Results of Aquatic Studies in the McLeod and Upper Smoky River Systems

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SUMMARY

Selenium is a naturally occurring element, commonly found in rocks and soil. It is a nutrient usually required in small amounts by humans and other organisms, but it can be toxic at only slightly higher levels. Studies in the scientific literature have shown selenium can cause increased incidences of developmental deformities (or teratogenesis), edema and mortalities that can cause population-level effects on a variety of fish and waterbird species in freshwater ecosystems. Many of the initial aquatic studies in the literature have focused on effects of selenium on warm-water fish species in lakes, reservoirs and irrigated areas in southern and western states of the U.S.A. There are limited studies that have examined the fate and effects of selenium in flowing and standing water ecosystems at northern latitudes.

Concerns related to the fate and effects of selenium in aquatic ecosystems near mountain coal mines in west-central Alberta arose in the late-1990s. Sampling by Alberta Environment in 1998 and 1999 confirmed that selenium concentrations at “exposed” stream sites (i.e., downstream of mine activities) were often an order of magnitude greater than Canadian and U.S.A. water quality guidelines for the protection of freshwater aquatic life. In comparison, selenium levels at reference or background sites, not affected by mines or other major disturbances, were typically less than the most stringent water quality guideline. Mobilisation of selenium from geologic sources into surface water due to mining has occurred at three coal mines in the upper McLeod River and upper Smoky River systems. Selenium concentrations at exposed sites near the mines are comparable to those that have shown adverse effects on aquatic life in published studies.

In 2000, Alberta Environment initiated various aquatic studies following a technical workshop and discussions in the Selenium Working Group. The goals of the studies were to: (1) continue and establish new ambient monitoring of selenium and other metals at reference and exposed sites in streams near the three mountain mines; (2) determine selenium levels in surface water and food web of streams, and to evaluate the data in a conceptual food web; and (3) conduct a pilot study to determine selenium levels at old closed coal mines in the foothills of south-western Alberta. This report includes a compilation and summary of data in the Alberta Environment studies from 1998 to 2003 inclusive. Available data before 1998 are also used to illustrate long-term trends for selenium in the McLeod River drainage.

Surface water data for the McLeod River mouth from 1984 to 2003 revealed selenium concentrations increased slightly in the late 1990s. More limited data for the headwaters (downstream of the CRC and Gregg River mines) over the same period showed selenium concentrations after 1998 were usually an order of magnitude higher than water quality guidelines in exposed streams. Available surface water data for the upper Smoky River also showed selenium concentrations from 1998 to 2003 were an order of magnitude higher than water quality guidelines in a stream downstream of recent open-pit mining. In comparison to the exposed sites, selenium concentrations were usually less than water quality guidelines at reference sites near the three mines. The small increase of selenium levels at the McLeod River mouth in the late 1990s may be due to cumulative coal mine activities in the headwaters.

Overall, selenium concentrations generally remained stable (with no overall increase or decrease) from 1998 to 2003 at key reference and exposed stream sites near the three mountain mines.

Surface water data for 28 metals from 1998 to 2003 showed most concentrations were higher at the exposed sites compared to reference sites in stream systems intersecting the mines. Concentrations increased by 10-fold for 11 metals and by 100-fold for four metals at the exposed sites compared to the corresponding reference sites. Comparing the metal data to available water quality guidelines, selenium was the only one that exceeded the guidelines at all exposed sites in the six stream systems examined.

Food web data from the streams showed similar patterns as the surface water results. Highest selenium concentrations were found in the food web components at the first exposed sites compared to reference sites. More extensive spatial sampling of lower trophic levels in the food showed selenium concentrations in sediment and biofilm declined at sites further downstream of the mines, to levels that were similar to those at reference sites.

A conceptual food web was developed (using comprehensive data from 2000 and 2001) to assess the fate and potential effects of selenium in representative reference and exposed streams near the mines. Overall, there was substantial bioconcentration of selenium from the surface water to lower trophic levels in the stream food web. In comparison, selenium biomagnification within the food web was not pronounced. However, it was most evident in the exposed stream, where incremental increases of selenium to highest concentrations in rainbow trout (mature) ovary were observed. Elevated selenium in mature fish ovary is of concern because of the potential transfer of selenium to the offspring, which can result in teratogenesis and edema in the fry.

Comparisons of the conceptual food web data to toxicity effects thresholds from the literature showed selenium concentrations in the diet and rainbow trout tissues, especially ovary, were usually above the thresholds in exposed streams compared to reference streams. These results for rainbow trout and data from other Alberta studies (comparing selenium concentrations in fish tissues to toxicity effects thresholds) near the mountain mines indicate that adverse effects on various fish species are expected in exposed streams compared to reference streams.

Results of laboratory toxicity studies support this conclusion in part by demonstrating adverse effects (increased teratogenesis and edema) on rainbow trout offspring (fry) from the exposed stream, compared to the reference stream. The adult fish used in these studies were taken from the same streams and sample period used in the food web evaluation. Brook trout were not as sensitive to selenium. A related experimental study proposed a physiological mechanism for selenium bioaccumulation causing teratogenesis in rainbow trout.

Results of a pilot study at old, closed or abandoned coal mines in south-western Alberta indicated selenium concentrations do not appear to be presently elevated at the sites sampled. However, it is not known if selenium was ever at higher levels than those currently observed.

Overall, results of the Alberta Environment studies and data from other fish studies from west-central Alberta show concern with potential influences of selenium in exposed streams near the mountain coal mines. Additional monitoring and research are required to fully evaluate the fate and effects of selenium at the mines, including aquatic ecosystems such as end pit lakes or wetlands in the reclaimed landscape.

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1.0 INTRODUCTION

Selenium is a naturally occurring element, commonly found in rocks and soil. It is a nutrient usually required in small amounts by humans and other organisms, but it can be toxic at only slightly higher levels. Concerns related to the fate and effects of selenium in aquatic ecosystems in the vicinity of mountain coal mines in west-central Alberta arose in the late-1990s. Sampling by Alberta Environment in 1998 and 1999 confirmed that selenium concentrations at "exposed" stream sites (which were downstream of mines) were often an order of magnitude greater than water quality guidelines for the protection of freshwater aquatic life[1]. In comparison, selenium concentrations at reference (or background) sites (not affected by mines or other major disturbances) in the same streams were typically less than the most stringent water quality guideline or less than analytical detection limits. Detailed results of the data are in an interim report by Alberta Environment (Casey and Siwik 2000). Mobilisation of selenium from geologic sources into surface water due to mining activities has occurred at the Cardinal River Coals Ltd. (CRC) and Gregg River mines in the upper McLeod River, and at the Smoky River Coal Ltd. mine in the upper Smoky River[2].

Sampling of fish near the three mines has shown selenium concentrations in tissues of various fish species were usually at higher levels at exposed sites compared to reference sites (Casey and Siwik 2000; Mackay 2005). Fish toxicity studies by researchers associated with the federal Department of Fisheries and Oceans (DFO) have shown selenium concentrations in fish eggs were statistically correlated with incidences of developmental abnormalities (or teratogenesis) and edema in rainbow trout fry, although this relationship was not found for brook trout (Holm 2002; Holm *et al.* 2003; Holm *et al.* 2005). Based on additional experiments, Palace *et al.* (2004a) proposed a physiological mechanism for selenium causing teratogenesis in rainbow trout fry. In another study, selenium concentrations in bull trout from the upper McLeod River downstream of mining were at levels that were expected to impair recruitment (Palace *et al.* 2004b).

Studies in the scientific literature have shown increased teratogensis and edema due to selenium in the early life stages of fish and wildlife, which have lead to population-level effects for some species in freshwater ecosystems (e.g., see reviews of Lemly 1993, 1996, 1998; US-DOI 1998; Maier and Knight 1994; Presser *et al.* 1994). Selenium concentrations in surface waters for these studies are generally comparable to those found in exposed streams of west-central Alberta. However, many of the initial aquatic studies in the literature focused on effects of selenium on warm-water fish species in lakes, reservoirs and irrigated areas in southern and western states of the U.S.A. There are limited studies that have examined the fate and effects of selenium in flowing and standing water ecosystems at northern latitudes. More recently in the 1990s, the

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[1] Water quality guidelines for the protection of freshwater aquatic life used in Alberta are: Canadian Council of Ministers of Environment (CCME) = 1 µg/L; and U.S.A. Environmental Protection Agency (US-EPA) = 5 µg/L (Alberta Environment 1999).

[2] The status of the mines has changed in recent years. The CRC (or Luscar) mine and Cheviot mine project, originally proposed by CRC Ltd., are now owned by Elk Valley Coal Corporation. Mining at the CRC mine has finished. The coal processing plant at the CRC mine will be used for the new Cheviot mine in the upper McLeod River. The Gregg River mine has closed and is being reclaimed by Luscar Ltd. The Smoky River Coals Ltd. mine has closed and reclamation is underway. A portion of the mine including some existing pits and new operations are controlled by a new company, Grande Cache Coal Ltd.

effects of selenium mobilisation due to mining have arisen as concerns at phosphate mines in Idaho, and coal and uranium mines in western Canada.

In September 2000, experts on the effects of selenium on fish and wildlife in North America were invited to a two-day technical workshop in Hinton, Alberta. The main goals of the workshop were to review the Alberta results and develop workplans to address data and knowledge gaps. Alberta Environment initiated several studies based on the workshop and discussions in the Selenium Working Group[3]. The focus of the Alberta Environment studies was to conduct ambient monitoring and determine the fate and potential effects of selenium in flowing-water systems surrounding the mines.

Specific objectives of the studies were to:

1. Continue and establish new ambient monitoring of selenium and other metals at sites near the CRC, Gregg River and Smoky River mines, including pairs of reference and exposed sites in stream systems that flow through the mines.

2. Determine the concentrations of selenium in surface water and components of the aquatic food web (i.e., sediment, biofilm[4], benthic macroinvertebrates and other non-fish biota[5]) in flowing-water systems, and to compare these data in a conceptual food web for streams near the mines.

3. Conduct a pilot study to determine selenium concentrations at old, closed or abandoned coal mines in the Rocky Mountain foothills of south-western Alberta.

This report is a compilation and summary of data collected in the Alberta Environment studies from 1998 to 2003[6]. Available data before 1998 are also used to illustrate longer-term trends for selenium at key sites in the McLeod River, and limited samples from lakes are included for comparative information.

Additional aquatic studies lead by other agencies include: sampling of fish tissues and stomachs by Alberta Sustainable Resource Development; fish toxicity and related experiments, and benthic invertebrate (community and food web) studies by DFO; and regulatory water quality monitoring at the mines by industry and Alberta Environment.

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[3] The Selenium Working Group, formed in 1999, includes membership by the three mountain coal mines, Alberta Environment, Alberta Sustainable Resource and Development, Energy and Utilities Board and DFO. The overall goal of the group is to develop a management plan for selenium at the mines.

[4] Biofilm is defined for the purposes of this work as the benthic (or bottom-dwelling) community of organisms and associated detritus found on hard substrate in flowing water habitats. The biota include algae, fungi, small invertebrates, entrapped plankton and smaller microbes such as bacteria and protozoans.

[5] Non-fish biota samples were mostly made up of aquatic insect larvae (a major group of benthic macroinvertebrates) that are common and important food for sport fish in mountain streams. Other samples were composed of filamentous algae, aquatic and riparian vegetation, and aquatic insect adults.

[6] These results include a small number of biofilm and other non-fish biota samples collected in 1999 that were not presented in the interim report by Alberta Environment (Casey and Siwik 2000).

2.0 STUDIES AND METHODS

2.1 Study Design, Sites and Sampling Schedule

The study design, sites and sampling schedule for each objective are outlined below and in Tables 1, 2 and 3. The sample sites in the McLeod River and upper Smoky River systems are shown in Figures 1 and 2. The reference sites were usually located upstream of the mines and any other major disturbances, such as haul roads and logging.

2.1.1 Objective 1 - Metals in Surface Water of McLeod and Upper Smoky River Systems

Surface water samples were taken at sites upstream and downstream of the CRC, Gregg River and Smoky River mines to determine spatial and temporal variability of metals in flowing-water systems influenced by mining activities (Tables 1 and 2). The samples were mostly collected from late-1998 to 2001 (Table 1). Some samples were analysed for other water quality variables including nutrients.

After 2001, surface water sampling was focused on pairs of reference and exposed sites to evaluate the overall influence of each mine on metal loads in streams: CRC mine - two sites on Luscar Creek; Gregg River mine - two sites on Gregg River; and Smoky River mine – a site on Beaverdam Creek and West Beaverdam Creek (Table 2). Beginning in 2003, routine sampling at these sites included the measurement of stream flow (Table 2) to allow future estimates of metal loads per unit of drainage area over time. This project is intended to be a long-term study. Sample collections have continued up to the present.

2.1.2 Objective 2 - Selenium in a Conceptual Food Web

Surface water and food web samples were collected at sites in the upper McLeod River in 2000 and 2001 (Tables 1 and 3). Many of the samples were taken concurrently at the same sites where fish were sampled for tissue analysis and toxicity studies by Alberta Sustainable Resource Development and DFO, respectively. Most of the food web work was focussed in the upper McLeod River system (Tables 1, 2 and 3), where the mobilisation of selenium into surface waters was more widespread and highest selenium concentrations were found to date. A subset of the data in streams near the CRC and Gregg River mines is used in the evaluation of a conceptual aquatic food web.

2.1.3 Objective 3 - Selenium at Old Coal Mines in South-western Alberta

For this pilot study, potential sample sites were identified based on information available in published documents (e.g., Radford and Graveland 1978; ERCB 1994), contacts with government and industry representatives, and site inspections. The samples were taken in September and October 2001 when water flow was stable and the potential influence of runoff on surface water was low.

Table 1 Study sites and sampling schedule for metal samples in selenium-related studies from 1999 to 2001

Sample Site	Type of Site		Sample Date and Water Variables Analysed (See Footnotes for Details)									
	Reference Sites	Sites Where Fish Collected for Toxicity Studies	Spring 1999	Summer 1999	Fall 1999	Winter 2000	Spring 2000	Summer 2000	Fall 2000	Spring 2001	Summer 2001	Fall 2001
			May.11,18, 19,20,21	Jul.27,28, 29,30	Oct.4, 5,6,7	Feb.15, 16,17	Apr.12, May.18	Jun.8,14	Sep.21,26, 27,28,29, Oct.12	May.24	Jun.5,Jul.3, 4,5,Aug.1,2	Sep. 4,5,6
Flowing-Water Sites - Rivers & Streams												
McLeod River Basin												
Cheviot Creek 20 m u/s of Cheviot Lake	Reference								C			
Cheviot Creek downstream Cheviot Lake & rock dumps									C			
Cheviot Creek near mouth (McLeod River)									C			
Old underground mine discharge to Thornton Creek (McLeod River)									C			
Whitehorse Creek 5 km u/s of Drummond Creek	Reference		C									
Whitehorse Creek near mouth (McLeod River)	Reference		A	A	A	B			C			
McLeod River 0.1 km u/s of Cadomin Creek	Reference		A	A	A	C			C			
Luscar Creek u/s of CRC mine	Reference		A	A	A	C	C		C			
Luscar Creek near mouth (McLeod River)		Bioassay	A	A	A	C	C	C	C		C	C
McLeod River 3.5 km d/s of Luscar Creek			A	A	A	B			C		C	C
Mackenzie Creek near mouth (McLeod River)	Reference								C			
Deerlick Creek 2 km u/s of mouth (McLeod River)	Reference	Bioassay					C	C		C	C	C
Wampus Creek near mouth (McLeod River)	Reference	Bioassay	C	A	A	B				C	C	
Mary Gregg Creek near mouth (McLeod River)				A	A	B						
McLeod River u/s of Gregg River			A	A	A	C			C			
McLeod River d/s of Gregg River												
Anderson Creek near mouth (McLeod River)	Reference						C					
McLeod River u/s of Embarras River			A	A	A	C			C			
Embarras River near mouth (McLeod River)	Reference					C			C			
McLeod River 1.5 km d/s of Hwy 32 crossing												
McLeod River south of Mahaska									C			
Gregg River Basin, Tributary of McLeod River												
Gregg River u/s of CRC mine	Reference		A	A	A	B			C			
Gregg River u/s Hwy 40, near Gregg River mine coal processing plant									C			
Berry's Creek u/s of Gregg River mine	Reference		A	A	A	B			C			
Berry's Creek near mouth (Gregg River)			A	A	A	C			C			
Falls Creek u/s Gregg River mine (u/s of D-6 dump)	Reference								C			
Falls Creek near mouth (Gregg River)			A	A	A	C			C			
Sphinx Creek u/s of Gregg River mine	Reference		A	A	A	B			C			
Sphinx Creek near mouth (Gregg River)			A	A	A	C			C			
Gregg River 9.5 km d/s of Sphinx Creek & 0.7 km u/s of Drinnan Creek		Bioassay									C	C
Drinnan Creek near mouth (Gregg River)				A	A	C			C			
Gregg River d/s of Warden Creek & u/s of Hwy 40			A	A	A	B			C			
Gregg River 8 km u/s of McLeod River			A	A	A	C			C			
Maskuta Creek, Tributary of Athabasca River												
Cold Creek u/s of Hwy 40	Reference	Bioassay							C		C	C
Cold Creek 0.5 km d/s of Hwy 40 & Still Creek	Reference	Bioassay						C	C			

Table 1 Study sites and sampling schedule for metal samples in selenium-related studies from 1999 to 2001 (continued)

Sample Site	Type of Site		Sample Date and Water Variables Analysed (See Footnotes for Details)									
	Reference Sites	Sites Where Fish Collected for Toxicity Studies	Spring 1999	Summer 1999	Fall 1999	Winter 2000	Spring 2000	Summer 2000	Fall 2000	Spring 2001	Summer 2001	Fall 2001
			May.11,18, 19,20,21	Jul.27,28, 29,30	Oct.4, 5,6,7	Feb.15, 16,17	Apr.12, May.18	Jun.8,14	Sep.21,26, 27,28,29, Oct.12	May.24	Jun.5,Jul.3, 4,5,Aug.1,2	Sep. 4,5,6
Smoky River Basin												
South trib. of Beaverdam Creek, u/s of Smoky River Coal mine	Reference				A				C			
West trib. of Beaverdam Creek (d/s of exploration roads)			A	A	A				C			
South-west trib. of Beaverdam Creek (d/s of B2 dump, forest clearing)			A	A	A	B			C			
Beaverdam Creek 2 km d/s of 12S-5 pond (d/s of B1 pit)					A	C			C			
West Beaverdam Creek near mouth (Beaverdam Creek)	Reference			A	A				C			
Beaverdam Creek 1 km d/s of West Beaverdam Creek					A							
Beaverdam Creek 0.5 km u/s of mouth (Copton Creek)			A	A					C			
Smoky River 0.5 km u/s Sheep Creek (d/s Coal Plant & H.R.Milner Power Plant)									C			
Sheep Creek u/s of Smoky River Coal mine	Reference		A	A	A	B			C			
Sheep Creek near mouth (Smoky River)			A	A	A	C			C			
Smoky River 3 km d/s of Sheep Creek									C			
Muskeg River near mouth (Smoky R), d/s of Flood Creek ash disposal site				A	A	C			C			
Lovett River, Tributary of Pembina River												
Lovett River at Hwy 40	Reference		A	A	A	C						
Lovett River near mouth (Pembina Rive)			A	A	A	C						
Lakes												
McLeod River Basin (except Fairfax Lake)												
Fairfax Lake (composite), Pembina River Basin	Reference		A	A					C			
Lac des Roches, CRC mine (composite)			A	A								
Lac des Roches, CRC mine (profile)				A								
Lac Des Roche, CRC mine - discharge pumped from lake						C						
Luscar Lake, CRC mine (composite)									C			
Luscar Lake, CRC mine (profile)												
Mary Gregg Lake (grab)				A								
Cheviot Lake, old mine pit (composie)									C			
Cadomin Pond, old mine pit, south-east of Cadomin (grab)									C			
Groundwater Springs, Seeps												
Spring entering McLeod River, u/s of Cadomin (opposite Cadomin Creek)							C		C			
Seeps u/s (at south end) of Luscar Lake, CRC mine									C			
Seep u/s of Lac des Roches (often referred to as "B-6 spring"), CRC mine						C						

Notes:

u/s = upstream; d/s = downstream; trib. = tributary

Surface water samples were taken close to where fish collections were made for tissues and fish toxocity studies by Alberta Sustainable Resources and DFO (see Section 1.0)

The term "spring" is used to describe a natural groundwater discharge, compared to "seep" that is used to describe groundwater coming from the base of rock dump(s)

Variables Analysed:

All metal samples were analysed for conductivity, pH, dissolved oxygen, temperature (using a field meter) and non-filterable residue.

A = (6 elements) Cd, Cu, Pb, Ni, Se and Zn - total and dissolved

B = (6 elements) Cd, Cu, Pb, Ni, Se and Zn - total

C = (29 elements) Al, Sb, As, Ba, Be, Bi, B, Cd, Ca, Cl, Cr, Co, Cu, Fe, Pb, Li, Mn, Mo, Ni, Se, Ag, Sr, Tl, Th, Sn, Ti, U, V and Zn - total

Table 2 Study sites and sampling schedule for general water quality samples including metals in the McLeod and Smoky River drainage basins from 1998 to 2003

Sample Site	Sample Date and Water Variables Analysed															
	Fall 1998	Winter 1999	Spring 1999	Summer 1999	Fall 1999	Winter 2000	Spring 2001	Summer 2001	Fall 2001	Winter 2002	Summer 2002	Fall 2002	Winter 2003	Spring 2003	Summer 2003	Fall 2003
	Sep.1, 15,30, Oct.19, 26,27	Feb. 16,17	Apr.22, May.6, 26	Jun.9,22, Jul.7,21, Aug.5, 18,31	Sep.1, 16,27, 28,30, Oct.1,4, 7,12,28	Feb. 16,17	May.24	Jun.4,5, 21,22, Jul.3,18, 19,Aug. 9,14,21	Sep.13, 14,26, 27,Oct. 10,11	Feb. 20,21	Jun.5,6, 19,20, Jul.3,4, Aug.6, 7,27,28	Sep. 18,19, Oct. 16,17	Mar. 25	Apr.1	Aug. 27,28	Sep. 24,25
McLeod River Basin																
Whitehorse Creek near mouth (McLeod River)								C								
McLeod River 0.1 km u/s of Cadomin Creek	C	C	C	C	C			C	C							
Luscar Creek u/s of CRC Mine	C							C	C	C	C	C			C,F	C,F
Jarvis Creek near Luscar Creek	C	C	C													
Luscar Creek u/s Jarvis Creek	C															
Luscar Creek near mouth (McLeod River)	C	C	C	C	C		C	C	C	C	C	C	C,F		C,F	C,F
McLeod River u/s of Gregg River	C	C	C	C	C											
McLeod River u/s of Embarras River	C	C	C	C	C			C	C							
Embarras River near mouth (McLeod River)	C	C	C	C	C											
McLeod River South of Edson	C	C	C	C	C	C		C	C							
McLeod River d/s Rosevear Ferry	C	C	C	C	C	C		C	C							
McLeod River at Whitecourt	C	C	C	C	C	C	C	C								
Gregg River Basin, Tributary of McLeod River																
Gregg River u/s of CRC mine	C							C	C	C	C	C	C,F		C,F	C,F
Gregg River near Gregg River Mine HI Pit	C															
Berry's Creek u/s of Gregg River mine	C															
Berry's Creek near mouth (Gregg River)	C	C	C	C	C											
Falls Creek near mouth (Gregg River)	C	C	C	C	C											
Gregg River d/s Falls Creek								C								
Gregg River near Hwy 40 d/s Falls Creek	C															
Sphinx Creek near mouth (Gregg River)		C		C	C											
Gregg River 9.5 km d/s of Sphinx Creek & 0.7 km u/s of Drinnan Creek							C	C	C	C	C	C	C,F		C,F	C,F
Gregg River 8 km u/s of McLeod River	C	C	C	C	C											
Smoky River Basin																
Beaverdam Creek 2 km d/s of 12S-5 pond (d/s of B1 pit)								C	C	C	C	C		C,F	C,F	C,F
West Beaverdam Creek near mouth (Beaverdam Creek)								C	C	C	C	C			C,F	C,F

Notes:

u/s = upstream; d/s = downstream; trib. = tributary

Variables Analysed:

All metal samples were analysed for conductivity, pH, dissolved oxygen, temperature (using a field meter) and non-filterable residue.

