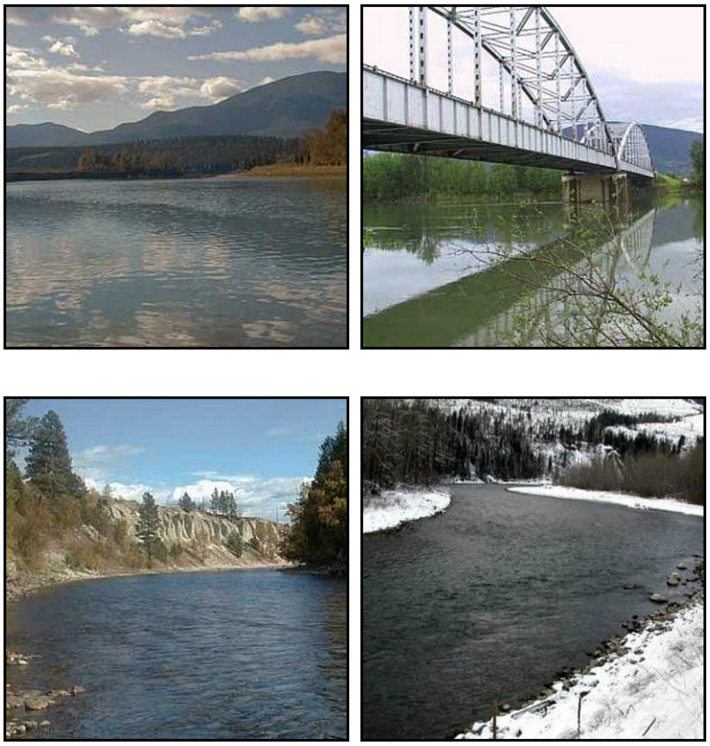
CANADA-BRITISH COLUMBIA WATER QUALITY MONITORING AGREEMENT

WATER QUALITY ASSESSMENT OF THE KOOTENAY, ELK AND ST. MARY RIVERS



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BRITISH COLUMBIA
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EXECUTIVE SUMMARY

The Kootenay River is 780 km long and stretches from the Rocky Mountains in southeast British Columbia through the U.S. before re-entering Canada and draining into the Columbia River at Castlegar. The Kootenay watershed drains an area of 50,300 km^2 and is an important power generating river. Major lakes in the watershed include Kootenay Lake and Lake Koocanusa.

There are currently five Canada-B.C. water quality monitoring stations located in the Kootenay watershed: the St. Mary River at Wycliffe, two sites on the Kootenay River located at Fenwick and at Creston, and two sites on the Elk River at Hwy 93 and Sparwood. Another surface water quality monitoring station at the Moyie River at Kingsgate was deactivated in the spring of 2009. Upstream impacts are diverse and vary, but well-known impacts include coal mining in the Elk River basin while the St. Mary River watershed includes a closed mine and fertilizer plant. Water uses include but are not limited to aquatic life, recreation and drinking water.

This report assesses water quality data collected from these sites over a broad timeframe. The sample period for each site varies, and data from the Elk River at Sparwood were not tested for trends due to the relatively short timeframe of the sample set. Flow (mean daily discharge) measurements taken from various Water Survey of Canada sites were used to describe seasonal flow patterns.

CONCLUSIONS

- Water quality in the Kootenay River mainstem was typically good with very few parameters that consistently exceeded relevant guidelines; parameters that exceeded guidelines were often driven by seasonal turbidity spikes as a result of freshet and generally not considered a concern.
- Water quality in the St. Mary River are generally stable or improving, likely as a result of the closure and waste abatement at the Teck Cominco mine and the closure of the fertilizer plant located upstream of the water quality monitoring site.

- Certain metals, specifically cadmium and zinc, do not correlate well with turbidity suggesting that exceedences are partly driven by dissolved concentrations of these parameters. Dissolved measurements should be analysed in addition to total for these parameters.
- There continues to be numerous deleterious trends and water quality issues with the Elk River: total (slope = 0.1 μg L^{-1} yr^{-1}) and dissolved selenium (slope = 0.2 μg L^{-1} yr^{-1}) continue to rise and consistently exceeds CCME and BC aquatic life guidelines; nitrogen (as NO_3+NO_2) is increasing at a rapid rate (slope = 0.01 mg L^{-1} yr^{-1}) and may impact downstream lentic systems; and sulphate continues to increase in this system (slope = 0.47 mg L^{-1} yr^{-1}) but is still below aquatic life guidelines. There are a variety of other water quality trends associated with this site, although these are not immediate concerns.
- There was a slight increasing trend in total phosphorus at the Kootenay River at Fenwick station. This increase, in combination with increasing nitrogen inputs from the Elk River, may lead to more frequent and unwanted algal blooms in downstream lentic systems; downstream data was not available to assess algal growth.
- The Kootenay River at Creston has numerous trends which appear to be associated with Elk River inputs including slight increases in total selenium, and increases in alkalinity and total hardness.
- Fecal associated microbiological measurements are significantly increasing along the Kootenay River mainstem.
- Water temperatures seasonally exceed daily maximum guidelines for the protection of bull trout, the most sensitive species in these systems. These seasonal exceedences appear to be common throughout the datasets. Recently installed continuous temperature loggers should allow for the determination of the intensity and duration of these exceedences, and trend detection, should any exist.

RECOMMENDATIONS

It is recommended that water quality monitoring stations located on the Kootenay and Elk rivers continue to operate to monitor changes in the Kootenay watershed due to upstream influences such as coal mining. It is recommended that algal growth be monitored at lentic sites below the Elk River to determine the effect of increased nutrient loads. Consideration should be given to the establishment or reactivation of hydrometric stations near the Elk River at Hwy 93 and the Kootenay River at Creston to allow for loading calculations.

In addition to total metals, dissolved metals should be monitored at all sites for guideline comparison. Also, tri- and hexavalent chromium should be monitored once suitable sampling and analytical methods are established for guideline comparison. Finally, sulphate should be monitored at both Kootenay River monitoring stations to assess the impact of sulphate concentrations from Elk River.

ACKNOWLEDGEMENTS

The data was reviewed and compiled by Ayisha Yeow, Sasha Wassick and Jessica Ingram, and a map of the Moyie River Basin was created by Jennifer MacDonald. This report was reviewed by Andrea Ryan of Environment Canada, and Jody Frenette and Carrie Morita of the B.C. Ministry of Environment. We thank these individuals for their contributions to this document. Any errors or omission are the responsibility of the author.

TABLE OF CONTENTS

Page

LIST OF FIGURES

INTRODUCTION

i) Introduction

Since 1985, the BC Ministry of Environment and Environment Canada have been cooperatively monitoring surface water quality at a number of locations across British Columbia. The primary purpose of this joint program is to determine the status and trends in surface water quality at sites across the province, although the data is also used for a range of other purposes. This assessment examines surface water quality at sites within the Kootenay River watershed, a major power-generating waterway with five active Canada-BC water quality trend stations (Figure 1). Another Canada-BC water quality trend site located at the Moyie River at Kingsgate was deactivated in April, 2009, and a water quality assessment was conducted prior to its deactivation (Dessouki 2009).

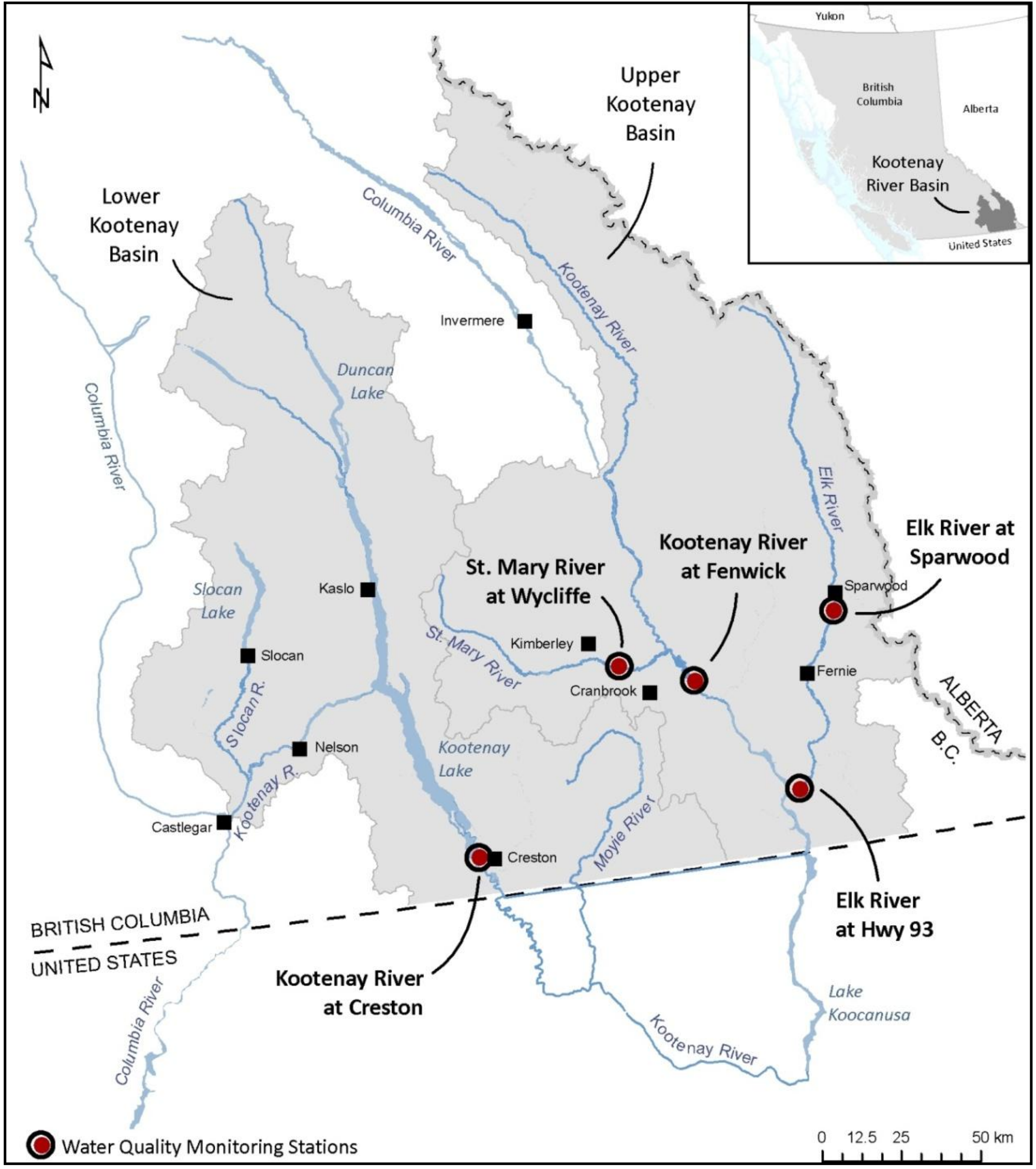
ii) The St. Mary River

The St. Mary River flows eastward from the Purcell Mountains into the Kootenay River near Fort Steele. The water quality monitoring station located on the St. Mary River at Wycliffe was established as a Federal-Provincial station in 1999 (Figure 1) and is operated with funding assistance from Teck Cominco Kimberley. The station monitors a drainage area of 2,360 km^2 (Pommen Water Quality Consulting 2004). The station is currently active although it was inactive from January to September of 2008 due to a lack of funding.

Water uses in the St. Mary River watershed include aquatic life, drinking water, irrigation, recreation and wildlife. Fish species include westslope cutthroat, brook trout, bull trout, mountain whitefish and burbot (Fisheries Information Summary System [FISS] 2009). There are 20 water licenses and applications listed for the St. Mary River including licenses for the City of Kimberly waterworks, and for irrigation and domestic purposes (Water License Report 2009).

Point-source impacts on water quality included the former Cominco Ltd. Sullivan mine which was closed in 2002, a concentrator and fertilizer plant which operated from 1953 to 1987, and treated sewage from the City of Kimberly (Pommen Water Quality Consulting 2004). Waste abatement from the Cominco operation and City of Kimberly sewage has resulted in improving trends in alkalinity, pH, hardness and turbidity; metals including copper, iron, lead, zinc; and nutrients including ammonia and phosphorus (Pommen 2004). Non-point source impacts currently include forestry and agriculture.

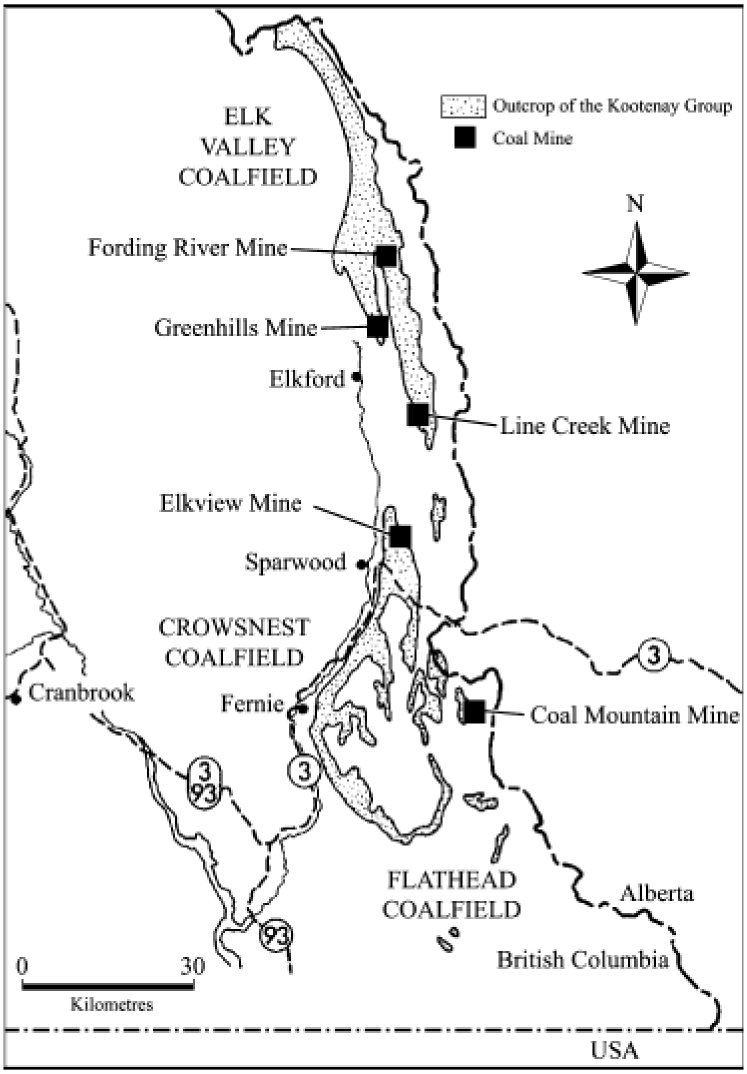
Figure 1: Map of the Kootenay River Watershed.



iii) The Elk River

The Elk River watershed is located in southeast British Columbia. With its headwaters in the Rocky Mountains, the Elk River is comprised of predominately high elevation fast-flowing streams and headwater lakes (Kennedy *et al.* 2000). The Elk River drains into the Kootenay River and Lake Koocanusa 20 km upstream from the U.S. border (Swain 2007a). There are currently two B.C.-Canada water quality monitoring stations on the Elk River, one at Sparwood and one at Highway 93 near Elko (Figure 1); the water quality monitoring site on the Elk River at Sparwood monitors a drainage area of 350 km^2 (Swain 2007b) while the monitoring site at Highway 93 monitors the majority of the watershed (4,450 km^2).

Figure 2: Coal Mines in the Elk River Valley, southeast B.C. Adapted from Lussier *et al.* 2003.



Water uses in the Elk River watershed include aquatic life, irrigation, recreation, domestic and industrial uses, and wildlife. Despite the impact of upstream industrial activities, healthy fish populations persist in the Elk River which include bull trout, westslope cutthroat trout and mountain whitefish (Kennedy *et al.* 2000; FISS 2009), and the Elk River is the most heavily-fished river in the Kootenay Region (Swain 2007a). There are 11 water licenses and applications listed for the Elk River including domestic, irrigation, coal washing, stored water for the City of Fernie, snow making and power generation (Water License Report 2009).

Main human influences in the Elk River basin include open-pit coal mining, forestry, tourism, agriculture, and residential and commercial development. Open-pit coal mining, in particular, has had a great impact on water quality in the Elk River. Coal has been mined in the Elk River Valley since 1897, but large-scale mining did not start until the late 1960s and there are currently five mines in operation in the Elk River Coalfield (Lussier *et al.* 2003; Figure 2). Selenium is currently being released into tributary streams from open-pit coal mining (McDonald and Strosher 1998). Although selenium is an essential trace element for animal nutrition, it is toxic to plants, animals and humans at high concentrations. The current B.C. aquatic life guideline is set at a mean of 2.0 μg L^{-1} (Nagpal and Howell 2001). Field studies have reported a variety of surface water selenium concentrations in the watershed: Harding *et al.* (2005) reported a maximum observed concentrations of 107 μg L^{-1} in one tributary; McDonald and Strosher (1998) reported a maximum concentration of 542 μg L^{-1} from waste dump seepage entering a settling pond; Minnow Environmental Inc., Interior Reforestation Co. Ltd. and Paine, Ledge and Associated (2007) reported mean Se concentrations ranging from 2.7 to 21.9 μg L^{-1} from mine-effected waterways; and Kennedy *et al.* (1999) reported mean Se concentrations as high as 28 μg L^{-1} in mine-effected tributaries and 13 μg L^{-1} in major rivers. Despite these high levels of selenium in the surface waters, no large-scale negative effects have been noted in aquatic lotic systems (Chapman 2005; Kennedy *et al.* 2000) or in terrestrial systems (Harding *et al.* 2005) in the Elk River Valley, although negative effects were noted in some high-risk lentic areas (Chapman 2005).

iv) The Kootenay River

The Kootenay River is 780 km long and stretches from its headwaters in the Rocky Mountains across the U.S. in Montana and Idaho before re-entering Canada and draining into the Columbia River at Castlegar (Figure 1). It has a total drainage area of 50,300 km^2. The most northerly of the major Columbia River tributaries, the Kootenay River provides 43% of the mean annual flow of the Columbia measured at Birchbank (Butcher 1992). There are two active

Canada-BC water quality monitoring stations on the Kootenay River located at Creston and at Fenwick (Figure 1). These sites are currently sampled every two weeks.

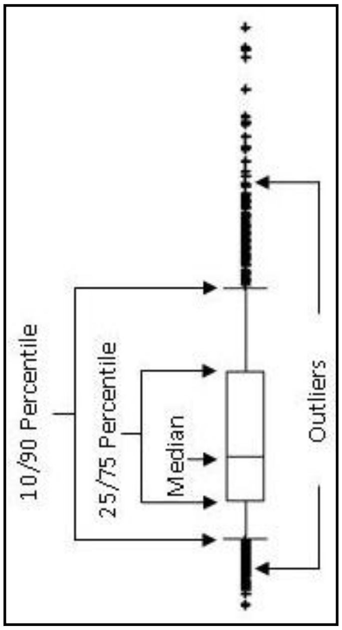
Water uses in the Kootenay River watershed include aquatic life, irrigation, recreation, domestic and industrial uses, and wildlife. There are 61 water licenses and applications for the Kootenay River, excluding tributaries and Kootenay Lake. These include licenses for power generation, irrigation, and storage and wildlife conservation (Water License Report 2009).

In addition to the point-source impacts noted above in the St. Mary and Elk rivers, the Kootenay River is impacted by the forest industry, power generation and impoundments, agriculture, treated sewage discharges and residential development.

