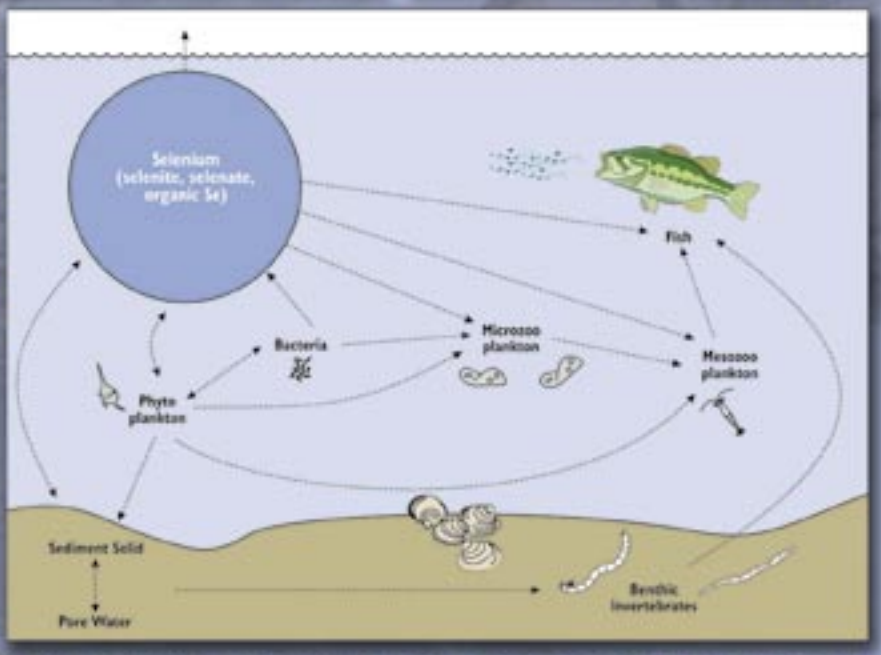
Selenium Status Report 2004

ELK RIVER VALLEY, BC



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

MAY 2005

EXECUTIVE SUMMARY

The *Selenium Status Report 2003* summarized studies conducted through October 2003 regarding elevated selenium concentrations in the Elk River Valley in southeastern British Columbia. The present *Selenium Status Report 2004*, produced under the direction of the multi-stakeholder Elk Valley Selenium Task Force (EVSTF), summarizes further studies conducted through March 2005, 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 and of water birds feeding in waterbodies containing high levels of selenium.

Investigations are continuing in the Elk River Valley to determine whether or not fish and water bird reproduction is being effected by the selenium released from coal mining. Previous studies indicated that fish and water bird populations in lotic (flowing) environments, the streams and rivers that comprise the majority of the Valley aquatic environment, are not being impacted; decreased hatchability has been documented in spotted sandpipers but productivity remains above the regional norm. The lack of population-level impacts in streams and rivers is not surprising as coal mining releases the inorganic form of selenium; for this selenium to affect fish and water bird reproduction, it has to be in the organic form. Transformation of inorganic selenium to the organic form typically occurs in lentic (non-flowing) environments such as ponds, wetlands and lakes, not in lotic environments.

Recent (2004) investigations have thus focused on lentic environments. Nestling survival of red-winged blackbirds feeding in these environments has decreased at some (e.g., Clode Pond) but not all lentic areas with elevated selenium concentrations. The reasons for these decreases, which included some dead fledglings, are uncertain and require further investigation. Decreased survival was not found at the lentic site with the highest selenium concentrations (Goddard Marsh), but two embryos from this site had visible abnormalities, which could have been due to selenium. Because other factors such as predation and inclement weather cannot be ruled out as possibly causing some of the mortalities and selenium cannot be definitively identified as responsible for the observed abnormalities, additional studies are being conducted in 2005.

Extensive efforts have been made to determine whether waterfowl in lentic areas are being affected by selenium. Eight species were studied in 2004 and no effects were found. However, the three high exposure sites examined were poorly represented in the brood counts. In addition, the sample size was small both because of the small number of each species of waterfowl nesting in the relatively small ponds and wetlands in the Elk River Valley, and because of the difficulty in finding nests, which are well hidden from predators. Finally, it was difficult to link the young birds, which leave the nest immediately after hatching, with the specific nests from which eggs were collected for selenium analysis. Because of these difficulties, further studies are not planned in 2005; instead the focus will be on red-winged blackbirds, which can be more easily studied.

Fish and frog reproduction was evaluated in a wetland which has high selenium concentrations (Goddard Marsh). Unfortunately, methodological problems precluded any definitive conclusions. For frogs, no egg masses could be found in a reference area so there were no reference comparisons. The fish studied, the long-

nose sucker, turned out to be a dwarf species which is very different from its larger cousin and lays fewer and smaller eggs. The incubation chambers had mesh that was too large to contain the fry, and sedimentation and fungus killed many of them. However, the very few data that were salvaged from these studies suggest that selenium may be causing deformities in longnose sucker fry and in frog tadpoles. Additional studies with fish and frogs in ponds and wetlands are being conducted in 2005, building on the information obtained from the 2004 studies.

Additional studies being conducted include:

- Mapping of aquatic lentic and lotic habitats to ensure that representative areas are being assessed and to provide the basis for evaluating the significance of any localized impacts to the overall health of the Elk River Valley aquatic ecosystem.
- Monitoring water quality to provide early warning of increased selenium concentrations and loadings.
- An effects study with cutthroat trout in Clode Pond to determine if there are any reproductive effects to this species in that highly selenium-enriched environment. Previous studies with this species in streams have not indicated any effects.

The results of studies conducted to date indicate that current levels of selenium in the Elk River Valley are not having large-scale negative effects, nor are key ecosystem components being impacted. However, some negative effects do appear to be occurring on a more localized level. The extent and significance of these negative effects, in particular whether or not there are population-level impacts, are being determined.

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ACKNOWLEDGEMENTS

This report was written by Dr. Peter M. Chapman, Golder Associates, North Vancouver, BC. Lee Harding (SciWrite) and Cynthia Russel (Minnow Environmental) reviewed sections relevant to studies they had conducted and provided useful comments. They also provided almost all of the photographs used in this report. Formatting of the document was done by Christa Wall, Golder Associates, North Vancouver, BC. Useful review comments were provided by members of the Elk Valley Selenium Task Force (EVSTF).

I. INTRODUCTION

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

The objective of the present *Selenium Status Report 2004* is to summarize, for the period between October 2003 and March 2005, the results of studies related to effects or impacts of selenium released from coal mining in the Elk River Valley on Valued Ecosystem Components (VECs).

VALUED ECOSYSTEM COMPONENT (VEC) - An environmental attribute or component having scientific, social, cultural, economic or aesthetic value. In terms of the potential environmental effects of selenium, fish and water birds are primary VECs.

EFFECT - A change to a VEC due to human activities. For instance, selenium released to the aquatic environment has the potential to adversely affect reproduction of fish and water birds. An effect is not necessarily a negative impact; an effect may be neutral or even positive. For example, selenium is an essential element; toxicity can occur both due to deficiency and excess, and there is an optimum range for selenium in organisms.

IMPACT - An effect on a VEC that adversely affects the utility or viability of that VEC. For instance, reproductive effects due to selenium could reduce the overall productivity of sensitive fish or water bird species.

The present document has been produced by the Elk Valley Selenium Task Force (EVSTF), whose membership includes the EVMEMC as well as the BC Ministry of Water, Land and Air Protection (WLAP), Environment Canada (EC), and the BC Ministry of Energy and Mines (MEM). The overall goal of the EVSTF is to further understanding of selenium issues in the Elk River Valley system, based on four 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.

Essentially, the EVSTF is addressing the two primary questions below, and the answers to those questions will be used to manage the issue of elevated selenium concentrations:

1. Is there evidence that any adverse ecological impact(s) have or will occur related to discharges of selenium associated with the Elk River Valley coal mining?