C = (29 elements) Al, Sb, As, Ba, Be, Bi, B, Cd, Ca, Cl, Cr, Co, Cu, Fe, Pb, Li, Mn, Mo, Ni, Se, Ag, Sr, Tl, Th, Sn, Ti, U, V and Zn - total

F = Instantaneous discharge (flow) measured

Table 3 Study sites and sampling schedule for metals analysed in sediment, biofilm and non-fish biota samples from 1999 to 2002[1]

Sample Site	Type of Site		Sample Date and Type of Sample (S=sediment; B=biofilm; M=macroinvertebrates; V=aquatic or riparian vegetation; O=Other Non-Fish Biota)							
	Reference Sites	Sites Where Fish Collected for Toxicity Studies	Spring 1999 [2]	Summer 1999 [2]	Fall 1999	Fall 2000	Summer 2001		Fall 2001	Winter 2002
			May. 18,19	Jul. 27,28	Sep.21, 22,23, Oct.4,5, 6,7	Sep.18, 19,20, 27,29	Jul.3, 4,5,	Aug. 1,2	Sep. 4,5,6	Feb. 21
McLeod River Basin										
Whitehorse Creek near mouth (McLeod River)	Reference		----	----	S	S,B,M	----	----	----	----
McLeod River 0.1 km u/s of Cadomin Creek	Reference		----	----	S,B,M,O	S,B,M	----	----	----	----
Luscar Creek u/s of CRC Mine	Reference		----	----	S	----	----	----	----	----
Luscar Creek near mouth (McLeod River)		Bioassay	----	----	S,B,M,V,O	S,B,M	S,B,M,V	S,B,M,V	S,B,M,V	S
McLeod River 3.5 km d/s of Luscar Creek			----	----	S,B	S,B,M	S,B,M,O		S,B,M,V	----
Deerlick Creek 2 km u/s of mouth (McLeod River)	Reference	Bioassay	----	----	----	----	S,B,M	S,B,M,O	S,B,M,O	----
Wampus Creek near mouth (McLeod River)	Reference	Bioassay	----	----	S	----	----	----	----	----
Mary Gregg Creek near mouth (McLeod River)			----	----	S	----	----	----	----	----
McLeod River u/s of Gregg River			----	----	S,B	----	----	----	----	----
McLeod River d/s of Gregg River			----	----	B	----	----	----	----	----
McLeod River u/s of Embarras River			----	----	S	----	----	----	----	----
McLeod River 1.5 km d/s of Hwy 32 crossing			----	----	V	----	----	----	----	----
McLeod River south of Mahaska			----	----	----	S,B,M,V,O	----	----	----	----
Gregg River Basin, Tributary of McLeod River										
Gregg River u/s of CRC Mine	Reference		----	----	S,B,V	----	----	----	----	----
Berry's Creek u/s of Gregg River mine	Reference		----	----	S	----	----	----	----	----
Berry's Creek near mouth (Gregg River)			----	----	S	----	----	----	----	----
Falls Creek near mouth (Gregg River)			----	----	S	----	----	----	----	----
Sphinx Creek u/s of Gregg River mine	Reference		----	----	S	----	----	----	----	----
Sphinx Creek near mouth (Gregg River)			----	----	S	----	----	----	----	----
Gregg River 9.5 km d/s of Sphinx Creek & 0.7 km u/s of Drinnan Creek		Bioassay	----	----	----	----	S,B,M	----	S,B,M	----
Drinnan Creek near mouth (Gregg River)			----	----	S	----	----	----	----	----
Gregg River d/s Warden Creek & u/s Hwy 40			----	----	S,B	----	----	----	----	----
Gregg River 8 km u/s of McLeod River			----	----	S,B	----	----	----	----	----
Maskuta Creek, Tributary of Athabasca River										
Cold Creek u/s of Hwy 40	Reference	Bioassay	----	----	----	S,B,M	S,B,M,O	S,B,M	S,B,M	----

Table 3 Study sites and sampling schedule for metals analysed in sediment, biofilm and non-fish biota samples from 1999 to 2002[1] (continued)

Sample Site	Type of Site		Sample Date and Type of Sample (S=sediment; B=biofilm; M=macroinvertebrates; V=aquatic or riparian vegetation; O=Other Non-Fish Biota)							
	Reference Sites	Sites Where Fish Collected for Toxicity Studies	Spring 1999 [2]	Summer 1999 [2]	Fall 1999	Fall 2000	Summer 2001		Fall 2001	Winter 2002
			May. 18,19	Jul. 27,28	Sep.21, 22,23, Oct.4,5, 6,7	Sep.18, 19,20, 27,29	Jul.3, 4,5,	Aug. 1,2	Sep. 4,5,6	Feb. 21
Smoky River Basin										
South trib. Of Beaverdam Creek, u/s of Smoky River Coal mine	Reference		----	----	S	----	----	----	----	----
South-west trib. of Beaverdam Creek (d/s of B2 dump, forest clearing)			----	----	S	----	----	----	----	----
Beaverdam Creek 2 km d/s of 12S-5 pond (d/s of B1 pit)			----	----	S	----	----	----	----	----
West Beaverdam Creek near mouth (Beaverdam Creek)	Reference		----	----	S	----	----	----	----	----
Beaverdam Creek 1 km d/s of West Beaverdam Creek			----	----	S	----	----	----	----	----
Muskeg River near mouth (Smoky R), d/s of Flood Creek ash disposal site					S					
Sheep Creek u/s of Smoky River Coal mine	Reference		----	----	S	----	----	----	----	----
Sheep Creek near mouth (Smoky River)			----	----	S	----	----	----	----	----
Muskeg River near mouth (Smoky R), d/s of Flood Creek ash disposal site			----	----	S	----	----	----	----	----
Lovett River, Tributary of Pembina River										
Lovett River at Hwy 40	Reference		----	----	S	----	----	----	----	----
Lovett River near mouth (Pembina Rive)			----	----	S	----	----	----	----	----
Lakes										
Fairfax Lake (composite), Pembina River Basin	Reference		S	S	----	S,M,O	----	----	----	----
Lac des Roches, CRC mine (composite), McLeod River Basin			S	S	----	----	----	----	----	----
Luscar Lake, CRC mine (profile), McLeod River Basin			----	----	----	V	----	----	----	----
Groundwater Seeps at Luscar Lake, CRC Mine										
Seeps u/s (at south end) of Luscar Lake, CRC mine			----	----	----	V	----	----	----	----

Notes:

[1] Only one sediment sample was collected in 2002.

[2] Results in Casey and Siwik 2000.

u/s = upstream; d/s = downstream; trib. = tributary

The term "seep" is used to describe groundwater coming from the base of rock dump(s) (compared to a "spring" used to describe a natural groundwater discharge; see Table 1)

Samples of sediment, biofilm and non-fish biota were taken close to where fish collections were made for tissues and fish toxocity studies by Alberta Sustainable Resources and DFO (see Section 1.0).

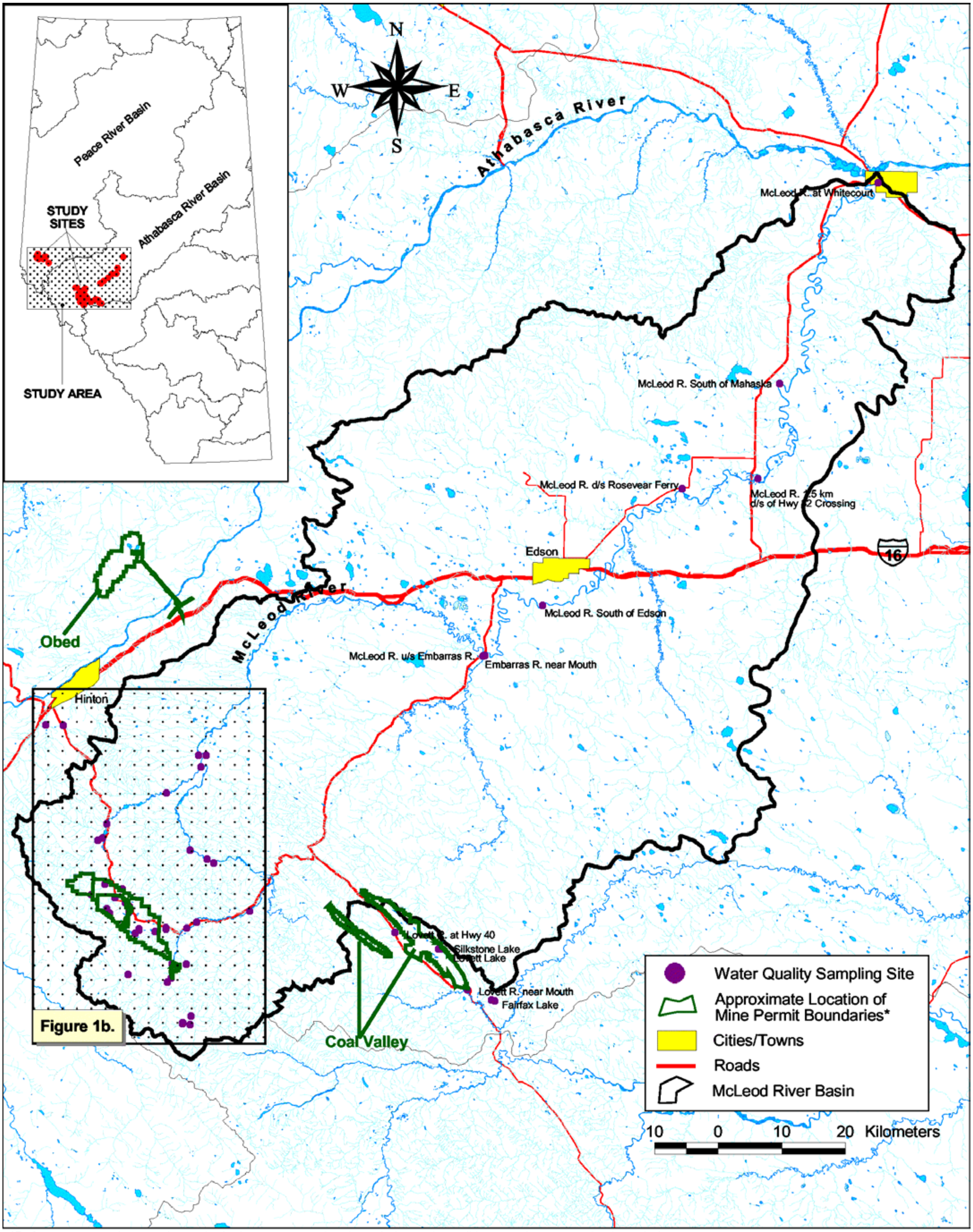
Variables Analysed:

Samples taken in 1999 were analysed for 6 elements: Cd, Cu, Pb, Ni, Se and Zn

Samples taken in 2000 and 2001 were analysed for 7 elements: As, Cd, Ca, Pb, Hg, Se, and Zn

The single sediment sample taken in Feb 2002 was analysed for 30 elements:Al, Sb, As, Ba, Be, Bi, B, Cd, Ca, Cl, Cr, Co, Cu, Fe, Pb, Li, Mn, Hg, Mo, Ni, Se, Ag, Sr, Tl, Th, Sn, Ti, U, V and Zn

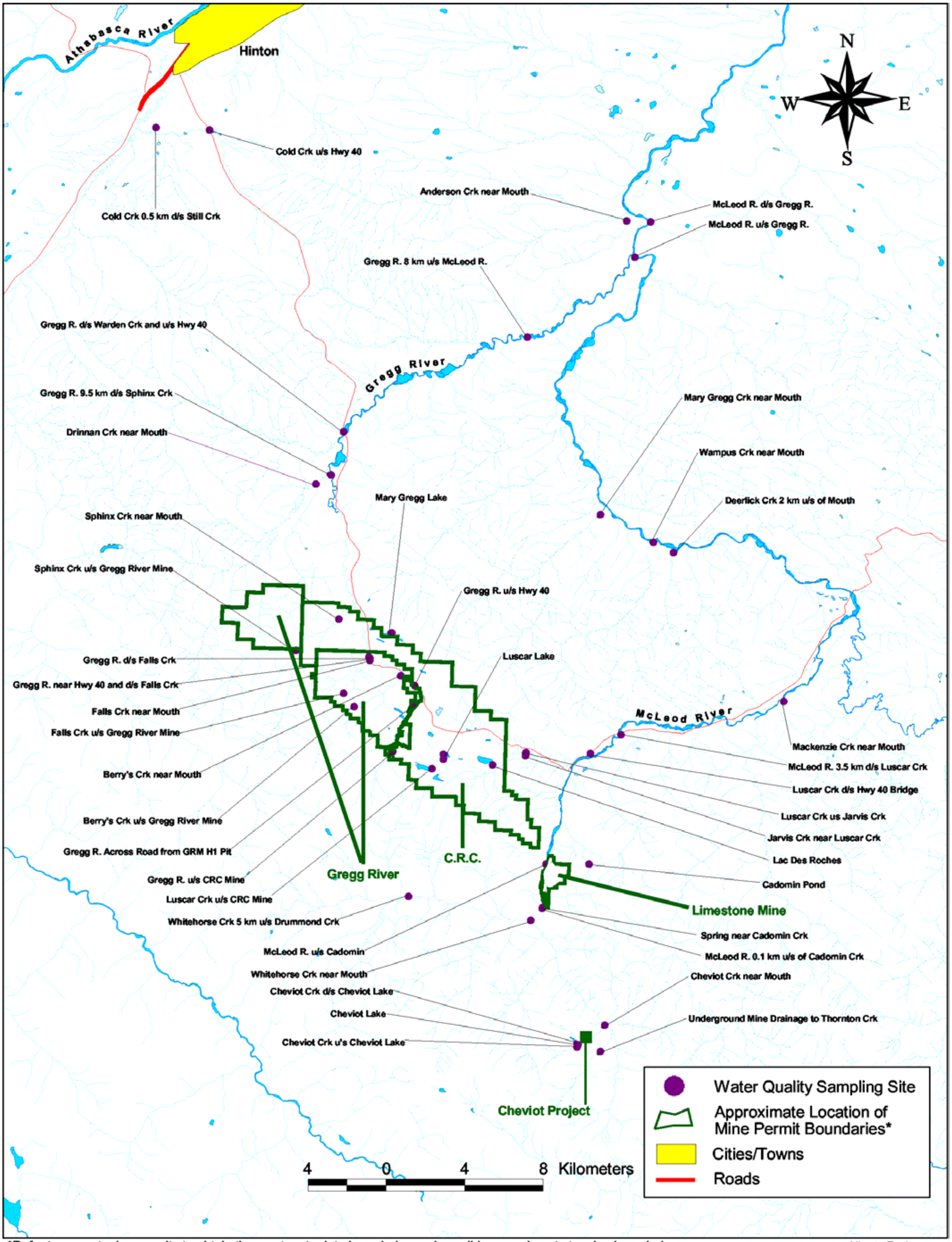
Sediment samples from 1999 to 2001 (inclusive) were analysed for total organic carbon and particle size



*Refer to current mine permits to obtain the most up to date boundaries and possible amendments to mine boundaries.

Alberta Environment

Figure 1a Location of water quality sampling sites in the McLeod and Smoky River basins, October 1998 to September 2003



*Refer to current mine permits to obtain the most up to date boundaries and possible amendments to mine boundaries.

Alberta Environment

Figure 1b Location of water quality sampling sites in the McLeod and Gregg River basins, October 1998 to September 2003

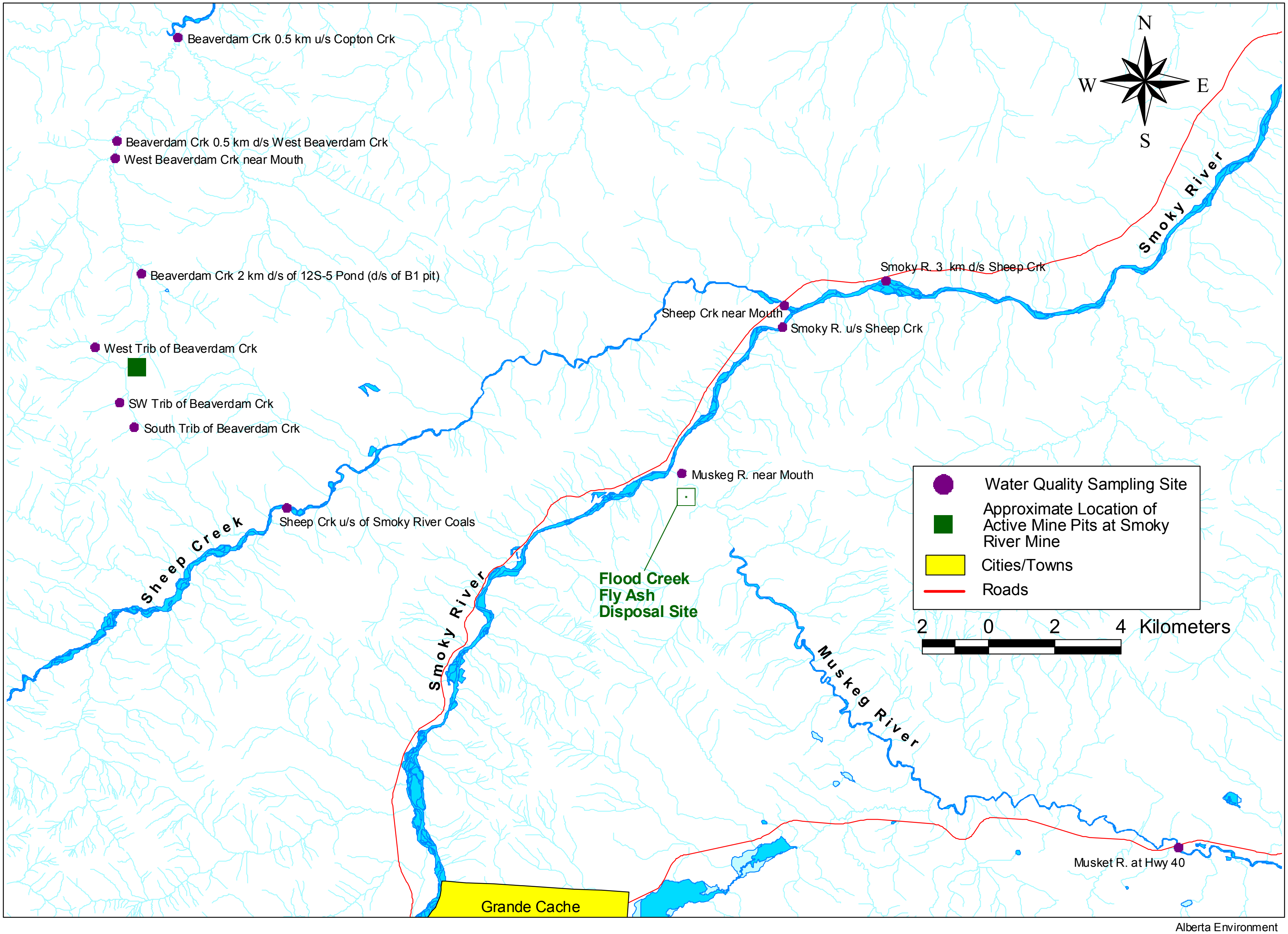


Figure 2 Location of water quality sampling sites in the Smoky River basin, October 1998 to September 2003

2.2 Field and Laboratory Methods

Methods and materials used in sample collections followed the field and laboratory protocols outlined in *Water Quality Sampling Methods* (Alberta Environment 2002). Additional information on some sampling methods is provided below.

2.2.1 Field

Surface Water

Surface water was sampled in flowing-water using grab samples, and in lakes using composite or profile samples. Field meters were used to measure conductivity, pH, dissolved oxygen and temperature at the surface water sites.

Sediment, Biofilm and Non-Fish Biota

Fine sediment (e.g., sand, silt, clay and fine organic material or detritus) was sampled in flowing-water habitats by taking a composite sample (>300 mL) of the upper 1-3 cm of substrate in depositional areas using a large plastic spoon. The samples were usually collected in the fall during low flow, stable conditions (Table 3). The method for sampling sediment in lakes is given in Casey and Siwik (2000). Sediment samples were stored in zip-lock plastic bags and transported on ice in a cooler to the analytical laboratory.

Biofilm was sampled in flowing water by scraping the upper surface of about 10 or more representative rocks into a plastic bag using a plastic knife. Benthic invertebrates were sampled by taking preliminary kick-net samples of the bottom substratum at a site to determine the most common taxa. Whenever possible, taxa that were abundant at other sites were chosen. This was done to allow direct comparisons of selenium (or metal) concentrations in the same taxon at different sites. For each taxon, organisms were collected using Teflon covered forceps, until a sample equivalent to about 1 g dry weight was obtained. Initial identifications of taxa were done in the field using experienced staff and specialists in insect identification. Specimens of each taxon were preserved and confirmed later in the laboratory using microscopes and appropriate keys (e.g., Clifford 1991; Merritt and Cummins 1996). Samples of other non-fish biota were collected opportunistically (Table 3). Each biofilm and non-fish biota sample was placed in plastic zip-lock bags, frozen in the field using dry ice, and transported in a cooler to the analytical laboratory.

2.2.2 Laboratory Analysis

The water samples were usually analysed for non-filterable residue (NFR) and total recoverable metals. In some cases the dissolved fraction of metals was analysed. Sediment and biological samples were analysed for total metal concentrations (using acid extraction). Metals in all media were analysed using an inductively coupled plasma mass spectrometer (ICP-MS) method.

Analytical detection limits[7] were low, usually <1 µg/L in water and <1 µg/g in other media on a dry weight basis. The samples were analysed for up to 30 elements (aluminum, antimony, arsenic, barium, beryllium, bismuth, boron, cadmium, calcium, chlorine, chromium, cobalt, copper, iron, lead, lithium, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, thallium, thorium, tin, titanium, uranium, vanadium, and zinc) (Tables 1, 2 and 3). In some cases, only 6 or 7 metals were analysed in the samples to reduce costs. The choice of these metals, which potentially interact with selenium in fish tissues, were based on the scientific literature and recommendations of experts at the workshop held in 2000 (Section 1.0). All samples analysed for metals and NFR were done by the Water Laboratory, Alberta Research Council, Vegreville (ARC). Total organic carbon and size fractions in sediments were analysed by Maxxam Analytics Ltd., Calgary.

2.2.3 Quality Assurance

Quality assurance (QA) samples were integrated into the concurrent field studies to reduce costs. The data included samples of blank water (submitted blind to the analytical laboratory) and duplicate or triplicate-splits (i.e., two or three sub-samples of the same sample) of water, sediment, biofilm and biological samples. During the studies, QA results were routinely reviewed to identify any concerns with the analytical results. Additional QA data such as spiked samples and replicates of water, sediment and biological samples were analysed by ARC.

2.3 Data Analysis

Before the results were presented in the report, any duplicate or triplicate-split samples were replaced by the mean of any replicate samples that were taken. In addition, any variables with concentrations less than the analytical detection limits were replaced by values equal to half of the detection limit. Box and whisker plots were used to summarise patterns in NFR and metal concentrations from 1998 to 2003. These graphs show the maximum, minimum, median, and other percentile concentrations (10, 25, 75, and 90%) of each variable over the 5-year period.

Before applying statistical tests, raw data were transformed using log10 (x+1) or arcsine for percentages to reduce non-normal distributions and dependence of the mean on variance (Zar 1984). The unpaired t-test was used to examine differences of selenium concentrations in sediments and aquatic insects at reference and exposed sites. Correlation analysis was used to examine the relationship between selenium and total organic carbon in sediment samples. Simple linear regression analysis was used to assess the functional relationship of changes in selenium concentrations from 1998 to 2003. Products of this analysis in the report are the r^2 value and an associated probability level. The r^2 value is equivalent to the strength of the linear relationship that can vary from no consistent relationship between concentration and time (i.e., $r^2 = 0$) to a perfect relationship between these variables ($r^2 = 1$). The probability level (P) (based on a one-way analysis of variance test) indicates whether the slope of the regression line is significantly

[7] The analytical detection limits in reports by the analytical laboratory are usually reported as the *method* detection limits (MDL). The *instrument* detection limit that can be slightly lower than the MDL may also be used. Metal data analysed by ARC (using ICP-MS) are currently reported in the Alberta Environment Water Data System (WDS) database as the instrument detection limit (or "minimum reported value"). Instrument detection limits are used in this report unless noted as the MDL.

different from a slope of zero. In all statistical tests, $P \leq 0.05$ was used to indicate statistically significant relationships or differences.

Water quality guidelines for the protection of freshwater aquatic life (i.e., Alberta, CCME and US-EPA) were used to evaluate potential effects of metals on aquatic biota (Alberta Environment 1999). These guidelines exist for 13 of the metals analysed in surface water samples (Alberta Environment 1999).

All data for selenium concentrations in fish tissues used in the report were converted from wet weight to dry weight concentrations. This allowed direct comparisons of the fish data to other food web components and effects thresholds that are reported on a dry weight basis. The conversion followed the procedure used by other selenium researchers, based on the assumption that fish tissues (muscle and eggs) have a moisture content of 75%. Dry weight concentrations in fish were calculated by multiplying the wet weight concentration by 4 [8] (Lemly 1996).

[8] The conversion factor of 4 is derived from: 100% tissue sample based on the wet weight divided by 25% as dry weight (after removal of moisture content).

3.0 RESULTS AND DISCUSSION

Results presented here include samples collected in the selenium-related field studies by Alberta Environment from 1998 to 2003. The raw data are stored in the Alberta Environment Water Data System (WDS) database. An electronic copy of the data can be requested from the Data Management Section (Environmental Monitoring and Evaluation Branch, Environmental Assurance Division).

3.1 Quality Assurance

Quality assurance data associated with the samples collected in the field studies provided a high level of confidence in the data obtained. The analytical results were within those routinely achieved by Alberta Environment and are considered satisfactory. For example, in the case of analysis of selenium in surface water, the field blank samples for all studies from 1998 to 2003 showed no detections of selenium above the method detection limit. These results indicate that there was no measurable contamination while collecting, handling and analysing the samples. Comprehensive analysis and reporting of the quality assurance data for samples taken in 1998 and 1999 did not show concerns with the field sampling and handling techniques by Alberta Environment and the analytical laboratory (ARC)[9].

3.2 Long-Term Patterns of Selenium in McLeod River, 1984 to 2003

Selenium data for numerous sites throughout the McLeod River drainage show mobilisation of selenium into surface waters is related to activities at the mountain coal mines in the headwaters (Casey and Siwik 2000; Alberta Environment WDS database). Available data from the mid-1980s to 2003 are used here to determine long-term trends for selenium concentrations at key sites in the McLeod River (Figure 3)[10]. The majority of these samples were analysed by the same laboratory (i.e., ARC) using similar analytical procedures and low analytical detection limits.

3.2.1 Upper McLeod River

Selenium concentrations were at very low concentrations (often less than the analytical detection limit) at the two reference sites in the upper McLeod River[11] from the mid-1980s to 2003 (Figure 3). These concentrations were usually less than the most stringent water quality guideline[12].

