SELENIUM MOBILIZATION FROM SURFACE COAL MINING IN THE ELK RIVER BASIN, BRITISH COLUMBIA: A SURVEY OF WATER, SEDIMENT AND BIOTA

Leslie E. McDonald, RP Bio
and
Mark M. Strosher, P Eng

Pollution Prevention
Ministry of Environment, Lands and Parks
Kootenay Region
Cranbrook, British Columbia

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Executive Summary

The mobilization of soluble selenium into the Elk River from surface coal mining was discovered in 1995 during an assessment for a mine effluent permit amendment. Levels of total selenium in the river above the mine were consistently less than 1 μg/L compared to 25 μg/L below. The current criterion for total selenium for the protection of freshwater aquatic life is 1 μg/L (Nagpal 1995). Various wastewaters at the coal mine contained total selenium from 19 to 54 μg/L. An average of 92% of the total selenium was in the dissolved form and not associated with particulate matter.

Also in 1995, while summarizing 10 years of water quality sampling results taken at a site near the mouth of the Elk River, 65 km downstream of the coal mines, the Ministry of Environment, Lands and Parks found a rising trend in selenium concentrations. Total selenium, analyzed at a very low detection of 0.1 μg/L, rose from 0.5 μg/L in the early 1980s to 2 μg/L by 1994.

These findings prompted further sampling in 1996, the results of which form the basis for this report. This sampling was a cooperative effort between the coal mine companies and BC Environment. The coal industry sampled and analyzed waste waters and streams around their operations on specific days through the year while BC Environment sampled sediment, attached algae, benthic invertebrates and fish for selenium accumulation over one week in September. Study objectives were to determine the spatial and temporal patterns of selenium concentrations in water and to compare accumulation in sediments and biota above and below the mines where selenium is being released into the river system. The level of bioaccumulation was also compared with levels reported in the literature as causing toxic effects in fish and aquatic birds.

The important findings of this study are summarized as follows:

* Selenium levels above the coal mines were consistently non-detectable at a 1 μg/L detection limit. In the major rivers below the mines levels ranged from 2 to 20 μg/L depending on levels in source tributaries and the distance downstream that samples were taken. With the exception of Michel Creek above Alexander Creek, total selenium consistently exceeded the provincial criteria for the protection of aquatic life of 1 μg/L in the portions of the basin downstream from the coal mines to the mouth of the Elk River.

* Selenium is being released from all the coal mines although to a greater or lesser degree depending on the mine and the particular tributary source. The highest level found, 542 μg/L, was a waste dump seepage entering a settling pond.

* Concentrations of selenium remained relatively similar through high spring runoff, despite stream flow dilution which is 10 times base flow. This indicates that considerably greater quantities of selenium were being released into streams in the spring compared to other times of the year.

* Despite 100 to 200 fold increases in waterborne selenium below the coal mines, levels in sediments, algae, aquatic insects and fish tissues were only 2 to 5 times greater than reference sites. This is an indication that only a limited amount of selenium bioaccumulation is occurring in this fast-flowing river system. None of the sediment samples exceeded the provincial criteria for the protection of freshwater aquatic life of 5 μg/g dry wt.

* Selenium levels in the tissues of westslope cutthroat trout were higher in fish from the site with the highest water, sediment and benthic insect levels than at the upstream reference site or the site much farther downstream. These levels exceeded published toxic effects thresholds, including some tissue samples from the reference site fish. This suggests that the fish in the Elk River may have a higher tolerance to selenium, or that there are chronic toxic effects occurring that have not been detected.

Research over the past 15 years on a few well known cases of selenium poisoning in fish and waterfowl has provided some insights into the unique behaviour of this element in aquatic systems. Selenium is a vertebrate micro-nutrient, required in small amounts for proper enzyme function. It is, however, highly toxic at levels only slightly higher than nutritional requirements. Selenium has been found to bioaccumulate in some wetland and small lake habitats and cause increased embryo mortalities and deformities in fish and aquatic birds, sometimes resulting in the complete elimination of some populations. These embryonic effects often occur with little or no pathology in the adult population.

The bioaccumulation pathway of selenium distinguishes it from most waterborne toxicants. Soluble inorganic selenium, released into surface waters in alkaline, oxidizing conditions, is taken up by rooted aquatic vegetation or the microflora living on organic detritus. Further bioconcentration occurs in the tissues of invertebrates in the next trophic level which are subsequently fed on by fish and waterfowl. Embryos of fish and birds are exposed to damaging levels of selenium in the yolk of the egg which is predominantly derived through the diet of the adult female, direct effects from waterborne selenium being much less important. This means that wetlands and shallow lakes with extensive marginal vegetation and large detrital accumulations are at considerably greater risk from elevated waterborne selenium than are fast-flowing rivers. Within rivers, however, slow-flowing reaches and marshy side-channels may be at greater risk.

Whether the current level of selenium bioaccumulation that is occurring in fish in the Elk River system is resulting in any toxic effects in embryos is unknown at this time. Populations of westslope cutthroat trout appear to be thriving in most of the system in response to conservative angling management. Further study is needed, particularly on the population in the upper Fording River which displays the highest levels of selenium in their tissues, because a chronic loss of juvenile recruitment could easily go unnoticed.

The following additional studies are recommended:

* Compare the frequency of embryonic mortalities and deformities in a westslope cutthroat trout reference population with those from an area of high selenium exposure, below the coal mines. Fertilized eggs from a number of females can be reared separately to statistically compare the frequency of effects to the level of selenium in the eggs.

* A more thorough investigation of selenium bioaccumulation in side-channel wetlands in the Elk Valley is required, comparing reference areas to sites exposed to high waterborne selenium.

* A survey of selenium bioaccumulation and toxic effects in aquatic birds in the Elk Valley is needed. This study will benefit from the side-channel wetland survey which will provide information on selenium bioaccumulation in vegetation and food-chain organisms.

* Lake Koocanusa is the recipient of the selenium discharged from the Elk River. A survey of bioaccumulation should be conducted in this reservoir, particularly in the zooplankton/kokanee community.

* An investigation into the geochemical mechanism responsible for the release of selenium into surface waters from coal mining is required. This study should also investigate the effect of current waste rock dump reclamation practices on the release of selenium.

Two other important recommendations from this report are:

* Water Quality Objectives: Site-specific water quality objectives for selenium in the Elk River system are needed. The fact that toxic effects are dependent on aquatic habitat factors greatly limits the usefulness of generic criteria. These objectives may well include values for water, sediment and/or biological tissues.

* Stream channel management and reclamation: To limit the potential for bioaccumulation, it is recommended that modifications to tributary channels and reclamation plans avoid the use of ponds and wetlands if the inflowing water contains elevated levels of selenium.

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1.0 Introduction

The need for a survey of selenium levels in various components of the aquatic environment throughout the Elk River system arose from the discovery in 1995 of the mobilization of significant quantities of this metalloid element into streams from a large surface coal mine. Sampling of wastewaters and streams at the mine employed a metals scan which included selenium at a 1 μg/L detection limit. The program consisted of 8 sites sampled twice, once in April, before freshet, and in May, during freshet. Total selenium was consistently <1 μg/L in the river above the mine and 26 μg/L below the mine prior to freshet and 22 μg/L during freshet. The level in various wastewaters ranged from 19 to 54 μg/L. In all 16 samples, the dissolved fraction averaged 92% of the total.

Also in 1995, the analysis of 10 years of low level metal data from the mouth of the Elk River revealed a rising trend of total selenium from 0.5 μg/L in 1984 to around 2 μg/L in 1994 (n=197) (Wipperman 1997). This trend has continued into 1998 (Figure 1). These selenium levels were by far the highest found throughout B.C. at 40 sampling sites on 30 rivers that have routinely been sampled for the past decade under the Canada/British Columbia Water Quality Monitoring Agreement.

The current water quality criterion for the protection of aquatic life is 1 μg/L (Nagpal *et al* 1995, CCREM 1987). The fact that this criterion was being exceeded by 25 fold in the river just below a mine and by 1.5 to 2.5 times at the mouth of the Elk River, 130 km downstream, meant that further investigation was necessary. Total selenium levels below this mine also exceeded the Canadian Drinking Water Guideline maximum acceptable concentration of 10 μg/L, although this stream is not used for domestic consumption.

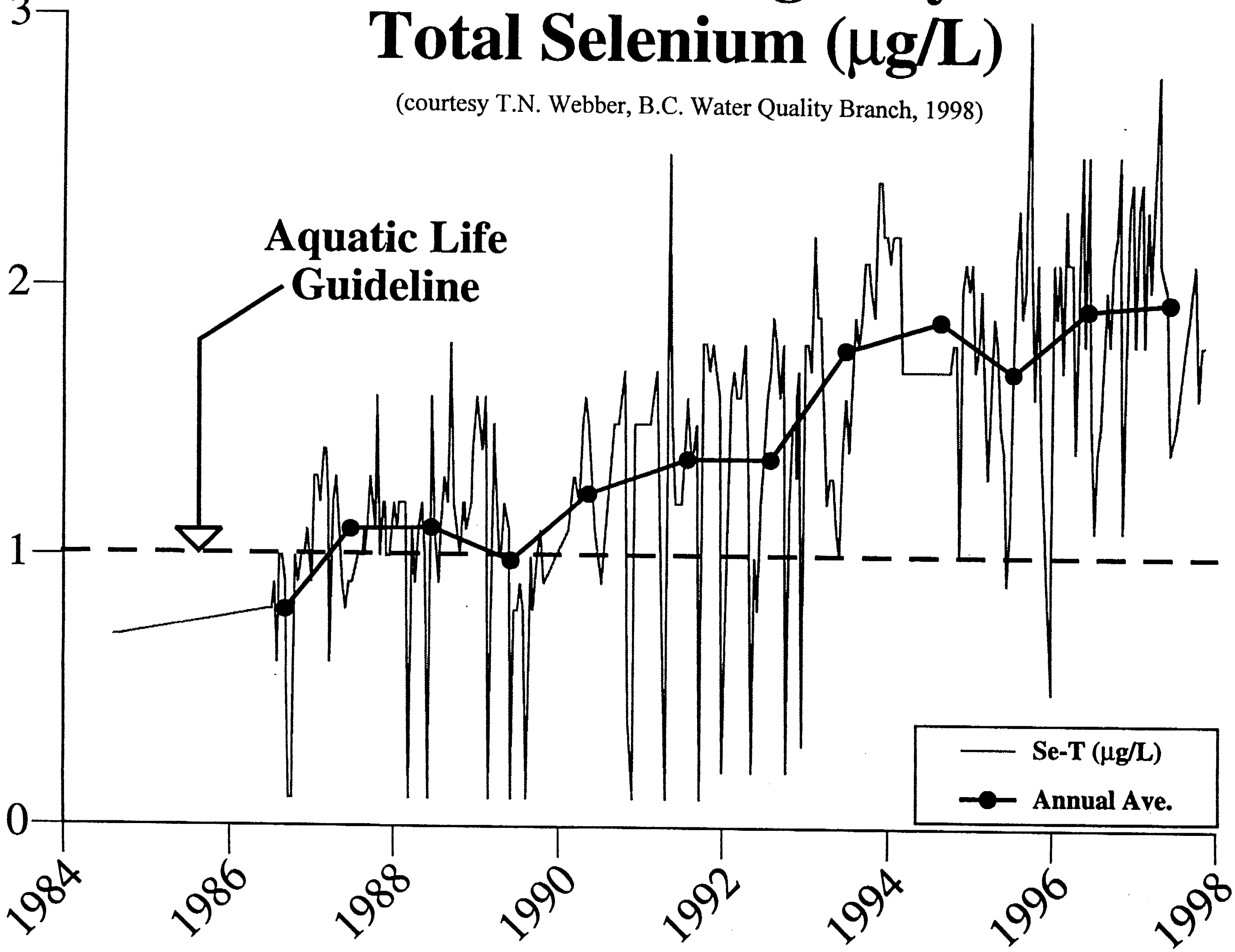
Although selenium is a micronutrient for many vertebrates, necessary for certain enzyme systems, it can be highly toxic at concentrations not much greater than required levels (Sorensen 1991). The potential toxicity of selenium to fish has been recognized for 60 years (Lemly 1993b, Sorensen 1991). Concentrations lethal to rainbow trout range from about 0.5 to 12.5 mg/L (500 to 12,500 μg/L) (Eisler 1985) but concentrations as low as 2 μg/L have been found to cause reproductive failure and/or increased numbers of deformed embryos in warm-water fish in pond or wetland habitats (Lemly 1993b, Presser *et al* 1994). In Colorado, however, there are numerous streams with naturally occurring elevated levels of selenium but recent studies have not reported any evidence of deformities in fish or other reproductive effects (Canton and Van Derveer 1997).

The type of aquatic habitat is extremely important in determining the ecological risk posed by elevated selenium levels. Water quality criteria in the U.S. and Canada have been derived from the toxic effects found in pond or wetland habitats and these may be significantly overprotective in flowing water (Canton and Van Derveer 1997).

Figure 1

Elk River at Highway 93
Total Selenium (µg/L)

(courtesy T.N. Webber, B.C. Water Quality Branch, 1998)



There have been no reports of the toxic effects characteristic of selenium (species eliminated, spinal deformities) in the fish or waterfowl in the Elk River basin. There have, however, been no scientific investigations to determine if less obvious chronic effects are occurring. The fact that selenium affects the early life stage of fish, causing outright mortality or deformities that soon lead to death, chronic effects (teratogenisis) can go unnoticed by casual observation (Lemly 1993b).

The objectives of this study were:

1. To monitor the extent of selenium mobilization into the river system from various tributaries and mine drainages and examine its spatial and seasonal variability.

2. By surveying levels in sediment and biological tissues throughout the river system, develop some understanding of how much of the mobilized selenium is being retained in the river ecosystem.

3. Because this is the first investigation of selenium release into surface waters in British Columbia, review the scientific literature, summarize the current understanding about selenium toxicology in aquatic systems, and place our findings in this broader context.

4. Combine the results of this survey with the current state of scientific understanding about selenium and recommend effective follow-up studies.

2.0 Methods

This study consisted of two distinct sampling elements. Throughout 1996 water sampling in the vicinity of each coal mine was conducted by each coal company for total selenium, with some supplementary sampling by BC Environment. In September 1996, the Ministry of Environment, Lands and Parks surveyed the extent of selenium bioaccumulation by sampling water, bottom sediment, attached algae, benthic invertebrates and fish over three days in a number of locations throughout the upper Elk River basin.

2.1 Seasonal and Spatial Water Sampling

Appendix I lists 22 sites in the vicinity of each of the four coal mines where samples for total Se were collected in April, May, August and December of 1996. This excludes Fording Coal Ltd. Fording River operations, where selenium mobilization was discovered in 1995. Sampling at this mine was more extensive, covering 40 sites over various dates from 1995 through early 1997 (Appendix II).

Sites in Appendix I were generally selected to determine if selenium was being mobilized from a given mine's operations and fall into the following categories:

Reference (R) -	generally upstream of the mines, these also included a sulphur spring to check natural sources.
Mine affected tributary (MT) -	these have in-channel settling ponds and/or waste rock dumps in their headwaters, often as valley fills.
Near-field (NF) -	sites in major streams not far downstream of mine tributary sources.
Far-field (FF) -	sites in major streams some distance below the mine sources.

Sites and sample dates at the Fording River mine (Appendix II) were determined by mine personnel with the intent to more thoroughly delineate sources of selenium throughout the mine and changes in concentration through the seasons.

Samples were collected by five different persons from each mine on the same day and additional days were sampled at the Fording River mine (Appendix II), using the same methods. Certified trace metal clean 250 ml polyethylene sample bottles were used and, to reduce the chance of contamination, placed in zip lock bags prior to going in the field. Instructions were to avoid smoke, dust, and vehicle exhaust, to keep the bottle capped and in the zip lock bag except when sampling, and to handle the bottles with clean bare hands. Being previously cleaned, bottles were not prior rinsed with sample water. Samples, including trip blanks, were preserved in the field with high purity nitric acid and shipped, on ice, to ASL Analytical Services Laboratories Ltd. in Vancouver for analysis. Laboratory analytical methods used are outlined in Table 1.

An additional 19 samples were collected by BC Environment staff on the same days and locations as the above program. These samples were collected in a similar fashion, but were analyzed by Zenon Laboratories in Burnaby (see Table 1 for analytical method). The purpose of this sampling was to provide further general confirmation of selenium levels over a wide concentration range using a different laboratory employing a different analytical method. These samples were not taken side by side with the coal company samples, but were obtained within a few hours at the same general location.

Table 1. Laboratory analytical methods.

Laboratories: ASL = Analytical Services Laboratories Ltd., Vancouver, B.C.; NLET = National Laboratory for Environmental Testing, Environment Canada, Burlington, Ont.; Zenon = Zenon Laboratories (division of Philip Analytical Services Corp.), Burnaby, B.C.; PESC = Pacific Environmental Sciences Centre, Environment Canada, North Vancouver, B.C.; RL&L = RL&L Environmental Services, Edmonton, Alta.