2. What are the trends in selenium concentrations in both standing (lentic) and flowing (lotic) water areas and biota of the watershed?

Differentiation of any impacts of selenium from effects is a focus of the EVSTF. However, for some individual studies, there may be different interim objectives due to the specific nature of those studies, as explained in the text.

Background information on selenium and on the Elk Valley coal mines is available in the *Selenium Status Report 2003*. Future Status Reports will be provided on an approximately yearly basis and/or as significant new information becomes available.

We hope that you, the reader, find this report useful. Comments and feedback would be much appreciated and will help us improve the next report.

You can contact:

Chair, Elk Valley Selenium Task Force
PHONE: (250) 865-5675
EMAIL: roger_berdusco@elkvalleycoal.ca

2. SELENIUM STATUS TO OCTOBER 2003

The *Selenium Status Report 2003* provided background information on the Elk River Valley, the coal mines, and selenium and its toxicity. Past and current studies were then reviewed. Key findings from those studies were as follows. A map showing key features of the Valley referred to in the present Report is shown in **Figure 1**.

2.1 SELENIUM RELEASES

Studies reported previously regarding selenium releases have shown that:

- 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.
- Lentic (non-flowing water) areas tend to have the highest water column selenium concentrations.

The current status of selenium water concentrations immediately downstream of the mines is shown in **Figure 2**. Status further downstream is shown in **Figure 3**. Concentrations of selenium have increased in downstream waters and are above the federal (1 µg/L) and BC (2 µg/L)water quality guideline value for protection of aquatic life .

Elk River Lower Oxbow - a lentic area

LOTIC - A flowing water body such as a stream or a river.
LENTIC - A non-flowing water body such as a pond or a lake.

2.2 LOTIC (FLOWING WATER) AREAS

The vast majority of the aquatic environment in the Elk River Valley consists of lotic (flowing) rather than lentic (non-flowing) water bodies. Thus, initial investigations were focused on lotic areas.

A fish lotic effects study was conducted in 1998 with cutthroat trout (Kennedy et al., 2000). Although selenium concentrations in the mature fish and in some of their eggs were above concentrations shown to be toxic in other areas with other fish species, there were no mortalities or deformities of larvae and fry characteristic of selenium poisoning. Although the work conducted by Kennedy et al. (2000) has generated controversy (commentary by Hamilton and Palace, 2001; response by McDonald and Kennedy, 2002), similar work conducted in Alberta with other trout species (Holm, 2002; Holm et al., 2003) appears to support a higher threshold for selenium in trout species than in some other species (Chapman and McPherson, 2004). **See Text Box 1 for more details.**

A water bird lotic effects study was conducted with American dippers and spotted sandpipers exposed to elevated concentrations of selenium (Harding and Paton, 2003). Selenium concentrations in the eggs of these two species were below reported toxicity thresholds, and there were no discernable adverse effects attributable to selenium on adult or juvenile birds. However, as part of revising a manuscript from this work submitted to an international, peer-reviewed journal, additional statistical analyses of the data were conducted as suggested by an external peer reviewer, with slightly different results (**see Section 3.2**).

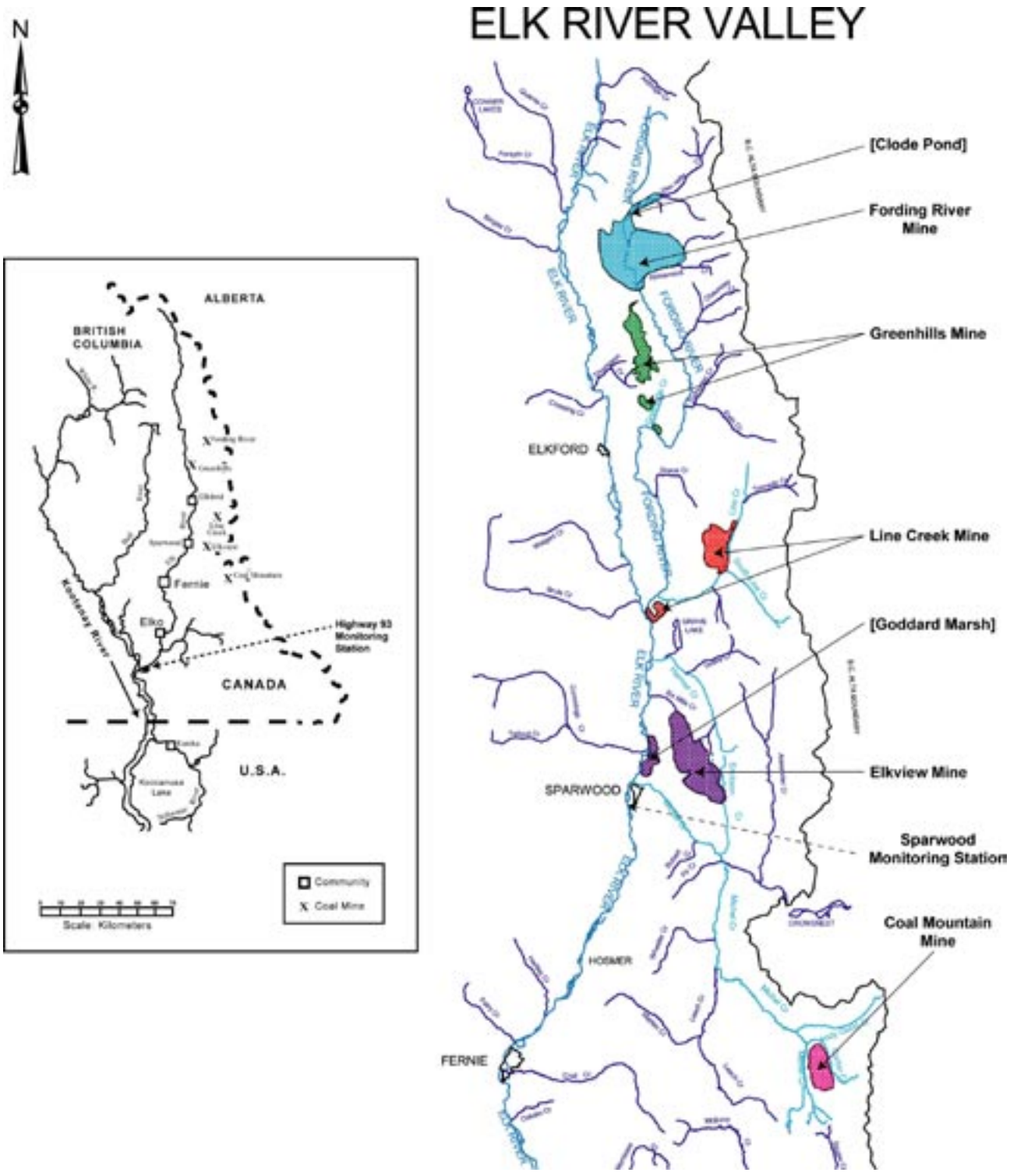


FIGURE 1. The Elk River Valley, showing the locations of the five coal mines, the federal-provincial water quality monitoring stations at Sparwood and at the Highway 93 Bridge, Goddard Marsh and Clode Pond.