QUALITY CONTROL AND QUALITY ASSURANCE

Efforts were taken to ensure quality control and quality assurance throughout the sample period. Duplicate or triplicate samples and field blanks were scheduled at regular intervals to assess potential sources of sample contamination and analytical precision. The water quality results were reviewed in advance of the preparation of this report and questionable or erroneous values were removed from the dataset. Additionally, total dissolved nitrogen results were known to be contaminated from filters used in the laboratory from 2003 to 2005. Efforts were taken to correct affected total dissolved nitrogen results when possible; uncorrected results from this period were excluded.

GRAPHS



In addition to time-series plots, box-and-whisker plots were used to compare water quality values where appropriate (see example on right). Box-and-whisker plots are useful since they visually display the entire statistical distribution of a dataset. The plots display central tendency (median), sample variability (inter-quartile and percentile range), and extreme results and outliers.

STATISTICS

Non-parametric statistical tests were largely used since most water quality parameters are not normally distributed. Therefore, time-series trend analyses were conducted using the Mann-Kendall (MK) trend test (Helsel and Hirsh 1991) and Sen's slope estimate was used to approximate change over time. Mann-Kendall trend tests were not conducted on Elk River at Sparwood data due to its temporally limited dataset.

Since certain statistical tests were conducted multiple times (i.e. on most parameters for each sampling site), the False Discovery Rate (FDR) was calculated to determine "field significance" (Wilks 2006). The FDR controls for falsely rejected null hypotheses (i.e. increased likelihood of a significant result) when conducting multiple significant testing (Benjamini and Hochberg 1995). In this regard, we applied the FDR in a similar manner to Yan *et al.* (2008) and considered trends significant when results were less than the calculated FDR with a statistical significance of $\alpha < 0.05$.

WATER QUALITY ASSESSMENT

The state of the water quality was determined by comparing the results to the B.C. Environment's *Approved Water Quality Guidelines* (Nagpal *et al.* 2006a) and *Working Guidelines for Water Quality* (Nagpal *et al.* 2006b), and the Canadian Council of Ministers of the Environment *Guidelines for the Protection of Aquatic Life Guidelines* (2007). Substances listed below are not discussed further since concentrations largely met guidelines or had no significant temporal trends. These substances include the following: antimony, arsenic, beryllium, bismuth, boron, bromide, magnesium, potassium, filterable residue (TDS), silica and silicon, thallium, tin, uranium and vanadium.

Table 1: Significant Mann-Kendall Trend Results and Sen’s Slope for Test Parameters from Surface Water Quality Sites in the Kootenay Watershed.

	St. Mary River at Wycliffe		Kootenay River at Fenwick		Elk River at Hwy 93		Kootenay River at Creston	
	Mann-Kendall		Mann-Kendall		Mann-Kendall		Mann-Kendall	
	p-value	Sen’s Slope (units annum^{-1})	*p*-value	Sen’s Slope (units annum^{-1})	*p*-value	Sen’s Slope (units annum^{-1})	*p*-value	Sen’s Slope (units annum^{-1})
Alkalinity (mg L^{-1})			<0.001	1.052	<0.001	1.227	0.015	0.375
Ammonia (mg L^{-1})	<0.001	-0.0003						
Aluminum, total (μg L^{-1})					<0.001	-1.687	0.008	-1.140
Barium, total (μg L^{-1})							0.007	0.149
Calcium, total (mg L^{-1})					<0.001	0.272		
Chloride (mg L^{-1})							0.017	-0.016
Cobalt, total (μg L^{-1})			<0.001	-0.003	<0.001	-0.003		
Chromium, total (μg L^{-1})			<0.001	-0.001				
Copper, total (μg L^{-1})			0.003	-0.010			<0.001	-0.015
Carbon, dissolved organic (mg L^{-1})					<0.001	0.014	0.009	0.040
Fecal Coliforms (CFU 100mL^{-1})			<0.001	0.137			<0.001	0.280
Fluoride (mg L^{-1})					<0.001	0.001		
Iron, total (μg L^{-1})			0.002	-2.848	<0.001	-1.120		
Hardness (mg L^{-1})					<0.001	1.268	0.001	0.295
Lithium, total (μg L^{-1})			<0.001	-0.083	<0.001	-0.072	0.002	-0.010
Manganese, total (μg L^{-1})					0.006	-0.060	0.002	-0.084
Molybdenum, total (μg L^{-1})			<0.001	0.012	<0.001	0.011	<0.001	0.006
Nickel, total (μg L^{-1})			<0.001	-0.014				
Nitrogen, total dissolved (mg L^{-1})							<0.001	0.003
Nitrate + Nitrite (mg L^{-1})	<0.001	-0.010			<0.001	0.013	<0.001	0.003
Phosphorus, total (mg L^{-1})			<0.001	0.0002				
Phosphorus, Ortho (mg L^{-1})							<0.001	0.0004
pH (units)			<0.001	-0.002	<0.001	-0.004	<0.001	0.006
Selenium, total (μg L^{-1})					<0.001	0.109	<0.001	0.012
Selenium, dissolved (μg L^{-1})					<0.001	0.191		
Specific Conductivity (μS cm^{-1})					<0.001	2.002	0.002	0.561
Sulphate (mg L^{-1})			<0.001	0.749	<0.001	0.473		
TSS (mg L^{-1})			<0.001	0.065				
Turbidity (NTU)			<0.001	0.065	0.025	0.018	<0.001	0.027
Zinc, total (μg L^{-1})			<0.001	-0.466	0.017	-0.016	<0.001	-0.025

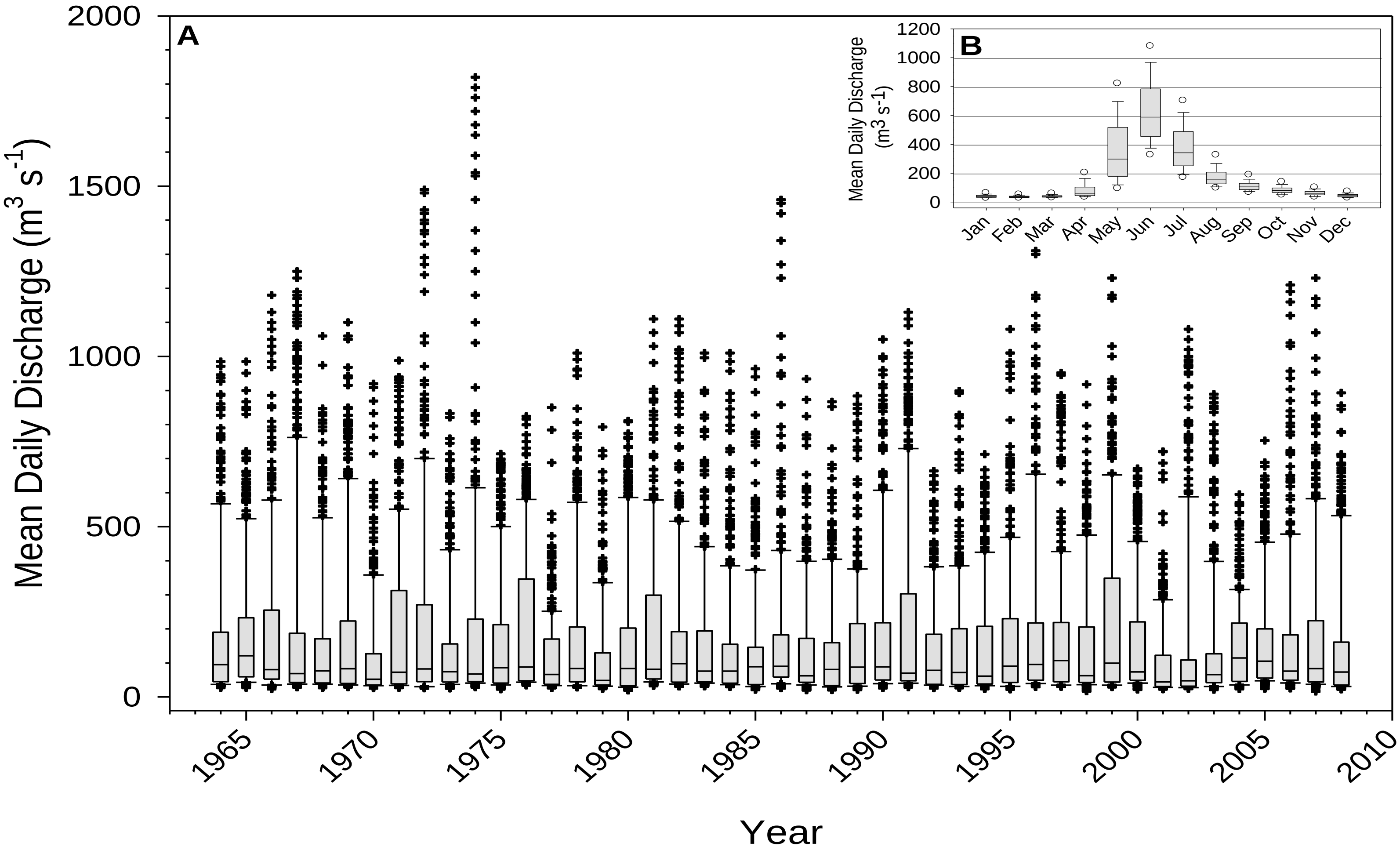
Note: Significant results presented in this table were also less than calculated FDRs (see Statistics section).

Flow: Flow, reported as mean daily discharge, is currently and has historically been measured at numerous sites within the watershed by the Water Survey of Canada (WSC). However, only two surface water quality monitoring sites included in this report are collocated with a WSC hydrometric station (Kootenay River at Fenwick station and St. Mary River at Wycliffe). These two stations, along with a hydrometric station at the Elk River at Fernie are used to describe flow seasonality.

The hydrometric station located at the Kootenay at Forte Steele (Fenwick) is used to describe flow in the Kootenay mainstem. The hydrometric station has been in operation since 1963, and river discharge intensity has varied greatly since 1964 (Figure 3A). Linear regression of total annual discharge (1964 – 2008) resulted in no significant trend.

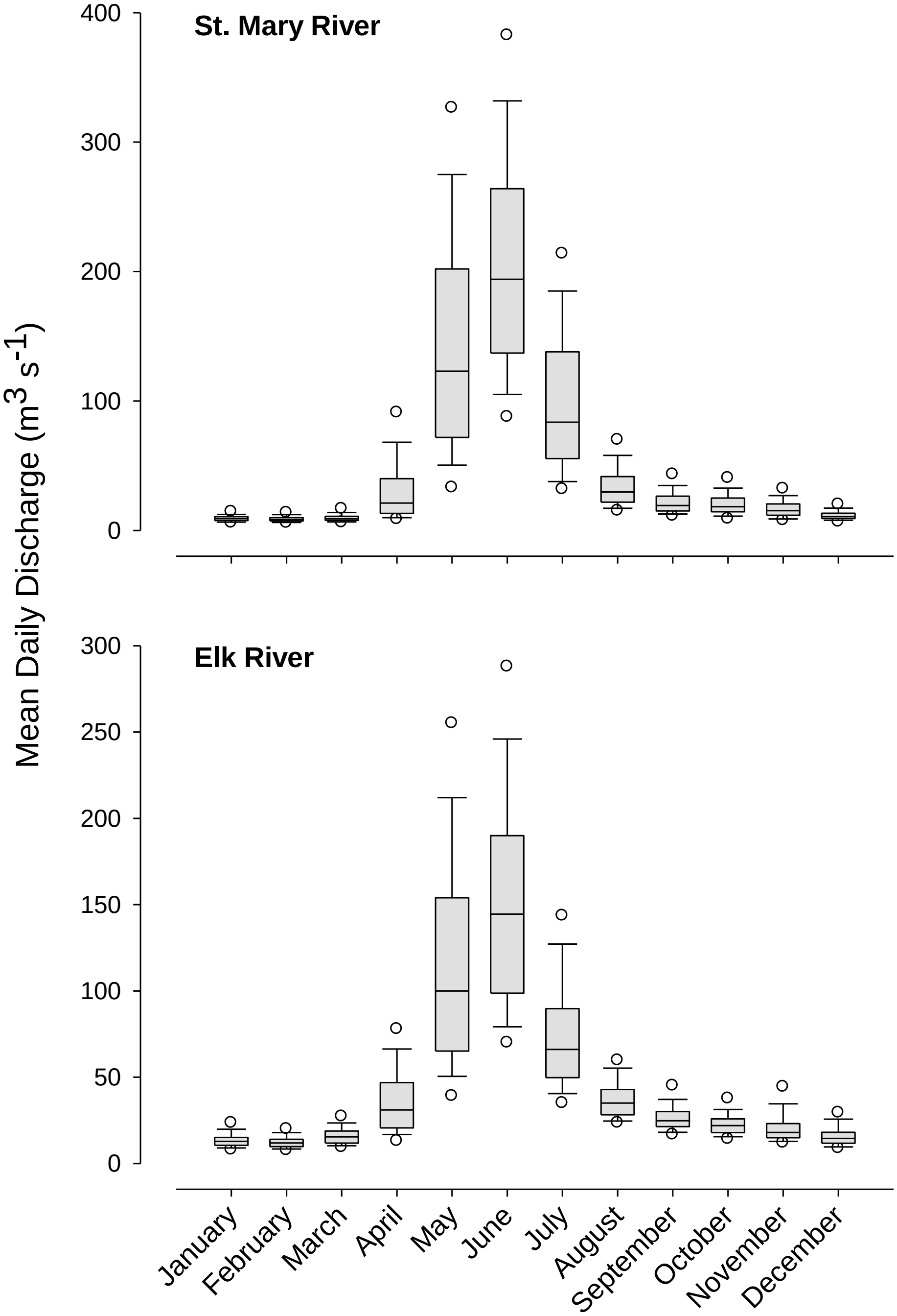
Monthly mean daily discharge plots from the Kootenay (Figure 3B), Elk and St. Mary rivers (Figure 4) have similar seasonal patterns and are typical of other rivers in the watershed such as the Moyie River (Dessouki 2009). Baseflows occur in winter and early spring months; the rising limb begins in April with the freshet peaking in June; and the falling limb occurs from summer to fall (Figure 3B; Figure 4). There were no temporal trends in annual discharge from the St. Mary's River at Wycliffe from 1950 to 1994 (08NG012; linear regression, $p > 0.05$).

Figure 3: Annual box-and-whisker plots of mean daily discharge from 1964 to 2008 (A) and monthly box-and-whisker plots of mean daily discharge from 1964 to 2008 (B) from the Kootenay River at Fort Steele (08NG065).



Note: open circles in Figure 2B represent the 5th/95th percentiles, not outliers.

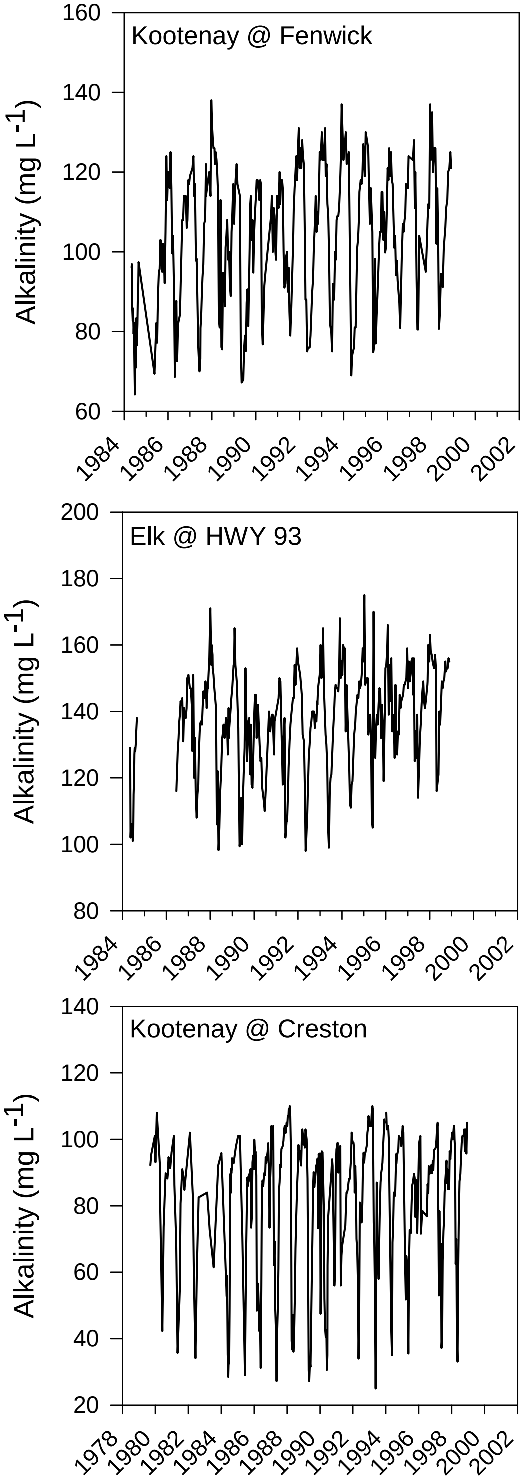
Figure 4: Monthly box-and-whisker plots of mean daily discharge from 1950 to 1994 from the St. Mary River at Wycliffe (08NG012) and from 1980 to 2007 from the Elk River at Fernie (08NK002).



Note: open circles represent the 5th/95th percentiles.

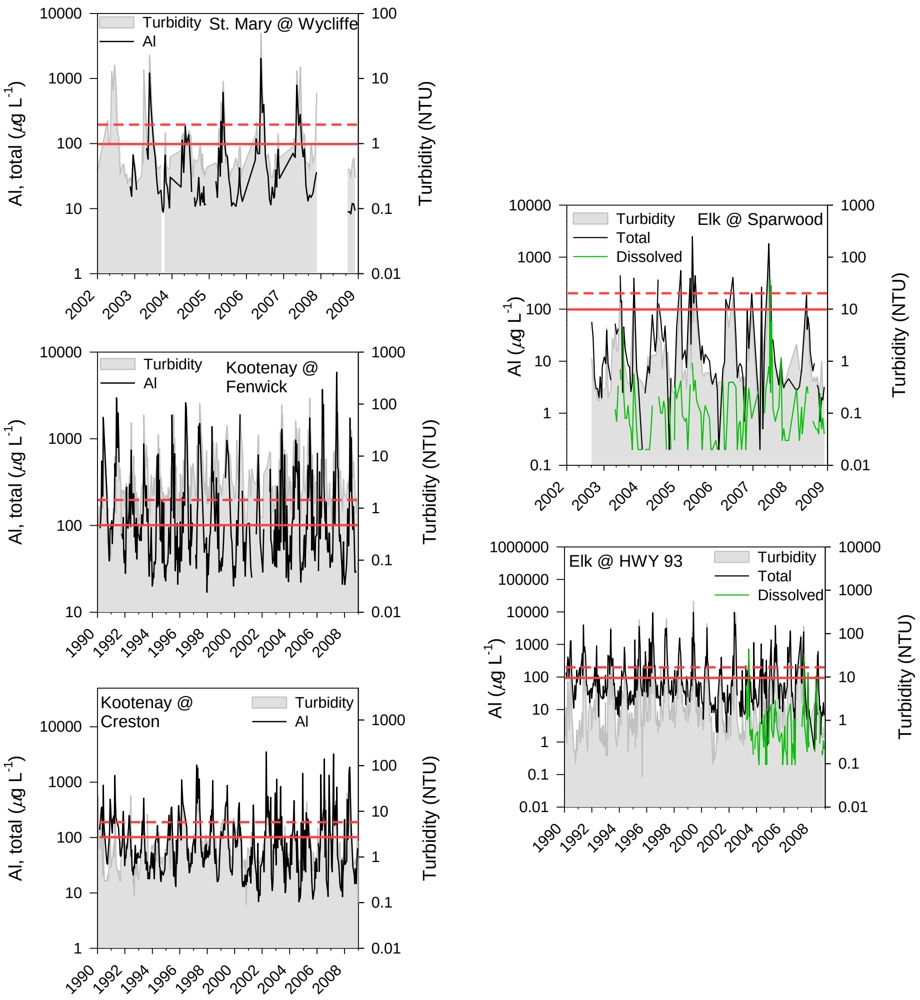
Alkalinity: Alkalinity was measured until 1999 and sufficient alkalinity data for trend tests exists for three sites: the Elk River at Hwy 93 and the Kootenay River at Fenwick and Creston. Alkalinity concentrations for all three sites were significantly increasing over the sample period, suggesting a broader regional trend in alkalinity concentrations (Table 1; Figure 5). The reasons for this regional trend are unknown at this time. Alkalinity concentrations in these waterbodies suggest that they are not sensitive to acid inputs.