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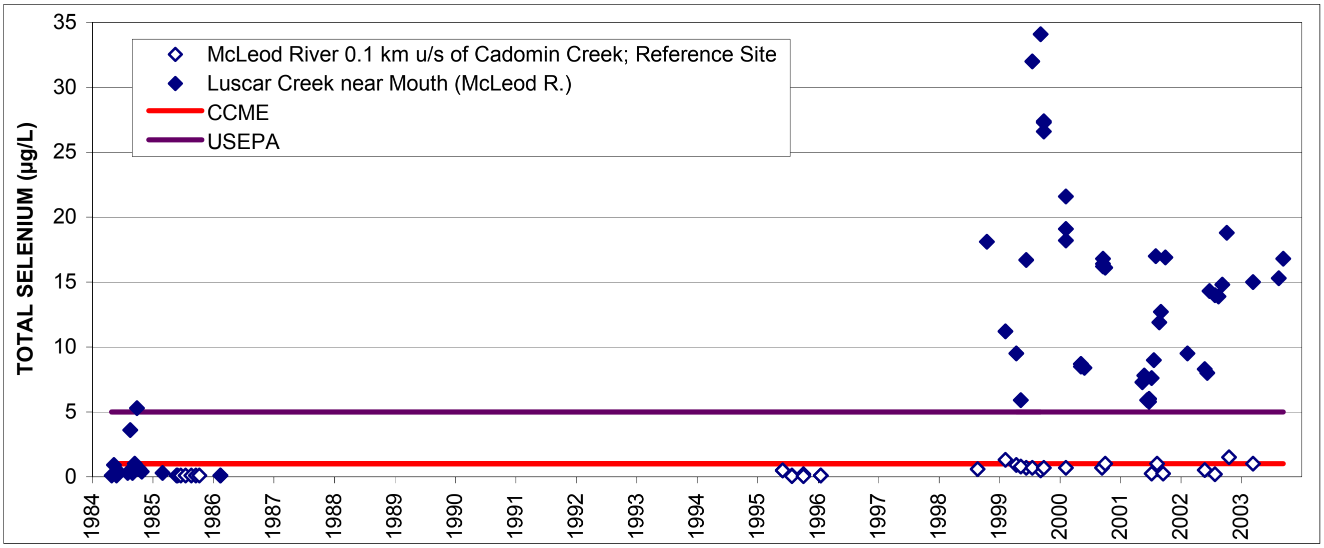
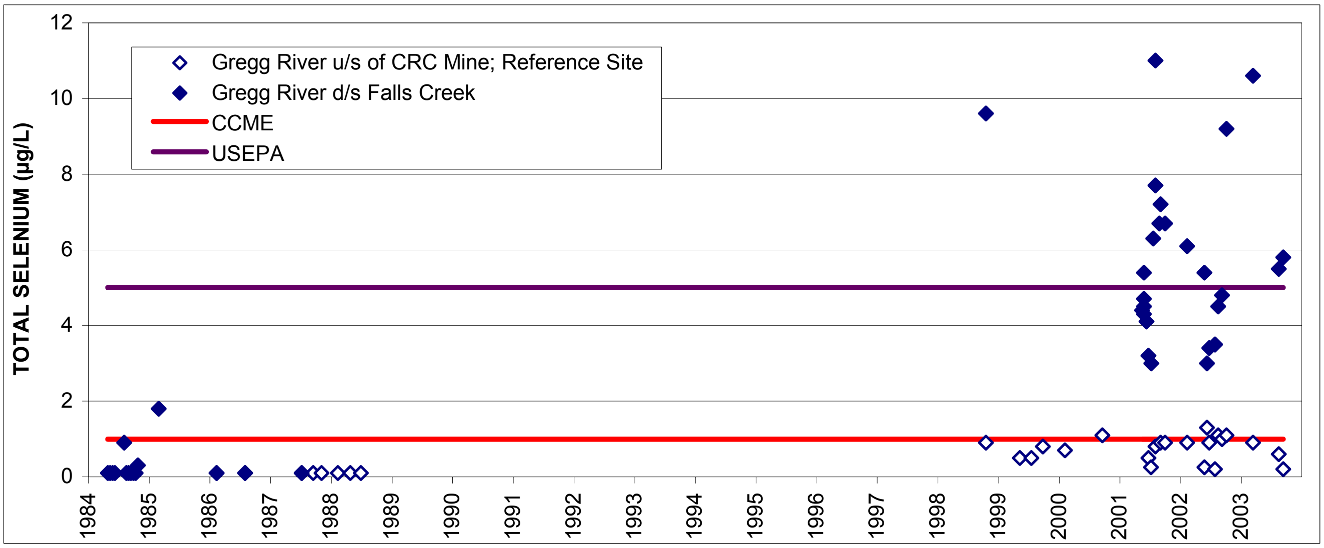
[9] These samples included: the analysis of selenium and other metals in field blanks and replicate samples; and percent recovery of metals in single and replicate spiked samples and/or standard reference samples of water, coal fly ash, soil and biological tissues (Casey and Siwik 2000).

[10] There are no comparable long-term data for the upper Smoky River in the WDS database.

[11] There are no selenium data for the Luscar Creek reference site (upstream of the CRC mine) in the WDS database before 1999. Thus, data from the McLeod River upstream of Cadomin were used. The McLeod River and Gregg River reference sites were moved upstream over time because of potential influences of major land-use activities (i.e., coal and limestone mining) that progressed upstream of the original sites.

[12] At the Gregg River reference site, selenium concentrations were slightly higher from 1998 to 2003 compared to the mid-1980s, when all concentrations were less than the analytical detection limit. This small increase did not appear to be related to a change in analytical methods or laboratory. However, it may be due to an unforeseen influence of a rock dump adjacent to the sample site. It is possible that shallow groundwater and/or surface runoff from the dump could have influenced surface water at the site. The site was moved upstream of the dump in 2004.





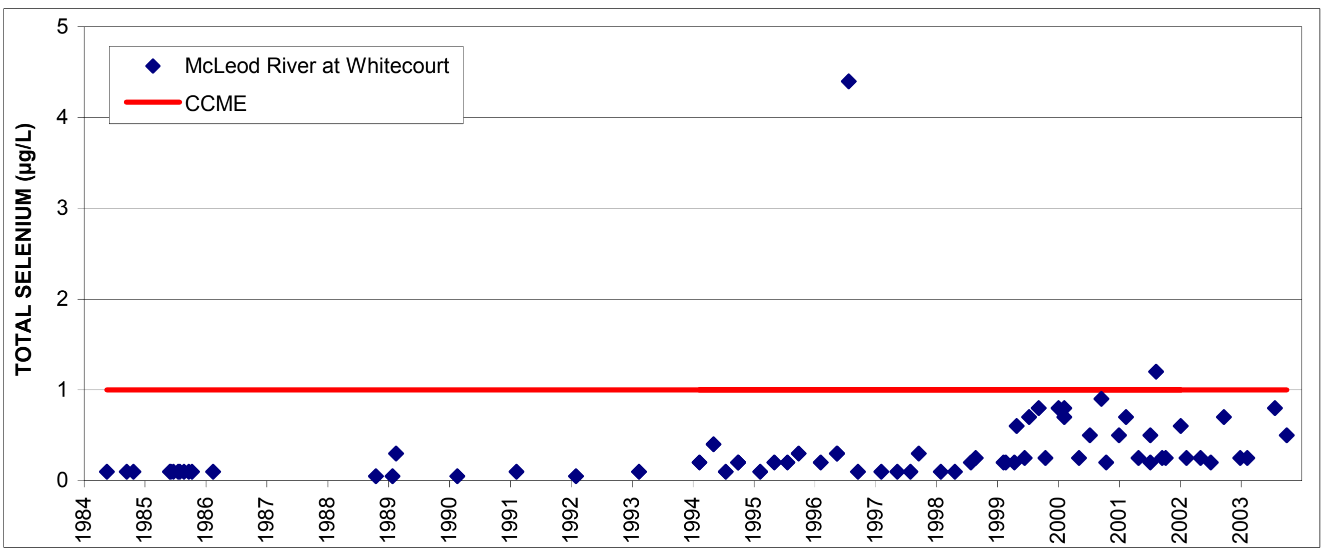


Figure 3 Long-term trends for total selenium concentrations at reference and exposed sites in the McLeod River basin, 1984 to 2003
Selenium water quality guidelines for the protection of freshwater aquatic life (CCME and US-EPA) are also shown.

In comparison, selenium concentrations at the two exposed sites showed a different trend over the two decades. Although there were no data for intermediate years (over about a 10-year period), selenium concentrations were usually at low levels at the exposed sites in the mid-1980s compared 1998 to 2003 (Figure 3). During the latter period, selenium concentrations at the exposed sites were often greater than the CCME and US-EPA water quality guidelines (Figure 3). Higher selenium concentrations at the exposed sites in Luscar Creek compared to Gregg River could be due to the greater proportional area of mine disturbance in the drainage upstream of the Luscar site (compared to Gregg River), and dilution by inflow from Sphinx Creek (Section 3.5.1).

3.2.2 McLeod River at Mouth

A more complete selenium dataset over the 20-year period is available for the mouth of the McLeod River. The site is at the town of Whitecourt about 360 km downstream of Cadomin, which is close to the eastern edge of the CRC mine (Figure 1). In general, selenium concentrations were at very low levels from the mid-1980s to 1998 (often less than the analytical detection limit), while slightly higher selenium concentrations occurred from 1999 to 2003 (Figure 3). This concentration increase does not appear to be due to a change in analytical method or laboratory. Overall, the selenium concentrations (with two exceptions)[13] were less than the most stringent water quality guideline for the protection of freshwater aquatic life.

Although there are no selenium data at the exposed headwater sites from mid-1980s to 1998, higher selenium concentrations at the mouth site beginning in 1999, generally corresponds to the timing of higher selenium concentrations at the headwater sites observed in late 1998. More frequent sampling at the mouth (beginning in 1994 with $\geq$ 3 samples per year) appears to support this trend.

A clear cause-and-effect explanation for higher selenium concentrations at the mouth of the McLeod River in the late-1990s is not explicitly evident. However, it may be due to overall increases of the spatial extent of coal mining and related reclamation activities in the upper McLeod River basin. Historically, the extent and intensity of coal mining in the McLeod River basin has varied throughout the 1900s. But in more recent decades, coal mining has been active at the CRC mine since the early 1970s, and at the Gregg River mine beginning in the early 1980s. Overall, the cumulative influences of these mines, including more specific processes, such as weathering and runoff from exposed overburden and disturbed areas, could have resulted in elevated selenium concentrations in surface waters downstream of the mines.

3.3 Selenium in Surface Water and Food Web, 1999 to 2001

Spatial and temporal patterns of selenium in surface water and components of a conceptual food web for streams near the coal mines are examined here.

[13] The unusually high selenium concentration of 4 µg/L at the mouth of the McLeod River in 1996 may not be accurate given all other samples throughout the 20-year were at much lower concentrations (Figure 3).

3.3.1 Longitudinal and Temporal Patterns, Fall 1999 and 2000

Longitudinal (upstream to downstream) patterns in surface water, sediment and biofilm samples were examined at sites in the same season (fall) over two years (Tables 1 and 3). The focus is on the McLeod River drainage where most samples were taken.

Surface Water

The main patterns in surface water were (Figures 4 and 5):

- Lowest selenium concentrations were found at the reference sites (11 reference sites; median = 0.7 µg/L, range of concentrations ≤0.25 to 2.2[14] µg/L, n = 13 in 1999 and 2000) compared to exposed sites.
- Highest selenium concentrations in each river system occurred at the first site downstream of the mines (Luscar Creek = 27.1 and 16.5 µg/L in 1999 and 2000, respectively; Falls Creek = 29.2 µg/L, Berry's Creek = 12.7 µg/L and Beaverdam Creek = 15.7 µg/L in 1999).
- Selenium concentrations gradually declined at sites further downstream of each mine to values that were similar to those at reference sites.
- Overall, similar longitudinal spatial patterns of selenium concentrations were found among the McLeod River sites in 1999 and 2000.
- Selenium concentration at the Luscar Creek exposed site was lower in 2000 than in 1999 (Figure 4). However, longer-term data show selenium concentrations in Luscar Creek have remained relatively stable over time (Figure 3; Section 3.5.1).
- In the Lovett River, selenium concentrations were at low or undetectable levels at the reference and exposed sites (near the Coal Valley mine) in the fall, spring and summer of 1999 (Figure 5; Casey and Siwik 2000).

Overall, longitudinal patterns of selenium concentrations among sites in McLeod River during fall of 1999 and 2000 were similar to those found at the same sites in the spring and summer of 1999 (Casey and Siwik 2000). Seasonal trends for selenium concentrations in surface waters are presented in Section 3.5.1.

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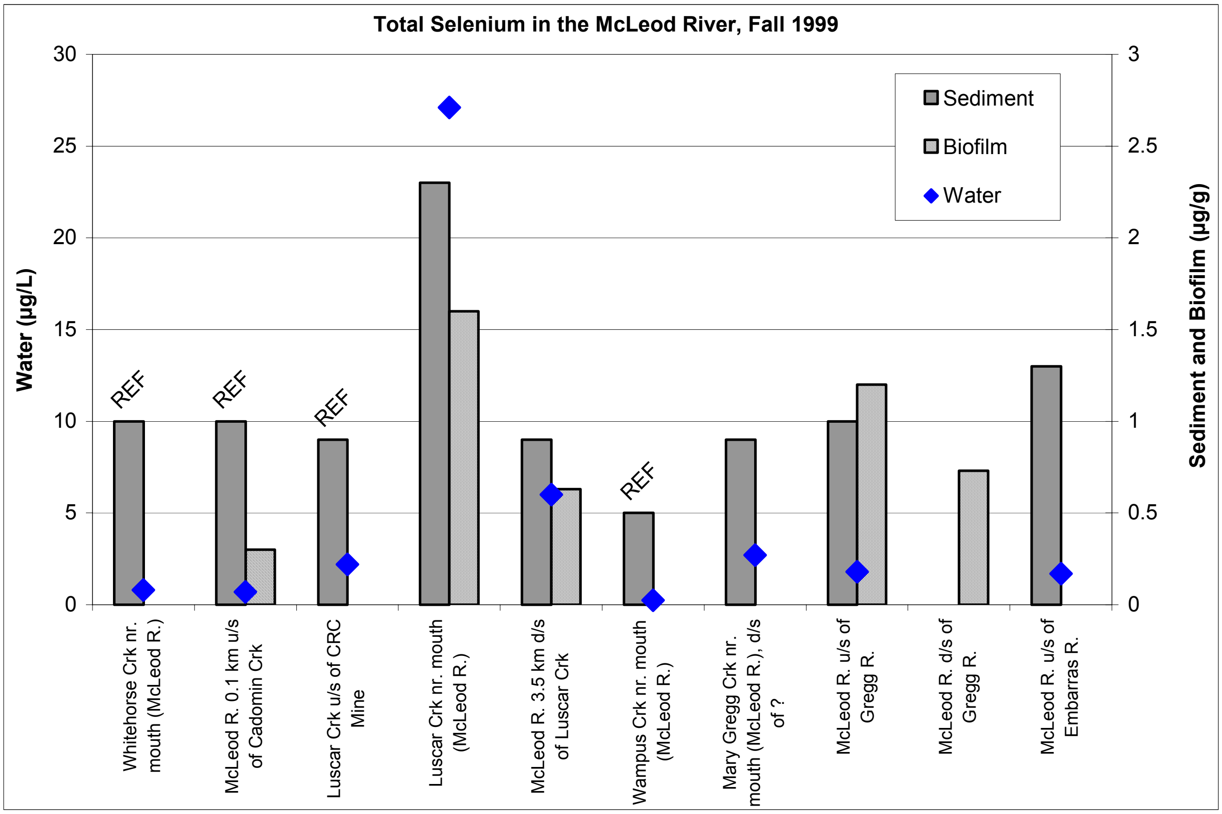
[14] Selenium concentrations in surface water at reference sites in west-central Alberta were typically less than the most stringent water quality guideline for the protection of freshwater aquatic life (Casey and Siwik 2000; Alberta Environment WDS database). However, exceptions occurred at some reference sites. For example, the highest selenium concentrations of all reference sites occurred at the Luscar Creek reference site, upstream of the CRC mine. All data for this site from 1998 to 2003 showed a median selenium concentration of 1.5 µg/L (range ≤0.25 to 2.5 µg/L; n = 22) that was slightly greater than the CCME water quality guideline (see Section 3.5.1 for data from other reference sites).



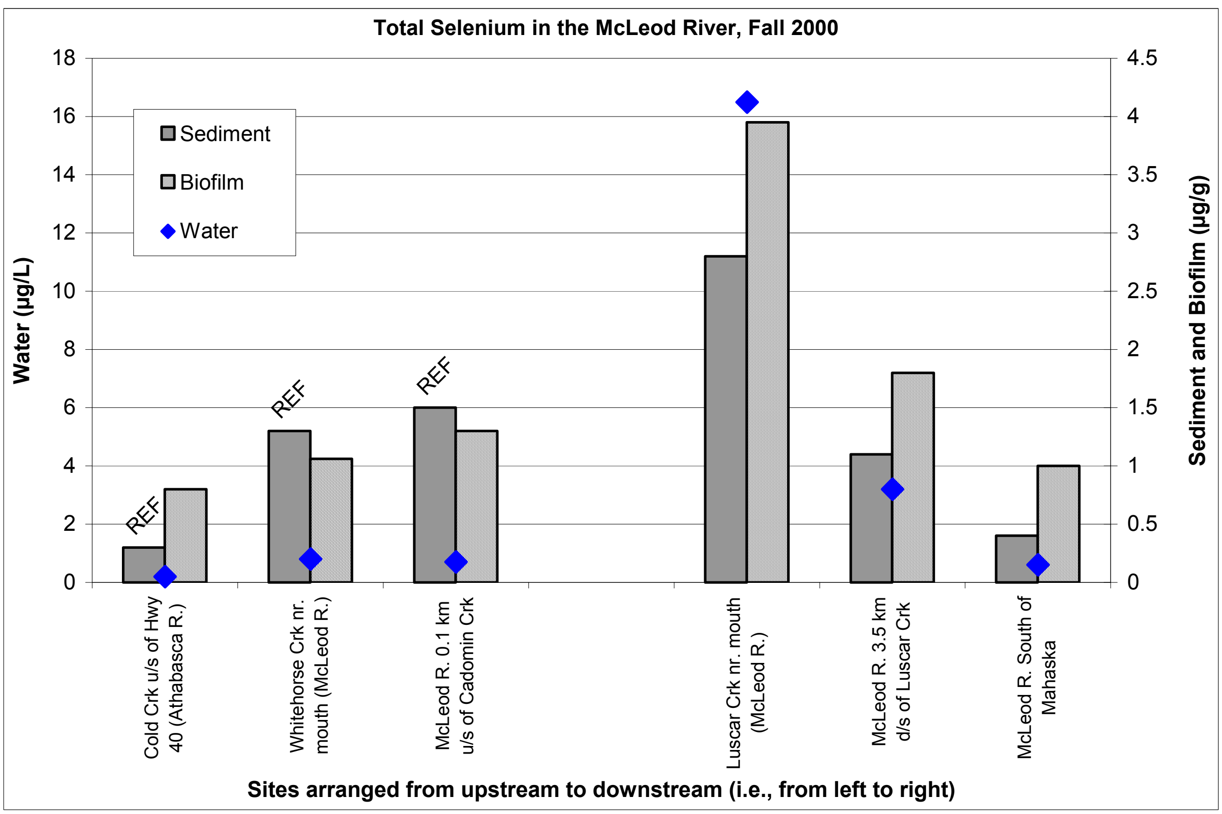
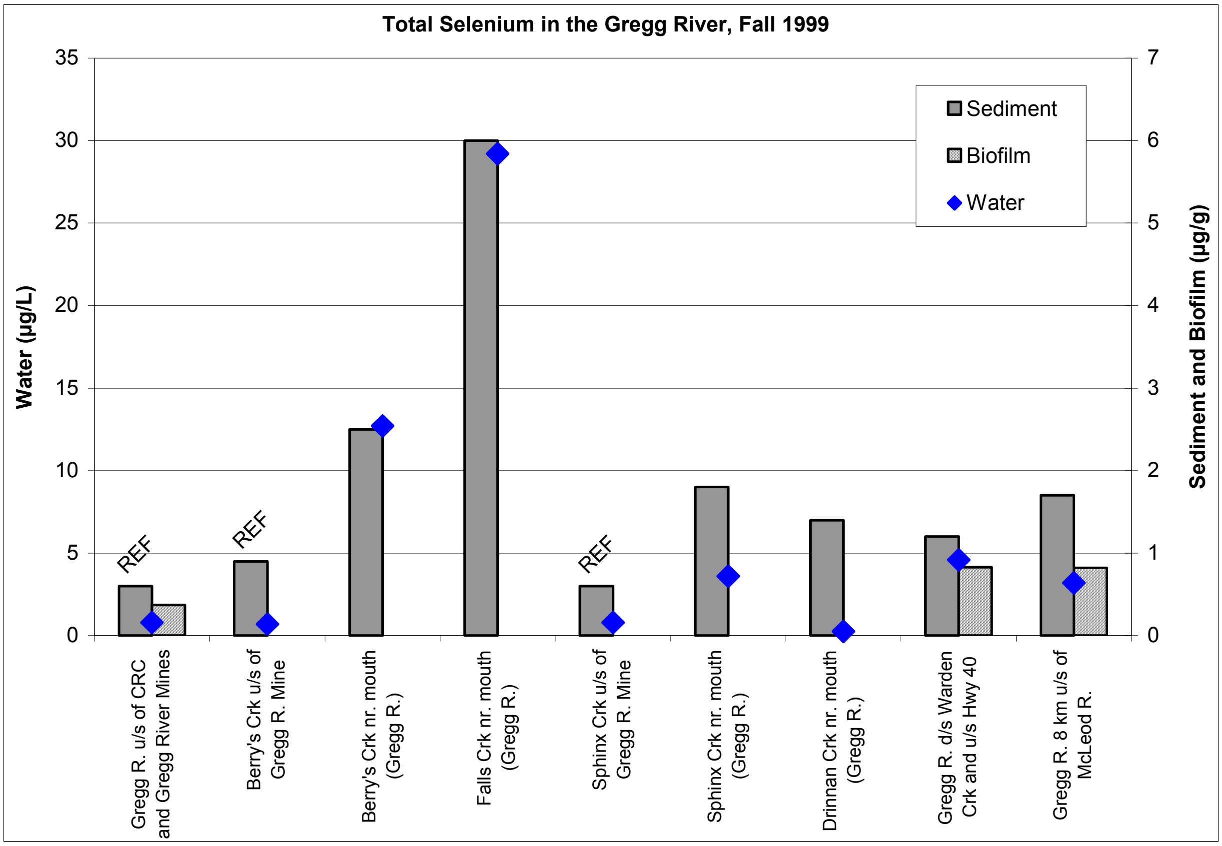


Figure 4 Total selenium concentrations in surface water, sediment and biofilm at reference (REF) and exposed sites in the McLeod River basin in the fall of 1999 and 2000



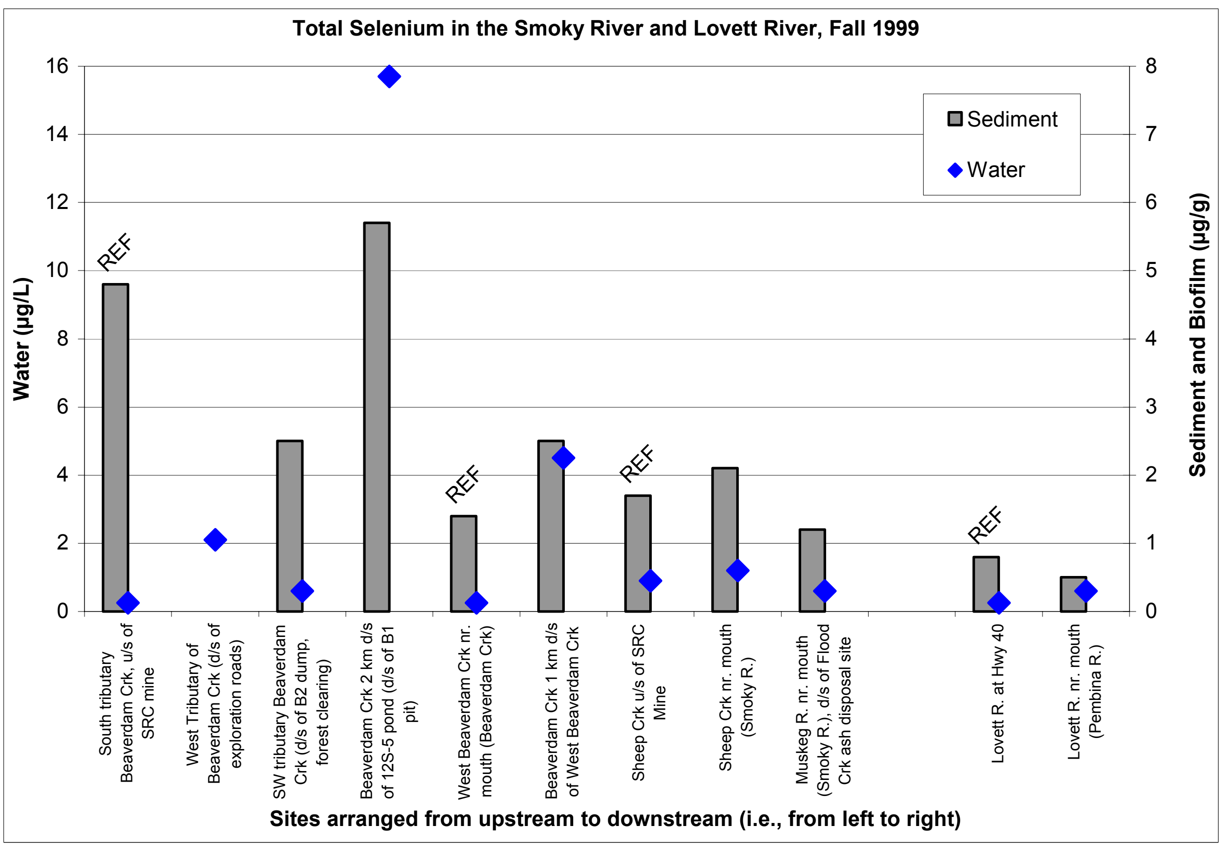


Figure 5 Total selenium concentrations in surface water, sediment and biofilm at reference (REF) and exposed sites in the Gregg River, Smoky River and Lovett River basins in the fall of 1999

Sediments

Major patterns in aquatic sediment data were (Figures 4 and 5):

- Similar to the surface water data, highest selenium concentrations occurred in sediments at the first exposed sites (Luscar Creek = 2.3 and 2.8 µg/g in 1999 and 2000, respectively; Falls Creek = 6.0 µg/g, Berry's Creek = 2.5 µg/g, Beaverdam Creek = 5.7 µg/g in 1999) compared to all other sites.
- Selenium concentrations at the reference sites were usually less than those at the first exposed sites (11 reference sites: median and range of concentrations for 1999 and 2000 data = 1.0 µg/g and 0.3 to 4.8[15] µg/g, respectively, n = 13).
- Selenium concentrations at the remaining sites downstream of the mines (range of concentrations = 0.4 to 2.5 µg/g) overlapped with those at reference sites.
- In the McLeod River where comparable sediment samples were collected, the longitudinal pattern for selenium concentrations among reference and downstream sites was similar in 1999 and 2000 (Figure 4).
- In the Lovett River system, selenium concentrations at both the reference and exposed sites were similar to those at reference sites in other river systems.

