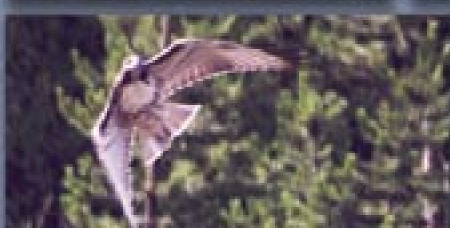
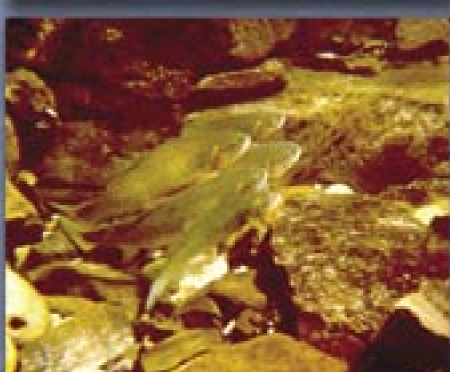
Selenium Status Report 2003

ELK RIVER VALLEY, BC






Elk Valley Mines Environmental Management Committee

OCTOBER 2003

EXECUTIVE SUMMARY

A report published by BC Environment in 1998 (based on studies begun in 1996) indicated that selenium concentrations in the Elk River Valley in southeastern British Columbia were elevated and could result in adverse environmental effects. Although the report found no evidence of an unhealthy ecosystem, a joint government and industry task force was formed to determine whether adverse effects due to selenium are occurring or could occur, and to provide input to regulatory management of selenium in the environment. The purpose of the present report is to summarize, at different technical levels and in a user-friendly format, studies conducted through October 2003 and to outline what further studies are needed and why.

Monitoring of selenium concentrations in water, sediments and biota near and away from the coal mines indicates that the coal mines are the primary source of elevated selenium concentrations. Selenium concentrations decrease with distance downstream away from the mines.

Investigations by the BC Ministry of Energy and Mines and the University of British Columbia into the release of selenium into surface waters from coal mining found that selenium is released naturally. However, coal mining enhances the natural selenium release processes, and selenium release is primarily associated with the waste rock.

A three-year monitoring program for flowing water areas in the Elk River Valley (2001 to 2003) assessed selenium concentrations in water, invertebrates, plants and fish. Concentrations in biota, although elevated, were less so than concentrations in water. Although BC Environment found elevated concentrations in fish tissues in 1996, tissue concentrations have not increased from 1996 to 2003.

Although flowing water (lotic) areas are most common in the Elk River Valley, still or standing water (lentic) areas may represent the worst case because there is more likelihood of inorganic selenium being converted into the much more toxic organic selenium. A reconnaissance study was conducted in 2002 of various lentic areas. Selenium concentrations were measured in water, sediment, fish and amphibians. The structure of communities of bottom-dwelling and water-dwelling organisms was assessed, and waterfowl were assessed qualitatively. The most contaminated lentic area, which had been previously assessed as contaminated in 2001 by BC Environment, was also the most productive area. There was no clear evidence that elevated selenium concentrations were adversely affecting lentic areas in the Elk River Valley, however more detailed studies are required before any definitive conclusions are reached. To this end, a study is presently being conducted to determine food webs for both lentic and lotic areas to provide a better understanding of how selenium accumulates within food chains in the Elk River Valley.

The primary concerns regarding elevated selenium concentrations in aquatic ecosystems are waterfowl and fish, in particular reproductive failures or abnormalities. In a study published in the scientific literature in 2000, BC Environment in cooperation with Simon Fraser University collected mature male and female cutthroat trout (the primary sport fish) from an area in the Elk River Valley contaminated with selenium, and an uncontaminated reference area, spawned them, determined selenium concentrations in fish and eggs, and determined whether or not the eggs and offspring were viable. Although selenium concentrations in the fish and some of their eggs were above concentrations shown to be toxic in other areas with other fish species, there was no demonstrated toxicity. The fry hatched and developed normally.

The lack of adverse effects of selenium on cutthroat trout in the Elk River Valley from these laboratory studies is supported by fisheries studies conducted in lotic (flowing water) areas of the Valley that have elevated selenium concentrations. Numbers of both cutthroat and bull trout have increased in these areas since the fisheries changed from catch-and-consume to catch-and-release in the 1980s; there has been a similar increase in reproduction.

A 2002 study on two common waterfowl (American dippers and spotted sandpipers) living in flowing water areas found no discernable adverse effects, and selenium concentrations in eggs were below thresholds at which adverse effects have been documented in other areas. The study concluded that there was no risk to these waterfowl unless selenium water concentrations increased. Future work will focus on waterfowl in still water (lentic) areas.

A human health risk assessment conducted in 2000 found that there was negligible risk to humans eating fish from the Elk River Valley. In fact, given the benefits of both selenium and fish consumption to human health it was concluded 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." There is no risk to humans related to selenium from contact with or drinking the water in the Elk River Valley.

Based on studies conducted since 1996, there is no evidence that adverse ecological impacts have or will occur related to discharges of selenium associated with Elk River Valley coal mining. Selenium concentrations in organisms and water may have reached a plateau over the last few years. However, additional studies are required before definitive conclusions can be reached. Such studies are outlined in the report and include additional investigations in lentic areas, in particular of waterfowl and fish as well as continued monitoring in lotic areas.

TABLE OF CONTENTS

EXECUTIVE SUMMARY i

TABLE OF CONTENTS iii

LIST OF FIGURES iv

LIST OF TABLES v

ACKNOWLEDGEMENTS vi

1. INTRODUCTION 1

2. BACKGROUND 3

- 2.1 Elk River Valley 3
- 2.2 The Coal Mines 3
- 2.3 Selenium and Toxicity 6

3. PAST AND CURRENT STUDIES 11

- 3.1 Overview Studies 11
  - 3.1.1 Water, Sediments, Periphyton, Invertebrates and Fish 11
  - 3.1.2 Waterfowl 11
  - 3.1.3 Assessment of Lotic Areas 13
  - 3.1.4 Assessment of Lentic Areas 13
- 3.2 Investigative Studies 15
  - 3.2.1 Laboratory Effects Study 15
  - 3.2.2 Status of Fisheries in the Elk River Valley 16
  - 3.2.3 Determination of Food Webs 18
  - 3.2.4 Human Health Risk Assessment 20
  - 3.2.5 Investigations into Geochemical Mechanisms 21

4. ADDITIONAL INFORMATION REQUIREMENTS 23

- 4.1 Additional Investigative Studies 23
- 4.2 Lake Koocanusa 24
- 4.3 The Terrestrial Environment 24

5. CONCLUSIONS 25

APPENDIX A List of Acronyms and Glossary 27

APPENDIX B Annotated Bibliography and References Cited 31

LIST OF FIGURES

FIGURE 1. The Elk River Valley, including the locations of the five coal mines and of the monitoring station at the Highway 93 bridge. 5

FIGURE 2. Selenium concentrations measured in waters downstream of the mines at Phillips Bridge over the Elk River (Highway 93 - see Figure 1 for location). These data are based on routine federal monitoring of selenium and other substances, and provide the most up-to-date information summary available from the monitoring agencies. 6

FIGURE 3. Toxicity curves for synthetic organic substances (A), essential substances such as selenium (B), and non-essential substances such as cadmium (C). 8

FIGURE 4. Comparison of American dipper productivity and egg selenium concentrations (wet weight) in areas with elevated selenium concentrations compared to areas with background selenium concentrations. Values for % hatched and % fledged are shown as decimal fractions. From SciWrite (2003). 12

FIGURE 5. Comparison of spotted sandpiper productivity and egg selenium concentrations (wet weight) in areas with elevated selenium concentrations compared to areas with background selenium concentrations. Values for % hatched and % fledged are shown as decimal fractions. From SciWrite (2003). 12

FIGURE 6. Egg selenium concentrations compared to percent deformities prior to yolk absorption for offspring of fish from the Elk River Valley (dark circles) and from a reference area (open circles). From Kennedy and co-workers (2000). 17

FIGURE 7. Egg selenium concentrations compared to percent mortalities prior to yolk absorption for offspring of fish from the Elk River Valley (dark circles) and from a reference area (open circles). From Kennedy and co-workers (2000). 17

FIGURE 8. Cross section of coal mine pit wall illustrating different types of material sampled by Lussier (2001). 22

FIGURE 9. Schematic diagram of a humidity cell. From Lussier (2001). 22

LIST OF TABLES

TABLE 1. Selenium concentrations (µg/g Se dry weight) in Elk River Valley cutthroat trout eggs compared to a suggested US threshold toxicity value. Where the suggested threshold was exceeded, the data (from Kennedy and co-workers 2000) are italicized and bolded. 17

TABLE 2. Numbers of trout per 100 m^2 of Line Creek. Data from Allan (2003). 19

TABLE 3. Bull trout redd counts in Line Creek. Data from Allan (2003). 19

ACKNOWLEDGEMENTS

This draft report was written by Dr. Peter M. Chapman and Ms. Cathy McPherson of EVS Environment Consultants (EVS), North Vancouver, BC. Formatting the document was done by Christa Wall of EVS. Useful review comments on an earlier draft were provided by members of the Elk Valley Selenium Task Force (EVSTF). The majority of the photographs were provided by Elk Valley Coal (Roger Berdusco). Jim Allan (Pisces Environmental Consulting, Alberta) provided the photographs of bull trout and rainbow trout underwater and Tables 2 and 3. Christine Lussier (University of British Columbia) provided the two figures (Figures 8 and 9) in the Text Box: Selenium Release from Coal Mining. Andrea Ryan (Environment Canada) provided the data for Figure 2. Chris Kennedy (Simon Fraser University) provided Figures 6 and 7. Photographs of birds in the Elk River Valley were provided by Lee Harding of SciWrite; he also provided Figures 4 and 5. Minnow Environmental provided photographs of lentic areas they sampled.

I. INTRODUCTION

In 1998, BC Environment published a report on concentrations of selenium in water, sediment and biota in the Elk River Valley (McDonald and Strosher, 1998). This report indicated that selenium concentrations exceeded levels at which adverse effects had been shown to occur in some other (primarily warm water) areas. To further address the potential for impact of selenium in the Elk River Valley, the Elk Valley Selenium Task Force (EVSTF) was formed. Membership of the EVSTF presently includes the Elk Valley coal mines, the BC Ministry of Water, Land and Air Protection, and the BC Ministry of Energy and Mines.

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:

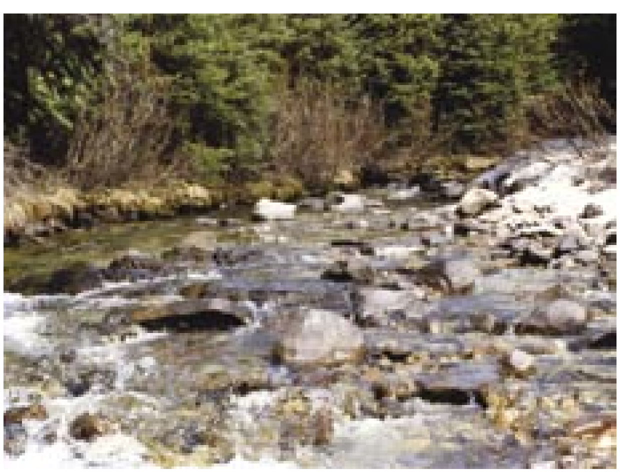
1. Is there evidence that any adverse ecological impact(s) have or will occur related to discharges of selenium associated with the Elk River Valley coal mining?