Figure 5: Alkalinity measurements over the sample period from surface water quality trend sites in the Kootenay watershed.



Aluminum: Total aluminum varies greatly seasonally, with aluminum spikes related to elevated turbidity. This suggests that spikes are related to suspended sediment. MK analyses found significant decreasing trends in total aluminum at the Elk River at Hwy 93 and the Kootenay River at Creston (Table 1), potentially due to improving analytical methods (i.e. decreasing method detection limits). The current B.C. aquatic life guideline for dissolved aluminum and the CCME aquatic life guideline for total aluminum is 100 μg L^{-1}; the B.C. drinking water supply guideline is 200 μg L^{-1} for dissolved aluminum. Total aluminum concentrations seasonally exceeded these water quality guidelines at all sites, however as these exceedences were associated with turbidity events, elevated aluminum concentrations were not likely bioavailable (Figure 6). Filtration or settling to remove suspended solids in advance of drinking water use would reduce aluminum associated with suspended sediment.

Figure 6: Total and dissolved aluminum concentrations from surface water quality trend sites in the Kootenay watershed.

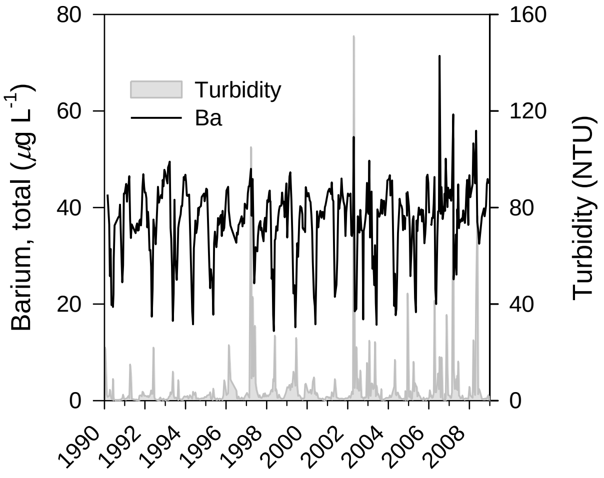


Note: Solid red line denotes CCME total Al and B.C. dissolved Al aquatic life guideline; dashed line represents B.C. drinking water supply guideline.

Dissolved aluminum measured at both Elk River sites were generally well below water quality guidelines. Since B.C. guidelines are specific to dissolved aluminum, efforts should be made to measure dissolved aluminum at all sites.

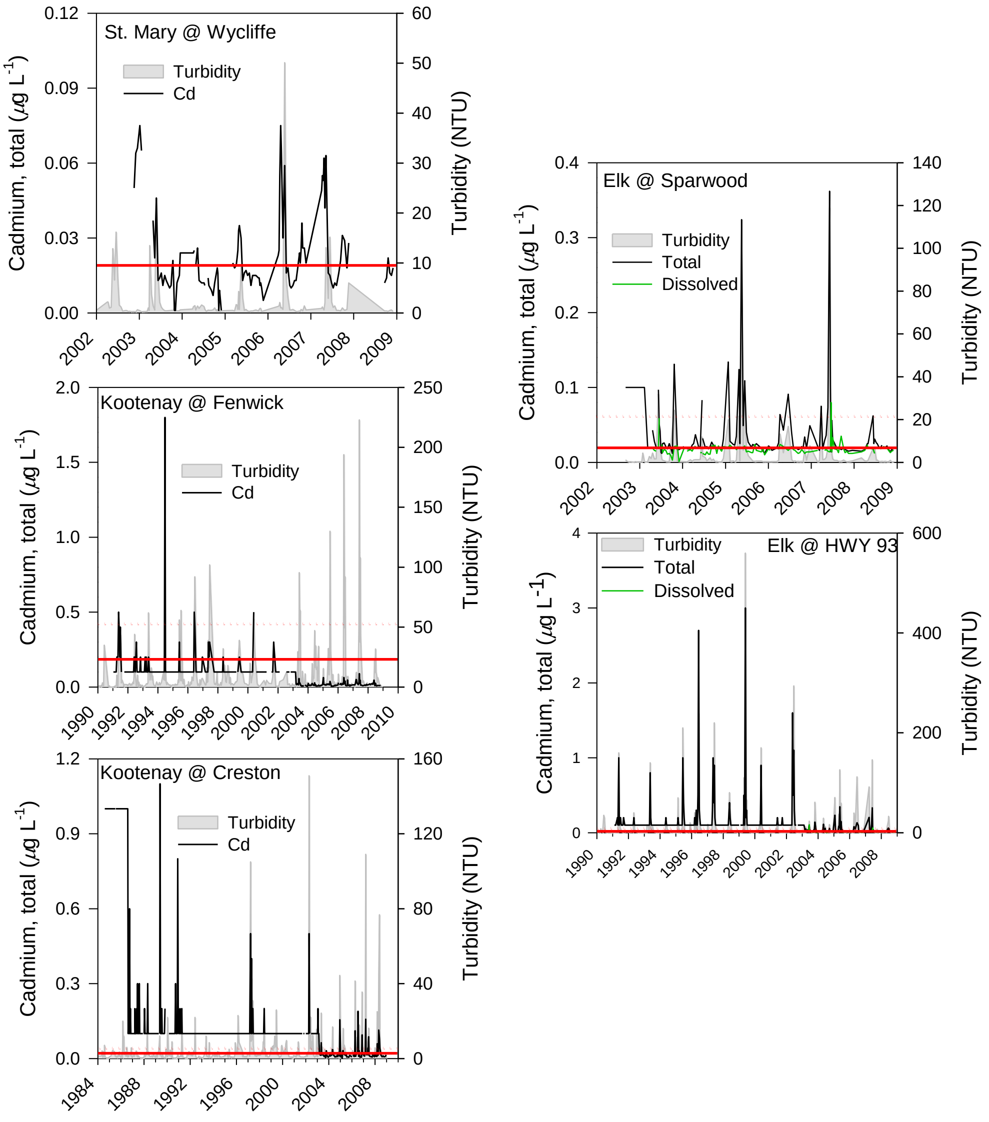
Barium: Total barium concentrations were measured at all sites in the Kootenay watershed. The Health Canada drinking water guideline and the B.C. maximum working aquatic life guideline for barium are 1 and 5 mg L^{-1}, respectively. At no time during the sample period did barium approach these guidelines. There was a significant increase in total barium in the Kootenay River at Creston over the sample period (Table 1; Figure 7). Reasons for this increase are not known, but current concentrations are well below guidelines. Total and dissolved barium should continue to be measured to monitor this trend. No trends were detected at the other water quality monitoring stations in the watershed.

Figure 7: Total barium concentrations from the Kootenay River at Creston from 1990 to 2009.



Cadmium: Cadmium was measured at all stations, although detection limits that allow for meaningful comparison to guidelines have only been available since 2003 (Figure 8). Trends results for cadmium were not considered meaningful due to this large decrease in minimum detection limits. In general, baseline measurements of total and dissolved cadmium are near or below CCME and B.C. guidelines; turbidity-driven spikes in cadmium result in seasonal exceedences of aquatic life guidelines, in particulate with total concentrations (Figure 8). Since these exceedences were closely associated with turbidity-spikes, cadmium may largely have been associated with suspended sediment and not likely bioavailable. The exception to this was the St. Mary's River station, where much of the cadmium appears to be in the dissolved form and often exceeds aquatic life guidelines. Reasons for the higher cadmium concentrations in the St. Mary's River, particularly in the non-particulate form, are possibly a result of mining activities; waste abatement at the Teck Cominco operation has resulted in declining cadmium concentrations (Pommen Water Quality Consulting 2004).

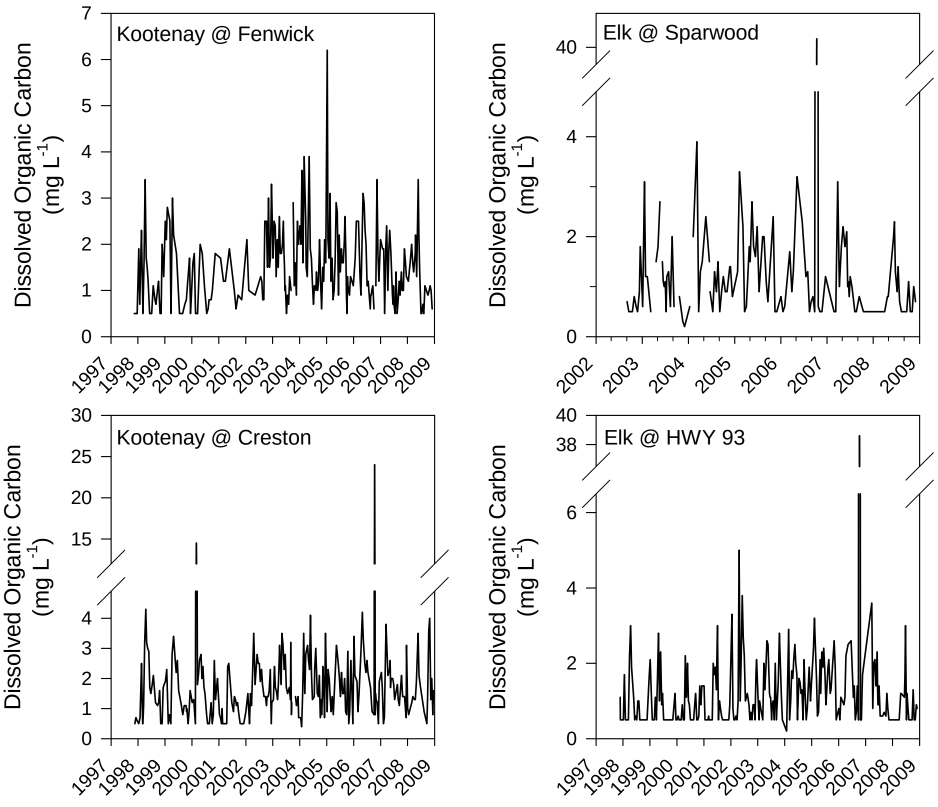
Figure 8: Total and dissolved cadmium concentrations from surface water quality trend sites in the Kootenay watershed.



Note: Solid red line denotes CCME and dotted red line denotes B.C. aquatic life guidelines.

Carbon, Dissolved Organic: Dissolved organic carbon was measured at all sites except the St. Mary River at Wycliffe (Figure 9). Dissolved organic carbon affects water colour (Eaton *et al.* 2005) and light penetration in water (Wetzel 2001). Dissolved organic carbon can also bond to organic and inorganic contaminants, altering the bioavailability of toxicants. In drinking water treatment systems which employ chlorination, chemical reactions with organic carbon can result in the production of trihalomethanes, a carcinogenic disinfection by-product (Moore 1998). As a result, limits total organic carbon – of which dissolved organic carbon is a sub-component – have been imposed for drinking water uses. Seasonal maxima at sites were generally below the drinking water source guideline for organic carbon of 4 mg L^{-1} (Figure 9). There were significant increasing trends in dissolved organic carbon at the Kootenay River at Creston and the Elk River at Hwy 93 (Table 1). Increases in the Elk River are possibly due to upstream coal mining activities; increases in the Kootenay River might be due to production in upstream lakes or run-off from agricultural activities. At present, the rate of increase and current concentrations at both sites are not of major concern.

Figure 9: Dissolved organic carbon concentrations from surface water quality trend sites in the Kootenay watershed.

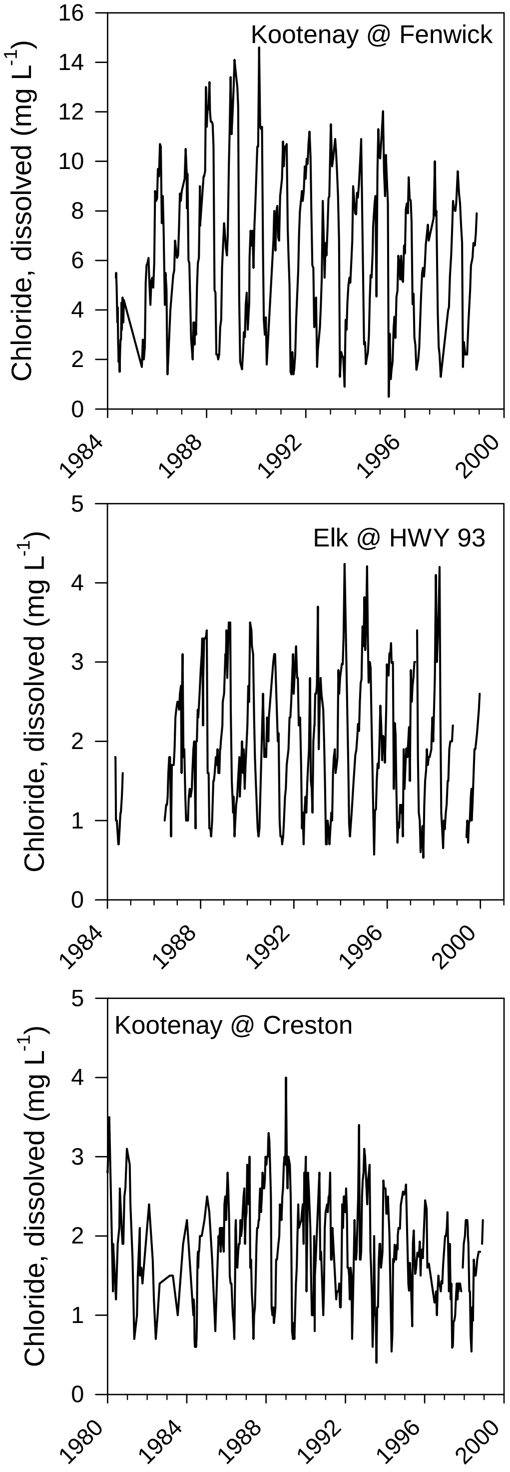


Chloride: Chloride is a common anion in natural waters (Kalff 2002) and is used for photosynthesis, osmoregulation, and enzyme regulation among other cellular processes (Wetzel

2001). Chloride was monitored in the Kootenay River at Fenwick and Creston and in the Elk River at Hwy 93 until 2000 (Figure 10). B.C. aquatic life and drinking water guidelines were at minimum an order of magnitude greater than concentrations in the Kootenay and Elk River during the sample period.

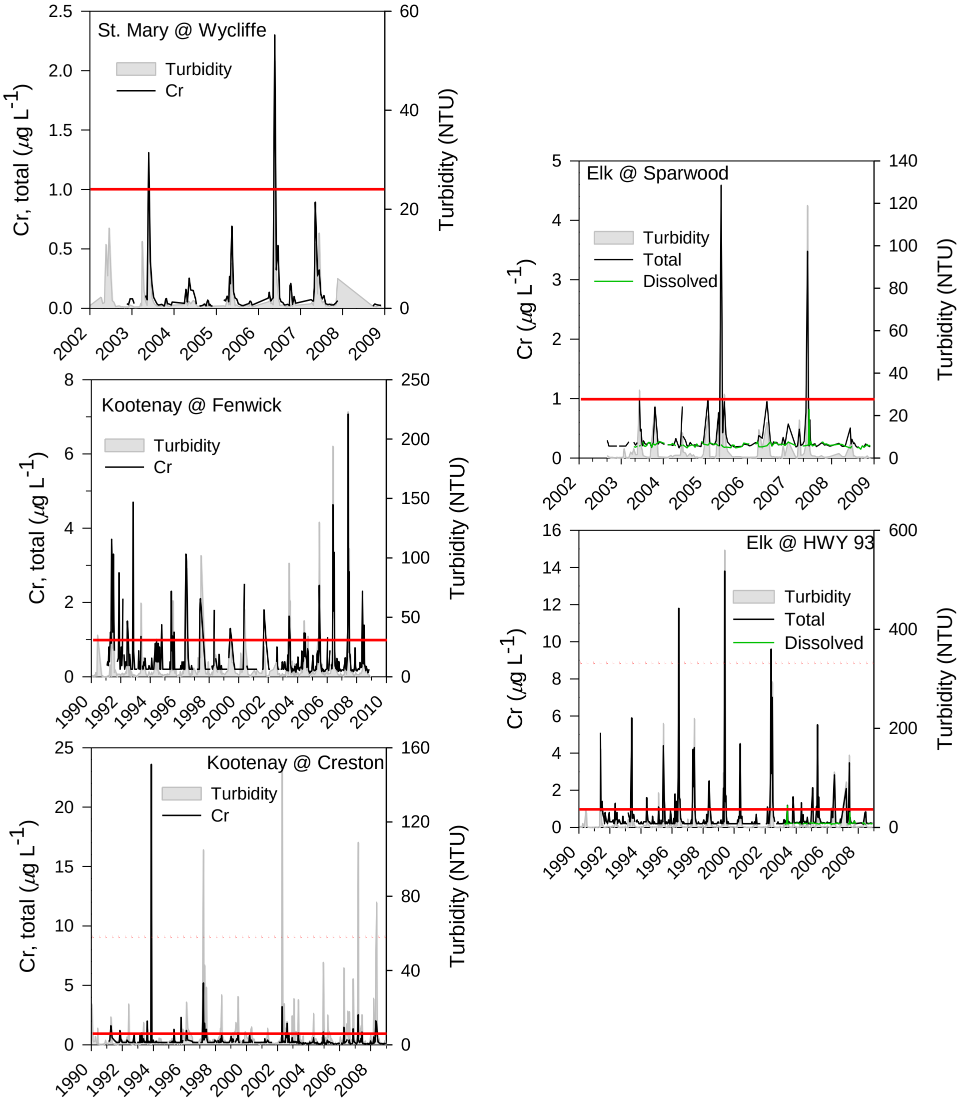
There was a significant decreasing trend in chloride in the Kootenay River at Creston over the sample period (Table 1). Chloride should be monitored at sites within the Kootenay watershed to ensure concentrations continue to remain stable.

Figure 10: Dissolved chloride concentrations at surface water quality trend sites in the Kootenay watershed.



Chromium: Chromium is measured as total chromium at all sites, and also as dissolved chromium at the Elk River stations (Figure 11). Guidelines presently exist for the two most toxic oxidizing states of chromium – Cr(III) or trivalent chromium and Cr(VI) or hexavalent chromium (Canadian Council of Ministers of the Environment 2007) – thus, these guidelines are not directly comparable with total nor dissolved chromium. Nevertheless, total and dissolved chromium concentrations were generally lower than the aquatic life guideline for Cr(VI), the most sensitive Cr guideline at 1 μg L^{-1}. Seasonal, turbidity-driven spikes often exceed the guideline for Cr(VI), but these elevated concentrations are likely associated with suspended sediment and not likely bioavailable (Figure 11). A decreasing trend in total chromium was detected in the Kootenay River at Fenwick (Table 1). This decline in total chromium concentrations is likely due to improving (decreasing) analytical detection limits over the sample period.

