CANADA-BRITISH COLUMBIA WATER QUALITY MONITORING AGREEMENT

WATER QUALITY ASSESSMENT OF THE KETTLE RIVER AT MIDWAY AND CARSON, BRITISH COLUMBIA (1990 – 2007)

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EXECUTIVE SUMMARY

This report assesses 18 years of data from two sites along the Kettle River at Midway and at Carson in south-central British Columbia (Figure 1). The Kettle River is a trans-boundary waterway with various water uses including municipal water works, domestic uses, aquatic life and irrigation. The Kettle River at Midway was established in 1972 and the Kettle River at Carson was established in 1980, and both sites are currently sampled bi-weekly. Watershed activities which may impact water quality include agriculture, mining, treated wastewater discharge, and forestry. The Kettle River at Midway is co-located with a Water Survey of Canada hydrometric station.

CONCLUSIONS

- Water quality at both sites is very similar and generally good.
- Analytes measured as total concentrations are often influenced by seasonal changes in river flow and turbidity.
- Dissolved chloride, fecal coliforms, total hardness, total molybdenum, total phosphorus, turbidity and dissolved fluoride had significant increasing trends at one or both water quality monitoring sites on the Kettle River.
- Total aluminum, total chromium, colour, total copper, flow, extractable gallium, total iron, extractable lanthanum, total lead, total lithium, total nickel, specific conductivity, total zinc, extractable potassium and total manganese had significant decreasing trends at one or both water quality monitoring sites on the Kettle River.
- Seasonal depressions in alkalinity suggest that the Kettle River is moderately sensitive to acid inputs.
- Colour seasonally exceeds the B.C. aesthetic objective for drinking water during high flows (freshet).
- Dissolved fluoride often exceeds the B.C. aquatic life guideline.

- A variety of total metal concentrations exceed guidelines seasonally but these exceedences are strongly correlated with turbidity and thus, likely bound to particulate matter and not bioavailable. These include the following:
  - Total aluminum concentrations exceeded the guidelines at times when turbidity was high. The guidelines are expressed as dissolved concentrations of the metal and so direct comparison will over estimate the number of values that exceed the guideline.
  - Total cadmium concentrations are currently near or at laboratory detection limits, and laboratory detection limits are near the B.C. working aquatic life guidelines. Detection limits should be five to ten times lower than the guideline level.
  - Total chromium concentrations seasonally exceed guidelines established for Cr (VI).
  - Total iron concentrations exceeded the B.C. aquatic life guidelines at times when turbidity was high.
- Turbidity had a statistically significant increasing trend over the sample period. Turbidity is generally correlated with total metals and nutrients and may result in increasing trends and concentrations in parameters related to suspended solids (i.e. total metals).
- Summer peak water temperature values exceed B.C. aquatic life and drinking water guidelines.
- A number of metals need to be measured differently if comparisons are to be made to guideline values as these exist. The metals and forms required to be measured are aluminum (dissolved and inorganic monomeric, when available), chromium (trivalent and hexavalent), and iron (continue to measure total but also dissolved).
- Since various total metal and nutrient concentrations in the Kettle River vary greatly due to freshet, it would be beneficial to measure dissolved metals in addition to total metals for guideline comparison.

- Both sites should be sampled on the same day so that direct comparisons can be made between sites and against guidelines which require an upstream comparison.

RECOMMENDATIONS

It is recommended that monitoring continue at both sites along the Kettle River for the following reasons: to assess the impact of various land uses in the Kettle River basin; to assess the Kettle River as source of drinking and irrigation water; and to monitor trans-boundary effects on between British Columbia and Washington State.

ACKNOWLEDGEMENTS

The data was reviewed by Ayisha Yeow and Shale Irwin, and a map of the Kettle River Basin was created by Jennifer MacDonald of Environment Canada. This report was reviewed by Les Swain of Tri-Star Environmental, Andrea Ryan of Environment Canada and Vic Jensen 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.

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INTRODUCTION

The Kettle River is located in the south-central portion of B.C. The Kettle River drains the Monashee Mountains and the Okanagan Highlands. There are two Federal-Provincial water quality stations on the Kettle River – the Kettle River at Midway and Carson. Both are long-term trend sites which monitor water entering and returning from Washington State, respectively as the river meanders across the border (Figure 1). Both sites are currently sampled bi-weekly.

The Kettle River at Midway is located at the town of Midway, B.C., before the Kettle River crosses Canada-U.S.A. border (Figure 1). This site has been monitored by Environment Canada since 1972 and data are stored in the federal (station number BC08NN0011) and provincial (station number 0920673) databases. This site monitors a drainage area of 5750 km^2 (Environment Canada 2007). This site is collocated with a Water Survey of Canada hydrometric station to measure flow or discharge (Environment Canada station number BC08NN013; Kettle River at Ferry). Flow is discussed below in the assessment portion of this report.

The Kettle River at Carson is located upstream from Grand Forks, B.C. where the Kettle River crosses the border from Washington State back into B.C. (Figure 1). The Kettle River at Carson monitors an additional 980 km^2 drainage area, with a total drainage area of 6730 km^2. This site was established in by Environment Canada in 1980 and data are stored in the federal (station number BC08NN0011) and provincial (station number 0920673) databases (BWP Consulting 2003a).

Other related but deactivated monitoring stations include the Kettle River at Gilpin which was downstream of Grand Forks, and Boundary Creek at Midway, a Kettle River tributary near the village of Midway.

Activities in the watershed upstream of Midway consist of dispersed human settlement, Big White ski hill, agriculture, forestry and mineral exploration. The Kettle River between the

Midway and Carson sites passes almost entirely within Washington State. Upstream impacts include forestry, mining, treated municipal wastewater from the village of Midway, and agriculture. There are numerous licensed water withdrawals from the Kettle River for agricultural, industrial and municipal domestic uses, including the municipal waterworks for Grand Forks.

This report assesses 18 years of data from 1990 through 2007 and compares measured parameters against relevant guidelines including aquatic life, drinking water and irrigation guidelines.

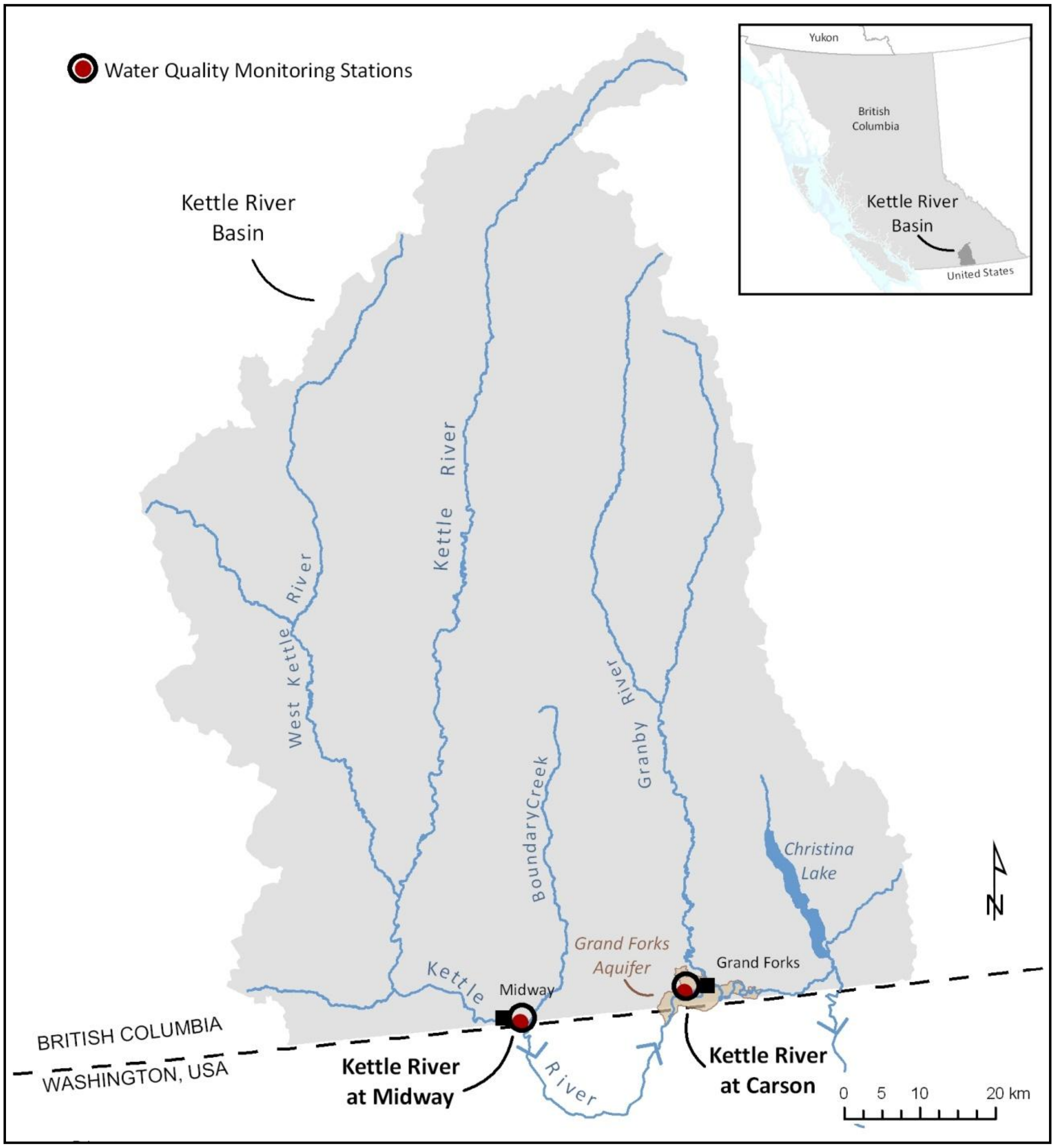


Figure 1: Map of the Kettle River.

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 to assess precision. The water quality results were reviewed in advance of this report and questionable or erroneous values were removed from the dataset. Total dissolved nitrogen results were known to be contaminated from filters used in analyses between 2003 and 2005 and thus, this parameter was not assessed for trends in this report.

STATISTICS

Non-parametric statistical tests were used since most water quality parameters are not normally distributed. Time series trend analyses were conducted using the Mann-Kendall trend (MK) and the Seasonal Kendall trend tests (SK). Sen's slope estimate was used to approximate change over time.

The MK test is used to determine significant changes over time, but it cannot account for seasonal changes in a parameter, such as changing concentrations due to freshet events. To account for seasonality in the results, the SK trend test is used. Here, the data is grouped seasonally and the MK test is computed on each individual season (Helsel and Hirsh 2001). Seasonality was defined using parameters which greatly influence water quality, in this case, turbidity. Spearman Rank Correlation was used to determine parameters that can be defined by turbidity seasonality, and then tested using the Kruskal-Wallis test. Parameters which had significant seasonal differences were further test for trends using the SK trend test.

Mann-Kendall and Seasonal Kendal trend tests were also flow-adjusted for the Kettle River at Midway only, when tested parameters were highly correlated with flow. For example, major ions are often diluted during high flows (freshet) and concentrated during base flows when groundwater inputs provide the main source of flow and thus, they are often negatively correlated with flow. Flow adjustments were conducting using WQStat Plus™. This program assumes a log-linear relationships between discharge (flow) and related parameters, and linear regressions are conducted to model the effect of flow on test parameters. Residuals from these linear regressions were subsequently tested for trends using the MK and SK test.

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 Criteria 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). No site-specific water quality objectives have been developed for the Kettle River. Substances not discussed below met or rarely exceeded guidelines and displayed no significant trends during the sample period and include the following: antimony, arsenic, barium, beryllium, bismuth, boron, dissolved bromide, dissolved organic carbon, total organic carbon, cobalt, cyanide, gallium, nitrate, pH, TDS, extractable rubidium, selenium, dissolved silica, silver, sodium, strontium, dissolved sulphate, thallium, tin, extractable uranium and vanadium.

Parameters with significant increasing or decreasing trends are outlined below and summarized in Table 1 for Midway and Table 2 for Carson. Parameters which exceeded guidelines are described below.

Table 1: Mann-Kendall and Seasonal Kendall results with Sen's Slope Estimation for parameters with statistically significant trends from the Kettle River at Midway.

Parameter	Mann Kendall		Seasonal Kendall	
	P-value	Slope (units a^{-1})	*P*-value	Slope (units a^{-1})
Aluminum, total ($\mu g\ L^{-1}$)	<0.01†	-1.716	<0.05†	-1.653
Chloride, dissolved ($mg\ L^{-1}$)	<0.01†	0.058	na	na
Chromium, total ($\mu g\ L^{-1}$)	<0.01†	-0.006	<0.05†	-0.005
Colour (Units)	<0.05†	-0.17	<0.01	-0.07
Copper, total ($\mu g\ L^{-1}$)	<0.01†	-0.011	<0.05†	-0.008
Fecal Coliforms (CFU $100ml^{-1}$)	<0.01	1.011	<0.01	0.859
Flow ($m^3\ s^{-1}$)	ns	na	<0.01	-0.209
Fluoride, dissolved ($mg\ L^{-1}$)	ns	na	<0.01	0.058
Hardness, total ($mg\ L^{-1}$)	ns	na	<0.05	0.058
Iron, total ($\mu g\ L^{-1}$)	<0.01†	-1.534	<0.05†	-1.325
Lanthanum, ext ($\mu g\ L^{-1}$)	<0.05	-0.004	<0.05	-0.002
Lead, total ($\mu g\ L^{-1}$)*	<0.01†	-0.008	<0.05†	-0.008
Lithium, total ($\mu g\ L^{-1}$)	<0.01†	-0.029	<0.05†	-0.029
Molybdenum, total ($\mu g\ L^{-1}$)	<0.05	0.014	<0.01	0.014
Nickel, total ($\mu g\ L^{-1}$)*	<0.01†	-0.003	<0.05†	-0.002
Phosphorus, total ($mg\ L^{-1}$)	<0.01†	0.001	<0.05†	0.002
Specific Conductivity ($\mu S\ cm^{-1}$)	<0.01†	-0.92	<0.05†	-1.058
Turbidity (NTU)	<0.01†	0.018	<0.05†	0.02
Zinc, total ($\mu g\ L^{-1}$)*	<0.01†	-0.017	<0.05†	-0.014

*Decrease likely due to changing MDLs
†Flow-adjusted
ns, non-significant
na, not applicable

Table 2: Mann-Kendall and Seasonal Kendall results with Sen's Slope Estimation for parameters with statistically significant trends from the Kettle River at Carson.