Overall, the aquatic sediment data showed consistent although small increases of selenium at the first site downstream of the mines compared to the reference sites. Some of the variation in selenium concentrations in sediments could have been influenced by sediment composition. For example, selenium was positively correlated with total organic carbon in the sediment samples (r = 0.547, N = 52). Other studies have also shown a strong positive relationship between selenium and organic content in aquatic sediments (e.g., Presser *et al.* 1994; Van Derveer and Canton 1997). Overall, there were no statistical differences for selenium concentrations or TOC (percent composition) in sediments between the reference and first exposed sites downstream of the mines (t-test critical values = 2.45, P = 0.26, df = 6; 2.45, P = 0.66, df = 6, respectively). The sediment samples also showed variable particle size; but overall, the samples were predominantly made up of fine particles (<1.00 mm) (Alberta Environment WDS database).

Sediment data in two lakes, although not directly comparable to stream habitats, also showed higher selenium concentrations in the exposed lake (Lac des Roches) compared to the reference lake (Fairfax Lake) (Figures 1a and 1b) (Casey and Siwik 2000).

Biofilm

Most biofilm samples were collected in the upper McLeod River. The data showed similar patterns to those found for selenium in surface water and sediment:

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[15] The range of selenium concentrations in sediments at all reference sites was 0.3 to 1.7 µg/g when the highest concentration of 4.8 µg/g at the South tributary of Beaverdam Creek reference sites was omitted. The unusually high selenium concentration at this site may have been influenced by the sample composition. The sample was mostly made up of organic material including small twigs compared to smaller materials (e.g., sand, silt, clay and fine detritus) more typical of sediment at most of the other sites (Alberta Environment unpublished field notes).

- In the McLeod River, the highest selenium concentrations in biofilm were at the first exposed site in both years, and lower concentrations were usually at the reference sites (Figure 4).
- In the Gregg River system, the lowest selenium concentration in biofilm was at the reference site, and slightly higher concentrations were at the two sites downstream of the Gregg River mine (Figure 5).

3.3.2 Food Web Samples from Sites Used in Fish Toxicity Studies

Intensive collections of food web data were collected at the reference and exposed sites where fish were sampled for toxicity studies (Tables 1 and 3)[16]. These data are used in a conceptual aquatic food web[17] (Section 3.4).

<u>Surface Water, Sediment and Biofilm, 2001</u>

Data presented here focus on an evaluation of trends at sites over three consecutive months (July to September).

The main patterns of selenium in these samples showed (Figure 6):

- Lowest selenium concentrations in surface water, sediment and biofilm were at the two reference sites (Cold and Deerlick creeks) compared to the three exposed sites in all months (with few exceptions).
- Overall, there were no large or consistent changes of selenium concentrations in surface water, sediment and biofilm samples at the reference sites over time. Although there was a small, consistent decline of selenium in biofilm at the Deerlick Creek site from July to September.
- In contrast, selenium concentrations in water and biofilm consistently increased at the exposed sites over the three months. However, selenium concentrations in sediment showed no consistent increase or decrease over time at the same sites.
- For each sample date and site, the highest selenium concentrations were always in biofilm compared to sediment.

<u>Benthic Macroinvertebrates, 2000 and 2001</u>

Selenium concentrations in aquatic insects at reference and exposed sites are shown in Figure 7. The samples were made up of the larvae of major insect taxa: stoneflies (Plecoptera:

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[16] The fish toxicity studies conducted by DFO included collections of gametes and tissue samples from rainbow trout in spring 2000 and 2001 and brook trout in the fall of 2000 and 2001 (e.g., Holm *et al.* 2005).

[17] Food webs in freshwater ecosystems are usually composed of three to five trophic levels or functional feeding groups of biota that transfer energy through the food web. Trophic levels in streams usually include: primary producers such as algae and plants at the lowest level; primary and secondary consumers such as herbivores and biota that feed on detritus (e.g., microbes, plankton and benthic macroinvertebrates); and tertiary and higher consumers such as carnivores (e.g., benthic macroinvertebrates and fish).

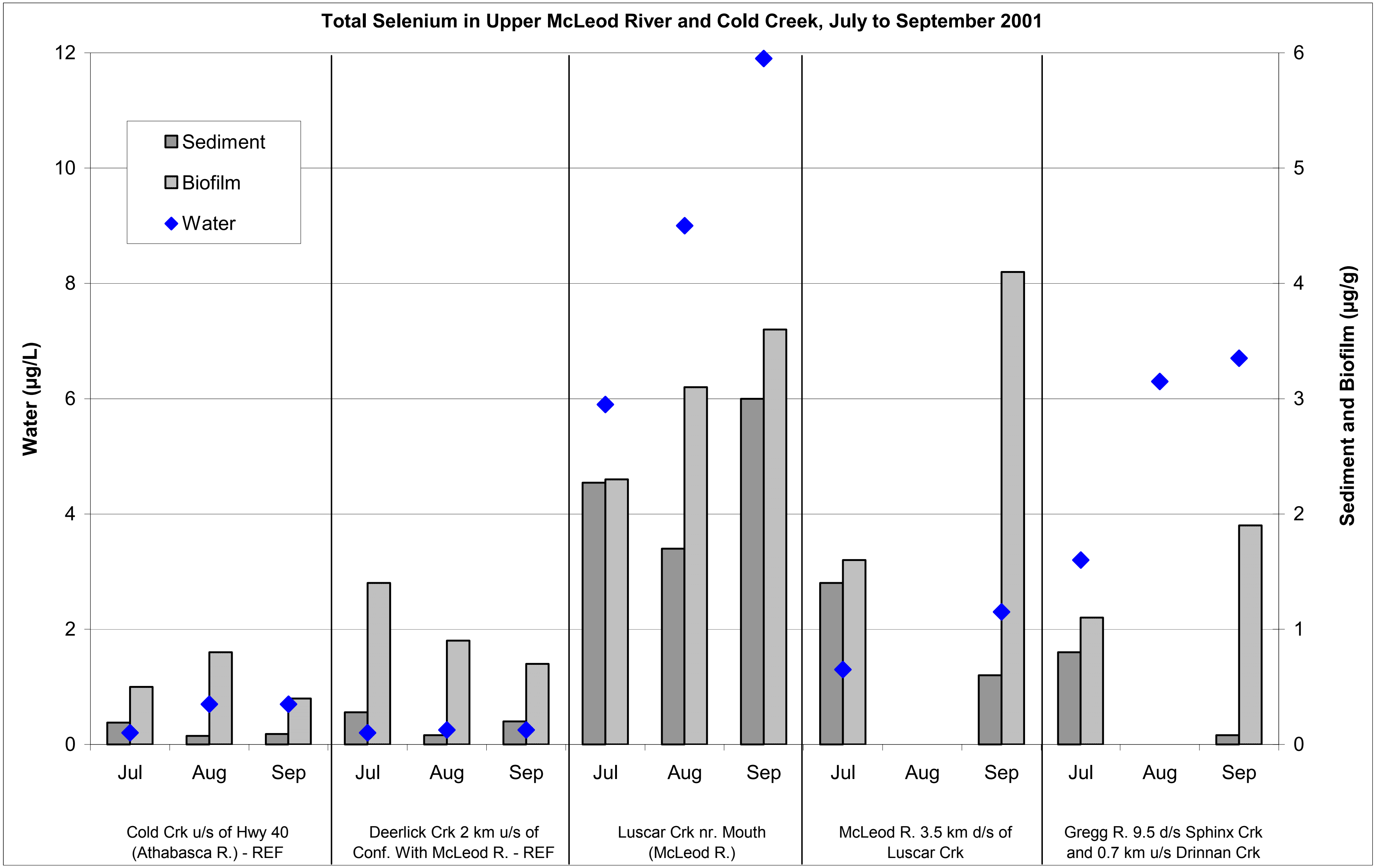

Figure 6 Total selenium concentrations in surface water, sediment and biofilm at reference (REF) and exposed sites in the upper McLeod River basin and Cold Creek (Athabasca River drainage) from July to September 2001

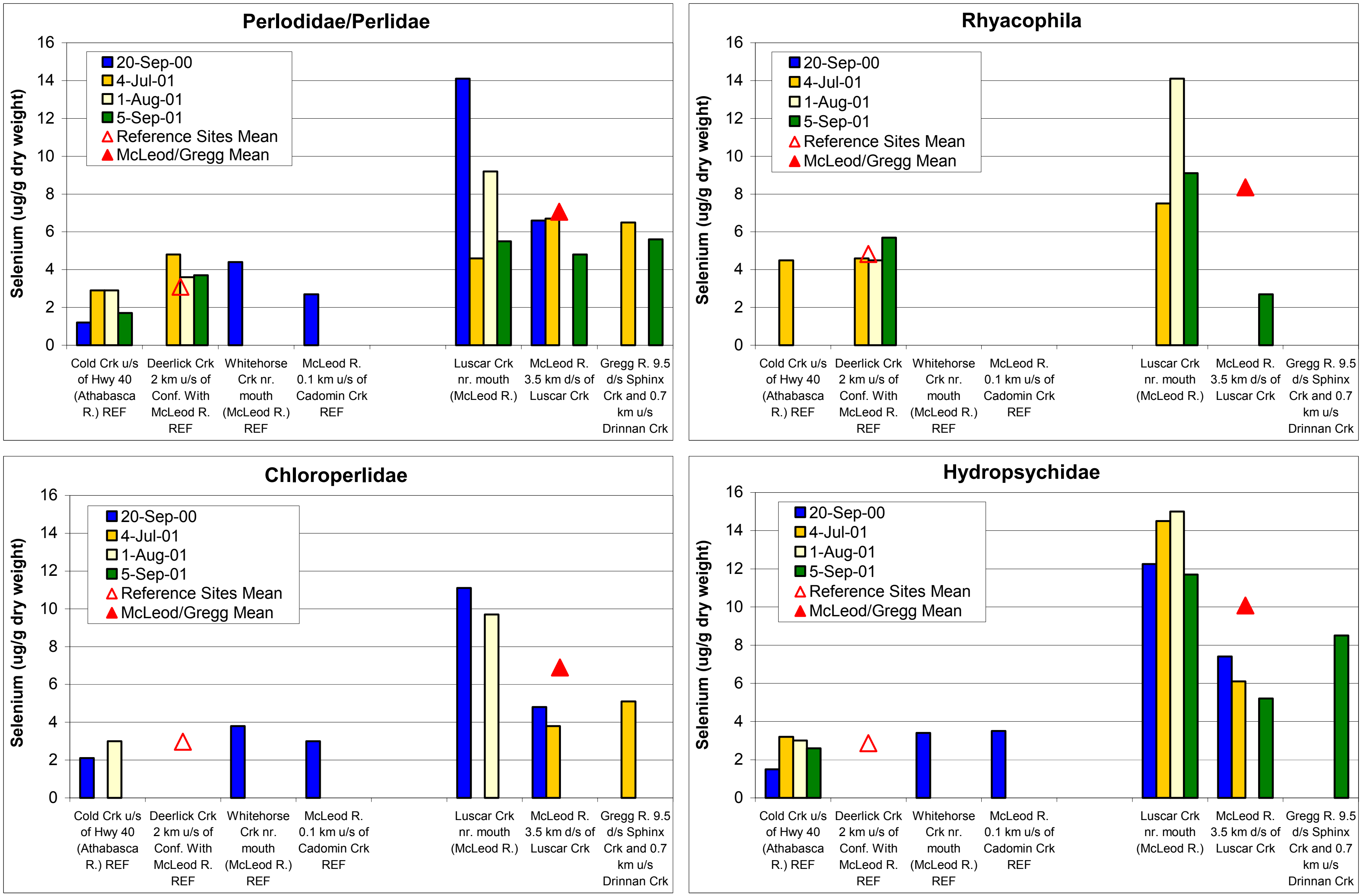

Figure 7 **Selenium concentrations and mean values for samples of aquatic insect larvae at reference (REF) and impacted sites in the McLeod and Gregg river basins from 2000 to 2001**

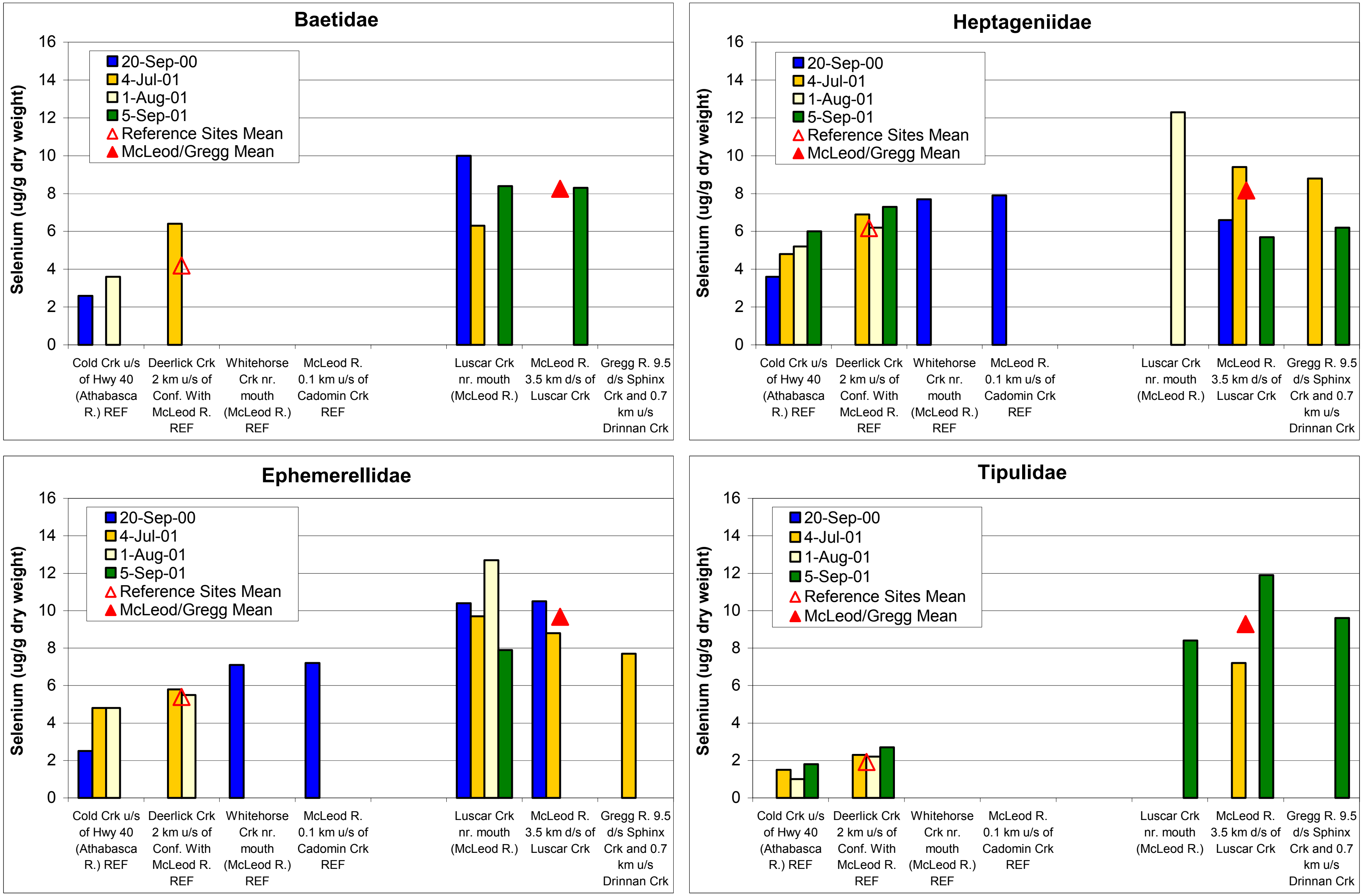

Figure 7 **Selenium concentrations and mean values for samples of aquatic insect larvae at reference (REF) and impacted sites in the McLeod and Gregg river basins from 2000 to 2001 (continued)**

Perlodidae/Perlidae and Chloroperlidae); caddis flies (Trichoptera: Rhyacophilidae, *Rhyacophila* spp., and Hydropsychidae); mayflies (Ephemeroptera: Baetidae, Ephemerellidae and Heptageniidae); and crane flies (Diptera: Tipulidae). These larvae are generalist feeders and their diet can vary as they mature. Overall, the taxa include collectors-gatherers and grazers of benthic algae and detritus (Baetidae, Ephemerellidae, Heptageniidae), filter feeders (Hydropsychidae) and predators (Perlodidae/Perlidae, Chloroperlidae, *Rhyacophila*) (Merritt and Cummins 1996). Most Tipulidae larvae are omnivores feeding on decaying plant and animal material (Clifford 1991). Analysis of the fish stomach samples from 1999 to 2001 showed the larvae of these aquatic insect taxa were common in the diet of different sport fish species (at reference and exposed sites) in the upper McLeod and Smoky river systems (Stantec 2004). Aquatic insect adults were also important components of the fish diet in some cases (Stantec 2004). The relative importance of the aquatic insect larvae and adults in the diet could depend on various factors including fish maturity, feeding habits and habitat conditions.

Major patterns of selenium in the aquatic insects showed (Figure 7):

- Mean selenium concentrations were generally greater at exposed sites compared to the reference sites.[18] Statistical tests for taxa with sufficient data[19] showed selenium concentrations were statistically greater at the exposed sites (compared to reference sites) for Perlodidae/Perlidae, Hydropsychidae and Ephemerellidae (t-test critical values = 2.12, $P < 0.001$, df = 16; 2.17, $P < 0.001$, df = 12; and 2.26, $P = 0.002$, df = 9, respectively), but not for Heptageniidae (t-test critical value = 2.26, $P = 0.10$, df = 9).
- For most taxa, the highest selenium concentration was usually at the first exposed site in Luscar Creek. This corresponded with the highest selenium levels in surface water and other food web components (sediment and biofilm) in Luscar Creek.
- Overall, there was no strong pattern for selenium concentrations among different insect taxa or trophic levels in the food web. For example, mean selenium concentrations in collector-gatherers and grazers (Baetidae, Ephemerellidae, Heptageniidae, Tipulidae) were similar and in some cases, even higher than mean selenium concentrations in predators (Perlodidae/Perlidae, Chloroperlidae, *Rhyacophila*).
- There was no consistent or pronounced trend of selenium concentrations in any insect taxon from June to September, although data for several taxa and dates were limited.

<u>Other Samples of Non-Fish Biota, 1999 to 2001</u>

Other non-fish biota were sampled opportunistically at flowing-water sites, mostly in the McLeod River system (Table 4). Collectively, the samples included a variety of aquatic and riparian vegetation, filamentous algae, stonefly adults and aquatic insect larvae [20]. With the

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[18] All data for the reference sites or exposed sites in both years were combined to obtain mean selenium concentrations with maximum sample sizes (Figure 7).
[19] Statistical comparisons were only done for taxa with $\geq$5 samples at both the reference and exposed sites.
[20] Two composite samples made up of different families of aquatic insect larvae are excluded from the discussion here (Table 4). These initial samples (taken in 1999) were used to determine the relative selenium concentrations in common benthic macroinvertebrates at reference and exposed sites.

Table 4 Selenium concentrations in samples of other non-fish biota, 1999 to 2001

Sample Site	Non-Fish Biota: Macroinvertebrate Larvae, Pupae or Adults; Algae; Aquatic or Riparian Vegetation	Sample Date	Selenium Concentration (µg/g, dry weight)
McLeod River Basin (excluding Cold Creek)			
McLeod R. 0.1 km u/s of Cadomin Crk	Aquatic Insect Larvae (composite sample)	21-Sep-99	3.88
McLeod R. 3.5 km d/s of Luscar Crk	Plecoptera Adults	4-Jul-01	6.2
McLeod R. 3.5 km d/s of Luscar Crk	Filamentous Algae	6-Sep-01	0.3
Gregg R. Above Luscar Valley (CRC) Mine	Macrophytes (unidentified)	22-Sep-99	1.3
Deerlick Crk Approx. 2 km u/s of Confluence with McLeod R.	Limnephilidae (*Dicosmoecus* sp. cases)	5-Sep-01	0.7
Deerlick Crk Approx. 2 km u/s of Confluence with McLeod R.	Limnephilidae (*Dicosmoecus* sp. pupae)	2-Aug-01	2.5
Deerlick Crk Approx. 2 km u/s of Confluence with McLeod R.	Limnephilidae (*Dicosmoecus* sp. pupae)	5-Sep-01	2.8
Luscar Crk Immediately d/s Hwy 40 Bridge	Filamentous Algae	3-Jul-01	5.5
Luscar Crk Immediately d/s Hwy 40 Bridge	Aquatic Insect Larvae (composite sample)	21-Sep-99	7.8
Luscar Crk Immediately d/s Hwy 40 Bridge	Macrophytes (unidentified)	21-Sep-99	17
Luscar Crk Immediately d/s Hwy 40 Bridge	Reedgrass (*Sparangium* sp.; Riparian/emergent Vegetation)	3-Jul-01	3.6
Luscar Crk Immediately d/s Hwy 40 Bridge	Reedgrass (*Sparangium* sp.; Riparian/emergent Vegetation)	1-Aug-01	3.8
Luscar Crk Immediately d/s Hwy 40 Bridge	Reedgrass (*Sparangium* sp.; Riparian/emergent Vegetation)	4-Sep-01	4.1
McLeod R. Near McLeod Valley - 1.5 km d/s of Hwy 32 Crossing	Moss and *Potamogeton* sp.	23-Sep-99	0.8
McLeod R. South of Mahaska	Gomphidae Larvae	29-Sep-00	2.7
McLeod R. South of Mahaska	*Brachycentrus* sp. larvae	29-Sep-00	5.4
McLeod R. South of Mahaska	*Chara*	29-Sep-00	0.7
McLeod R. South of Mahaska	Clasping Pond Weed (*Potamogeton* sp.)	29-Sep-00	1.3
McLeod R. South of Mahaska	Grasses on Shoreline	29-Sep-00	0.3
McLeod R. South of Mahaska	Heptageniidae Larvae	29-Sep-00	5.3
McLeod R. South of Mahaska	Hydropsychidae Larvae	29-Sep-00	3.2
McLeod R. South of Mahaska	Perlodidae/Perlidae Larvae (replicate sample - 1)	29-Sep-00	3.48
McLeod R. South of Mahaska	Perlodidae/Perlidae Larvae (replicate sample - 2)	29-Sep-00	2.5
Cold Crk u/s of Hwy 40 (Maskuta Creek, Athabasca R.)	Plecoptera Adults	4-Jul-01	3.1
Lakes & Groundwater Seeps			
Fairfax Lake	Anisoptera Larvae	20-Sep-00	<0.15
Fairfax Lake	Baetidae/Caenidae Larvae	20-Sep-00	0.9
Fairfax Lake	Phyrganeidae/Limnephilidae Larvae	20-Sep-00	0.5
Fairfax Lake	Zygoptera Larvae	20-Sep-00	<0.15
Fairfax Lake	Sphaeridae (sample analysed included shell)	20-Sep-00	0.42
Fairfax Lake	Gastropoda (sample analysed included shell)	20-Sep-00	0.4
Luscar Lake	Filamentous Algae (taken at shoreline)	27-Sep-00	3.8
Groundwater Seeps Entering South End of Luscar Lake	Filamentous Algae (replicate sample - 1)	27-Sep-00	5.1
Groundwater Seeps Entering South End of Luscar Lake	Filamentous Algae (replicate sample - 2)	27-Sep-00	5.5

exception of one sample, selenium concentrations in all samples together ranged from 0.3 to 6.2 µg/g [21] (Table 4). Overall these data, although limited in sample size, showed much overlap or similarity in selenium concentrations among various taxa and trophic levels.

A small number of non-fish biota samples were also obtained in two lakes and groundwater seeps at the base of a rock dump (Figure 1b). Data for the reference lake (Fairfax Lake) showed low selenium concentrations (<0.15 to 0.9 µg/g) in a variety of benthic macroinvertebrates. In comparison, higher selenium concentrations (3.8 to 5.5 µg/g) were found in filamentous algae in the exposed lake (Luscar Lake) and groundwater seeps draining into the lake (Table 4). Overall, these data are very limited in sample size and scope, and they are not sufficient to determine the fate and effects of selenium in lake or wetland habitats at the mines.

3.4 Conceptual Food Web and Effects of Selenium in Flowing Water

A conceptual food web for streams near the mountain coal mines is presented here. The results and discussion consider selenium concentrations in surface water and major trophic levels of the food web (i.e., sediment, biofilm, aquatic insect larvae and one fish species) in a reference and exposed stream. The information is used to evaluate the fate and potential effects of selenium in streams.

