTF.

3.3.2 Regional Monitoring of Water and Biota

In early 2006 the EVSTF released a request for proposal (RFP) to conduct a regional aquatic monitoring program and spatial and temporal analyses of selenium data in water and biota. This competitive RFP was won by a consultant team led by Minnow Environmental and included Interior Reforestation, Paine, Ledge and Associates, and Anatum Ecological Consultants. This team of consultants is presently completing this work, which will supplement and expand on long-term water quality monitoring at the two federal-provincial stations (Section 3.3.1).

The regional monitoring program includes both lotic and lentic habitats in the Elk River Valley. Its overall objective is to evaluate any temporal and spatial trends in selenium concentrations based on routine water quality and flow monitoring data collected by the coal mines (details of this routine monitoring, which is separate from the long-term monitoring detailed in Section 3.3.1, are provided in the *Selenium Status Report 2004*; regional monitoring stations are shown in **Figure 12**). Trends in selenium concentrations in sediment and biota are also being determined.

The findings of this monitoring program will be reported in the next *Selenium Status Report*, including determining whether or not selenium concentrations have increased in biota in lotic areas compared to previous studies. Preliminary data comparisons indicate that, although selenium concentrations and loadings have increased each year in water, fish tissue selenium concentrations have not shown similar increases (**Figure 13**).

FIGURE 10: Data sources for the long-term selenium water quality evaluation.
Data sources were: Elk River total selenium concentrations from the Sparwood (2002-2005) and Highway 9 (1984-2005) Federal-Provincial Water Quality Monitoring Stations (FPWQMP); Elk River flow data at Fernie (1984-2005) from the Water Survey of Canada (WSC); precipitation (rain and snow) data from the Elkview Operations weather station near Sparwood (1984-2004).