Parameter	Mann Kendall		Seasonal Kendall	
	P-value	Slope (units a^{-1})	*P*-value	Slope (units a^{-1})
Aluminum, total (μg L^{-1})	<0.01	-2.271	<0.01	-1.892
Chromium, total (μg L^{-1})*	<0.01	-0.009	<0.01	-0.006
Colour (Units)	na	na	<0.01	-0.52
Copper, total (μg L^{-1})	<0.01	-0.04	<0.01	-0.038
Fluoride, dissolved (mg L^{-1})	ns	ns	<0.01	0.003
Iron, total (μg L^{-1})	<0.01	-2.819	<0.01	-2.32
Lanthanum, ext. (μg L^{-1})	<0.01	-0.004	<0.01	-0.002
Lithium, total(μg L^{-1})	<0.01	-0.043	<0.01	-0.051
Manganese, total (μg L^{-1})	<0.01	0.116	ns	na
Magnesium, extractable (μg L^{-1})	<0.01	-0.133	<0.01	-0.108
Molybdenum, total (μg L^{-1})	0.01	0.012	<0.01	0.014
Nickel, total (μg L^{-1})*	<0.01	-0.006	<0.01	-0.006
Phosphorus, total (mg L^{-1})	<0.01	0.002	ns	na
Potassium, extractable (mg L^{-1})	0.04	0.007	<0.01	-0.08
Zinc, total (μg L^{-1})*	<0.01	-0.066	<0.01	-0.062

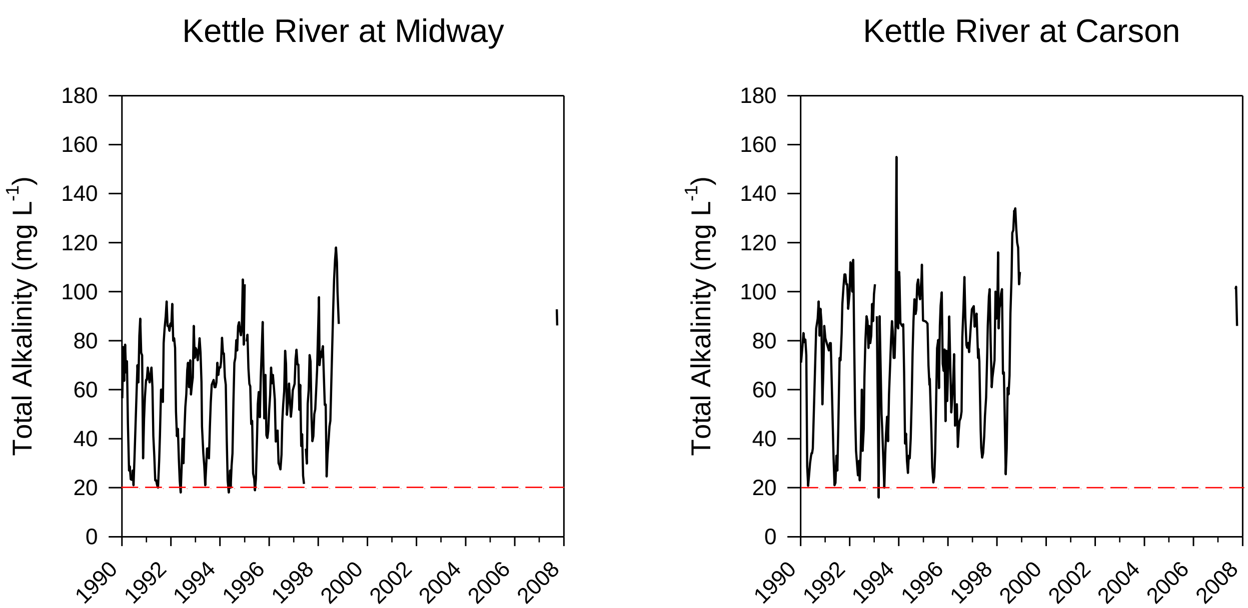
*Decrease likely due to changing MDLs

ns, non-significant

na, not applicable

Alkalinity: Alkalinity was measured at both sites until 1999 and again starting 2007. Alkalinity varies seasonally with flow (Spearman Correlation, r_s = -0.53). Both sites along the Kettle River exhibit similar seasonal patterns, although concentrations tend to be higher at the downstream sampling site at Carson. Flow-driven depressions in the concentration of alkalinity often approach or are below 20 mg L^{-1} (Figure 2), suggesting that Kettle River is moderately sensitive to acid inputs during these time periods.

Figure 2: Alkalinity measurements sampled from the Kettle River at Midway (left) and Carson (right) from 1990 to 2008.

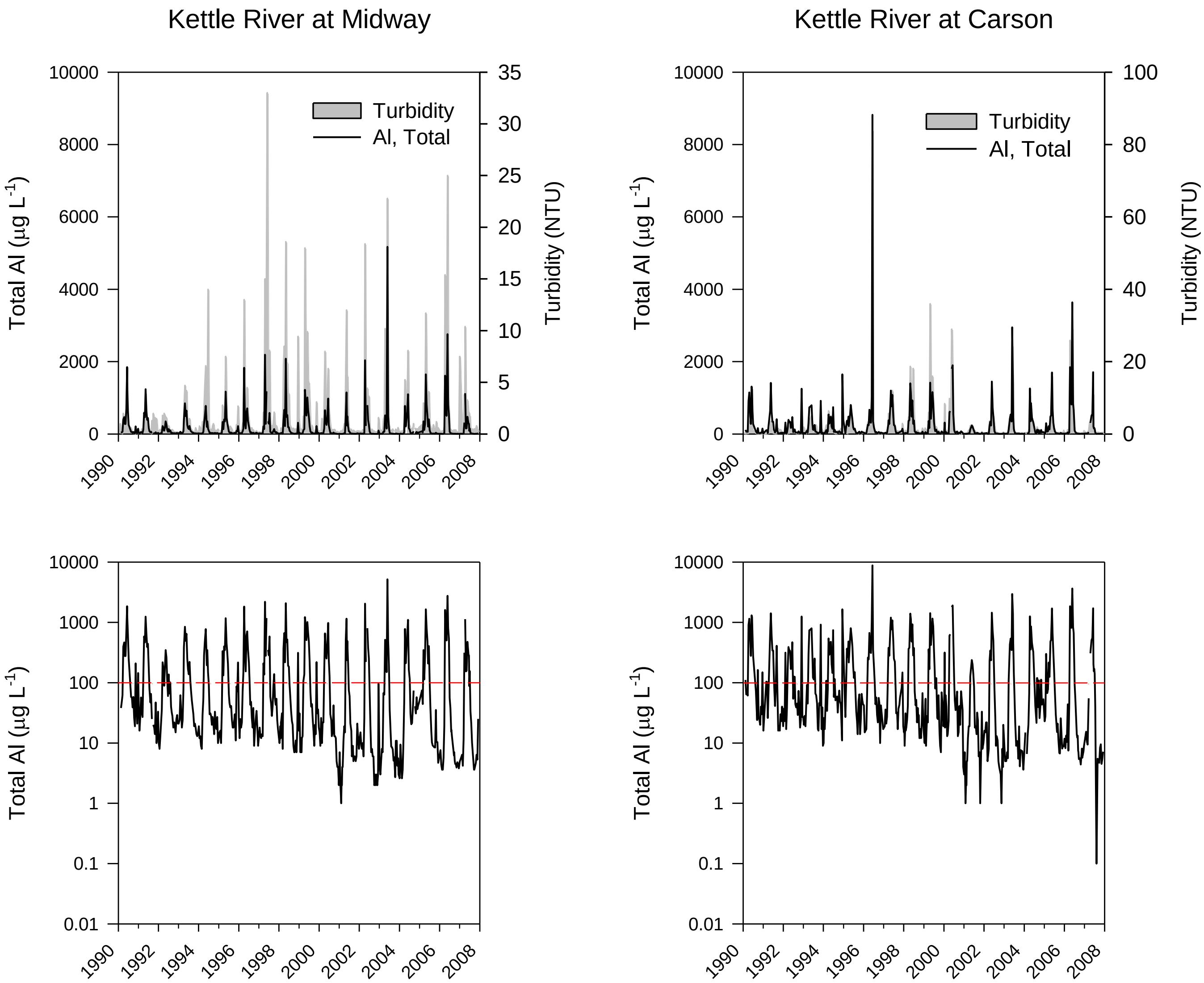


Note: Dashed red line denotes the B.C. working aquatic life guideline for waterbodies with moderate sensitivity to acid inputs.

Aluminum: Aluminum concentrations in the Kettle River vary seasonally and are strongly correlated with turbidity (Midway, Spearman Correlation, $r_s = 0.73$; Carson, Spearman Correlation, $r_s = 0.74$; Figure 3). Total aluminum concentrations significantly decreased at the Kettle River at Midway (MK test, $p < 0.01$, slope = -1.716 μg L^{-1} a^{-1}; SK test, $p < 0.05$, slope = -1.653 μg L^{-1} a^{-1}; Table 1) and the Kettle River at Carson (MK test, $p < 0.01$, slope = -2.271 μg L^{-1} a^{-1}; SK test, $p < 0.01$, slope = -1.892 μg L^{-1} a^{-1}; Table 2) over the sample period. Total aluminum concentrations at both sites are very similar and exceed the established B.C. maximum guidelines for dissolved aluminum for aquatic life and drinking water of 100 μg L^{-1} and 200 μg L^{-1}, respectively at some times during the year. This means that at times when the total concentration is less than the guideline, so too will be the dissolved fraction and so there will be no concern. The only time when there may be a concern is when total concentrations exceed the guideline – at those times the dissolved fraction <u>may</u> also exceed the guideline. However, since these seasonal spikes are highly correlated with turbidity, they are likely bound with particulate matter and not biologically available.

In order to make direct comparison to guidelines, aluminum should be measured as the dissolved fraction. Also, the CCME (2005 draft) are considering revising the aluminum guideline to protect aquatic life to the inorganic monomeric form; however, at present, few laboratories have the capability to measure this form.

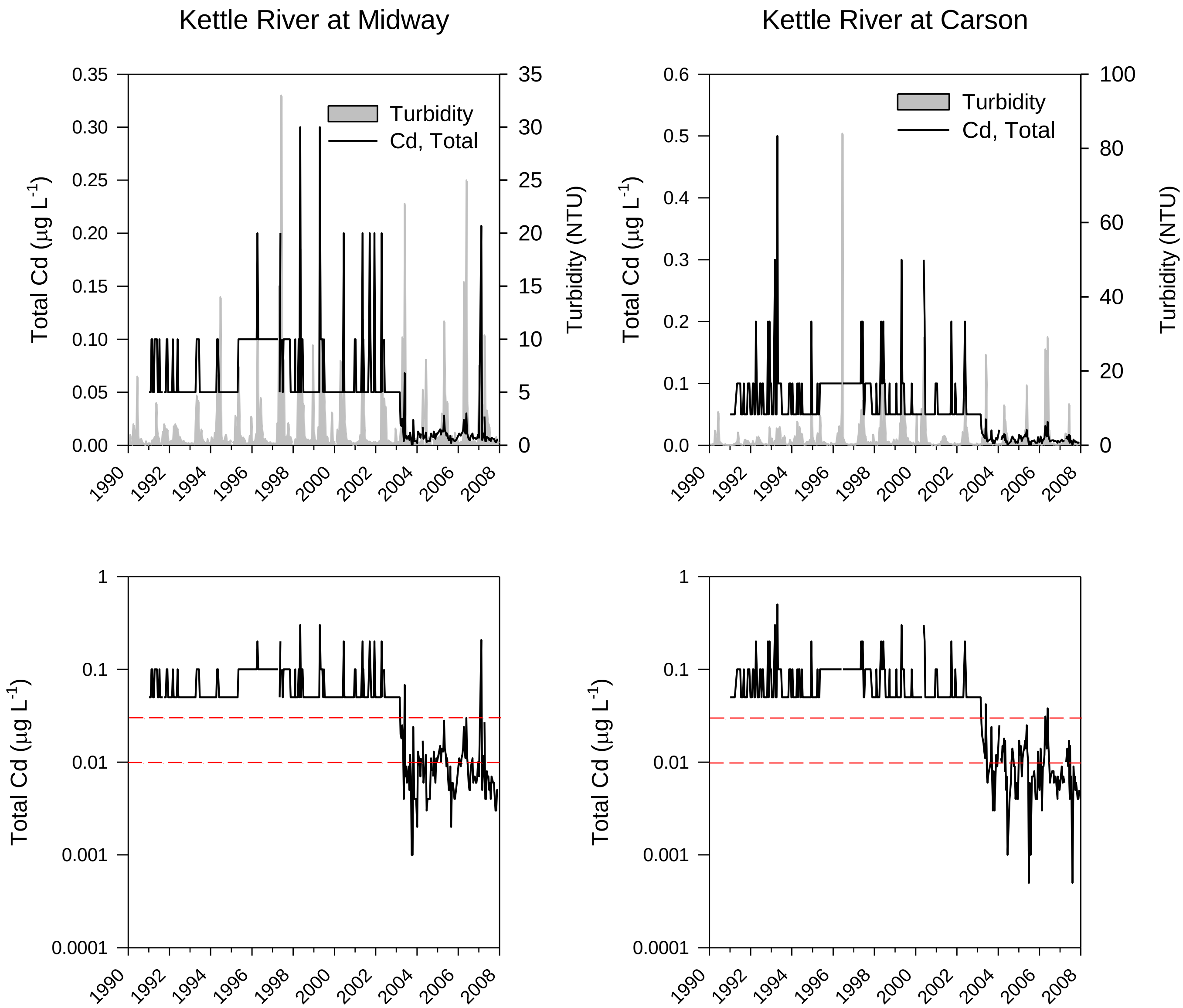
Figure 3: Total aluminum and turbidity measurements from the Kettle River at Midway (left) and Carson (right) from 1990 to 2008.



Note: Dashed red line denotes the B.C. aquatic life guideline for dissolved aluminum.

Cadmium: Total cadmium concentrations have been decreasing due to improving (lowering) detection methods and are at or below guidelines at both sites (Figure 4). Since cadmium is often near the analytical detection limit, and guidelines fluctuate with total hardness, and it is difficult to compare low-level cadmium concentrations with the guidelines. The hardness-dependent working aquatic life guidelines varied between 0.01 and 0.05 μg L^{-1} over the sample period.

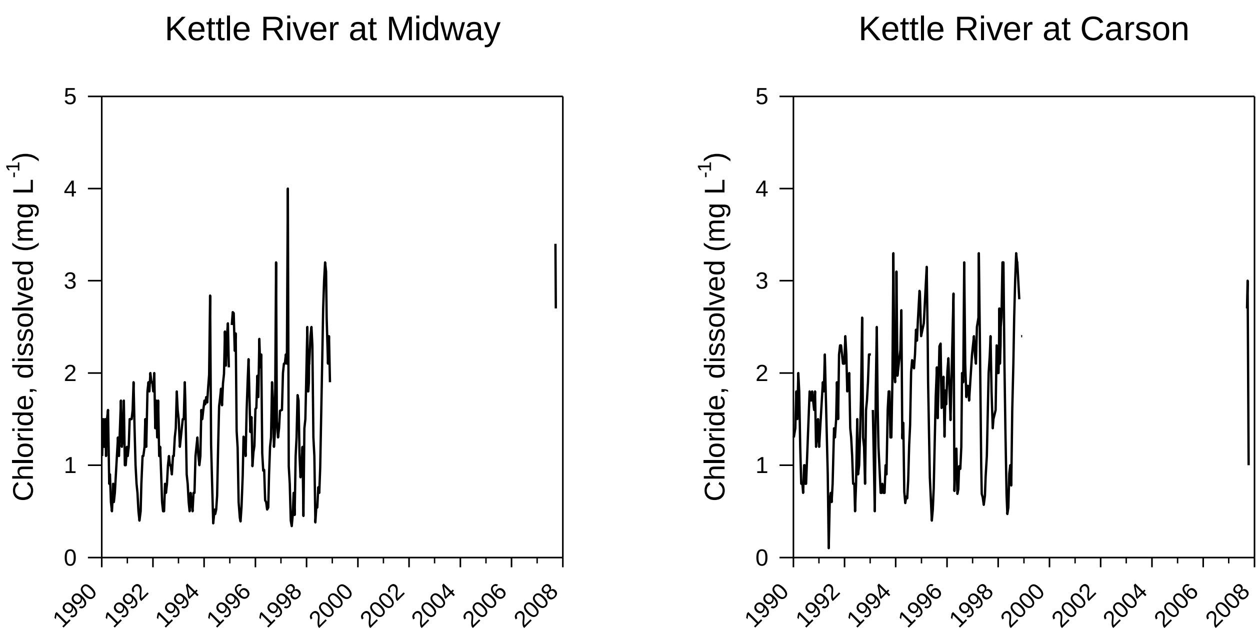
Figure 4: Total cadmium and turbidity measurements from the Kettle River at Midway (left) and Carson (right) from 1990 to 2008.