3.4.1 Conceptual Food Web

In freshwater ecosystems, selenium can be present in different chemical forms such as selenate, selenite and organic selenium compounds, with varying levels of toxic or adverse effects (e.g., Maier and Knight 1994). Direct toxicity of water-borne inorganic forms of selenium (e.g., selenite and selenate) on aquatic life generally occurs at relatively high concentrations, and aquatic invertebrates are usually more susceptible than vertebrates at the same selenium concentration (US-EPA 2004). Organisms at lower trophic levels in an aquatic food web, however, can bioconcentrate selenium from the surface water environment. Filamentous algae, vegetation, biofilm and surficial sediments[22] are used here as indicators of bioconcentration in the aquatic systems sampled in this study. The ratio of selenium concentrations in each of these media relative to surface water concentrations is used to calculate bioconcentration factors (BCFs). Bioaccumulation of contaminants within aquatic food webs is usually shown by increasing concentrations or biomagnification of the substance to highest concentrations at the top of the food web (e.g., in predacious fish). Diet is considered to be an important exposure pathway for selenium to bioaccumulate or biomagnify to toxic levels in fish tissues (Lemly 1993, 1996; Maier and Knight 1994; Presser *et al.* 1994; Hamilton 2002; US-EPA 2004).

As noted in Section 1.0, adverse effects of selenium on fish include teratogensis and edema in the fry (to the swim-up stage). These are due to the maternal transfer of elevated selenium in mature ovary (eggs) to fertilised eggs. When the eggs hatch, early development of the larval fish can be influenced by the selenium-contaminated yolk sac, which the fry depend on for energy

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[21] The exception was for an unidentified macrophyte at the exposed Luscar Creek site that had the highest selenium concentration (17 µg/g) of all non-fish biota samples in the Alberta Environment studies.
[22] Biofilm and surficial sediments can contain varying amounts of benthic algae, fungi, bacteria and other microbes, invertebrates and detritus, including decomposing remains of biota.

and as a source of protein (Lemly 1998). The measurement of selenium in mature ovary can be used as an integrated measure of selenium exposure from surface water environment and diet (or food web), and to determine the potential of reproductive impairment due to adverse effects on their progeny. Thus, the concentration of selenium in mature ovary (compared to diet or other fish tissues) is a key biological endpoint to determine toxicity effects on fish (Lemly 1993).

Figure 8 is a simplified diagram to illustrate major components and potential pathways for the bioaccumulation of selenium in the aquatic food web of streams in the study area. It also shows some relationships with parts of inter-connected riparian and terrestrial food webs. The diagram is not intended to show all relationships in these food webs. But it should be recognized that potential pathways for exchange of materials among aquatic, riparian and terrestrial food webs are important when considering the overall fate and effects of selenium at the mountain mines in west-central Alberta.

Data for selenium in the surface water and aquatic food web from 2000 and 2001 (Section 3.3.2) were used to illustrate the fate of selenium in representative streams (Figure 9) [23]. Rainbow trout tissue data (from Mackay 2005) were used because their progeny were more sensitive to selenium than brook trout in the toxicity studies. Rainbow trout is also a valued and important fish species in the McLeod River. Top predators such as other fish species, amphibians and waterbirds were not considered in the assessment.

The main patterns in the conceptual food web data were:

- For most individual taxa and trophic levels, the highest selenium concentrations were usually in the exposed stream compared to reference stream (Figure 9).
- Selenium bioconcentration in the food web varied from increases of two to three orders of magnitude in the exposed and reference streams, respectively (Table 5). Higher bioconcentration in the reference stream was due to very low or undetectable selenium in water. Bioconcentration and biomagnification of selenium in the reference stream may not be unusual, given that many organisms require selenium at low (non-toxic) levels, where it is incorporated into healthy tissues.[24]
- Overall, biomagnification of selenium from the lowest to higher trophic levels in the food web was not pronounced. However, it was most evident in Luscar Creek where there were incremental increases of selenium concentrations from fine sediment to: biofilm; aquatic insect larvae; and rainbow trout ovary (Figure 9).

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[23] Luscar Creek was chosen because it generally showed the highest selenium concentrations in surface water. Deerlick Creek was chosen because it was a comparable tributary of the McLeod River. Both streams generally have similar flow and habitat characteristics, and rainbow trout were present. Deerlick Creek also had the greatest number of samples for the same insect taxa as found in Luscar Creek; samples of two taxa from another reference stream, Cold Creek, were used when these taxa were not found in Deerlick Creek.

[24] It should also be noted that the estimates of biomagnification at the reference site could have been biased compared to the exposed site. This was because of the relatively low selenium concentrations and small changes among trophic levels at the reference site, that resulted in similar proportional changes as those at the exposed site. Therefore, biomagnification would be biased high at the reference (compared to exposed) site. Also, only two of the four trophic groups sampled at the exposed site were obtained at the reference site.

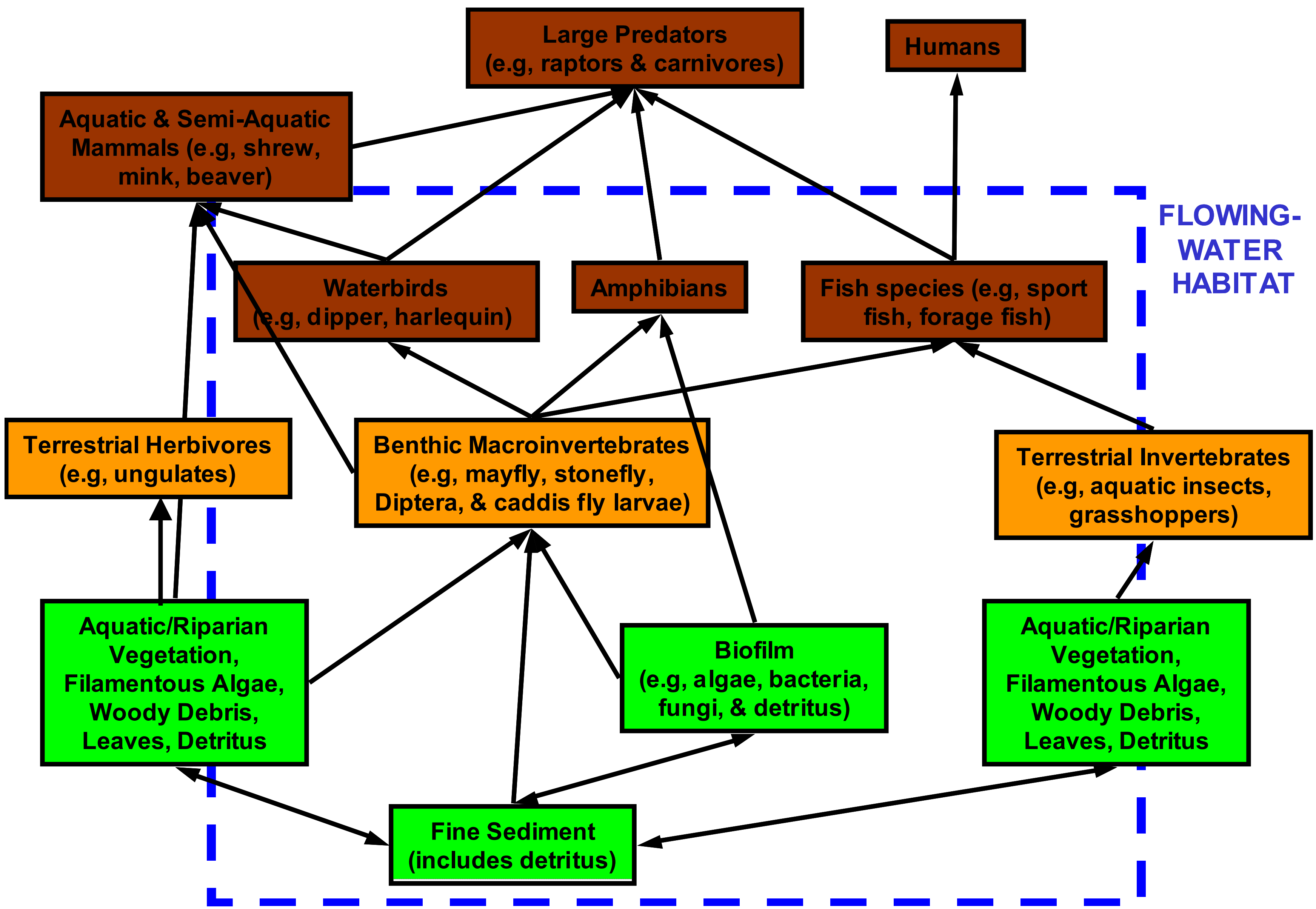

Figure 8 Conceptual food web in a flowing water ecosystem showing potential exposure pathways for selenium among various trophic levels including some interactions with riparian and terrestrial food webs

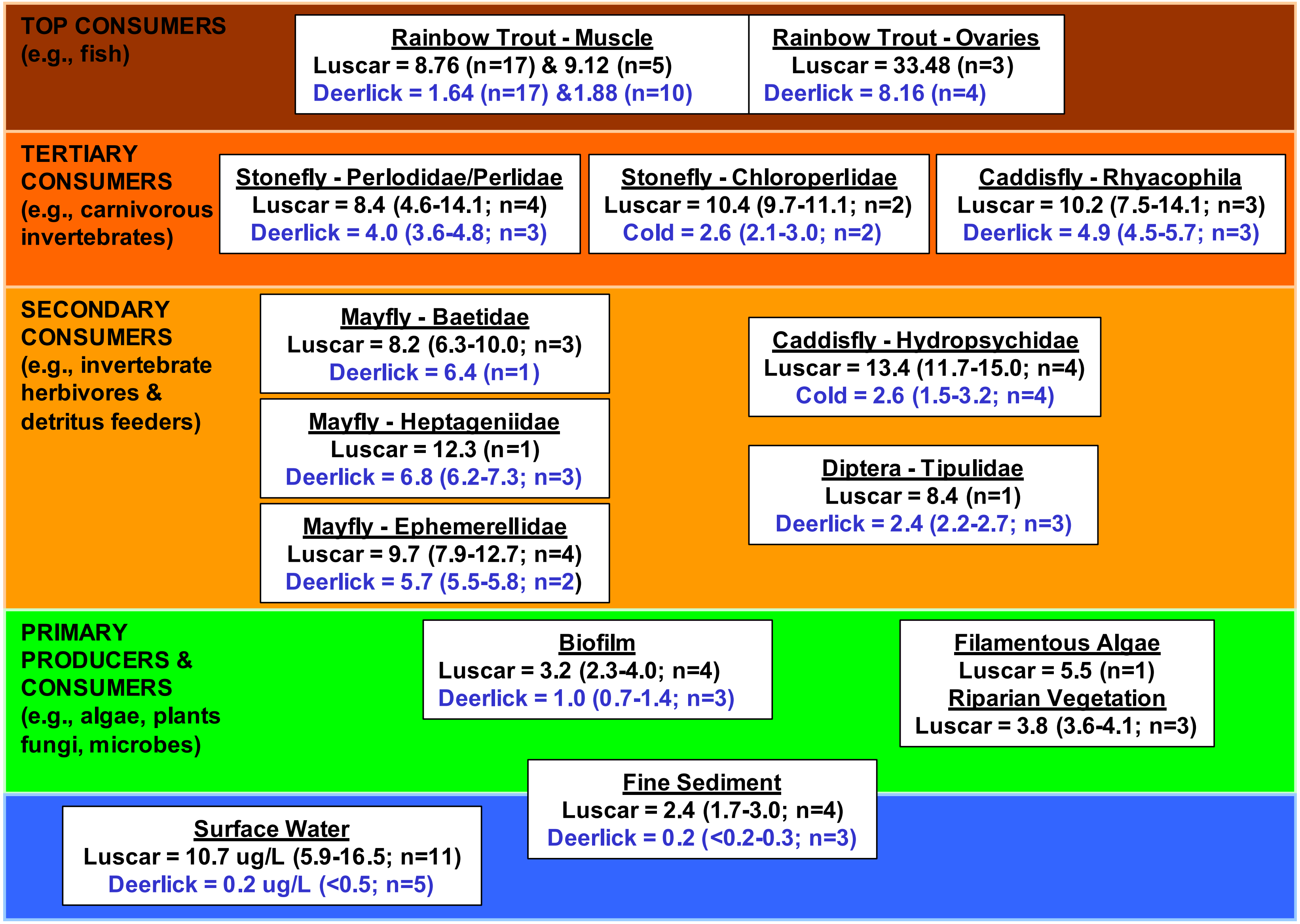

Figure 9 Selenium concentrations (µg/g dry weight; mean, range and sample number) in trophic levels of an aquatic food web in montane flowing water ecosystem

Table 5 Selenium concentration and bioaccumulation in the aquatic food web in reference and exposed streams (based on data in Figure 9)

Flowing-Water Environment & Food Web Components	Selenium Concentration		Selenium Bioaccumulation in Food Web	
	Reference Stream	Exposed Stream	Reference Stream	Exposed Stream
	Deerlick/Cold	Luscar	Deerlick/Cold	Luscar
	Mean Concentration (parts per million) [1]		Bioconcentration Factor	
Surface Water	0.0002	0.0107	---	---
Sediment	0.2	2.4	1000	224
Biofilm	1	3.2	5000	299
Filamentous Algae	---	5.5	---	514
Riparian Vegetation	---	3.8	---	355
			Biomagnification at Each Trophic Level	
Lowest Trophic Levels [2]	1	3.8	---	---
Secondary & Tertiary Consumers [3]	4.5	10.0	4.5	2.6
Rainbow Trout - Muscle [4]	1.76	8.94	0.4	0.9
Rainbow Trout - Ovary	8.16	33.48	1.8	3.4
			Biomagnification From Lowest to Highest Trophic Level	
Lowest Trophic Levels [2]	1	3.8	---	---
Rainbow Trout - Muscle [4]	1.76	8.94	1.8	2.4
Rainbow Trout - Ovary	8.16	33.48	8.2	8.8

Notes:

[1] Equal to mg/L for water and ug/g dry weight for other media

[2] Median of mean concentrations for biofilm, filamentous algae and riparian vegetation

[3] Median of mean concentrations for secondary and tertiary consumers

[4] Median of two mean concentrations

An important finding of the food web assessment was that selenium bioaccumulated or biomagnified to highest concentrations in rainbow trout ovary in the exposed stream (Luscar Creek) compared to the reference stream. Earlier collections of fish showed even higher (up to two-fold higher) selenium concentrations in rainbow trout tissues from Luscar Creek in 1999 [25] compared to 2000 or 2001 (Figure 9).

Other data from 1999, although not directly comparable to the stream data, showed selenium concentrations in rainbow trout from Lac des Roches, [26] were about two to three times higher than those in Luscar Creek (Figure 9). Higher selenium concentrations in fish from Lac des Roches compared to Luscar Creek could be related to higher selenium concentrations in surface

[25] Mean selenium concentrations (converted to dry weights) in immature and mature rainbow trout from Luscar Creek in 1999: muscle = 16.5 µg/g (n = 10); ovary = 78.0 µg/g (n = 7) (Casey and Siwik 2000).

[26] Mean selenium concentrations (converted to dry weights) in mature rainbow trout from Lac des Roches: muscle = 27.3 µg/g, n = 19; ovary = 87.8 µg/g, n = 19 (Casey and Siwik 2000).

water of the lake compared to the stream (Casey and Siwik 2000). This finding could also have been influenced by differences in the food webs and fish diets in the lake and stream habitats.

3.4.2 Comparisons of Food Web Data to Toxicity Effects Thresholds for Selenium

It is evident in the scientific literature that there is debate related to the fate and effects of selenium in freshwater ecosystems (e.g., see reviews and references cited therein by US-EPA 1998; Hamilton 2003; Hamilton 2004; US-EPA 2004). Concerns related to effects thresholds include the fact that their development is often based on the response of the most sensitive fish species or effects studies, which can include a variety of habitat and environmental conditions. For example, the fate of selenium in flowing and standing water habitats, and effects of selenium on specific fish species can vary. Thus, the resulting thresholds may not be directly applicable to the specific ecosystem being evaluated. Toxicity effects thresholds, however, are important assessment tools that can be used as an initial step in evaluating the food web data and potential of adverse effects in streams near the mountain coal mines. Additional steps such as toxicity and effects studies can be used to determine more specific toxicity due to selenium.

The toxicity effects thresholds used here include conservative and less stringent (or lowest and highest) thresholds for diet and fish tissues [27] which are available in the scientific literature. They were developed based on reviews of laboratory and field studies which documented adverse effects of selenium (including deformities, reduced survival and mortality) on variety of fish, including cold-water species. The thresholds published in peer-reviewed journals and technical reports, were recommended by representatives from academia, government, consultants and industry (Lemly 1993, 1996; Maier and Knight 1994; Skorupa *et al.* 1996; Stephens *et al.* 1997; US-DOI 1998[28]; DeForest *et al.* 1999[29]; URS 2000; Hamilton 2004).

The effects thresholds typically do not include a safety factor. Thus, adverse effects are expected when the selenium concentration in the tissue exceeds the threshold value.

Effects thresholds for selenium in aquatic sediment have also been developed. For example, Hamilton (2004) presented four thresholds in his recent review of selenium toxicity in aquatic food webs. These threshold values were similar with adverse effects expected at >4 µg Se/g. In another study, a sediment-based water quality guideline was developed (Canton and Van Derveer 1997; Van Derveer and Canton 1997). In general, this latter method and sediment thresholds do not appear to be widely used or accepted (e.g., see discussion in US-EPA 1998; Hamilton and Lemly 1999; Hamilton 2002). The development and application of sediment thresholds are hindered partly due to the importance of diet as an exposure pathway for selenium effects on aquatic biota at higher trophic levels (especially fish). Also, there are limited data on relationships between effects on aquatic life and selenium in sediment of varying characteristics (e.g., particle size and organic content). There are no Alberta or Canadian (CCME) sediment guidelines for the protection of freshwater aquatic life.

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[27] The effects thresholds used here are for fish muscle and ovary. Thresholds for "whole body" samples of fish have recently been proposed in the U.S.A. (e.g., Hamilton 2002; US-EPA 2004). These sample types were not analysed in the Alberta studies.
[28] This publication supercedes Skorupa *et al.* 1996 (J. Skorupa personal communication).
[29] A similar review and the same toxicity effects thresholds were presented in Brix *et al.* 2000.

Table 6 Toxicity effects thresholds and selenium in food web (based on data in Figure 9)

Toxicity Effects Thresholds			Reference Stream	Exposed Stream
			Deerlick/Cold	Luscar
	Selenium Concentration (µg/g, dry weight)	Author	Mean Selenium Concentration (µg/g, dry weight)	
Diet [1]			**Aquatic Insect Taxa (2000 & 2001)**	
	>4 3 3-8 >3 >3 10-11 >7 3	Maier and Knight 1994 Lemly 1993, 1996 [2] Skorupa *et al.* 1996 [3] Stephens *et al.* 1997 [4] US-DOI 1998 [5] DeForest *et al.* 1999 [6] URS 2000 [4] Hamilton 2004	2.4 to 6.8	8.2 to 13.4
Fish Muscle			**Rainbow Trout Muscle (2000 & 2001)**	
	8	Lemly 1993, 1996 [2]	1.64 & 1.88	8.76 & 9.12
Fish Ovary			**Rainbow Trout Mature Ovary (2000)**	
	10 7-13 17	Lemly 1993, 1996 [2] Skorupa *et al.* 1996 [3] DeForest *et al.* 1999	8.16	33.48

Notes:

[1] Adverse effects on fish; in some cases, studies on the diet of waterfowl were included

[2] Applicable to freshwater and anadromous fish

[3] Cited in DeForest *et al.* 1999

[4] Cited in Hamilton 2004

[5] This publication supercedes Skorupa *et al.* 1996 (Joseph Skorupa personal communication)

[6] 10 µg/g = warmwater fish; 11 µg/g = coldwater anadromous fish

Comparisons of food web data to toxicity effects thresholds showed (Table 6):

- Mean selenium concentrations in aquatic insects were usually higher than effects thresholds in the exposed stream, compared to reference stream (where selenium concentrations were similar to the thresholds). These insects are common in the diet of rainbow trout and other fish species in the streams (Stantec 2004).
- Mean selenium concentrations in rainbow trout muscle from the exposed stream were slightly higher than the effects threshold. In contrast, mean selenium concentrations in fish muscle from the reference stream were well below the effects threshold.
- Mean selenium concentration in rainbow trout ovary at the exposed stream was about 2-fold higher than the highest effects threshold. In comparison, mean selenium concentration in fish ovary from the reference stream was usually less than the effects thresholds.

3.4.3 Summary and Comparisons to Other Effects Data From West-Central Alberta

Comparisons of the food web data to toxicity effects thresholds for freshwater fish showed selenium concentrations in the diet and rainbow trout tissues were usually greater than effects thresholds in the exposed stream compared to the reference stream. For the key tissue measurement related to adverse effects on fish, the mean selenium concentration in rainbow trout eggs was much higher than the highest (or least stringent) effects threshold in the exposed stream, Luscar Creek (compared to the reference stream). Even higher selenium concentrations in rainbow trout eggs were found in Luscar Creek in 1999. Overall, these results indicate that adverse effects on rainbow trout in the exposed stream are expected, compared to the reference stream. Results of laboratory toxicity studies support this conclusion.

Three separate toxicity studies for rainbow trout and brook trout each were conducted in 2000, 2001 and 2002 (Holm *et al.* 2005). Fry were reared from the gametes of adult fish taken from reference and exposed streams near the Luscar and Gregg River mines. These studies included fish from the same streams and sample period used in the food web evaluation (Section 3.4.1). Based on all data for the three rainbow trout studies together, there were statistically significant relationships between selenium concentration in eggs and incidences of developmental abnormalities (i.e., for craniofacial and skeletal deformities) and edema in the offspring. These effects are characteristic of selenium toxicity in fish (e.g., Lemly 1998; Hamilton 2004). In subsequent experiments, Palace *et al.* (2004a) proposed a physiological mechanism for selenium causing teratogenic deformities (due to oxidative stress) in rainbow trout fry.

In comparison to the data for rainbow trout, brook trout were less sensitive to selenium over the same time period. The brook trout data for the three studies combined did not show statistically significant relationships between selenium levels in eggs and incidences of deformities or edema in the offspring (Holm *et al.* 2005). Overall, these findings indicate a species-specific responses to selenium by rainbow trout and brook trout.

Two other Alberta studies compared selenium in fish tissues from flowing water systems near the mountain mines to the toxicity effects thresholds developed by Lemly (1996) (Table 6). In one study, selenium concentrations in bull trout (muscle and ovary) from the upper McLeod River were at levels greater than the effects thresholds, and thus they were expected to impair population recruitment (Palace *et al.* 2004b). In the second study, Mackay (2005) summarised fish tissue (muscle, ovary and liver) samples collected in 2000 and 2001 by Alberta Sustainable Resource Development. Overall, the data showed selenium concentrations in rainbow and brook trout were usually greater than the toxicity effects thresholds in the exposed streams compared to reference streams. General patterns for selenium concentrations in the remaining fish species (bull trout, mountain whitefish, arctic grayling and longnose sucker) compared to effects thresholds were not always as evident. This was partly due to limitations of the dataset (i.e., small sample size and limited sample locations), and the potential influences of spawning migrations of mountain whitefish and bull trout between the reference and exposed sites.

Overall, the Alberta data showed selenium concentrations in various fish species were often greater than toxicity effects thresholds in exposed streams compared to reference sites. In addition, adverse effects on rainbow trout fry (associated with elevated selenium levels in the eggs of the adults) were evident. Additional fate and effects studies could be used to address uncertainties related to the aquatic data collected to date, and to obtain new knowledge on data gaps in west-central Alberta. For example, the influence of the observed adverse effects (in the fish toxicity studies) on potential recruitment to fish populations in exposed streams is not currently known. Also, the effects of selenium on other fish species (including forage fish) and other aquatic life, which are important to the ecological integrity and function of aquatic ecosystems at the mountain mines is not well understood at present. New studies should also consider questions related to the fate and effects of selenium in aquatic ecosystems such as end pit lakes or wetlands proposed in the reclamation landscape at the mines.

3.5 Metal Concentrations in Surface Water at Each Mine, 1998 to 2003

Trends for selenium concentrations at pairs of reference and exposed sites in stream systems at each mountain mine are presented here. Data for a variety of metals at the same sites and time period are also summarised to illustrate overall patterns for metals in streams intersecting the mines.

3.5.1 Trends of Selenium Concentrations at Pairs of Reference and Exposed Sites

<u>Long-Term Data for Paired Sites at Each Mine</u>

Major patterns for selenium concentrations in surface water samples taken near the CRC, Gregg River and Smoky River mines from 1998 to 2003 were (Figure 10):

- For all sample dates, the highest selenium concentrations occurred at the exposed sites compared to the corresponding reference sites.
- During most years (when sufficient data were available), selenium concentrations increased at the exposed sites from spring to fall. This could be due to a dilution effect from spring runoff. In winter compared to other seasons, there was no consistent pattern for selenium concentrations at the reference or exposed sites. However, winter data were more limited compared to the open-water period.