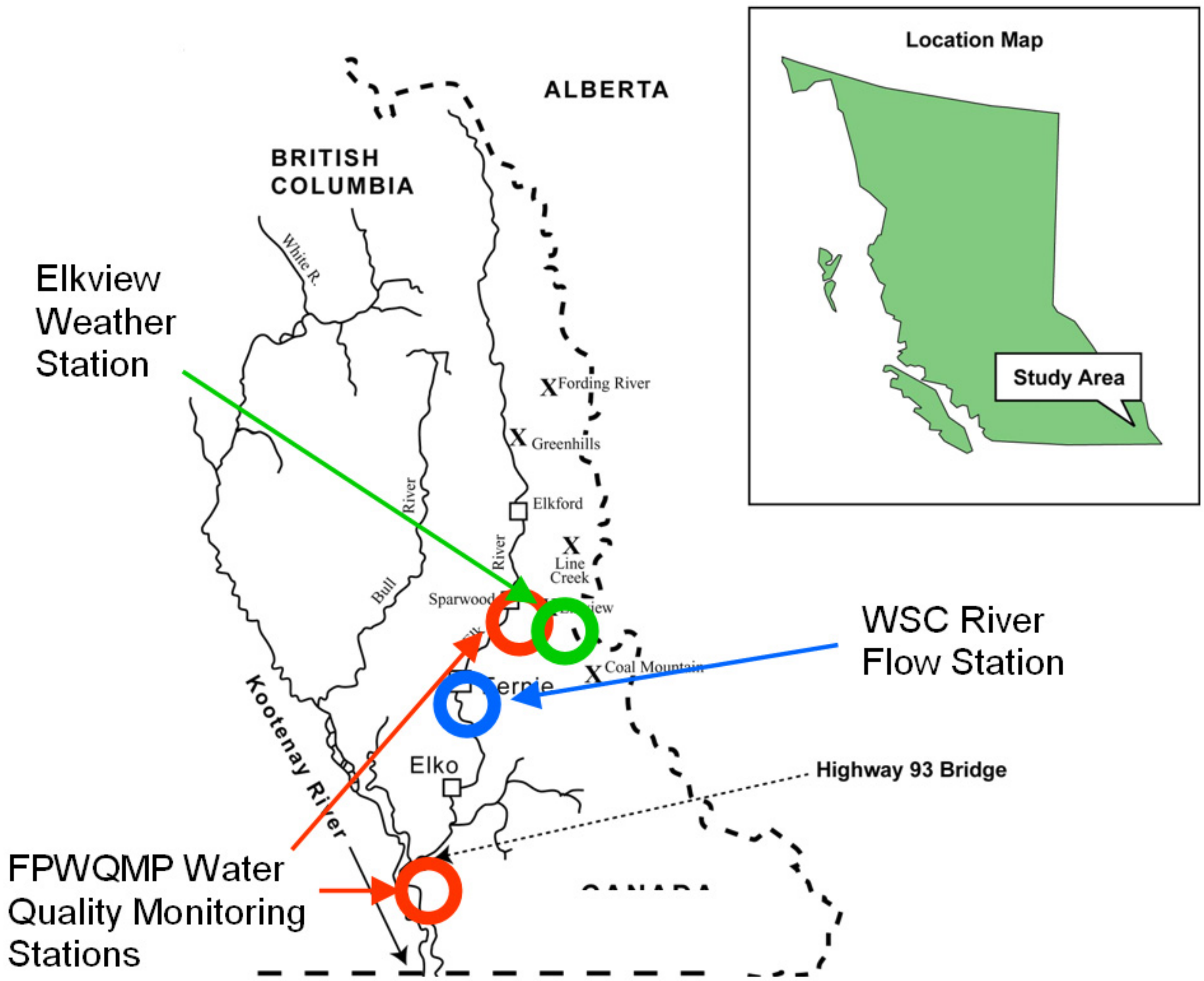


FIGURE II: Selenium concentrations measured in waters downstream of the mines at two federal-provincial water quality monitoring stations.

Points represent annual mean selenium concentrations.

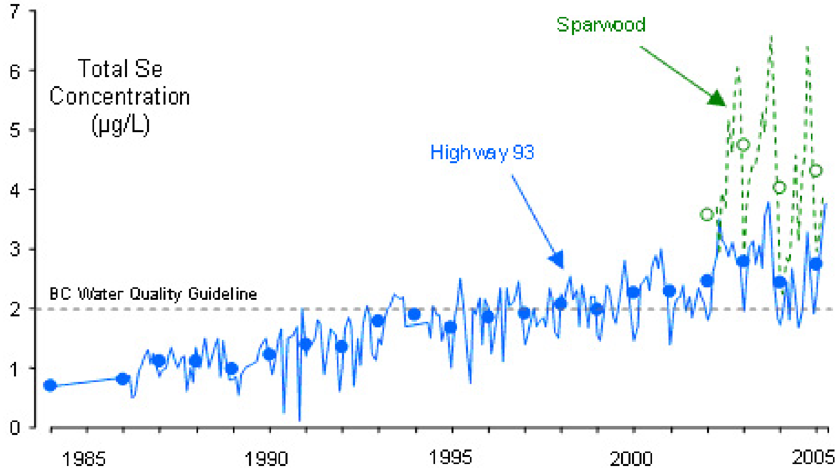


FIGURE 12: Regional monitoring station locations.