Note: Dashed red lines denote the lower and upper thresholds for the hardness-dependent B.C. aquatic life guideline for total cadmium.

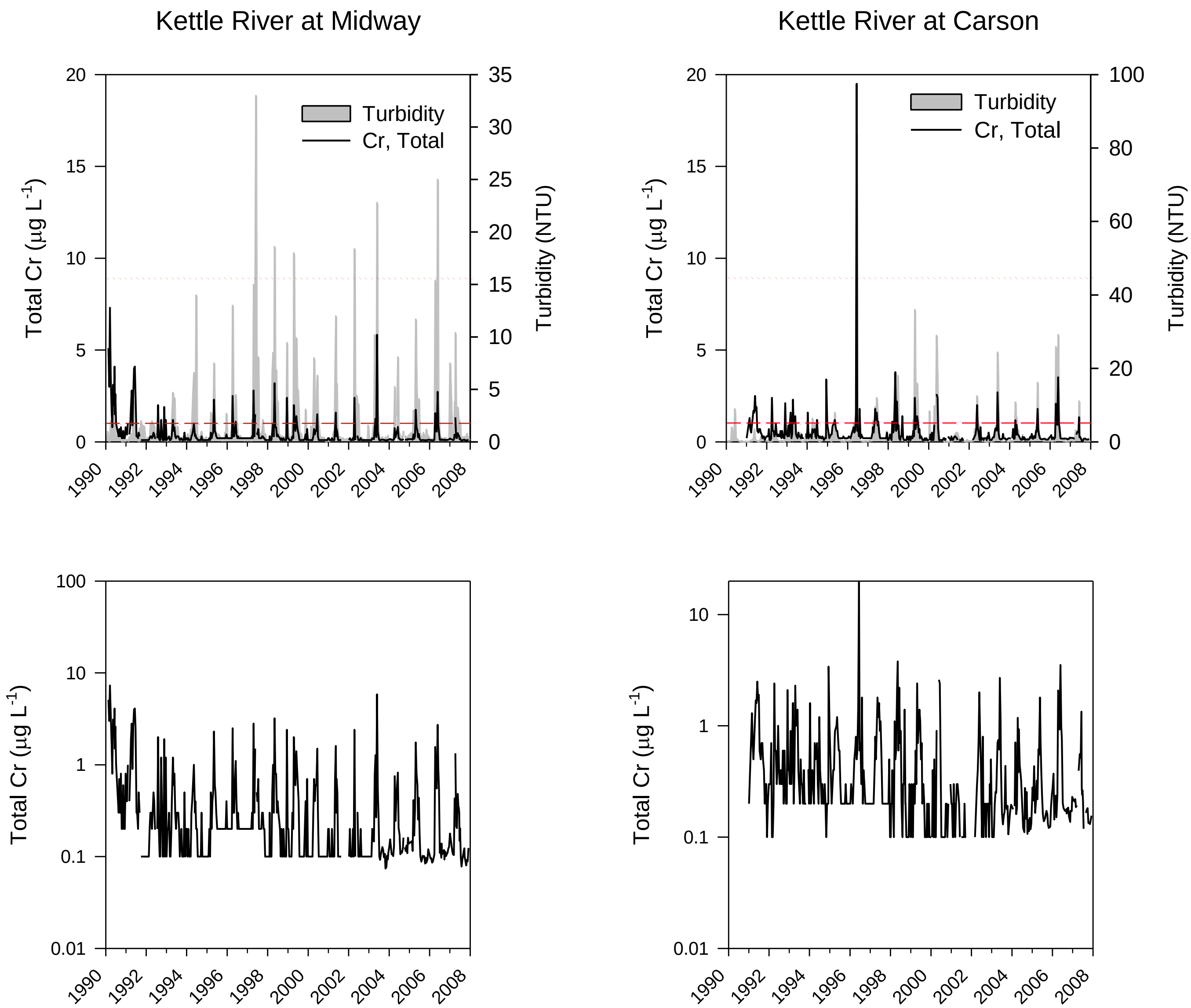
Chloride: Dissolved chloride was measured at both sites along the Kettle River from 1990 to 1999 and again starting in 2007 (Figure 5). A significant increasing trend was detected at the Kettle River at Midway (MK test, $p < 0.01$, slope = 0.058 mg L^{-1} a^{-1}; Table 1). Recent and previous dissolved chloride concentrations in the Kettle River are well below the B.C. aquatic life and drinking water guidelines of 600 and 250 mg L^{-1}, respectively. Since an increasing trend in dissolved chloride was detected in the Kettle River, it is recommended that it continued to be measured at both sites.

Figure 5: Dissolved chloride concentrations from the Kettle River at Midway (left) and Carson (right) from 1990 to 2008.



Chromium: Total chromium varies with seasonally at both sites and is positively correlated with turbidity (Spearman Correlation, $r_s = 0.48$) and mean daily discharge (Spearman Correlation, $r_s = 0.66$) at the Midway site and positively correlated with turbidity (Spearman Correlation, $r_s = 0.55$) at the Carson site (Figure 6). Significant decreasing trends were detected at both sites (Table 1 and Table 2); however, these significant trends are likely due to lowering analytical detection limits. Current B.C. working aquatic life guidelines for chromium are set for Cr VI (1 μg L^{-1}) and Cr III (8.9 μg L^{-1}). Although not directly comparable, total chromium concentrations exceeds the working aquatic life guideline for Cr^{6+} on a seasonal basis, but these seasonal exceedences are likely associated with particulate matter and thus, not biologically available. Efforts should be made to measure both forms of chromium (Cr VI and Cr III) so that comparisons to the guidelines are possible. Total chromium concentrations do not frequently exceed working irrigation or livestock guidelines established for Cr VI and Cr III.

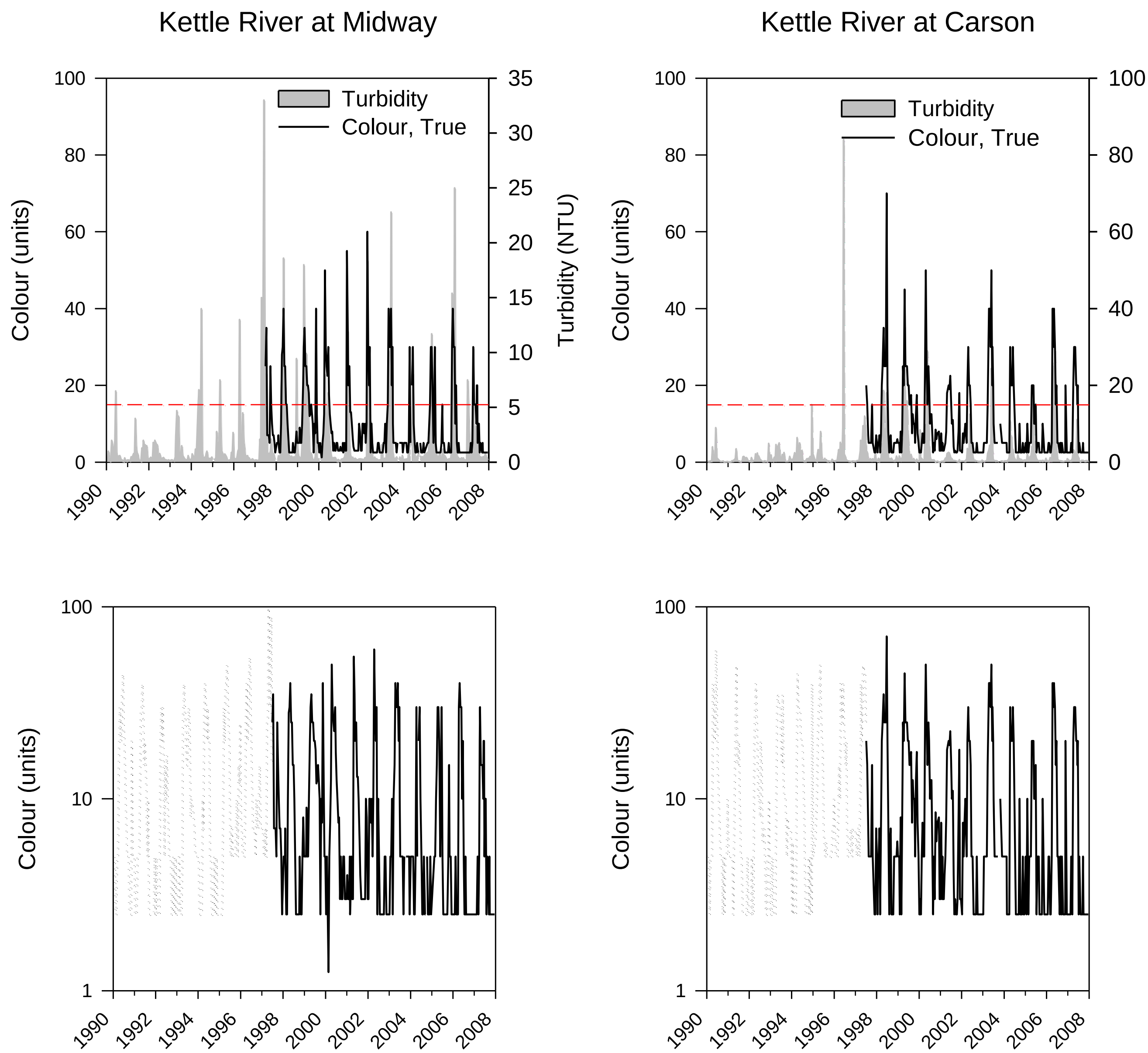
Figure 6: Total Chromium and Turbidity measurements (above) and log-scale total chromium concentrations (below) from the Kettle River at Midway (left) and Carson (right) from 1990 to 2008.



Note: The dashed red line represents the B.C. working aquatic life guideline for Cr (VI) and the dotted red line represents the B.C. working aquatic life guideline for Cr (III).

Colour: Colour, measured as apparent colour until 1998 and as true colour thereafter, varies seasonally and is positively correlated with flow (Spearman Correlation, $r_s = 0.74$) and turbidity (Spearman Correlation, $r_s = 0.65$) at the Midway site and turbidity at the Carson site (Spearman Correlation, $r_s = 0.61$). Many B.C. water quality guidelines are dependent on an upstream site for comparison and that is true for colour; in this case, the upstream site (Midway) often has higher colour measurements than the downstream site (Carson), suggesting that colour measurements are often diluted the between sites. The catchment area increases by 17% between the stations and so there are too many influences in such a distance to be able to make any meaningful upstream to downstream comparisons. The approved B.C. drinking water guideline is seasonally exceeded at both sites during freshet (Figure 7) and could be a concern for water treatment facilities (treatment should likely include settling and possibly filtration); however, these seasonal increases in colour are a natural result of spring freshet and washout.

Figure 7: True colour and turbidity measurements (top) and log-scale apparent and true colour measurements (bottom) from the Kettle River at Midway (left) and Carson (right) from 1990 to 2008.

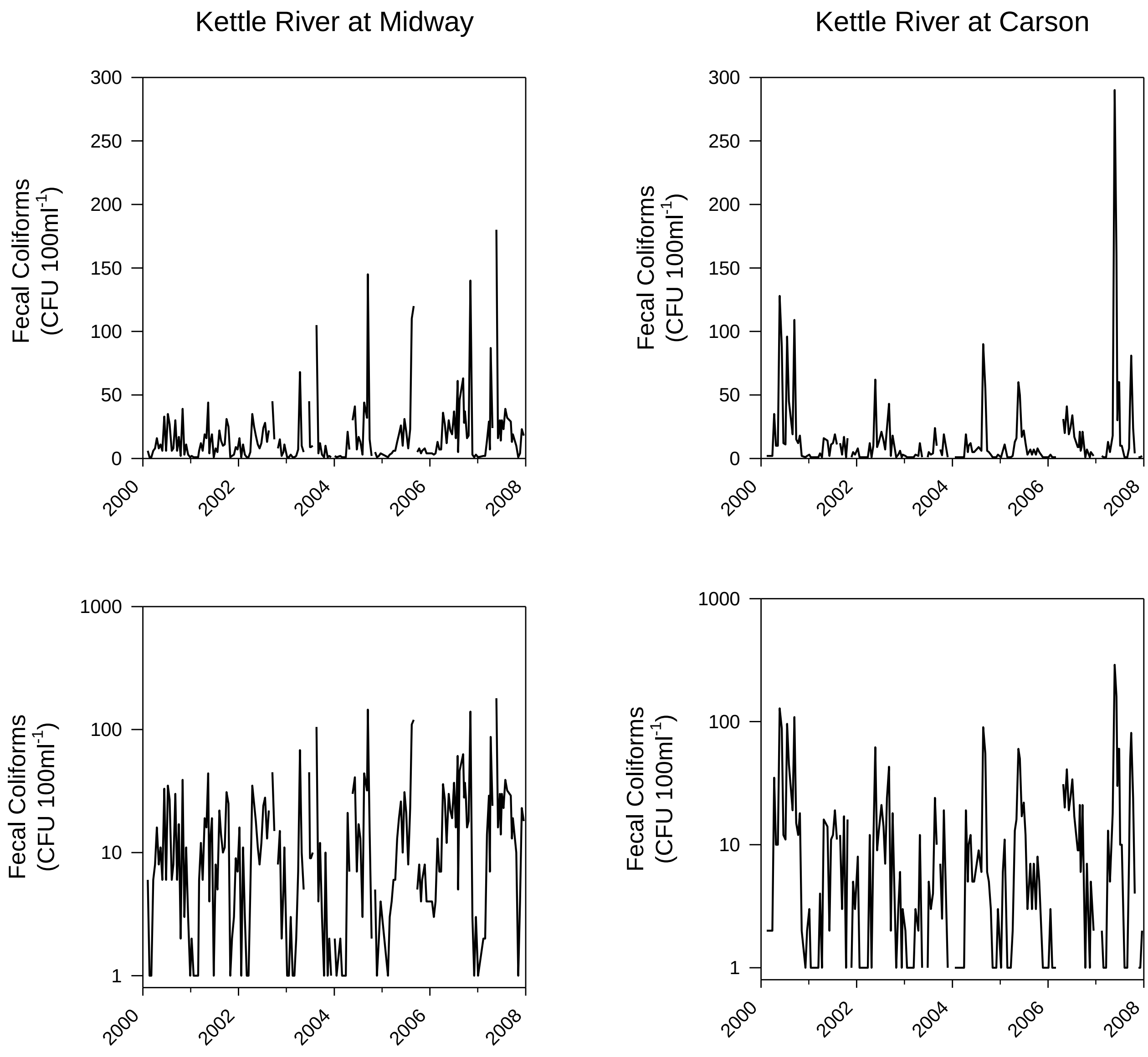


Note: The dashed red line represents the B.C. aesthetic guideline for drinking water.

Fecal Coliforms: Fecal coliforms have been measured at both sites in the Kettle River since 2000. Fecal coliform measurements vary seasonally at both sites, with low measurements during the winter and higher measurements during the summer. There was a statically significant trend in fecal coliforms in the Kettle River at Midway (MK test, $p < 0.01$, slope = 1.011 CFU $100mL^{-1}$ a^{-1}; SK test, $p < 0.01$, slope = 0.859 CFU $100mL^{-1}$ a^{-1}; Table 1). Thus, while fecal bacteria values at Midway were initially lower than at Carson, the Midway site values approached or were greater than those at Carson over the study period (Figure 8).