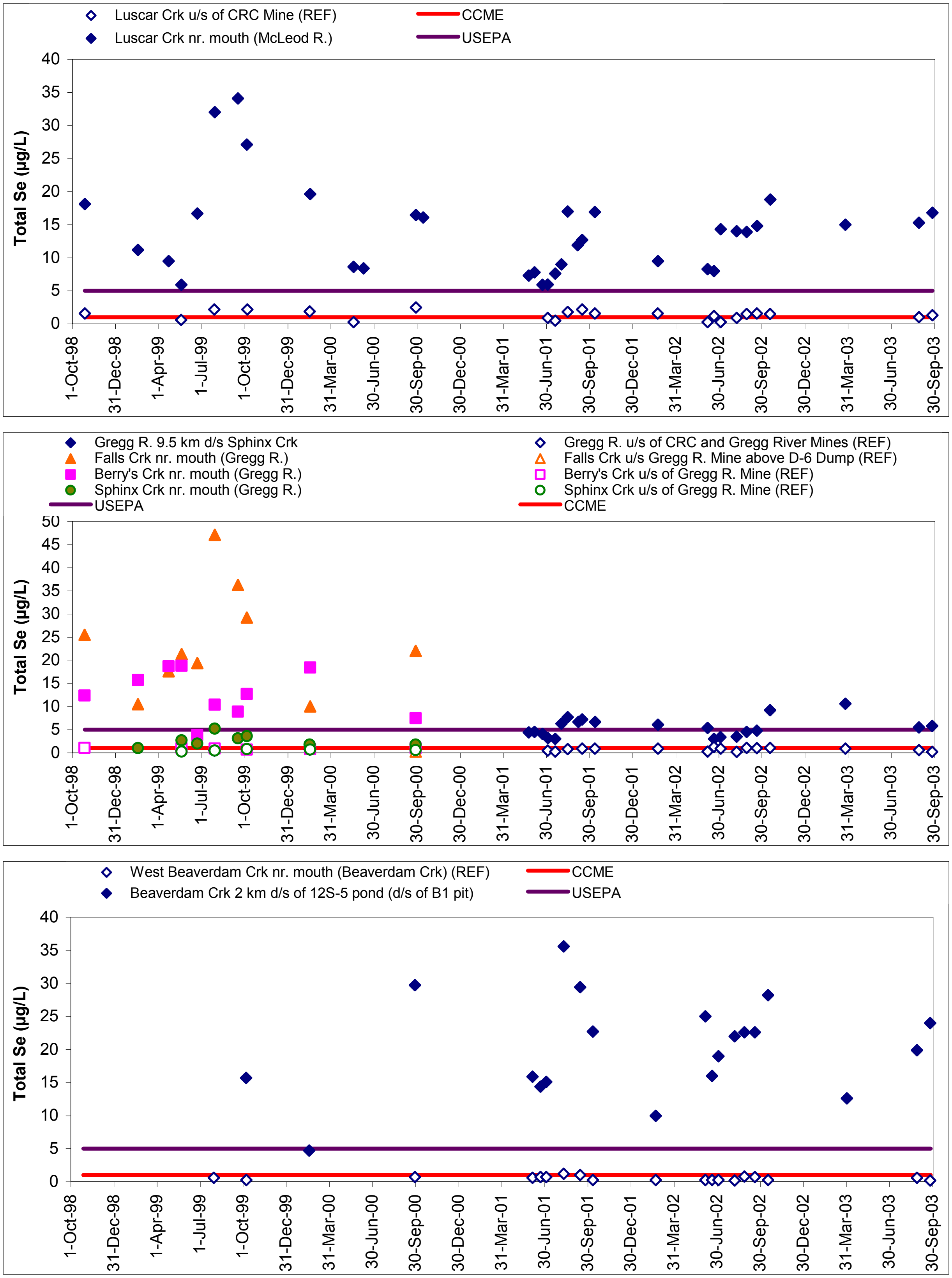


Figure 10 Total selenium concentrations at reference (REF) and exposed sites close to the CRC, Gregg River and Smoky River mines from 1998 to 2003
Selenium water quality guidelines for the protection of freshwater aquatic life (CCME and US-EPA) are also shown.

- At the reference sites, changes of selenium concentrations among seasons were not as evident because concentrations were usually at very low levels or less than the analytical detection limit.
- Over the 5-year sample period, selenium concentrations were generally stable (with no overall increase or decrease) over time at the reference sites (Luscar Creek: r^2 = 0.060, P = 0.286, n = 21; Gregg River: r^2 = 0.0003, P = 0.946, n = 20; and West Beaverdam Creek: r^2 = 0.048, P = 0.383, n = 18), and at exposed sites (Luscar Creek: r^2 = 0.042, P = 0.252, n = 33; Gregg River: r^2 = 0.045, P = 0.368, n = 20; and Beaverdam Creek: r^2 = 0.025, P = 0.516, n = 19).

Comparisons of the metal data to water quality guidelines for the protection of freshwater aquatic life showed (Figure 10):

- Selenium concentrations at reference sites were less than, or in some cases, slightly greater than the most stringent guideline (Luscar Creek: median = 1.5 µg/L, ≤0.25 to 2.5 µg/L, n = 22; Gregg River: median = 0.8 µg/L, ≤0.2 to 1.3 µg/L, n = 21; West Beaverdam: median = 0.6 µg/L, ≤0.2 to 1.2 µg/L, n = 19).
- In contrast, selenium concentrations at exposed sites in Luscar Creek and Beaverdam Creek (excluding one sample) were greater than the CCME and US-EPA water quality guidelines.

Selenium concentrations at the Gregg River exposed site were greater than the CCME water quality guideline, but not always greater than US-EPA guideline. These lower concentrations (compared to the exposed sites in Luscar and Beaverdam creeks) may have been due to differences in the proportion of disturbance within the drainages and potential dilution by the relatively large inflow from Sphinx Creek[30] (Figure 1).

Shorter-Term Dataset for Gregg River Tributaries

The main patterns in data for the Gregg River tributaries (Berry's Creek, Falls Creek and Sphinx Creek) from 1998 to 2000 were (Figure 10):

- Highest selenium concentrations occurred at the exposed compared to reference sites.
- Selenium concentrations at the exposed sites were usually greater than water quality guidelines for the protection of freshwater aquatic life. In comparison, selenium concentrations at the reference sites were usually less than the most stringent (CCME) water quality guideline.

The main seasonal pattern evident in the data was of increasing selenium concentrations from the spring to fall at the exposed sites in Falls and Sphinx Creek.

[30] Selenium concentrations in Sphinx Creek were usually much lower than those in the smaller tributaries of the Gregg River affected by mining (i.e., Falls and Berry's creeks).

3.5.2 Overview of Metal Concentrations at Reference and Exposed Sites

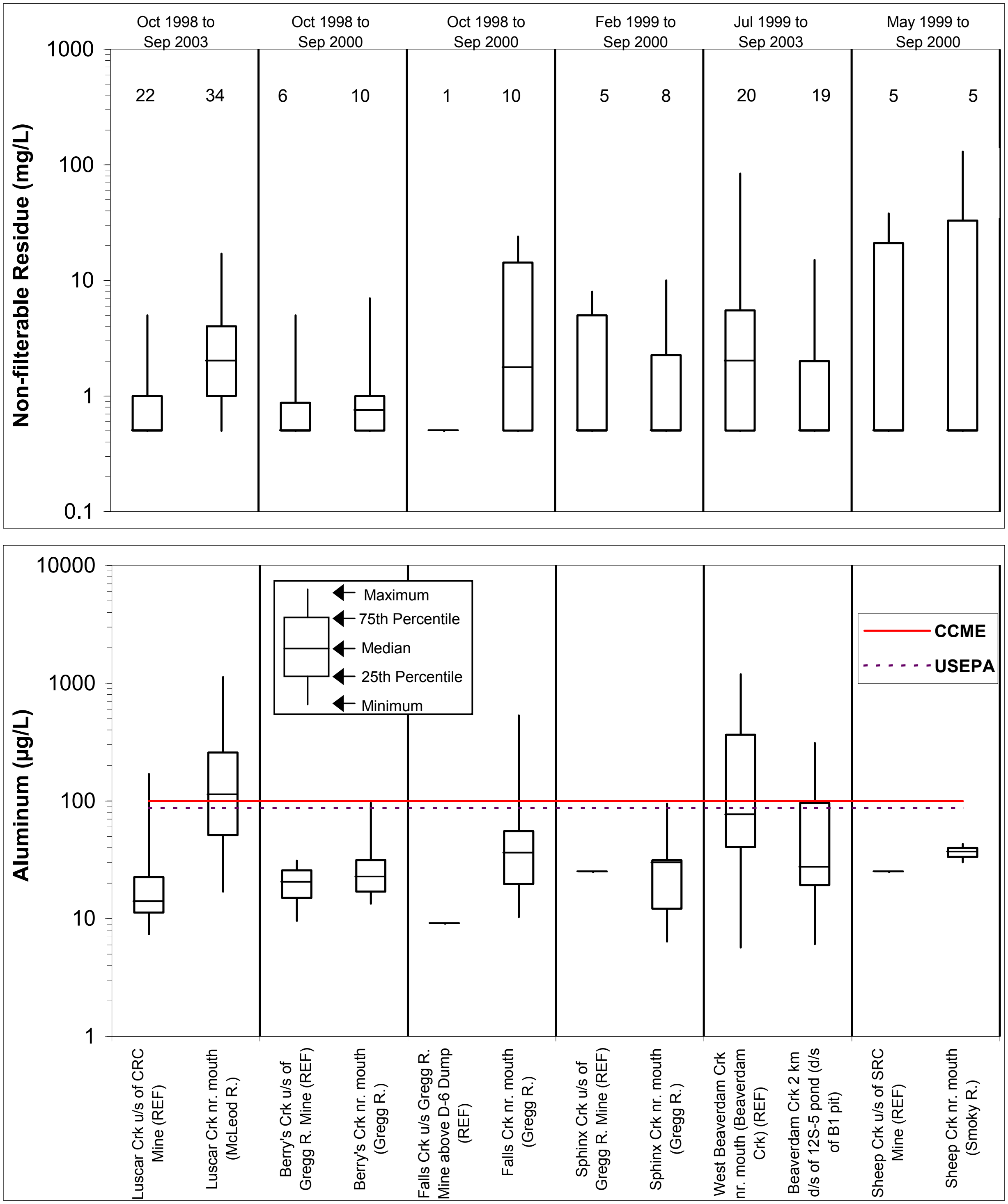
An overview of the concentrations of non-filterable residue and metals in streams intersected by the mines (Table 1 and 2) is shown in Figure 11 and Table 7. It is not a detailed analysis of seasonal or long-term trends in the data.

Non-filterable residue (NFR) is generally equivalent to total suspended solids in surface water samples. Sources of NFR include runoff (especially following heavy precipitation) and mine wastewaters that can lead to corresponding increases of some metals and nutrients in surface water. Overall, there were small increases of median NFR concentrations from the reference sites to corresponding exposed sites in the same stream system (Figure 11; Table 7). This indicates that metal concentrations were unlikely to be strongly influenced by NFR.[31] Indirectly, the NFR data also indicate that the samples were mostly obtained during normal, more stable flows rather than unusually high flow events. Excessive erosion of soils and associated metals into streams would be expected due to storm events and subsequent high stream flows.

The main patterns for metals were (Table 7 and Figure 11):

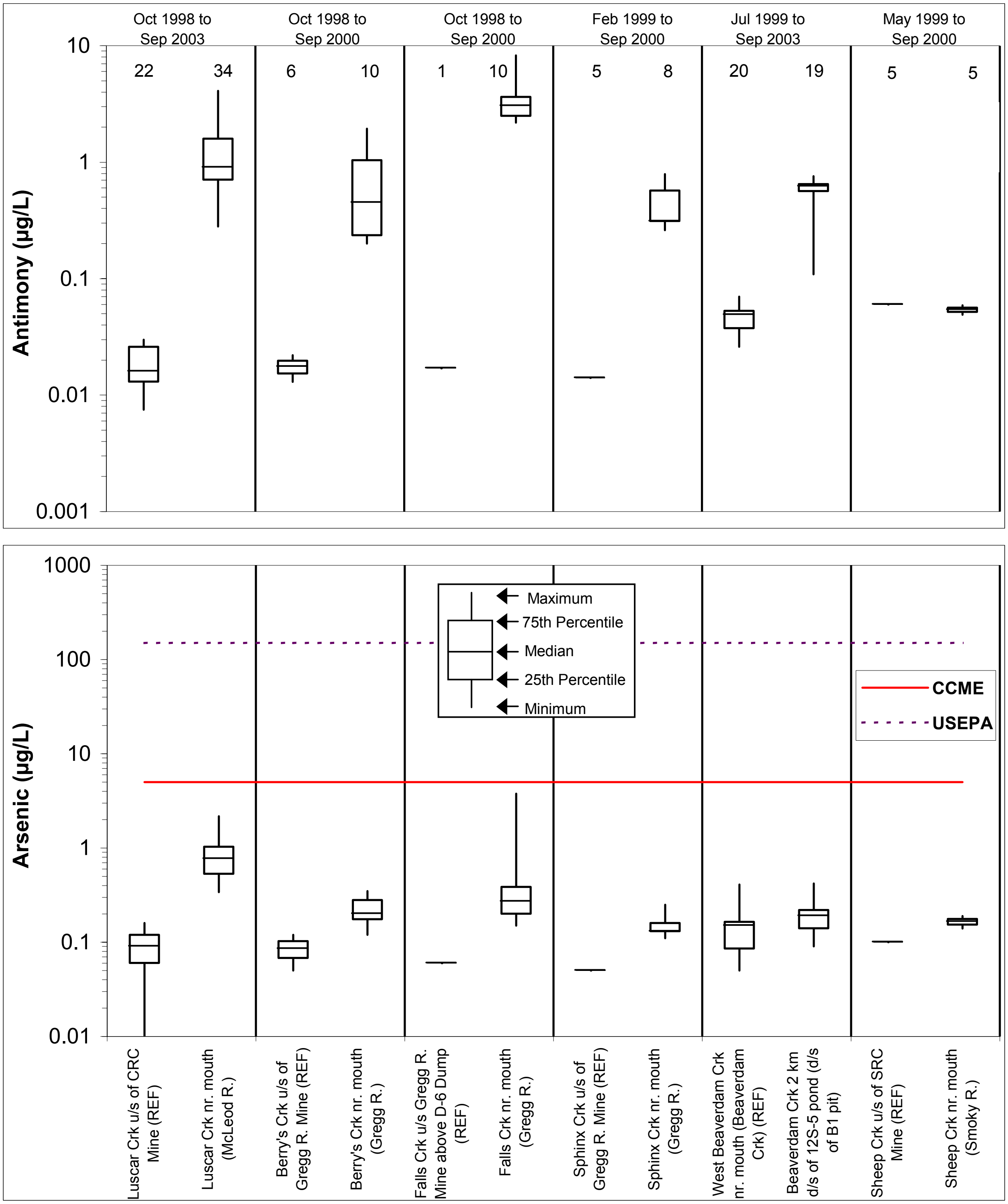
- Most metals showed higher median concentrations at the exposed sites compared to corresponding reference sites. Only three metals (for beryllium, bismuth and tin) showed no change or decreases of median concentrations at all six exposed sites compared to reference sites.
- Median concentrations of 11 metals increased by $\geq$10-fold at the exposed sites compared to reference sites (i.e., antimony, cobalt, iron, lithium, manganese, molybdenum, nickel, selenium, strontium, thallium and uranium).
- Median concentrations of four of these metals increased by $\geq$100-fold at the exposed sites in Falls Creek (antimony, cobalt, manganese and nickel) and Berry's Creek (nickel), compared to the reference sites.
- Based on the comparisons of the metal data to water quality guidelines for the protection of freshwater aquatic life, selenium is the only one where median concentrations consistently exceeded the guidelines at the exposed sites in all stream systems.
- Overall, most metals increased at the exposed sites compared to reference sites. The greatest overall increases of metal concentrations at exposed sites frequently occurred in Falls, Luscar and Beaverdam creeks (Table 7). These streams intersect each of the three mountain mines. Future assessment of metal concentration data along with stream flow measurements (beginning in 2003) can be used to evaluate metal loads from the mines (e.g., metal mass per unit of stream drainage area).

[31] In the case of selenium, NFR and selenium concentrations were negatively correlated in streams near the mines ($r = -0.109$, $N = 376$); the data also showed selenium is mostly in the dissolved form in the streams (WDS database).



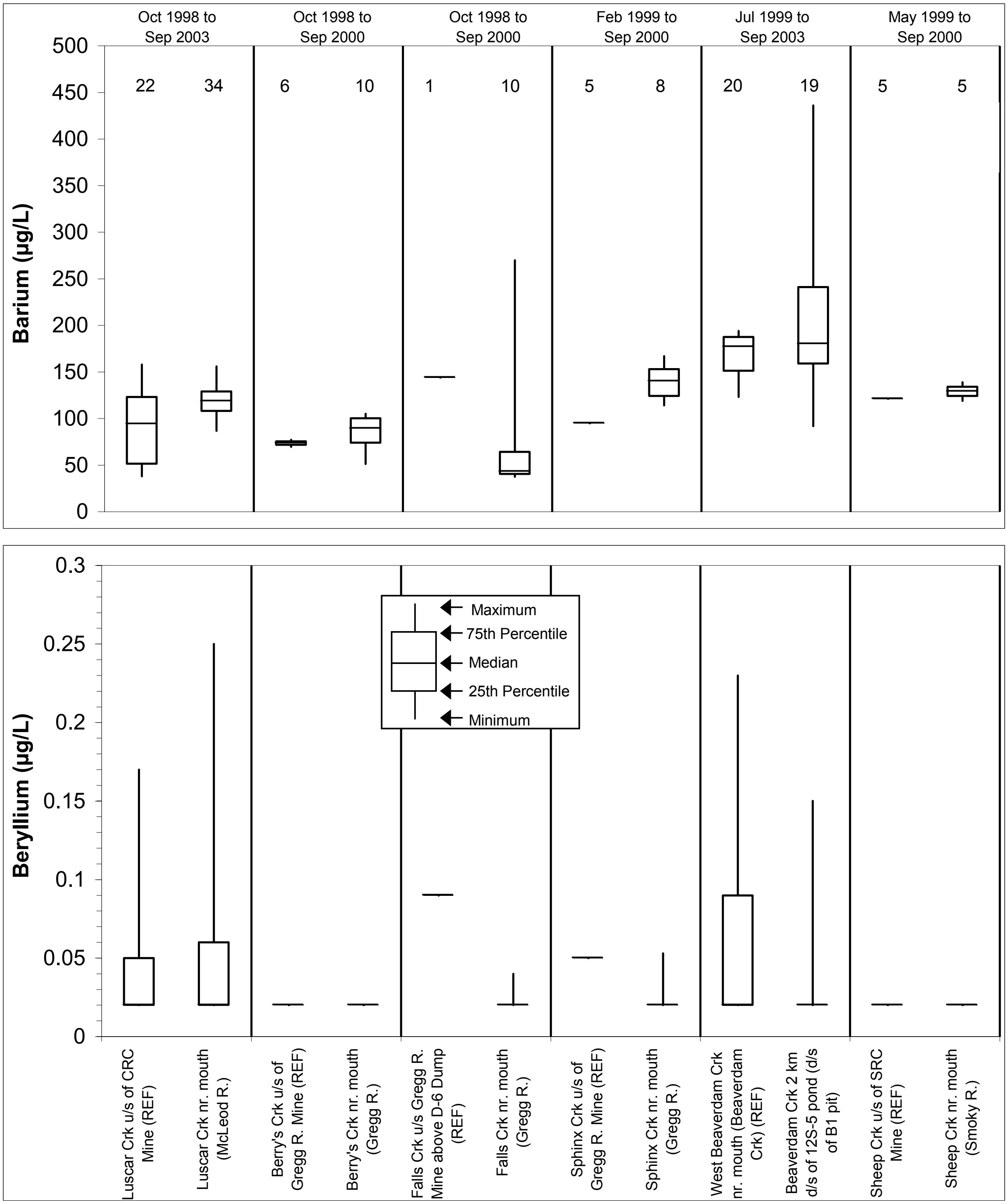
Notes: The first and last sample months and number of samples are shown at the top of each page. Reference sites are labelled as "(REF)". Water quality guidelines for the protection of freshwater aquatic life (i.e., Alberta, CCME and USEPA) are shown where available.

Figure 11 Non-filterable residue and total metal concentrations at pairs of reference and exposed sites in the McLeod, Gregg and Smoky River basins, October 1998 to September 2003



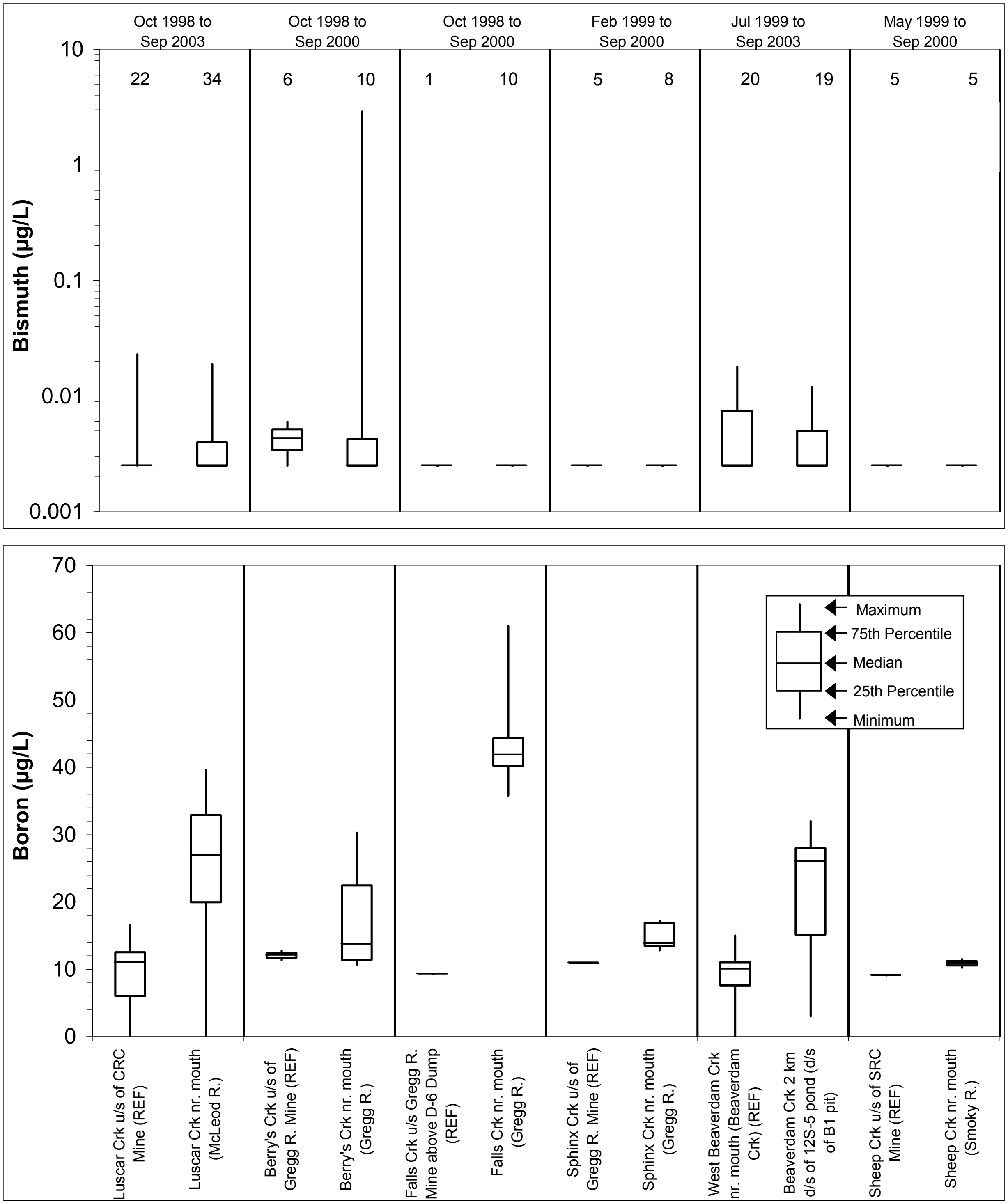
Notes: The first and last sample months and number of samples are shown at the top of each page. Reference sites are labelled as "(REF)". Water quality guidelines for the protection of freshwater aquatic life (i.e., Alberta, CCME and USEPA) are shown where available.

Figure 11 Total metal concentrations at pairs of reference and exposed sites in the McLeod, Gregg and Smoky River basins, October 1998 to September 2003 (continued)



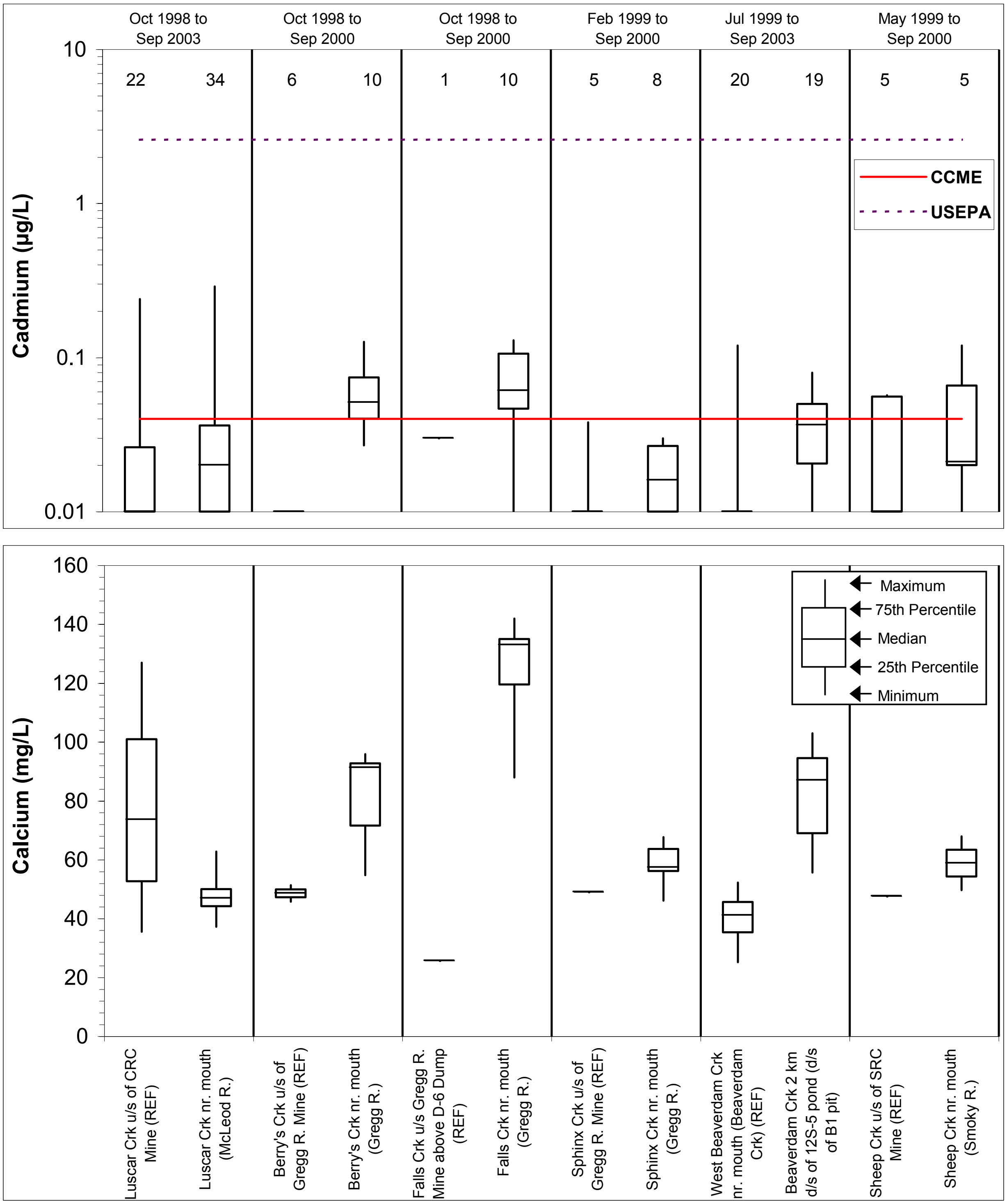
Notes: The first and last sample months and number of samples are shown at the top of each page. Reference sites are labelled as "(REF)". Water quality guidelines for the protection of freshwater aquatic life (i.e., Alberta, CCME and USEPA) are shown where available.