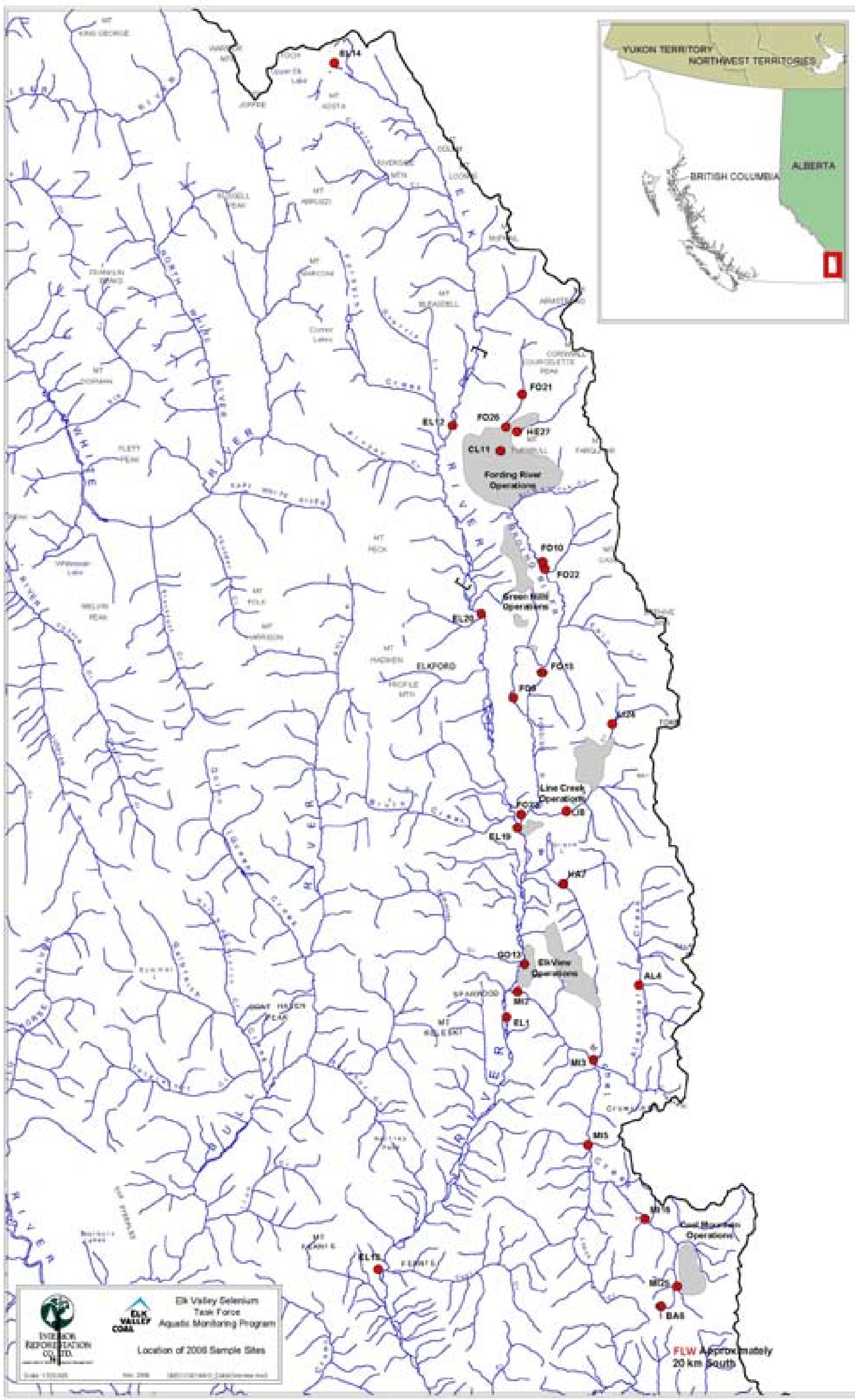
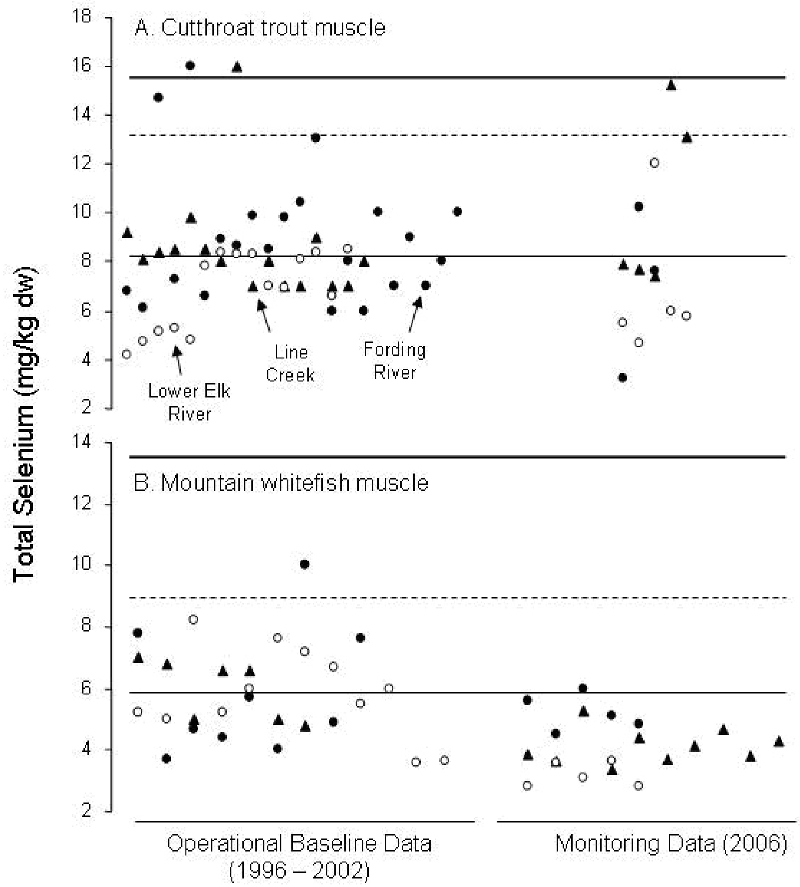