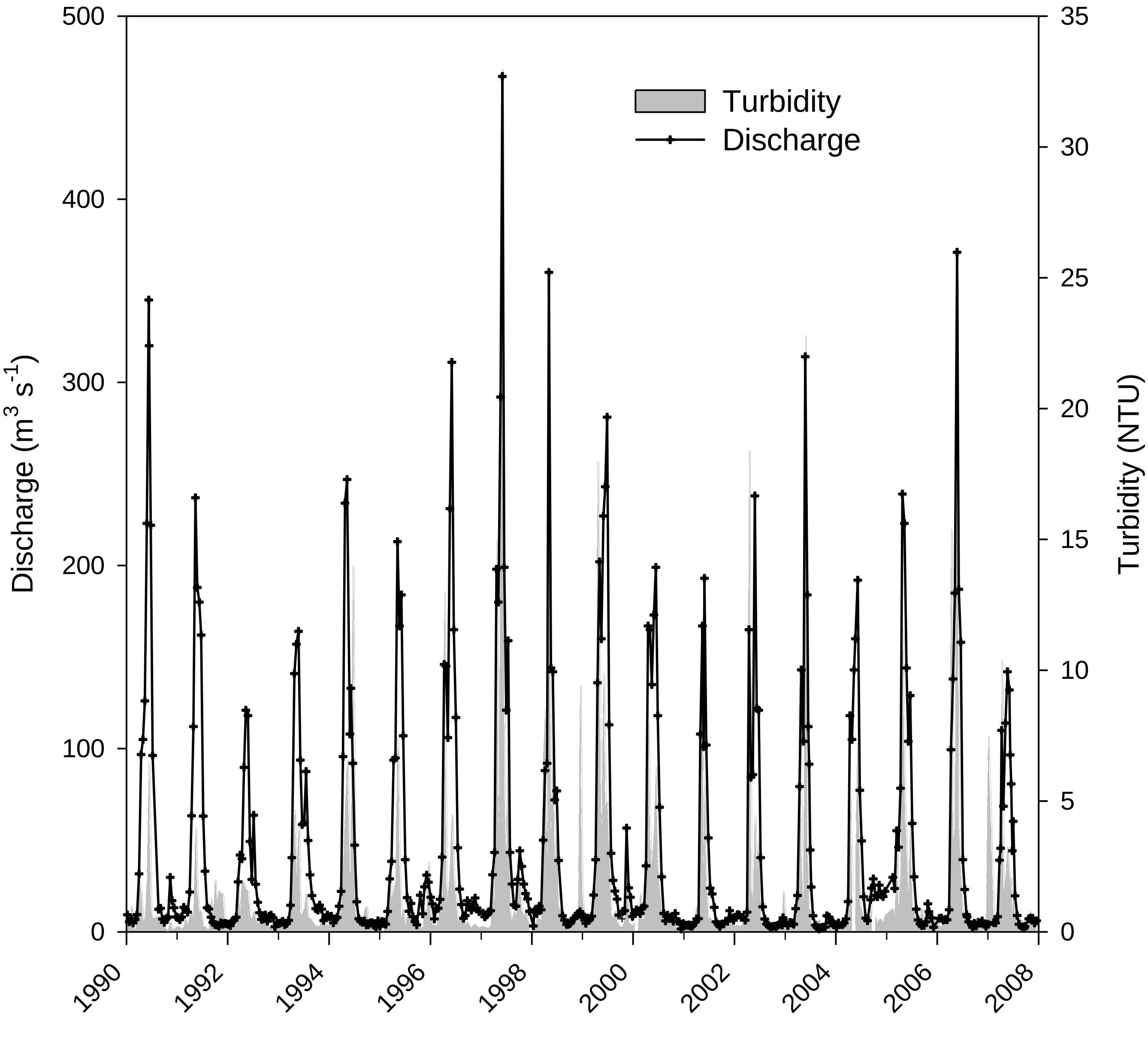
Current B.C. water quality guidelines are based on a calculation requiring 5 samples in 30 days. Requisite sampling was conducted once (2007) at the Kettle River at Midway, and twice (2006 and 2007) at Carson. The 90^{th} percentile from results from the Kettle River at Midway was 30 CFU $100mL^{-1}$; the 90^{th} percentile from results from the Kettle River at Carson were 16 and 120 CFU $100mL^{-1}$ in 2006 and 2007, respectively. Although results were below recreational guidelines, they were above various drinking water guidelines depending on level of treatment. Disinfection is required in advance of drinking water use. Also, it is recommended that requisite fecal coliform guideline sampling be incorporated into the regular sampling schedule at both sites a minimum of once per year during the late-spring and summer months.

Figure 8: Normal- (top) and log-scale (bottom) fecal coliform measurements from the Kettle River at Midway (left) and Carson (right) from 2000 to 2008.



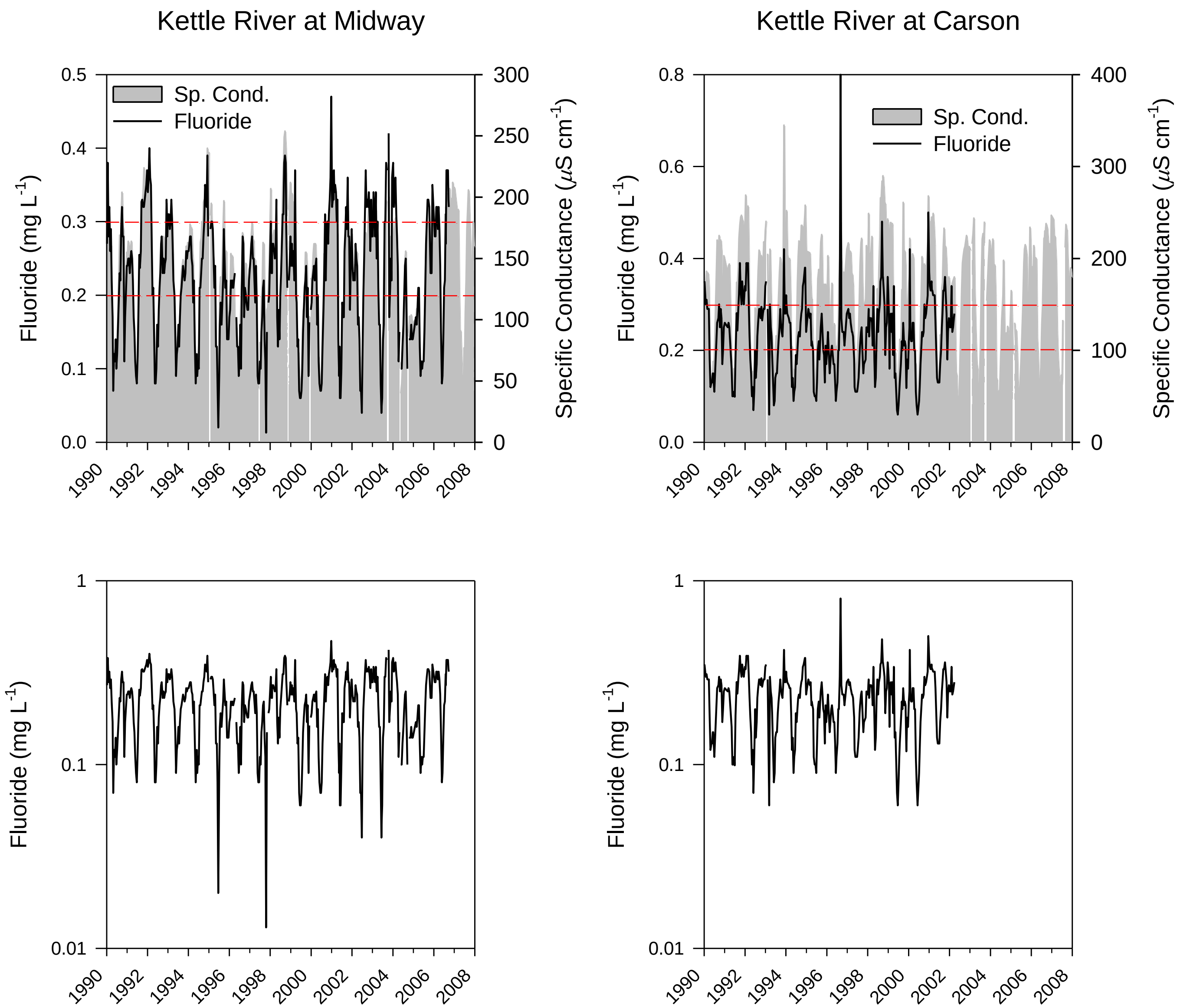
Flow: Flow measurements are collected at Midway by a collocated Water Survey of Canada hydrometric station. Mean daily discharge is positively correlated with turbidity (Spearman Correlation, $r_s = 0.70$; Figure 9) which the seasonal concentrations of many parameters, particularly those measured as total rather than dissolved portions. A statistically significant decreasing trend was detected for mean daily discharge measurements on sampling days (SK test, $p < 0.01$, slope = -0.209 $m^3\ s^{-1}\ a^{-1}$; Table 1). This decrease could influence the concentrations of various parameters, especially those measured as totals measurements.

Figure 9: Mean daily discharge and corresponding turbidity measurements from the Kettle River at Midway from 1990 to 2008.



Fluoride: Dissolved fluoride concentrations were measured at the Kettle River at Midway until 2006 and at Carson until 2003 (Figure 10). The current approved B.C. aquatic life guidelines are hardness-dependent (0.2 mg L^{-1} and 0.3 mg L^{-1}) and were exceeded seasonally during low flows at both sites. Significant increasing trend were detected for both the Kettle River at Midway (SK test, $p < 0.01$, slope = 0.058 mg L^{-1} a^{-1}; Table 1) and the Kettle River at Carson (SK test, $p < 0.01$, slope = 0.003 mg L^{-1} a^{-1}; Table 2). Since fluoride concentrations have been significantly increasing and exceed aquatic life guidelines seasonally, it is recommended that fluoride monitoring recommence at both Kettle River sites. Drinking water, irrigation and wildlife guidelines were not exceeded during the sample period.

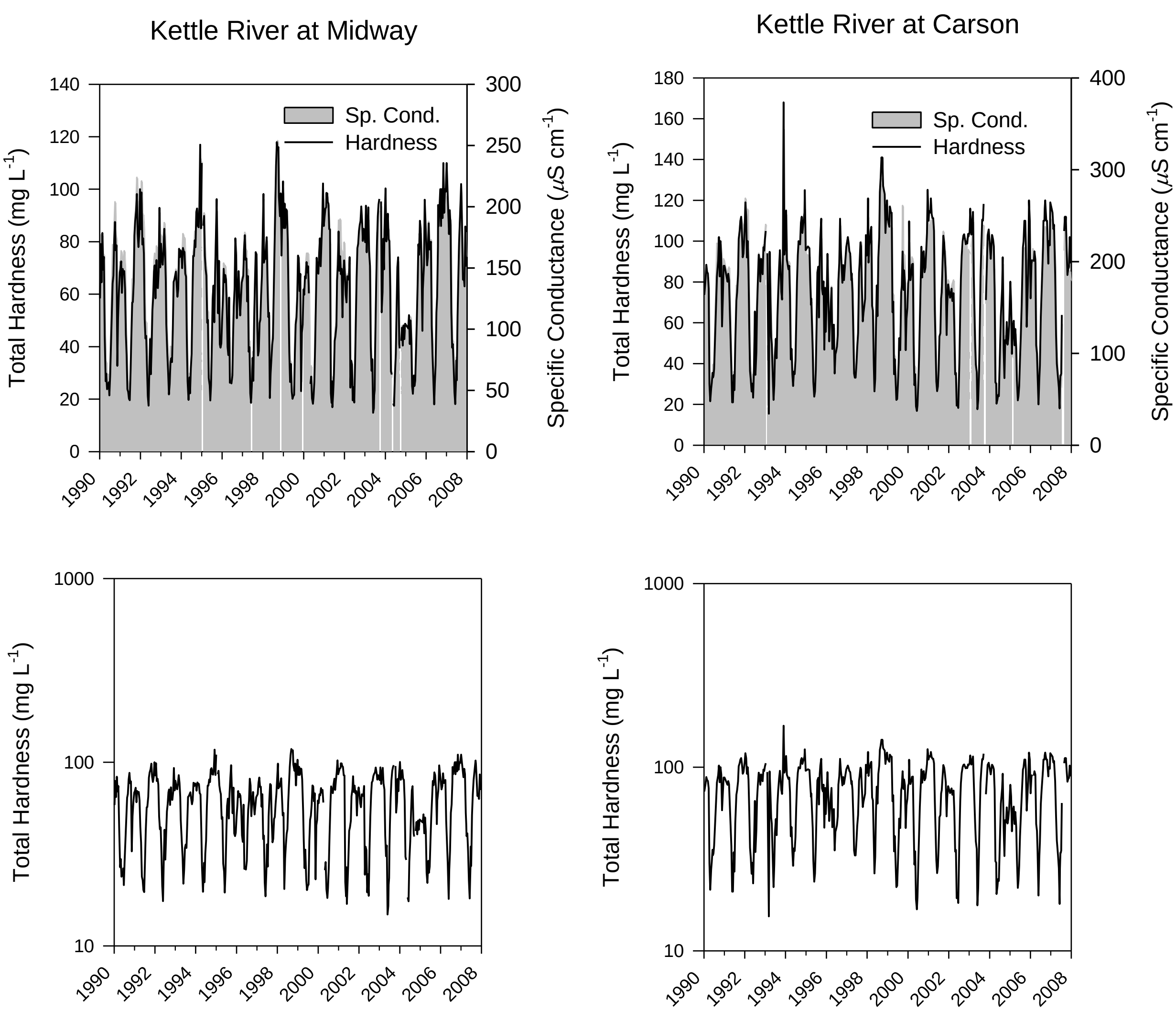
Figure 10: Fluoride and specific conductivity measurements (top) and log-scale fluoride concentrations (bottom) from the Kettle River at Midway (left) and Carson (right) from 1990 to 2008.



Note: Dashed red lines denote the lower and upper thresholds for the hardness-dependent B.C. aquatic life guideline for fluoride.