Figure 11 Total metal concentrations at pairs of reference and exposed sites in the McLeod, Gregg and Smoky River basins, October 1998 to September 2003 (continued)



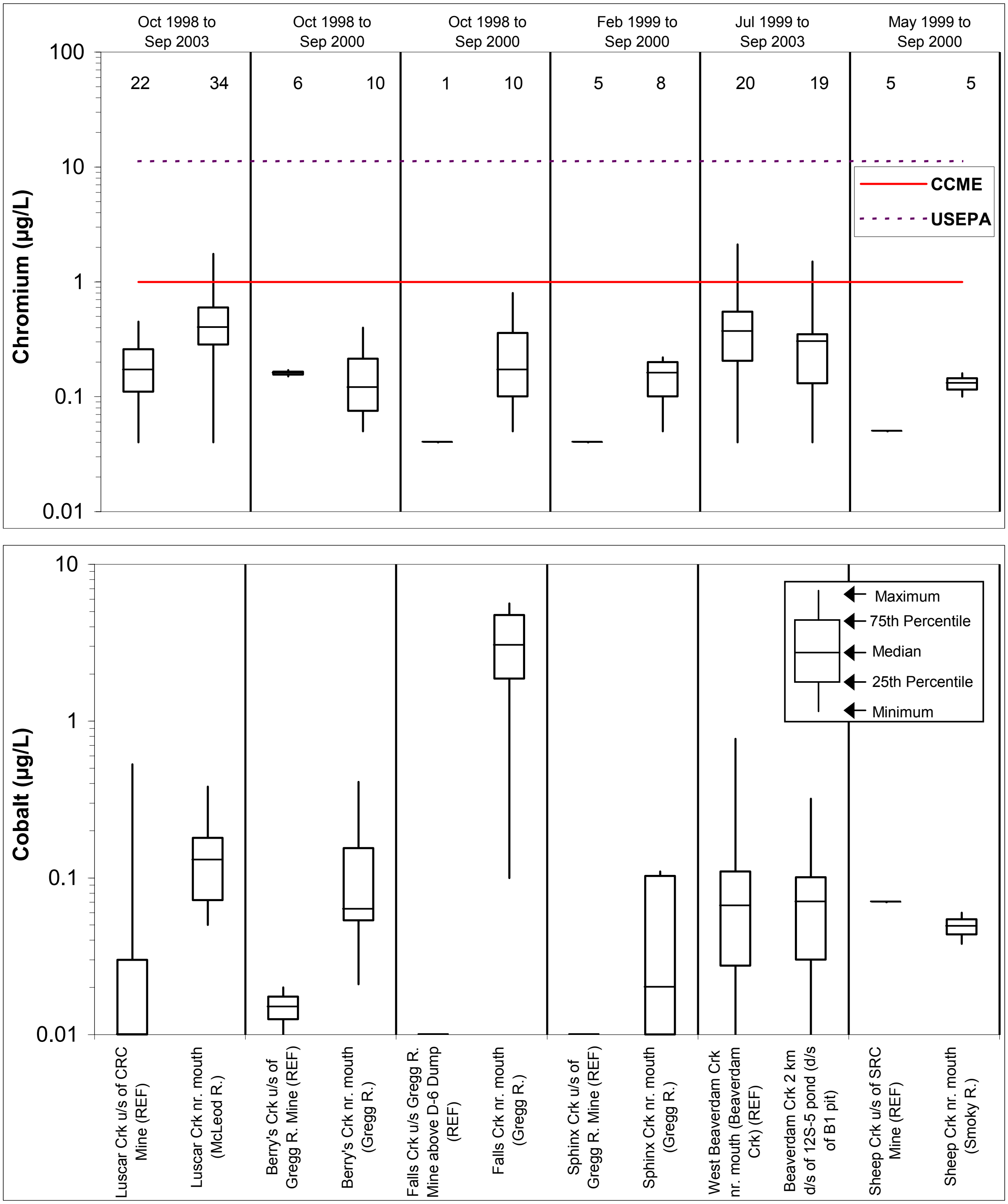
Notes: The first and last sample months and number of samples are shown at the top of each page. Reference sites are labelled as "(REF)". Water quality guidelines for the protection of freshwater aquatic life (i.e., Alberta, CCME and USEPA) are shown where available.

Figure 11 Total metal concentrations at pairs of reference and exposed sites in the McLeod, Gregg and Smoky River basins, October 1998 to September 2003 (continued)



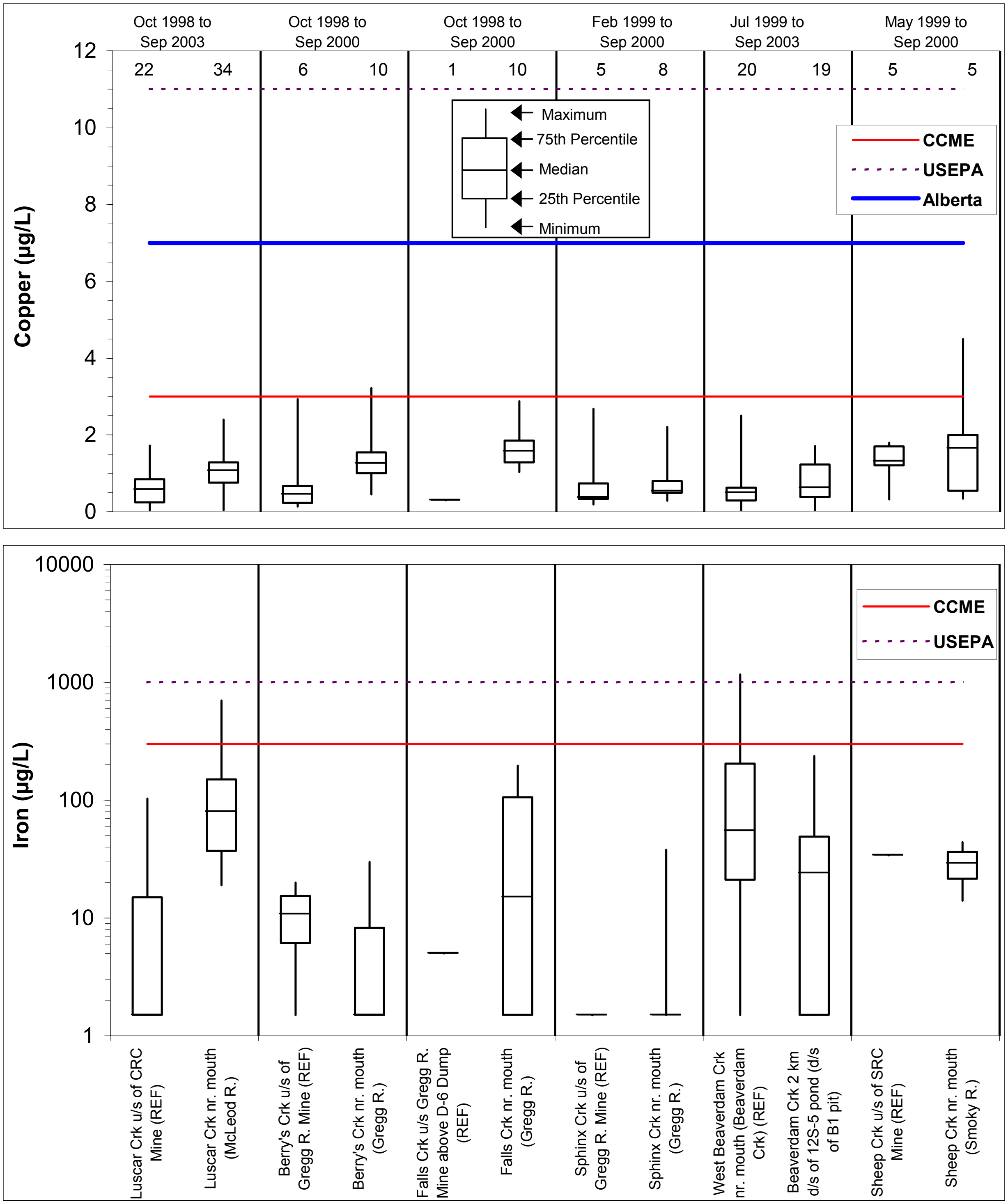
Notes: The first and last sample months and number of samples are shown at the top of each page. Reference sites are labelled as "(REF)". Water quality guidelines for the protection of freshwater aquatic life (i.e., Alberta, CCME and USEPA) are shown where available.

Figure 11 Total metal concentrations at pairs of reference and exposed sites in the McLeod, Gregg and Smoky River basins, October 1998 to September 2003 (continued)



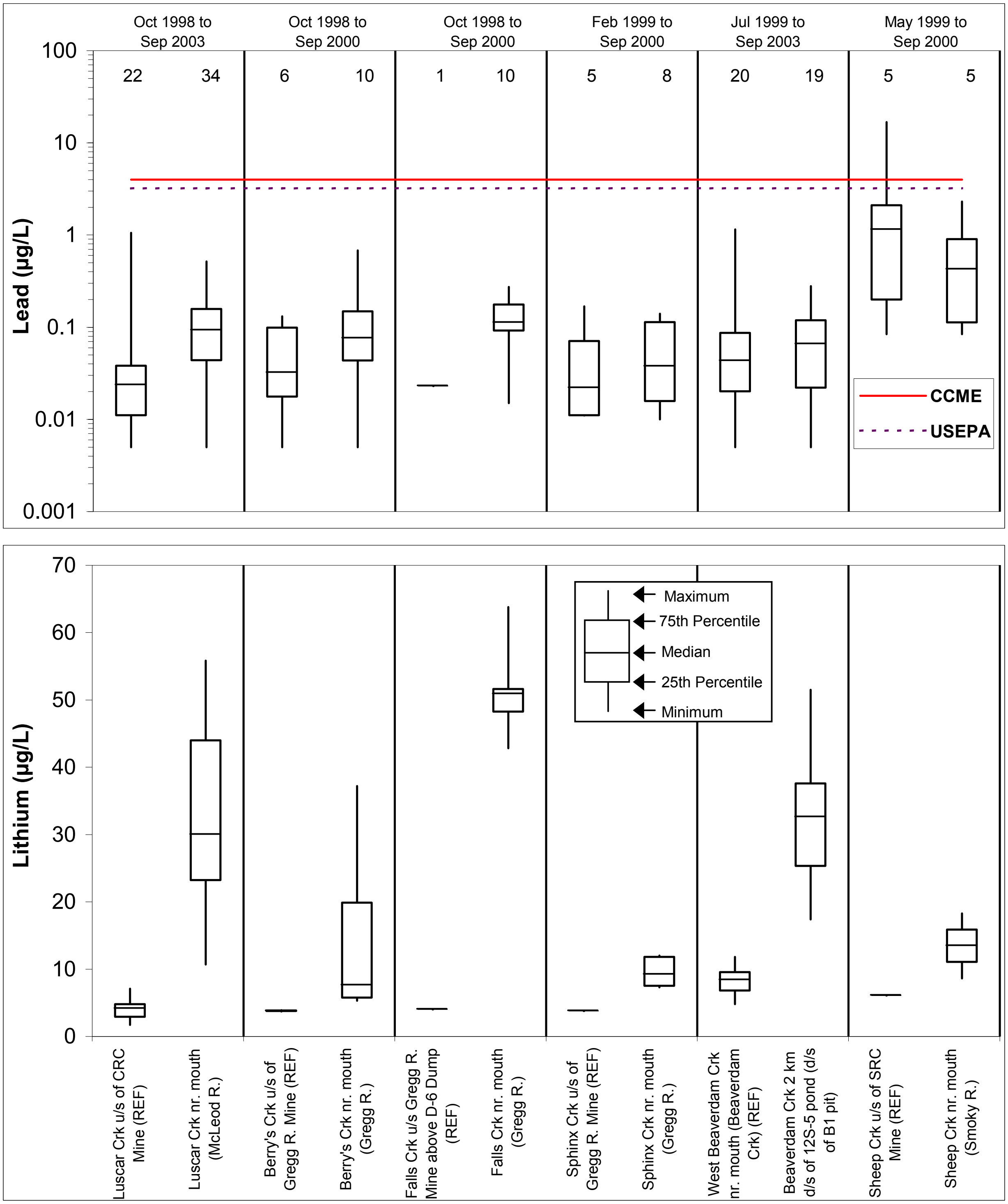
Notes: The first and last sample months and number of samples are shown at the top of each page. Reference sites are labelled as "(REF)". Water quality guidelines for the protection of freshwater aquatic life (i.e., Alberta, CCME and USEPA) are shown where available.

Figure 11 Total metal concentrations at pairs of reference and exposed sites in the McLeod, Gregg and Smoky River basins, October 1998 to September 2003 (continued)



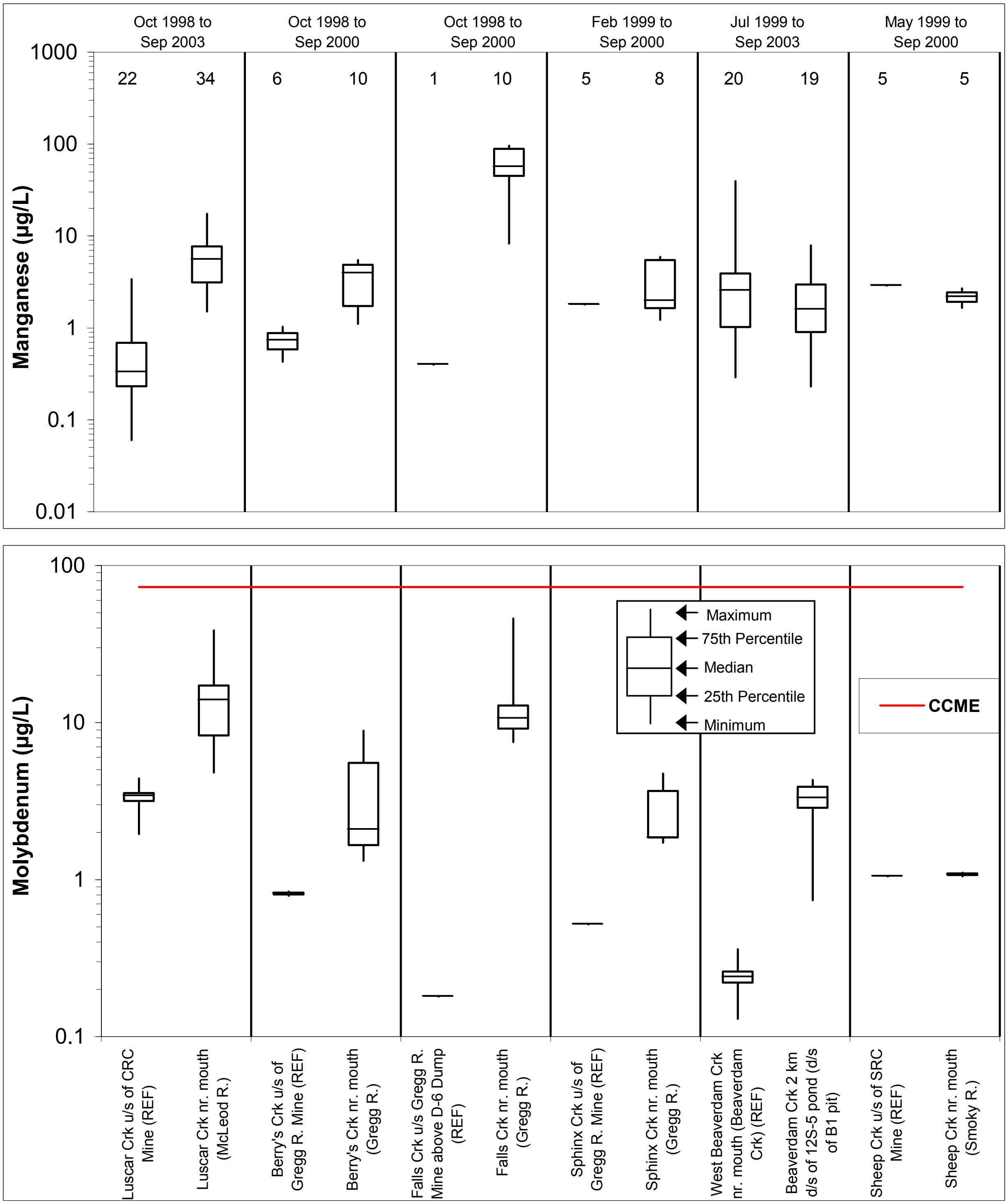
Notes: The first and last sample months and number of samples are shown at the top of each page. Reference sites are labelled as "(REF)". Water quality guidelines for the protection of freshwater aquatic life (i.e., Alberta, CCME and USEPA) are shown where available.

Figure 11 Total metal concentrations at pairs of reference and exposed sites in the McLeod, Gregg and Smoky River basins, October 1998 to September 2003 (continued)



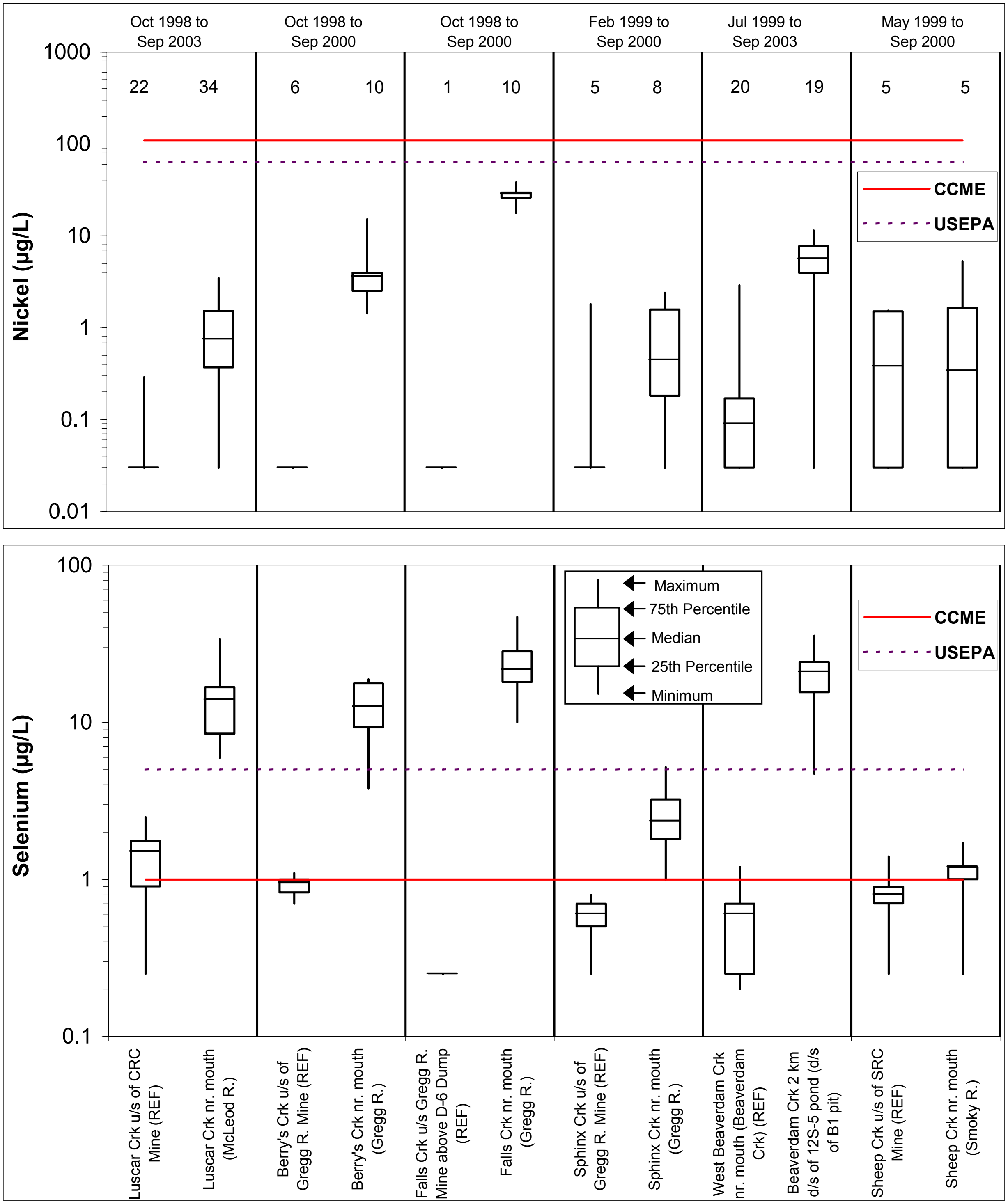
Notes: The first and last sample months and number of samples are shown at the top of each page. Reference sites are labelled as "(REF)". Water quality guidelines for the protection of freshwater aquatic life (i.e., Alberta, CCME and USEPA) are shown where available.

Figure 11 Total metal concentrations at pairs of reference and exposed sites in the McLeod, Gregg and Smoky River basins, October 1998 to September 2003 (continued)



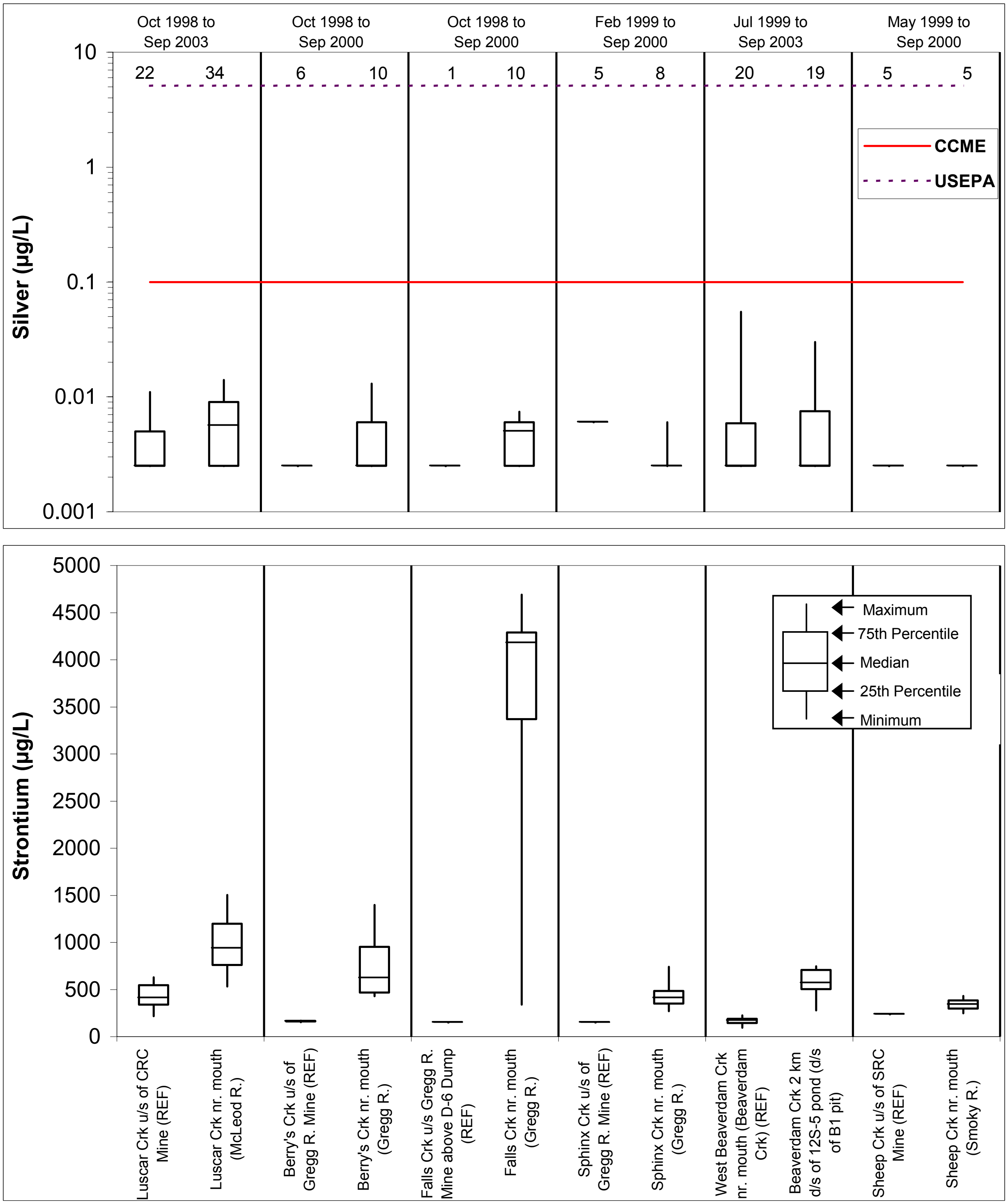
Notes: The first and last sample months and number of samples are shown at the top of each page. Reference sites are labelled as "(REF)". Water quality guidelines for the protection of freshwater aquatic life (i.e., Alberta, CCME and USEPA) are shown where available.