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

Studies conducted to date, though not yet definitive, do not provide indications of adverse effects on aquatic biota or waterfowl in the Elk River Valley. Further studies into this issue will continue, with an increasing focus on effects-based studies.

Flowing water bodies such as streams and rivers are called "lotic". Ponds, lakes and other static water bodies are called "lentic".

The purpose of this document is to provide a synthesis of what has been accomplished to date related to the above two questions, and to indicate future research priorities (e.g., the "path forward"). This document attempts, based on all available information, to provide two key pieces of information related to the on-going studies into selenium contamination from coal mining in the Elk River Valley:



Lotic (flowing) and lentic (still) waterbodies provide different habitats for aquatic organisms

1. What we know.
2. What we need to know and why.

This document is intended to be user-friendly and can be read at different technical levels. Simply reading the main text will provide broad information to all readers. Text boxes, figures and tables provide additional information, not all of which may be of interest to all readers. If additional, more detailed information is required, Appendix A provides a List of Acronyms and a Glossary, while Appendix B provides an annotated bibliography of the site-specific technical reports that are summarized herein as well as a listing of additional references cited in the text.

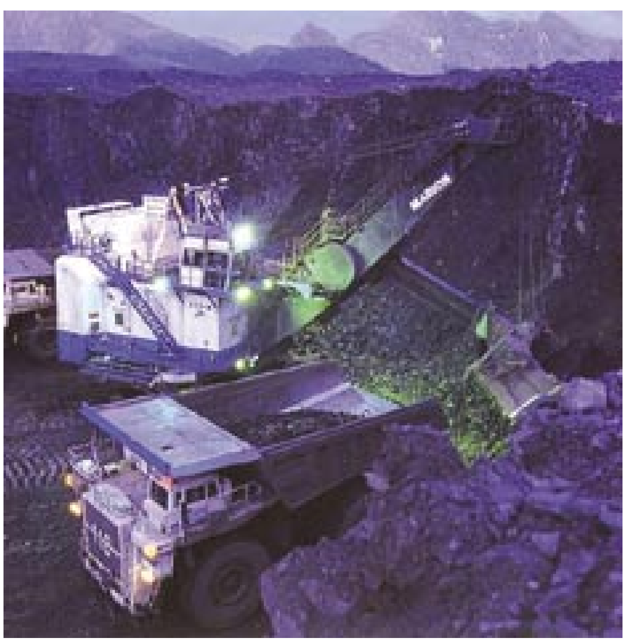
Contamination means a substance present at higher levels than would occur naturally. Pollution means contamination that causes adverse effects. Contamination does not necessarily result in pollution.

This document begins with background information on the Elk River Valley, the coal mines, and selenium in the aquatic environment (Chapter 2). It then focuses on past and current studies and what they have told us (Chapter 3), followed by what additional information is required and why (Chapter 4). The report ends with a conclusions section (Chapter 5).

2. BACKGROUND

2.1 ELK RIVER VALLEY

The Elk River Valley is located in the extreme southeastern corner of British Columbia, within the Kootenay geological formation, which is an area where soils naturally contain elevated concentrations of selenium. This area, which is located close to the borders of both Alberta and Montana, has played an important part in the coal mining history of British Columbia for over 100 years. It contains the largest producing coalfield in the province, which produces coal that is shipped to steel mills around the world.



Mining technology in operation

The small communities of Fernie, Sparwood and Elkford are located in the Elk River Valley. The Valley provides year-round recreational opportunities and welcomes visitors from around the world.

The Elk River Valley has a large, diverse population of big game animals including bighorn sheep, mountain goat, elk, deer, moose, bear, and cougars. Recreational fisheries in the Elk River are dominated by westslope cutthroat trout, however bull trout and mountain whitefish are also present. Other waterbodies in the Valley contain rainbow trout, kokanee and eastern brook trout.

2.2 THE COAL MINES

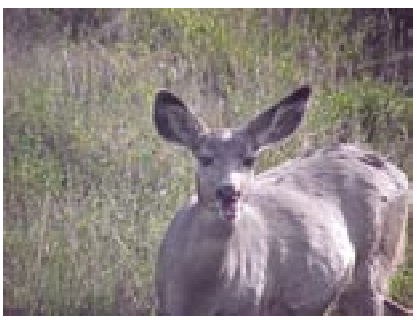
The first European to find coal in the Elk River Valley was Father de Smet, about 1842 (Cousins, 1981). In 1889 the Crow's Nest Coal and Mining Company was established in the Elk River Valley. The first coal was extracted at Coal Creek in late 1897. Large-scale coal mining in the Elk River Valley began in 1970 and has since expanded to five major coalmining operations producing over 25 million metric tons of coal each year: Fording River, Elkview, Coal Mountain, Greenhills and Line Creek (see Figure 1).

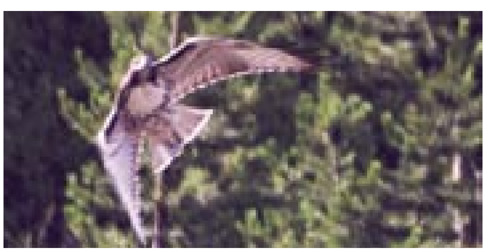
[The Elk River Valley] "is destined to be one of the most valuable and most productive coalfields in Canada" – 1891, Geological Survey of Canada.

Because the areas being mined are naturally elevated in selenium, mine wastes contain selenium. Over time, mining has resulted in increased selenium concentrations downstream of the mines.

Selenium was first identified as a potential problem in the Elk River Valley in 1995 during an unrelated assessment for an effluent permit amendment. During this assessment BC Environment noted elevated concentrations of selenium in discharges from the mines.

The Elk Valley is home to a diverse range of wildlife and aquatic species





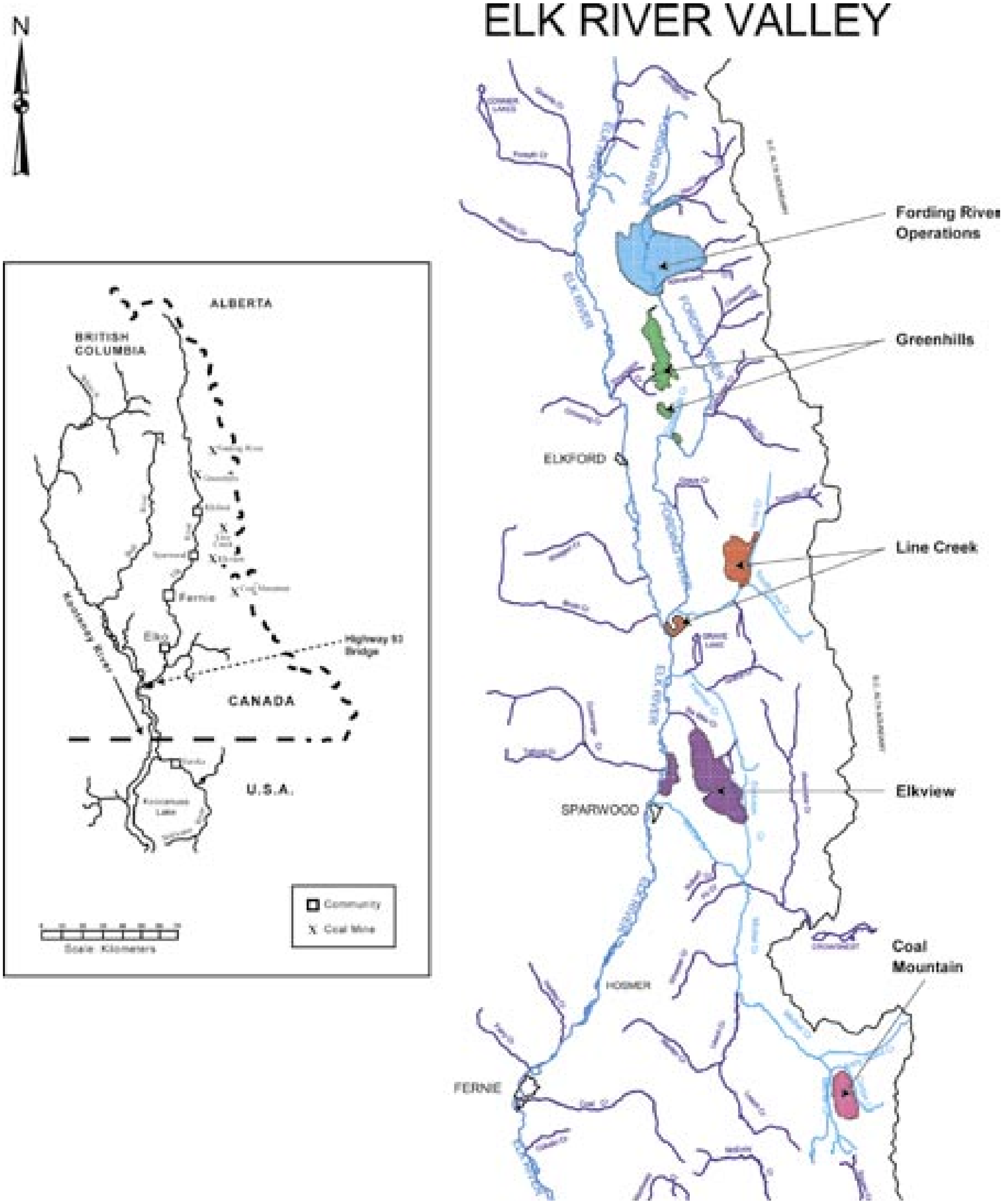


FIGURE 1. The Elk River Valley, including the locations of the five coal mines and of the monitoring station at the Highway 93 bridge.