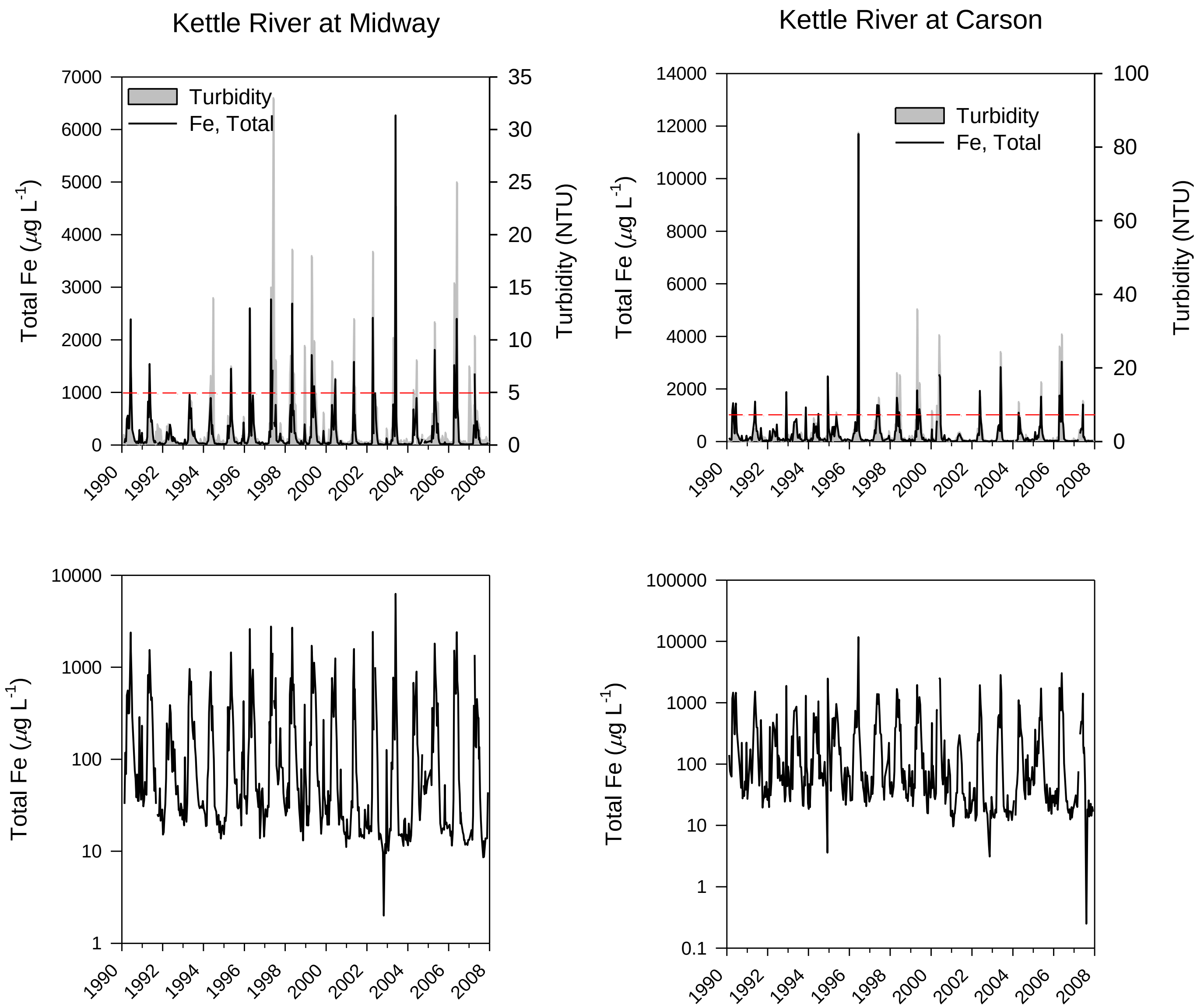
Hardness: Total hardness has been significantly increasing at the Kettle River at Midway (SK test, $p < 0.05$, slope = 0.058 mg L^{-1} a^{-1}; Table 1) over the sample period. This may be a function of the declining flows in the river. Although there are no established water quality guidelines, total hardness is an important toxicity-modifying factor for a variety of parameters; therefore, this change could be an important safeguard against toxicity of metals.

Figure 11: Total hardness and specific conductivity (top) and log-scale total hardness concentrations (bottom) from the Kettle River at Midway (left) and Carson (right) from 1990 to 2008.



Iron: Total iron concentrations vary greatly seasonally and are positively correlated with flow (Spearman Correlation, $r_s = 0.91$) and turbidity (Spearman Correlation, $r_s = 0.74$) at the Midway site and turbidity (Spearman Correlation, $r_s = 0.75$) at the Carson site (Figure 12). Significant decreasing trends in flow-adjusted total iron concentrations were detected at both the Kettle River at Midway (MK test, $p < 0.01$, slope = -0.004 μg L^{-1} a^{-1}; SK test, $p < 0.05$, slope = -0.002 μg L^{-1} a^{-1}; Table 1). There was also a significant decreasing trend in total iron in the Kettle River at Carson (MK test, $p < 0.01$, slope = -0.004 μg L^{-1} a^{-1}; SK test, $p < 0.01$, slope = -0.002 μg L^{-1} a^{-1}; Table 2). The approved B.C. aquatic life guideline for total iron of 1000 μg L^{-1} is often seasonally exceeded during peak freshet (Figure 12); however, since these exceedencess are turbidity- and flow-related, it is likely that these elevated concentrations are bound to particulate and not biologically available.

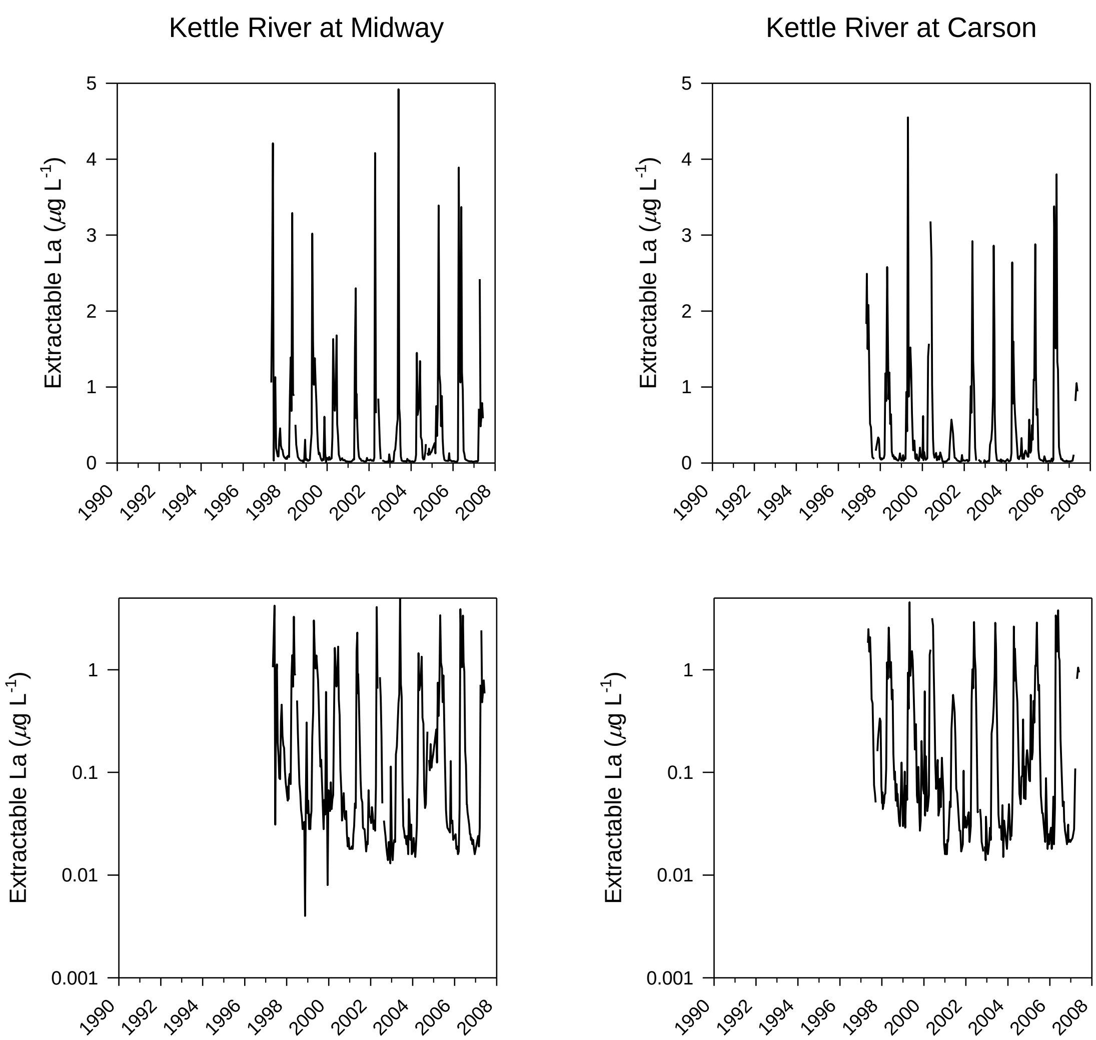
Figure 12: Total iron and turbidity measurements (top) and log-scale total iron measurements from the Kettle River at Midway (left) and Carson (right) from 1990 to 2008.



Note: A dashed red line denotes the B.C. aquatic life guideline for total iron.

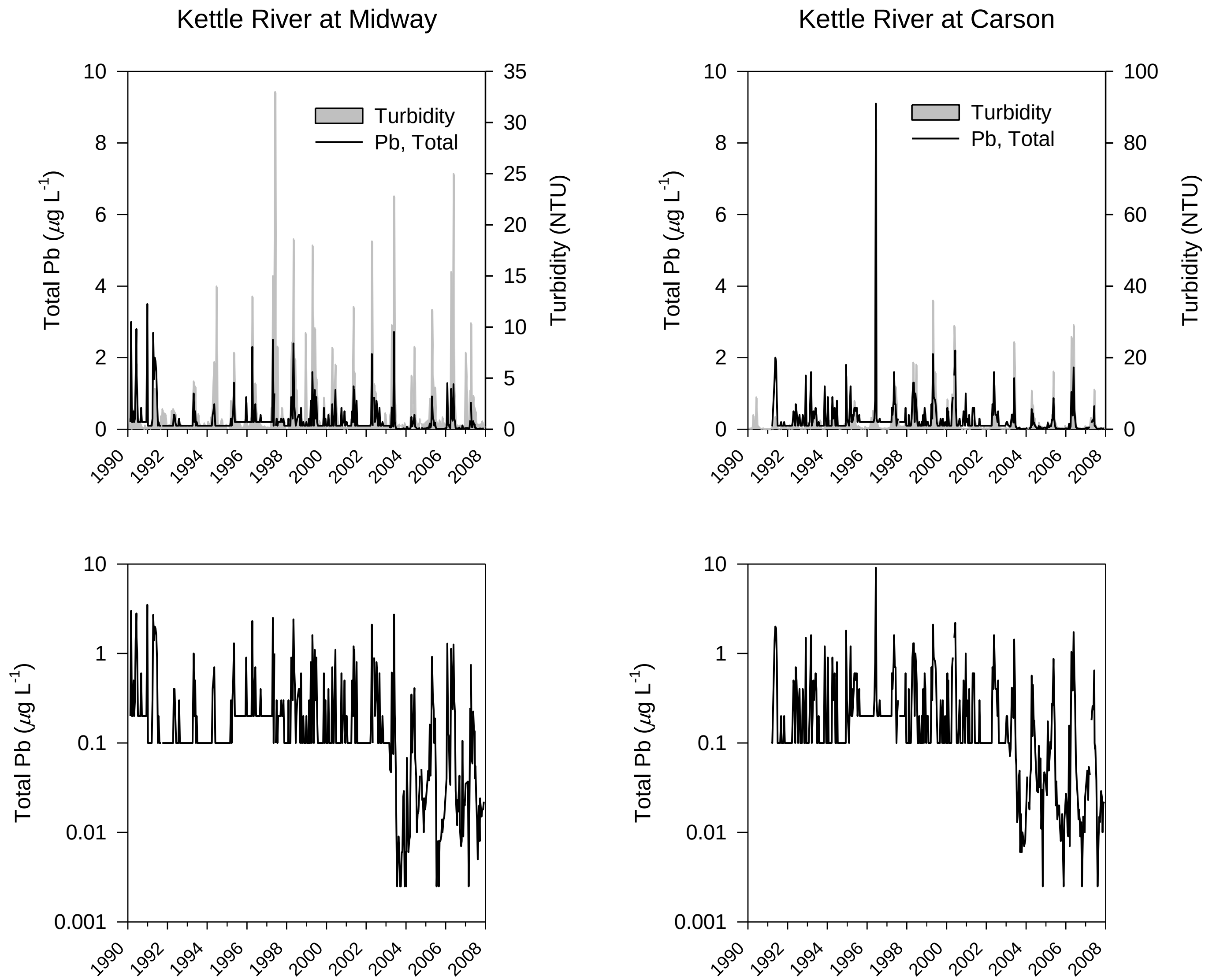
Lanthanum: Extractable lanthanum was measured at both sites in the Kettle River from 1997 until 2007. Extractable lanthanum concentrations were significantly decreasing at the Kettle River at Midway (MK test, $p < 0.01$, slope = -1.534 μg L^{-1} a^{-1}; SK test, $p < 0.05$, slope = -1.325 μg L^{-1} a^{-1}; Table 1) and the Kettle River at Carson site (MK test, $p < 0.01$, slope = -2.819 μg L^{-1} a^{-1}; SK test, $p < 0.05$, slope = -2.32 μg L^{-1} a^{-1}; Table 2) during the sample site. There are currently no guidelines developed for lanthanum.

Figure 13: Normal- (top) and log-scale (bottom) extractable lanthanum concentrations from the Kettle River at Midway (left) and Carson (right) from 1990 to 2008.



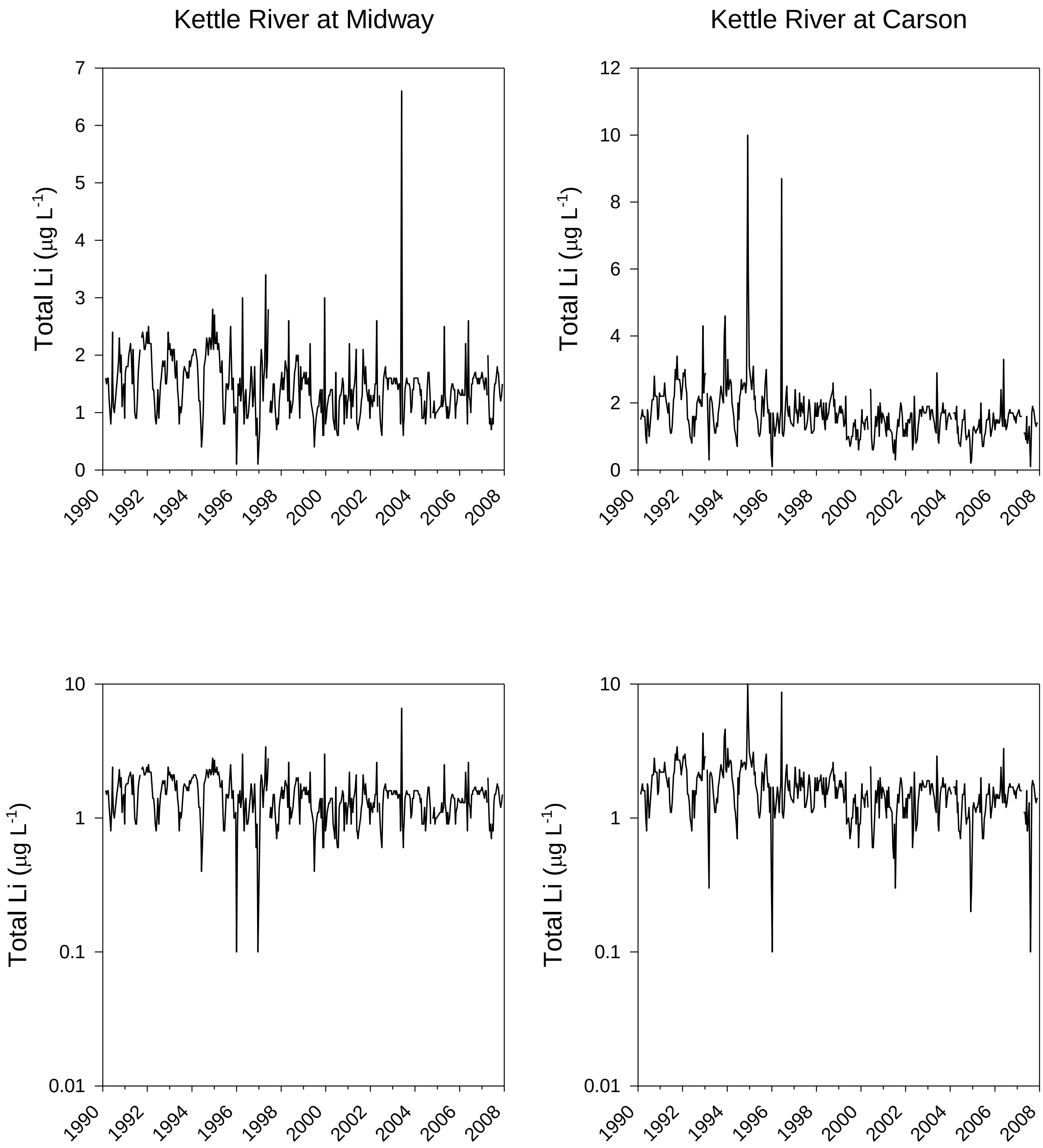
Lead: Total lead is positively correlated with mean daily discharge (Spearman Correlation, r_s = 0.52) and turbidity (Spearman Correlation, r_s = 0.34) at the Kettle River at Midway and turbidity (Spearman Correlation, r_s = 0.48) at the Kettle River at Carson. Significant decreasing trends in total lead concentrations were detected at both sites (Table 1 and Table 2); this is due to lowering laboratory detection limits which has improved our ability to measure low-level concentrations (Figure 14). Total lead concentrations were very similar at both Kettle River sites and are generally near or slightly above detection limits, increasing slightly during freshet, over the sample period. Current lead measurements are below approved B.C. water quality guidelines.

