# CANADA-BRITISH COLUMBIA WATER QUALITY MONITORING AGREEMENT

## WATER QUALITY ASSESSMENT OF THE COWICHAN AND KOKSILAH RIVERS


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# Executive Summary

The Cowichan and Koksilah rivers are both located on the south-eastern coast of Vancouver Island, B.C. Both watersheds are adjacent to one another, originate in the Vancouver Island Ranges and share very similar weather patterns. The Cowichan River watershed, which includes Cowichan Lake, drains an area of 939 $km^2$ while the Koksilah River watershed drains an area of 302 $km^2$.

There is currently a federal-provincial water quality monitoring station located on each of the rivers near their outlets to Cowichan Bay. Both sites have been monitored as federal-provincial stations since 1999. Water quality objectives were established for both rivers in 1989 to protect for various water uses including domestic and industrial uses and aquatic life. While permitted discharges occur only in the Cowichan River, both rivers are impacted by forestry, agriculture, on-site sewage disposal and urbanization.

Although both sites have been monitored since at least the 1980s, only the previous 10 years of data have been analysed for the purposes of this report as the more recent, routinely collected data is more suitable for status and trends assessment.

## Conclusions

- Water quality in the Cowichan and Koksilah rivers was typically good.
- Aluminum, copper and iron seasonally exceeded relevant guidelines and objectives, but these exceedences were generally related to increased seasonal flow and not considered a water quality concern.
- Cadmium rarely exceeded the CCME guideline for the protection of aquatic life and exceedences coincided with turbidity in most cases. It is recommended that dissolved cadmium be measured in addition to total to ensure that exceedences are related to suspended sediment and not to increases in dissolved portions of the analyte.

- Fecal Coliform levels continue to be an issue in both the Cowichan and Koksilah rivers, and levels were significantly increasing in the Cowichan River over the sample period at around 1 CFU per 100mL per year. Fecal coliform measurements exceeded the objectives established for the Koksilah River. It is recommended that the shellfish harvesting activities in Cowichan Bay be considered if the water quality objectives for the Cowichan and Koksilah rivers are updated in the future.
- Manganese seasonally exceeded the aesthetic drinking water objective.
- Dissolved oxygen exceeded the seasonal objectives established for the two rivers. Water temperatures also generally exceeded guidelines, although the magnitude and duration of these exceedences were not measured. Increases in these parameters may impact fisheries, especially if air temperatures and river flows change.
- Dissolved phosphorus concentrations in the Cowichan River were negatively correlated with flow and tended to increase during the summer months.
- There was a statistically significant increase in turbidity in the Koksilah River over the sample period although the rate of increase was not very large. This may result in increased loadings of associated metals and nutrients due to increases in suspended sediment.
- Since both watersheds are adjacent to one another, they share very similar weather patterns. As a result, there was a high degree of correlation in flow between the two rivers. This resulted in a high degree of correlation in flow-associated parameters in both rivers (i.e. various total metals) and flow in one river generally correlated well with certain metal concentrations in the other river (coherence).
- The Koksilah River appears to be more greatly influenced by groundwater, where as the Cowichan River is influenced by Cowichan Lake, a large headwater lake.

## RECOMMENDATIONS

Due to the high degree of coherence between both sites, it is recommended that the Koksilah River water quality monitoring station be deactivated. The Cowichan River water quality monitoring station should continue to operate to monitor surface water quality. It is recommended that *E. coli*, dissolved oxygen, water temperature, dissolved metals, turbidity and total suspended solids be considered as sampling parameters for any future surface water quality monitoring programs conducted in the Koksilah River. Additionally, due to its influence on surface water quality in the Koksilah River, ground water quality monitoring conducted in the Koksilah watershed should include dissolved metals and nutrients in the parameter suite. It is also recommended that the hydrometric stations on the Cowichan and Koksilah rivers continue to monitor river discharge.

It is recommended that dissolved metals be monitored in the Cowichan River for appropriate guideline comparisons. Additionally, tri- and hexavalent chromium should be monitored once suitable sampling and analytical methods are established for guideline comparison. It is also recommended that chlorophyll *a* be monitored during the summer months in both rivers to determine the effects of nutrients in the rivers and as a measure of algal growth. Finally, it is recommended that if the water quality objectives for the Cowichan and Koksilah rivers be reviewed, that the approved provincial aquatic life guidelines for copper, lead and zinc should be considered. In addition, shellfish harvesting activities in Cowichan Bay should be considered when updating the fecal coliforms and *E. coli* objectives, especially in the lower watershed.

## ACKNOWLEDGEMENTS

The data was reviewed and compiled by Ayisha Yeow, Sasha Wassick and Jessica Ingram, and a map of the Cowichan and Koksilah watersheds was created by Jennifer MacDonald. This report was reviewed by Andrea Ryan of Environment Canada, and Nicole Obee, Deb Epps and John Deniseger 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

### 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 report examines surface water quality monitoring sites located on the Cowichan and Koksilah rivers (Figure 1). These rivers are located adjacent to one another and are subject to essentially the same climatic conditions resulting in similar flow regimes.