Figure 11: Total and dissolved chromium concentrations from surface water quality trend sites in the Kootenay watershed.



Note: Solid red line represents CCME and B.C. aquatic life guideline for Cr(VI) while dotted line represents Cr(III) guideline.

Cobalt: Cobalt is essential for growth for many microbiota such as algae (Wetzel 2001). Cobalt was measured in the total form at all sites and also in dissolved form at the Elk River sites

(Figure 12). The B.C. aquatic life maximum guideline is 110 μg L^{-1} and was not exceeded over the sample period at any site. There were significant decreasing trends in total cobalt at both sites along the Kootenay River and the Elk River at Hwy 93 (Table 1). The reason for this change is likely due to a change in analytical detection limits in 2003 which resulted in lower minimum concentrations (Figure 12) and likely false trends.

Figure 12: Total and dissolved cobalt concentrations from surface water quality trend sites in the Kootenay watershed.

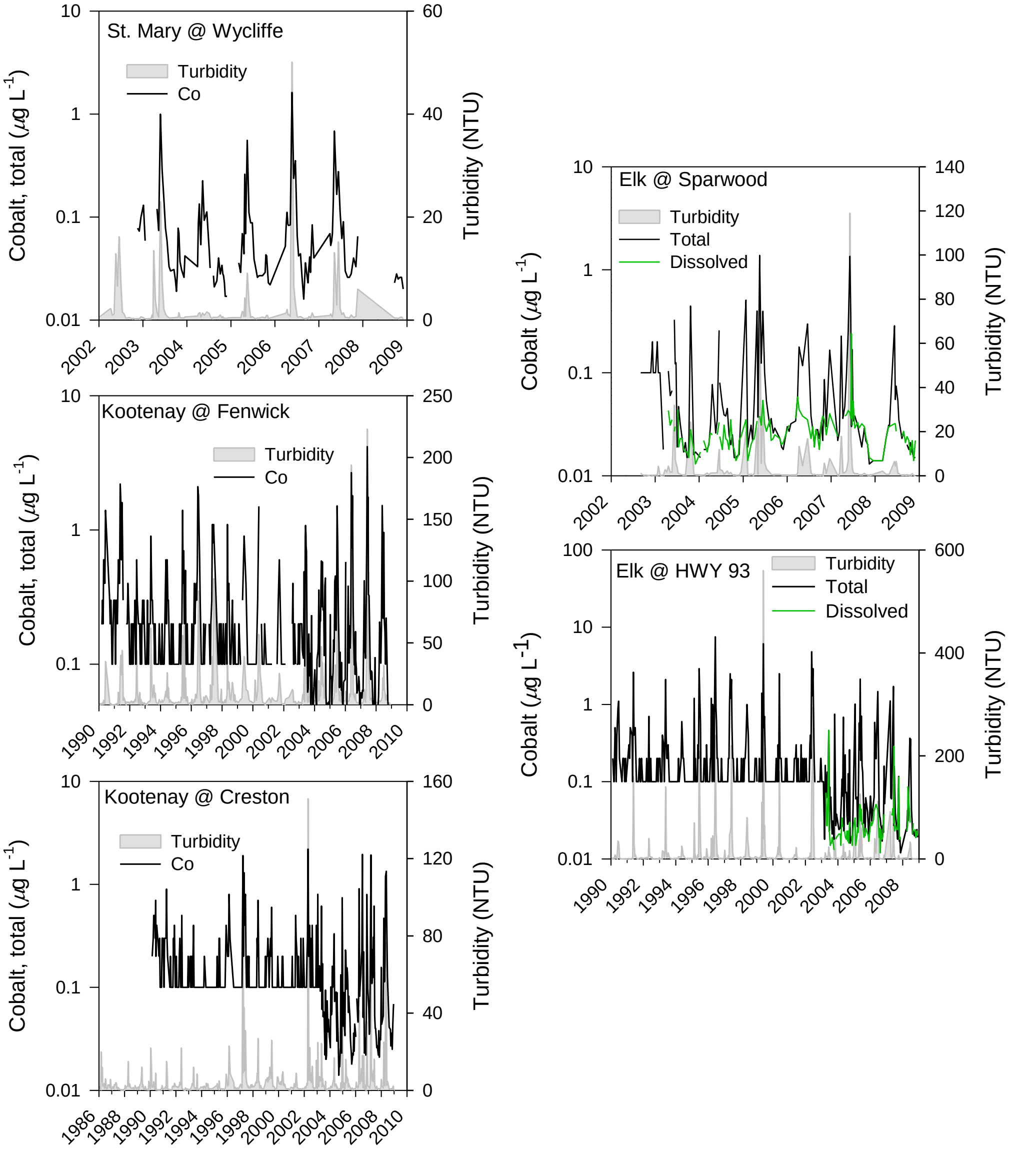
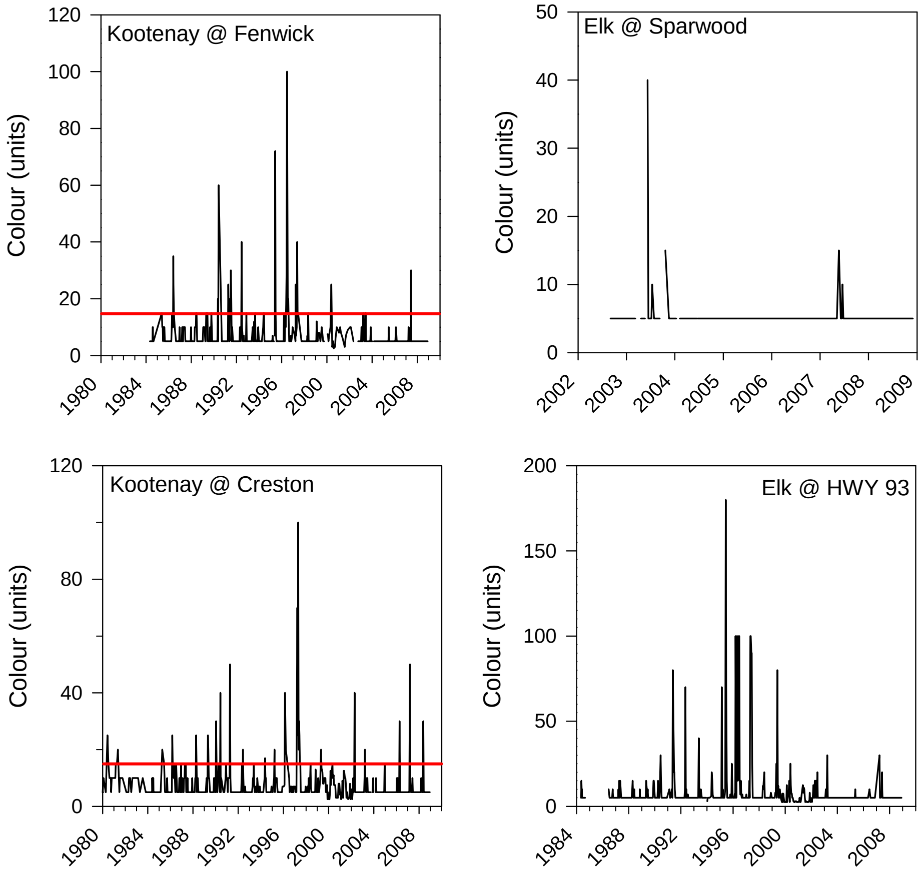


Figure 13: Colour measurements from surface water quality trend sites in the Kootenay watershed.



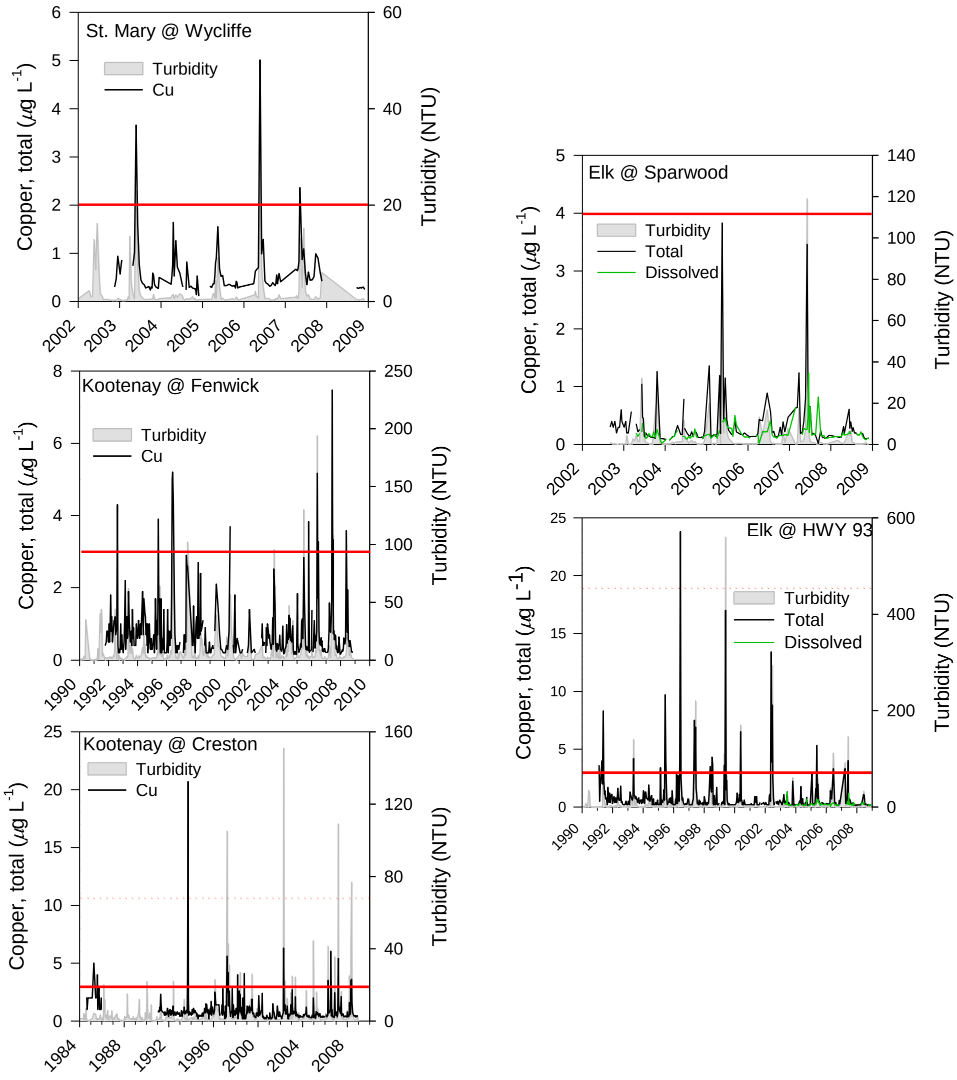
Note: Solid red line denotes B.C. and Health Canada drinking water aesthetic objective.

Colour: Water colour results primarily from the presence of natural organic matter, and in particular, humic substances (Eaton *et al.* 2005). As a result, colour is often correlated with dissolved organic carbon content. Colour was measured at all sites except for the St. Mary River at Wycliffe (Figure 13). Prior to July 1997, colour was measured as apparent colour which is a visual comparison with known standards; post-July 1997 measurements were analysed as true colour using multi-wave spectrophotometry.

The current B.C. aquatic life guideline for colour is dependent on upstream or background concentrations. Although there are upstream and downstream sites on both the Kootenay and Elk rivers, their locations are relatively far apart and the influences between these sites preclude specific upstream-downstream comparisons.

B.C. and Health Canada drinking water guidelines are established for aesthetic purposes at 15 mg Pt L^{-1}. Drinking water is a main designated use for the Kootenay River. Colour seasonally exceeds the drinking water guideline in the Kootenay River although base concentrations are below this guideline. These seasonal exceedences are related to spring freshet and increasing river discharge, with higher water colour measurements occurring in April, May and June. There were no long-term trends in colour and these seasonal changes are considered natural. Source water should be treated for colour before use during freshet.

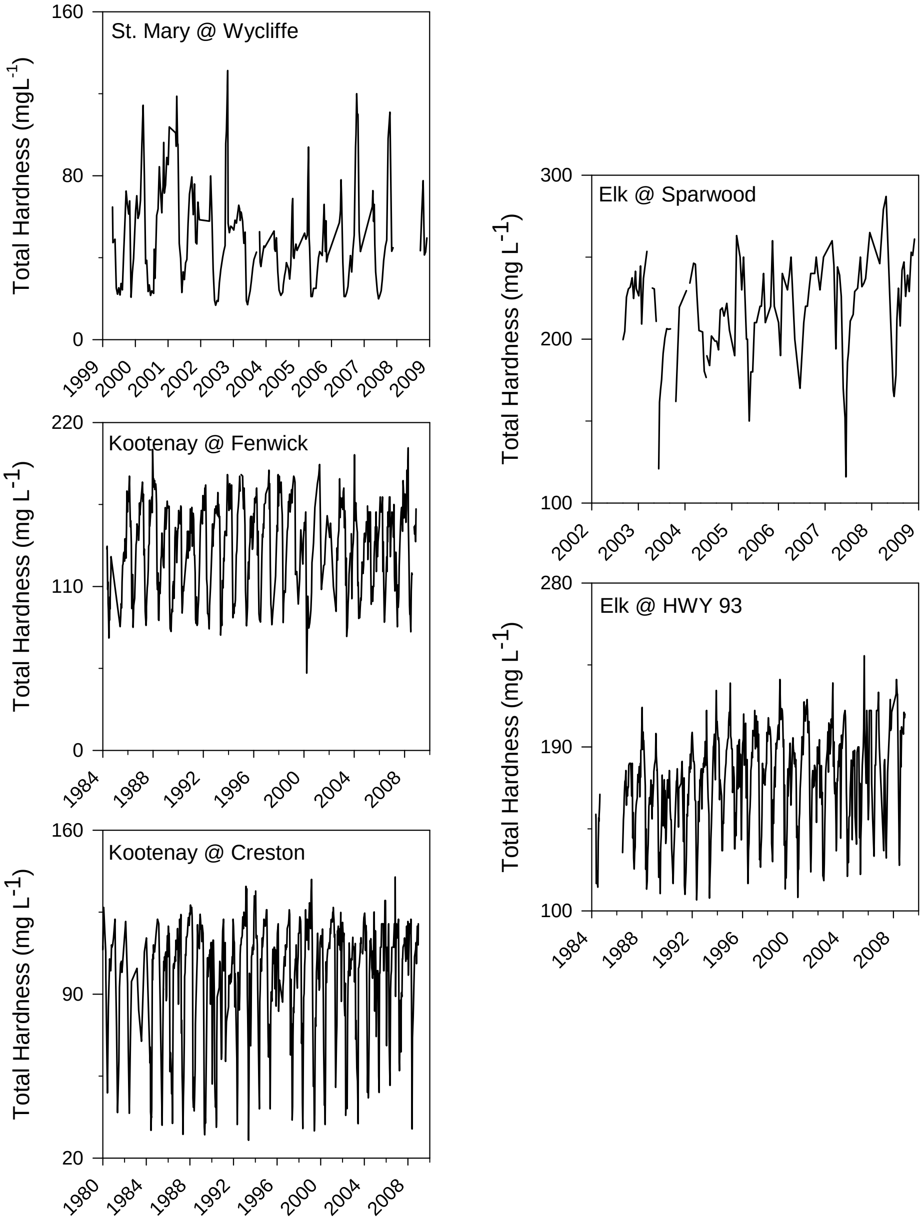
Figure 14: Total and dissolved copper concentrations from surface water quality trend sites in the Kootenay watershed.



Note: Solid red line denotes CCME and dotted red line represents B.C. aquatic life guidelines.

Copper: Copper was measured at all sites (Figure 14). In general, copper concentrations were generally low with seasonal spikes which were associated with elevated turbidity. Both the CCME and B.C. aquatic life guidelines are derived using hardness concentrations. Since seasonal exceedences were associated with turbidity, copper concentrations were likely associated with particulate matter and not likely bioavailable. Copper was significantly decreasing at both locations in the Kootenay River from 1992 to 2009 (Table 1). Both rates of decrease were fairly small and may be related to improved analytical techniques in 2003, which enhanced the ability to accurately measure copper concentrations.

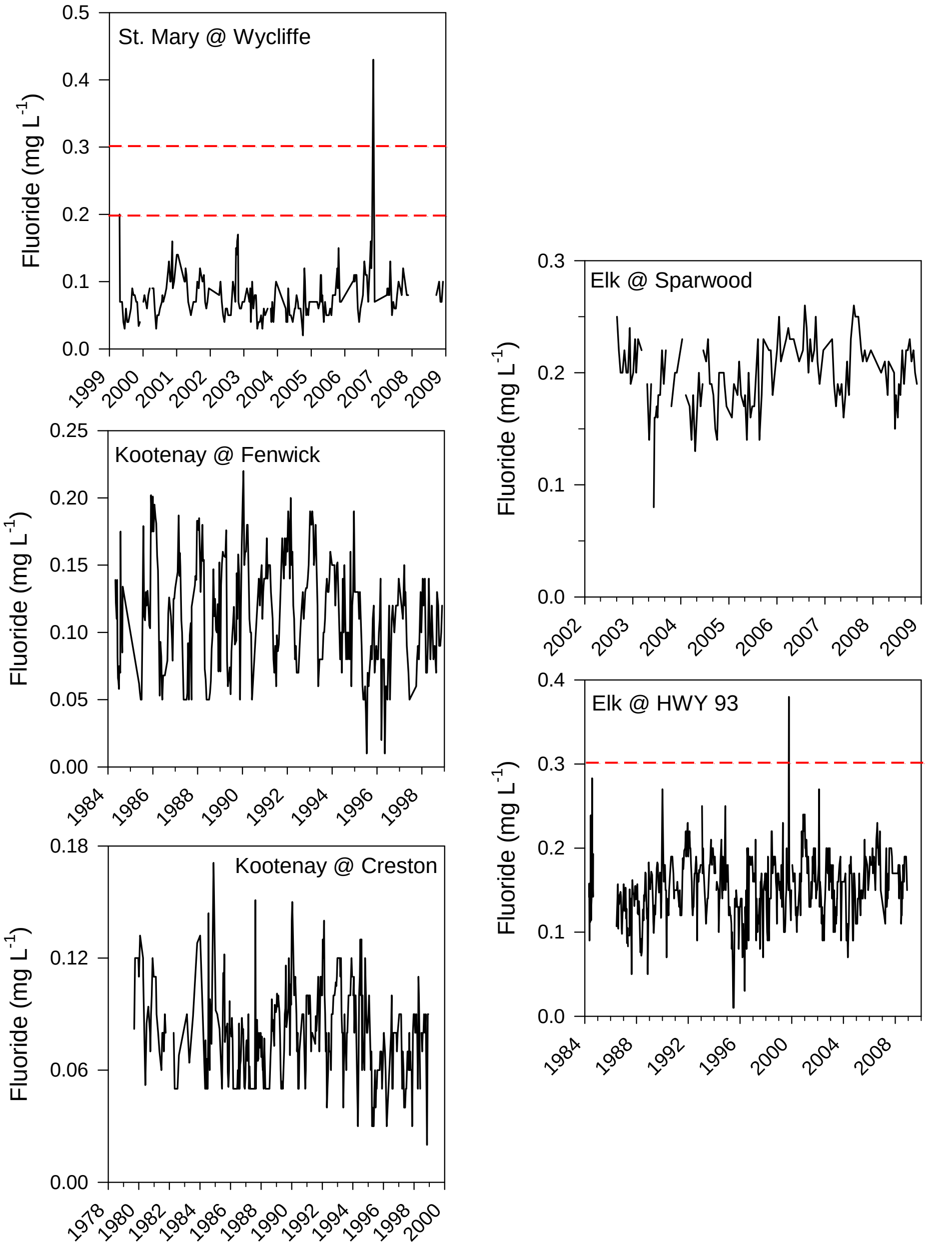
Figure 15: Total hardness concentrations from surface water quality trend sites in the Kootenay watershed.