Figure 14: Total lead and turbidity measurement (top) and log-scale total lead concentrations (bottom) from the Kettle River at Midway (left) and Carson (right) from 1990 to 2008.



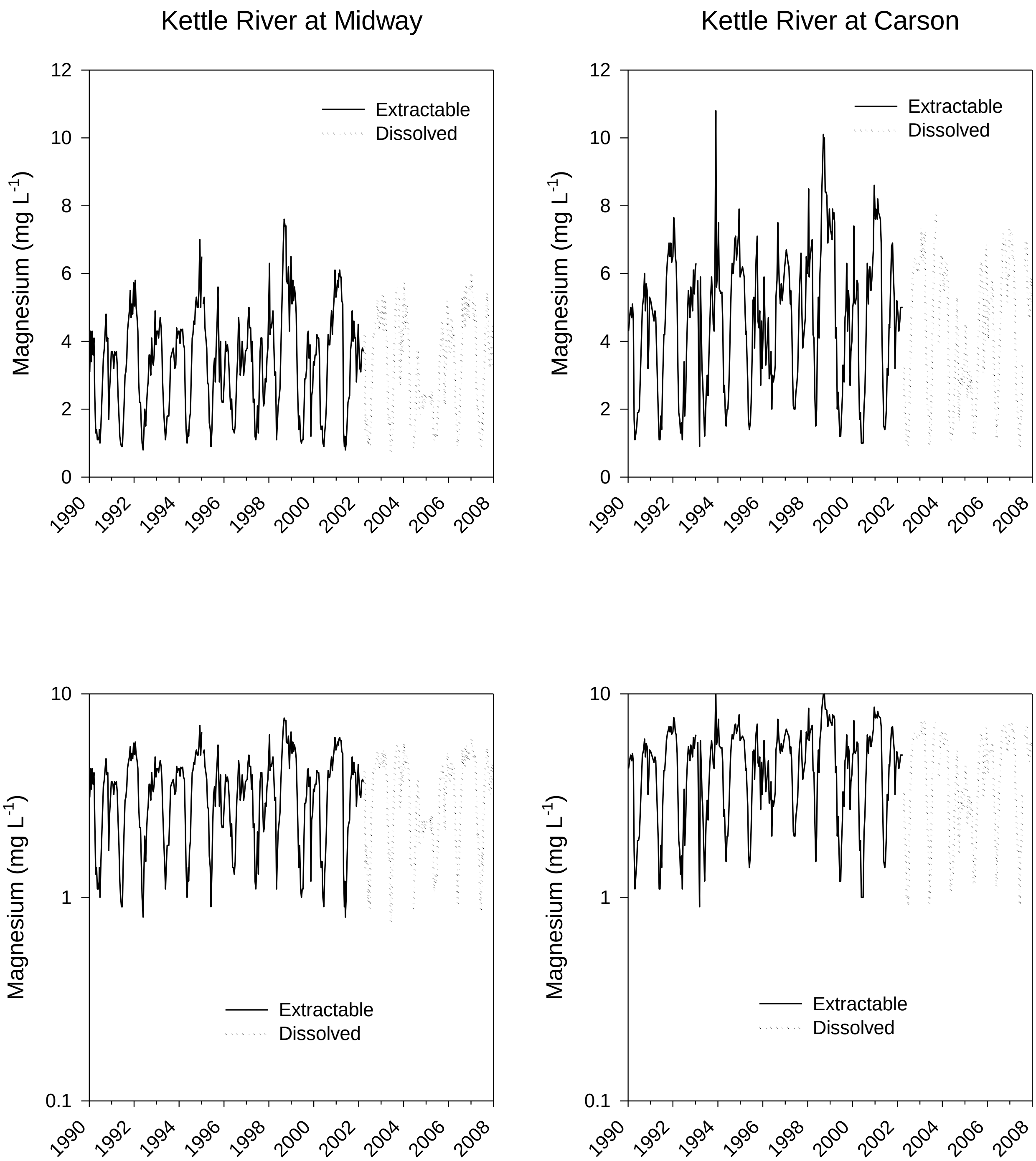
Lithium: Total lithium concentrations are generally similar at both sites (Figure 15) with concentrations slightly higher at the Kettle River at Carson. Significant decreasing trends were detected for total lithium at the Kettle River at Midway (MK test, $p < 0.01$, slope = -0.029 $\mu g\ L^{-1}\ a^{-1}$; SK test, $p < 0.05$, slope = -0.029 $\mu g\ L^{-1}\ a^{-1}$; Table 1) and at Carson (MK test, $p < 0.01$, slope = -0.043 $\mu g\ L^{-1}\ a^{-1}$; SK test, $p < 0.01$, slope = -0.051 $\mu g\ L^{-1}\ a^{-1}$; Table 2). Total lithium concentrations are currently below B.C. working water quality guidelines.

Figure 15: Normal- (top) and log-scale (bottom) total lithium concentrations from the Kettle River at Midway (left) and Carson (right) from 1990 to 2008.



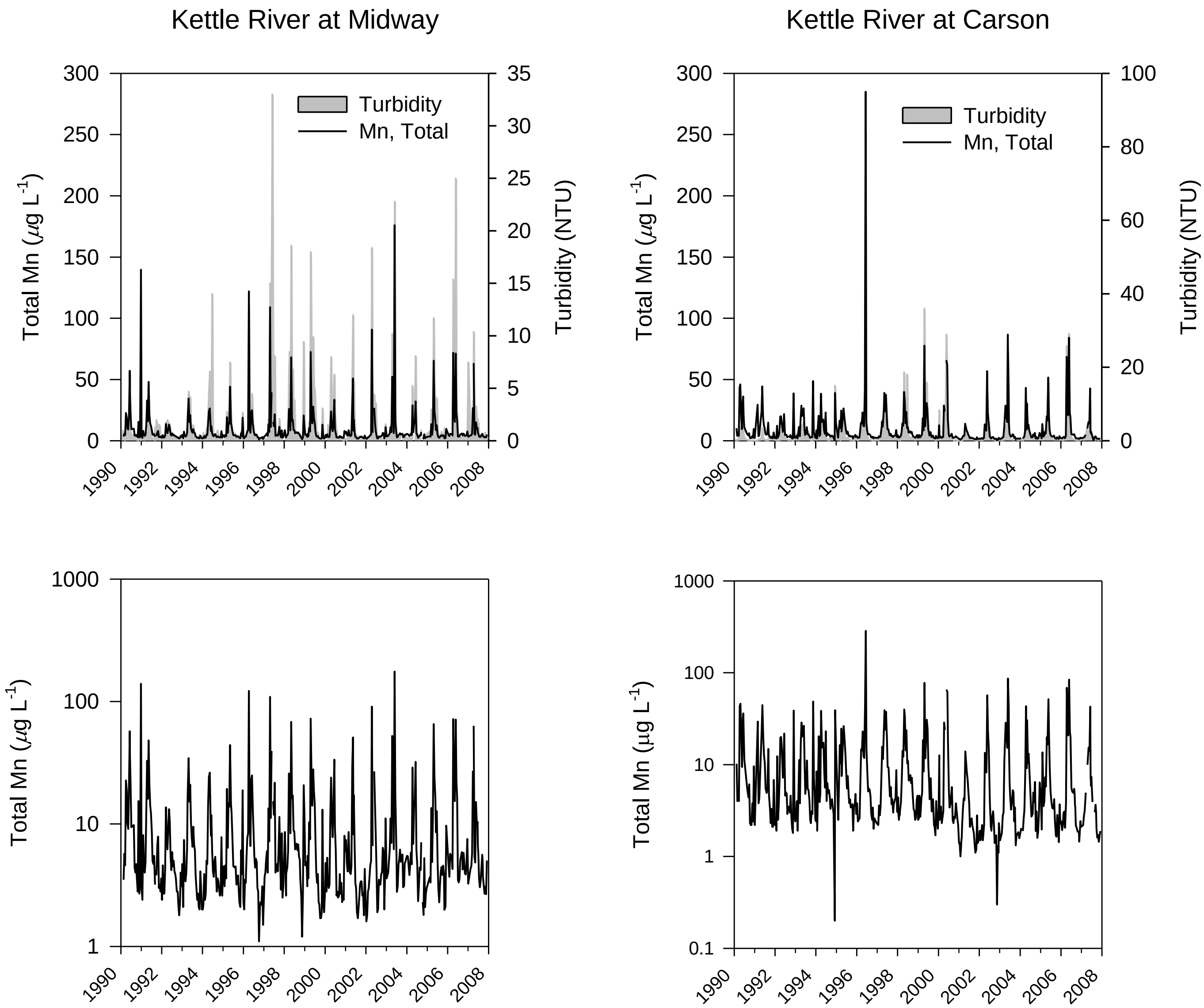
Magnesium: Magnesium was measured as extractable until 2002 and then as dissolved thereafter (Figure 16). Although similar in pattern, magnesium concentrations are slightly elevated downstream at the Kettle River at Carson (Figure 16). Extractable magnesium increased significantly from 1990 to 2002 in the Kettle River at Carson (MK test, $p < 0.01$, slope = 0.116 mg L^{-1} a^{-1}; Table 2). There are currently no B.C. water quality guidelines from magnesium. Magnesium and calcium are used to calculate total hardness, and the change in magnesium has resulted in the change in total hardness. Current total manganese concentrations are well below the approved B.C. aquatic life guideline.

Figure 16: Normal- (top) and log-scale (bottom) extractable and dissolved magnesium concentrations from the Kettle River at Midway (left) and Carson (right) from 1990 to 2008.



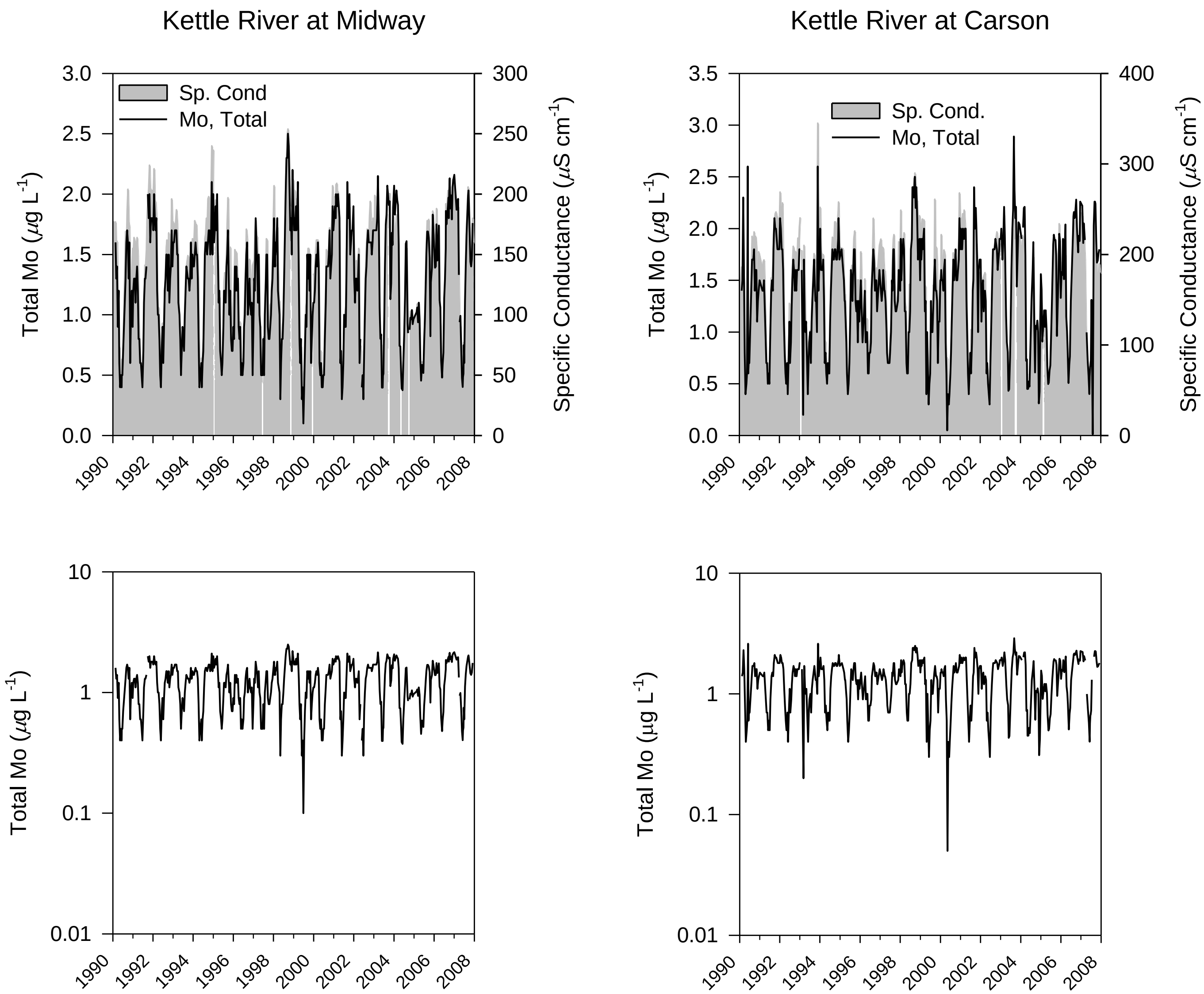
Manganese: Total manganese has a similar pattern at both sites along the Kettle River but is typically higher in concentration at the Kettle River at Midway during freshet (Figure 17). Manganese is positively correlated with turbidity (Spearman Correlation, r_s = 0.66) and flow at the Midway site (Spearman Correlation, r_s = 0.55) and with turbidity (Spearman Correlation, r_s = 0.74) at the Carson site, suggesting that elevated manganese concentrations are associated with spring freshet and particulate matter. Total manganese concentrations have been significantly decreasing in the Kettle River at Carson (MK test, $p < 0.01$, slope = -0.133 μg L^{-1} a^{-1}; SK test, $p <$ 0.01, slope = -0.108 μg L^{-1} a^{-1}; Table 2), but no significant trend was detected in the Kettle River at Midway.