Laboratory	Method	Detection Limit	Analytical Range
Water:			
ASL	Graphite furnace/Atomic Absorption spectrophotometry (GF/AA)	1.0 µg/L	1 to 100 µg/L
NLET	Inductively Coupled Plasma-Atomic Emission Spectroscopy - Hydride Generation (ICP-AES/HG) Method #02-2200	0.1 µg/L	0.1 to 20 µg/L
Zenon	$HCl/K_2S_2O_8$ digestion, Hydride Generation/Atomic Absorption Spectrophotometry	0.5 µg/L	0.5 to 20 µg/L
Sediment:			
PESC	Dried 60°C, grind, sieve 150 µ, HCl/HNO_3 digestion, GF/AA	0.2 µg/g (dry wt)	0.2 to 16 µg/g
Sediment TOC:			
Zenon	Dry, Grind, Induction Furnace - Gasometric Analyzer	Total - 1 µg/g Inorganic - 0.5 µg/g Organic - calculated	0.5 to 140 mg/g
Biota:			
PESC	Homogenize, freeze-dry, HCl/HNO_3/30% H_2O_2 digestion, GF/AA	0.1 µg/g dry weight	0.1 to 8 µg/g dry wt.
Fish Ageing:			
RL&L	Mackay *et al* 1990 (otoliths)		

2.2 September 1996 Bioaccumulation Survey

Water

Figure 2 shows sample site locations and the types of samples proposed to be taken at each site. Water samples for this part of the study were taken at 10 of the proposed sites (Figure 5) in a

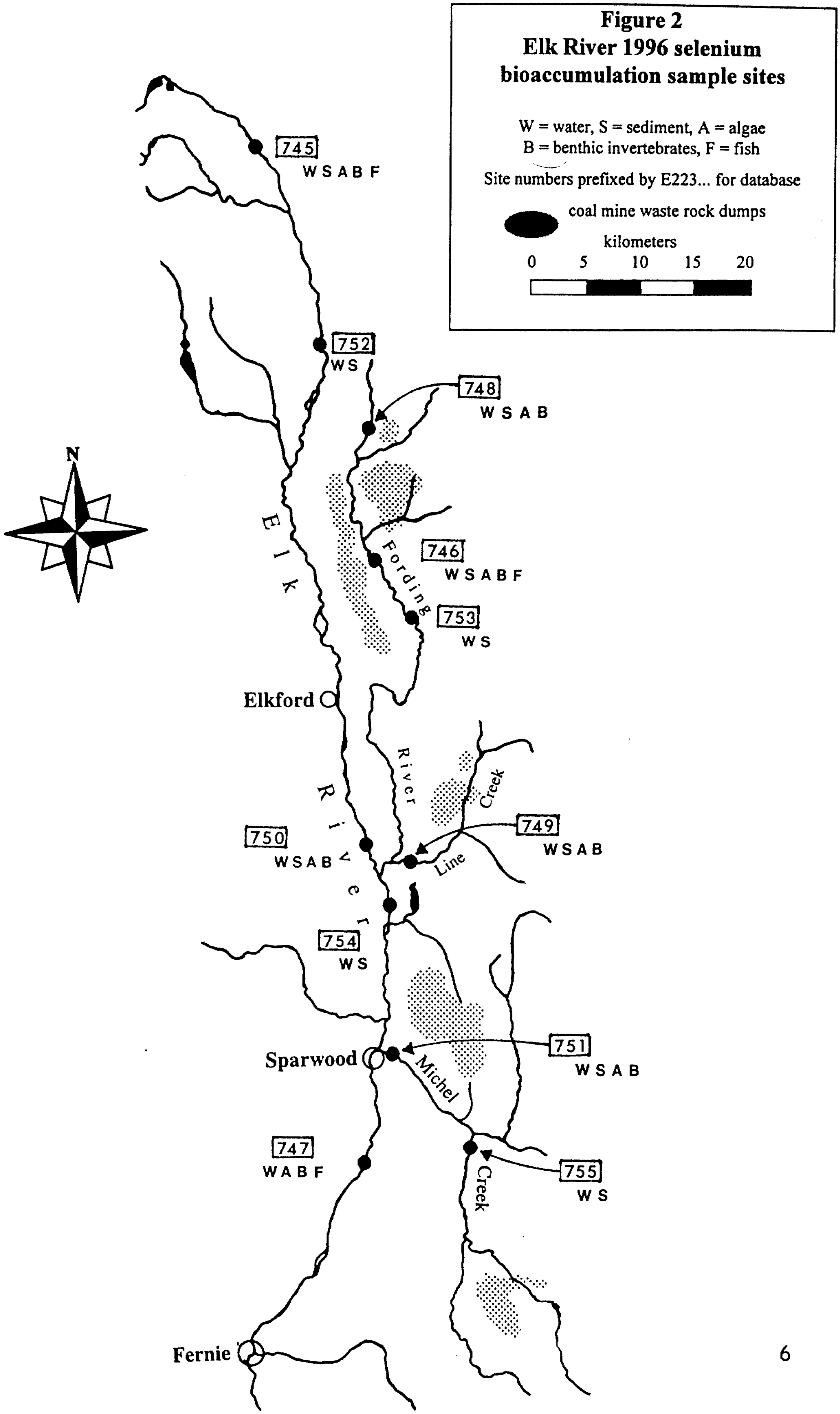


Figure 2
Elk River 1996 selenium bioaccumulation sample sites

similar fashion to the seasonal/spatial sampling but were analyzed by Environment Canada's National Laboratory for Environmental Testing in Burlington, Ontario (see Table 1 for analytical methods). This facility provided an order of magnitude lower detection limit at 0.1 μg Se/L. In all cases, samples were labelled, packed in coolers with ice packs and shipped as soon as possible. Samples were refrigerated if there were any delays in shipping.

Bottom Sediment

River bottom sediment was sampled at 11 sites (Figure 2). At each general site location fine bottom sediments were sought out in pools or backwaters, avoiding obvious bank sloughing. Within an area of fine sediment accumulation approximately 3 sub-samples of the top 2 to 3 cm were composited in a stainless steel bowl. This approach was intended to account for intra-site variance over approximately 10 m^2 without the expense of analyzing multiple sub-sample and is not unlike the approach used by Van Derveer and Canton (1997). The composite sample was mixed, allowed to settle and the excess water decanted away. A sub-sample was taken in a 100 ml polyethylene cup and shipped on ice to the Pacific Environmental Science Centre (PESC) (Table 1). A further sub-sample of this was forwarded from PESC to Zenon Environmental Services Ltd. for sediment total organic carbon (TOC) analysis (see Table 1 for analytical method).

Attached Algae

Attached benthic algae (periphyton) were sampled at 6 of the 7 proposed sites (Figure 2 and 5), there being insufficient algae to sample at site 748. Filamentous or mat growths on rocks were sought out at each site and removed with forceps or scraped off with a utility blade, avoiding as much sediment from the sample as possible. Approximately 5 g of wet tissue was placed in a 100 ml polyethylene cup, removing large invertebrates or debris and decanting away excess water. Samples were frozen in the field and kept frozen until shipped on ice to PESC for Se analysis (see Table 1 under 'Biota' for analytical method). The most abundant algal growths were chosen at each site, and where more than one type was dominant, subsamples of each were composited.

Benthic Invertebrates

Benthic macroinvertebrate samples were taken at the same 7 sites as the periphyton. A Hess sampler was used to acquire the samples, though only boulders and cobble were cleaned to limit the amount of sediment and debris. The sample catch was emptied into a porcelain tray, and the taxa of largest size removed to a 100 ml polyethylene cup. The process was repeated until approximately 5 g was collected. The largest benthos were usually Perlodid stoneflies and/or Hydropsychid caddisflies. Smaller mayflies and stoneflies were taken if necessary. Samples were field frozen and shipped frozen to PESC for Se analysis (see Table 1 under 'Biota' for analytical method).

Fish

All fish were obtained by angling at 3 sites: a reference site on the Elk River near Cadorna Creek, a near-field site just below the Fording River coal mine, and a far-field site on the Elk River below Michel Creek (Figure 2). Being the only species at the near-field site above Josephine Falls on the Fording River (Lister 1980), westslope cutthroat trout, *Oncorhynchus clarki lewisi,* was the target species. Other species taken included mountain whitefish, *Prosopium williamsoni,* and bull trout, *Salvelinus confluentus.*

In a mobile laboratory, each fish was weighed, fork length and sex recorded. Otoliths for ageing were cleaned in alcohol and stored in glycerine. Liver and gonad weights were also recorded for each fish and frozen in 100 ml polyethylene cups. Small livers and gonads were composited to produce 5 g samples required by the laboratory (Appendix III). If these organs were large enough they were analyzed discreetly (i.e. the whitefish ovaries were gravid and large, the cutthroat ovaries were very small). Five gram samples of skeletal muscle from above the lateral line were taken from each fish, two of these were blind duplicated to check tissue analytical variance (Appendix III). Stomachs and their contents were preserved in ethanol for later semi-quantitative examination by the authors (Appendix IV). Instruments and the counter area were cleaned between the processing of each fish to reduce the chance of cross contamination. All fish tissue samples were field frozen and shipped frozen to PESC for Se analysis (see Table 1 under 'Biota' for analytical method).

3.0 Results

3.1 Water Sampling

The results of the seasonal and spatial water sampling, conducted by the coal mine companies throughout the upper Elk River basin in 1996, are listed in Appendices I and II. Appendix I also contains some same day samples taken by B.C. Ministry of Environment, Lands and Parks. Though these pairs of samples were not taken at the same time of day and perhaps not at exactly the same location as those taken by the mine personnel, the reasonably close match of these sample pairs demonstrates little effect on Se concentrations due to analysis by two different laboratories, micro-site differences or dirunal variation.

Quality Assurance

In order to check combined sampling and analytical precision, 16 of the 87 samples taken by the coal mine personnel in Appendix I were duplicated by taking the two samples side by side simultaneously. These were submitted "blind", using fictitious site names so the laboratory was unaware that the samples were duplicates. An additional 9 such duplicates were taken at the

Fording River mine (Appendix II). Sixteen field or trip blanks, to check for sampling contamination, were also submitted at the same time as the Appendix I duplicates, as were a further 8 such blanks with those from Appendix II. These 25 duplicates and 24 blanks are listed in Table 2.

Table 2. Quality assurance results for total selenium in water.
Results in µg/L. Deviation = replicate #1 - replicate #2; * = samples with levels > 5 times the MDL; Relative Percent Difference (RPD) = ((replicate #1 - replicate #2)/(#1 + #2)/2) * 100. Highlighted RPD values are ≥ 25% control limit for values > 5x MDL. All analyses performed by ASL Laboratories Ltd.

Replicate #1	Replicate #2	Deviation	> 5 x MDL	Relative Percent Difference	Field blank
1	1	0		0	<1
46	44	2	*	4.4	<1
5	53	-50	*	-178	<1
23	25	-2	*	-8.3	<1
11	11	0	*	0.0	<1
7	7	0	*	0.0	<1
10	8	2	*	22.2	<1
24	24	0	*	0.0	<1
19	20	-1	*	-5.1	<1
1	2	-1		-66.7	<1
56	61	-5	*	-8.5	<1
5	5	0		0.0	<1
4	4	0		0.0	<1
1	1	0		0.0	<1
2	1	1		66.7	<1
1	1	0		0.0	<1
26	39	-13	*	-40.0	
41	53	-12	*	-25.5	<1
2	2	0		0.0	<1
5	5	0		0.0	<1
184	182	2	*	1.1	<1
80	81	-1	*	-1.2	<1
18	25	-7	*	-32.6	1
75	77	-2	*	-2.6	<1
9	10	-1	*	-10.5	<1

Duplicate sample precision can be evaluated using relative percent difference (RPD), which is simply the difference between duplicates as a function of the average of the two results. A RPD control limit of 25% has been recommended by Cavanagh *et al* (in prep) for the B.C. Ministry of

Environment, Lands and Parks and has also been adopted by the U.S. EPA (PTI Env. Ser. 1991). Only duplicates with concentrations greater than 5 times the minimum detection limit (MDL) are evaluated for RPD because values close to the MDL have poor confidence limits. Of the 16 sets of duplicates with total selenium levels >5 μg/L, only 4 were out of control, the worst of these having a RPD of 178%. It appears that one of these duplicates in this set may have been mislabelled and should not be included in this QA evaluation. Eleven sets of these duplicates, or 68%, had RPDs of <10%. It can be concluded that the sampling and analytical methods employed for water in this study had an acceptable level of precision.

Twenty-three of the 24 field blanks showed Se concentrations less than the MDL with one blank reported at the MDL of 1 μg/L. This indicates no selenium contamination introduced by the sampling procedure employed.

Results

In order to help illustrate changes in total selenium throughout the basin at different times of the year, the results from selected sites from Appendices I and II are illustrated on maps in Figures 3 and 4. Figure 3 shows the Se levels at sites on the Elk River and its major tributaries before and during freshet, and in the summer and winter. Figure 4 shows Se levels for the same dates in smaller tributaries, with an emphasis on those located within the coal mines. Note that the value axis scale for the major rivers (Figure 3) is 0 to 25 μg Se/L, while the small tributary plots (Figure 4) ranges from 0 to 100 μg Se/L.

Appendices I and II include 5 reference sites, 4 located above mining operations plus a sulphur spring near Hosmer, sampled to determine if natural groundwater had elevated Se levels. All the results from these sites were below detection (1 μg/L). Site selection for this study did not include tributary streams from non-mining areas, which may have shown an effect of other land uses on Se mobilization. Some of the main river reference sites, however, were downstream of various human activities involving much less land disturbance than surface coal mining. The site on the Elk River upstream of Greenhills operations (Appendix I and Figure 3) includes the entire upper Elk River watershed with varying levels of forestry, mine/oil and gas exploration, and back country recreation, all with associated road construction. In addition, mine exploration has identified coal seam outcrops in the Elk River channel 33 km upstream of this sampling site. None of these activities or the presence of coal seams in the river appear to be releasing significant quantities of Se, as the levels in the upper Elk River were consistently <1 μg/L.

By contrast, mine affected tributaries in Appendix I averaged 28 μg/L total Se (n = 34, ASL data only) throughout 1996, ranging from Corbin Creek below the mine settling pond, which averaged 2.7 μg/L, to Erickson Creek, which averaged 60 μg/L over the four dates. The highest Se levels found were from the Eagle Settling Pond discharge to the Fording River (Appendix II) which averaged 172 μg/L over 6 dates sampled in 1996. One small drainage from a waste dump entering this pond had a total Se of 542 μg/L, the highest concentration found in the study. In

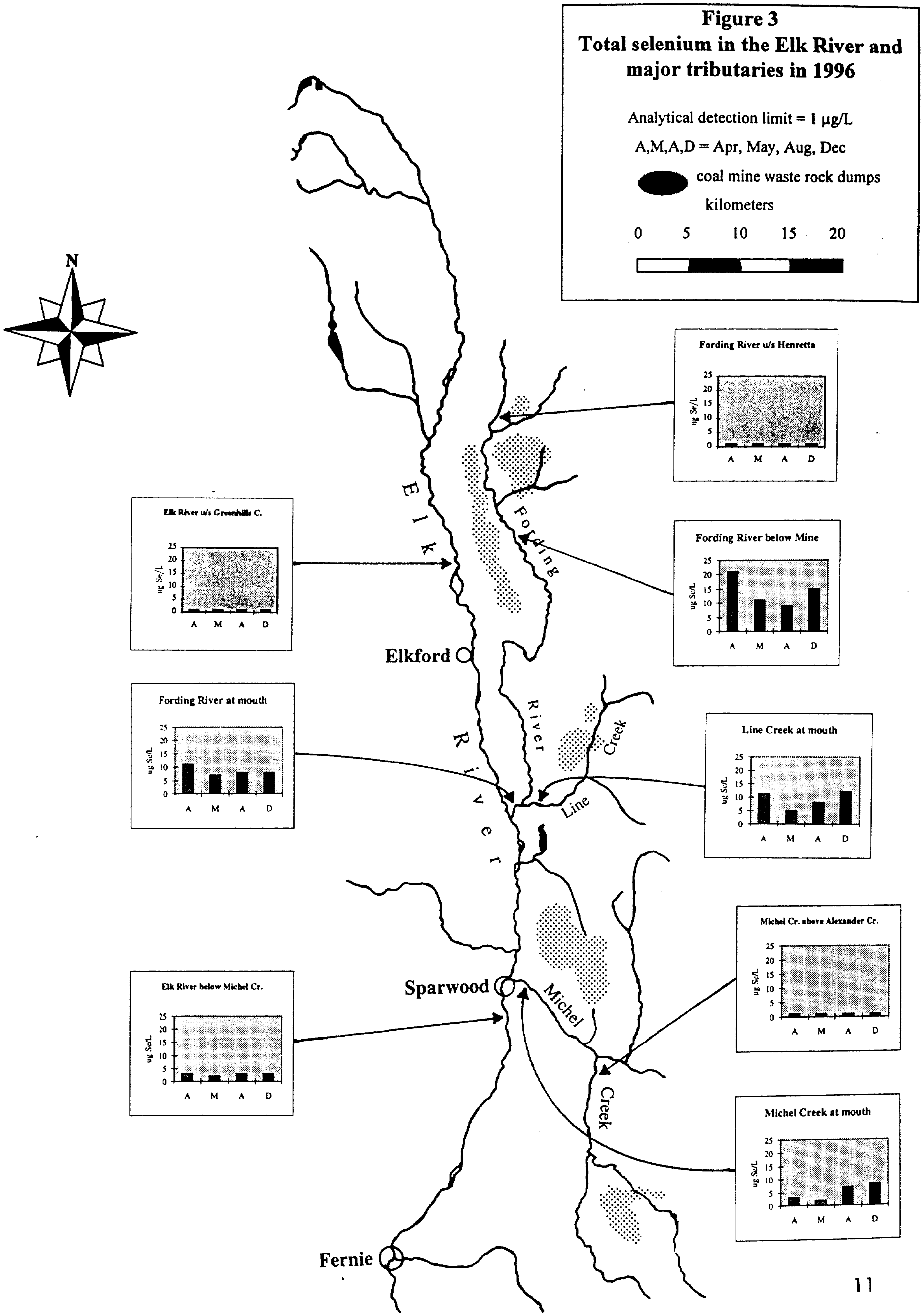


Figure 3
Total selenium in the Elk River and major tributaries in 1996
Analytical detection limit = 1 µg/L
A,M,A,D = Apr, May, Aug, Dec
coal mine waste rock dumps
kilometers
0 5 10 15 20
N
Fording River u/s Henretta
Fording River below Mine
Elk River u/s Greenhills C.
Fording River at mouth
Line Creek at mouth
Michel Cr. above Alexander Cr.
Elk River below Michel Cr.
Michel Creek at mouth
ug Se/L
A M A D
Elk River
Fording River
Line Creek
Michel Creek
Elkford
Sparwood
Fernie