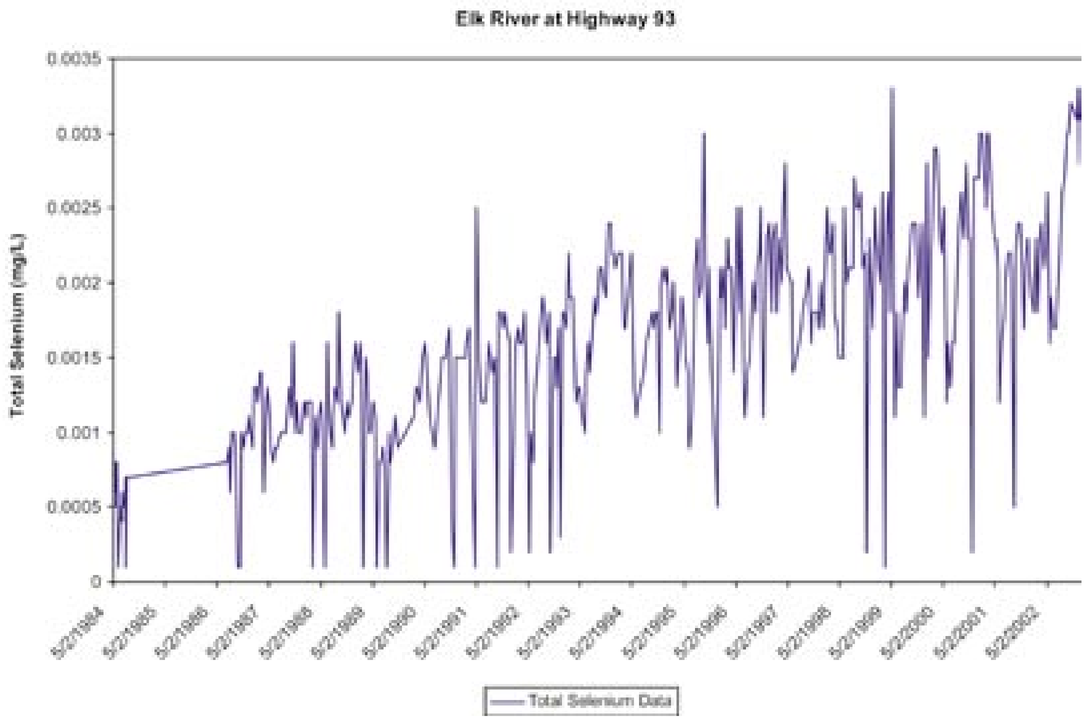


FIGURE 2. Selenium concentrations measured in waters downstream of the mines at Phillips Bridge over the Elk River (Highway 93 - see Figure I for location). These data are based on routine federal monitoring of selenium and other substances, and provide the most up-to-date information summary available from the monitoring agencies.

They also noted a trend of elevated selenium concentrations at a downstream monitoring station near the mouth of the Elk River, at the Highway 93 bridge above Lake Koocanusa (Figure 2). These findings led to further studies beginning in 1996 and published in McDonald and Strosher (1998 – See Section 3.1).

2.3 SELENIUM AND TOXICITY

Selenium was discovered in 1818 by the Swedish chemist Berzelius, and named after Selene, the Greek goddess of the moon. It is a naturally occurring substance, a metalloid. It can enter the aquatic environment naturally as a result of weathering. Human activities such as mining (metal, coal and phosphate mines) and those associated with the use of coal as a fuel (combustion, fly ash leaching) can enhance this process.

Selenium, like all substances, can be toxic at elevated concentrations. In some parts of the world, the soils naturally have an over-abundance of selenium, and selenium-accumulating plants tend to grow in these areas (Oldfield, 2000). Livestock such as horses and

The well-known Periodic Table of the Elements is based on the recognition that chemical behavior is correlated with valence electron configuration. Based on their electron configuration, some elements can adopt either metallic or non-metallic behaviour depending on the particular chemical circumstances in which they exist. These elements are termed metalloids to specify their special chemical ambiguity. Selenium is a metalloid. Other metalloids include arsenic, boron, silicon, germanium, tellurium, polonium and astatine.

cattle grazing on these plants will be poisoned and can die. Such natural poisoning by selenium was first documented in South Dakota in the 1930s as a result of what was then named "alkali disease" and "blind staggers". Based on his diaries, it is believed that Marco Polo's horses succumbed to natural selenium poisoning during his 13th century overland trip to China (there were places along the Silk Road where, when his horses ate the local range plants, their hoofs cracked and dropped off – symptoms of selenium poisoning). Similarly, cracked hooves and even deaths of cavalry horses in parts of the United Stated in the 1800s have been linked to natural selenium poisoning. Plants are not similarly poisoned by excess selenium.

Selenium concentrations in Elk River Valley soils are not sufficiently elevated to result in natural poisoning. Adverse effects to livestock and other grazers (sheep, elk) have neither been observed nor reported. In fact, Valley ranchers regularly feed their cattle selenium supplements.

Selenium is also an essential element; it is required for the health of humans, animals and plants. Deficiency is more common than overabundance. Soils in many parts of the world are deficient in selenium, which does not affect the plants growing on those soils but rather the animals (and humans) eating those

Ranchers in the Elk River Valley feed selenium supplements to their cattle year round and particularly to pregnant cows in the late stages of pregnancy and to weaned calves. Symptoms of selenium deficiency in the Valley prior to supplementation included placental retention and infection, and weak leg joints in calves.

plants. Typically, in most countries, soil selenium deficiencies are rectified by the use of supplements. Similarly, selenium is widely supplemented in animal feed including fish hatcheries. As a result, agricultural drainage is also a source of selenium to water bodies. When supplements are not used, humans and animals living in selenium deficient areas can suffer from a variety of ills and deficiencies that can result in death. Animal selenium deficiencies include adverse effects to muscles (heart and skeletal, growth depression due to decreased muscle mass), liver and pancreas. Human selenium deficiencies can result in Keshan disease, which affects the heart; this disease is most common in children and young women of childbearing age and responds to selenium supplements in the diet. Selenium deficiencies can also result in Kashin-Beck disease, which is estimated to affect some two million people, particularly children, in parts of China, and

Elk herd on a reclaimed site, and swimming across a settling pond

TEXT BOX I: TOXICITY AND DEFICIENCY

Essential substances such as selenium demonstrate toxicity due to both deficiency and excess. Synthetic, organic substances (that is, substances that do not normally occur in nature), demonstrate the toxicity curve shown in Figure 3A. Because these substances do not occur in nature, organisms have little tolerance for them and toxicity results relatively rapidly. Natural substances such as metals that are not essential, for instance cadmium and mercury, show the slightly different toxicity curve shown in Figure 3C. Because organisms have adapted to the presence of these elements in the natural environment, there is a period of tolerance before toxicity begins. In contrast, essential substances such as selenium, zinc and copper show a very different bell-shaped curve (Figure 3B). There is an optimum concentration range. Below and above this optimum range, toxicity occurs. Of the essential substances, selenium has the smallest range between deficiency and toxicity.

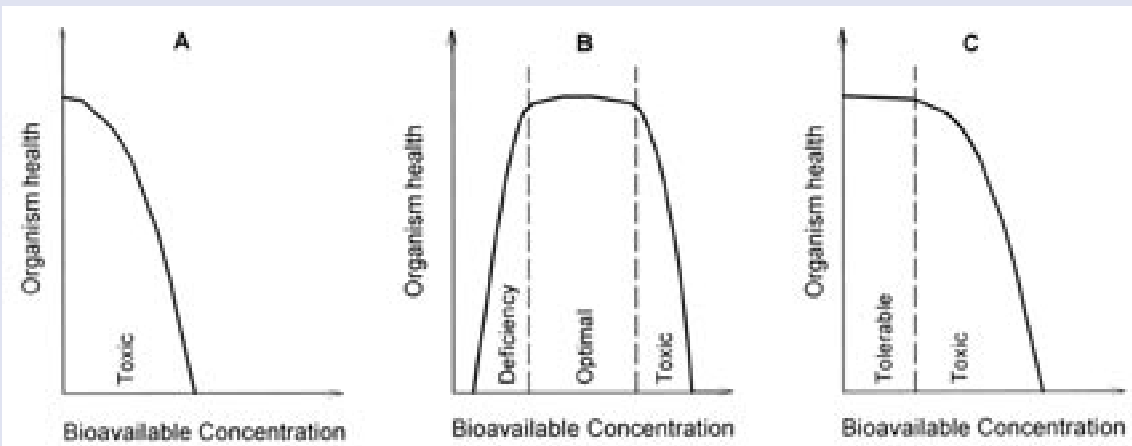


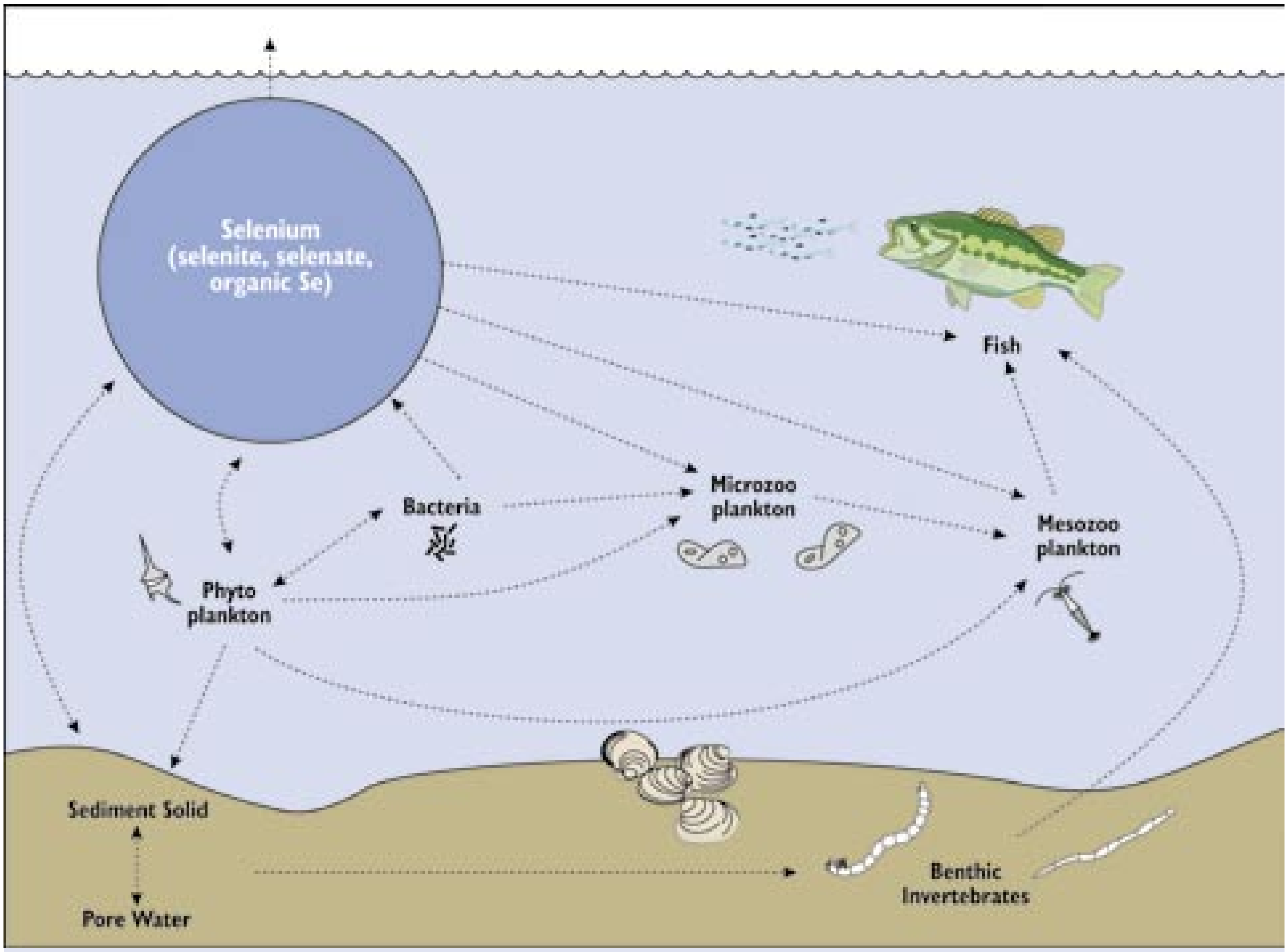
FIGURE 3. Toxicity curves for synthetic organic substances (A), essential substances such as selenium (B), and non-essential substances such as cadmium (C).

which does not respond well to selenium supplements. This disease is characterized by decreased limb length and short stature. Selenium deficiency in humans has also been associated in the medical literature with increased cancer risk, kidney disease, and some aspects of Crohn's disease and Down's syndrome.