Hardness: Total hardness is a measure of alkaline earth minerals and is an important component affecting the toxicity of a variety of metals, but not considered a parameter of concern for drinking water or aquatic life purposes. Total hardness is a calculated result derived using the following equation: Total Hardness = 2.497[Ca, mg L^{-1}] + 4.118[Mg, mg L^{-1}] (Eaton *et al.* 2005). MK analyses found significant increasing trends in the Elk River at Hwy 93 and the Kootenay River at Creston (Table 1). Calcium is significantly increasing in the Elk River at Hwy 93 which likely explains much of the trend in hardness at this site.

Minor increases in either calcium or magnesium may have resulted in the hardness trend in the Kootenay River at Creston. There are no drinking water, wildlife or aquatic life guidelines for total hardness.

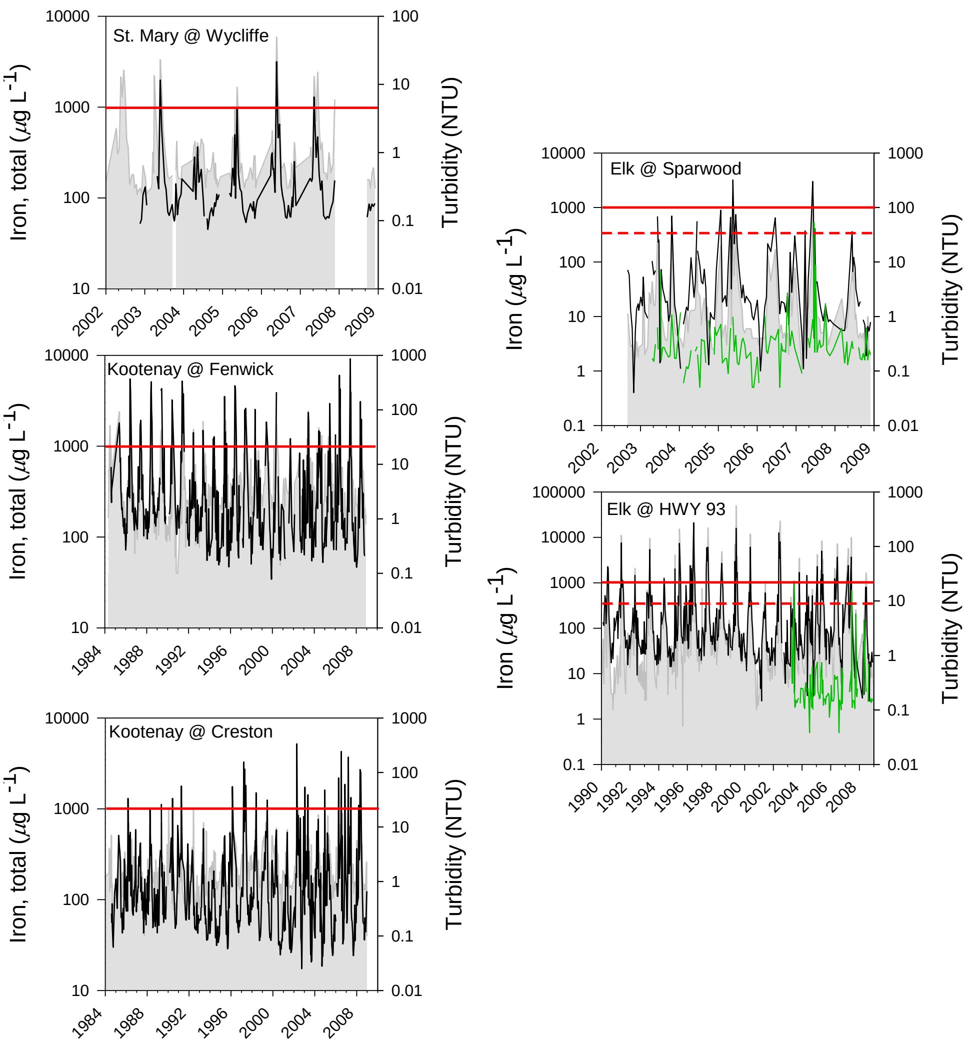
Figure 16: Fluoride concentrations from surface water quality trend sites in the Kootenay watershed.



Fluoride: Fluoride is a common anion in surface waters and was measured at all sites, although monitoring for fluoride in the Kootenay River ceased in 1999 (Figure 16). B.C. aquatic life guidelines for fluoride are hardness-dependent and vary between 0.2 and 0.3 mg L^{-1}. The fluoride guideline was exceeded once in the St. Mary River and once in the Elk River at Hwy 93 over the sample period (Figure 16). There was a significant increasing trend in fluoride at the Elk River at Hwy 93 over the sample period (Table 1), but the rate of increase was quite small. Nevertheless, fluoride should continue to be monitored in the Elk River.

Iron: Total iron was measured at all sites while dissolved iron was measured at both sites in the Elk River (Figure 17). Total iron concentrations were highly positively correlated with turbidity concentrations at all sites (Spearman's Rank Order, $r_s > 0.7$). The B.C. aquatic life guideline for total iron is 1 mg L^{-1} and 0.35 mg L^{-1} for dissolved iron. Although total iron concentrations were generally below the aquatic life guideline, seasonal exceedences of this guideline occur during freshet when turbidity is greatest. These exceedences are not considered a major concern since total iron concentrations were likely associated with suspended particulate and not likely bioavailable.

Figure 17: Total and dissolved iron concentrations from surface water quality trend sites in the Kootenay Watershed.

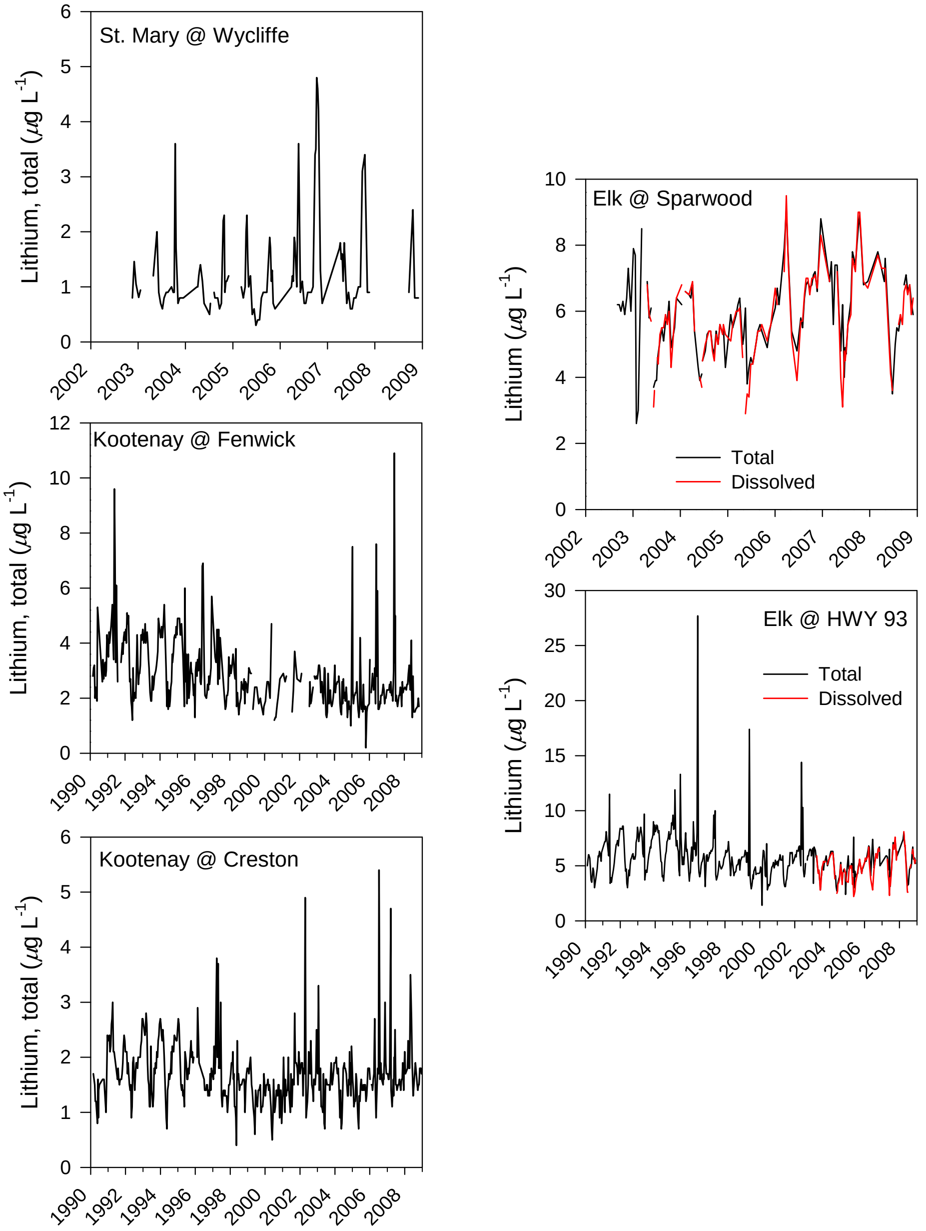


Note: Solid red line denotes B.C. and dashed red line denotes CCME aquatic life guidelines for total iron. Shaded area represents turbidity; black line represents total iron; green line represents dissolved iron.

There were significant decreasing trends in total iron in Kootenay River at Fenwick and the Elk River at Hwy 93 (Table 1). Reasons for the decreasing trend in the Kootenay River at Fenwick and in the Elk River at Hwy 93 are not known. These changes may be due to improving laboratory methods or changing sediment composition.

Dissolved iron measurements from the Elk River rarely exceeded the B.C. aquatic life guideline. In general, concentrations of total and dissolved iron in the lower Elk River were greater than upstream concentrations.

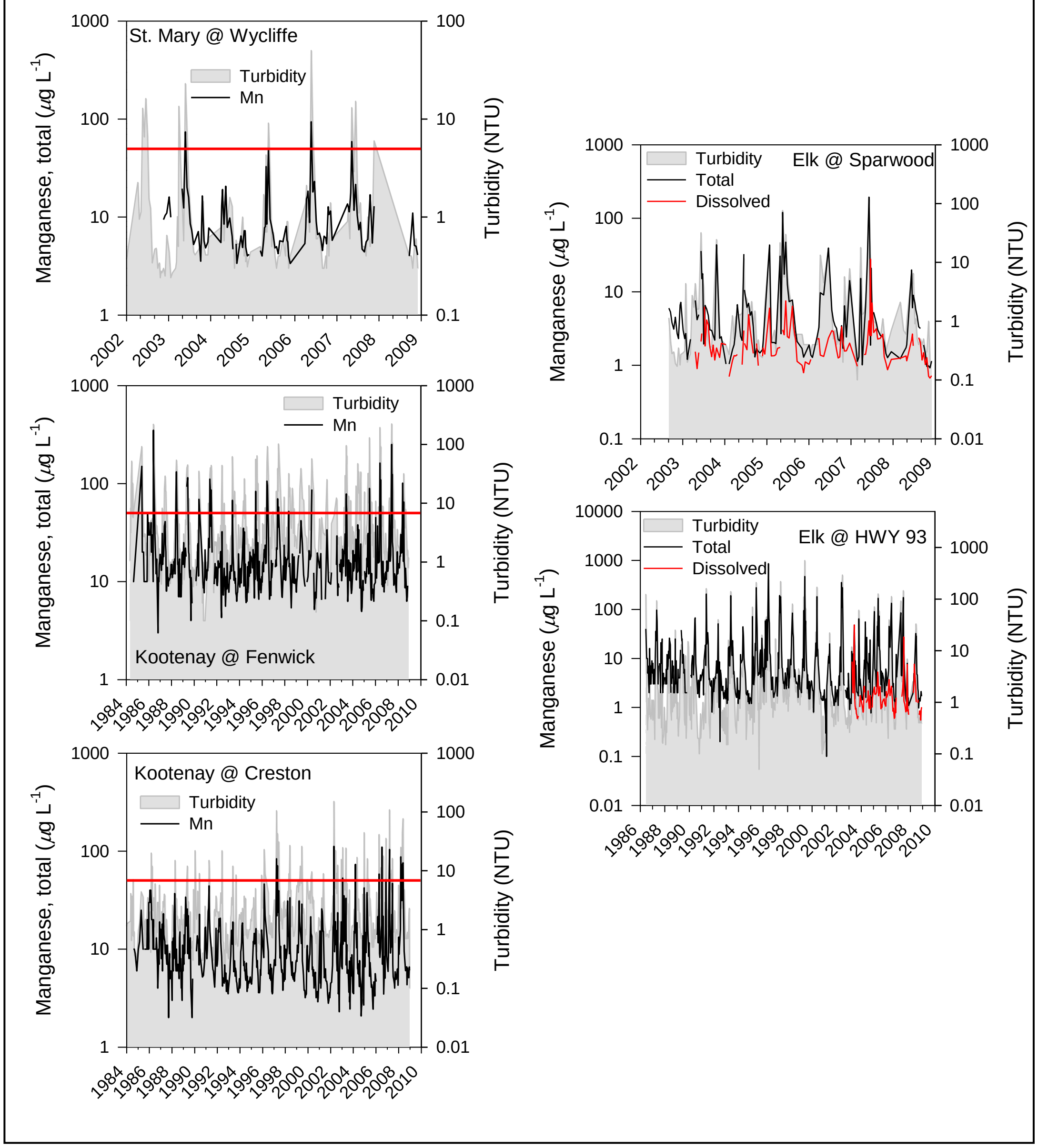
Figure 18: Total and dissolved lithium concentrations from surface water quality trend sites in the Kootenay Watershed.



Lithium: Lithium was measured as total lithium at all sites, while dissolved lithium was also measured at both Elk River sites (Figure 18). The most sensitive B.C. working aquatic life guideline is 14 μg L^{-1}. This working guideline was only exceeded at one site over the sample period, the Elk River at Hwy 93, and was only exceeded twice at this site over the sample period.

There were significant decreasing trends in total lithium concentrations at both sites in the Kootenay River and the Elk River at Hwy 93 (Table 1). Reasons for this decline are not known but may be due again to decreasing method detection limits.

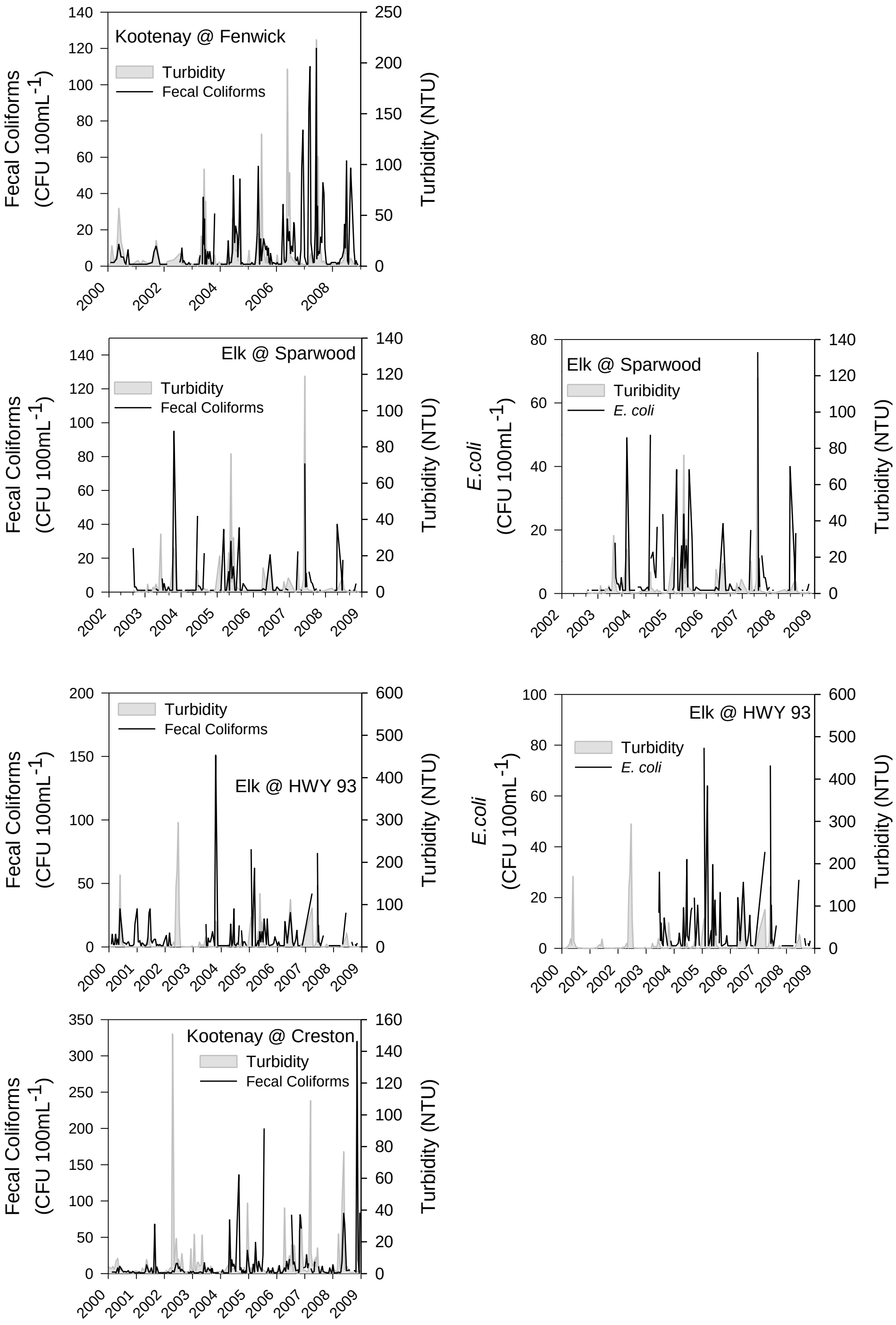
Figure 19: Total and dissolved manganese concentrations from surface water quality trend sites in the Kootenay watershed.



Manganese:

Manganese is a micronutrient which is essential for enzyme activation and reactions involved with photosynthesis (Wetzel 2001). Total manganese was measured at all sites while sites on the Elk River also include dissolved measurements (Figure 19). The B.C. aquatic life guideline is hardness-dependant, and at no time was this guideline exceeded at any site during the sample period. Health Canada does have an aesthetic drinking water guideline for manganese of 50 μg L^{-1}, and this guideline was often exceeded on a seasonal basis. However, total manganese concentrations were correlated with turbidity at all sites (Spearman Rank Order, $r_s > 0.5$) and thus, filtration or sedimentation in advance of drinking water use should remove much of the manganese in the water.

Figure 20: Fecal coliform and *E. coli* measurements from surface water quality trend sites in the Kootenay watershed.



There was a decreasing trend in total manganese in the Elk River at Hwy 93 and in the Kootenay River at Creston over the sample period (Table 1). The reason for these declines is likely again improving analytical methods, as turbidity overall displays increasing trends.