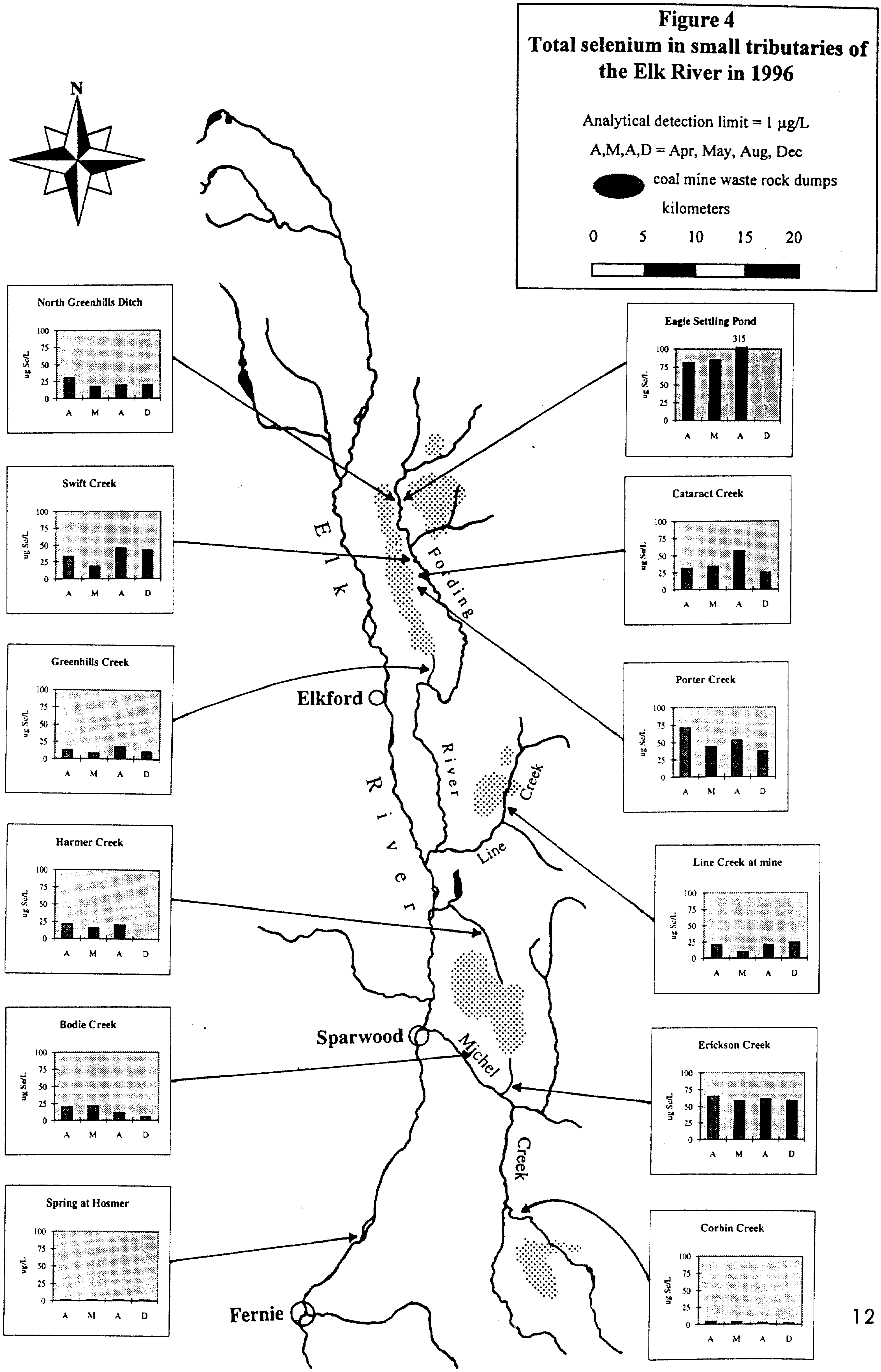


Figure 4
Total selenium in small tributaries of the Elk River in 1996

comparison to the reference and mine affected tributaries, the near-field sites, those just downstream of mines, averaged 13 μg/L total Se (n = 12), while far-field sites averaged 4.3 μg/L (n = 16) (Appendix I).

In summary, average total Se levels in the Elk River system in 1996 were <1 μg/L above the coal mines, 28 μg/L in mine affected tributaries, 13 μg/L in streams just below the mines, 4.3 μg/L some distance downstream, and 1.7 μg/L near the mouth of the Elk River. These data strongly suggest that the coal mines are the major source of Se in the basin although more monitoring of non-mine affected streams is necessary to confirm that no other significant sources, natural or from human activities, exist.

The large variance in the level of selenium from various mine affected tributaries raises interesting questions about the mechanism of selenium mobilization from mine disturbance. For example, the total Se from the Clode settling pond, a creek which has seen mine waste dump development for about 25 years, averaged 20 μg/L (n = 12) (Appendix II), Porter Creek, where mining activity began some 15 years ago, averaged 51 μg/L (n = 4) (Appendix I), and the Eagle settling pond, with about 27 years of mining activity, averaged 172 μg/L (n = 6) (Appendix II). There seems to be no correlation between the duration or extent of mine activity and the magnitude of Se mobilization. Selenium mobilization from the Coal Mountain operations (represented by the Corbin Creek d/s of settling ponds site in Appendix I) was very low, averaging 2.7 μg/L (n = 4) and this mine has operated for over 25 years. Understanding the mechanism of Se mobilization from surface coal mining in this area will require considerable additional study.

The seasonal patterns of Se levels also provide some insight into the mobilization mechanism. In the large rivers (Figure 3) the lowest levels were usually found, not unexpectedly, in May, during freshet. The low-flow April and December samples usually had the highest concentrations. If the loading or mass quantity of Se released into streams was constant, concentrations of Se during freshet would be much lower than was found as a result of dilution by snowmelt runoff. Using the Fording River at mouth site to illustrate this point, the concentration of total Se dropped by 27% in freshet, from 11 μg/L on April 16 to 7 μg/L on May 21. The river flow at this site, however, increased over this period by 183% from 6.74 m^3/s to 19.1 m^3/s (M. Evin, pers. comm.), which represents a 79% increase in Se loading from 6.4 kg/d to 11.5 kg/d. Mine affected tributaries (Figure 4) show similar seasonal patterns of concentrations but flows were not gauged. This significant increase in the mass loading of Se in freshet suggests that mobilization and/or transport through the waste rock dumps is greater in the spring during snowmelt.

In our Fording River at mouth example, although the August and December samples had the same total Se concentration, 8 μg/L, diminishing flows (6.71 m3/s in August, 3.41 m3/s in December) mean diminishing Se loadings (4.6 and 2.3 kg/d). This is consistent with our hypothesis that mobilization and/or transport of Se from waste dumps is positively correlated with the amount of water flowing through the dump.

The monitoring of numerous potential Se sources at the Fording Coal Ltd. mine on the Fording River (Appendix II) provide evidence that coal, as well as the host rock (waste dumps), releases selenium. The accumulated water (supernatant) in the large tailings ponds (Appendix II) contained significant amounts of Se (an average of 19 µg/L (n = 9) in the older pond (NTP Barge), and 56 µg/L (n = 14) in the newer pond (STP Barge)). The tailings are the water used to wash the coal plus very fine coal particles, unsuitable as product. In the tailings ponds the fine particles settle and the supernatant is re-used as plant wash water.

Further evidence that Se is released from coal can be found in the supernatant of a mixture of clean, product coal and water which had a total Se level of 30 µg/L after settling (Appendix II, 'Clean Coal' site). The presence and release of Se from coal and related overburden has been reported by others. Dreher and Finkleman (1992) found similar modes of Se occurrence in coal and overlying sediments in the Niobrara Formation in the Powder River Basin in Wyoming.

The results of the low level (0.1 µg/L detection limit) Se sampling done in September 1996 show a similar pattern to the more extensive sampling done by the mine companies (Table 3 and Figure 5). The two reference samples from the headwaters of the Elk River, far from any industrial activity, had total Se levels of 0.1 and 0.2 µg/L. These results may indicate naturally occurring low levels of Se in the basin or, being at or near detection, merely be false positives. More extensive sampling employing this analytical method is necessary to confirm these background levels. As with the higher detection limit data, there was a distance effect below the coal mines with near-field sites averaging 9.5 µg/L (n = 4) and far-field sites averaging 1.3 µg/L (n = 4).

Table 3. Low level total selenium in water, September 1996.
MDL = 0.1 μg/L. R = reference, NF = near-field, FF = far-field. NS = no sample.

Site Description	Site #	Site Type	Total Se μg/L
Elk R. above Cadorna Cr.	E223745	R	0.1
Elk R. above Aldridge Cr.	E223752	R	0.2
Elk R. above Fording R.	E223750	FF	0.4
Fording R. above Henretta Cr.	E223748	R	NS
Fording R. above Swift. Cr.	E223746	NF	8.6
Fording R. above Chauncey Cr.	E223753	NF	9.6
Line Cr. At Fish Fence	E223749	NF	10.5
Elk R. above Grave Cr.	E223754	FF	2.2
Michel Cr. Above Alexander Cr.	E223755	FF/R	0.6
Michel Cr. at Highway 3	E223751	NF	7.1
Elk R. below Michel Cr.	E223747	FF	2.2

3.2 Bottom Sediment

During the survey of September 1996, fine bottom sediments (silt and sand) were sampled at 10 sites throughout the basin. The results are tabulated in Table 4 and illustrated, along with water, algal, and benthos tissue levels, in Figure 5. Increases in selenium below the coal mines is somewhat less clearly demonstrated in fine bottom sediment than in water. The highest sediment levels were still found below mines on the Fording River and Michel Creek, but the highest level found, 2.41 μg/g dry wt. was only 5 times greater than the lowest level found (0.5 μg/g dry wt.), compared to two to three orders of magnitude increases in the water column. Selenium levels at all sites were below the current provincial sediment criterion of 5 μg/g dry wt. (Nagpal *et al*, 1995).

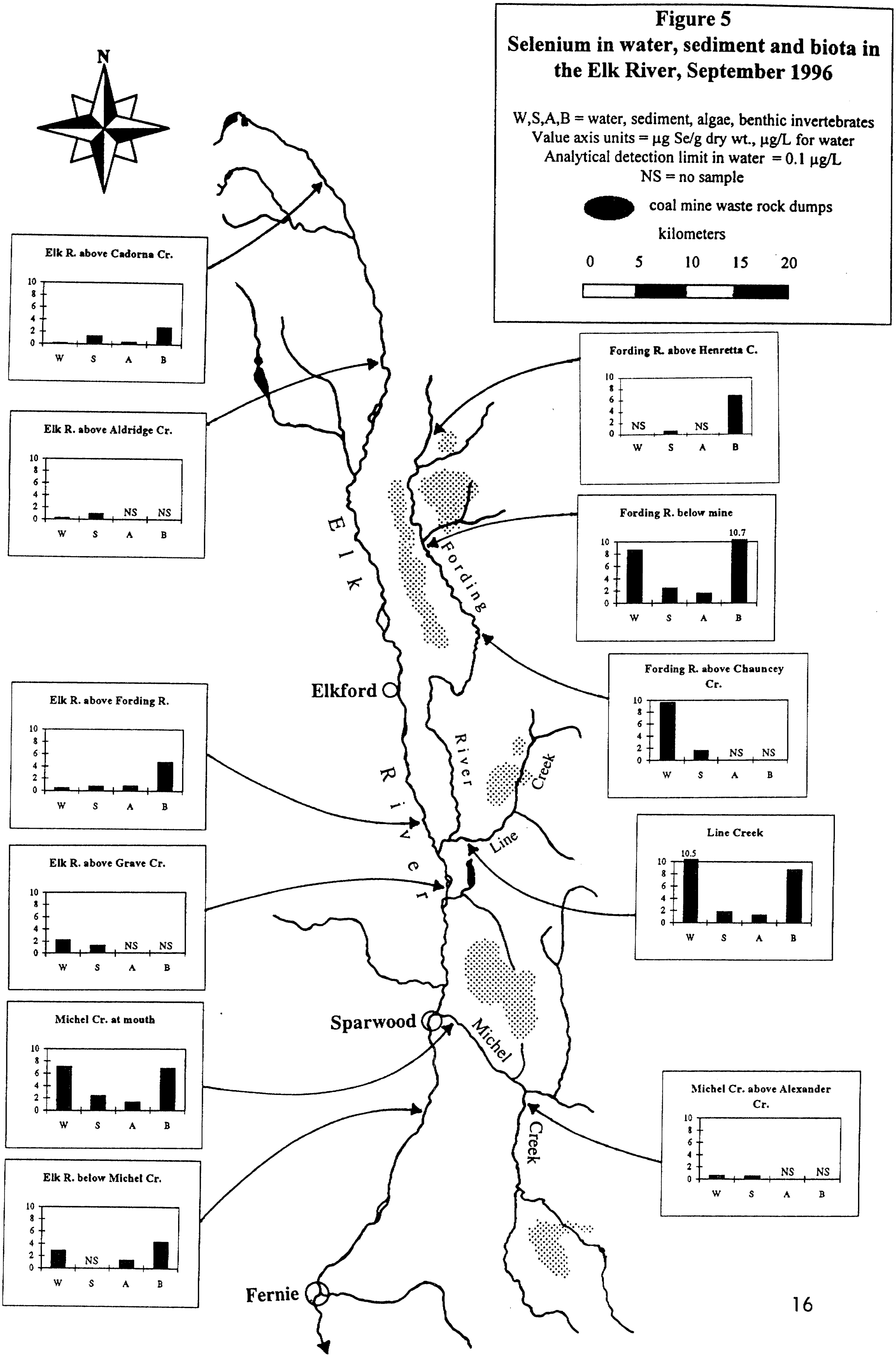


Figure 5
Selenium in water, sediment and biota in the Elk River, September 1996
W,S,A,B = water, sediment, algae, benthic invertebrates
Value axis units = µg Se/g dry wt., µg/L for water
Analytical detection limit in water = 0.1 µg/L
NS = no sample
coal mine waste rock dumps
kilometers
0 5 10 15 20
N
Elk R. above Cadorna Cr.
Elk R. above Aldridge Cr.
Fording R. above Henretta C.
Fording R. below mine
10.7
Fording R. above Chauncey Cr.
Elk R. above Fording R.
Elk R. above Grave Cr.
Line Creek
10.5
Michel Cr. at mouth
Michel Cr. above Alexander Cr.
Elk R. below Michel Cr.
NS
W S A B
Elk
River
Fording
River
Creek
Line
Michel
Creek
Elkford
Sparwood
Fernie

Table 4. Selenium in fine bottom sediments in Elk River, September 1996.
Site types: R = Reference; NF = Near-field, Se-contaminated site immediately below a mine; FF = Far-field, some distance below mines.