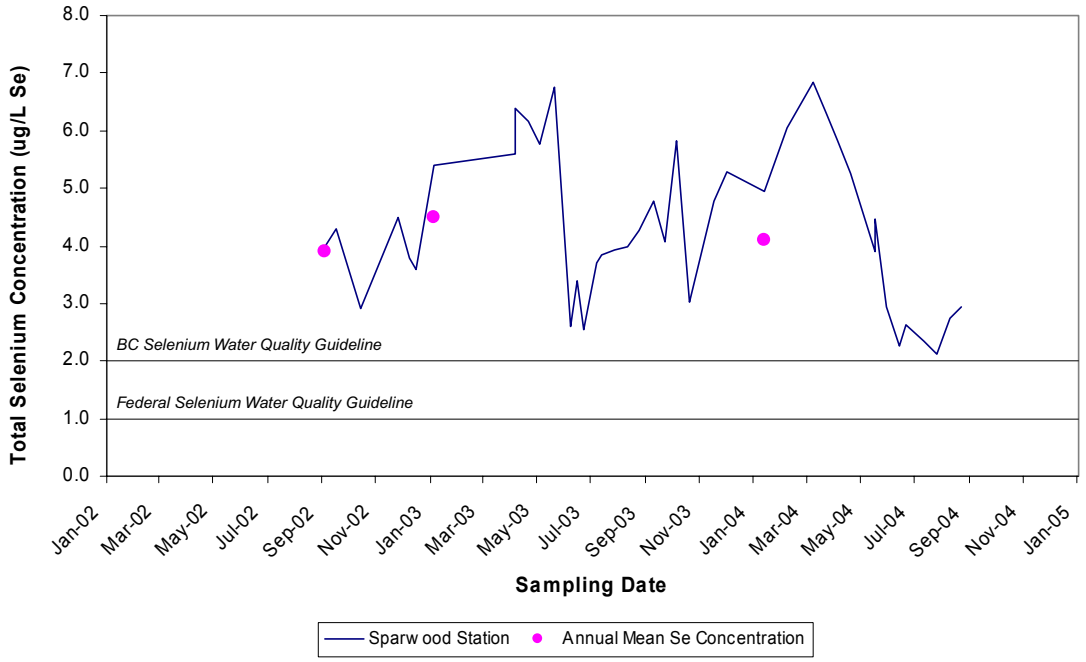


FIGURE 2. Selenium concentrations measured in waters downstream of the mines at the Sparwood federal-provincial water quality monitoring station (see Figure 1 for location).

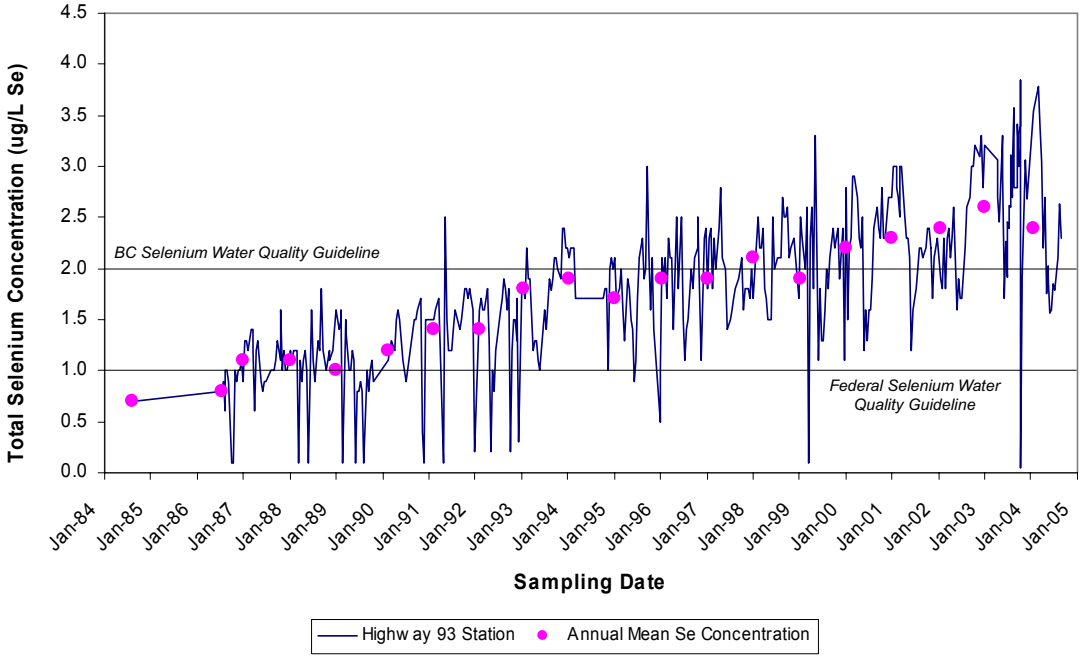


FIGURE 3. Selenium concentrations measured in waters downstream of the mines at the Highway 93 federal-provincial water quality monitoring station (see Figure 1 for location).

TEXT BOX I: TROUT LOTIC EFFECTS STUDIES

To date there have been two published trout lotic effects studies, one in Alberta and the other in BC. The Alberta study (Holm, 2002; Holm et al., 2003) involved both rainbow and brook trout. Rainbow trout were collected from two streams with elevated selenium concentrations and from two reference streams (all four streams were sampled in 2001, but only one exposure and one reference stream were sampled in 2000). The 2000 results are based on 3 exposed and 4 reference fish; the 2001 results are based on 2-10 fish from each stream. Four categories of deformities were assessed: skeletal, craniofacial, finfold and edema. There were no significant differences in fertilization, mortality or time to hatch in either year. However, there were significant differences in all deformities in 2000 (exposure: 3.2 – 30.8% incidence; reference: 0.2 – 0.7% incidence), largely driven by a single fish; edema was the most commonly observed deformity (30.8%). There were no significant differences in deformities in 2001 (exposure: 6.8 – 19.9% incidence; reference: 1.5 – 15.6% incidence). Holm (2002) suggested a 4-6 μg/g wet weight effects threshold; subsequently, Holm et al. (2003) suggested a 6 μg/g wet weight effects threshold for selenium in eggs. Assuming 75% moisture content (Lemly 1993) and a 6 μg/g wet weight effects threshold, this would translate into 24 μg/g dry weight selenium in eggs.

Brook trout were collected from two streams with elevated selenium concentrations and from one reference stream (one exposure stream was only sampled in 2001, the other streams were sampled in 2000 and 2001); 5-11 fish were collected from each stream. The experimental design was the same as for rainbow trout. For brook trout there were no significant differences in fertilization, mortality or time to hatch in either year. The overall incidence of deformities was lower in brook trout than in rainbow trout, but significant differences did occur in craniofacial deformities in 2000 (13.6% versus 3.0%) and in finfold deformities in 2001 (4.1% versus 0.1%). However, the responses of the fish from the two streams with elevated selenium concentrations showed no relationship to selenium egg concentrations; the highest incidence of these two deformities occurred in fish with low selenium concentrations, while fish with high selenium concentrations showed responses consistent with reference site fish. Egg selenium concentrations of up to about 15 μg/g wet weight (≅ 60 μg/g dry weight) in individual fish resulted in no deformities (a few fish with lower egg selenium [2-8 μg/g wet weight] did show deformities); mean egg selenium concentrations were 6.37-8.02 μg/g wet weight in exposed sites and 1.25-1.35 μg/g wet weight in reference sites. Given that there was no relationship between tissue selenium concentrations and adverse effects, selenium egg concentrations would probably have to be greater than the higher mean egg selenium value (>8 μg/g wet weight; >32 μg/g dry weight) for adverse selenium-related effects to occur.

Kennedy et al. (2000) conducted the study in BC with cutthroat trout. The experimental design was similar to the Alberta studies, with one exposed and one reference site, except that the sample size of adult fish was larger, only one year was tested (1998), and the eggs were fertilized in the field (the Alberta study fertilized the eggs in the laboratory). There were no significant differences between reference and exposed fish in fertilization, time to hatch, percent hatch, survival or incidence of deformities. Mean selenium egg concentrations were 21.2 μg/g dry weight for exposed fish and 4.6 μg/g dry weight for reference fish; the highest egg selenium concentration in a selenium-exposed fish was 81.3 μg/g dry weight.

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).

TABLE 1. Comparison of different ovary/egg selenium trout threshold concentrations (mean values).