Figure 17: Total manganese and turbidity measurements (top) and log-scale total manganese concentrations from the Kettle River at Midway (left) and Carson (right) from 1990 to 2008.



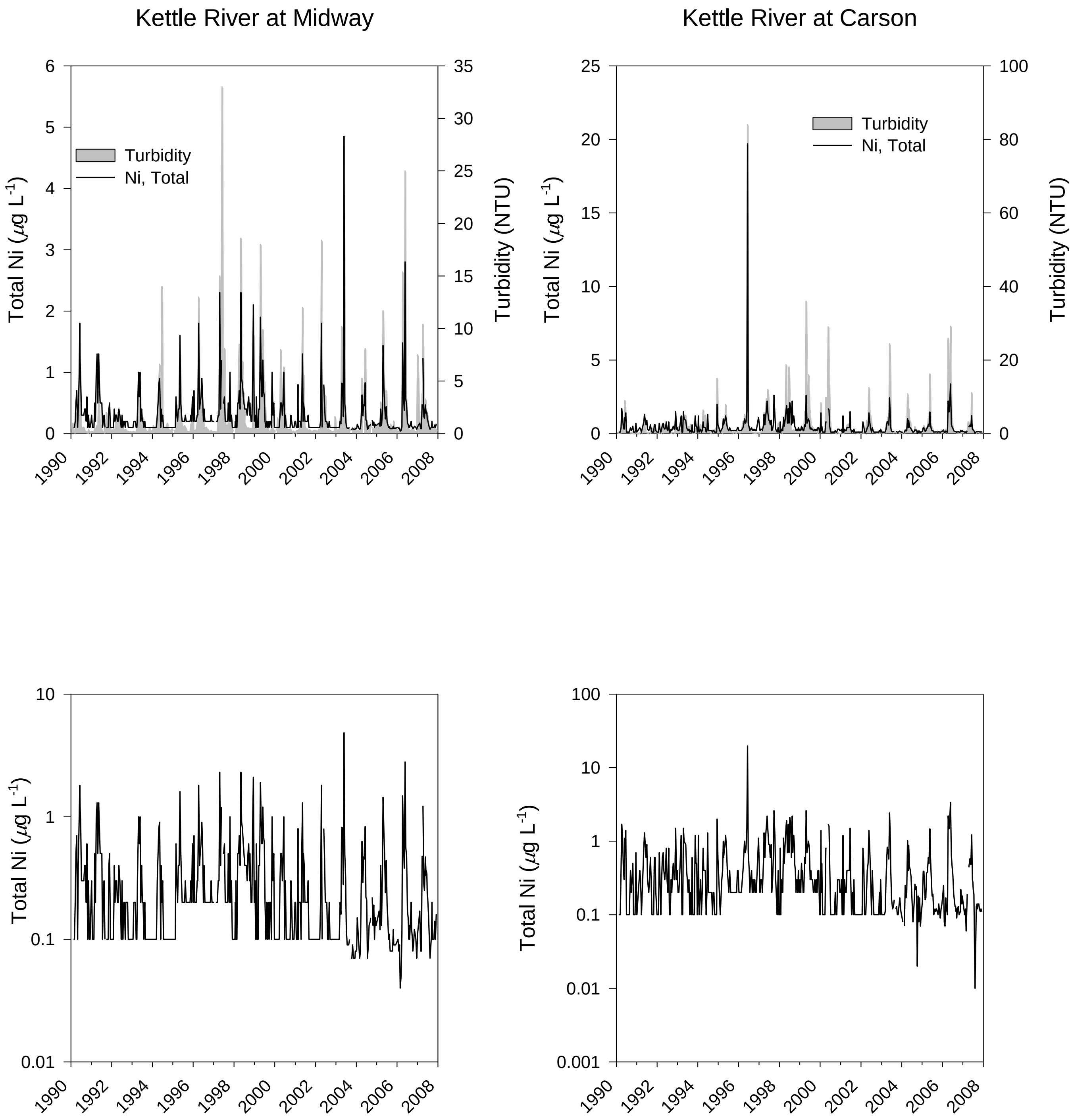
Molybdenum: Total molybdenum concentrations have similar patterns and concentrations at both sites (Figure 18). Significant increasing trends in total molybdenum were detected in the Kettle River at Midway (MK test, $p < 0.05$, slope = 0.014 $\mu g\ L^{-1}\ a^{-1}$; SK test, $p < 0.01$, slope = 0.014 $\mu g\ L^{-1}\ a^{-1}$; Table 1) and at Carson (MK test, $p = 0.01$, slope = 0.012 $\mu g\ L^{-1}\ a^{-1}$; SK test, $p < 0.01$, slope = 0.014 $\mu g\ L^{-1}\ a^{-1}$; Table 2). Total molybdenum concentrations are well below approved B.C. water quality guidelines over the sample period.

Figure 18: Total molybdenum and specific conductivity measurements (top) and log-scale total molybdenum concentrations (bottom) from the Kettle River at Midway (left) and Carson (right) from 1990 to 2008.



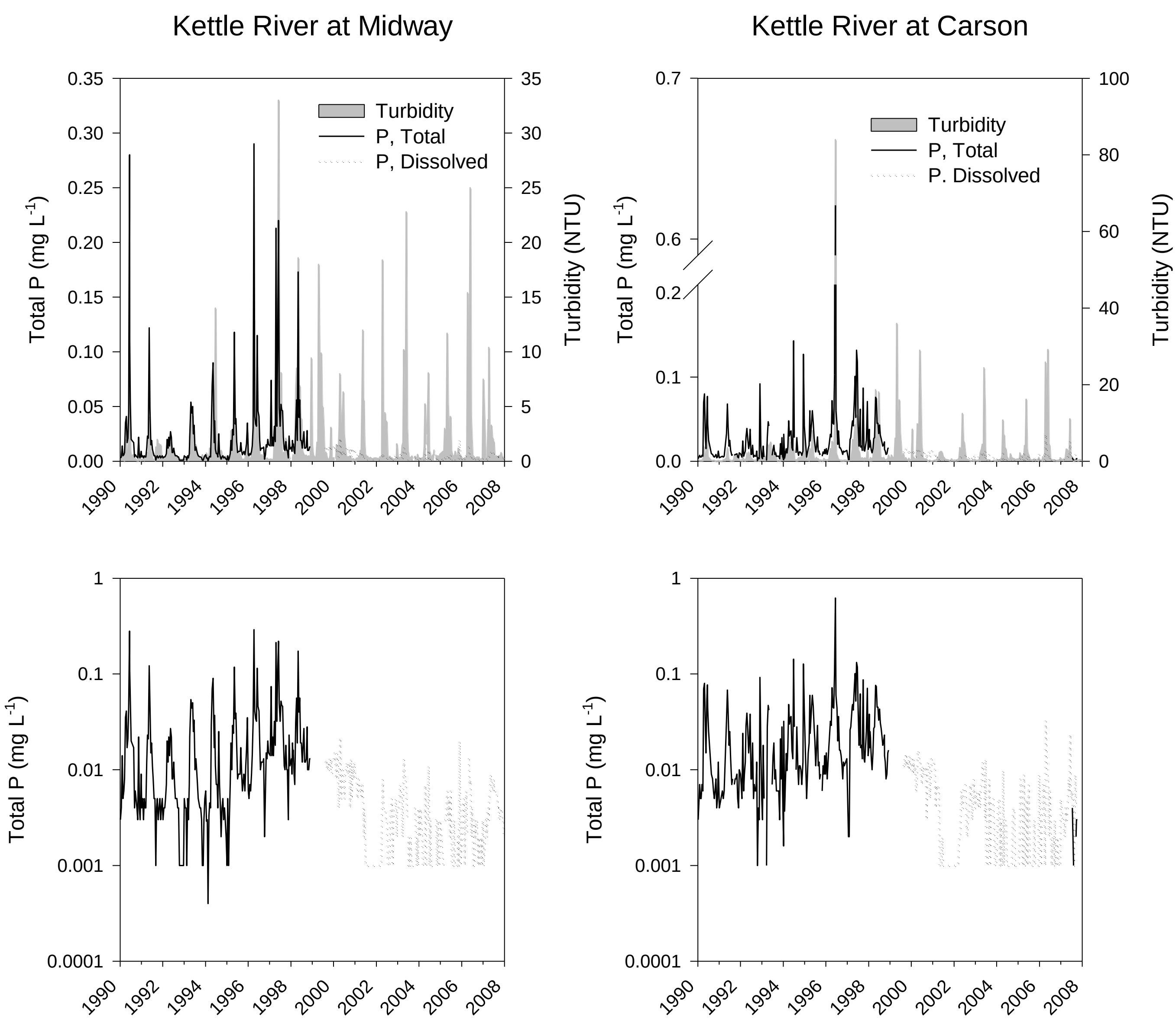
Nickel: Total nickel measurements have been affected by changing analytical detection limits over the sample period (Figure 19) resulting in false trends over the sample period. Total nickel was positively correlated with turbidity (Spearman Correlation, $r_s = 0.61$) and flow (Spearman Correlation, $r_s = 0.70$) in the Kettle River at Midway and with turbidity (Spearman Correlation, $r_s = 0.59$) in the Kettle River at Carson. Total nickel concentrations peaked during freshet. Concentrations at both sites are very similar and were well below B.C. working water quality guidelines during the sample period.

Figure 19: Total nickel and turbidity measurements (top) and log-scale total nickel concentrations (bottom) from the Kettle River at Midway (left) and Carson (right) from 1990 to 2008.



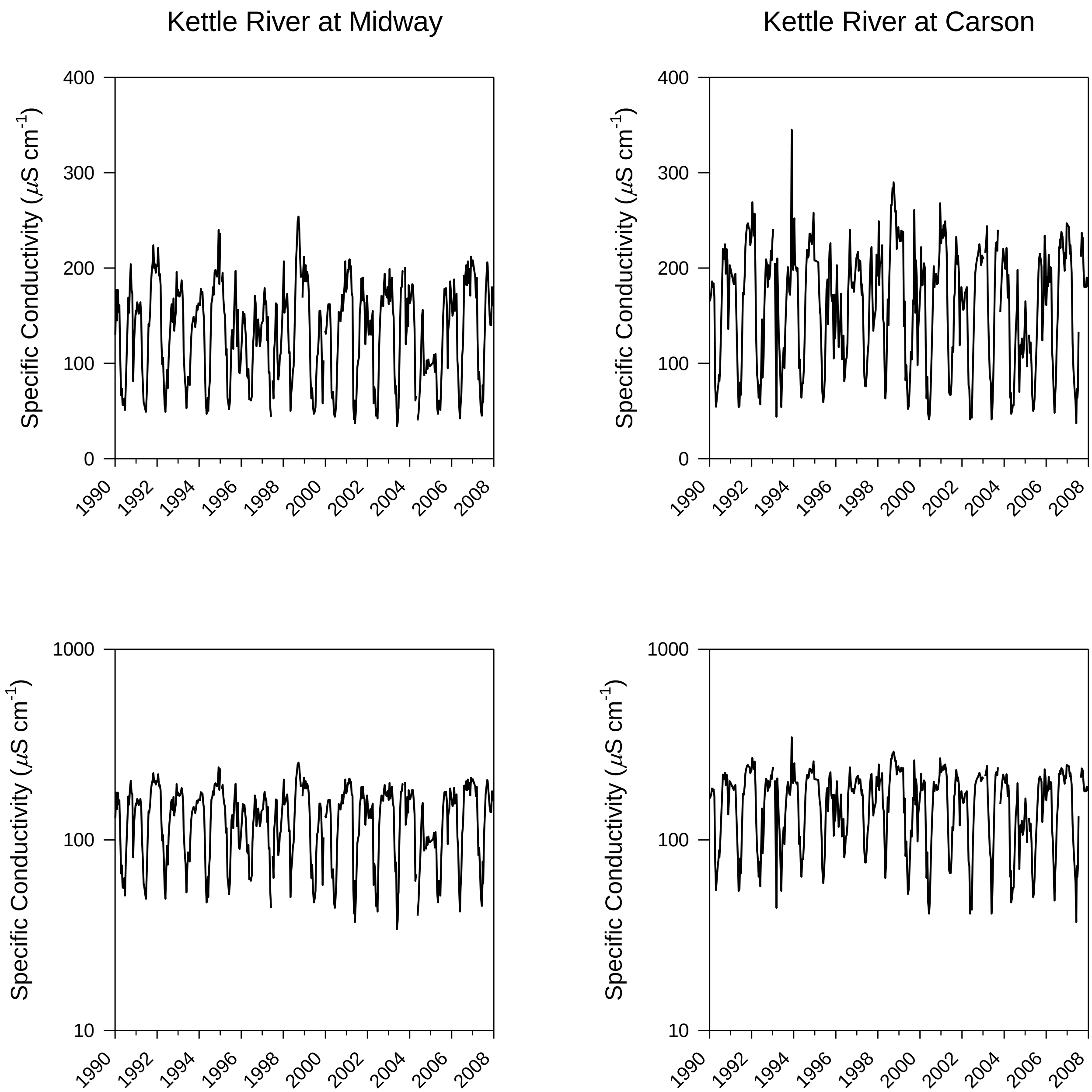
Phosphorus: Phosphorus was measured in the Kettle River as total phosphorus until 1998 and as dissolved phosphorus from 1998 to present (Figure 20). Significant trends in total phosphorus were detected in the Kettle River at Midway (MK test, $p < 0.01$, slope = 0.001 mg L^{-1} a^{-1}; SK test, $p < 0.01$, slope = 0.002 mg L^{-1} a^{-1}; Table 1) and at Carson (MK test, $p = 0.01$, slope = 0.002 mg L^{-1} a^{-1}; Table 2); dissolved phosphorus concentrations have remained stable and low over the sample period (Figure 20). It is recommended that total phosphorus be measured in addition to dissolved phosphorus in the Kettle River since total dissolved phosphorus is currently near detection limits. There are currently no B.C. water quality guidelines for phosphorus in lotic systems since periphyton chlorophyll *a* is used to measure the impact of nutrients.

Figure 20: Total and dissolved phosphorus, and turbidity measurements (top) and log-scale total and dissolved phosphorus (bottom) from the Kettle River at Midway (left) and Carson (right) from 1990 to 2008.