Figure 11 Total metal concentrations at pairs of reference and exposed sites in the McLeod, Gregg and Smoky River basins, October 1998 to September 2003 (continued)



Notes: The first and last sample months and number of samples are shown at the top of each page. Reference sites are labelled as "(REF)". Water quality guidelines for the protection of freshwater aquatic life (i.e., Alberta, CCME and USEPA) are shown where available.

Figure 11 Total metal concentrations at pairs of reference and exposed sites in the McLeod, Gregg and Smoky River basins, October 1998 to September 2003 (continued)



Notes: The first and last sample months and number of samples are shown at the top of each page. Reference sites are labelled as "(REF)". Water quality guidelines for the protection of freshwater aquatic life (i.e., Alberta, CCME and USEPA) are shown where available.

Figure 11 Total metal concentrations at pairs of reference and exposed sites in the McLeod, Gregg and Smoky River basins, October 1998 to September 2003 (continued)

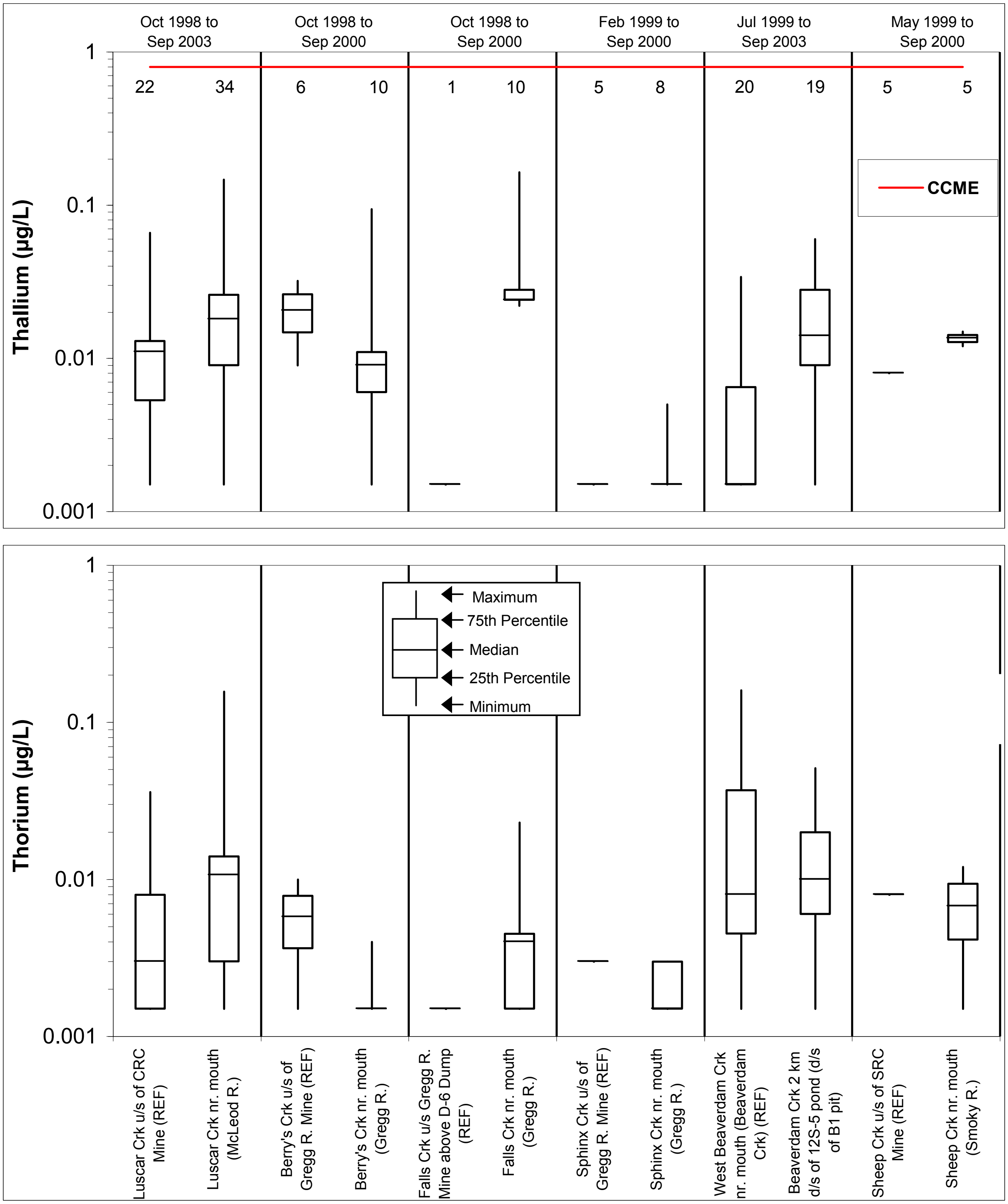


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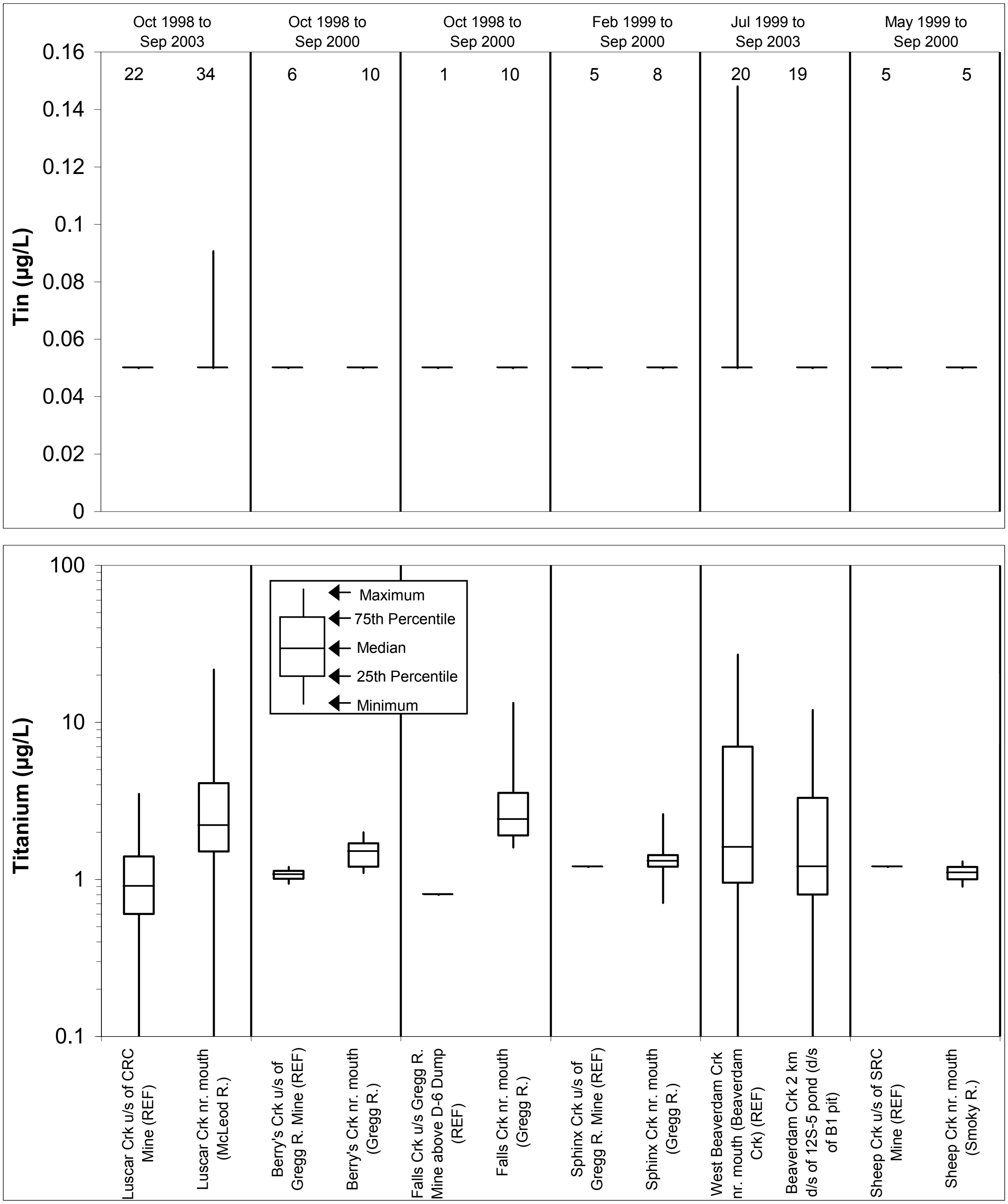
Figure 11 Total metal concentrations at pairs of reference and exposed sites in the McLeod, Gregg and Smoky River basins, October 1998 to September 2003 (continued)



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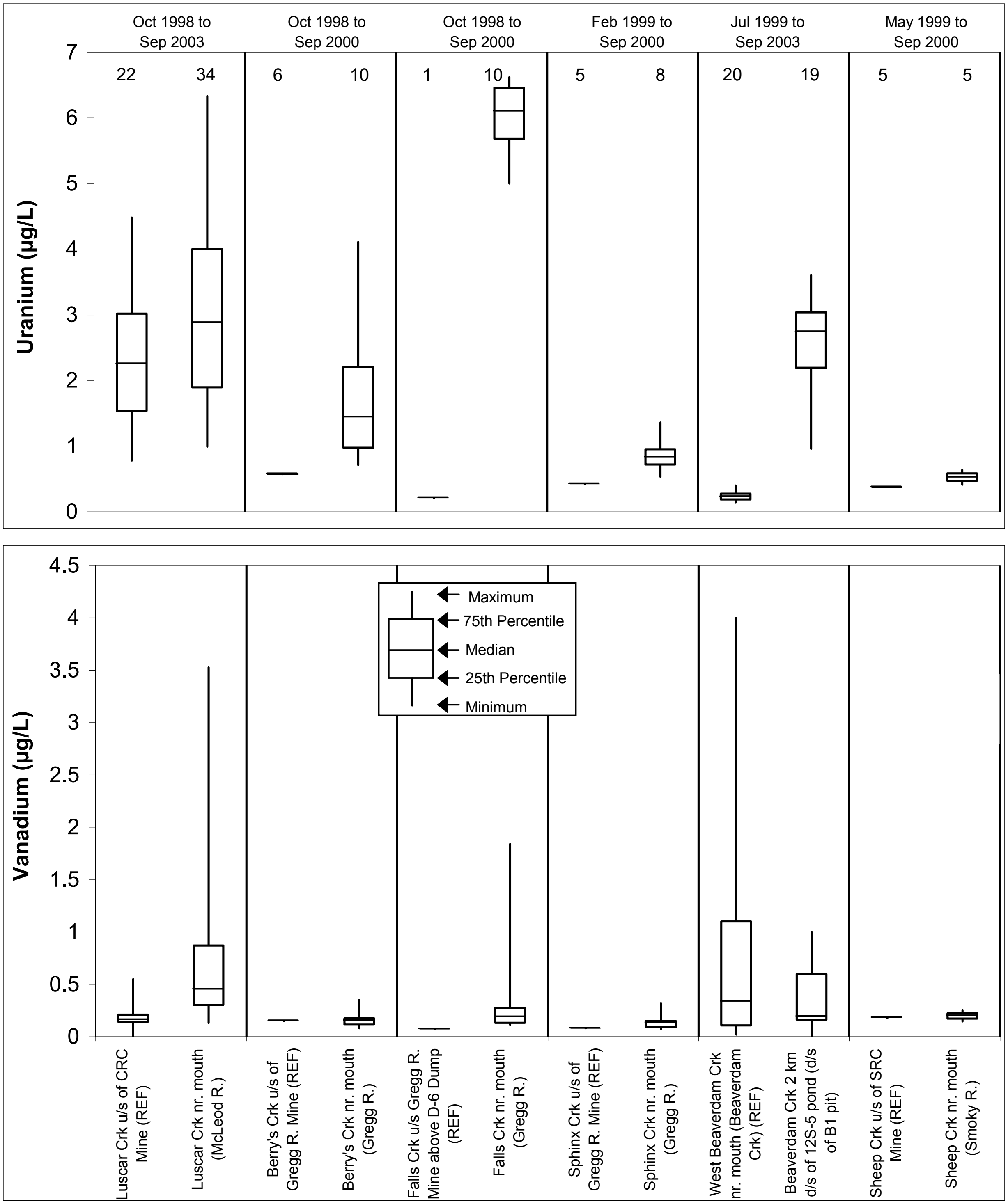

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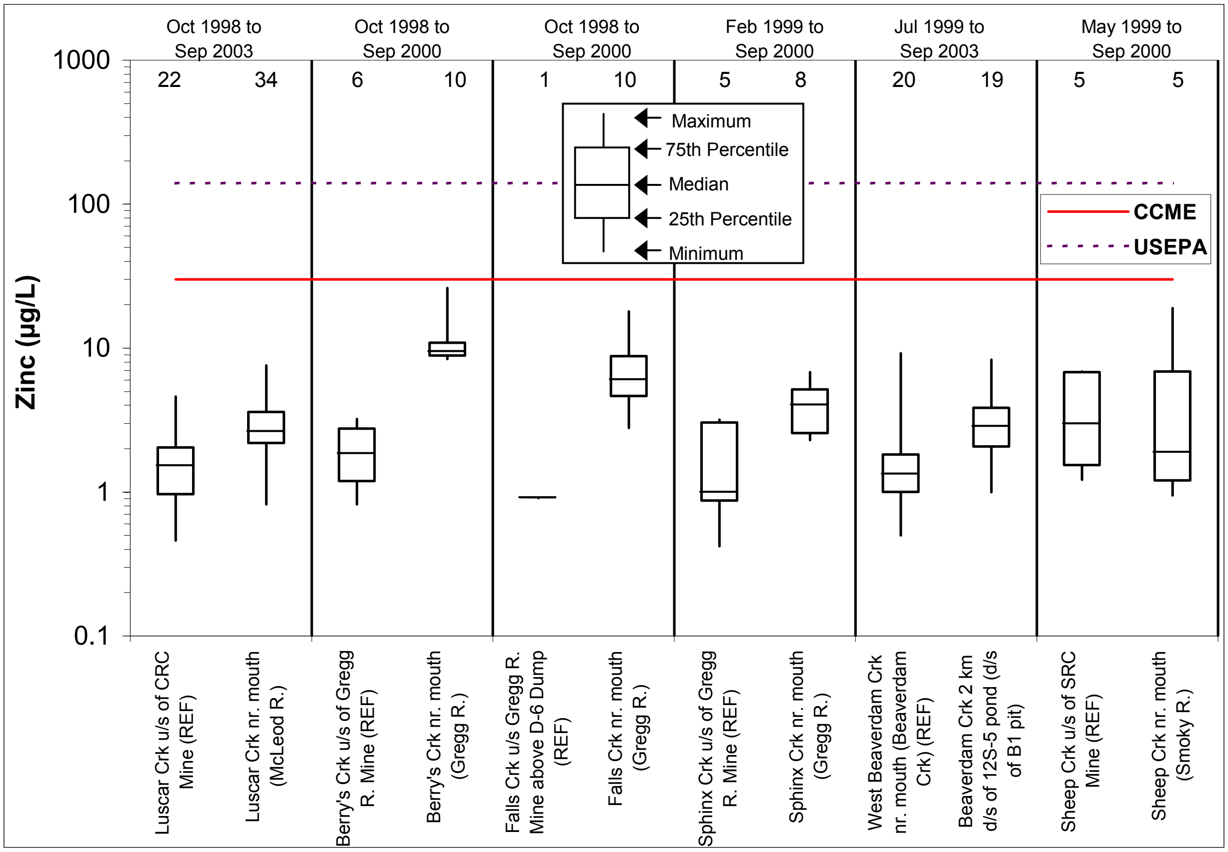

Notes: The first and last sample months and number of samples are shown at the top of each page. Reference sites are labelled as "(REF)". Water quality guidelines for the protection of freshwater aquatic life (i.e., Alberta, CCME and USEPA) are shown where available.

Figure 11 Total metal concentrations at pairs of reference and exposed sites in the McLeod, Gregg and Smoky River basins, October 1998 to September 2003 (continued)

Table 7 Summary of metal data showing higher median concentrations for metals at exposed compared to reference sites in the same stream system

Median concentrations are compared to water quality guidelines for the protection of freshwater aquatic life.

Water Quality Variable	Increase of Median Concentration for Each Metal at Exposed and Reference Sites in Each Stream System (based on data from 1998 to 2003)								Median Concentration (1998 to 2003) Exceeding Water Quality Guidelines for Protection of Freshwater Aquatic Life	
	Streams Ranked from Greatest to Lowest Increase of Median Concentrations (i.e., from 1 to 6; ranks of 1 to 3 are bold)						Streams with an Order(s) of Magnitude Increase of Median Concentrations at Downstream Site		No. of Reference Sites (max. = 6)	No. of Downstream Sites (max. = 6)
	Luscar	Berry's	Falls	Sphinx	Beaverdam	Sheep	>10-fold	>100-fold		
Non-filterable Residue	**1**	**3**	**2**	NC	D	NC				
Aluminum	**1**	4	**2**	5	D	**3**			0	1 (Luscar)
Antimony	**2**	4	**1**	5	**3**	D	Luscar, Berry's, Falls, Sphinx, Beaverdam	Falls		
Arsenic	**1**	**3**	**2**	4	6	5			0	0
Barium	**2**	**3**	D	**1**	5	4				
Beryllium	NC	NC	D	D	NC	NC				
Bismuth	NC	D	NC	NC	NC	NC				
Boron	**3**	6	**1**	4	**2**	5				
Cadmium	5	**1**	**2**	6	**3**	4			0	2 (Berry's, Falls)
Calcium	D	**3**	**1**	5	**2**	4				
Chromium	**1**	D	**2**	**3**	D	4			0	0
Cobalt	**2**	**3**	**1**	4	5	D	Luscar, Falls	Falls		
Copper	**3**	**2**	**1**	5	6	4			0	0
Iron	**1**	D	**2**	NC	D	D	Luscar		0	0
Lead	**2**	**3**	**1**	5	4	D			0	0
Lithium	**2**	6	**1**	5	**3**	4	Falls			
Manganese	**2**	**3**	**1**	4	D	D	Luscar, Falls	Falls		
Molybdenum	**2**	5	**1**	4	**3**	6	Falls, Beaverdam		0	0
Nickel	4	**3**	**1**	5	**2**	D	Luscar, Berry's, Falls, Sphinx, Beaverdam	Berry's, Falls	0	0
Selenium	**3**	4	**1**	5	**2**	6	Berry's, Falls, Beaverdam		1 (Luscar) [1]	6 (All streams)
Silver	**1**	NC	**2**	D	NC	NC			0	0
Strontium	**2**	**3**	**1**	5	4	6	Falls			
Thallium	**3**	D	**1**	NC	**2**	4	Falls		0	0
Thorium	**1**	D	**2**	D	**3**	D				
Tin	NC	NC	NC	NC	NC	NC				
Titanium	**2**	**3**	**1**	4	D	D				
Uranium	4	**3**	**1**	5	**2**	6	Falls, Beaverdam			
Vanadium	**1**	5	**2**	**3**	D	4				
Zinc	5	**1**	**2**	**3**	4	D			0	0

Notes:

NC = no change; D = decrease

[1] Luscar Creek - median selenium concentration = 1.5 µg/L (see Section 3.3.1)

3.6 Selenium Concentrations at Old Coal Mines in South-Western Alberta

This pilot study was initiated to determine selenium concentrations in surface water at old, closed or abandoned coal mines in the Rocky Mountain foothills of south-western Alberta. Seven sites were sampled including discharges from underground mines and two end pit lakes (Table 8). Only two of the samples had detectable selenium at low concentrations. [32] They were less than water quality guidelines for the protection of freshwater aquatic life.

Overall, the results indicate selenium concentrations do not appear to be currently elevated at old mountain coal mines in south-west Alberta, compared to the more recent mines in west-central Alberta. However, it should be noted that the pilot study was not extensive covering all mine sites, and it was limited to one sampling event per site. Also, it is not known if selenium concentrations at the old mines were ever at higher levels than those currently observed. Investigation of the Alberta Environment WDS database and published reports with water quality data for coal mines in south-west Alberta (e.g., Radford and Graveland 1978) did not reveal any selenium data.

Table 8 Selenium concentrations in water samples obtained at old, closed coal mines in south-western Alberta, 2001

River Basin/Sample Site	Sample Date	Non-filterable Residue (mg/L)	Selenium (µg/L)
Crowsnest River Basin - Crowsnest Pass			
Coleman Mine - discharge from underground mine portal, upstream of settling pond	13-Sep-01	14	<0.25
Grassy Mountain Mine - "east" end pit (grab sample)[1], north of Blairmore	13-Sep-01	<0.5	<0.25
Lille Mine - Gold Creek at Hwy 3 bridge, about 5 km downstream of the former Lille townsite	13-Sep-01	1	<0.25
Bellevue Mine - discharge from mine-disturbed area at culvert/pipe to Crowsnest River	13-Sep-01	5	<0.25
Castle River Basin			
Beaver Mines - groundwater seepage/spring about 100 m from tailings piles	13-Sep-01	195	0.9
Bow River Basin - Canmore Area			
Quarry Lake - end pit lake (composite sample)	18-Oct-01	1	<0.25
No. 3 Mine - discharge from mine portal, east of Canmore	31-Oct-01	1	0.4

Notes:

[1] A second end pit lake 50 m to the west of the "east" end pit was not sampled.

4.0 SUMMARY AND CONCLUSIONS

- The mobilisation of selenium from geological sources into headwater streams due to coal mining has occurred at three mountain mines in the upper McLeod and upper Smoky river systems in west-central Alberta.

- Surface water data for the McLeod River basin over 20 years (1984 to 2003) revealed that selenium concentrations increased slightly in the late 1990s at the river mouth. More limited data for the headwaters (downstream of the CRC and Gregg River mines) over the same period showed selenium concentrations after 1998 were usually an order of magnitude higher than water quality guidelines in exposed streams. The small increase of selenium concentrations at the McLeod River mouth may be due to overall increase or cumulative influences of coal mine activities (e.g., runoff from exposed overburden and disturbed areas) in the headwaters of the drainage basin.

- In the upper Smoky River system, available surface water data also showed selenium concentrations were an order of magnitude higher than water quality guidelines from 1998 to 2003 in a stream downstream of recent open-pit mining at the Smoky River mine.

- In comparison to the exposed sites, selenium concentrations were usually below water quality guidelines at reference or background sites near the three mountain mines.

- Overall, selenium concentrations generally remained stable (with no overall increase or decrease) from 1998 to 2003 at key reference and exposed stream sites near the three mountain mines.

- Surface water data for 28 metals from 1998 to 2003 showed most concentrations were higher at the exposed sites compared to reference sites in stream systems intersecting the mines. Concentrations increased by 10-fold for 11 metals and by 100-fold for four metals at the exposed sites compared to the corresponding reference sites. Comparing the metal data to available water quality guidelines, selenium was the only one that exceeded the guidelines at all exposed sites in the six stream systems examined.

- Food web data from the streams (from 1999 to 2001) showed similar patterns as the surface water results. Highest selenium concentrations were found in sediment, biofilm and aquatic insects at the first exposed sites compared to reference sites. More extensive spatial sampling of lower trophic levels in the food showed selenium concentrations in sediment and biofilm declined at sites further downstream of the mines, to levels that were similar to those at reference sites.

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[32] Although the NFR concentration was high in the groundwater "spring" near mine tailings at Beaver Mines, this sample was not expected to have higher selenium concentrations (Section 3.5.2).

- A conceptual food web was developed (using comprehensive data from 2000 and 2001) to assess the fate and potential effects of selenium in representative reference and exposed streams near the mines. Overall, there was substantial bioconcentration of selenium from the surface water to lower trophic levels in the stream food web. In comparison, selenium biomagnification within the food web was not pronounced. However, it was most evident in the exposed stream, where incremental increases of selenium to highest concentrations in rainbow trout (mature) ovary were observed. Elevated selenium in mature fish ovary is of concern because of the potential transfer of selenium to the offspring, which can result in teratogenesis and edema in the fry.

- Comparisons of the conceptual food web data to toxicity effects thresholds from the literature showed selenium concentrations in the diet and rainbow trout tissues, especially ovary, were usually above the thresholds in exposed streams compared to reference streams.

- These results for rainbow trout and data from other Alberta studies (comparing selenium concentrations in fish tissues to toxicity effects thresholds) near the mountain mines indicate that adverse effects on various fish species are expected in exposed streams compared to reference streams.

- Results of laboratory toxicity studies support this conclusion in part by demonstrating adverse effects, i.e., increased incidences of developmental deformities (or teratogenesis) and edema, on rainbow trout offspring (fry) from the exposed stream, compared to the reference stream. The adult fish used in these studies were taken from the same streams and sample period used in the food web evaluation. Brook trout were not as sensitive to selenium. A related experimental study, proposed a physiological mechanism for selenium bioaccumulation causing teratogenesis in rainbow trout.

- A pilot study was conducted to determine selenium levels at old, closed or abandoned coal mines in south-western Alberta. The limited data from this study indicated selenium concentrations do not appear to be presently elevated at the sites sampled. However, historic data were not found for these sites, to determine if selenium was ever at higher levels than those currently observed.

- Overall, results of the Alberta Environment studies and data from other fish studies from west-central Alberta show concern with potential influences of selenium in exposed streams near mountain coal mines. Additional monitoring and research are required to fully evaluate the fate and effects of selenium at the mines, including aquatic ecosystems such as end pit lakes or wetlands in the reclaimed landscape.

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