SELENIUM CONCENTRATION (µG/G DRY WEIGHT)	HOLM (2002); HOLM ET AL. (2003)		KENNEDY ET AL. (2000)	LEMLY (1993)
	RAINBOW TROUT	BROOK TROUT	CUTTHROAT TROUT	FRESHWATER FISH
EFFECTS THRESHOLD	≅ 24[a]	>32[b]	>21.2[c]	10

[a] From Holm et al. (2003), number proposed by them.

[b] Highest mean value from Holm (2002) for fish from exposed sites; no effects found in individual fish at egg selenium concentrations as high as about 60 µg/g dry weight (interpolated from figures, no raw data available). Note that a few fish with lower egg selenium concentrations (2-8 µg/g wet weight) did show deformities.

[c] Mean value; no effects found at egg selenium concentrations as high as 81.3 µg/g dry weight.

2.3 LENTIC (NON-FLOWING WATER) AREAS

Lentic areas are expected to be most at risk from selenium toxicity. Selenium releases from natural or human activities occur initially as inorganic selenium. Conversion of this inorganic selenium into the more toxic organic selenium occurs much more readily in lentic than in lotic environments, as explained in detail in the *Selenium Status Report 2003*. Because there were no indications of impacts in lotic areas, investigations shifted to lentic areas.

A reconnaissance survey of selenium concentrations in water, sediment and biota in lentic systems was conducted (Minnow Environmental, 2003). This survey included assessments of the structure of communities of bottom-dwelling organisms (the benthos), and of the small animals living in the water column (the zooplankton). There were no obvious indications of selenium-related effects in any of the lentic areas examined; all areas contained established, multi-trophic level food webs. However, this reconnaissance laid the groundwork for more detailed assessments that were conducted in 2004 (**see Sections 3.3, 3.4, 3.5**).

2.4 HUMAN HEALTH

A conservative human health risk assessment (EVS Environment Consultants, 2000) found that there was negligible risk to humans eating fish containing selenium. In fact, the assessment 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 impact on human health."

3. SELENIUM STUDIES OCTOBER 2003 TO MARCH 2004

The following summary of work conducted during the 18 months subsequent to the *Selenium Status Report 2003* includes a publication arising from a previous report. It is the intention of the EVSTF, with funding from the EVMEMC, to publish appropriate studies in the international, peer-reviewed scientific literature. Presentations regarding work conducted on the selenium issue in the Elk River Valley have been made at the 2004 Mine Reclamation Symposium in BC (Chapman, 2004a; Harding et al., 2004) and at the 2004 Aquatic Toxicity Workshop, the premier Canadian meeting of environmental scientists, in PEI (Orr et al., 2004; Chapman, 2004b).

3.1 SELENIUM UPTAKE ROUTES

An assessment of selenium uptake routes in both lentic and lotic habitats, which began in 2002, was completed (Minnow Environmental, 2004a). This study involved six lentic areas, three with elevated selenium levels, and three lotic areas, two with elevated selenium levels. Water, sediment, algae, plants, zooplankton, benthic invertebrates and fish were collected and analyzed. Stable isotope analysis (SIA), which measures distinctive signatures for carbon, nitrogen and sulphur related to an organism's position in the food chain, was conducted together with selenium analyses (for additional information regarding SIA, see the *Selenium Status Report 2003*).

This study clearly showed that selenium uptake by organisms was greater in lentic than in lotic areas due to the enhanced biological transformation of inorganic selenium to organic selenium that occurs in these areas. These results confirm a long-standing hypothesis in the scientific literature (Simmons and Wallschläger, 2005). Specifically, uptake and cycling of organic selenium occurs via sediment-detrital pathways typical of lentic areas, but not of lotic areas. Benthic invertebrates in lentic areas had substantially higher tissue selenium concentrations than those in lotic areas. Thus, this study emphasized the importance of focusing on lentic areas where effects and possibly impacts from selenium are most likely to occur. Accordingly, subsequent studies have focused on lentic areas in the Valley.

3.2 LOTIC (FLOWING WATER) WATER BIRD STUDIES

During 2001 and 2002, American dippers and spotted sandpipers living in lotic areas of the Elk River Valley and exposed to elevated concentrations of selenium were studied (Harding and Paton, 2003). Both species nest along rivers and streams and eat aquatic invertebrates. The study was published in the scientific literature (Harding et al., 2005). Such publication involved peer review, in other words, the journal sends manuscripts submitted to independent outside experts to get their opinion on the work conducted and on the conclusions drawn. One of these experts recommended a change to the statistical analyses of the data. As a result, the publication differs from the report in that whereas, previously, data on sandpiper egg hatchability were slightly below statistical levels of significance, the data are now slightly above such levels. Thus, an effect was recorded for sandpiper hatchability. This effect is not an impact on populations because overall productivity was higher than the regional norm for both sandpipers and dippers. **See Text Box 2 for more details.**

Harding et al. (2005) found no elevated concentrations of selenium (relative to uncontaminated control sites) in American dipper eggs, and only slightly elevated concentrations in spotted sandpiper eggs despite relatively high concentrations of selenium in their stream habitat. They conjectured that this was "likely due to their lotic environment's low biological transformation [of inorganic to organic selenium] and uptake rates." Thus, subsequent bird studies have focused on lentic areas where biological transformation and uptake of selenium are higher than in lotic areas (**see Sections 3.3 and 3.4**).

TEXT BOX 2: WATER BIRD LOTIC EFFECTS STUDY

Harding et al. (2005) conducted studies on American dipper (*Cinclus mexicanus*) to assess potential effects of selenium associated with coal mining activities in the Elk River Valley in southeastern BC. Selenium concentrations were measured in the eggs of this species and compared to measures of productivity (eggs laid, hatchability, and nestling survival). Mean egg selenium (MES) concentrations in dipper eggs were 8.4 µg/g dry weight in exposed areas and were not significantly different than the 7.4 µg/g dry weight measured in eggs from reference areas. No abnormalities in embryos or chicks (one of the indicators of selenium toxicosis) were seen, and there were no differences in hatchability or fledgling survival between exposed and reference sites.

Harding et al. (2005) conducted similar studies with spotted sandpipers (*Actitis macularia*), and found that this species had MES concentrations of 7.3 µg/g dry weight in exposed areas and 3.8 µg/g dry weight in reference areas. Sandpipers in exposed areas had slightly reduced hatchability compared to those in reference areas, but no evidence of teratogenic effects, and overall productivity was higher than the regional norm for this species; in other words, a possible effect but not an impact. Harding et al. (2005) hypothesized that reduced hatchability could have been the result of selenium toxicity or the result of non-selenium effects including predation, floods and higher levels of human activity (highway and industrial) in the areas where most of the nest failures occurred.

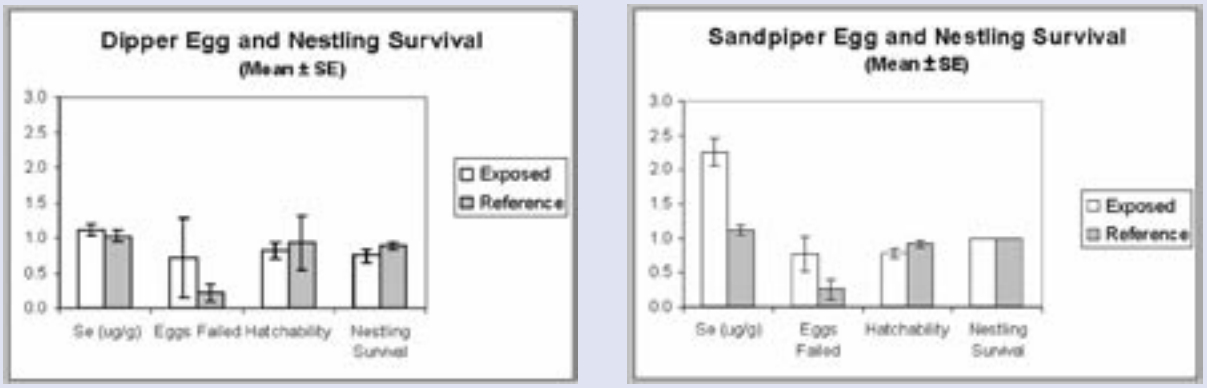


FIGURE 4. American dipper and spotted sandpiper productivity and mean egg selenium (MES) concentrations (mean ± standard error [SE] wet weight). Y axis is mean number of eggs failed, mean hatchability, and mean nestling survival per nest as decimal fractions (I.0=all hatched or all survived to fledging) and µg/g wet weight for selenium.