FIGURE 13: A: Cutthroat trout muscle selenium concentrations in three areas of the Elk River Valley in 1996, 2001, 2002, and 2006. B: Mountain whitefish muscle selenium concentrations in the same three areas of the Elk River Valley in 1996, 2001 and 2006. 1998 data from McDonald and Strosher (1998); 2001 and 2002 data from EVS Environment Consultants (2005); 2006 data from Minnow Environmental Consultants (unpublished data). Operational baseline data from 1996 and 2001/2002 (left) are compared to 2006 monitoring data (right). Horizontal lines indicate the mean, mean + 2SD (standard deviations), and mean + 3SD. Source: Chapman and de Bruyn (in review).



3.3.3 Vegetation

Terrestrial plants that can accumulate selenium to dangerous levels (hyperaccumulators) have not been found on reclaimed lands, and mine reclamation seeding does not currently involve such plants (CE Jones and Associates 2006). Selenium concentrations measured in plants to date indicate no cause for concern that animals grazing on these plants could be poisoned by selenium. However, additional measurements of selenium in plants growing on reclaimed lands are being made for further certainty. In addition, seed suppliers have been notified of the need to exclude selenium hyperaccumulators.

A study for EVCC's Alberta coal mines (McCallum 2006) found that selenium concentrations in bighorn sheep grazing on reclaimed lands had normal levels of selenium in liver and hair and slightly higher levels in whole blood and serum but well below values shown to be toxic. Vegetation analyses found no evidence of selenium hyperaccumulation and soil selenium concentrations were below potentially toxic levels. It was noted that since 1988, a total of 284 bighorn sheep have been captured and translocated from the Luscar Mine in Alberta to the USA and other parts of Alberta to augment existing herds in those locations. Most of these animals were examined by a veterinarian. None of the animals that were examined exhibited any signs of selenium toxicity. In summary, this study found no clinical signs of selenium toxicity in bighorn sheep grazing on reclaimed coal mine lands; populations were high quality, healthy and expanding.

3.3.4 Resident Fish Communities

Previous *Selenium Status Reports* have provided information regarding the status of Elk River Valley fisheries based on monitoring in Line Creek, which contains elevated levels of selenium from coal mining activities. Comprehensive data were reported through 2001 (Allan 2003); however, data for 2002 and 2004 were not comparable to previous data due to both inconsistencies in data collection identified by the current contractor, and to exceptionally high and variable water flows that made sampling physically dangerous (Robinson and Wright 2005). Surveys were not conducted in 2005. Surveys conducted in 2006 (Interior Reforestation 2007) indicated for bull trout a "trend of stabilization around 100 redds [egg nests in gravel] and 200 spawning fish" (see **Text Box 5**). Successful reproduction by both bull trout and cutthroat trout was indicated by the presence of young-of-the-year (YoY) of both species. Abundance was lower than historic highs, but there appears to be a relationship between high flows (as in 2004) and YoY survival and year-class strength (Robinson and Wright 2005). Future enhancements to the monitoring program will reduce the physical and seasonal variability in abundance determinations.