Because of the adverse effects associated with selenium deficiency, health agencies have developed recommended minimum daily intake ranges for selenium. Current research indicates that moderate doses of selenium can provide protection against certain degenerative diseases in humans, particularly certain types of cancer and heart disease. Selenium in the environment can protect against toxicity from methyl mercury and cadmium.

Selenium deficiency or excess can injure or kill animals and humans.

Selenium enters the aquatic environment as an inorganic substance but, in some aquatic environments, can be metabolically transformed by bacteria and algae into organic selenium. Such transformations tend to occur in lentic (still water bodies) rather than in lotic environments (flowing water bodies). Organic selenium can move through the food chain and substitute for sulfur in sulfur-containing amino acids, altering the normal functioning of the proteins into which these amino acids are incorporated. The primary problems with organic selenium in water bodies are reproduc-



TEXT BOX 2: SELENIUM CYCLING IN AQUATIC SYSTEMS

Selenium cycling in aquatic systems is complex and tends to be site-specific. Selenium can exist in inorganic forms (selenite, selenate) or organic forms. The organic forms can bioaccumulate through food chains to fish and waterfowl and can result in reproductive failures and other adverse effects to these organisms. Similar pathways exist for water birds (not shown). Phytoplankton are small plants that live in the water column. Zooplankton are small animals that live in the water column; microzooplankton are smaller than mesozooplankton. Benthic invertebrates are animals without backbones that live in the sediments. Release of selenium from water to the atmosphere occurs but is relatively insignificant. Bacterial conversion of inorganic selenium to organic forms, which occurs mostly in lentic systems (standing or stagnant water, such as ponds and swamps), is a critical transformation process. Adapted from Chapman (1999).

tive failures of fish and waterfowl embryos when the egg yolks are enriched with amino acids containing selenium (Lemly, 2002; Spallholz and Hoffman, 2002). Other problems include reduced growth, deformities, tissue damage, and death. These effects are less for lotic waterbodies than for lentic waterbodies. Similar effects do not occur with humans.

3. PAST AND CURRENT STUDIES

3.1 OVERVIEW STUDIES

3.1.1 Water, Sediments, Periphyton, Invertebrates and Fish

An initial survey of selenium contamination and bioaccumulation (uptake into organisms) in the Elk River by McDonald and Strosher (1998) found elevated concentrations of selenium in water, sediment and fish tissues but no evidence of an unhealthy ecosystem. Selenium concentrations in sediments, algae, invertebrates and fish were not as elevated as water column concentrations, indicating a limited amount of selenium bioaccumulation.

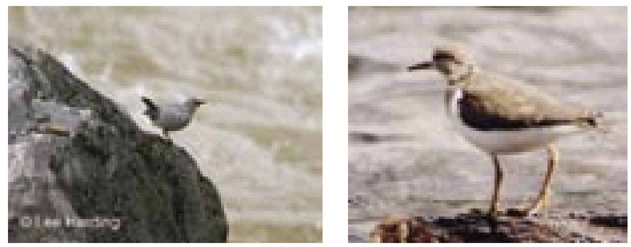
EVS Environment Consultants (2003a) summarize monitoring of selenium concentrations in water associated with each of the five mines. This monitoring is independent of the large-scale monitoring described in Sections 3.1.3 and 3.1.4, below. Because this monitoring is not required by regulatory agencies but is conducted by the mines for their own information, it reflects different levels of effort and objectives at the different mines. Future monitoring by the mines will involve more uniformity in order to more accurately determine near-field trends, for instance, similar levels of effort, timing and frequency of sampling.

Based on information available to date, it appears that:

- Selenium is being released from the waste rock.
- Selenium concentrations tend to decrease with distance downstream away from the mines.
- Selenium concentrations in downstream waters are highest during low flow periods.
- Selenium release is highest during high flow periods (highest run-off), but concentrations in the water are lower due to dilution.

3.1.2 Waterfowl

In 2002 a study was conducted on American dippers and spotted sandpipers living in lotic areas of the Elk River Valley and exposed to elevated concentrations of selenium (SciWrite, 2003 – and see Text Box 3). The focus was on: eggs laid, eggs hatched, hatchlings fledged, and any abnormalities. This study found that the eggs of these two bird species, even from areas with elevated concentrations of selenium, contained selenium concentrations below those at which adverse effects would be expected (based on studies in other areas). In addition, there were no discernable adverse effects attributable to selenium on adult or juvenile birds.



"The American dipper (left) and the spotted sandpiper (right) are common in the Elk River Valley"

There were differences between the two bird species in terms of both home range and feeding preferences. Sandpipers from selenium-contaminated areas accumulated selenium in their bodies at concentrations significantly higher than birds from uncontaminated areas, though not to toxic levels. Dippers had similar selenium body concentrations in both contaminated and uncontaminated areas.

American dipper and spotted sandpiper egg selenium concentrations are below reported toxicity thresholds

The study concluded that there is no risk to either of these waterfowl unless selenium concentrations in the eggs increase. Such increases would not occur unless selenium water concentrations increased; the level of increase that would result in risk to these waterfowl, if any, is presently unknown.

The results of this study indicate "that selenium, although present, is not being taken up through the food

TEXT BOX 3: WATERFOWL EFFECTS STUDY

SciWrite (2003) assessed reproduction of two species of waterfowl, American dipper and spotted sandpipers, relative to selenium concentrations in their environment and in their eggs. Figure 4, from that report, shows that, for American dipper, there was no difference between selenium-contaminated areas in the Elk River Valley and uncontaminated reference areas.

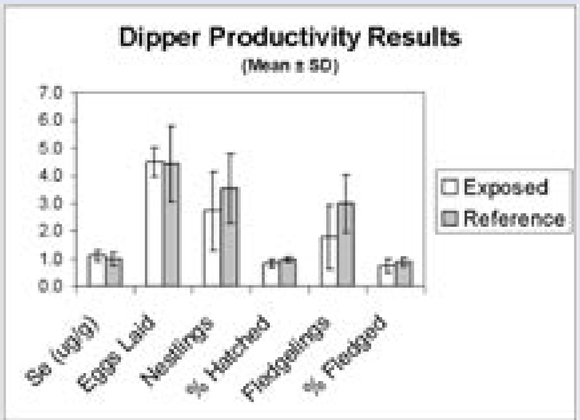


FIGURE 4. Comparison of American dipper productivity and egg selenium concentrations (wet weight) in areas with elevated selenium concentrations compared to areas with background selenium concentrations. Values for % hatched and % fledged are shown as decimal fractions. From SciWrite (2003).

The only difference for spotted sandpipers, as is apparent from Figure 5, also from SciWrite (2003), is that egg selenium concentrations were appreciably higher in parts of the Elk River Valley contaminated with selenium than in reference areas. But, again, there was no difference in reproduction, thus the elevated selenium concentrations were not causing adverse effects to these waterfowl.

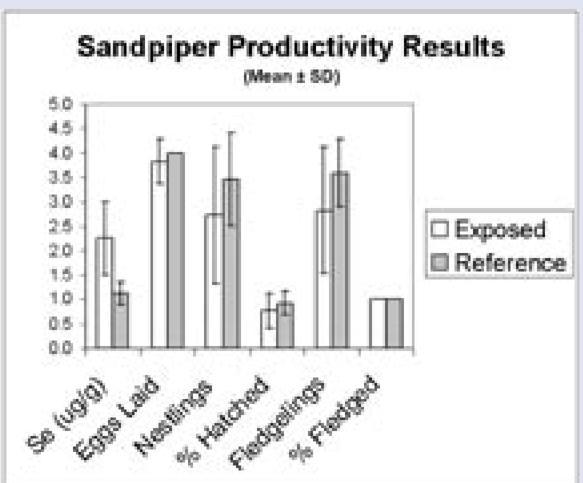


FIGURE 5. Comparison of spotted sandpiper productivity and egg selenium concentrations (wet weight) in areas with elevated selenium concentrations compared to areas with background selenium concentrations. Values for % hatched and % fledged are shown as decimal fractions. From SciWrite (2003).

The differences in selenium accumulation between the two birds may relate to their diets. Sandpipers feed mainly on adult insects at the water's edge, while dippers feed mostly underwater on a variety of prey.

chain as much as expected." The lack of uptake was attributed to the relatively low level of conversion of inorganic selenium into toxic organic selenium in the lotic areas where this study was conducted. Future work will focus on lentic areas that, though less common in the Elk River Valley, are likely to have higher concentrations of toxic organic selenium.

3.1.3 Assessment of Lotic Areas

Lotic (flowing-water) systems are by far the most common in the Elk River Valley. EVS Consultants (2002, 2003b) assessed selenium concentrations in water and fish (cutthroat trout and mountain whitefish), invertebrate and plant tissues collected from various locations in the Elk River Valley in 2001 (three times for water – April, June, October, once in April for cutthroat trout and once in October for all other biota) and 2002 (three times for water - May, July, October and once in April for cutthroat trout).

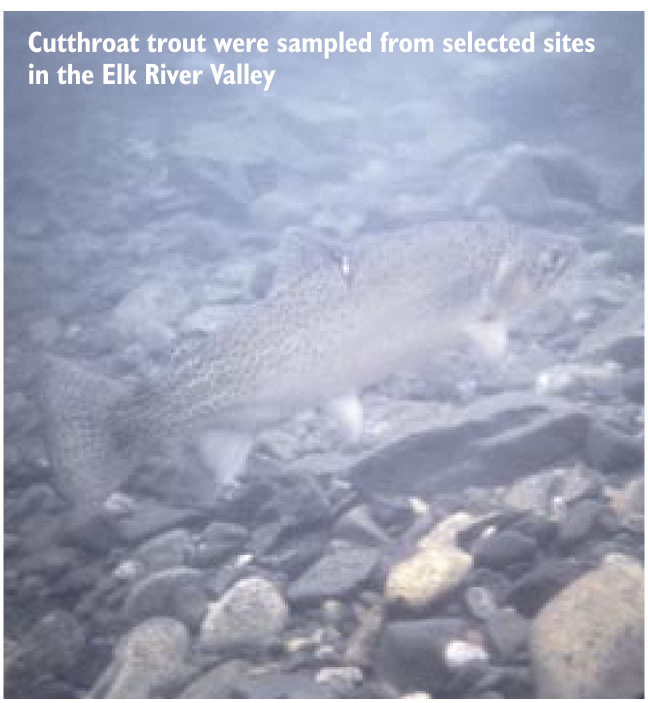
Based on information available to date:

- The most variable and highest selenium concentrations in waters were found below mine inputs.
- Downstream water selenium concentrations may have reached a plateau.
- Selenium fish tissue concentrations measured in 1996 (McDonald and Strosher, 1998), 1998 (Kennedy and co-workers, 2000), 2001 and 2002 were not appreciably different, indicating no clear trend of increasing concentrations.
- There is "no indication of adverse effects occurring at the population level".