3.3 LENTIC (NON-FLOWING WATER) MARSH BIRD STUDIES – RED-WINGED BLACKBIRDS

Red-winged blackbirds (*Agelaius phoeniceus*) nest in colonies in emergent vegetation in marshes and feed primarily on invertebrates such as insects and beetles in the marsh vegetation as well as the seed heads of certain marsh plants. Because marshes represent lentic areas that will tend to accumulate the toxic organic form of selenium, and these birds may accumulate selenium through their diet, studies were undertaken in 2003 and 2004 to determine any differences in productivity between blackbirds nesting in marshes with elevated selenium concentrations (exposed marshes) and marshes with background selenium concentra-

Female Red-winged Blackbird

Red-winged Blackbird nest

Male Red-winged Blackbird

Examining a Red-winged Blackbird embryo

tions (reference marshes) (SciWrite, 2004a). These studies followed from recommendations made in the *Selenium Status Report 2003*.

At the high exposure sites (Clode Pond, Goddard Marsh, and a marsh in Line Creek below the Line Creek Mine – **Figure** 1), selenium egg concentrations were high enough that selenium toxicity might have been expected, based on thresholds reported in the literature for other species in other locations. Both hatchability (proportion of eggs incubated to full term that hatched) and nestling survival (proportion of hatched eggs that survived to become fledglings) were assessed, as these are the most sensitive measures of selenium toxicity in birds. There was no difference in the number of eggs laid (clutch size) nor in hatchability between sites. However, there were differences in nestling survival between sites; nestling survival was highest in the reference (background selenium) and lowest in the exposure marshes with the exception of the marsh with the highest selenium concentrations, Goddard Marsh, where survival was 100%. However, 2 of the Goddard Marsh embryos had visible abnormalities. No embryonic abnormalities were seen at the other sites. Dead nestlings (found in the nests just prior to when they would have fledged) were seen at four of the exposed marshes but not at the reference marshes and not, again, at Goddard Marsh. In one of the cases (a low exposure site on the Elk River below Fernie), the mortalities were thought to be due to predation of the parents, leaving the nestlings unattended. In the case of the other three sites, which included Clode Pond, there was no obvious explanation; selenium toxicity is a possibility. **See Text Box 3 for more details.** Additional studies to determine the role of selenium in the observed mortalities and abnormalities and whether or not there are any impacts, will be conducted in 2005 (**see Section 4.3**).

3.4 LENTIC (NON-FLOWING WATER) WATERFOWL STUDIES

In addition to the red-winged blackbirds lentic effects studies, similar studies were also conducted on waterfowl in 2003 and 2004 (SciWrite, 2004b). This work also followed from recommendations made in the *Selenium Status Report 2003*. Unfortunately, the work was only moderately successful for several reasons. First, only a low number of waterfowl nest in the marshes. Second, it was extremely difficult to find nests – adult birds are very effective at hiding their nests from potential predators including humans. Third, young waterfowl leave their nests immediately after hatching, precluding the possibility of linking each brood with a specific nest from which an egg was taken for selenium analysis.

In 2003 a total of three eggs were collected, two from areas with high selenium levels. In 2004 a total of 26 eggs were collected from 19 active nests, and 50 broods of eight species of waterfowl were counted: American coot, hooded merganser, mallard, blue-and green-winged teal, ring-necked duck, Canada goose, Barrow's goldeneye, bufflehead. Sampling sites were the same as those for the red-winged blackbird study (**see Section 3.3 and Text Box 3**).

The highest egg selenium concentration was measured in an American coot egg from Clode Pond (34.7 µg/g dry weight); selenium egg concentrations were generally highest in the marshes with highest water selenium concentrations, with the exception (again) of Goddard Marsh. Selenium concentrations were high enough that toxicity might have been expected, based on threshold levels reported in the literature for different species in other areas. Because only Canada goose and mallard eggs were collected at more than two sites, the data set was not robust enough for statistical comparisons. In fact, given the fact that the potential breeding population at each marsh was only about six or seven successful pairs, virtually all of them would have had to be found and sampled and the broods linked to specific nests (for example, by radiotelemetry) to generate adequate sample sizes for statistical analyses.

Based on the limited data obtained, there was no evidence of adverse effects due to selenium (e.g.,

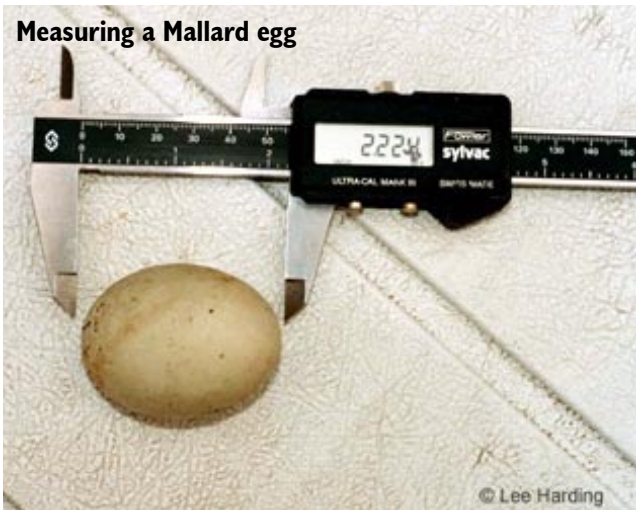
TEXT BOX 3: RED-WINGED BLACKBIRD LENTIC EFFECTS STUDY

Sampling of red-winged blackbird nests included four reference marshes with water total selenium concentrations below the federal water quality guideline value for protection of aquatic life (1 µg/L), two intermediate exposure marshes with water selenium concentrations up to 10-fold the federal guideline value, and three high exposure marshes with water selenium concentrations greater than 10-fold the federal guideline value. The two marshes with the highest selenium levels were Clode Pond and Goddard Marsh (locations shown on **Figure 1**). Mean egg selenium (MES) concentrations for 2003 and 2004 ranged as follows for the low, intermediate and high selenium marshes (all values in µg/g dry weight): 3.7-5.3; 7.3-9.7; 6.1-20.6. Highest MES (µg/g dry weight) concentrations were in Clode Pond (15.1) and Goddard Marsh (20.6).

There was no difference between sites in the number of eggs laid (clutch size), nor in the proportion of eggs incubated to full term that hatched between sites. However, there were differences in nestling survival between sites; nestling survival was highest in the reference (low selenium marshes) and lowest in the high exposure marshes (highest selenium marshes). Surprisingly, nestling survival was higher at Goddard Marsh (100%) than at Clode Pond, despite higher (about 30%) selenium water concentrations in Goddard Marsh. Development abnormalities that could have been due to selenium were noted at Goddard Marsh (2 embryos - 14 embryos in total but only 8 mature enough to examine) and another site with high selenium levels (Line Creek Marsh - one deformed nestling), but not at Clode Pond. In addition to data on nestling survival, dead nestlings were seen at two of the high selenium marshes and at two of the low selenium marshes, but no dead nestlings were seen at the reference marshes. Again, surprisingly, no dead nestlings were seen at Goddard Marsh, but seven were seen at Clode Pond (36% of the nestlings in that area – the highest proportion recorded; the next highest proportion was three or 17% from a low selenium marsh). All of the dead nestlings were over a week old and appeared healthy, with no signs of trauma or malnutrition although their digestive tracts were empty. Elevated liver selenium concentrations (approximately 55 µg/g dry weight) suggested that selenium could have been a cause of death. Unfortunately, data on selenium liver concentrations in live nestlings from the same nest as dead nestlings were not collected. And other causes of the observed mortalities, including predation on the young and on the adults feeding the young, and inclement weather, could not be excluded as possible reasons for at least some of the observed dead fledglings.