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 (Wilkinson 2006a,b). This M.Sc. (Masters-level) research is investigating the population dynamics of both bull trout and cutthroat trout in the Elk River Valley. The findings of this research will be reported in the next *Selenium Status Report*.

3.4 OTHER STUDIES

No other studies were conducted between March 2005 and January 2007.

Two parallel bull trout redds (nests) in Line Creek, September 28, 2006

TEXT BOX 5: Line Creek Fisheries

Line Creek receives discharges from the Line Creek Mine (Figure 1); water selenium concentrations are about 10-fold the provincial water quality guideline value of 2 µg/L. The creek supports a resident population of cutthroat trout, a migratory adult bull trout population that uses the creek for spawning, a resident juvenile bull trout population that rears in the creek, and a migratory mountain whitefish population that uses the lower creek for summer feeding. Historically, the major adverse effect on these and other fish populations in the Elk River Valley was over-fishing. In 1985 angling was prohibited in Line Creek. After fishing pressure was eliminated, fish densities in Line Creek and elsewhere in the Elk River Valley increased and, following "two or more years in succession of near ideal conditions for spawning, incubation and early rearing in Line Creek", fish densities were at the mid to upper levels of those reported within the region (Allan 2003).

The latest fisheries investigation in Line Creek following some years of less than ideal conditions due to variable, high water flows indicates that bull trout redds (nests in the gravel for their eggs) are close to historic highs (Interior Reforestation 2006; **Table 2**).

TABLE 2: Bull trout redd counts in Line Creek.
Data from Allan (2003) and Interior Reforestation (2006).

YEAR	# OF REDDS	YEAR	# OF REDDS	YEAR	# OF REDDS
1986	35	1993	48	1999	131
1987	28	1994	56	2000	122
1989	28	1995	114	2001	133
1990	56	1996	77	2002	94
1991	56	1997	57	2004	29
1992	45	1998	66	2006	108

Based on the number of redds, a spawning population of 200 bull trout (2 fish – one male and one female per redd) was estimated. Resident abundance of bull trout is lower than historic highs in 2006, likely the result of high water flows in 2002 and 2004 (Interior Reforestation 2006).

Young-of-the-year juvenile cutthroat trout and bull trout were recorded in Line Creek, indicating successful reproduction. The collection of a wide range of age classes indicated apparently healthy populations of these two fish species in the creek. Methodological limitations of previous studies have been pointed out by the current contractor, who has made recommendations that will be implemented to improve the overall effectiveness of future Line Creek fisheries surveys.

4.0 FUTURE STUDIES

4.1 MANAGEMENT

As detailed in Section 3.1, three major management initiatives will continue, with findings reported in the next *Selenium Status Report*: selenium source / release studies and water quality predictions, selenium cycling studies, and finalization of the decision framework. In addition, research is being conducted at Teck Cominco's Trail (BC, Canada) research facility to assess the viability of bacterial treatments to reduce selenium concentrations in the aquatic environment. Bench-scale laboratory studies have demonstrated good potential for selenium reductions. Future work will focus on scaling up from the laboratory to the field. This research, which is proprietary, is promising but remains to be proven in the field.

As noted in **Figure 2**, the EVSTF is also considering conducting a summary and assessment of all available selenium data in 2007, possibly using weight-of-evidence (WOE) and ecological risk assessment (ERA) components. This summary would combine all available data on selenium fate and effects in the Elk River Valley to determine: what we know; what we don't know; and key uncertainties.

The EVSTF is also developing a website for information dissemination and exchange. Past and future *Selenium Status Reports* will be posted to this website.

Finally, EVCC has joined with other industries in Canada to form the Canadian Industry Selenium Group (CISWG), and this group has joined with similar industries in the United States to form the North American Industry Selenium Working Group (NAISWG). The purpose of these two Working Groups is both information exchange and pooling of resources so that studies of general importance (i.e., not just to the Elk River Valley) can be conducted.