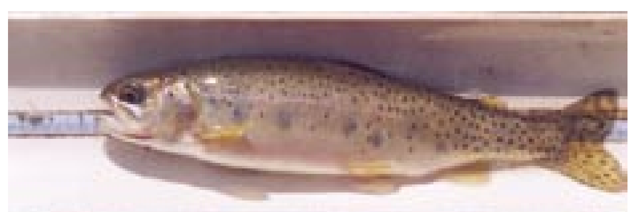
Whether relatively similar selenium concentrations in waters and fish tissues over time indicate that the aquatic system, at least in the lotic areas, has reached equilibrium, is uncertain. Additional monitoring will be required to verify or refute this possibility.

3.1.4 Assessment of Lentic Areas

Although lentic (standing water) systems are less common than lotic (flowing water systems) in the Elk River Valley, they may represent the worst case in terms of selenium toxicity because conversion of inorganic selenium to organic selenium most commonly occurs in lentic systems. Accordingly a reconnaissance survey of selenium concentrations and bioaccumulation in lentic areas was conducted, comparing lentic sites exposed



Cutthroat trout were sampled from selected sites in the Elk River Valley




Examples of lentic habitats sampled in the Elk River Valley

to high concentrations of waterborne selenium to suitable reference areas (Minnow Environmental, 2003).

An initial reconnaissance was conducted of lentic environments in the Elk River Valley, followed by surveys in six exposed and four reference lentic environments. Specifically, selenium concentrations were measured in water, sediment, fish and amphibians. The structure of communities of bottom-dwelling organisms (benthos) and of small animals living in the water column (zooplankton) was evaluated. Waterfowl were assessed qualitatively.

Goddard Marsh was the most productive lentic site sampled, despite also having the highest selenium concentrations

The lentic area most contaminated with selenium was Goddard Marsh, located downstream of the Elkview coal mine. An investigation of this marsh by BC Environment in 2001 also found elevated concentrations of selenium in water and in the tissues of aquatic plants, invertebrates (amphipods [shrimp-like creatures], diving beetles, dragon fly and other nymphs, snails) and fish (suckers). However, this was also the most productive of the ten lentic areas examined, including the four reference areas. It had the highest density of fish, high densities of zooplankton and benthos, abundant waterfowl and other species.

All ten lentic habitats had established, multi-trophic level aquatic food webs. However, the same species were not found in all lentic areas, which is not surprising given habitat differences between these areas. There was no correlation between elevated selenium concentrations and the consistent absence of particular species. Fish (cutthroat and brook trout, longnose sucker and longnose dace) were found at all locations where habitat was suitable, waterfowl and other birds with a life-cycle associated with aquatic habitats via their diet (e.g., red winged blackbird) were found in all areas, and amphibians were found in two of the six lentic areas contaminated with selenium.

The lentic (static water) area most contaminated with selenium was also the most productive lentic area examined in the Elk River Valley.

Red winged blackbirds are found in all lentic study areas

3.2 INVESTIGATIVE STUDIES

3.2.1 Laboratory Effects Study

The initial monitoring work by McDonald and Strosher (1998) pointed out the need for direct evidence of the existence or lack of selenium toxicity in the Elk River Valley. As a result, Kennedy and co-workers (2000) conducted investigative studies to determine whether cutthroat trout from the Valley were in fact able to successfully reproduce. This study involved collecting mature male and female fish from an area in the Valley that was contaminated with selenium from the mines and from an area that was not, spawning the fish, determining selenium concentrations in the fish and eggs, and determining whether or not the eggs and offspring were viable. 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 was no toxicity. Specifically, there was no difference between the following parameters for fish exposed to and accumulating high concentrations of selenium in their tissues, and those that did not: fertilization success; percent and time to egg hatch; incidence of mortalities, deformities or abnormalities (for eggs, larvae and fry). In other words, deformities characteristic of "excessive selenium in eggs…did not occur."

Although cutthroat trout egg selenium concentrations exceeded reported toxicity thresholds, there were no adverse effects and the fry hatched and developed normally.

Bull trout are part of sport fishing in the Elk River Valley, however the primary sport fish are cutthroat trout

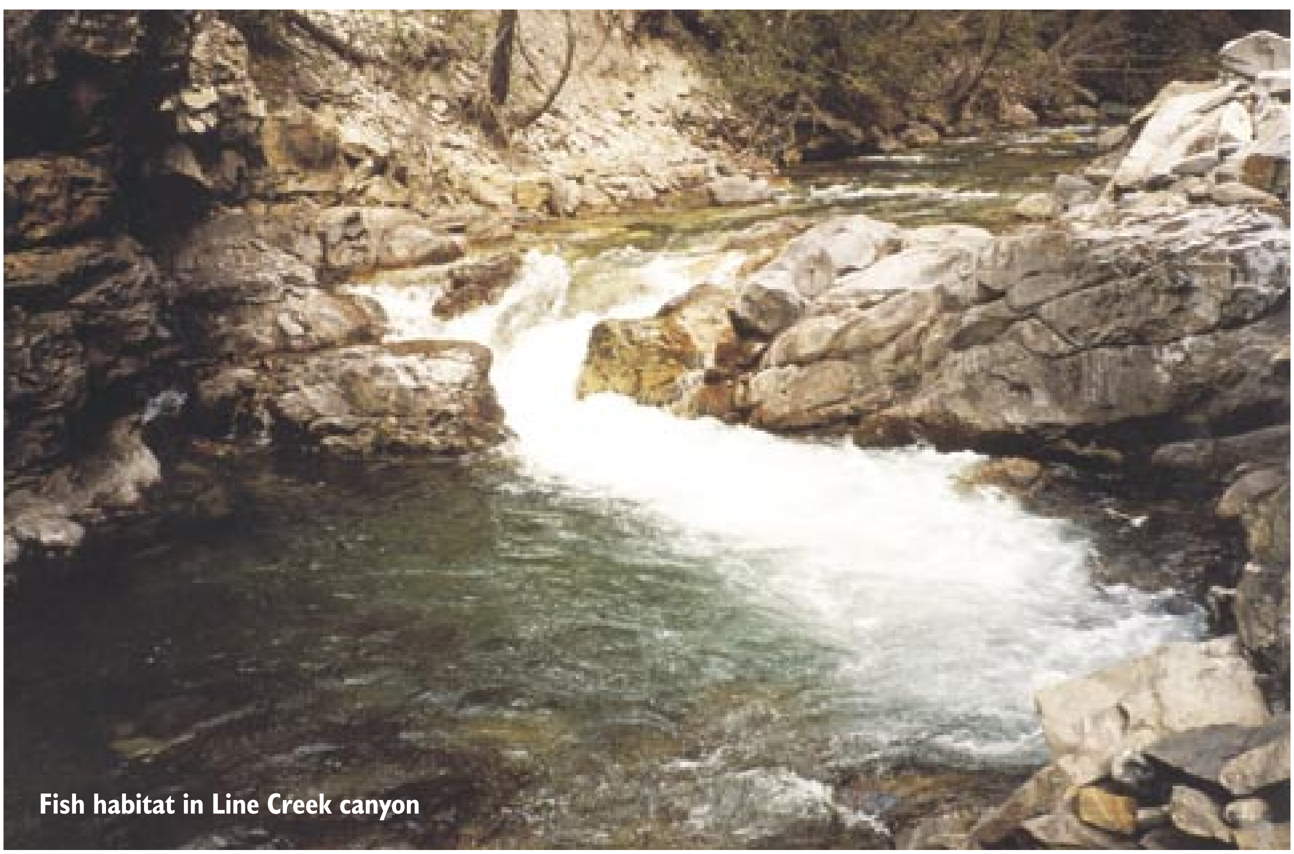
The authors suggested that this lack of effects might be due to an evolved tolerance, since the Elk River Valley is naturally high in selenium. Because the results of this study do not conform to similar studies done in other (more southerly, warmer) areas with other species of fish, the study has generated discussion in the scientific literature (see commentary by Hamilton and Palace [2001] and reply by McDonald and Kennedy [2002]). However, it is clear from this study that there should be no major adverse effects from selenium on cutthroat trout populations living in lotic areas of the Elk River Valley (see Text Box 4). This is an important finding since cutthroat trout are the dominant sport fish in this river system (the other sport fish are bull trout and mountain whitefish).

Rainbow trout appear to be more sensitive to selenium than brook or cutthroat trout.

In Alberta, where rainbow and brook trout are important sport fish, government and university researchers (Holm and co-workers, 2002) have studied their development and survival in waters containing elevated selenium concentrations both in the laboratory and in the field. Adult trout of both species appeared to be unaffected by relatively high selenium concentrations in their tissues; variations in tissue concentrations suggested that "exposure to Se laden waters or prey species may be intermittent". However, strong correlations have been found between deformities in rainbow trout fry (spinal abnormalities and edema – excess fluid in tissues) and selenium concentrations in eggs. In contrast, brook trout fry not only show lower rates of deformities than rainbow trout fry, but these deformities show no correlations with selenium concentrations in eggs. Additional studies are being conducted in Alberta, including determining selenium concentrations in bull trout.

3.2.2 Status of Fisheries in the Elk River Valley

Prior to 1995 the major impact on recreational fisheries in the Elk River Valley, which is dominated by



Fish habitat in Line Creek canyon

TEXT BOX 4: TROUT EFFECTS STUDY DATA

In Table 1, below, selenium concentrations in cutthroat trout eggs (data from Kennedy and co-workers 2000) are compared to the threshold for adverse effects suggested by Lemly (2002) for warm-water fish (i.e., not salmonids). As is apparent, there are many exceedances.

TABLE I. Selenium concentrations (μg/g Se dry weight) in Elk River Valley cutthroat trout eggs compared to a suggested US threshold toxicity value. Where the suggested threshold was exceeded, the data (from Kennedy and co-workers 2000), are italicized and bolded.

REFERENCE AREA		ELK RIVER		SUGGESTED THRESHOLD
MEAN	RANGE	MEAN	RANGE	
4.6	2.0 - 8.8	***21.0***	8.7 - ***81.3***	10

Figures 6 and 7, below, from Kennedy and co-workers (2000) show the relationship between egg selenium concentration and percent deformities and mortalities prior to yolk absorption. As noted by McDonald and Strosher (2000), exposure of the embryo to selenium in the egg yolk is the cause of any related deformities, and these effects end when external feeding begins. The percent deformities in fry, even those with the highest egg selenium concentrations, was very low, less than half a percent, and showed no correlation with egg selenium content. Similarly, percent mortalities, though high in three cases, showed no correlation with egg selenium content. The three cases of highest egg selenium concentrations had similar levels of mortalities (less than 10%) to many of the reference fish. Thus, no adverse effects were detected even though a suggested threshold value was exceeded by most of the Elk River Valley cutthroat trout (Table 1).