Site Description	Site #	Site Type	Selenium µg Se/g dry wt.	TOC %	Field Notes
Elk R. above Cadorna Cr.	E223745	R	1.28	3.1	fine silt
Elk R. above Aldridge Cr.	E223752	R	0.94	2.9	sand + some silt
Elk R. above Fording R.	E223750	FF	0.7	0.8	fine silt
Fording R. above Henretta Cr.	E223748	R	0.57	1.4	hard to find, fine sand in side pool
Fording R. above Swift. Cr.	E223746	NF	2.41	8.1	fine silt + decomposing Hydrurus
Fording R. above Chauncey Cr.	E223753	NF	1.53	3.3	fine silt from backwater
Line Cr. at Fish Fence	E223749	NF	1.74	35.0	silt + coal sand
Elk R. above Grave Cr.	E223754	FF	1.18	2.0	silt + sand
Michel Cr. above Alexander Cr.	E223755	R	0.5	0.5	silt + fine sand
Michel Cr. at Highway 3	E223751	NF	2.32	2.7	silt + decaying Hydrurus

Saiki *et al* (1993) reported that microbial organisms living on detrital particles accumulated high levels of selenium suggesting a positive correlation with sediment organic carbon. Eliminating the sample from Line Creek, which contained quantities of coal sand that would confuse the comparison to other sites where the sediment TOC was comprised mainly of detritus, the correlation between sediment selenium and TOC is not statistically significant ($p = 0.05$) but this may simply be due to the small sample size ($n = 9$).

3.3 Attached Algae (Periphyton)

Periphyton was only sampled at six sites in September 1996 and the range of Se concentrations found was quite narrow, from 0.31 to 1.56 µg Se/g dry wt. (Table 5 and Figure 5). The two lowest values were found above or away from coal mines, in the headwaters of the Elk River and just above the confluence with the Fording River, respectively. It is interesting, however, that the most remote site, Elk River above Cadorna Creek, had a selenium level that was about 20% of the highest level found below the mine on the Fording River where water levels were 100 to 200 times greater. Inter-site comparisons are complicated by the lack of sample replication and the fact that different species of algae dominated the periphyton communities at different sites (see field notes in Table 5), and each of these species may accumulate Se at different rates.

Table 5. Selenium in attached algae in Elk River, September 1996.
Site types: R = Reference; NF = Near-field, Se-contaminated site immediately below a mine; FF = Far-field, some distance below mines.

Site Description	Site #	Site Type	Selenium µg Se/g dry wt.	Moisture %	Field Notes
Elk R. above Cadorna Cr.	E223745	R	0.31	94.7	green filamentous, green crustose and a gelatinous green.
Elk R. above Fording R.	E223750	FF	0.78	73.4	Lygnbya only significant growth present, fine silt in sample.
Fording R. above Swift. Cr.	E223746	NF	1.56	90.4	Hydrurus from riffles.
Line Cr. at Fish Fence	E223749	NF	1.28	85.6	Hydrurus taken but a healthy diatom film present.
Michel Cr. at Highway 3	E223751	NF	1.26	89.3	Hydrurus in the early stages of die-back.
Elk R. below Michel Cr.	E223747	FF	1.28	87.2	Hydrurus, more dead tissue taken than at other sites.

Selenium levels in fine sediments and attached periphyton tissue appear to be quite similar at the sites where both could be sampled (n = 5), but the low sample number prevents any statistical comparisons.

3.4 Benthic Invertebrates

Single benthic invertebrate samples were collected at seven sites in September 1996 for analysis of tissue selenium content. As with the periphyton, the inter-site range of Se in benthic invertebrate tissue was relatively narrow, from 2.74 to 10.7 µg Se/g dry wt. (Figure 5 and Table 6). Tissue quantity requirements for analysis necessitated selecting the largest taxa present at each site, which varied between sites. The largest taxa were usually Perlodid stonefly nymphs (predators), Hydropsychid caddis fly larvae (net spinning collectors) or Tubificid worms (detritivors). Smaller stoneflies and mayflies were often taken to ensure sufficient tissue in the sample (Table 6). In addition, the time required to procure sufficient tissue prevented replicate sampling.

Table 6. Selenium in benthic invertebrates in the Elk River, September 1996.
Site types: R = Reference; NF = Near-field, Se-contaminated site immediately below a mine; FF = Far-field, some distance below mines.

Site Description	Site #	Site Type	Selenium µg Se/g dry wt.	Moisture %	Field Notes
Elk R. above Cadorna Cr.	E223745	R	2.74	84.7	mostly large Perlodid stoneflies, Hydropsychid caddisflies, 2 large Tubificid worms.
Fording R. above Henretta Cr.	E223748	R	6.84	82.6	mostly large Hydropsychid caddisflies, also took smaller stoneflies and mayflies.
Fording R. above Swift. Cr.	E223746	NF	10.7	88.7	some large Perlodids and Hydropsychids, used medium sized stoneflies and mayflies.
Line Cr. at Fish Fence	E223749	NF	8.69	82.7	diverse benthos, used all forms.
Elk R. above Fording R.	E223750	FF	4.62	82.5	large Perlodid stoneflies dominant.
Michel Cr. at Highway 3	E223751	NF	6.82	88.7	most forms medium or small sized, sought out Tubificids in decaying Hydrurus for bulk.
Elk R. below Michel Cr.	E223747	FF	4.29	79.2	medium and small forms taken, took longer to get 5 g than at any other site.

These preliminary survey data do provide some useful initial insights into Se bioaccumulation in this river system. The fact that the most remote reference sight, Elk River above Cadorna Creek, though having the lowest Se level, was 25% of the highest sample level, Fording River above Swift Creek, is highly significant. First, this represents only a 4 fold increase in benthic invertebrate bioaccumulation at the exposed site despite the fact that water levels were 100 times higher. The second important observation is the fact that invertebrates at this reference site actually contained significant levels of Se. The sample at our only other reference site, Fording River above Henretta Creek (Figure 4), contained 6.84 µg/L, which was the third highest level of all 7 sites.

Lemly (1993a) suggests a toxic effects threshold for food-chain organisms of 3 µg Se/g dry wt. above which reproductive failure can occur in fish. The empirical data used to develop this criterion are derived from field studies on warm-water fishes in standing-water habitats and from controlled laboratory feeding experiments. It is possible, perhaps probable, that this threshold is not applicable to cold-water species in fast-flowing rivers, particularly in areas with seleniferous geology. Seven of our 8 benthic invertebrate composite samples exceeded Lemly's threshold, including a reference site, the most remote reference site being very close to this threshold at 2.74 µg Se/g dry wt.

These data suggest a significant background level of Se bioaccumulation in the organisms that form an important component of the diet of fish in this river system. They also suggest that large increases in water levels are not accompanied by similar increases in bioaccumulation. Additional sampling effort is required to confirm these observations.

3.5 Fish

All the data gathered for each fish collected in September 1996 can be found in Appendix III. Table 7 is a summary of the numbers of each species of fish collected and a description of the three sample sites. For clarity, the fish sample sites will be referred to as follows: the upper Elk River near Cadorna Creek = the reference site; the Fording River below the mine = the near-field site; the Elk River below Michel Creek (at Olson) = the far-field site. These correspond roughly with sample sites for water, sediment, algae and benthos (Figure 5) but extended over reaches of 1 to 4 km.

Table 7. Summary of fish captured in Elk River, September 1996.
CT = cutthroat trout; MWF = mountain whitefish; BT = bull trout

Site	Site Description	Date	Number of Species Captured			
			CT	MWF	BT	Total
Elk River near Cadorna Cr. (reference)	3 locations within a reach from 4 km U/S Cadorna Cr. to just below Lower Elk L.	96/9/9 & 10	10	1	0	11
Fording River (near-field)	1.5 km of stream sampled from Kilmarnock Cr. d/s.	96/9/10	10	0	0	10
Elk R. at Olson (far-field)	4 km of stream sampled starting from 8 km below Michel Cr. d/s.	96/9/11	5	2	1	8

Table 8 summarizes the physical data gathered from the cutthroat trout sampled. Small sample sizes preclude statistical comparisons between the fish from each of the three sites. It would appear that the age structure of the populations at the three sites was different (Figure 6) though the sample size is too small to make statistical comparisons. Fish from the reference site were older than the other two sites, with only 5 and 6 year fish found. The near-field population was mostly comprised of 3 year fish with no older fish. These were definitely smaller than cutthroat from the other two sites, being on average 8.6 cm and 217 g smaller than the reference fish. Past studies of this isolated population of cutthroat trout in the upper Fording River have found an older age structure than this study (Lister 1980, Norecol 1983), although these studies relied on scale ageing methods as opposed to otolith ageing, now considered more reliable. Several smaller fish of a younger age class, approximately 15 cm fork length, were caught and released because they were too small to provide sufficient tissue.

Figure 6. Age distribution of cutthroat trout in the Elk River, September 1996.

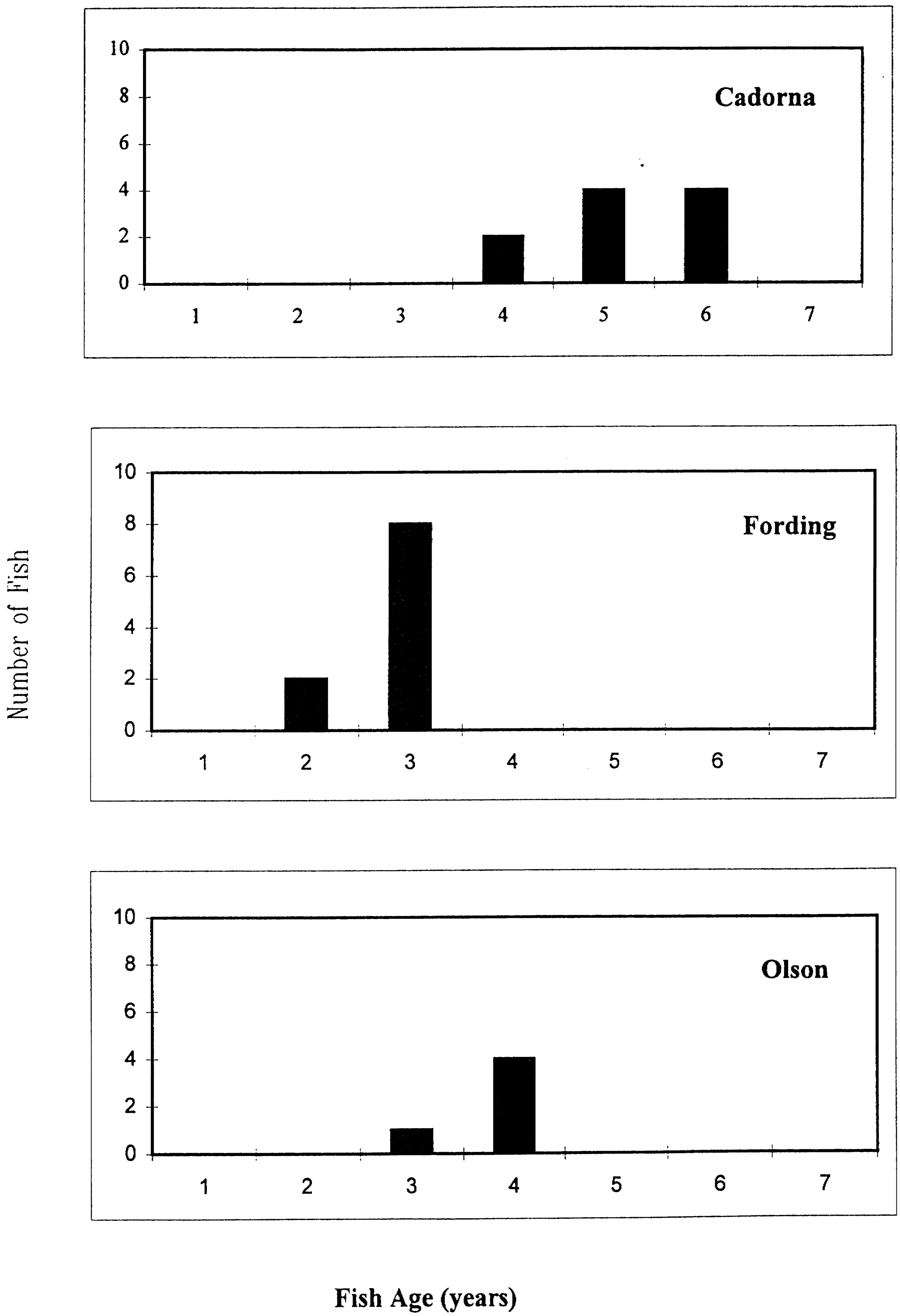


Table 8. Physical data from cutthroat trout sampled from Elk River, September 1996. 1. Condition Factor = [(weight in g x length in cm)$^{-3}$] x 100. 2. Hepatosomatic Index = (liver wt. in g/total wt. in g) x 100. 3. Sample size under weight refers to number of female gonads in composite. 4. Gonadosomatic Index = (gonad wt. in g/total wt. in g) x 100.

		Cadorna (reference) (n = 10)	Fording (near-field) (n = 10)	Olson (far-field) (n = 5)
Age	Mean	5.2	2.8	3.8
(yr)	Standard Deviation	0.79	0.63	0.45
Fork Length	Mean	30.1	21.5	34.4
(cm)	Standard Deviation	3.29	3.16	5.47
Wet Weight	Mean	342.8	125.8	537
(g)	Standard Deviation	115.3	63.1	245
Condition Factor [1]	Mean	1.22	1.17	1.24
	Standard Deviation	0.08	0.08	0.07
Liver Weight	Mean	3.95	1.8	4.66
(g)	Standard Deviation	0.92	0.96	1.65
Hepatosomatic Index [2]	Mean	1.22	1.39	0.9
	Standard Deviation	0.38	0.28	0.2
Gonad Weight [3]	Mean	2.65	1.55	6.45
(g)	Standard Deviation	2.71	1.91	2.19
		(n=6)	(n=2)	(n=2)
Gonadosomatic Index [4]	Mean	0.77	1.2	1.55
	Standard Deviation	0.66	1.13	0.21

The stomach contents of each fish were qualitatively/semi-quantitatively examined in the laboratory. These results can be found in Appendix IV. They generally indicated that the benthic component of the cutthroat diet was mostly comprised of adult stoneflies and mayflies that had been taken from the surface. There was a significant proportion of the diet comprised of true terrestrial insects, grasshoppers at the near-field site, winged ants at the far-field site. The variability in the terrestrial and aquatic components of the diets of these fish is probably a function of the available food organisms in the micro-habitat occupied by each fish.

Figures 7 and 8 show the selenium content in cutthroat skeletal muscle and liver at the three sites. Immediately apparent is the elevated selenium levels found in fish from the near-field site, and the fact that fish from the far-field site were nearly identical to those at the reference site. It is also interesting that the range of selenium levels in both tissues was much greater in the near-field fish than those from either the reference or far-field sites. This may be due to the varying diets of these fish, there being a greater Se content in the aquatic component versus the terrestrial component in the near-field fish.

Site comparisons are complicated by the different ages of the fish at each site (Figure 6). It would seem, however, that age can be ruled out as a major factor influencing Se tissue content because the fish with the highest tissue levels (Fording site) were also the youngest (2 and 3 year compared to 4 to 6 year at the reference site).

Also shown on Figures 7 and 8 are toxic effects thresholds from a toxicological review published by Lemly (1993a). Because these are levels of Se in fish tissues that were found to produce toxic effects in field and laboratory studies on a variety of fishes, including rainbow trout and chinook salmon, they have a greater probability of being applicable to a wide range of fish species from various habitats than the dietary organism threshold referred to in Section 3.4, which may produce varying levels of bioaccumulation in fish depending on habitat differences. Exceedance of these toxic effects thresholds does not necessarily mean that the cutthroat trout we sampled are suffering actual effects, to determine this a specific study on these fish is required. There is a greater probability that fish with tissue Se levels that exceed these published thresholds are suffering toxic effects than those that do not exceed.

Figure 7 shows that skeletal muscle levels from the 15 cutthroat trout from the reference site and the far-field site were all about half the threshold level of 8 µg Se/g dry wt. The 10 fish from the near-field site ranged from 6.13 to 14.7 µg Se/g dry wt., with 6 fish exceeding the threshold. Figure 8 shows that all 15 cutthroat trout discreet and composite liver samples from the 25 fish at all sites exceeded Lemly's threshold of 12 µg Se/g dry wt. Trout from the near-field had the highest liver Se levels, from 2.8 to 4.3 times the threshold.

The three Mountain whitefish caught, one from the reference site, two from the far-field site, all had skeletal muscle Se levels around 3 µg Se/g, below the threshold of 8 µg Se/g dry wt.. Liver levels ranged from 21.3 µg Se/g at the reference to 35.0 µg Se/g at the far-field, all well above the threshold of 12 µg Se/g dry wt.

The single male Bull trout from the far-field site had a skeletal muscle level of 3.53 µg Se/g dry wt., below the threshold, and a liver level of 18.4 µg Se/g dry wt., above the threshold of 12 µg Se/g. dry wt.

According to Lemly (1993a), the most sensitive indicator of potential toxic impacts on fish is the selenium content of gravid ovaries and eggs. As westslope cutthroat trout spawn in May and

June, none of the ovaries were gravid. To provide sufficient tissue for analysis, a single composite of non-gravid ovaries was obtained at each site with the following results: Reference, 22 μg Se/g dry wt. (n=6); Near-field, 28.2 μg Se/g dry wt.(n=2); Far-field, 47.8 μg Se/g dry wt.(n=2). These are all substantially over Lemly's (1993a) ovary/egg threshold of 10 μg Se/g dry wt. The 3 mountain whitefish, which were in pre-spawning condition, had gravid ovary levels of 20 μg Se/g dry wt. (reference site) and 26.9 and 25.8 μg Se/g dry wt. (far-field site), all of these were 2 to 2.5 times Lemly's threshold. These results can be found in Appendix III.