4.2 EFFECTS

Effects studies post-2005 were originally unspecified except for a repeat of the spotted sandpiper lotic effects study in 2009, as recommended by the investigators who conducted the original spotted sandpiper effects study (Harding and Paton 2003). However, from 2006 onwards allowance has been made for other selenium effects studies as necessary and appropriate based on the findings of studies conducted to that date (**Figure 2**). As previously noted (Section 3.2.4), at their December 2006 meeting the EVSTF agreed to repeat the cutthroat trout effects study beginning in 2007 as recommended by the 2005 trout effects study investigators (Rudolph et al. 2007). Specifically, effects studies will be conducted in reference, moderate, and high selenium areas in the Elk River Valley.

No other selenium effects studies are planned for 2007. The investigators who conducted the 2005 blackbird effects study did not recommend further studies post-2005 (SciWrite Environmental Sciences 2007).

The investigators who conducted the 2005 longnose sucker effects study (Minnow Environmental and Paine, Ledge and Associates 2006) stated that further effects studies with this fish "may not represent the best use of resources at this time. To date, few LNS [longnose sucker] populations have been found in the Elk Valley and, of these, only the population at GM [Goddard Marsh], which appears to be sustaining itself, has shown tissue selenium concentrations well within the range associated with effects on fish in other studies." They recommend that future effects studies concentrate on more abundant species such as cutthroat trout. However, they also recommend monitoring of both selenium concentrations in longnose sucker in Goddard Marsh and population health there over time.

Similar recommendations were provided by the investigators who conducted the Columbia spotted frog effects study (Minnow Environmental 2006): further effects studies "…may not represent the best use of resources at this time. Overall, low densities of frogs were found among both reference and mine-exposed areas in the current study and previous studies in the Elk Valley (Minnow 2003, 2004, 2005) suggesting frogs may be naturally sparsely distributed in this area. Furthermore, few areas have been found that exhibit both elevated selenium concentrations and provide adequate CSF [Columbia spotted frog] breeding or overwintering habitat (i.e., near-field, mine-exposed lentic areas)." However, the investigators also recommended monitoring selenium concentrations in Columbia spotted frog egg masses in two areas (Goddard Marsh and Michel Creek) which had the highest embryo selenium concentrations and, "…especially if concentrations exceed 20 mg/kg dw [dry weight] in multiple clutches per area, the mines should consider additional investigation of selenium related risk to CSF tadpoles."

The decision as to whether or not effects studies will be conducted in 2008 will depend on the findings of studies conducted through the end of 2007, which will be reported in the next *Selenium Status Report*.

4.3 MONITORING

Site-specific monitoring of selenium and other parameters in discharge water will continue at the five mines as originally outlined in the *Selenium Status Report 2004*. Regional monitoring of water and biota will be completed in 2007 and reported in the next *Selenium Status Report*. The next cycle of this regional monitoring will occur in 2009 (**Figure 2**). Monitoring of fish populations and reproduction in Line Creek will continue on a yearly basis. The larger-scale graduate (M.Sc.) thesis study of two key fish species in the Elk River Valley will continue; finalization of this work in the form of a written thesis is expected to occur by 2008 and will be reported in the corresponding *Selenium Status Report.*

4.4 OTHER STUDIES

4.4.1 Mapping of Lentic and Lotic Habitats

Watershed mapping to determine all lentic areas potentially at risk from selenium (e.g., wetlands, marshes, backwater areas) and the relative proportion of lentic and lotic areas in the Elk River Valley will be conducted in 2007. This mapping had originally been scheduled to occur in 2006 following release of a competitive RFP and short-listing of two consulting companies to do the work. However, additional costs required for the 2005 effects studies coupled with a re-evaluation of the scope of work, agreed to by the EVSTF, delayed this work. The results of this mapping will be reported in the next *Selenium Status Report*.

4.4.2 Lake Koocanusa

Lake Koocanusa is the reservoir formed by the Libby Dam on the Kootenay River in Montana (**Figure 1**). As such it receives all selenium transported downstream from the Elk River and from other sources. As noted in previous *Selenium Status Reports*, the Lake is not "a high risk compared to lentic areas within the Elk Valley." These *Reports* recommended that investigations regarding the status of the Lake only be considered if there are impacts at upstream lentic areas. Such impacts have not been determined to date.