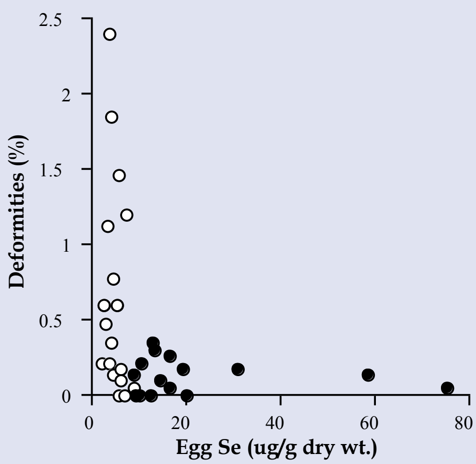


FIGURE 6. Egg selenium concentrations compared to percent deformities prior to yolk absorption for offspring of fish from the Elk River Valley (dark circles) and from a reference area (open circles). From Kennedy and co-workers (2000).

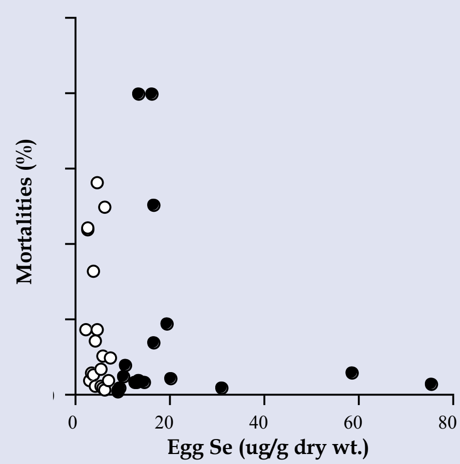


FIGURE 7. Egg selenium concentrations compared to percent mortalities prior to yolk absorption for offspring of fish from the Elk River Valley (dark circles) and from a reference area (open circles). From Kennedy and co-workers (2000).

westslope cutthroat trout, was the catch-and-consume fisheries. Over-harvesting caused dramatic declines. From 1931 to 1985 the daily limit for trout decreased progressively from 15 to 2. In 1985, due to the greatly reduced numbers of trout, angling was prohibited in all of Line Creek. In 1995, in response to the perceived effects of a major flood on fish populations, most of the streams in the basin, including the main stem, were placed under catch-and-release regulations (no harvest). Presently, catch-and-consume fisheries (e.g., one trout or one char) are only allowed in a few areas of the Elk Basin. As a result of the catch-and-release regulations, fish populations have increased, and the Elk River Valley has been featured in fishing magazines and television fishing shows. This publicity has resulted in large numbers of non-residents coming to the Valley for the excellent fishing.

The major adverse effect on fish populations in the Elk River Valley has been over-fishing.

A good example of increases in fish populations due to the regulatory change from catch-and-consume to catch-and-release, is provided by the fisheries populations in Line Creek, which were decimated by 1985, at which time all angling was prohibited. Allan (2003) analyzed cutthroat trout and juvenile bull trout populations in Line Creek over time, including data from studies conducted in 1987 and then from 1993 to 2001. Although Line Creek is contaminated with selenium above BC Environment guidelines for water quality, there was no evidence of adverse effects to fisheries populations due to selenium contamination. In fact, despite natural annual variability, both trout species "exhibited a tendency to increasing numbers since 1987", and there was evidence for increased reproduction (see Text Box 5), which would not be occurring if adverse selenium-related effects were occurring. Previous fisheries studies (e.g., West Slope Fisheries, 2001) have similarly found no evidence for adverse effects related to selenium.

3.2.3 Determination of Food Webs

Adverse effects of selenium on the reproduction of waterfowl and fish result from uptake of this element via the food web. In order to understand how selenium cycles through the environment and, most importantly, to predict when problems may occur in future if concentrations increase, knowledge of food webs is important. Traditional means of determining what is eating what depend on analyses of stomach contents. However, this approach is not always either effective (for smaller organisms), nor accurate (due to digestive processes and variations in diet over time and location). A better way to determine food webs is by the use of stable isotope analysis (SIA). SIA uses the fact that distinctive stable isotope signatures for carbon, nitrogen and sulfur exist depending on where in the food chain an organism is located (see Text Box 6).

Food web models are being developed for waterfowl and fish

TEXT BOX 5: LINE CREEK FISHERIES

Line Creek receives discharges from the Line Creek Mine (Figure 1) and is contaminated with concentrations of selenium above the provincial water quality guideline value. The creek supports a resident population of westslope 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. As is evident from Table 2, below, resident trout populations, although showing expected annual variability, have increased substantially since 1987. The large densities of fish in 2001 are attributable to "two or more years in succession of near ideal conditions for spawning, incubation and early rearing in Line Creek", which have resulted in near-maximal trout densities for this creek (Allan, 2003).

TABLE 2. Numbers of trout per 100 m^2 of Line Creek. Data from Allan (2003).

YEAR	RESIDENT JUVENILE BULL TROUT		RESIDENT CUTTHROAT TROUT	
	LOWER SECTION	UPPER SECTION	LOWER SECTION	UPPER SECTION
1987	Not Sampled	1.4	Not Sampled	1.4
1993	Not Sampled	3.4	Not Sampled	1.2
1994	0.99	5.2	0.34	1.3
1995	1.14	1.7	0.12	2.1
1996	1.18	1.02	1.36	2.5
1997	2.46	5.97	2.8	0.42
1998	10.02	5.07	3.47	2.99
1999	1.79	3.18	2.91	4.01
2000	17.44	8.42	3.25	6.87
2001	24.96	15.36	5.98	10.76

Large numbers of recently emerged trout fry were noted in both 2000 and 2001, indicating not only successful reproduction but also successful development despite elevated concentrations of selenium. The number of redds (nests for eggs) has also increased and is now probably close to the maximum carrying capacity of the creek (see Table 3, below).

TABLE 3. Bull trout redd counts in Line Creek. Data from Allan (2003).

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		
1991	56	1997	57		
1992	45	1998	66		

TEXT BOX 6: STABLE ISOTOPE ANALYSIS

Stable Isotope Analysis (SIA) is based on the fact that stable isotope ratios of carbon ($^{13}C/^{12}C$), nitrogen ($^{15}N/^{14}N$) and sulfur ($^{34}S/^{32}S$) provide critical information concerning feeding relationships in aquatic environments. They provide a time-integrated view of diet and trophic position that is not possible based on traditional analyses of stomach contents. The carbon signature at multiple trophic levels differentiates between the relative reliance of organisms on pelagic (open water) and benthic (bottom-associated) food webs. The nitrogen signature shows consistent enrichment as energy is transferred from prey to predator (in other words, up the food web). The consistency of this nitrogen enrichment indicates relative trophic position in a food web, and can be correlated with contaminant concentrations to estimate uptake rates. The sulfur signature provides additional information on energy sources that can help resolve ambiguities in the carbon signatures.

The term "trophic" refers to the feeding habits or food relationships of different organisms in a food chain

SIA analysis is currently being used by Minnow Environmental to determine both lotic and lentic food webs in the Elk River Valley, focused ultimately on fish (cutthroat trout or longnose sucker) and waterfowl. The end products of this research will be food web models for different lentic and lotic areas combined with selenium concentration data. This research is expected to provide a better understanding of how selenium accumulates within food chains in the Elk River Valley, in both lentic and lotic areas.

3.2.4 Human Health Risk Assessment

A human health risk assessment was conducted (EVS Consultants, 2000 – and see Text Box 7). It conservatively evaluated the possibility that humans living in the Elk River Valley may be exposed to elevated concentrations of selenium from eating fish that have bioaccumulated selenium. It also considered positive benefits from both selenium and fish consumption to human health. Drinking water containing elevated concentrations of selenium or skin contact with such waters do not pose a significant risk of harm to humans based on studies by regulatory agencies in Canada and elsewhere.

Data from surveys and investigative studies conducted by BC Environment (McDonald and Strosher, 1998; Kennedy and co-workers, 2000) were used in plausible but conservative fish ingestion scenarios for both aboriginal fishers and non-aboriginal recreational fishers. Both groups would have greater than average exposure to local freshwater fish. Children were not directly evaluated both because they have a lower daily fish intake than adults, and because children need more selenium than adults and thus are less sensitive than adults.

There are benefits to humans from eating Elk River Valley fish.

This study concluded that there was "negligible risk of selenosis in human populations consuming Elk River Basin fish, regardless of the exact location of fish capture." This conclusion did not take into account the benefits of selenium and fish consumption to human health: it is an essential element for the maintenance of good health (adequate ingestion prevents deficiency symptoms); it may have anti-carcinogenic properties due to its role as an antioxidant; it may have benefits for cardiovascular health. Fish consumption has its own benefits, including the positive effect of fish oils in preventing cardiovascular disease. When these benefits were considered, it was concluded "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."

3.2.5 Investigations into Geochemical Mechanisms

Investigations have been conducted into geochemical mechanisms responsible for release of selenium into surface waters from coal mining (Ryan and co-workers, 2001; Lussier, 2001 – see Text Box 8). These investigations included effects of waste rock dump reclamation practices. It was hoped that they would help explain the wide variation in selenium concentrations in various mine-affected tributaries. In fact, the work by Ryan and co-workers (2001) provided detailed, useful information regarding selenium within areas being mined and as part of the mining process.

These studies determined that high concentrations of selenium were associated with coal-bearing strata, not the coal itself. They also found that:

- Selenium is released naturally, however generation of waste rock enhances the natural selenium release processes;
- Selenium release is associated with the waste rock.

Text Box 7: Human Health Risk Assessment

Human health risk assessments are based on two separate sub-assessments: exposure and effects. Assessment of exposure involved determining, in the case of ingestion of selenium-contaminated fish, reasonable but conservative doses that might apply to high-exposure groups (aboriginal and non-aboriginal fishers). These doses had to take into account background ingestion, that is, all other sources of selenium. Selenium is naturally found in foods such as fish, meat, poultry, cereals and grains. The exposure sub-assessment also had to take into consideration fish consumption rates. Where local information was not available, information from other sources was used. For instance, fish consumption data for aboriginal and recreational fishers for similar areas were available from various government publications and reports.

Assessment of effects considered four main components: selenium essentiality (minimum dose required to prevent symptoms of deficiency); positive aspects of selenium supplementation beyond essential doses; negative aspects of selenium supplementation beyond essential doses; and, positive aspects of fish ingestion irrespective of selenium concentrations. Based on the published literature, a conservative background-normalized tolerable daily intake was determined, about 2.5 times higher than the amount recommended for the maintenance of good health.

Integration of the exposure and effects assessment involved determining hazard quotients (HQs) for both the aboriginal and recreational fishers. The HQs were determined by dividing the estimated daily intake of selenium from fish ingestion by the background-normalized selenium tolerable daily intake. HQs of 1.0 or greater indicate a potential risk (i.e., greater than the tolerable daily intake), values below 1.0 indicate no risk. The following HQs were determined prior to considering the beneficial benefits of selenium ingestion: aboriginal fisher, 0.74; recreational fisher, 0.26. Thus no risk exists despite very conservative assumptions.

Conservative assumptions included: an aboriginal subsistence fishery although one is not known to exist; a catch-and-consume fishery even though the fishery is primarily catch-and-release for conservation reasons; 100% of fish come from the most contaminated portion of the Elk River; no loss of selenium due to cooking; upper bound (i.e., probably unrealistically high) exposure values.