Figure 7. Selenium in cutthroat trout skeletal muscle from Elk River, September 1996.
Effects threshold (reproductive failure and teratogenicity) from Lemly (1993a). Error bars = ± 1 standard deviation.

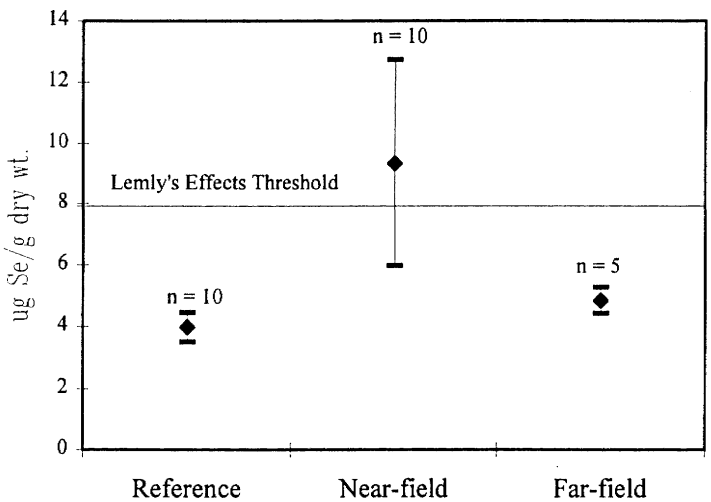
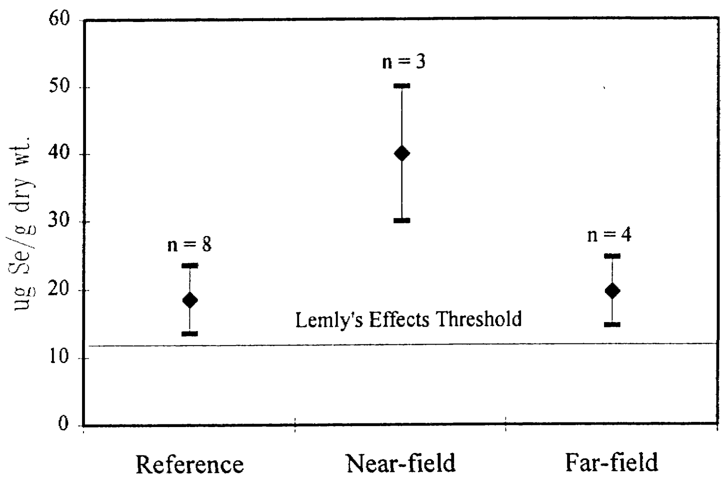


Figure 8. Selenium in cutthroat trout liver from Elk River, September 1996.
Effects threshold (reproductive failure and teratogenicity) from Lemly (1993a). Sample sizes include discreet analysis on larger fish and composites of smaller fish: Reference = 6 discreet, 2 composites; Near-field = 3 composites; Far-field = 1 composite, 3 discreet. Error bars = mean ± 1 standard deviation.



4.0 Discussion

4.1 Selenium Mobilization from Surface Coal Mining

The results presented in Section 3.1 confirm that significant quantities of selenium, mostly in the dissolved form, are being mobilized by surface coal mining into the Elk River system. This survey did not sample a sufficient number of tributaries affected by other land uses to conclude that coal mining is the only source of Se in the basin. The fact that levels decline in the major rivers with the distance downstream from the coal mines and that no Se was detected above indicate that the mines are by far the largest source.

Selenium in western North America is found predominantly in Cretaceous marine sedimentary formations, outcrops of which cover an estimated 780,000 km^2 from Mexico to Canada (Presser *et al* 1994). Coals of the Elk Valley are found in the Mist Mountain Formation of the Jurassic-Cretaceous Kootenay Group (Grieve and Goddarzi 1993). In alkaline, aerobic conditions, elemental Se and selenide minerals are oxidized releasing soluble selenate ions, which can be transported in runoff to surface waters (Eisler 1985).

Selenium mobilization has been found in irrigation under-drainage of seleniferous dry belt soils in the western United States (Saiki *et al* 1993), and in the effluents from coal-fired power plants in the east (Lemly 1985). The situation in the Elk Valley appears to be the first example of significant selenium mobilization into surface freshwater resulting from coal mining. Selenium mobilization into groundwater from surface coal mining was discovered in the Powder River Basin, Wyoming in the early 1980s (Dreher and Finkelman 1992).

Large scale surface coal mining in the Elk Valley commenced in 1970 and has since expanded in production and area disturbed. In 1996, coal production at the five large mines in the valley was 20×10^6 tonnes. At typical coal to waste rock stripping ratios of around 7 to 1, approximately 140×10^6 tonnes of rock is blasted and dumped along mountainsides and as small tributary valley fills each year. This massive disturbance of Se bearing strata introduces oxygen, altering chemical equilibria including the redox/pH dependent selenide/selenite/selenate balance (Dreher and Finkelman 1992). Water from snowmelt, rain or groundwater from upslope can pass much more easily through the waste rock dumps than the in-place formations prior to mining thus providing the transport mechanism to carry the soluble, oxidized Se out to surface waters.

Dreher and Finkelman (1992) reported that in the Powder River Basin, Wyoming, Se had similar modes of occurrence in coal and overlying rock and found that most of the waste rock Se was either water soluble or ion exchangeable. They found the unsaturated strata, above the water table, had Se levels greater than saturated zones. Mining into the saturated levels introduced oxygen raising the redox potential from reducing conditions, where insoluble selenide predominates, to oxidizing conditions, where soluble, mobile selenate dominates. The Powder River mine is located on flat terrain, employing a trench/backfill method. Selenium mobilization in this area has raised concerns that contaminated groundwater exceeds guidelines for livestock watering but no contamination of surface waters has been reported.

Various drainages from waste dumps exhibit widely varying levels of selenium, suggesting that Se is not homogeneously distributed throughout the coal bearing strata and/or the mobilization mechanism is complex and dependent on site specific conditions. Much more work is required in order to fully understand the mechanism of Se mobilization from the Elk Valley coal mines.

4.2 Potential Toxic Effects

Selenium is considered to be one of the most toxic elements to fish, when compared to other metals like arsenic, chromium and copper (Sorensen 1991). Sorensen (1991) reported 96-h LC_{50} values for golden shiners of 11.2 mg/L, and 48-h LC_{50} values of 0.4, 0.5 and 1.1 mg/L for bluegills, rainbow trout and fathead minnows. Concentrations this high are seldom encountered in surface freshwater, even in Se-contaminated systems. The highest level found in this study was 0.542 mg/L (542 µg/L) (see Section 3.1), and in most other streams seldom exceeded 0.1 mg/L (100 µg/L).

Selenium is also a vital trace nutrient for many animals, required for the proper function of the enzyme glutathione peroxidase, an antioxidant that protects cell membranes from lipid peroxidation (Eisler 1985, Spallholz 1994, Lemly 1997). Sorensen (1991) reported that rainbow trout required dietary Se levels of 0.07 µg/g dry wt. and/or aqueous levels of 0.4 µg/L. Lemly (1997) reports that fish require 0.1-0.5 µg/g dry wt. in their diet. The toxicity of Se is due to the fact that it is biochemically very similarity to sulphur. Selenium, in excess of nutritional requirements, becomes substituted for sulphur in cellular proteins impairing their proper function (Lemly 1997).

Although the direct toxicity of waterborne Se to adult fish occurs at relatively high concentrations, greater than 400 µg/L, species of fish have been eliminated from lakes and wetlands due to reproductive failure while other species suffered embryonic deformities at water concentrations as low as 10 µg/L (Lemly 1985).

Research over the past ten years has clearly shown that the major pathway of selenium bioaccumulation in fish and waterfowl is through the diet (Lemly 1985, Hamilton and Waddell 1994, Heinz *et al* 1989, Crane *et al* 1992, Maier and Knight 1994, Stanley *et al* 1996, Zhang and Moore 1996) and not directly from the water column. Sorensen (1991) estimated that in fish, bioaccumulation of Se from water was only 29 to 44% of that from a complex food chain, most of this direct uptake being through the gills (Lemly 1997).

Food chain organisms, notably algae and aquatic invertebrates, can accumulate very high residues without suffering any negative effects (Kiffney and Knight 1990, Lemly 1993a). Other studies have shown that algal populations can actually adapt to selenium exposure and that algal and invertebrate sensitivity are not related to bioconcentration factors, which can easily exceed 1000 times water column concentrations (Maier and Knight 1993, Dobbs *et al* 1996). Many of the field studies reported in the literature indicate biomagnification of Se through food chains in contaminated habitats but laboratory research has not clearly demonstrated progressively higher Se residues in successive trophic levels (Lemly 1993a).

The toxic effects resulting from Se bioaccumulation in fish include reproductive failure in the female, manifested as a loss of oocytes and gonad tissue necrosis (Hamilton and Waddell 1994), and/or teratogenic deformities in the embryo (Lemly 1993b, Lemly 1997). Selenium bioaccumulation in male fish, based on studies of bluegills (Gillespie and Baumann 1986 reported in Hodson 1990), does not causing teratogenisis when contaminated males were crossed with clean females. Similarly, Hamilton and Waddell (1994) found that the eggs of razorback sucker females fed a high-Se diet exhibited elevated Se levels but the milt of the males did not.

Lemly (1997) reports that dietary Se levels >3 µg Se/g dry wt. cause deposition in developing eggs, particularly in the yolk, and that the prevalence of teratogenisis in embryos increases rapidly at egg levels >10 µg Se/g dry wt. He further states that, once juvenile fish stop relying on the yolk sac and begin external feeding, the potential for teratogenisis declines and soon stops.

There have been no known reports of Se toxicity in the form of embryo deformities or reproductive failure in fish or birds from the Elk River. There have, however, been no scientific investigation of these potential effects. The presence of robust populations of three game fish species is certainly evidence of the lack of severe effects but does not mean that chronic Se toxicity is not occurring. Affected embryos that either die or prematurely fall victim to predation or competition can go unnoticed (Lemly 1993b), particularly in fish species where many such mortalities may occur prior to emergence of fry from the spawning gravels. There have been cases of Se induced reproductive failure with little or no tissue pathology or mortalities in adult fish (Lemly and Smith 1987). Lemly (1993b) found deformed adult fish in a lake receiving Se-laden effluent from a coal fired power plant. He concluded that these deformed individuals could only survive to been found because predatory species had been eliminated from the lake due to Se poisoning. Lemly (1997) states that entire populations of fish may disappear with little evidence of toxicity because the major impacts occur in the early life stages, while the surviving adults appear quite healthy. Deformed juvenile fish in a river would have the additional challenge of maintaining themselves against the current, including the rigors of spring freshet.

Throughout the Elk River system the sizes and numbers of cutthroat and bull trout have actually been increasing in response to angling restrictions first introduced 15 years ago (W. Westover pers. com. 1997). These populations were heavily over-fished in the 1960s and 70s and their recovery, particularly noticeable in the past 5 years, has been remarkable. At the same time the isolated population of westslope cutthroat trout in the upper Fording River (the near-field site in this study) is reported to have diminished in size between 1979 and 1990 by 47% (Norecol 1990). The cause of this apparent reduction in this population of fish is unknown, but at this point selenium can not be ruled out as a contributing factor.

This study does not attempt to evaluate the presence of Se-induced teratogenic effects in the embryos of fish or waterfowl directly, but it does serve as an initial examination of selenium residues in the food chain and in fish tissues. Comparison of these findings, in particular the levels in the tissues of fish, to toxic effects thresholds reported in the literature (Lemly 1993a), show that some of the thresholds are exceeded. These findings are not evidence that toxic effects are occurring in the fish in the Elk River, specifically the cutthroat in the Fording River with the highest tissue levels. However, they clearly indicate the need for additional study to determine if there are toxic effects in these fish. A study on the frequency of embryo mortalities and deformities in both fish and birds from the Elk River system in relation to tissue Se levels is required to determine if the Se mobilization into the river water is causing reproductive failure or teratogenic effects and, if so, at what Se level in the eggs. Lemly (1997) has proposed this method for evaluating the impacts of selenium contamination, describing it as a "teratogenic deformity index".

4.3 Comparison of Selenium Levels in the Elk River with Other Aquatic Ecosystems

As discussed in Section 4.1, the large scale land disturbance due to surface coal mining in the Elk Valley is releasing significant quantities of Se into the river system. The seleniferous geology of the basin and some of our findings suggest that Se mobilization due to natural erosional processes may be occurring at a much slower rate above the mines. This may well give rise to higher Se levels throughout the aquatic ecosystem than in streams located in low or non-seleniferous strata.

Table 9 compares Se levels in water, sediment and biota from this initial survey of the Elk River basin with other rivers, lakes and wetlands throughout North America. The best comparisons require sufficiently low detection limit analytical methods at all locations. Unfortunately, data from areas with low, background levels of Se often employed high detection limits. Much of these data were from programs that were not specifically intended to monitor Se and only exist because of the use of multi-element scans. Biologically important differences in the levels of various analytes can often exist between sites or occur over time but be completely unknown because all levels are below analytical detection limits. Using a hypothetical example to illustrate, Se levels in a relatively unimpacted stream in a seleniferous basin might range from 0.07 - 0.3 µg/L, while a stream in a non-seleniferous area might range from 0.005 - 0.02 µg/L. This difference may have significant biological implications, fish in the seleniferous stream may be relatively Se tolerant, while fish at the non-seleniferous site may suffer from Se deficiency. A comparative monitoring program, even one employing a fairly low detection limit of 1 µg/L, would probably conclude, because all the results would be non-detects, that the streams were identical with respect to selenium.

Discussion in sections 4.3.1 to 4.3.4 below is based on Table 9. Information sources are cited in the table but are not re-cited in the text.

4.3.1 Water (Table 9A)

There has been a substantial amount of selenium monitoring on the Elk River system although mostly below the sources of selenium. These data include a 10 year trend site at the mouth (Wipperman 1997), where 95% of the data (n = 190) are above the detection limit of 0.1 µg/L, and extensive spatial sampling nearer the selenium sources, where all the data are above the 1.0 µg/L detection limit. We are lacking in data from the control reaches of the basin where we only have two samples analyzed using the 0.1 µg/L detection limit method. The 24 reference reach samples at or below the 1 µg/L detection do not allow us to compare the Elk River to other East Kootenay rivers where we have long records at 0.1 µg/L detection.

The Moyie River, a relatively soft-water system draining the mineralized Purcell Mountains 60 km west of the Elk River, had very low total Se, with a maximum of 0.2 µg/L and only 8% of the

Table 9. Selenium residues in water, sediment and biota in various aquatic systems in North America.

	MDL	Mean	Range	n	# of sites	% > MDL	Reference
A. Water (ug Se/L)							
Elk River (total Se)							
reference	0.1	0.1	0.1 - 0.2	2	1	50	This study
reference	1.0		< 1.0 - 1.0	24	4	0	This study
Se-exposed area							
major tributaries	1.0	11.7	2 - 26	63	10	100	This study
small tributaries	1.0	49.5	2 - 542	105	18	100	This study
mouth	0.1	1.2	< 0.1 - 2.5	190	1	95	Wipperman 1997
Other B.C. Rivers (total Se)							
Kootenay River	0.1		< 0.1 - 0.7	190	1	50	Webber 1996
Moyie River	0.1		< 0.1 - 0.2	70	1	8	Webber and Wipperman 1996
Flathead River	0.1		< 0.1 - 0.7	190	1	74	Shaw and Taylor 1994
U.S. Rivers (dissolved Se)							
Ohio			< 0.01				Eisler 1985
Mississippi			0.14				Eisler 1985
Arkansas River, CO	1.0	31.1	5 - 188	22	9	100	Van Derveer and Canton 1997
Gunnison/Uncompahgre, CO		48.2		75	8		Van Derveer and Canton 1997
Bell Fourche, SD		6.7		22	4		Van Derveer and Canton 1997
Angostura, SD		4		21	6		Van Derveer and Canton 1997
Middle Green, UT		20	4 - 140	19		100	Presser et al 1994
U.S. Wetlands and Lakes (dissolved Se)							
Belews Lake, NC		10	3.0 - 22.3				Lemly 1985
Kesterson NWR, CA			14 - 350				Presser et al 1994

Table 9. Selenium residues in water, sediment and biota in various aquatic systems in North America.

		MDL	Mean	Range	n	# of sites	% > MDL	Reference
B. Sediment	**(ug Se/g dry wt.)**							
Elk River								
	reference	0.2	0.8	0.5 - 1.3	4	4	100	This study
	Se-exposed areas	0.2	1.7	0.7 - 2.4	6	6	100	This study
Other B.C. Rivers								
	Columbia & Kootenay	1.0		< 1.0 - 1.0	14	10	0	Norecol 1993
U.S. Rivers								
	Arkansas River, CO	0.23	1.8	0.33 - 8.7	8	8	100	Van Derveer and Canton 1997
	Gunnison/Uncompahgre, CO		5.8	1.9 - 16.0	8	8		Van Derveer and Canton 1997
	Bell Fourche, SD		1.7	0.8 - 3.2	4	4		Van Derveer and Canton 1997
	Angostura, SD		3.0	0.6 - 12.0	6	6		Van Derveer and Canton 1997
	Middle Green, UT	0.1	7.5	0.1 - 95.0	9			Presser et al 1994
U.S. Wetlands and Lakes								
	Great Lakes			0.35 - 0.75				Eisler 1985
	Belews Lake, NC		4.8	1.3 - 10.0				Lemly 1985
	Kesterson NWR, CA		2.9	2.5 - 6.5				Lemly 1985

Table 9. Selenium residues in water, sediment and biota in various aquatic systems in North America.