Microbiological Indicators: Microbiological indicators, such as fecal coliforms and *E. coli*, are used to determine potential fecal contamination and thus, potential sources of pathogens in waterways. Fecal coliforms and *E.*

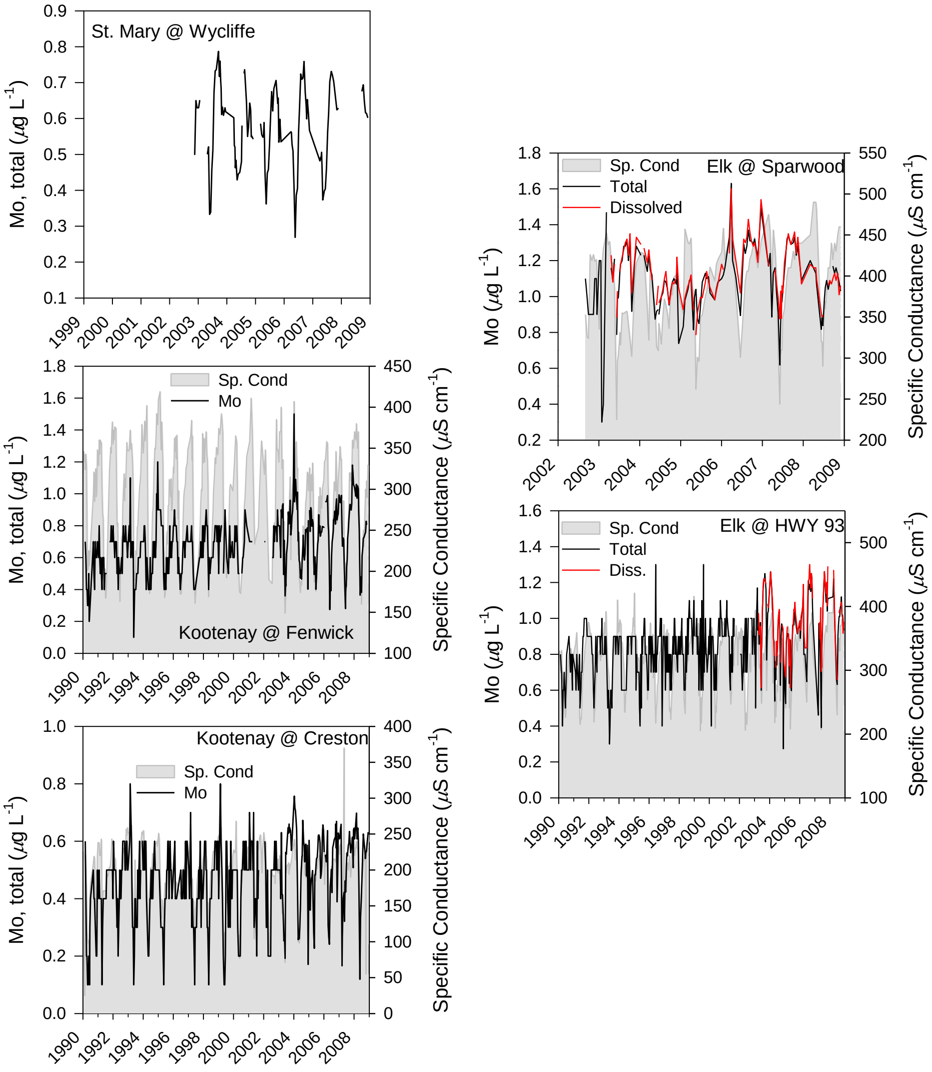
coli are present in the gut and feces of warm-blooded animals (Eaton *et al.* 2005) and their presence can be the result of sewage or septic discharges, ranching activities and wild animals. B.C. source water guidelines for drinking water vary by indicator group and the level of treatment. Relevant comparison to B.C. guidelines requires five samples in a 30 day period, with the 90th percentile calculated from these results serving as the guideline comparison. Requisite sampling was not met at any point during the sample period and guideline comparisons cannot be made.

Medians calculated for the sample period were low, with median fecal coliform results of 2 CFU 100 mL^{-1} at both locations along the Kootenay River. Median fecal coliform and *E. coli* results from the Elk River were 1 and 3 CFU $100mL^{-1}$ at Sparwood and Hwy 93, respectively. There were significant increasing trends in fecal coliforms over the sample period in the Kootenay River at Fenwick and Creston (Table 1; Figure 20). The source of these increases might be due to numerous factors including sewage/septic discharge and agricultural inputs. Source water should be disinfected prior to drinking water use.

Molybdenum: Molybdenum is a micronutrient essential for nitrate reduction and nitrogen fixation (Wetzel 2001).Total molybdenum was measured at all sites and dissolved molybdenum was measured at sites along the Elk River (Figure 21). Total molybdenum tended to vary with specific conductivity which suggests that concentrations are largely in the dissolved form, as demonstrated by the similarities of total and dissolved molybdenum concentrations in the Elk River (Figure 21). Provincial and national water quality guidelines exist for molybdenum, but current concentrations of are orders of magnitude lower than these guidelines.

Significant increasing trends in total molybdenum were observed at both sites in the Kootenay River and at the Elk River at Hwy 93. This trend may be due to changing hydrology such as changing surface or groundwater discharge, although no surface water trends were significant. Although these trends in molybdenum are of interest, current molybdenum concentrations are well below aquatic life guidelines.

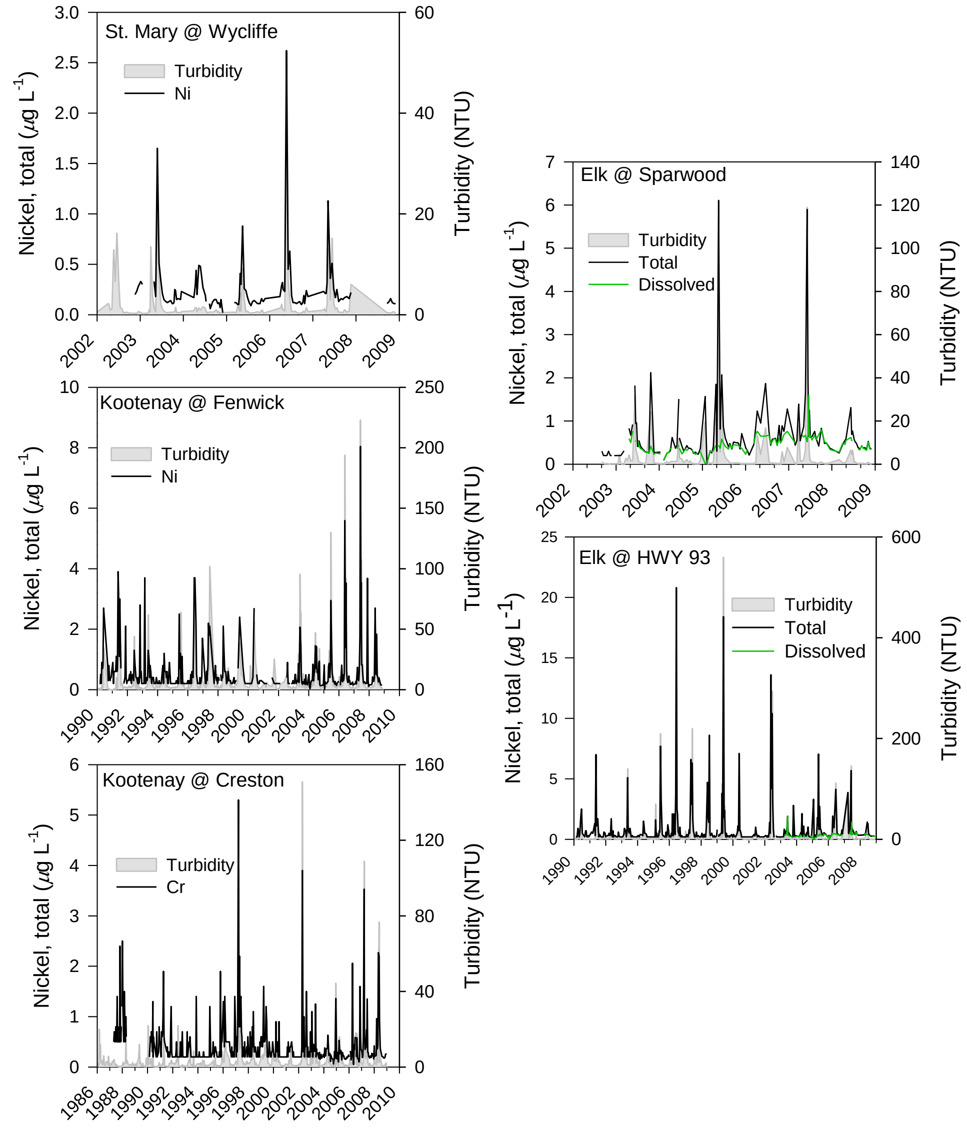
Figure 21: Total and dissolved molybdenum concentrations over the sample period from surface water quality trend sites in the Kootenay watershed.



Nickel: Nickel is a micronutrient used for nitrogen fixation and iron absorption, among other biochemical reactions (Wetzel 2001). Total nickel was measured at all sites and dissolved nickel was measured at sites along the Elk River (Figure 22). The CCME aquatic life and the B.C.

working aquatic life guidelines vary based on hardness. For example, the nickel guideline for soft water (0 – 60 mg L^{-1}) systems is 25 $\mu g\ L^{-1}$. Nickel concentrations did not exceed any guidelines over the sample period.

Figure 22: Total and dissolved nickel concentrations over the sample period from surface water quality trend sites in the Kootenay watershed.

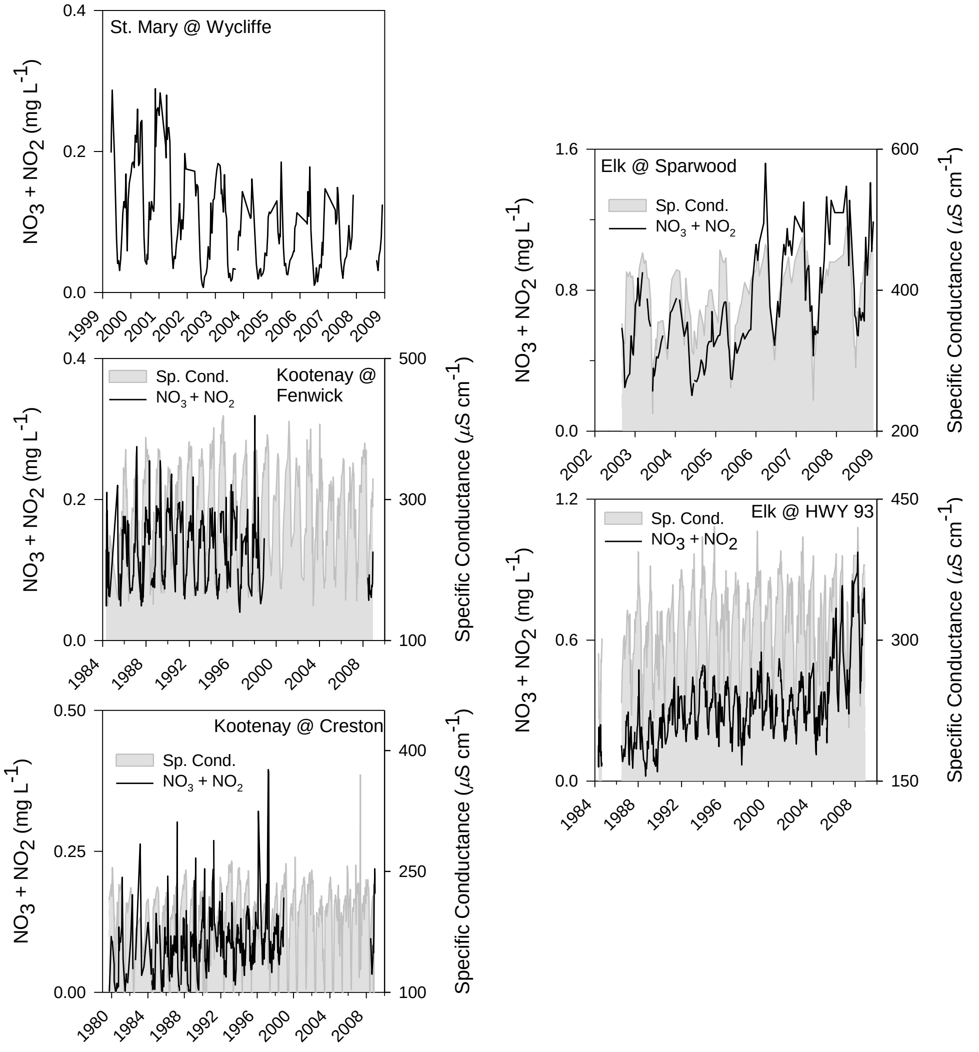


There was a significant decreasing trend in total nickel at the Kootenay River at Fenwick (Table 1), although turbidity was increasing (Table 1), and was positively correlated with total nickel concentrations (Spearman Rank Order test, $r_s = 0.66$). Improving (decreasing) analytical detection limits in 2003 might also have contributed to this decreasing trend.

Nitrate and Nitrite:

Nitrate plus nitrite trends in the Kootenay watershed differ by location (Table 1; Figure 23): there was a declining trend in nitrate plus nitrite in the St, Mary River over the sample period (a similar trend in ammonia was detected at this site [Table 1]); concentrations were significantly increasing in the Elk River, as demonstrated by Mann-Kendall (Table 1) and mean annual linear trend tests ($p < 0.001$; Figure 24), and is likely a result of explosives residue (ammonium nitrate) used for coal mining upstream; concentrations in the Kootenay River at Creston were steadily increasing over the sample period, possibly due to contributions from the Elk River, although there is a large, recent gap in the dataset.

Figure 23: Nitrate plus nitrite concentrations from surface water quality trend sites in the Kootenay watershed.



Nitrate plus nitrite is a major constituent of total dissolved nitrogen, and nitrogen is a potential limiting nutrient in aquatic systems. Although nitrite is much more toxic than nitrate, the nitrite component is often very small in well-oxygenated systems. Nitrate plus nitrite concentrations are very close to the concentrations of total dissolved nitrogen in the Kootenay watershed (Figure 25), and the trends in total dissolved nitrogen are driven by trends in nitrate plus nitrite.

Figure 24: Linear regression of $\log_{10}$ mean annual nitrate plus nitrite concentrations over time from the Elk River at Hwy 93.

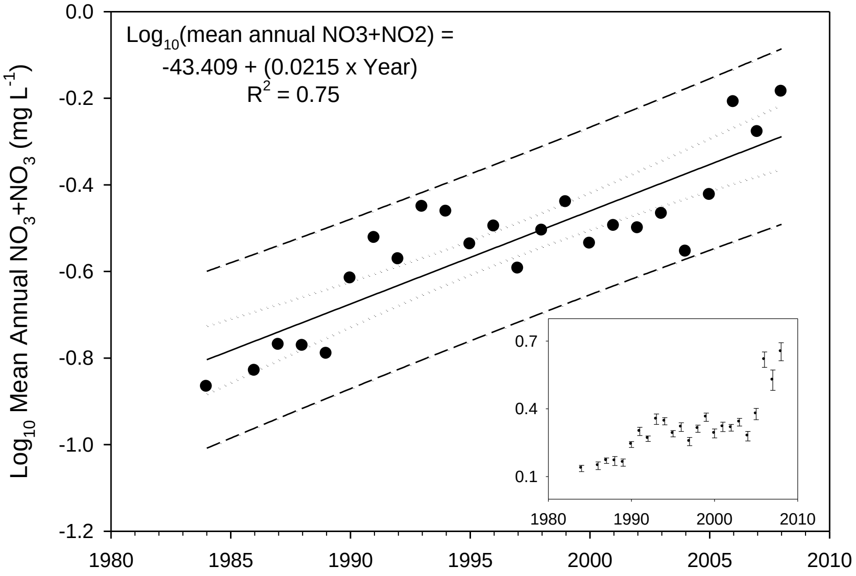
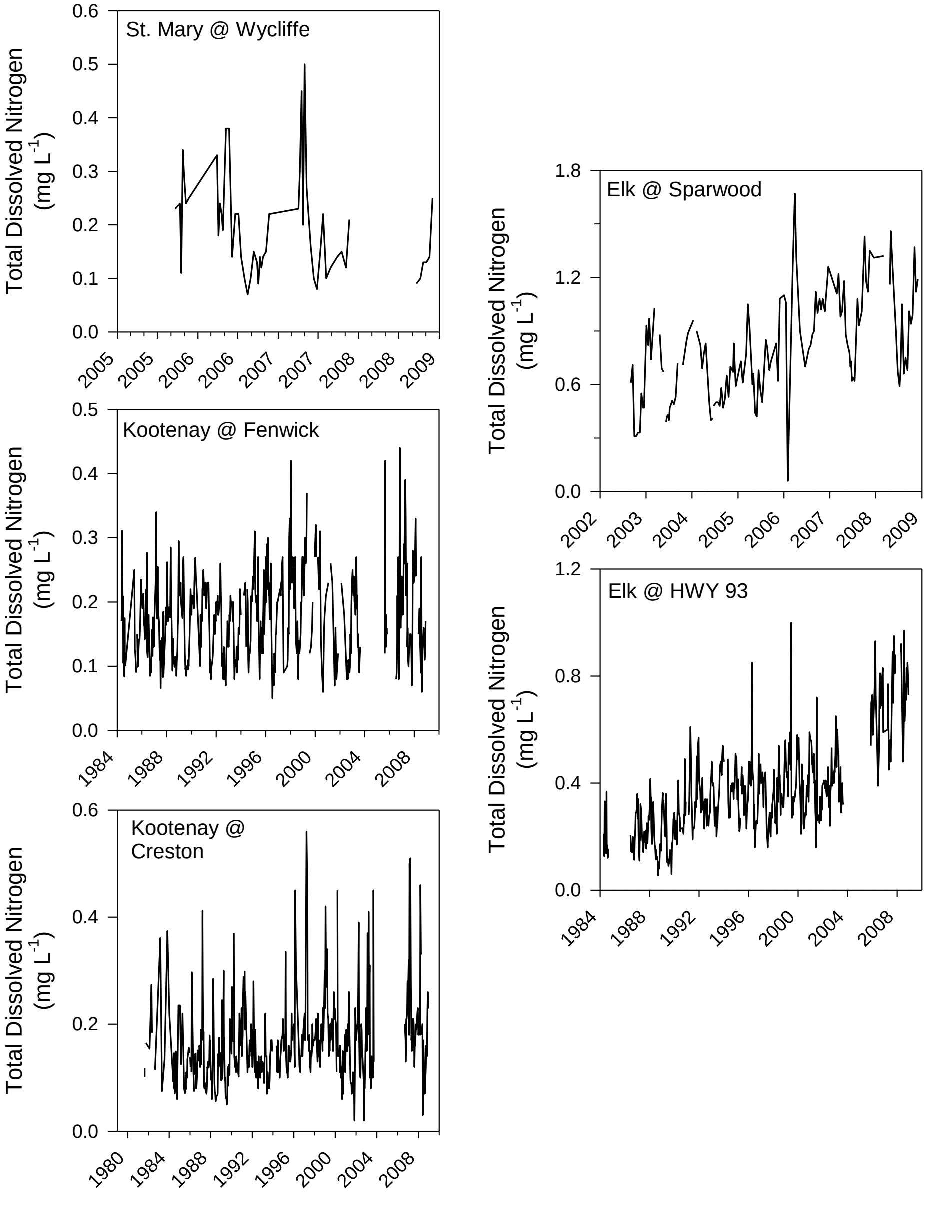
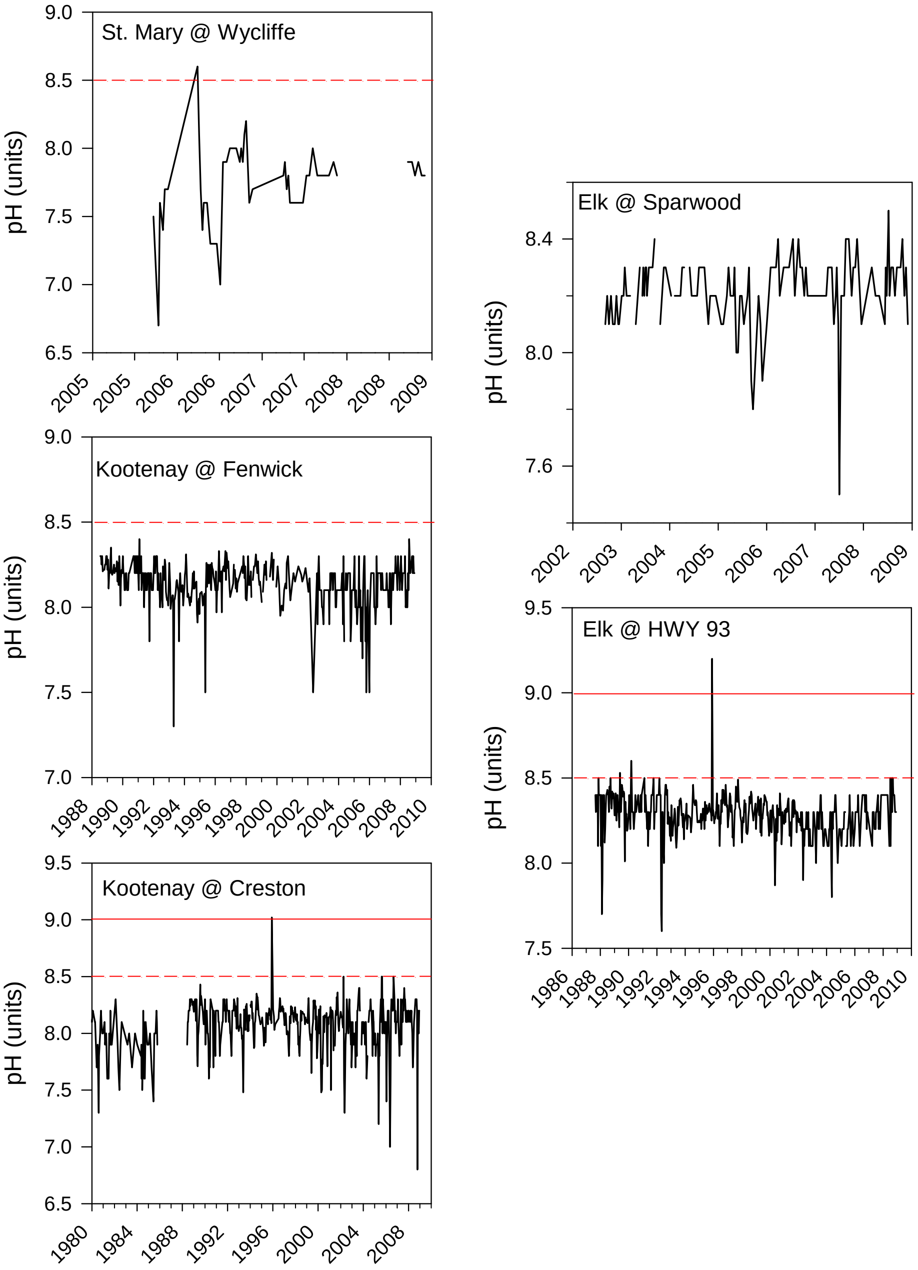