Interestingly, a recent M.Sc. thesis (Vasterling, 2003) assessing the effects of selenium from phosphate mining in Idaho on reproductive success of red-winged blackbirds concluded that effects may occur when egg selenium concentrations exceed 20 µg/g dry weight. Such exceedances are presently occurring in both Clode Pond (maximum value 22.3 µg/g dry weight) and Goddard Marsh (maximum value 24.6 µg/g dry weight) (SciWrite, 2004a).


Collecting goose eggs



Measuring a Mallard egg


Ring-necked Duck nest


Canada Goose contents showing vein structure and embryo


American Coot nest


Hooded Merganse chick

no mortality, no abnormalities), and no differences in productivity between waterfowl from areas with elevated selenium levels compared to those from reference areas. Clutch and brood sizes for all waterfowl were within or above the normal ranges for BC at all sites and did not differ between marshes with high selenium and reference marshes. However, the three high exposure sites were poorly represented in brood counts. Again, Goddard Marsh results were surprising for the low selenium concentrations in eggs – the authors noted "this site seems to be an outlier in terms of selenium uptake in waterfowl" despite having the highest selenium water levels of any of the lentic sites assessed. Clode Pond also provided a surprise in that there were no nesting ducks although the habitat and food supply were more than adequate for such activities. However, at least one brood of goslings was raised in Clode Pond, and one brood of coots hatched there.

3.5 LENTIC (NON-FLOWING WATER) LONGNOSE SUCKER AND SPOTTED FROG STUDIES

Aquatic lentic effects studies focused on a fish (longnose sucker) and an amphibian (Columbia spotted frog) in Goddard Marsh and a reference site (Minnow Environmental, 2004b). These studies follow from recommendations made in the *Selenium Status Report 2003* regarding aquatic effects studies not restricted to trout.

Adult Longnose Sucker with dorsal tag, from Goddard Marsh

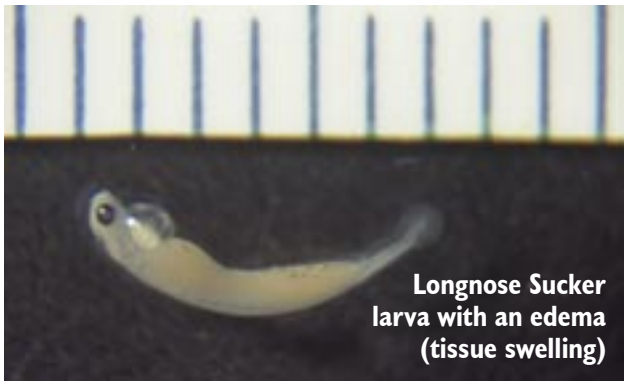
Goddard Marsh was chosen for study because of its very high water and biota selenium concentrations. Despite elevated selenium concentrations, the marsh remains productive, supporting many species of birds, fish, amphibians and invertebrates. Similar studies could not have been conducted at Clode Pond, which consists of three small, interconnected ponds that were constructed to control sedimentation during mining. The only fish found in Clode Pond are cutthroat trout; effects studies with this species from the Pond will be conducted in 2005 (**see Section 4.5**).

Both species (fish and amphibian) were chosen for study based on a previous reconnaissance study of lentic areas (Minnow Environmental, 2003; **see Section 2.3**). The study focus was on species that were resident in lentic areas and, in the case of high selenium areas exemplified by Goddard Marsh, most likely to demonstrate adverse effects from selenium. The overall approach was to follow the development of fertilized eggs using incubation boxes within the marsh and in a reference area .

Extracting milt from a male Longnose Sucker

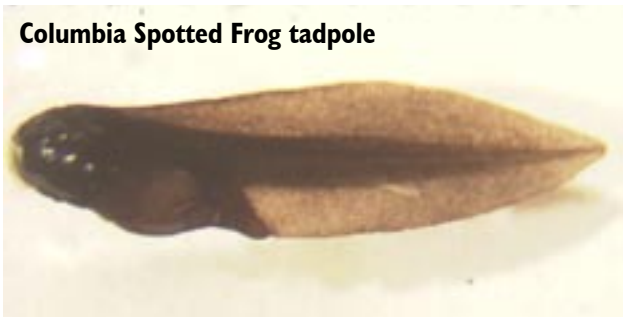

Extracting eggs from a female Longnose Sucker

However, as the study progressed, it was discovered that adult longnose suckers in Goddard Marsh were smaller than normal, leading to the conclusion that these suckers are a dwarf variety which spawns at a different time, producing less and smaller eggs than the non-dwarf variety. (Genetic determinations to establish whether or not this is a different species of sucker are currently being conducted.) As a result, there were problems obtaining sufficient breeding adults and thus sufficient fertilized eggs. In total, three females from Goddard Marsh (including one used to refine the test methods) and five females from the reference area were found in ripe, pre-spawning condition. In addition, when dwarf suckers were spawned and eggs were fertilized with sperm, the incubation containers proved inadequate (mesh size was too large for dwarf eggs) and fungus growth and sedimentation killed many eggs. Of 6,687 fertilized and incubated eggs, only 94 larvae emerged from the incubation containers – 56 from five females from a reference area and 38 from a single female from Goddard Marsh. The sucker eggs from Goddard Marsh did have higher selenium concentrations than those from the reference area, and the data are suggestive of more deformities in Goddard Marsh larvae than in those from the reference area. However, because of the small sample size and other problems noted above, no definitive conclusions are possible.


Longnose Sucker larva with an edema (tissue swelling)


Columbia Spotted Frog eggs

There were also problems, though different ones, with the frog study. No frog egg masses were found in the reference area despite extensive searches, and only three viable egg masses were found in Goddard Marsh. As a result, there are no reference data for comparison. Thus, although frog deformities were noted and there was a positive correlation with elevated selenium egg concentrations, causation could not be established. There are other factors than selenium that can cause frog deformities, for example virus infections, ultraviolet light irradiation. Again, the data are suggestive but not definitive that selenium may be causing some deformities in frog tadpoles in Goddard Marsh.


Columbia Spotted Frog tadpole

4. FUTURE STUDIES

4.1 MAPPING OF LENTIC AND LOTIC HABITATS

A reconnaissance study was conducted before the lentic effects studies documented in this report were conducted (Minnow Environmental, 2003; **see Section 2.3**). However, there has been no detailed watershed mapping to determine all lentic areas that are potentially at high risk from selenium such as lakes, wetlands, marshes and backwater areas. Thus, a comprehensive inventory of lentic areas in the Elk River Valley from the Highway 93 bridge to well upstream of the mines (**Figure 1**) is being conducted in 2005. The objectives of this study are to:

1) Determine the relative proportions of lentic versus lotic habitat that may be exposed to selenium releases from mining.
2) Provide necessary information to ensure that appropriate monitoring is being done of both lotic and lentic areas relative to selenium releases from mining.
3) Ensure that studies determining whether or not there are effects / impacts from selenium in lentic areas are in fact studying representative areas.

4.2 WATER QUALITY MONITORING

Water quality monitoring has been conducted independently by the five coal mines (EVS Environment Consultants, 2004) and as part of a larger region-wide monitoring program (EVS Environment Consultants, 2005). Previous monitoring by the mines suffered from spatial and/or temporal limitations: sampling was not conducted over similar, periodic time periods and not all stations were sampled at the same time, nor by the same methods. A standardized water quality monitoring program has been developed that involves all of the five mines, for which regular trend reports will be developed. The purpose of this water quality monitoring, which includes all active permitted discharges, is to provide early warning of near-field changes to selenium concentrations; even though water is not the primary exposure mechanism for selenium effects to fish and waterfowl reproduction, increases are indicative of potential increases to the primary exposure route, fish and waterfowl food items. Sampling stations are shown in **Figure 5**; sampling for selenium occurs a minimum of monthly at each of these stations. When a full year of sampling has been completed (mid-2005), the findings for this first year will be analyzed to determine trends.