TEXT BOX 8: SELENIUM RELEASE FROM COAL MINING

Lussier (2001) determined the magnitude of selenium release from different types of material common to coal mining (see Figure 8 below).

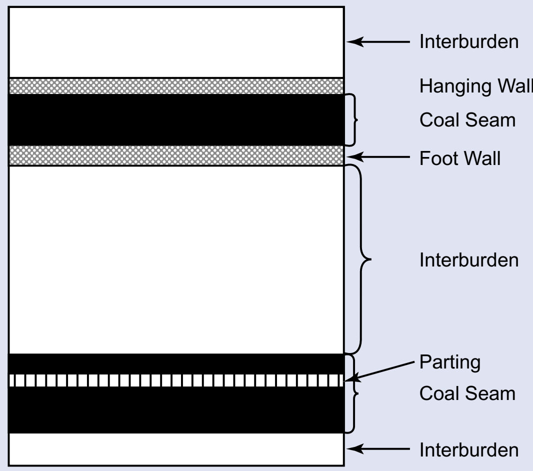


FIGURE 8. Cross section of coal mine pit wall illustrating different types of material sampled by Lussier (2001).

These materials were separately subjected to 20-week tests to determine the magnitude of selenium release and to attempt to identify the corresponding geochemical mechanisms. The materials were placed in humidity cells (see Figure 9 below) into which air and water were introduced. Water passing over the material was collected as leachate and analyzed for selenium.

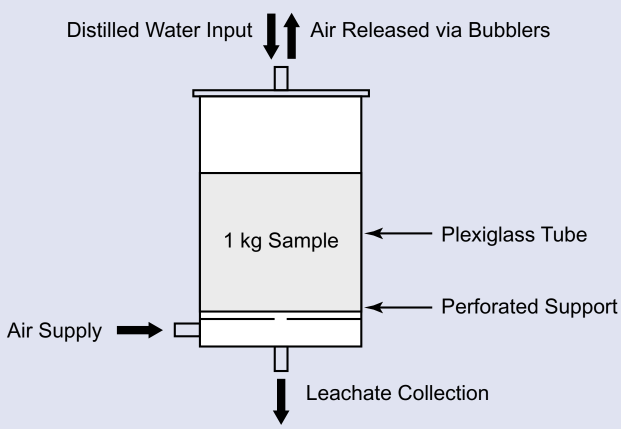


FIGURE 9. Schematic diagram of a humidity cell. From Lussier (2001).

All materials tested released selenium. Over 20 weeks, from 2.0 to 8.5% of the total selenium in each material was leached (of 5.0 to 21.3% that was potentially water-soluble). Results suggest that the rate of release of selenium from the Elk River Valley coal mines will "remain relatively constant, fluctuating as a function of the rate of waste rock production and pit expansion."

4. ADDITIONAL INFORMATION REQUIREMENTS

Current BC Environment (BCMWLAP, 2001) selenium water quality guidelines for the protection of aquatic life in freshwater are exceeded in some parts of the Elk River watershed. Similarly, guidelines for selenium concentrations in fish and their eggs are exceeded in some cases (but do not appear to result in adverse effects, see Section 3, above). The guidelines document states "in certain natural environments fish can tolerate selenium concentrations that may exceed those found to be toxic in other environments or in the laboratory. Obviously, in such environments, there will be a need to develop site-specific water quality conditions to account for local environmental conditions." The development of site-specific water quality objectives for selenium in the Elk River Valley has been advocated by BC Environment (McDonald and Strosher, 1998).

Selenium concentrations are elevated in the Elk River watershed, but do not appear to cause adverse effects.

To determine the highest concentrations of selenium in water and in the tissues of organisms that are "safe" for those organisms would require determining concentrations at which adverse effects begin to occur. If these cannot be determined on site because there are no adverse effects (as may well be the case in the Elk River Valley), then laboratory studies could be conducted to try to determine these concentrations. Although such studies do not mimic reality and are often conservative (i.e., "worst case"), they can provide useful "red flag" information.

Moreover, there is a need to understand the conditions under which adverse effects may occur, in both lotic and lentic environments and ultimately in the downstream water body receiving inputs of selenium from the Elk River Valley: Lake Koocanusa.

Key studies that need to be conducted include the following:

- Near-field and far-field water quality trends based on a small number of stations sampled at least quarterly and preferably monthly (are concentrations of selenium in water increasing, decreasing or staying the same?).
- Effects studies, which are not restricted to trout, and which focus on lentic environments and sensitive species - other fish and possibly amphibians (are adverse effects due to selenium occurring at the most heavily contaminated lentic sites?).
- Fate and effects studies that provide information as to whether protective mechanisms such as other chemicals released by the mines, and/or natural adaptation are preventing adverse effects from occurring (if there are no adverse effects due to selenium, why not and could this situation change?).

4.1 ADDITIONAL INVESTIGATIVE STUDIES

Laboratory studies similar to those conducted by Kennedy and co-workers (2000) should be done using species other than cutthroat trout, to ensure that the results with the trout were not species-specific and that in fact other fauna in the Elk River Valley are similarly tolerant to elevated selenium concentrations in waters and in their tissues. (The studies by Holm and co-workers [2002] in Alberta suggest a similar tolerance for brook trout but not for rainbow trout.)

In addition, it may be useful to repeat the laboratory study done by Kennedy and co-workers (2000) with cutthroat trout, 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.

As part of this repetition of the work by Kennedy and co-workers (2000), the hypothesis that tolerance is due to adaptation should be tested. Specifically, naïve cutthroat trout (i.e., fish from an area similar to the Elk River Valley but absent selenium) should be exposed in cages in areas of the Valley with high selenium water concentrations. These fish should be mature and should be exposed for a sufficient time prior to the spawning season to allow accumulation of selenium in their tissues and in eggs.

Further, monitoring should be conducted to ensure that water and fish tissue selenium concentrations remain stable. Non-destructive tissue sampling techniques should be used to obtain muscle samples from fish without killing them. Sampling should be conducted at one site on the lower Elk River that will respond to changes in selenium concentrations and that will be relatively easy to sample. Water should be sampled annually and tissues should be sampled every two or three years, unless there is an increase in water selenium concentrations, in which case tissue sampling should occur annually.

Finally, monitoring of fish populations in Line Creek should continue to ensure that there are no unexpected declines that cannot be attributed to natural variability. Alternatively or perhaps additionally, studies should be conducted in the Fording River. Trout populations in the Fording River are isolated above Josephine Falls (near Elkford), which limits immigration, but likely permits some emigration.

4.2 LAKE KOOCANUSA

Lake Koocanusa is the reservoir formed by the Libby Dam on the Kootenay River in Montana (Figure 1). It receives all the selenium transported downstream from the Elk River (and from other sources). The Lake should not presently comprise a high risk compared to lentic areas within the Elk River Valley. However, if there are indications that adverse effects are occurring in upstream lentic areas, which is not presently the case, then a survey should be conducted of selenium concentrations in reservoir water and of concentrations bioaccumulated by zooplankton (small organisms living in the water column), fish (kokanee) that feed on the zooplankton, and fish that feed on the kokanee (bull trout). A similar survey should be done on a reference lake or reservoir that does not receive selenium inputs from coal mining or other human sources (BC Environment has suggested that Kinbasket Lake, west of Golden, BC, would be an appropriate reference lake).

4.3 THE TERRESTRIAL ENVIRONMENT

Although there is currently no reason to believe that selenium from the mines is affecting the terrestrial environment, this possibility has not been directly investigated. If there were severe adverse effects occurring to grazers due to selenium accumulation in terrestrial vegetation (the primary exposure pathway), decreases to the elk populations and/or elk with evidence of selenosis (e.g., cracked hooves) would have been expected. Neither has been observed nor reported; in fact, monitoring of elk populations indicates that populations are increasing and local ranchers supplement their cattle feed with selenium. However, for purposes of precaution, periodic analyses of vegetation near the mines would be useful, as would examination of elk opportunistically for any evidence of hoof cracking.


Elk grazing on reclaimed land

5. CONCLUSIONS

The previous sections provide information regarding both what we know and what we need to know. In this section this information is summarized relative to the two questions driving investigations into selenium contamination in the Elk River Valley:

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?

Presently there is no such evidence despite studies directly investigating the health of fish and waterfowl, the two groups of animals most likely to be adversely affected by selenium contamination. Serious selenium-related effects cannot be occurring, or they would have been observed. In fact, observations to date indicate relatively healthy populations. For instance, fish populations in Line Creek are now at levels that appear to be maximal – despite elevated selenium concentrations.

There may be several reasons for the lack of adverse effects. Aquatic biota may have adapted to the selenium concentrations and/or there may be a relatively steady state between inorganic selenium accumulation, sequestering and excretion such that the toxic organic form of selenium makes up a very small portion of the total selenium, at least in lotic areas where there is very little opportunity for selenium to be incorporated into organic forms via microbial action. However, studies are continuing to ensure that there are no adverse effects.

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

Available evidence suggests that selenium concentrations in organisms have not increased beyond levels observed in the mid- to late 1990s. Selenium concentrations in water may also have reached a plateau over the last few years. However, monitoring of water selenium concentrations (yearly) and of biota tissue concentrations (every 2 to 3 years) is required to establish trend lines and to ensure, as part of additional, investigative studies, that there are no unexpected findings.

APPENDIX A

LIST OF ACRONYMS AND GLOSSARY

LIST OF ACRONYMS

EVSTF	Elk Valley Selenium Task Force
HQ	Hazard Quotient
SD	Standard Deviation
SIA	Stable Isotope Analysis

GLOSSARY

Amino acids
The building blocks of proteins.

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

Benthic invertebrates
A collective term for all animals without a backbone or spinal column (e.g., insects, worms, clams, snails, etc.) associated with the bottom of a water body.

Bioaccumulation
A general term, meaning that an organism stores within its body a higher concentration of a substance than is found in its environment. Includes uptake of substances from water and from food. This phenomenon is not necessarily harmful. For example, freshwater fish must bioaccumulate common salt if they are to live because the water in which they swim dissolves the salts out of their bodies. All organisms, including humans, bioaccumulate essential substances such as selenium, copper and zinc. Many toxicants, such as arsenic, can be excreted by aquatic organisms.

Contamination
The presence of a substance or substances at higher concentrations than would occur naturally. Contamination does not necessarily result in the occurrence of adverse effects resulting in pollution.

Edema
Leakage of fluid into the tissues.

Effect
Significant and meaningful difference measured in an environmental variable between an exposed and reference area, or operational vs. baseline conditions.

Fledge
To acquire the feathers required for flight. A fledgling is a young bird that has just fledged.

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.

Hazard Quotient (HQ)
The ratio of the potential exposure to the substance and the concentration at which no adverse effects are expected. For example, HQs can be calculated by dividing environmental concentrations by benchmark values such as water quality guidelines. If the HQ is <1, no adverse effects are expected; if the HQ is >1, there is a potential risk of adverse effects.

Impact
An adverse effect on a valued ecosystem component.

Leachate
Water or any other liquid that may contain dissolved (leached) soluble materials, such as organic salts and mineral salts, derived from a solid material. For example, rainwater that percolates through waste rock and picks up dissolved contaminants 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.