However, the BC Ministry of Environment did conduct reconnaissance studies in 2001 related to Lake Koocanusa. Unfortunately, incorrect sample locations were chosen relative to downstream selenium inputs from the coal mines. The BC Ministry of Environment was planning to repeat the 2001 work in 2007 at appropriate sampling locations, determining the concentration of selenium in the water column, zooplankton (small animals that live in the water column), and fish eating those zooplankton (cutthroat trout and kokanee) downstream of the confluence with the Elk River. However, this work was not approved in the Ministry's budget allocation process for 2007 so this work is now tentatively scheduled for 2008. This work, when completed, will be reviewed and approved by the EVSTF, and summarized in the appropriate *Selenium Status Report.*

4.4.3 The Terrestrial Environment

As reported in previous *Selenium Status Reports* and in Section 3.3.3, there is currently no reason to believe that selenium from the mines is adversely affecting the terrestrial environment. There have been no decreases in ungulate herds (elk and sheep) and no evidence of selenium toxicity such as cracked hooves or hair loss. Nor are plant selenium hyperaccumulators, which could cause poisoning of grazing ungulates, found on coal mine reclaimed lands. In fact, monitoring of elk and sheep populations undertaken routinely by the coal mines indicates that these populations are thriving. Accordingly, the only terrestrial studies planned are continued monitoring of the health of the ungulate herds and analysis every 5 years (next in 2011) of selenium concentrations in vegetation.

4.4.4 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. A BC Ministry of Environment representative on the EVSTF (Jody Frenette) is planning to complete a Masters Degree in 2008. Her thesis will be based on evaluating any alterations to benthic invertebrate communities below active coal mines in the Elk River Valley (Frenette 2006). Available, relevant findings from this work will be reported in the next *Selenium Status Report*.

5.0 CONCLUSIONS

Based on the studies conducted to date, current levels of selenium in the Elk River Valley do not appear to be having large-scale negative effects or impacts. An effect becomes an impact when it adversely affects the utility or viability of a valued ecosystem component. For instance, reduced hatchability of sandpipers is not an impact because productivity is not affected, i.e., number of young produced remains high, in fact higher than the provincial average. If productivity were reduced, then this would be an impact.

Studies conducted to date suggest that some negative effects are occurring on a more localized level (see **Table 3**). However, even in lentic areas, which are at higher risk of adverse effects from selenium than the lotic areas that predominate in the Elk River Valley, any selenium-related deformities to fish (longnose sucker) or amphibians (Columbia spotted frogs) appear to be highly localized and largely indistinguishable from regional background levels of deformities (Minnow Environmental 2006). Although the results of the 2005 lentic cutthroat trout effects study contradict to some extent the earlier lotic cutthroat trout effects study, the findings still indicate a relatively high tolerance to selenium. As well, the preliminary findings of a regional monitoring study do not indicate increased selenium concentrations in cutthroat trout or mountain whitefish in the Elk River Valley over the last 10 years despite increasing selenium water concentrations.

Terrestrial or human health effects or impacts from selenium are not occurring and are not expected to occur in future.

However, increasing selenium water concentrations are a concern in the aquatic environment. Thus, management efforts are focusing on managing selenium inputs and understanding how to intervene in the selenium cycle once selenium is in the environment (to reduce production of the more toxic organic form of selenium). It is clear that if selenium concentrations continue to increase in the Elk River Valley, the extent of presently very localized effects could increase and impacts could possibly occur in future. It is the primary goal of the EVSTF, which is determining if any adverse ecological effects (i.e., impacts) are occurring or could occur due to selenium in the Elk River Valley, to prevent this possibility from occurring.

It is anticipated that the next *Selenium Status Report* will be released in 2008.

TABLE 2. Summary of effects studies conducted to date.