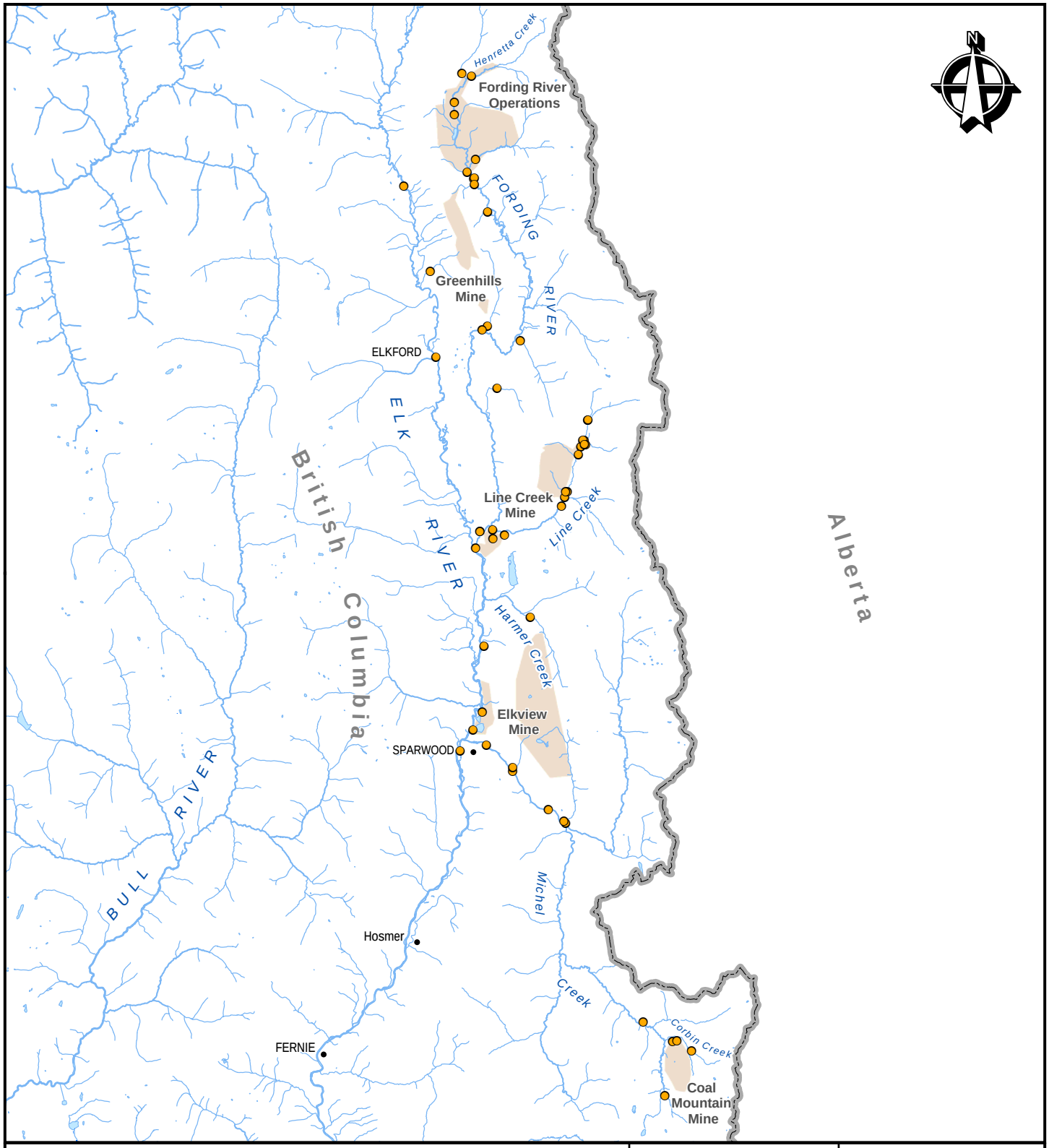
Data mining is also being undertaken, matching flow and selenium concentration data from the Highway 93 Bridge federal monitoring station (**see Figures 1 and 3)** to determine any trends and relationships between concentrations and loadings. Analyses indicate that, as flows increase, loadings increase. The pattern is similar to that for nitrogen, which indicates that selenium releases are directly related to precipitation and high water flows.

In addition, investigations are planned to determine sources of selenium and assess alternatives relative to their potential reduction. Specifically, loadings from active and dormant waste rock drainages will be compared under different conditions, using trend data together with loadings to determine whether useful data related to future loadings can be obtained for predictive purposes.

Finally, laboratory research is being conducted to investigate selenium removal. Testing undertaken to date has shown that selenium removal is possible under certain conditions, though such removals are not presently practical. This research is attempting to develop a means to opportunistically remove significant loadings from sources with high selenium concentrations and low flows – effectively shaving off peak concentrations entering the environment.

4.3 LENTIC EFFECTS STUDIES – RED-WINGED BLACKBIRDS

As noted in **Section 3.3**, nestling survival appears to be affected in some lentic areas with high selenium



LEGEND

- Water Monitoring Location
- Populated Place
- Mine Locations (Approximate)
- Provincial Border

Projection: UTM Zone 11N, NAD '83

0 5 10 20 30 40 Kilometers

EVS environment consultants
a member of the Golder group of companies

PROJECT: Elk Valley Selenium

LOCATION: Elk Valley, Southeastern BC

CLIENT: Elk Valley Coal Corporation

TITLE:

Stations for measurements of selenium in water at each of the five coal mines

DWG BY:	CHK BY:	PROJECT No.:
GGC	PMC	04-1421-029
SCALE: 1:449,966	DATE: 02/2005	**FIGURE 5**

concentrations; dead nestlings, embryos with abnormalities and one deformed nestling were found in 2004 in some, but not all areas with elevated selenium concentrations. This initial work poses three key questions that will be addressed with additional studies conducted in 2005:

1) Was selenium the cause of the nestling mortalities, a nestling deformity and embryo abnormalities?
2) Why were there no nestling mortalities at the marsh with the highest selenium concentrations (Goddard Marsh), and why did this same marsh not have the lowest nestling survival and instead have 100% nestling survival but also have embryo abnormalities?
3) What is the population-level significance of the observed effect, if in fact it is due to selenium; in other words, is there a population-level impact as well as an effect?

4.4 LENTIC EFFECTS STUDIES – SUCKERS AND FROGS

The 2004 lentic effects studies attempted to determine whether or not longnose sucker and Columbia spotted frogs in Goddard Marsh, which has some of the highest selenium concentrations measured to date in lentic areas of the Elk River Valley, showed reproductive effects due to selenium. Unfortunately, there were problems with these studies (e.g., extremely small sample sizes, no reference data for the frog study, larvae only assessed for a single female sucker from Goddard Marsh), as detailed in **Section 3.5**. Thus, further studies are being conducted in 2005, building on the information collected in 2004 and possibly investigating an additional or alternative fish species (e.g., longnose dace), in order to:

1) Determine whether the reproduction of fish and frogs living in lentic areas with elevated selenium concentrations is being adversely affected by selenium.
2) Assess whether any effects could in fact be impacts.
3) If possible, determine threshold tissue selenium levels that correspond with both effects and impacts (if such occur).