Figure 25: Total dissolved nitrogen concentrations over the sample period from surface water quality trend sites in the Kootenay watershed.



pH: pH is a measure of acidity and affects the availability and toxicity of a variety of toxicants in water. The pH of natural waters can vary greatly (Wetzel 2001), and aquatic life and drinking water guidelines are expressed as a range; the B.C. and CCME aquatic life guideline is 6.5≤pH ≥9.0 while the drinking water guidelines are 6.5≤pH ≥8.5. pH measurements in the Kootenay watershed were slightly basic (Figure 26). Measurements over the sample period rarely exceeded aquatic or drinking water guidelines except for one instance (drinking water) at the St. Mary River and once for the aquatic life guideline in the Elk River at Hwy 93 and the Kootenay River at Creston (Figure 26). The exceedence in the Elk and Kootenay rivers were likely a result of the same event since they both occurred in a 2-day timeframe (November 26-28th, 1995).

Figure 26: pH measurements over the sample period from surface water quality trend sites in the Kootenay watershed.



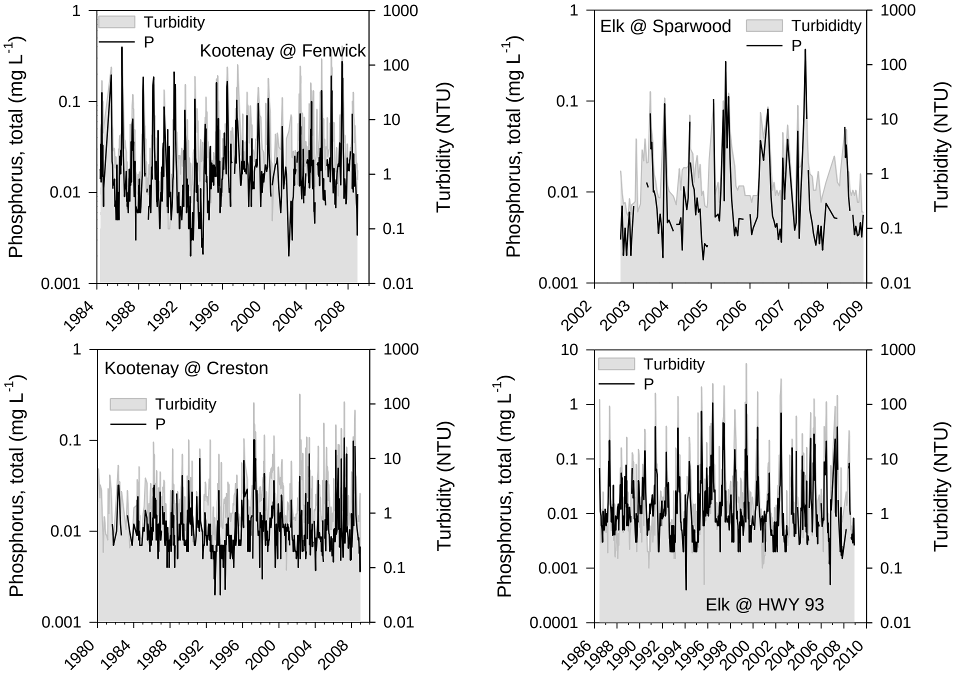
Note: Solid red line and dashed red line represent B.C. and CCME aquatic life and drinking water guidelines, respectively.

There were significant decreasing trends in pH at the Elk River at Hwy 93 and the Kootenay at Fenwick and Creston sites (Table 1). It is believed that these decreasing trends are a result of improving analytical techniques over the sample period, such as the switch to measurement of LIS-pH during the period of record; LIS-pH tends to produce lower pH values than the regular method. This has improved our ability to measure more accurate and meaningful pH concentrations, and likely does not reflect changes in the environment.

Phosphorus: Phosphorus is a major and often limiting macronutrient in aquatic systems. Total phosphorus was measured at sites along the Kootenay and Elk rivers (Figure 27). Median phosphorus concentrations ranged from 5 (Elk River at Sparwood) to 14 μg L^{-1} (Kootenay River at Fenwick) over the sample period, which suggests that these rivers are generally oligotrophic (Kalff 2002) and can only support low-levels of primary production.

Total phosphorus concentrations were more closely correlated with turbidity in the Elk River (r_s = 0.81 [Sparwood] and 0.78 [HWY 93]) than in the Kootenay mainstem (r_s = 0.64 [Fenwick] and 0.6 [Creston]), which could suggest that phosphorus concentrations in the Elk River are largely in particulate form compared to the Kootenay River. There was a significant increasing trend in total phosphorus in the Kootenay River at Fenwick over the sample period and in dissolved orthophosphate in the Kootenay River at Creston (Table 1).

Figure 27: Total phosphorus concentrations over the sample period from surface water quality trend sites in the Kootenay watershed.



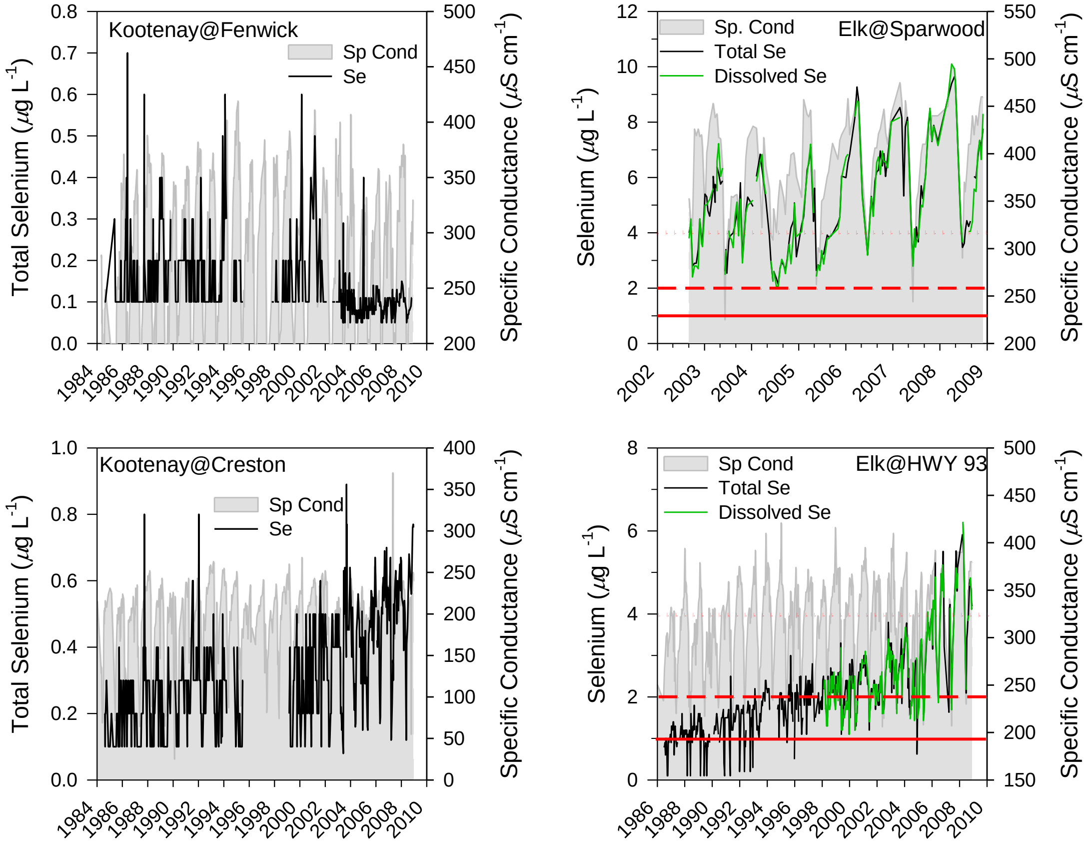
The combination of increasing phosphorus at the Kootenay River at Fenwick and nitrogen from the Elk River (Table 1; Figure 23; Figure 24; Figure 25) may result in enhanced phytoplankton growth and eutrophication in downstream lentic systems, in particular Lake Koocanusa. Although the trophic status of the total phosphorus at the Kootenay River at Fenwick is considered oligotrophic for lotic systems, it would be considered mesotrophic for lentic systems (Kalff 2002). It is unknown whether these increasing trends in P and N have had a long-term impact on Lake Koocanusa, but the changes in these two limiting macronutrient may be of future concern.

Selenium: The increase in selenium in the Elk River has been well documented (Harding *et al.* 2005; Swain 2005a; McDonald and Strosher 1998; BC Ministry of Environment, Lands and Parks and Environment Canada 2000) and is readily visible when examining time-series plots (Figure 28). Mann-Kendall trend analyses of total and dissolved selenium concentrations from the Elk River at Hwy 93 and of total selenium concentrations from the Kootenay River at Creston resulted in significantly increasing trends (Table 1). In fact, the rate of increase of selenium in the Elk River at Hwy 93 was estimated to be 0.56 and 0.59 μg L^{-1} per annum for total and dissolved selenium. Linear regression analysis of mean annual total selenium from the Elk River at Hwy 93 also resulted in a significant increasing trend ($p < 0.001$; Figure 29).

The increase in total selenium concentrations at the Kootenay River at Creston is of great concern (Figure 28) and was noticed in a previous assessment report (Swain 2007c). While considerably downstream of the Elk River, it appears as though this increase is a result of upstream coal mining activities, although the reach of the Kootenay (Kootenai) River which flows in the Unites States has not been assessed for potential sources of Se. Total selenium concentrations are increasing at a rate of 0.012 μg L^{-1} per annum. Although seemingly a small rate of increase, this rate is similar in proportion to the rate of increase in the Elk River when compared to their median total selenium concentrations over the same time period. Depending on the rate of increases estimated from the dataset, it is anticipated that selenium concentrations at the Kootenay River at Creston will consistently exceed CCME aquatic life guidelines within 15 to 32 years.

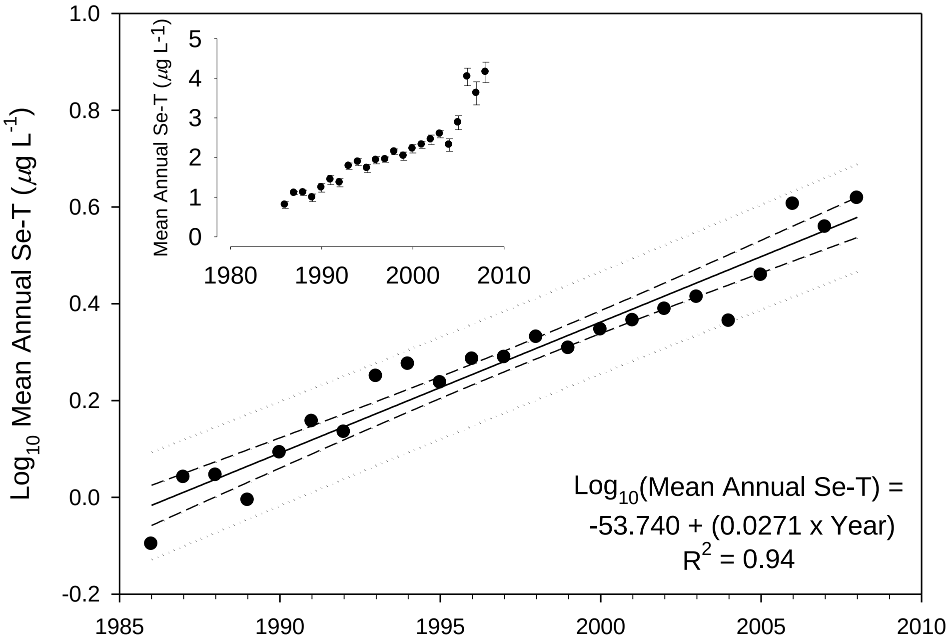
Total selenium concentrations in the Elk River have long exceeded CCME and BC MoE aquatic life guidelines, with concentrations at the Sparwood station generally ~ 2 to 4 μg L^{-1} greater than those at the Hwy 93 station. Dissolved selenium data suggest that total selenium measurements are nearly entirely in dissolved form (Figure 28), likely increasing its bioavailability. Yet despite this, there is little evidence to suggest that aquatic and terrestrial organisms are impacted by elevated selenium concentrations (Chapman *et al.* 2007; Harding *et al.*2005) in the Elk River. Nevertheless, the sustained increase in selenium concentrations in the Elk River continues to be a major water management issue made more complicated by increasing downstream trends.

Figure 28: Total and dissolved selenium concentrations over the sample period from surface water quality trend sites in the Kootenay watershed.



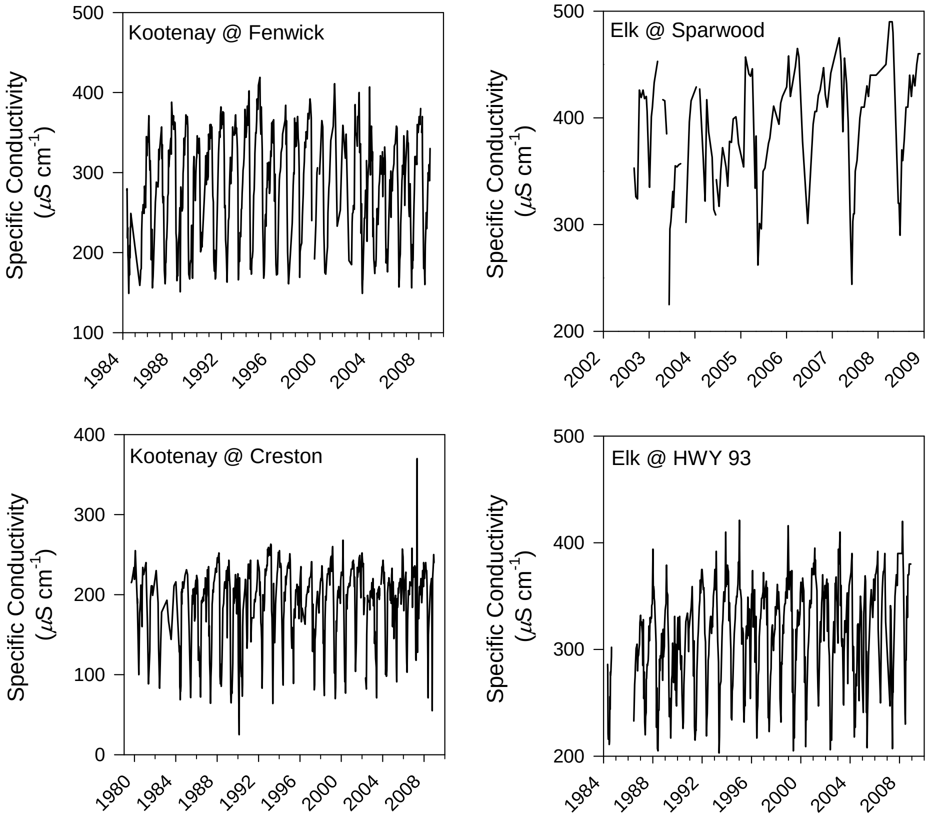
Note: the solid red line denotes the CCME aquatic life guideline, the red dashed line represents the B.C. mean aquatic life guideline and the dotted red line represents the B.C. mean wildlife guideline.

Figure 29: Linear regression of log10 mean annual total selenium concentrations over time from the Elk River at Hwy 93.



Specific Conductance: Specific conductance, or electrical conductance, measures the concentrations of salts, acids and bases in natural waters at a standard temperature (25°C). Specific conductance is often used as a surrogate for salinity and TDS (Kalff 2002), especially since it is easily measured. Specific conductance was measured in the Kootenay and Elk rivers (Figure 30). There are no approved water quality guidelines for specific conductivity. Specific conductance was significantly increasing in both the Elk River at Hwy 93 and the Kootenay River at Creston (Table 1). These increasing trends in specific conductivity were a result of trends in other ions and dissolved constituents at these sites.

Figure 30: Specific conductivity measurements over the sample period from surface water quality trend sites in the Kootenay watershed.