SPECIES	EFFECT?	IMPACT?	COMMENTS
		LOTIC	
Cutthroat trout	No	No	Note the findings of lentic studies with this same species (**Section 3.2.4** and below)
American dipper	No	No	Significant selenium uptake in exposed areas and sandpiper hatching success slightly depressed but productivity high; no effects to dipper and productivity high
Spotted sandpiper	*Yes*	No	
		LENTIC	
Red-winged blackbirds	No	No	Significant selenium uptake in exposed areas but no significant selenium-related effects and high productivity
Eight species of waterfowl	Inconclusive	No	Significant selenium uptake in exposed areas, but clutch and brood sizes within regional norms. Small sample size; findings not conclusive – see *Selenium Status Report 2004*
Longnose sucker	No	No	Selenium cannot be eliminated as a potential stressor but other factors appear to contribute to observed embryo and larval mortalities and deformities
Columbia spotted frog	See comments	No	Selenium appears to be contributing to tadpole mortalities and deformities; however, other unknown factors are also contributing to mortalities and deformities, even in reference populations
Cutthroat trout	Inconclusive	Inconclusive	Studies conducted in 2005 in lentic areas produced some conflicting results compared to studies conducted previously with this same species in lotic areas; additional studies will be conducted to resolve uncertainties (**Section 4.2**)

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APPENDIX A

LIST OF ACRONYMS AND GLOSSARY

LIST OF ACRONYMS

AB	Alberta
BC	British Columbia
CISWG	Canadian Industry Selenium Working Group
CSF	Columbia Spotted Frog
DFO	Department of Fisheries and Oceans
DW	Dry Weight
ERA	Ecological Risk Assessment
EVCC	Elk Valley Coal Corporation
EVMEMC	Elk Valley Mines Environmental Management Committee
EVSTF	Elk Valley Selenium Task Force
FPWQMS	Federal-Provincial Water Quality Monitoring Station
GM	Goddard Marsh
GSI	Graduated Severity Index
HHRA	Human Health Risk Assessment
LNS	Longnose Sucker
MES	Mean Egg Selenium
MSc	Master of Science
NAISWG	North American Industry Selenium Working Group
RFP	Request For Proposal
SD	Standard Deviation
SFU	Simon Fraser University
SIA	Stable Isotope Analysis
UBC	University of British Columbia
WOE	Weight Of Evidence
WSC	Water Survey Canada
WWB	Wet Weight
YoY	Young of Year

GLOSSARY

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

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

Clutch
A number of birds hatched at the same time.

Craniofacial
Referring to the skull and face.

Dissolution
The process of going into solution, for example dissolving sugar in tea or coffee.

Edema
Leakage of fluid into tissues.

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

Finfold
Fold of larval skin from which fins develop.

Fledgling
A young bird that has just acquired the feathers required for flight.

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.

Glutathione peroxide
A selenium-dependent enzyme that can indicate selenium exposure.

Graduated severity index
A means to score deformities based on their severity.

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

Hydrologic cycle
The cycle of the Earth's water supply from the atmosphere to the earth and back including precipitation (e.g., rain, snow), evaporation, runoff, infiltration, and storage in water bodies and groundwater.

Hyperaccumulators
Plants known as hyperaccumulators take up and sequester high concentrations of potentially toxic elements such as selenium from soils enriched with those elements.

Impact
An effect to a valued ecosystem component that adversely affects the utility or viability of that component.

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

Kyphosis
An outward curvature of the spine giving a humpback appearance.

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

Lordosis
An inward curvature of the spine giving a swayback appearance.

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

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

Milt
Fish sperm.

Necropsy
Examination and dissection of a dead body to determine cause of death or the changes produced by disease.

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

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

Quadratic
Of or relating to a square. A quadratic equation is an equation in which the highest power of an unknown quantity is a square.

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.

Scoliosis
An abnormal lateral (sideways) curvature of the spine.

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

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.

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

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

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).

Ungulate
A hoofed animal (e.g., horse, sheep, cow, elk).

Valued ecosystem component
An environmental attribute or component having scientific, social, cultural, economic, or aesthetic value.

Water birds
Birds that frequent water.

Waterfowl
Swimming / diving water birds (e.g., ducks, geese, coots). Wading birds such as sandpipers or songbirds such as dippers or red-winged blackbirds are water birds, but they are not waterfowl.

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

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