4.5 LENTIC EFFECTS STUDIES – CUTTHROAT TROUT

As previously noted for the lentic bird effect studies (**Sections 3.3 and 3.4, Text Box 3**), Clode Pond appears to behave very differently than Goddard Marsh related to potential effects from selenium. However, unlike Goddard Marsh, Clode Pond is an artificial construct, and the only fish living in it are cutthroat trout, which have moved into the three small, interconnected sediment control ponds and use them for overwintering cover, rearing and spawning. There will be increased sediment loadings from mining to the ponds, and chemical flocculants may be used to settle these sediments. To protect these fish, they are presently being removed and relocated (Robinson et al., 2004). About 5000 cutthroat trout were removed and relocated in 2004. Additional removals and relocations will occur in 2005, which provides an unique opportunity to determine whether or not these fish, exposed to very high levels of selenium in the Pond, are showing effects on their reproduction. Studies involving raising fertilized eggs through to fry will be conducted in 2005 similar to those conducted previously (Kennedy et al., 2000; Holm, 2002; Holm et al., 2003; **see Text Box 1**). These data will be used to:

1) Determine whether reproductive effects are occurring to cutthroat trout resident in Clode Pond compared to tissue body burdens of selenium.
2) Extend the data of Kennedy et al. (2000) for this species in the Elk River Valley and possibly determine an effects threshold for this species (if effects in fact occur). Determining a tissue-based effects threshold would be invaluable in terms of future predictions of the status of this important fish species in the Elk River Valley.

The above studies follow from recommendations made in the *Selenium Status Report 2003*. Specifically,

it was recommended that the work of Kennedy et al. (2000) be repeated, "attempting to catch and test additional fish with elevated selenium concentrations in their tissues and eggs, to further explore the relationship between elevated selenium tissue concentrations in this species and the lack of adverse effects."

4.6 RESIDENT FISH COMMUNITIES

The *Selenium Status Report 2003* 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. Data on resident juvenile bull trout, resident cutthroat trout, and bull trout redd (nest) counts were reported through 2001. Such monitoring was not conducted in 2003. A different contractor was involved from 2002 onward using different methodologies. The years 2002 and 2004 were also very different than previous years in terms of high and variable water flows that exceeded values seen since the 1970s and made sampling physically dangerous (Robinson and Wright, 2005). Thus, data from 2002 and 2004 are not directly comparable to previous data. Successful spawning has been documented in Line Creek in both 2002 and 2004, but quantification has been questionable due to the high flows. Accordingly, more accurate means of measuring fish populations are being considered (e.g., fish fences).

4.7 UNGULATES

The primary risk to ungulates such as sheep and elk is from consumption of plant species that have accumulated selenium to toxic levels. Monitoring of the health of ungulate herds (sheep and elk) indicates that there are no impacts; populations are thriving. Incidental observations providing no indications of selenium poisoning (first apparent through cracking of hooves and hair loss) also suggest that there are no effects. Unless the current ungulate monitoring programs indicate changes to populations or early warning signs of selenium poisoning occur, additional studies involving ungulates are not anticipated.

4.8 MAMMALS OTHER THAN UNGULATES

The Elk River Valley contains four to five species of shrews, nine species of voles and mice, seven species of squirrel as well as beaver, muskrat, porcupine, hoary marmot, pica, water vole, water shrew, mink and river otter. Effects of selenium on mammals occur at higher exposure levels than those that affect reproduction in fish and birds. For example, raccoons at a wetland with very high selenium levels in California, where bird reproduction was severely reduced (Kesterton Reservoir), were not affected (Clark et al., 1989). Given the relatively low level of effects detected to date in the Elk River Valley compared to Kesterton Reservoir, it is highly unlikely that mammals are presently at risk from selenium poisoning. Thus, studies with mammals are not presently anticipated.

4.9 LOTIC MONITORING – FISH AND OTHER ORGANISMS

Monitoring of selenium concentrations in tissues of fish (cutthroat trout and mountain whitefish), plants, and small fish prey organisms was conducted 2001-2003 (EVS Environment Consultants, 2005). Given that there had been no increase in selenium concentrations in cutthroat trout tissues over several years, the absence of effects (or impacts) to this species, and documented healthy fish populations in the rivers and streams of the Elk River Valley, additional monitoring was postponed until 2006. In 2006, the lotic monitoring program will be repeated to determine whether or not selenium concentrations have increased in organism tissues compared to previous studies, and similar monitoring will begin in lentic areas.

4.10 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). However, as noted in the *Selenium Status Report 2003*, the Lake is not "a high risk compared to lentic areas within the

Elk River Valley." Investigations regarding the status of the Lake, as described in that Report, should only be considered if there are impacts at upstream lentic areas that have much higher selenium concentrations. Lentic studies are presently focused on "worst case" near-field ponds and wetlands.

5. 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 (VEC). 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. As previously noted, studies in 2005 will determine whether there are impacts to red-winged blackbirds and whether there are effects / impacts to fish and frogs living in high-risk lentic areas with high levels of selenium.

However, studies conducted to date do suggest that some negative effects are occurring on a more localized level (**see Table 2**). The extent and significance of negative effects in lentic areas with high levels of selenium, i.e., whether or not there are population-level impacts, remains to be determined.

The results of effects studies conducted in 2005 will be evaluated in terms of the significance and extent of any effects / impacts. Water selenium concentrations (early warning) will be used to project future scenarios. The possibility of management actions, if necessary, will be assessed accordingly.

TABLE 2. Summary of effects studies conducted to date in lotic and lentic areas.

SPECIES	EFFECT?	IMPACT?	COMMENTS
LOTIC			
Cutthroat trout	No	No	Additional studies underway in Clode Pond, a lentic area (**Section 4.5**)
American dipper	No	No	Sandpiper hatching success depressed but productivity high; further studies recommended if water selenium concentrations increase
Spotted sandpiper	***Yes***	No	
LENTIC			
Red-winged blackbirds	***Yes***	Uncertain	Nestling survival decreased at some high-selenium sites; other factors than selenium may have contributed to mortalities at some sites, embryo abnormalities at one site, one deformed nestling at another; additional studies underway (**Section 4.3**)
Eight species of waterfowl	No	No	Sample size very small; findings not conclusive; elevated selenium in some eggs at high-exposure sites and high exposure sites not well represented in brood counts; small populations and difficulty finding nests preclude further studies without the use of sophisticated radiotelemetry
Longnose sucker	Uncertain	Uncertain	Indications that selenium may be causing deformities in fry/tadpoles; studies far from definitive due to methodological problems; additional studies underway (**Section 4.4**)
Columbia spotted frog	Uncertain	Uncertain	

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APPENDIX A

LIST OF ACRONYMS AND GLOSSARY

LIST OF ACRONYMS

EC	Environment Canada
EVMEMC	Elk Valley Mines Environmental Management Committee
EVSTF	Elk Valley Selenium Task Force
MEM	[B.C.] Ministry of Energy and Mines
MES	Mean Egg Selenium
SIA	Stable Isotope Analysis
VEC	Valued Ecosystem Component
WLAP	[BC Ministry of] Water, Land and Air Protection

GLOSSARY

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

Clutch
Collection of eggs – usually refers to bird eggs.

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

Edema
Leakage of fluid into the 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.

Emergent
Extending out to the air from below water.

Fledge
To acquire the feathers required for flight.

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.

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

Impact
An effect on 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.).

Interpolate
To insert a value between known values using a procedure specifically related to the known values.

Leachate
Water or any other liquid that may contain dissolved (leached) soluble substances, such as organic salts and mineral salts, derived from a solid material. For example, rainwater that percolates through waste rock and picks up substances such as inorganic selenium is considered leachate of the waste rock.

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

Lotic
Flowing water bodies such as streams and rivers.

Marsh Birds
Birds that frequent marshes, for instance, red-winged blackbirds.

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

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

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.

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.

Teratogenic
Causing birth defects. Capable of causing defects in the reproductive process resulting in either reduced productivity due to fetal or embryonic mortality or in the birth of offspring with physical, mental, behavioural or developmental defects.

Toxic
Descriptor of a substance, a dose exposure, or a concentration that is poisonous, carcinogenic, or otherwise directly harmful to a living organism.

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 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.