	MDL	Mean	Range	n	# of sites	% > MDL	Reference
C. Food Chain Organisms (ug Se/g dry wt.)							
Elk River							
Periphyton							
reference	0.1		0.3	1	1	100	This study
Se-exposed areas	0.1	1.2	0.8 - 1.6	5	5	100	This study
Benthic Invertebrates							
reference	0.1	4.8	2.7 - 6.8	2	2	100	This study
Se-exposed areas	0.1	7.0	4.3 - 10.7	5	5	100	This study
Columbia & Kootenay							
Marcophytes	0.5		< 0.5	2	2	0	Norecol 1993
Adult Caddis flies	0.5	2.1	1.3 - 2.7	6	4	100	Norecol 1993
Great Lakes							
plankton & benthic inverts.			0..8 - 4.7				Hodson 1990
Belews Lake, NC							
Zooplankton			40 - 100				Hodson 1990
Benthic Invertebrates			70				Hodson 1990
Kesterson NWR, CA							
Algae			13 - 246				Presser et al 1994
Macrophytes			12.9 - 35.4				Lemly 1985
Plankton			18.1 - 35.6				Lemly 1985
Aquatic insects			6.4 - 96.3				Lemly 1985

Table 9. Selenium residues in water, sediment and biota in various aquatic systems in North America.

		MDL	Mean	Range	n	# of sites	% > MDL	Reference
D. Fish	**(ug Se/g dry wt.)**							
Elk River (*Oncorhynchus clarki lewisi*)								
Skeletal muscle	reference	0.1	4.0	3.0 - 4.6	10	1		This study
	Se-exposed area	0.1	9.3	6.1 - 16	10	1		This study
Liver	reference	0.1	18.5	11.7 -25.7	8	1		This study
	Se-exposed area	0.1	40	33.5 - 51.5	3	1		This study
Gonad	reference	0.1		22	1	1		This study
	Se-exposed area	0.1		28.2	1	1		This study
Slocan River (*Prosopium williamsoni*)								
Skeletal muscle		2.0		all < 2.0	17	1	0	Antcliffe et al 1997
Columbia River (*Prosopium williamsoni*)								
Skeletal muscle		2.0		< 2.0 - 3.0	34	2	3	Antcliffe et al 1997
Belews Lake, N C (*Gambusia affinis*)								
Whole body								
During effluent disch.		0.079	99.7	50.6 - 131	~50	1	100	Lemly 1993a
After effluent stopped		0.079	17.7	16.5 - 18.9	~20	1	100	Lemly 1993a
Reference Lakes		0.079	1.55	1.05 - 2.06	~60	2	100	Lemly 1993a
San Joquin Valley, CA (*Gambusia affinis*)								
Whole body								
Volta WMA (control)			1.3	1.2 - 1.4				Eisler 1985
Kesterson WMA			170	115 - 283				Eisler 1985
Wyoming (*Oncorhynchus clarki lewisi* and *O. mykiss*)								
* Streams with natural Se levels of 12.3 to 13.3 ug/L								
Skeletal muscle				< 2.0				Eisler 1985
Liver				50 - 70				Eisler 1985

70 samples above the detection limit. The Kootenay River, into which the Elk River empties (below the sample site), had a maximum of 0.7 µg/L and about 50% of the 190 samples were over detection. The east part of the Kootenay River basin, above the sample site, drains the continental divide north of the Elk River basin, the west part drains the Purcell range. A site on the Kootenay River at Kootenay Crossing located in Kootenay National Park (not in Table 9), draining only the Rocky Mountains, had a maximum of 1.5 µg/L (0.4 µg/L was the next highest) and 11% of the 150 samples were greater than the 0.1 µg/L detection limit (Pommen, L.W. pers. comm.).

The Flathead River, which drains the continental divide south of the Elk River had total Se levels similar to the Kootenay River with a 0.7 µg/L maximum and 74% of the 190 samples over detection.

Rivers in the U.S. east of the Mississippi, appear to have very low Se levels. The Arkansas River basin has been found to have naturally high dissolved Se, ranging from 2 - 30 µg/L (with some small seeps ranging as high as 240 µg/L). This Se originates from the weathering of Cretaceous marine shales (Van Derveer and Canton 1997). Other dry belt U.S. streams in Table 9 receive Se-contaminated irrigation drainage and have Se levels similar to the Elk River below the coal mines.

Belews Lake, NC, contaminated by thermal power plant effluent, and the Kesterson wetlands in California, receiving Se-laden irrigation drainage, are included in Table 9 to show the waterborne Se levels in waters where serious effects on fish and birds have occurred. Se concentrations in these aquatic systems do not differ greatly from those in various streams, including the Elk, yet the biological impacts are apparently far worse, illustrating the importance of the habitat type, not just the water column concentration, in determining the extent of Se aquatic toxicity.

4.3.2 Sediments (Table 9B)

Selenium has been analyzed, as part of multi-element scans, in sediment surveys on a number of streams and lakes throughout British Columbia over the past 15 years. The detection limit for most of these scans, 10 µg Se/g dry wt., is higher than the current B.C. criterion for the protection of freshwater aquatic life of 5 µg/L (Nagpal et al. 1995) and too high to compare to Se surveys using detection limits in the order of 0.2 µg Se/g dry wt.

Sediment sampling in the Columbia and Kootenay Rivers near their confluence in 1992 found sediment Se at or below the detection limit of 1 µg Se/g dry wt. at 9 sites, including two sites below a large lead-zinc smelter (Norecol 1993). These data indicate that Se in river sediments in the Elk River, at both reference and Se-exposed areas (0.5 to 2.41 µg Se/g dry wt.), are higher than in these major rivers. More sampling effort is required to confirm this.

Sediment Se in the Arkansas River basin, where there is significant dissolved Se in the water, generally ranged from 0.33 - 1.5 μg Se/g dry wt., although one small creek had a significantly higher level of 8.7 μg Se/g dry wt. (Van Derveer and Canton 1997). These levels of sediment Se are very similar to those we found in the Elk River. The other U.S. rivers in Table 9B are generally lower gradient streams than the Elk River, and drain seleniferous areas, often receiving Se-contaminated irrigation drainage. The highest sediment Se reported in these slow-flowing systems, the Middle Green River in Utah, was 40 times the maximum found in the Elk River system.

Sediment Se in wetland habitats where serious toxic effects have occurred, Belews Lake and Kesterson, were less than twice the highest level found in the Elk River or in much of the Arkansas River. Neither the Elk River nor the Arkansas River basins exhibit the rather obvious Se toxicity in fish and birds of Belews or Kesterson, suggesting that sediment Se levels alone are insufficient to predict toxic effects.

4.3.3 Food-Chain Organisms (Table 9C)

There has been very little sampling for Se in aquatic vegetation or benthic invertebrates in B.C. except as part of multi-element scans with relatively high detection limits. Sampling of river macrophytes (*Potomegeton sp.*) in the Columbia and Kootenay Rivers near their confluence in 1992 found less than 0.5 μg Se/g dry wt. in two samples, including one below a large lead/zinc smelter. In the same study, adult caddis flies, captured by light trap as they emerged from the river, had Se levels slightly below those found at the reference sites on the Elk River.

Saiki et al. (1993) reported levels of Se in algae and benthic invertebrates from non-seleniferous habitats usually averaged less than 5 μg Se/g dry wt., a level that, in the Elk River, was exceeded in benthic insect samples from one reference site and the near-field sites but never exceeded in algal samples. Net plankton and benthic invertebrates in the Great Lakes, a low Se environment, contained levels similar to the Elk River control sites (0.8 - 4.70 μg Se/g dry wt.). Eisler (1985) reviewed the literature and reported that filamentous algae from various reference areas had less than 0.5 μg Se/g dry wt. compared to 12 - 68 μg Se/g dry wt. in contaminated areas (wetlands). Rooted macrophytes had 0.4 μg Se/g dry wt. in reference areas, 18 - 79 μg Se/g dry wt. at contaminated sites (wetlands). Similarly benthic insects had 1.1 - 3.0 μg Se/g dry wt. in reference areas, 20 - 218 μg Se/g dry wt. contaminated areas.

Maximum Se levels found in food-chain organisms in Belews Lake and the Kesterson NWR wetlands, where serious Se toxicity in fish and birds has been recorded, were 7 to 10 times the maximums found in the Elk River. This illustrates the critically important difference between standing and flowing water habitats with respect to Se bioaccumulation and subsequent toxic effects. Despite the fact that Se levels in the water of these wetlands is similar to the Elk River, food-chain bioaccumulation is much greater.

Further bioaccumulation monitoring is required in the Elk River to better characterize the Se content of various food-chain organisms. It should be possible to collect sufficient quantities of the large Hydropsychid caddis fly larvae and Perlodid stonefly nymphs to analyze separately to examine the detrital Se bioaccumulation pathways at different sites. Aquatic vegetation and invertebrates in stream-side wetlands should also be sampled to evaluate higher risk micro-habitats.

4.3.4 Fish (Table 9D)

Little information exists on Se levels in fish in British Columbia. Multi-element scans that included Se were often at detection limits that were too high to be meaningful. Studies on the Slocan and Columbia Rivers in the West Kootenays had reasonably low detection limits at 2 μg Se/g dry wt., and the large numbers of Mountain whitefish sampled had skeletal muscle levels at or below this value. These levels are lower than the same tissue levels in reference site cutthroat trout in the Elk River and considerably lower than those from Se-exposed sites.

Table 9D also includes data from fish in Belews Lake and the Kesterson NWR to illustrate the levels of Se in fish tissues where toxic effects have been observed. In both cases, analyses were performed on the whole body of the small mosquito fish, one of the only species to survive. Keeping the species and habitat differences in mind, reference sites for Belews and Kesterson were similar to or slightly lower than Elk River reference sites. During the effluent discharge period at Belews Lake, when the toxic effects were occurring, the mosquito fish whole body Se was 8 to 10 times the highest cutthroat muscle levels in the Elk River. Adding the internal organs to the cutthroat analysis (whole body) would produce levels somewhat higher than the skeletal muscle, the tissue with the greatest mass, but the Belews mosquitofish would still have been around 5 or 6 times this level when the toxic effects occurred. Mosquitofish from Kesterson wetlands had even higher Se levels, from 15 to 20 times greater than the cutthroat from contaminated reaches of the Elk River.

As a final comparison, rainbow and cutthroat trout from streams in Wyoming, where water levels are 12.3 to 13.3 μg/L due to naturally occurring Se (similar to the exposed sites on the Elk River), had skeletal muscle levels of less than 2 μg Se/g dry wt., which are lower than all sites on the Elk River, including the reference site. Interestingly, liver tissue from these Wyoming trout contained 50 to 70 μg Se/g dry wt., which are higher than the 30 to 50 μg Se/g dry wt., found in our near-field Elk River site. As previously discussed the differences in Se bioaccumulation between fish in various streams depends more on the habitat factors than the relative concentrations of Se in the water.

4.4 The Importance of Detritus in Selenium Bioaccumulation

Lemly and Smith (1987) concluded that Se was introduced into aquatic food chains either through uptake by rooted plants or by detritus, either of which forms a food source for organisms which are, in turn, consumed by fish or birds. Selenium may be released by rooted plants or detrital decomposer flora back into the water in organic forms such as selenocysteine and selenomethionine (Lemly and Smith 1987, Besser et al. 1989, Saiki et al. 1993). These organoselenium compounds are much more readily bioaccumulated than inorganic forms such as selenate, the most common form in irrigation drainage (Presser et al. 1994). Besser et al. (1993) reported that selenomethionine at less than 1 μg/L bioconcentrated 50,000 times in algae and 350,000 times in daphnid zooplankton to levels of 5 - 12 μg Se/g dry wt.

In fast-flowing river systems, like the Elk River, there is relatively little rooted vegetation and much less accumulation of detritus compared to shallow lakes and wetlands. This means a reduced opportunity for conversion of inorganic selenate to organoselenium, so that bioconcentration in dietary organisms is considerably less in rivers than in standing-water habitats. This being said, Lemly and Smith (1987) point out that backwater pools or slow-moving reaches of rivers may experience greater levels of Se bioaccumulation than faster flowing sections.

The association of Se with fine-textured, organic bottom sediments or detritus (decaying organic matter) has been well documented in recent years. Besser et al. (1989) found that dissolved Se, composed of selenate, selenite and selenomethionine, was more readily adsorbed to organic pond sediments than to sandy river sediments. Presser et al. (1994), studying the Kesterson National Wildlife Refuge in California, found that, while whole sediment Se levels ranged from 5 - 10 μg Se/g dry wt., the detrital component contained 40 - 130 μg Se/g dry wt. Saiki et al. (1993) proposed that bioaccumulation of Se by bacteria and other microfloral living on the detritus was a more probable accumulation mechanism than detrital particle adsorption.

Recent research on streams in Colorado has shown that, despite the fact that dissolved Se levels in some tributaries range as high as 50 μg/L, ten times the EPA criteria, healthy fisheries thrive and no biological effects have been observed (Canton and Van Derveer 1997). This is believed to be due to the paucity of organic detritus and subsequent low level of Se uptake from the water. These studies have found that the level of Se in river sediments is dependent, not only on the amount of dissolved Se in the water, but also on the amount of organic detritus in the sediment, which can be measured by analyzing sediment total organic carbon (TOC) (Van Derveer and Canton 1997). Sediment TOC appears to be a major factor in determining whether elevated Se in water has the potential to bioaccumulate in the aquatic food chain and produce toxic effects in fish and birds.

4.5 Water Quality Criteria and Objectives

Water quality criteria for the protection of aquatic life are established through a critical review of recent laboratory and field toxicological research. A vast majority of this research involves the measurement of a biological endpoint (growth, reproductive success, number of mortalities) following the exposure of a test species to various waterborne toxicant concentrations. Maier and Knight (1994) discuss the inappropriateness of this approach for toxicants like selenium that cycle naturally through aquatic systems and can bioaccumulate to levels that produce toxic effects. As has been discussed, the level of bioaccumulation of Se and subsequent severity of toxic response is probably more dependent on the type of the aquatic habitat than it is on the waterborne concentration.

The current Canadian Water Quality Guideline for total selenium for the protection of freshwater aquatic life is 1 μg/L (CCREM 1987). This was based on toxicological research up to about 1983 and thus does not benefit from extensive field and laboratory research conducted over the past 15 years. The British Columbia Ministry of Environment, Lands and Parks, in cooperation with the Canadian Council of Ministers of Environment, is presently reviewing and updating this criterion.

The universal application of a generic waterborne Se criterion for the protection of aquatic life on any waterbody carries the risk of being under-protective in areas of high bioaccumulation potential, such as terminal wetlands, and over-protective in fast-flowing rivers with minimal opportunity for bioaccumulation. It would seem there could be no better case for the establishment of a site-specific water quality objective, which takes into account the habitat characteristics affecting bioaccumulation. Objectives for levels of Se in dietary organisms and/or the tissues of sensitive species may be an even better approach (Maier and Knight 1994). Diet or tissue objectives would require that some level of toxic effect be measurable which can be statistically correlated to the Se levels in a sentinel species.

Van Derveer and Canton (1997) discovered that in the middle Arkansas River basin sediment Se showed positive ln - ln correlations with mean dissolved Se, sediment TOC, and the interaction term of mean dissolved Se x sediment TOC. Using these empirical relationships, the authors were able to develop a regression model for the calculation of a site-specific water quality objective. Inserting the literature derived predicted effects level for sediment Se of 2.5 μg Se/g dry wt. and a typical Colorado stream sediment TOC of 0.5% into the model produces a dissolved Se objective of 31 μg/L, which is considerably higher than the EPA criterion of 5 μg/L. When a sediment TOC of 5% is used, typical of wetlands where serious Se toxicity has been found, the dissolved Se objective falls to 3 μg/L.

In the Elk River we also found positive ln - ln correlations ($n = 8$) of sediment Se with sediment TOC ($r = 0.88$, $p < 0.01$), and the interaction factor of sediment TOC x water column total Se ($r = 0.85$, $p < 0.01$), but not with water column total Se ($r = 0.65$, $p > 0.05$). Van Derveer and Canton (1997) found sediment Se to behave similarly in various habitat types despite the waterborne speciation and recommend using total Se (used in our Elk River study) for model development.

Van Derveer and Canton (1997) found sediment TOC levels ranging from 0.07 - 0.67% in most of the Colorado streams they studied ($n = 7$), although one Se-contaminated stream had a value of 1.56%. In our study, we found most sites (n = 9) ranged from 0.5 - 8.1% with 35% TOC in Line Creek where sand-sized coal particles were visible (Table 4). This sample was omitted from the above ln - ln correlations. The presence of coal particles in the fine sediment sampled throughout the Elk River system, particularly below active coal mines, complicates the application of the sediment TOC approach used by Van Derveer and Canton (1997) for calculating a water quality objective.