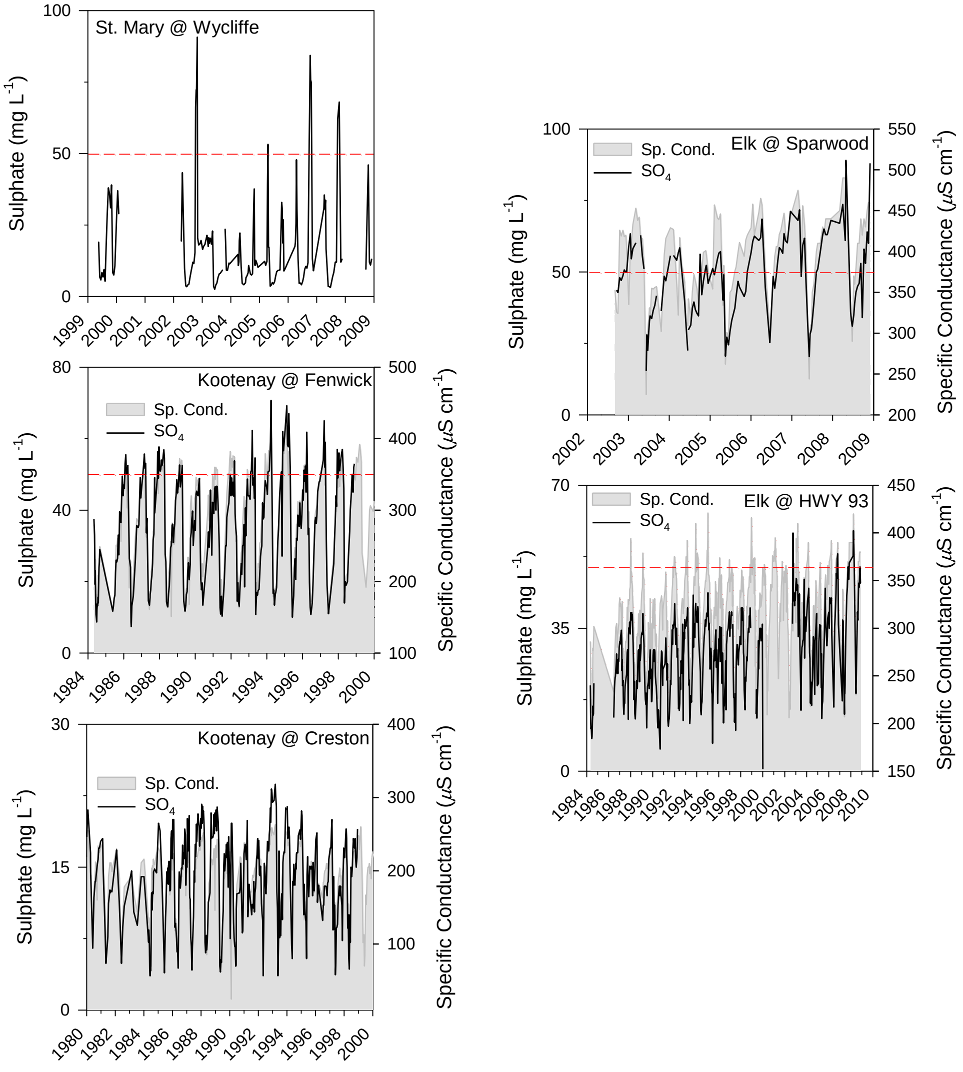
Sulphate: Sulphate is widely distributed in natural waters and ranges in concentration from a few to many thousand mg L^{-1} (Eaton *et al.* 2005). Sulphate was measured at all trend sites in the Kootenay watershed, although only until 2000 in the Kootenay River (Figure 31). B.C. aquatic life guidelines are established for sulphate at 100 mg L^{-1}; an alert level to monitor the health of aquatic mosses in a system is also set at 50 mg L^{-1}

There was an increasing trend in sulphate at the Elk River at Hwy 93 over the sample period (Table 1) at an estimated rate of near half a milligram per litre, and although sulphate concentrations at the Elk River at Sparwood was not tested for trends, visual examination of the time-series plot suggests an increase at this site (Figure 31). This trend in sulphate in the Elk

River was likely a result of upstream coal mining, with sulphur being associated with coal in the Elk River Valley (Lussier *et al.* 2003).

There was an increasing trend in sulphate at the Kootenay River at Fenwick over the sample period ending in 1999, and specific reasons for this are not known. Seasonal low water peaks in sulphate often exceeded the alert level for aquatic moss monitoring.

Figure 31: Sulphate concentrations over the sample period from surface water quality trend sites in the Kootenay watershed.

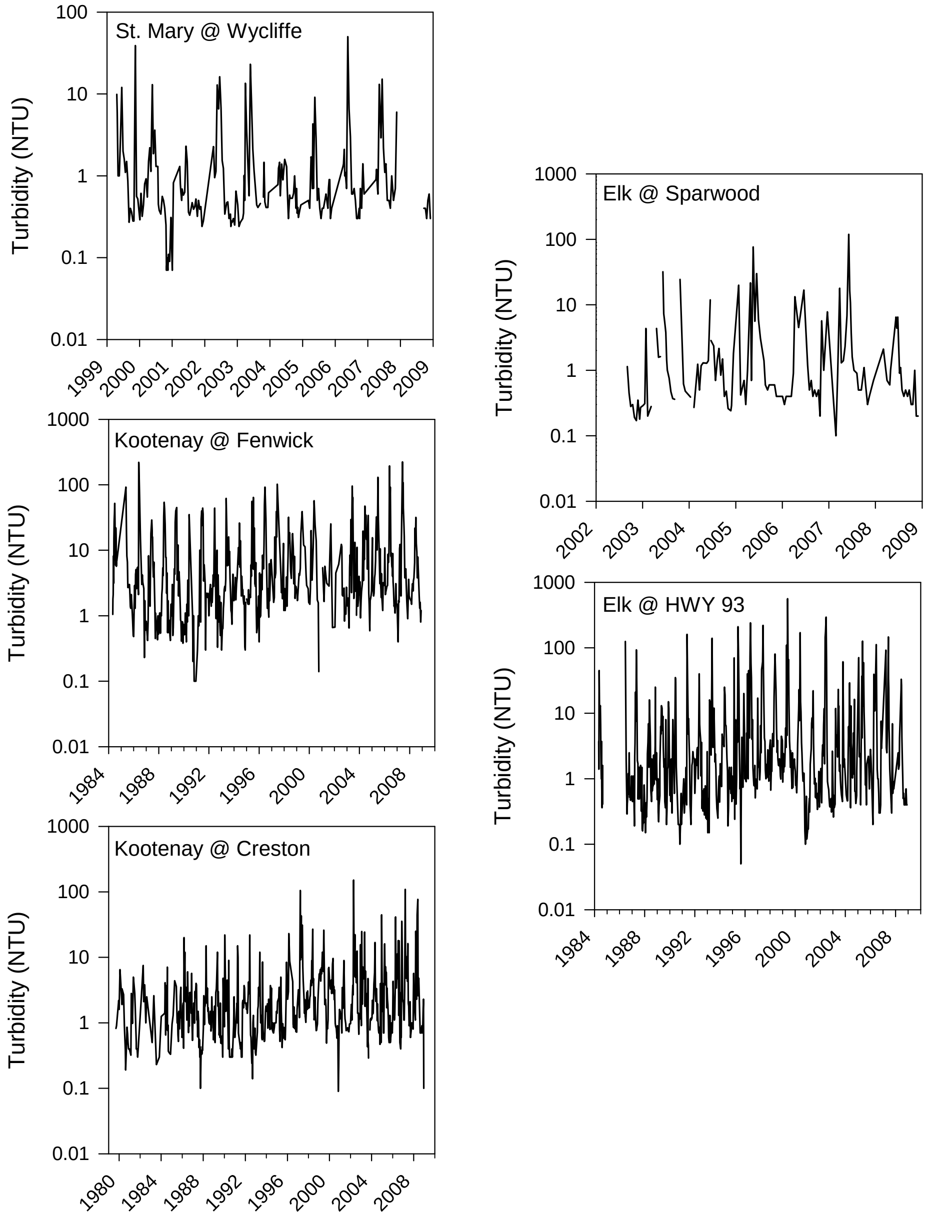


Note: Dashed red line denotes B.C. aquatic life alert guideline to monitor the health of aquatic mosses.

Sulphate should continue to be monitored in the Elk River since concentrations are approaching or exceeding alert levels (Figure 31), and sulphate should be added to the Kootenay River sites to determine if there are increases at these sites. Although sulphate concentrations in the St. Mary River seasonally exceed alert levels (Figure 31), base concentrations remain quite low and there was no significant trend over time.

Turbidity: Turbidity measures light scatter in water and is caused by suspended and colloidal matter including silt, clay, organic and inorganic matter and microscopic organisms such as phytoplankton (Eaton *et al.* 2005). Thus, turbidity is often closely associated with suspended sediment and seasonally increases with spring freshet and run-off since it is usually consists of soil erosion in catchment basins (Wetzel 2001). Due to turbidity's close relationship with suspended sediment, it is often closely related with total measurements of metals and nutrients associated with those sediments.

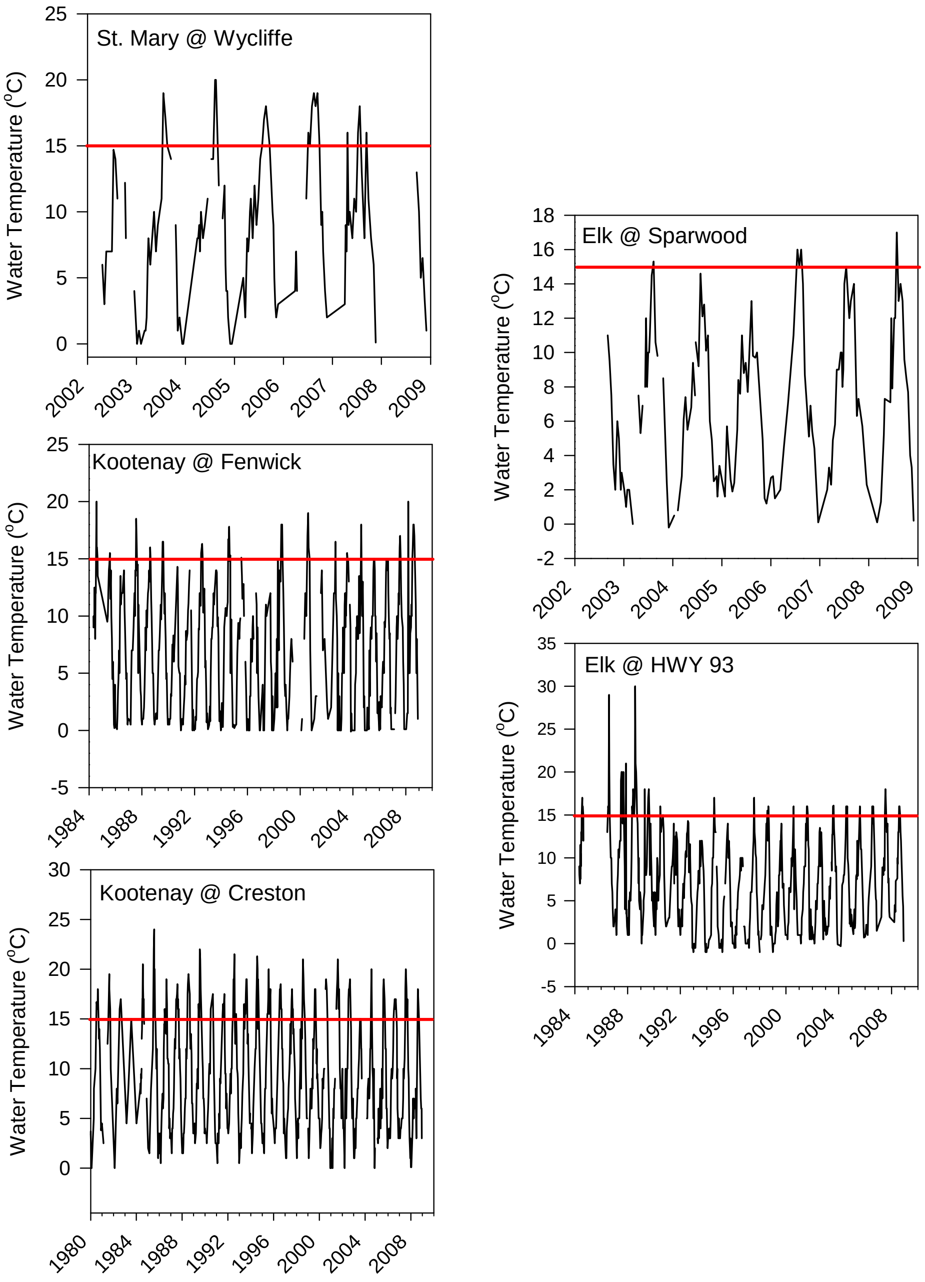
Figure 32: Turbidity measurements over the sample period from surface water quality trend sites in the Kootenay watershed.



Turbidity was measured at all trend sites in the Kootenay watershed (Figure 32). Significant increasing trends were observed at the Kootenay River at Fenwick and Creston, and the Elk River at Hwy 93 (Table 1). These trends were likely due to upstream land-uses including deforestation and agriculture. These trends are important since turbidity effects the concentration and trends related to total metals and nutrients which are associated with suspended particulate.

Current B.C. water quality guidelines are dependent upon background or upstream comparisons. Based on the distance on context of each site, relevant upstream sites for comparative purposes are not available for guideline comparisons. Nevertheless, turbidity should be continued to be monitored along with total suspended sediments (TSS) due to their impact on numerous water quality parameters, as well as aquatic life.

Figure 33: Water temperature measurements over the sample period from surface water quality trend sites in the Kootenay watershed.



Note: B.C. daily maximum guideline for waterbodies with dolly varden or bull trout.

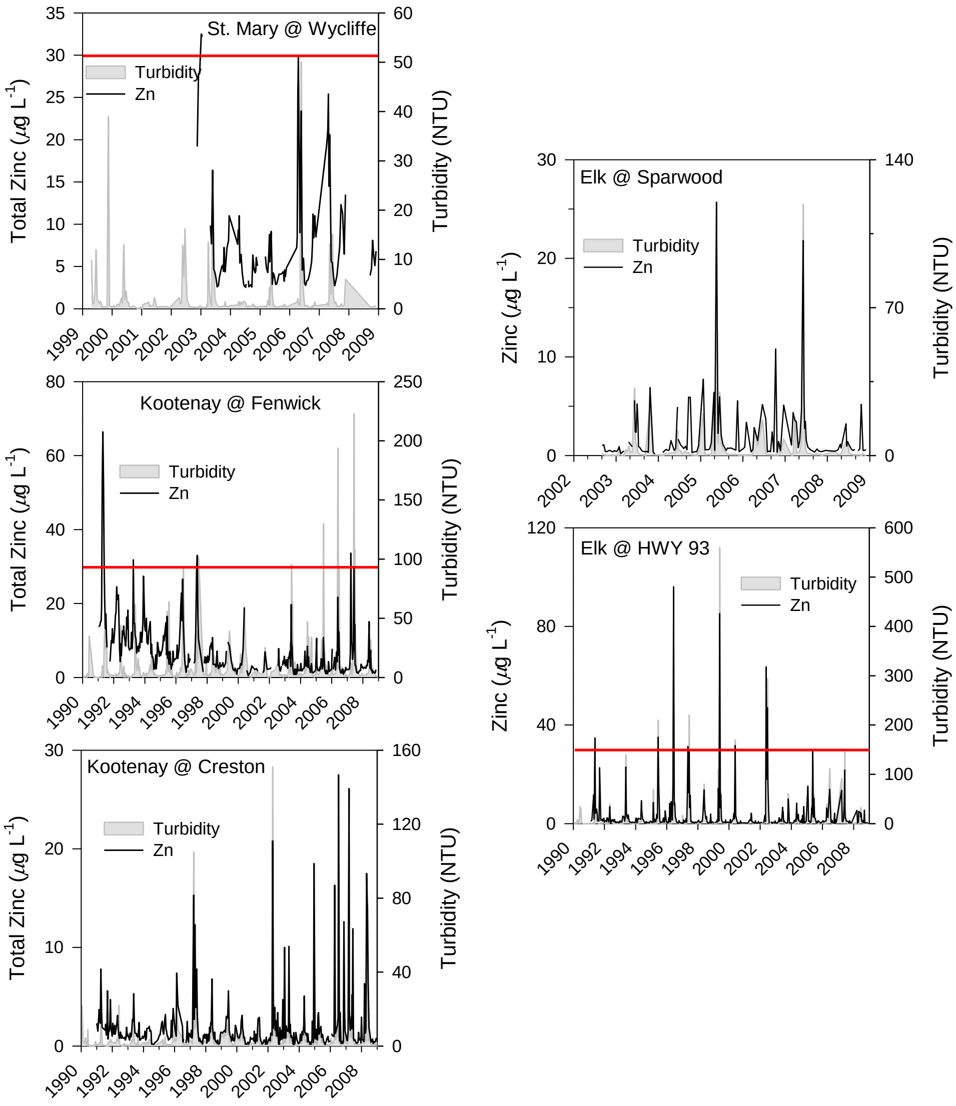
Water Temperature: Water temperature is measured in the field when grab samples are taken. Water temperature can impact aquatic biota and the toxicity of some chemical parameters, specifically ammonia. The B.C. drinking water and aquatic life guideline (daily maximum for waterways with dolly varden or bull trout) is 15°C. This guideline was often seasonally exceeded at all sites to some extent (Figure 33). Summer maxima in the Elk River typically exceeded the temperature guideline for a short duration and by a few degrees. Summer maxima in the St. Mary and Kootenay River sites tended to exceed the guideline by up to 5 degrees or more (Figure 33). Although the guideline was often exceeded in the Kootenay and St. Mary rivers, the danger to aquatic organisms will depend on their sensitivity to temperature changes and availability of refugia.

Based on the dataset, these exceedences appear natural, although the intensity and duration of these exceedences might increase over time. Continuous temperature loggers have been installed at Kootenay and Elk River sites to gather hourly surface water temperature data. This will allow for intensity/duration examination of exceedences and more accurate temperature measurements.

Zinc: Zinc is a micronutrient used for a variety of cellular functions and metabolic functions (Wetzel 2001). Total zinc was measured at all trend sites in the Kootenay watershed (Figure 34). Zinc concentrations fluctuated with turbidity with seasonal maxima occurring during freshet. The CCME aquatic life guideline for zinc is 30 μg L^{-1}, while the B.C. maximum aquatic life guideline is derived from a hardness-dependent equation with minimum of 33 μg L^{-1}. Total zinc periodically exceeded these guidelines in the Elk and Kootenay rivers, but these exceedences were associated with turbidity spikes and not likely bioavailable. Significant decreasing trends in total zinc occurred over the sample period at the Kootenay at Creston and the Elk River at Hwy 93 (Table 1). Specific reasons for this decline are not evident, although it may be possible that improving laboratory techniques have enhanced our ability to accurately estimate zinc concentrations and have reduced variability, thus leading to decreasing trends as an artefact.

Total zinc concentrations in the St. Mary's River are very weakly associated with turbidity, suggesting that a larger proportion of zinc is in the dissolved form and not associated with particulate matter. Dissolved zinc in addition to total zinc should be measured at this site.

Figure 34: Total and dissolved zinc concentrations over the sample period from surface water quality trend sites in the Kootenay watershed.



Note: Red line denotes CCME aquatic life guideline for total Zn.

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