Metalloid
An element whose chemical behavior can include both metallic and non-metallic aspects.

Pelagic
Organisms inhabiting the water column and subject to the current therein (i.e., not free swimming). Term applied to organisms that inhabit the open water of a sea or lake.

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

Pollution
The addition of something to the environment, resulting in a measurable effect, which is deleterious to some use of the water by living organisms, including humans.

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 then after spawning the eggs are covered with gravel and left to incubate for several months until the hatched juvenile fish are ready to emerge.

Selenosis
Selenium poisoning. Symptoms in humans may include gastrointestinal upsets, hair loss, white blotchy nails, and mild nerve damage. Symptoms in wildlife such as elk may include cracked hooves.

Stable Isotope Analysis (SIA)
A process that uses stable isotope ratios of carbon ($^{13}C/^{12}C$), nitrogen ($^{15}N/^{14}N$), and sulphur ($^{34}S/^{32}S$) to provide information about feeding relationships in aquatic environments.

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).

Tolerable daily intake
An estimate of the quantity of a chemical contaminant in food or water that can be ingested daily over a lifetime without posing a significant risk to health.

Toxicity curve
The curve obtained by plotting the median survival times of a population of test organisms against concentration.

Valence (or valence electron configuration)
The capacity of an element to form chemical bonds with other elements. For example, in MgO, the ions present are Mg^{2+} and O^{2-} and the valence of each element is 2.

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

APPENDIX B

ANNOTATED BIBLIOGRAPHY AND REFERENCES CITED

[Appendix B1 provides brief summaries of relevant reports and publications specific to the selenium issue in the Elk River Valley, while Appendix B2 provides reference citations for other documents used in the preparation of this status report.]

APPENDIX BI - ANNOTATED BIBLIOGRAPHY

The following is an alphabetical listing and short description of reports and publications (from September 1998 through July 2003) relevant to the selenium issue in the Elk River Valley.

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

Description:
The Line Creek Mine conducts regular monitoring of fish populations in Line Creek as part of their environmental monitoring program. Fish population monitoring conducted in 2001 is detailed, and the results are compared to historic data. "The cutthroat trout and juvenile bull trout populations in Line Creek have exhibited a tendency to increasing numbers since 1987." Similarly, spawning activity by bull trout has increased since 1986. Both trout populations and spawning activity may be at the carrying capacities of the creek.

EVS Environment Consultants. 2000.
Human health risk assessment for ingestion of selenium-contaminated fish. Report prepared for the Elk River Basin Coal Producers.

Description:
A conservative evaluation was conducted of the potential for adverse human health effects associated with selenium in waters and biota in the Elk River Valley, including consideration of the known and potential benefits of selenium ingestion. The evaluation concluded that there was negligible human health risk without taking into account the potential benefits of selenium to human health. When the latter benefits were considered, it was concluded "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."

EVS Environment Consultants. 2002.
Elk Valley selenium monitoring study 2001. Report prepared for the Elk Valley Mines Environmental Management Committee.

Description:
Samples of water and of fish, invertebrate and plant tissues were collected from various locations at various times in the Elk River Valley and analyzed for selenium. Concentrations of selenium in invertebrates and plants were not always related to selenium water concentrations. The relationship between selenium concentrations in water and those in cutthroat trout tissues is complex and not linear: "relatively small increases in tissue concentration occurred over comparatively large changes in water concentrations." In contrast, tissue selenium concentrations in mountain whitefish "did not appear to be related to water concentrations or clearly to location." Based on comparisons with historical data, concentrations of selenium in cutthroat trout tissues have remained stable over time. Increased concentrations of selenium over trophic levels were "relatively modest".

EVS Environment Consultants. 2003a.
Elk Valley Mines selenium trend analysis. Report prepared for the Elk Valley Mines Environmental Management Committee.

Description:
Each of the five coal mines in the Elk River Valley independently monitors selenium concentrations in water at a number of near-field locations (i.e., locations near the mines). This monitoring is not required by regulatory agencies. A summary of the available data was conducted along with a trend analysis to investigate temporal changes in selenium concentrations associated with each of the five mines. Overall, there was no evidence at most of the mines of long-term trends of increasing selenium concentrations. However, the earliest sampling began in 1995, and there are differences in levels of monitoring, number of stations, etc. conducted by each mine.

EVS Environment Consultants. 2003b.
Elk Valley selenium monitoring study 2002. Report prepared for the Elk Valley Mines Environmental Management Committee.

Description:
Samples of water and fish tissues were collected from various locations at various times in the Elk River Valley and analyzed for selenium. Results were consistent with similar monitoring conducted the previous year (cf. EVS Environment Consultants, 2002 - above). Concentrations in cutthroat trout tissues have remained stable since tissue sampling was first conducted in 1996.

Kennedy CJ, McDonald LE, Loveridge R and Strosher MM. 2000.
The effect of bioaccumulated selenium on mortalities and deformities in the eggs, larvae and fry of a wild population of cutthroat trout (*Oncorhynchus clarki lewisi*). Archives of Environmental Contamination and Toxicology: Vol 39, pp 46-52.

Description:
This peer reviewed journal publication (of a study conducted by Simon Fraser University in conjunction with the BC Ministry of the Environment), describes the results of raising fertilized eggs from exposed and reference cutthroat trout in the laboratory to determine whether or not elevated selenium concentrations in waters and tissues were causing reproductive or other adverse effects. There was no evidence of such effects. Specifically, this study found "no significant effect on fertilization; time to hatch; percent hatch; or egg, larvae, and fry deformities or mortalities."

Lussier C. 2001.
Geochemistry of selenium release from the Elk River Valley Coal Mines. M.Sc. Thesis, Department of Mining and Mineral Processing, University of British Columbia, Vancouver, BC, Canada.

Description:
This Thesis had three major components designed to determine selenium release from representative coal mining materials and potential trends in geochemical factors influencing that release. First, sample mineralogy was characterized (x-ray diffraction, scanning electron microscopy and chemical analyses). Second, the modes of occurrence of selenium were determined. Third, humidity cells were used to determine the rates of selenium release over a 20-week leaching period.

McDonald LE and Strosher MM. 1998.
Selenium mobilization from surface coal mining in the Elk River Basin, British Columbia: A survey of water, sediment and biota. BC Environment, Cranbrook, BC, Canada.

Description:
This report summarizes work that began in 1995 with the realization that selenium concentrations in the Elk River exceeded the current water quality guidelines. In 1996, with the cooperation of the coal mines, detailed sampling and analyses for selenium were conducted of waste waters, streams, sediments, attached algae, benthic (bottom-dwelling) invertebrates and fish. The study concluded that: "selenium is being released from all the coal mines" though at a variable rate; water bodies downstream of the mines exceeded the water quality guidelines. Selenium accumulation in sediments, algae, invertebrates and fish was not as elevated as water column concentrations, indicating a limited amount of selenium bioaccumulation. Despite apparently healthy populations of westslope cutthroat trout, tissue concentrations of fish living in waters with elevated selenium concentrations as well as some fish that did not, exceeded published toxic effects thresholds. Additional studies were recommended.

Minnow Environmental. 2003.
Selenium study of lentic areas in the Elk Valley. Report prepared for the Elk Valley Mines Environmental Management Committee.

Description:
A reconnaissance was conducted of lentic areas in the Elk River Valley to determine a smaller subset of such areas to examine in greater detail. This smaller subset was examined, comprising both areas with elevated selenium concentrations and reference sites, to determine habitat, species present, and selenium concentrations in water, sediment, plants, invertebrates, amphibians and fish. The most contaminated lentic area, Goddard Marsh, was more productive than any

lentic area examined, including uncontaminated areas. All lentic areas examined, whether contaminated by selenium or not, had established, multi-trophic level aquatic food webs.

Ryan B, Fournier M and Dittrick M. 2001.
Selenium concentrations in mine refuse and Mist Mountain rocks: Evaluations of variations laterally and over time. Geological Fieldwork 2001, Paper 2002-1, pp 151-167.

Description:
This study investigated changes in selenium concentrations within mine waste material over time, variations in selenium within coal seams, and controls on selenium in those coal seams. Cores from tailings ponds did not indicate substantial loss of selenium compared to the materials being mined, though some loss did occur. There were no clear patterns in selenium concentrations within coal seams.

SciWrite. 2003.
Effects of selenium on American dippers and spotted sandpipers in the Elk River Valley, British Columbia. Report prepared for the Elk Valley Mines Environmental Management Committee.

Description:
The focus of these investigations was two species of waterfowl living in lotic areas of the Elk River Valley. The two species, American dipper and spotted sandpipers, were selected following preliminary analyses and reconnaissance surveys in 2001, as were the study locations. Productivity in 2002 (number of eggs laid per nesting pair, proportion of eggs hatching and proportion of hatchlings that successfully fledged) was compared to selenium concentrations in selected eggs. These eggs were also examined for viability and evidence of any abnormalities. No adverse effects related to selenium were observed.

APPENDIX B2 - REFERENCES CITED

BCMWLAP (BC Ministry of Water, Land and Air Protection). 2001. Ambient Water Quality Guidelines for Selenium. Victoria, BC, Canada.

Chapman PM. 1999. Selenium – A potential time bomb or just another contaminant? Human and Ecological Risk Assessment: Vol 5, pp 1123-1138.

Cousins WJ. 1981. A History of the Crow's Nest Pass. Historic Trails Society of Alberta, Lethbridge, AB, Canada.

Hamilton SJ and Palace VP. 2001. Assessment of selenium effects in lotic ecosystems. Ecotoxicology and Environmental Safety: Vol 50, pp 161-166.

Holm J, Palace VP, Wautier K, Evans RE, Baron CL, Podemski C, Siwik P and Sterling G. 2002. An assessment of the development and survival of wild rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*) exposed to elevated selenium in an area of active coal mining. In: The Big Fish Bang. Proceedings of the 26th Annual Larval Fish Conference, July 22-26, 2002, Bergen, Norway.

Lemly AD. 2002. Symptoms and implications of selenium toxicity in fish: the Belews Lake case example. Aquatic Toxicology: Vol 57, pp 39-49.

McDonald LE and Strosher MM. 2000. Selenium in the Elk River Basin, British Columbia – A review of findings and discussion of implications for assessment and management. In: Planning for End Land Use in Mine Reclamation, Proceedings of the 24th Annual British Columbia Mine Reclamation Symposium, Williams Lake, BC, June 19-24, 2000, pp 160-173.

McDonald LE and Kennedy CJ. 2002. Reply to commentary on the effects of selenium bioaccumulation in a wild population of cutthroat trout. Society of Environmental Toxicology and Chemistry (SETAC) Globe: Vol 3, number 4, pp 36-37.

Oldfield JE. 2000. Selenium World Atlas. Selenium-Tellurium Development Association, Grimbergen, Belgium. palmieri@pandora.be

Spallholz JE and Hoffman DJ. 2002. Selenium toxicity: cause and effects in aquatic birds. Aquatic Toxicology: Vol 57, pp 27-37.

West Slope Fisheries. 2001 Overwintering and spawning habitats of Westslope cutthroat trout in the Elk River, B.C. Report prepared for the Columbia-Kootenay Fisheries Renewal Partnership.