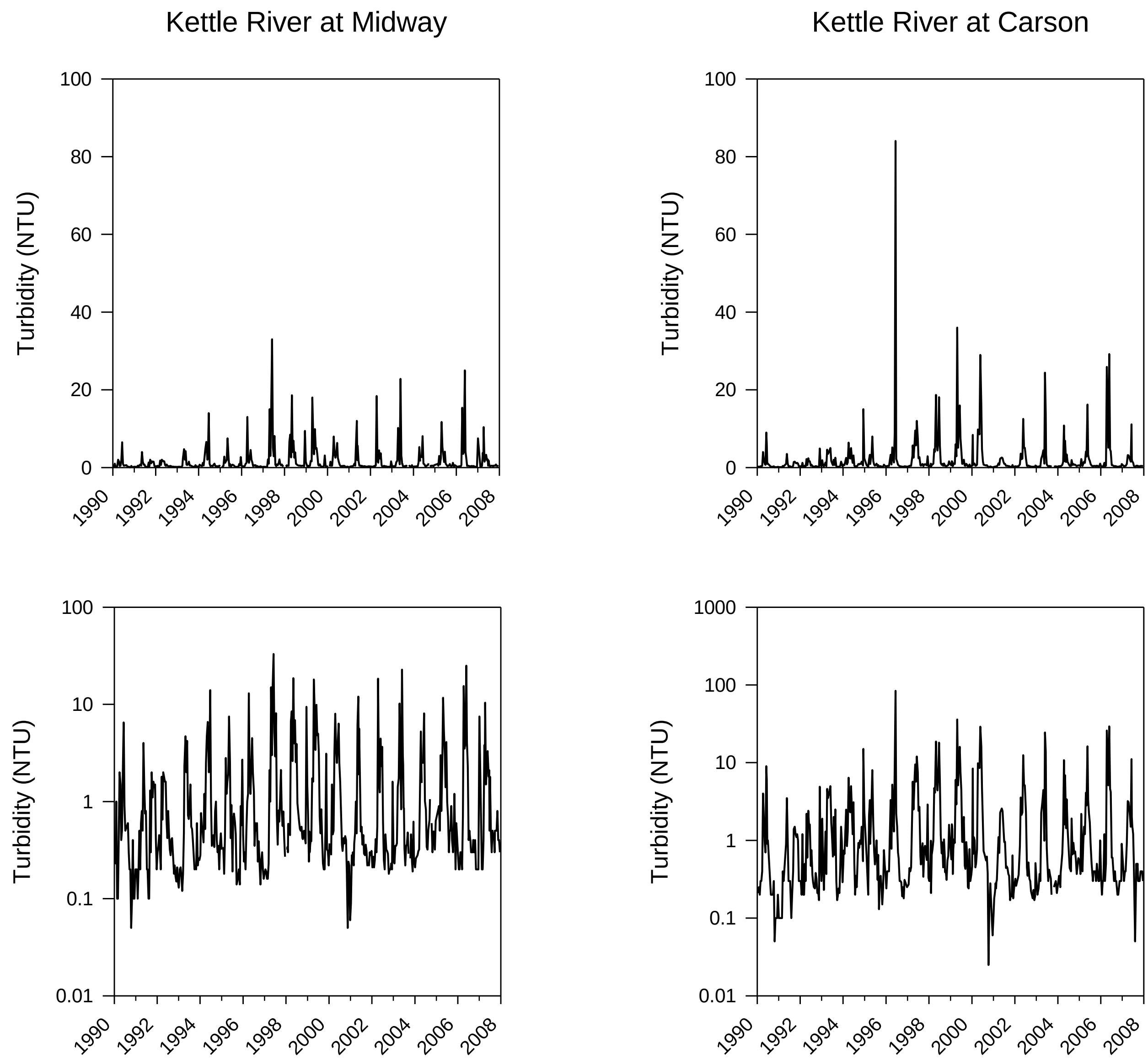
Specific Conductivity: Specific conductivity is a surrogate for total dissolved solids in a water body. Values were generally greater in the Kettle River at the Carson (downstream) site over the sample period (Figure 21) and there were significant decreasing trends in specific conductivity detected at the Kettle River at Midway (upstream) site (MK test, $p < 0.01$, slope = -0.92 $\mu S\ cm^{-1}\ a^{-1}$; SK test, $p < 0.01$, slope = -1.058 $\mu S\ cm^{-1}\ a^{-1}$; Table 1). Differences in specific conductivity measurements in the Kettle River may be due to greater groundwater inputs between sites, resulting in differing long-term trends and concentrations. There are currently no B.C. guidelines for specific conductivity; however, the guideline for total dissolved solids of 500 mg/L maximum equates to a conductivity of about 700 μS/cm. Therefore, there does not appear to be a concern for the water quality related to dissolved solids.

Figure 21: Normal- (top) and log-scale (bottom) specific conductivity measurements from the Kettle River at Midway (left) and Carson (right) from 1990 to 2008.



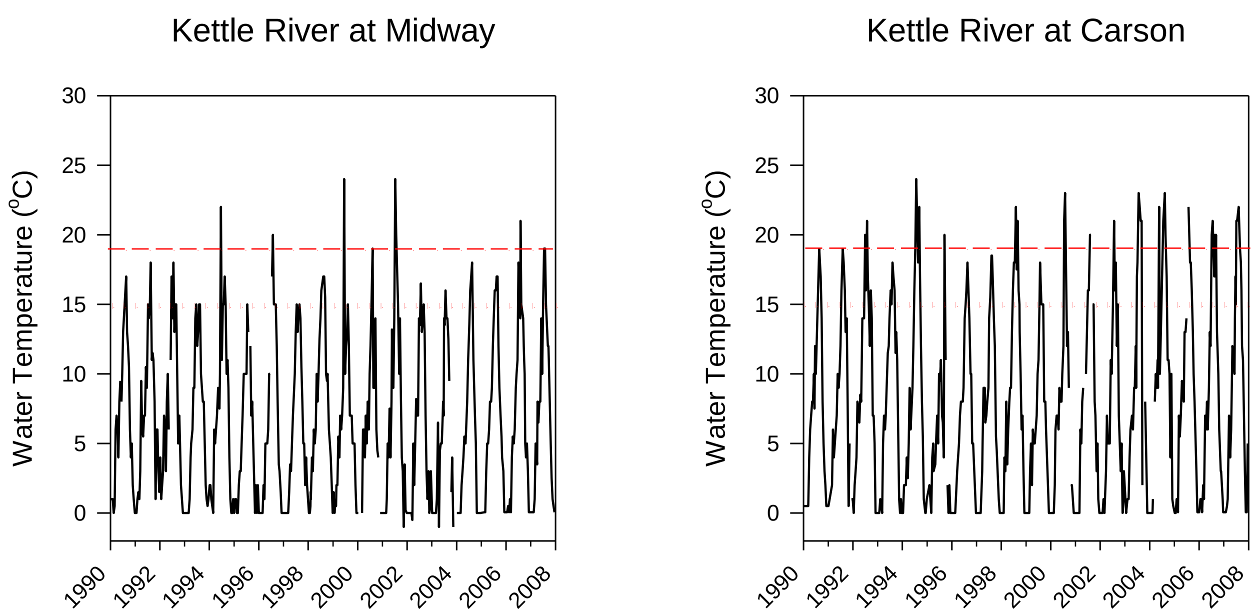
Turbidity: Turbidity measurements were generally similar at both sites on the Kettle River (Figure 22). Turbidity measurements were positively correlated with flow (Spearman Correlation, $r_s = 0.70$) and had a statistically significant increasing trend over the sample period in the Kettle River at Midway (MK test, $p < 0.01$, slope = 0.018 NTU a^{-1}; SK test, $p < 0.05$, slope = 0.02 NTU a^{-1}; Table 1). Current B.C. water quality guidelines are dependent on background or upstream comparisons, and unfortunately both sites have differing sampling schedules, therefore, no guidelines comparisons can be made. To compare turbidity measurements against guidelines, it is recommended that sites be sampled on the same day. A variety of total metal and nutrient concentrations are highly correlated to turbidity and significant increases in turbidity can result in corresponding trends in total metal and nutrient concentrations.

Figure 22: Normal- (top) and log-scale (bottom) turbidity measurements from the Kettle River at Midway (left) and Carson (right) from 1990 to 2008.



Water Temperature: Water temperature is measured at the time of sample collection. The B.C. aquatic life guideline of 19°C (daily maximum for streams with unknown fish distribution) and the B.C. drinking water guideline of 15°C are often exceeded during the summer at both sites (Figure 23), although with greater frequency and magnitude at the Kettle River at Carson (downstream site). Reasons for the differences are unclear, although it may be wholly or partly due to differences in canopy coverage at both sites. Results suggest that the aesthetic value of Kettle River source drinking water may be compromised during the summer, and more importantly, fish species may be in danger should there be no suitable refugia during these seasonal temperature peaks. Continuous temperature monitors have been installed in the Kettle River to monitor hourly surface water temperature for trend detection and to determine the extent and duration of aquatic life and drinking water exeedences.

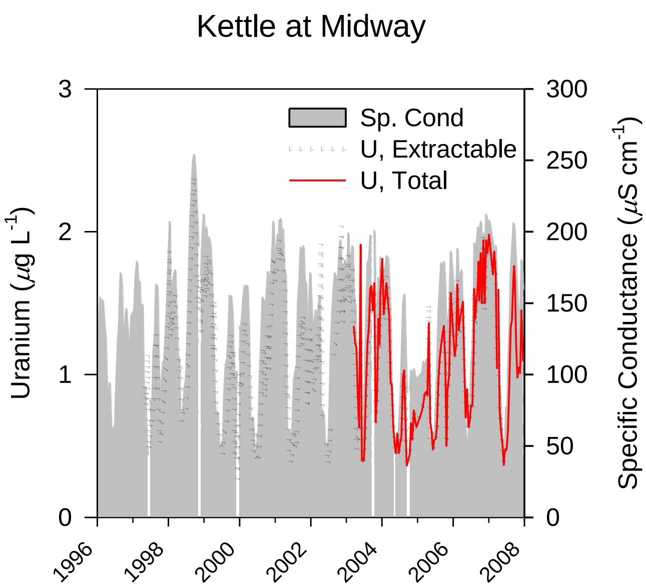
Figure 23: Surface water temperatures from the Kettle River at Midway (left) and Carson (right) from 1990 to 2008.

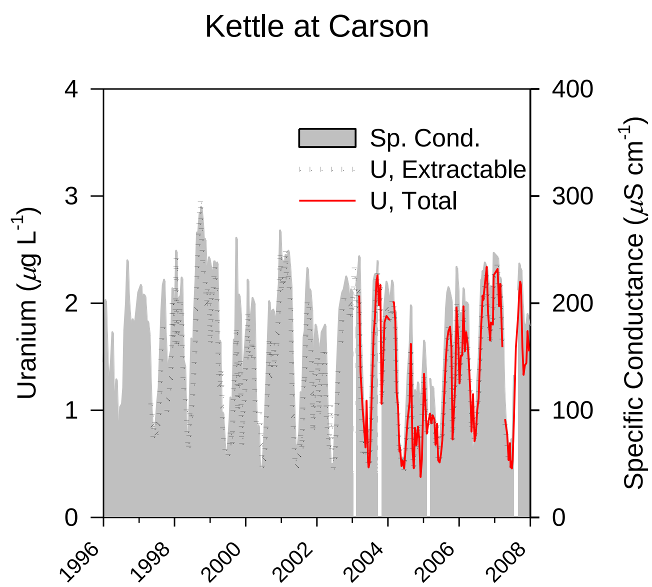


Note: Dashed red line denotes the B.C. aquatic life guideline for water bodies with unknown fish distribution. Dotted red line denotes the B.C. drinking water supply maximum.

Uranium: Uranium was measured as extractable uranium from 1997 to 2007 and as total uranium from 2003 to present. Uranium is associated with specific conductivity, and concentrations have been stable over the sample period, ranging from < 1 μg L^{-1} to < 3 μg L^{-1}. Current and historic concentrations are below the Canadian drinking water guideline of 20 μg L^{-1}.

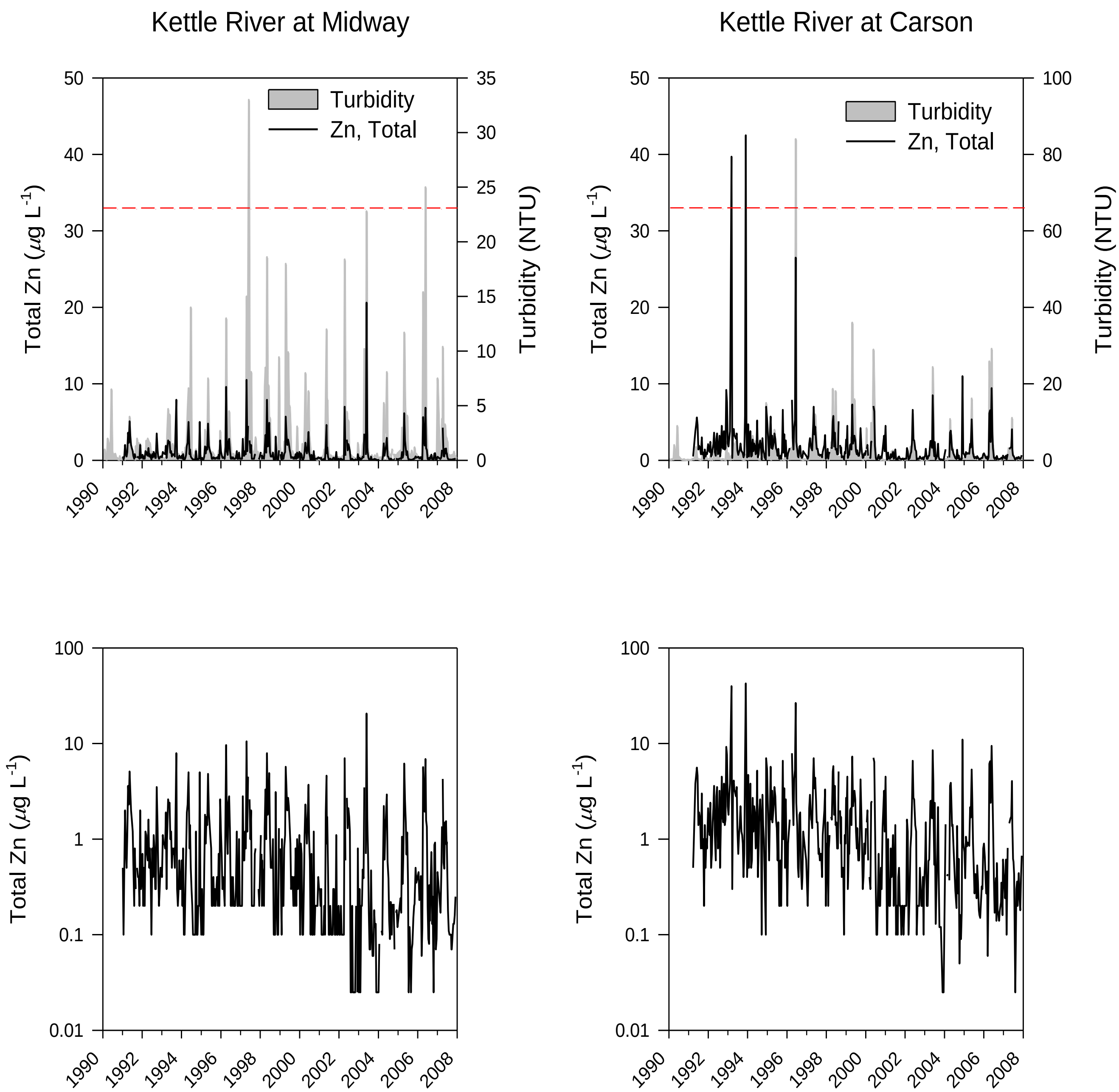
Figure 24: Uranium and turbidity measurements from the Kettle River at Midway (left) and Carson (right) from 1997 to 2008.





Zinc: Total zinc concentrations from the Kettle River were positively correlated with turbidity (Spearman Correlation, r_s = 0.65) and flow (Spearman Correlation, r_s = 0.53) at the Midway site and turbidity (Spearman Correlation, r_s = 0.51) at the Carson site. Statistically significant trends were detected for total zinc at both sites (Table 1 and Table 2); however, changing analytical detection limits impede our ability to conclude that total zinc concentration has been decreasing in over time (Figure 25). The B.C. aquatic life guideline for total zinc is a hardness-dependent guideline, and total zinc concentrations rarely exceeded this guideline at the Carson site and did not exceed this guideline at the Midway site (Figure 25). Total zinc concentrations are well below B.C. drinking water and irrigation guidelines.

Figure 25: Total zinc and turbidity measurements (top) and log-scale total zinc concentrations (bottom) from the Kettle River at Midway (left) and the Kettle River at Carson (right) from 1990 to 2008.



Note: Dashed red line denotes the B.C. aquatic life guideline for maximum total zinc.

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