Finely divided coal particles may well sequester dissolved Se from the water either through direct adsorption or uptake by the microbial flora, which the authors have seen colonizing freshly introduced coal silt. Unlike detritus, however, coal particles are not sought out as a food source by macroinvertebrates, though fine particles mixed with detritus may be consumed incidentally. Larger particles of coal will produce considerably elevated sediment TOC results, as in Line Creek, but will adsorb proportionately less Se due to smaller surface area to volume ratios and are even less likely to be consumed by benthic insects.

Canton and Van Derveer (1997) have proposed that in fast-flowing rivers, with their lower accumulation of organic detritus, water-based Se criteria derived largely from toxic effects that occur in slow-flowing or standing water systems will be over-protective. These authors have proposed that sediment Se criteria, based on the quantity of sediment organic matter (TOC) will be more meaningful in river systems. Further work is required in the Elk River to determine, if possible, the relative proportions of sediment TOC that are coal versus detritus, and if this can be used to predict levels of sediment Se that are likely to result in adverse biological effects.

A study to determine whether increased waterborne Se levels are causing an increase in the frequency of embryonic deformities and mortalities has been discussed (section 4.2). If these toxic effects exist and correlate to the level of Se in the eggs, an egg Se objective may be the most meaningful criterion.

5.0 Conclusions

1. Surface coal mines in the Elk Valley are a significant source of waterborne selenium which enters streams and rivers via smaller tributaries draining mine disturbed lands, usually waste rock dumps. This is resulting in levels in streams, just below contributing tributaries, that are up to 25 times the current B.C. water quality criteria for the protection of aquatic life of 1 μg/L.

2. Although waterborne selenium increased 100 to 200 times from reference sites to those just below source tributaries, levels in fine bottom sediments, attached algae, benthic invertebrates and fish tissues, only increased 2 to 5 times at these sites. This is an indication that a limited amount of selenium bioaccumulation is occurring in this fast-flowing river system.

3. Selenium levels in the tissues of westslope cutthroat trout in a population just below coal mine tributary sources, were elevated compared to those from a remote reference site and a site far downstream. These levels often exceeded literature reported toxic effects thresholds, as indeed did some fish tissue samples from the reference site.

4. These findings, plus information in the literature, suggest that there is a need to investigate selenium bioaccumulation in fast-flowing river systems and relate the levels in fish eggs to the frequency of embryonic mortalities and deformities in exposed versus reference populations. This is ultimately the only way to determine the applicability of current water quality criteria, conservatively set to protect fish in wetland habitats where the potential for bioaccumulation is comparatively high.

6.0 Recommendations

6.1 Site-Specific Water Quality Objectives

As discussed in 4.5 above, it is not reasonable or useful to apply generic selenium water quality criteria for the protection of aquatic life to all aquatic habitats. These criteria are purposely set to protect the most sensitive environments. Because bioaccumulation and subsequent toxic effects of selenium occur in organically enriched, standing-water habitats, water-based criteria must be very low and thus overly protective in fast-flowing streams.

When studies on the effects, or lack thereof, of current levels of bioaccumulation in fish and aquatic birds are complete, site-specific water quality objectives for selenium in the Elk River basin should be developed. These may include Se objectives for water, sediment, food-chain organisms, or fish and bird tissues.

6.2 Water Course and Stream Channel Management

Surface coal mining in the Elk Valley has resulted in many modifications to stream channels. Settling ponds, diversions, rock drains and valley fills from waste rock, are some examples. Some of these modifications are intended to be permanent, being designed as part of a final reclamation plan.

The discovery of selenium mobilization into surface waters coupled with recent research showing that bioaccumulation in fish and aquatic birds occurs predominantly in standing-water, wetland environments, has implications for stream channel reclamation. Simply put, if significant selenium mobilization is occurring upstream, fast-flowing channels should be restored and maintained while water retention structures (ponds, wetlands) should be avoided.

There are a number of settling ponds at some of the older mines that have been in place for as long as 25 years. Those receiving significant quantities of soluble selenium may provide excellent microhabitats for studying selenium bioaccumulation and help understand the implications of such manipulations of the natural aquatic environment and validate the above recommendation.

6.3 Additional Studies Required

Studies thus far have shown rising Se levels at the mouth of the Elk River over the past 10 years, some indication of the seasonal pattern of mobilization, a reasonable picture of the main sources, and an initial survey of Se accumulation in bottom sediments and biota. We currently have no information on the presence of toxic effects or the ecological implications of the release of large quantities of Se into the river. It is premature to make recommendations regarding remediation until additional study provides us with an understanding of the biological implications of this phenomenon.

The following are considered the most important follow-up studies needed:

- **Occurrence and frequency of embryonic mortalities and deformities in westslope cutthroat trout in Elk River system.**

  In order to determine if the relatively high levels of waterborne selenium are producing any significant reproductive or teratogenic effects, fertilized eggs from exposed and non-exposed (reference) fish should be raised in a laboratory and the relative numbers of embryonic mortalities and deformities compared. Westslope cutthroat trout (*Oncorhynchus clarki lewisi*) is proposed as the sentinel species as it is the only species found at the site with the highest selenium exposure (the Fording River) as well as all other areas throughout the basin. The eggs from each female should be reared separately so that the rate of mortalities and deformities can be related to the selenium content of the eggs. To be statistically significant it is recommended that the eggs from at least 20 females per site, ideally fertilized by 20 separate males, from two exposed and two reference sites be examined. As many biological end-points as possible (% mortalities, % deformities, abdominal distension, growth, respiration, etc.) should be examined.

- **Selenium bioaccumulation in stream side-channel wetland vegetation and food chain in the Elk River system.**

  More thorough bioaccumulation sampling in the Elk River basin is needed. The most likely sites for selenium bioaccumulation into detritus and the food chain, and hence into fish and birds, are side-channel wetlands or marshes. Water, fine sediments, emergent vegetation and invertebrates in several of these "micro-habitats" in both selenium exposed and reference areas should to be sampled for selenium accumulation.

- **Selenium bioaccumulation and embryo effects in aquatic birds in the Elk River system.**

  Birds which feed on emergent vegetation or aquatic invertebrates that have accumulated large amounts of selenium may suffer the same or worse effects (embryo mortalities and/or deformities) than fish in the same habitats. A survey of birds species that feed in side-channel wetland habitats, comparing nestling mortality and deformity rates between selenium exposed and reference populations, should be conducted.

- **Selenium bioaccumulation in zooplankton and fish in Lake Koocanusa.**

  Lake Koocanusa, the reservoir formed by the Libby Dam on the Kootenai River in Montana, receives all the selenium transported downstream from the Elk River. There is a need to survey selenium levels in reservoir water and bottom sediments and to examine the level of bioaccumulation in zooplankton, planktivorous fish (kokanee), and predatory fish (bull trout). Sampling in another similar large lake or reservoir not receiving increased loadings of selenium can be used as a comparative reference site.

- **Selenium mobilization mechanism in surface coal mining.**

  A study to determine the geochemical process that releases selenium from the coal bearing strata being mined in the Elk Valley is required. Hopefully this study can help explain the wide variation in selenium levels in various mine affected tributaries. Other issues that should be addressed include the duration of selenium release from various sources (waste rock dumps, tailings, etc.), and whether current rock dump reclamation practices reduce the level of mobilization over time.

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APPENDICES

I Total selenium in the Elk River basin in 1996.

II Total selenium at the Fording Coal Ltd. Fording River mine in 1995-96.

III Fish captured in September 1996 bioaccumulation survey: raw data.

IV Fish stomach contents.

Appendix I. Total selenium in the Elk River basin in 1996

Site Description	Site Type	Figure	96/04/16 ASL	96/04/16 Zenon	96/05/01 ASL	96/05/07 Zenon	96/05/21 ASL	96/05/21 Zenon	96/08/13 ASL	96/08/13 Zenon	96/12/03 ASL
Fording R. d/s of Smith Ponds	NF		16	15.3		19.6	6		10		12
Swift Cr. d/s of Settling Ponds	MT	4	33				18		45		42
Cataract Cr. d/s of Settling Ponds	MT	4	31				34		57		25
Porter Cr. d/s of Settling Ponds	MT	4	71		78.7		44		53	60.8	37
Greenhills Cr. d/s of Settling Pond	MT	4	13					8.9	18		11
Greenhills Tailings Pond supernatant	PW		3				7		13		10
Elk R. u/s of Greenhills Operations	R	3	<1				<1		<1		<1
Elk R. u/s of Elkford Bridge	FF/R		1	0.9			<1		<1		4
Line Cr. u/s of South Line Cr.	NF	4	21		16.5		10		21	18.4	24
Line Cr. at mouth	NF	3	11	8.9			5		8		12
Fording R. at mouth	FF	3	11	10.8			7		8		8
Harmer Cr.d/s of dam	MT	4	22		29.1		16		21		n/a
Goddard Cr. d/s of coal refuse	MT		7				7		22		16
Elkview Tailings Pond supernatant	PW		9				5		6		8
Elk R. d/s of Michel Cr.	FF	3	3				2		3		3
Sulphur Spring south of Hosmer	R	4	<1	<0.5			<1		<1		<1
Michel Cr. near mouth	FF	3	3	2.6			2		7		8
Bodie Cr. d/s of Settling Pond	MT	4	20		21		21	27.2	11	13.5	5
Erickson Cr. near mouth	MT	4	65				58	126	61	106	59
Michel Cr. u/s of Alexander Cr.	FF/R	3	<1				<1		1		<1
Michel Cr. u/s of Corbin Cr.	R		<1				<1		<1		<1
Corbin Cr. d/s of Settling Ponds	3	4	4				3	4	2		2

All analyses in ug/L.
Site Types: R = reference; MT = mine affected tributary; NF = near-field; FF = far-field
Figure column refers the figure in the report that a particular site is plotted on.

Appendix II

Total selenium at the Fording Coal Ltd. Fording River mine in 1995-96

Sample Site	04/25/95	05/14/95	02/14/96	03/18/96	04/16/96	05/21/96	06/19/96	07/15/96	08/13/96	09/24/96	23/10/96	19/11/96	03/12/96	21/01/97
							Selenium T-Se	(milligrams/litre)						
UFR1	n/a	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ic	ic	ic	ic	ic	<0.001	<0.001
HC2	n/a	0.001	n/a	0.001	<0.001	<0.001	<0.001	ic	ic	ic	ic	<0.001	<0.001	<0.001
HC1	n/a	n/a	0.001	0.001	<0.001	<0.001	ic	ic	ic	ic	ic	ic	<0.001	<0.001
FR1	n/a	0.001	n/a	n/a	n/a	n/a	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	nf	nf
Fish Creek	n/a	n/a	<0.001	0.001	<0.001	<0.001	<0.001	ic	ic	ic	ic	ic	<0.001	<0.001
CC1	n/a	n/a	0.001	0.016	0.034	0.034	0.026	0.030	0.031	<0.001	0.030	0.018	0.013	0.004
FR above NGD1	n/a	n/a	n/a	0.013	0.010	0.003	0.002	0.002	0.005	0.007	0.007	0.014	0.009	0.002
Mtn. Lake	n/a	n/a	n/a	n/a	n/a	n/a	<0.001	<0.001	ic	ic	ic	ic	ic	ic
NGD Below Mtn. Lk.	n/a	n/a	n/a	0.014	<0.001	<0.001	<0.001	<0.001	<0.001	0.020	nf	nf	nf	nf
NGD Below Rock Drain	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.012	nf	nf	nf	nf
NGD Pond Inlet	n/a	n/a	n/a	0.032	0.026	0.017	0.004	0.010	0.019	0.022	0.034	0.026	0.020	0.023
NGD1	n/a	n/a	0.022	0.030	0.030	0.017	0.004	0.010	0.018	0.015	0.031	0.022	0.019	0.021
WSCFR	n/a	n/a	0.008	0.014	0.016	0.005	0.002	<0.001	0.005	0.005	0.013	0.012	0.009	0.009
Breaker Ditches to Eagle	n/a	n/a	n/a	0.042	0.040	0.040	0.041	0.094	0.083	0.034	0.050	0.108	0.045	0.056
Eagle North Flow	n/a	n/a	n/a	nf	nf	nf	nf	nf	nf	0.339	0.289	0.542	0.075	0.206
Eagle 1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.212	nf	nf	nf
Eagle 2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.328	nf	nf	nf
Eagle Primary	n/a	n/a	n/a	n/a	n/a	n/a	0.105	n/a	0.124	0.177	0.163	nf	nf	nf
Eagle Secondary	n/a	n/a	n/a	n/a	n/a	n/a	0.093	n/a	0.184	n/a	0.450	0.435	nf	0.184
EC1	n/a	n/a	0.192	0.071	0.081	0.085	nf	0.315	nf	0.289	nf	nf	nf	nf
Multi Plate	n/a	n/a	0.023	0.022	0.017	0.007	0.002	0.003	0.007	0.015	0.017	0.030	0.018	0.022
Lees Lake	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.016
NTP Barge	n/a	n/a	0.019	0.022	0.022	0.017	0.016	ic	ic	ic	0.028	0.021	0.016	0.014
Shandley	0.019	0.013	0.025	0.017	0.011	0.017	0.028	ic	ic	ic	ic	ic	ic	0.016
Reject Bin	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.017	0.025
Clean Coal	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.030
BXL Bridge	0.025	0.017	0.021	0.022	0.020	0.007	0.002	n/a	n/a	n/a	0.012	0.028	0.017	0.022
NL1	n/a	n/a	0.002	0.002	0.003	0.002	0.005	n/a	n/a	n/a	n/a	0.014	0.015	0.012
CIL Ditch	n/a	n/a	0.013	0.002	0.012	0.009	0.003	n/a	n/a	0.009	0.006	0.015	0.013	0.019
Smith Pond	0.054	0.021	0.004	0.005	0.015	0.014	0.029	0.024	0.019	0.011	0.009	0.010	0.003	0.004
STP Barge	0.054	0.031	0.060	0.043	0.051	0.041	0.049	0.067	0.076	0.063	0.064	0.067	0.036	0.080
SR Well	0.010	0.005	0.004	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
GES Pond	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.001
FR2	0.026	0.020	0.018	0.015	0.019	0.008	0.002	0.005	0.009	0.010	0.011	0.016	0.012	0.018
KC1	n/a	n/a	0.006	0.007	0.018	0.028	0.007	n/a	n/a	0.010	0.009	0.010	0.007	0.007
SKP1	n/a	n/a	nf	nf	nf	nf	0.008	nf	nf	nf	nf	nf	nf	nf
SC1	n/a	n/a	n/a	0.031	0.051	0.077	0.045	0.041	n/a	0.093	0.080	0.154	0.055	0.099
FR4	n/a	n/a	nf	0.022	0.021	0.011	0.004	0.006	0.009	0.010	0.013	0.015	nf	nf
FR Above Chauncey	n/a	n/a	n/a	n/a	n/a	0.015	0.007	n/a	n/a	n/a	n/a	n/a	0.011	0.015
FR Bridge Highway	n/a	n/a	n/a	0.013	0.014	0.009	0.004	n/a	n/a	n/a	n/a	n/a	0.008	nf
BL1 (Blind Duplicate)	n/a	n/a	n/a	n/a	0.039	0.053	0.002	0.005	0.182	n/a	0.081	0.025	0.077	0.010
MT1 (Trip Blank)	n/a	n/a	n/a	n/a	n/a	<0.001	<0.001	<0.001	<0.001	n/a	<0.001	0.001	<0.001	<0.001

< = Less than detection limit indicated

n/a = Not included in sample set

nf = No flow or open water

ic = Insignificant change in previous results/effect on downstream results

box highlighting signifies blind duplicate pairs

Total selenium at the Fording Coal Ltd. Fording River mine in 1995-96

Site Key

Sample Site	Site Location Description
UFR1	Fording River upstream of Henretta Creek (E216777)
HC2	Henretta Creek upstream of McMillian Creek (E216779)
HC1	Henretta Creek upstream of Fording River(E216778)
FR1	Fording River downstream of Henretta Creek (0200251)
Fish Creek	Groundwater stream upstream of Clode Creek
CC1	Clode Settling Pond outlet (E102481)
FR above NGD1	Fording River upstream of Lake Mountain Creek
Mtn. Lake	Headwater lake on Lake Mountain Creek
NGD Below Mtn. Lk.	Lake Mountain Creek downstream of lake
NGD Below Rock Drain	Lake Mountain Creek downstream of rock drain
NGD Pond Inlet	Lake Mountain Creek at catch basin inlet
NGD1	Lake Mountain Creek upstream of Fording River (E105060)
WSCFR	Fording River downstream of Lake Mountain Creek
Breaker Ditches to Eagle	Roadside ditches upstream of Eagle Pond north east cell
Eagle North Flow	Subsurface flow into Eagle Pond north west cell
Eagle 1	Eagle Pond north east cell
Eagle 2	Eagle Pond north west cell
Eagle Primary	Eagle Pond primary cell (south east)
Eagle Secondary	Eagle Main Pond
EC1	Eagle Pond discharge (E102480)
Multi Plate	Fording River downstream of Eagle Settling Pond
Lees Lake	Subsurface fed pond at south toe of 'A' Spoil reject dump
NTP Barge	North Tailings Pond supernatant (E102475)
Shandley	Water accumulation in mined out 3-Pit
Reject Bin	Water draining from coarse coal reject bin
Clean Coal	Supernatant from a clean coal/water solution
BXL Bridge	Fording River adjacent to North Tailings Pond
NL1	North Loop Pond (E102476)
CIL Ditch	Groundwater stream at north west edge of South Tailings Pond
Smith Pond	Pond discharge to Fording River from the west adjacent to South Tailings Pond
STP Barge	South Tailings Pond supernatant (E206660)
SR Well	Seepage return wells at the south toe of South Tailings Pond
GES Pond	Groundwater fed pond at the south west toe of South Tailings Pond
FR2	Fording River upstream of Kilmarnock Creek (0200201)
KC1	Kilmarnock Creek at the highway (0200252)
SKP1	South Kilmarnock Phase 1 Settling Pond discharge (E208394)
SC1	Swift Creek Settling Pond discharge
FR4	Fording River downstream of Fording River Operations (0200311)
FR Above Chauncey	Fording River upstream of Chauncey Creek
FR Bridge Highway	Fording River at Highway Bridge
BL1 (Blind Duplicate)	Blind duplicate as per highlighting
MT1 (Trip Blank)	Trip Blank

Appendix III (page 1) Fish Captured in September 1996 Bioaccumulation Survey: Raw Data.

Site	Fish #	Date sampled	Time identifier	Tissue	Sex	Age (years)	Fork length (cm)	Whole wt. (g)	Condition Index	Liver wt. (g)	Hepatosomatic Index	Liver comp. link #	Gonad wt. (g)	Gonadosomatic Index	Gonad comp. link #	QA	% Moisture	Selenium ug/g (dry)
Elk R. above Cadorna Creek	CT-745-1 (Req 967)	09-Sep	0500	M	F	5	28.1	241.3	1.09	2.6	1.1		0.7	0.3			77.9	3.02
			0501	M												dup	83	2.92
			0502	L								LC1					78	16.3
			0503	G											GC1		71.2	22
Elk R. above Cadorna Creek	CT-745-2 (Req 967)	09-Sep	0505	M	?	5	29.5	302	1.18	2.7	0.9		-				79	3.73
			0502	L								LC1					liver composite LC1 above	
Elk R. above Cadorna Creek	CT-745-3 (Req 968)	09-Sep	0510	M	F	6	31.6	432	1.37	5.4	1.3		7.0	1.6			77.7	4.04
			0511	L								Discrete					78.8	23.3
			0503	G											GC1		gonad composite GC1 above	
Elk R. above Cadorna Creek	CT-745-4 (Req 968)	10-Sep	0900	M	M	6	35.2	541	1.24	4.5	0.8		-				75.6	3.64
			0901	L								Discrete					88.2	14.9
Elk R. above Cadorna Creek	CT-745-5 (Req 968)	10-Sep	0905	M	M	6	36.0	521	1.12	4.3	0.8		-				79.2	4.53
			0906	L								Discrete					78.2	25.7
Elk R. above Cadorna Creek	CT-745-6 (Req 969)	10-Sep	0910	M	F	6	30.0	327	1.21	4.2	1.3		1.9	0.6			78	4.64
			0911	L								Discrete					76.6	16.6
			0503	G											GC1		gonad composite GC1 above	
Elk R. above Cadorna Creek	CT-745-7 (Req 969)	10-Sep	0915	M	M	4	28.3	286	1.26	3.5	1.2		-				78.1	3.82
			0916	L								LC2					78.4	16.3
Elk R. above Cadorna Creek	CT-745-8 (Req 969)	10-Sep	0920	M	F	4	27.5	252	1.21	3.1	1.2		0.6	0.2			77.9	4.21
			0916	L								LC2					liver composite LC2 above	
			0503	G											GC1		gonad composite GC1 above	
Elk R. above Cadorna Creek	CT-745-9 (Req 970)	10-Sep	0925	M	F	5	28.9	309	1.28	4.7	1.5		5.0	1.6			77.2	3.98
			0926	L								Discrete					78.2	11.7
			0503	G											GC1		gonad composite GC1 above	
Elk R. above Cadorna Creek	CT-745-10 (Req 970)	10-Sep	0930	M	F	5	25.8	217	1.26	4.5	2.1		0.7	0.3			77.8	4.15
			0931	L								Discrete					86.8	23.6
			0503	G											GC1		gonad composite GC1 above	
Elk R. above Cadorna Creek	MWF-745-11 (Req 971)	10-Sep	0935	M	F	7	24.0	174	1.26	2.9	1.7		14.1	8.1			76.3	3.07
			0936	L								Discrete					77.5	21.3
			0937	G											Discrete		62.6	20

Appendix III (page 2) Fish Captured in September 1996 Bioaccumulation Survey: Raw Data.

Site	Fish #	Date sampled	Time identifier	Tissue	Sex	Age (years)	Fork length (cm)	Whole wt. (g)	Condition Index	Liver wt. (g)	Hepatosomatic Index	Liver comp. link #	Gonad wt. (g)	Gonadosomatic Index	Gonad comp. link #	QA	% Moisture	Selenium ug/g (dry)
Fording R. below Fording Coal	CT-746-1 (Req 972)	10-Sep	1000 1001 1002	M L G	F	3	23.5	148	1.14	2.8	1.9	LC1	2.9	2.0	GC1		71.9 78.2 69.9	6.81 33.5 28.2
Fording R. below Fording Coal	CT-746-2 (Req 972)	10-Sep	1010 1001	M L	M	3	27.5	264	1.27	3.5	1.3	LC1	-				69.2 liver composite	6.13 LC1 above
Fording R. below Fording Coal	CT-746-3 (Req 972)	10-Sep	1020 1021	M L	M	3	23.8	168	1.25	2.5	1.5	LC2	-				74.7 76.4	14.7 51.5
Fording R. below Fording Coal	CT-746-4 (Req 973)	10-Sep	1030 1021	M L	M	3	23.5	163	1.26	2.1	1.3	LC2	-				75.2 liver composite	7.3 LC2 above
Fording R. below Fording Coal	CT-746-5 (Req 973)	10-Sep	1040 1021	M L	M	3	21.7	118	1.15	1.8	1.5	LC2	-				73.6 liver composite	16 LC2 above
Fording R. below Fording Coal	CT-746-6 (Req 973)	10-Sep	1050 1051	M L	M	3	20.5	106	1.23	1.9	1.8	LC3	-				71.4 77.5	6.62 34.9
Fording R. below Fording Coal	CT-746-7 (Req 973)	10-Sep	1100 1051	M L	M	2	20.5	105	1.22	1.2	1.1	LC3	-				76.4 liver composite	8.91 LC3 above
Fording R. below Fording Coal	CT-746-8 (Req 973)	10-Sep	1110 1051	M L	M	2	18.2	67.8	1.12	0.8	1.2	LC3	-				75.7 liver composite	8.62 LC3 above
Fording R. below Fording Coal	CT-746-9 (Req 974)	10-Sep	1120 1051	M L	M	3	18.2	64.2	1.06	0.8	1.2	LC3	-				78.4 liver composite	9.87 LC3 above
Fording R. below Fording Coal	CT-746-10 (Req 974)	10-Sep	1130 1051 1002	M L G	F	3	17.4	54.4	1.03	0.6	1.1	LC3	0.2	0.4	GC1		76.3 liver composite gonad composite	8.54 LC3 above GC1 above

Appendix III (page 3) Fish Captured in September 1996 Bioaccumulation Survey: Raw Data.

Site	Fish #	Date sampled	Time identifier	Tissue	Sex	Age (years)	Fork length (cm)	Whole wt. (g)	Condition Index	Liver wt. (g)	Hepatosomatic Index	Liver comp. link #	Gonad wt. (g)	Gonadosomatic Index	Gonad comp. link #	QA	% Moisture	Selenium ug/g (dry)
Elk R. Below Michel Cr.	CT-747-1 (Req 975)	11-Sep	1100 1101 1102	M L G	F	4	36.7	563	1.14	5.4	1.0	Discrete	8.0	1.4	GC1		78 77.9 73.3	4.18 16.2 47.8
Elk R. Below Michel Cr.	CT-747-2 (Req 975)	11-Sep	1105 1106	M L	M	3	28.8	287	1.20	2.3	0.8	LC1	-				78.6 79.2	4.75 14.5
Elk R. Below Michel Cr.	CT-747-3 (Req 976)	11-Sep	1110 1111 1112	M M L	M	4	40.5	834	1.26	6.1	0.7	Discrete	-			dup	79.5 79.7 78.2	5.16 5.18 24.3
Elk R. Below Michel Cr.	CT-747-4 (Req 976)	11-Sep	1115 1106 1102	M L G	F	4	28.5	292	1.26	3.6	1.2	LC1	4.9	1.7	GC1		78 liver composite LC1 above gonad composite GC1 above	5.26
Elk R. Below Michel Cr.	MWF-747-5 (Req 977)	11-Sep	1120 1121 1121	M L G	F	8	36.3	566	1.18	10.4	1.8	Discrete	60.8	10.7	Discrete		76.5 77 64.1	3.6 35 26.9
Elk R. Below Michel Cr.	MWF-747-6 (Req 977)	11-Sep	1125 1126 1127	M L G	F	7	32.0	379	1.16	7.5	2.0	Discrete	48.4	12.8	Discrete		77.2 77.8 64	3.66 26 25.8
Elk R. Below Michel Cr.	BT-747-7	11-Sep	1130 1131	M L	M	3	27.5	202	0.97	2.0	1.0	Discrete	-				80 81	3.53 18.4
Elk R. Below Michel Cr.	CT-747-8	11-Sep	1135 1136	M L	M	4	37.7	709	1.32	5.9	0.8	Discrete	-				76.8 76.1	4.81 23.5

Appendix IV (page 2) Fish Stomach Contents.

Site	Fish #	Date sampled	Time identifier	Tissue	Age (years)	Selenium ug/g (dry)	Stomach Contents
Fording R. below Fording Coal	CT-746-1 (Req 972)	10-Sep	1000 1001 1002	M L G	3	6.81 33.5 28.2	Full. Mainly true terrestrials: wasp, spider, ants, Ichnewman fly, leafhoppers. Adult stoneflies, very few benthics.
Fording R. below Fording Coal	CT-746-2 (Req 972)	10-Sep	1010 1001	M L	3	6.13	Full. Mostly adult stoneflies and mayflies. True terrestrials: grasshopper, lady bug, ants. Few benthics.
Fording R. below Fording Coal	CT-746-3 (Req 972)	10-Sep	1020 1021	M L	3	14.7 51.5	Very full. Mostly adult stoneflies and mayflies.
Fording R. below Fording Coal	CT-746-4 (Req 973)	10-Sep	1030 1021	M L	3	7.3	Very full. Mostly adult stoneflies and mayflies. Also 2 grasshoppers and leafhopper.
Fording R. below Fording Coal	CT-746-5 (Req 973)	10-Sep	1040 1021	M L	3	16	Small stomach but full. Most of mass 2 grasshoppers, one very large. Also leafhoppers and adult stoneflies and mayflies. Few benthics.
Fording R. below Fording Coal	CT-746-6 (Req 973)	10-Sep	1050 1051	M L	3	6.62 34.9	Small but full. Grasshopper parts, adult stoneflies and mayflies.
Fording R. below Fording Coal	CT-746-7 (Req 973)	10-Sep	1100 1051	M L	2	8.91	Full. Large grasshopper, adult stoneflies and mayflies, leafhoppers.
Fording R. below Fording Coal	CT-746-8 (Req 973)	10-Sep	1110 1051	M L	2	8.62	Small but full. Grasshopper parts, leafhoppers, adult stoneflies and mayflies.
Fording R. below Fording Coal	CT-746-9 (Req 974)	10-Sep	1120 1051	M L	3	9.87	Full. Mostly adult stoneflies and mayflies. True terrestrials: grasshopper, centipede, leaf hoppers. No benthics.
Fording R. below Fording Coal	CT-746-10 (Req 974)	10-Sep	1130 1051 1002	M L G	3	8.54	Full. Large grasshopper, adult stoneflies and mayflies, horsefly.

Appendix IV (page 1) Fish Stomach Contents.

Site	Fish #	Date sampled	Time identifier	Tissue	Age (years)	Selenium ug/g (dry)	Stomach Contents
Elk R. above Cadorna Creek	CT-745-1 (Req 967)	09-Sep	0500 0501 0502 0503	M M L G	5	3.02 2.92 16.3 22	Full. Mostly adult stoneflies and mayflies, also some flying ants and dipterans. Only benthic was *Brachyentrus* (17).
Elk R. above Cadorna Creek	CT-745-2 (Req 967)	09-Sep	0505 0502	M L	5	3.73	Very full. Vertebrae of small fish. Most of mass made up of adult stoneflies. A few stonefly nymphs, 2 diving beetles.
Elk R. above Cadorna Creek	CT-745-3 (Req 968)	09-Sep	0510 0511 0503	M L G	6	4.04 23.3	Not full, 4 large Hydroptilid caddis fly larvae, 2 *Brachycentrus*. True terrestrials: 1 caterpillar, parts of Oligochaetes
Elk R. above Cadorna Creek	CT-745-4 (Req 968)	10-Sep	0900 0901	M L	6	3.64 14.9	Not full. Contents hard to identify, amorphous black material, some wings and stonefly parts.
Elk R. above Cadorna Creek	CT-745-5 (Req 968)	10-Sep	0905 0906	M L	6	4.53 25.7	6 Hydroptilid caddisfly larvae, parts of other mayfly and stonefly . nymphs
Elk R. above Cadorna Creek	CT-745-6 (Req 969)	10-Sep	0910 0911 0503	M L G	6	4.64 16.6	Small quantity. 50% mix of benthic (mayflies, stoneflies, chironomids and adult stonefly) and terrestrial (dipterans, beetles)
Elk R. above Cadorna Creek	CT-745-7 (Req 969)	10-Sep	0915 0916	M L	4	3.82 16.3	Full. Contents hard to ID. Mix of smaller benthics (mayflies, stoneflies) and terrestrial. One Nematomorph worm.
Elk R. above Cadorna Creek	CT-745-8 (Req 969)	10-Sep	0920 0916 0503	M L G	4	4.21	Very little. One stonefly adult, other benthics: caddis, may and stoneflies and numerous chironomids.
Elk R. above Cadorna Creek	CT-745-9 (Req 970)	10-Sep	0925 0926 0503	M L G	5	3.98 11.7	Very little. Similar to previous fish.
Elk R. above Cadorna Creek	CT-745-10 (Req 970)	10-Sep	0930 0931 0503	M L G	5	4.15 23.6	Very little, least yet. Same as previous 2 fish.
Elk R. above Cadorna Creek	MWF-745-11 (Req 971)	10-Sep	0935 0936 0937	M L G	7	3.07 21.3 20	Almost nothing. A few small benthics.

Appendix IV (page 3) Fish Stomach Contents.

Site	Fish #	Date sampled	Time identifier	Tissue	Age (years)	Selenium ug/g (dry)	Stomach Contents
Elk R. Below Michel Cr.	CT-747-1 (Req 975)	11-Sep	1100 1101 1102	M L G	4	4.18 16.2 47.8	Moderately full. Mostly true terrestrials: flies, ants (winged and wingless). A few benthics.
Elk R. Below Michel Cr.	CT-747-2 (Req 975)	11-Sep	1105 1106	M L	3	4.75 14.5	Very little. One *Brachyentrus*, parts of other benthics. Parts of terrestrials.
Elk R. Below Michel Cr.	CT-747-3 (Req 976)	11-Sep	1110 1111 1112	M M L	4	5.16 5.18 24.3	Large stomach, full. Very insects: robber fly, Hydropsche caddis fly larvae. Many other terrestrials and benthics *(Brachyentrus)*.
Elk R. Below Michel Cr.	CT-747-4 (Req 976)	11-Sep	1115 1106 1102	M L G	4	5.26	Moderately full. Parts of several large *Isoperla* and larval caddis flies. True terrestrials: spider, flying ants.
Elk R. Below Michel Cr.	MWF-747-5 (Req 977)	11-Sep	1120 1121 1121	M L G	8	3.6 35 26.9	Large stomach, very little. One *Brachyentrus*, parts of *Isoperla*.
Elk R. Below Michel Cr.	MWF-747-6 (Req 977)	11-Sep	1125 1126 1127	M L G	7	3.66 26 25.8	Very little. Parts of *Isoperla*.
Elk R. Below Michel Cr.	BT-747-7	11-Sep	1130 1131	M L	3	3.53 18.4	Full. 12 large caddis fly larvae, some other benthics. True terrestrials: many flying ants.
Elk R. Below Michel Cr.	CT-747-8	11-Sep	1135 1136	M L	4	4.81 23.5	Full. Almost exclusively flying ants, all same size.