### ii) The Cowichan River

The Cowichan River watershed is located on the south-eastern coast of Vancouver Island, B.C. and is a Canadian Heritage River. The headwaters are located in the Vancouver Island Ranges surrounding Cowichan Lake, and the river flows forty-seven kilometres east (CHRS 2010) and drains into the Cowichan Bay estuary near Duncan. The watershed drains a total area estimated at 939 $km^2$. The Cowichan River water quality monitoring station is located two and one-half kilometres downstream from the Highway 1 Bridge, two kilometres upstream from the confluence with the Koksilah River and three kilometres upstream from the mouth at Cowichan Bay (Pommen Water Quality Consulting 2004a). Although water quality data has been collected since 1985 at this site, it has only been monitored as a federal-provincial station with bi-weekly monitoring since 1999 (Pommen Water Quality Consulting 2004a).

The Cowichan River is dominated by high winter precipitation resulting in elevated winter flows and soft water (McKean 1989). River flow is monitored at the Cowichan River near Duncan by the Water survey of Canada (08HA011, 826 $km^2$). This station has been continuously monitored since 1965, although seasonal and periodic measurements extend to 1912 (WSC 2010). Cowichan River flow is regulated at the outlet of Cowichan Lake by a B.C. Forest Products weir (McKean 1989), and water storage capacity provided by Cowichan Lake allows for higher summer flows in the Cowichan River than in the adjacent Koksilah River (McKean 1989).

The Cowichan River watershed provides for a number of water uses. The river supports significant sports and commercial fish species including coho, chum and chinook salmon, and steelhead and trout (Pommen Water Quality Consulting 2004a). The municipal and domestic licenses within the watershed include the Town of Lake Cowichan which withdraws water from Cowichan Lake, and numerous domestic and irrigation licenses exist for the river mainstem. Industrial uses include Catalyst Paper Corporation which has licenses for industrial and storage use (BC Water Licenses 2010). Recreational uses include swimming and hiking with five provincial parks and numerous regional, municipal and community parks established within the watershed (Rideout *et al*. 2000).

Point source discharges include the Duncan-North Cowichan Joint Utilities Sewage Treatment Lagoons and effluent from a provincial trout hatchery, both located within two kilometres of the water quality monitoring site (Pommen Water Quality Consulting 2004a). The Town of Lake Cowichan sewage treatment plant also discharges into the Cowichan River (Rideout *et al*. 2000) above the water quality site. Non-point source impacts include logging, agriculture, urbanization and numerous onsite sewage disposal systems (Rideout *et al*. 2000).

iii) The Koksilah River

The Koksilah River watershed is located on the south-eastern corner of Vancouver Island, immediately south of the Cowichan River. The Koksilah River originates in the Vancouver Island Range on Waterloo Mountain and has an approximate length of forty-four kilometres (Rideout *et al*. 2000). The Koksilah River drains an area of approximately 302 $km^2$ before draining into the Cowichan River one kilometre upstream of the Cowichan Bay. The water quality monitoring site is located at the Highway 1 bridge crossing, two kilometres upstream of the confluence with the Cowichan River (Pommen Water Quality Consulting 2004b). Although water quality data has been collected since 1971 at this site, it has only been monitored as a federal-provincial station with bi-weekly sampling since 1999 (Pommen Water Quality Consulting 2004b).

Water flow in the Koksilah River follows a similar pattern to that in the Cowichan River, but the lack of a large headwater lake has resulted in lower summer flows (McKean 1989) and a greater influence of groundwater inputs, resulting in some differences in water chemistry. River discharge has been monitored by the Water Survey of Canada near Cowichan continuously from 1960 to present (08HA003, 209 $km^2$; WSC 2010).

The Koksilah River has a number of water uses. The Koksilah River supports numerous commercial and sports fish including those found in the Cowichan River except brown trout (Rideout *et al*. 2000). The Koksilah River provides water for industrial, domestic and irrigation uses (BC Water Licenses Report 2010), and supports numerous recreational activities.

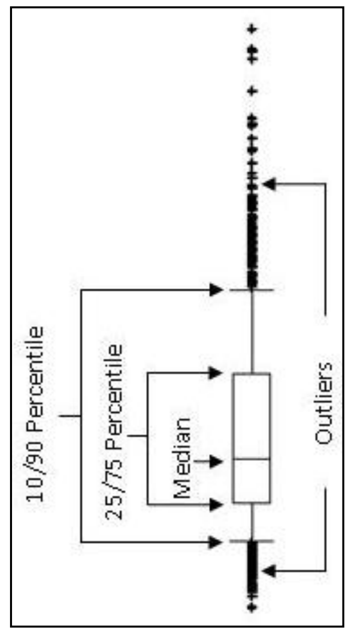
The Koksilah River does not receive any authorised discharges and although there is some urban development (Pommen Water Quality Consulting 2004b), the extent of development is much less than that along the Cowichan River (Rideout *et al*. 2000). Non-point source impacts include agriculture, mainly dairy farms, and onsite sewage disposal systems which are sources of bacteriological and nutrient contamination in the Koksilah River (Rideout *et al*. 2000). Other sources of contamination include upstream forestry, run-off from gravel washing and a landfill/incinerator (Pommen Water Quality Consulting 2004b).

**Figure 1:** Map of the Cowichan and Koksilah watersheds, Vancouver Island, British Columbia.

### 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

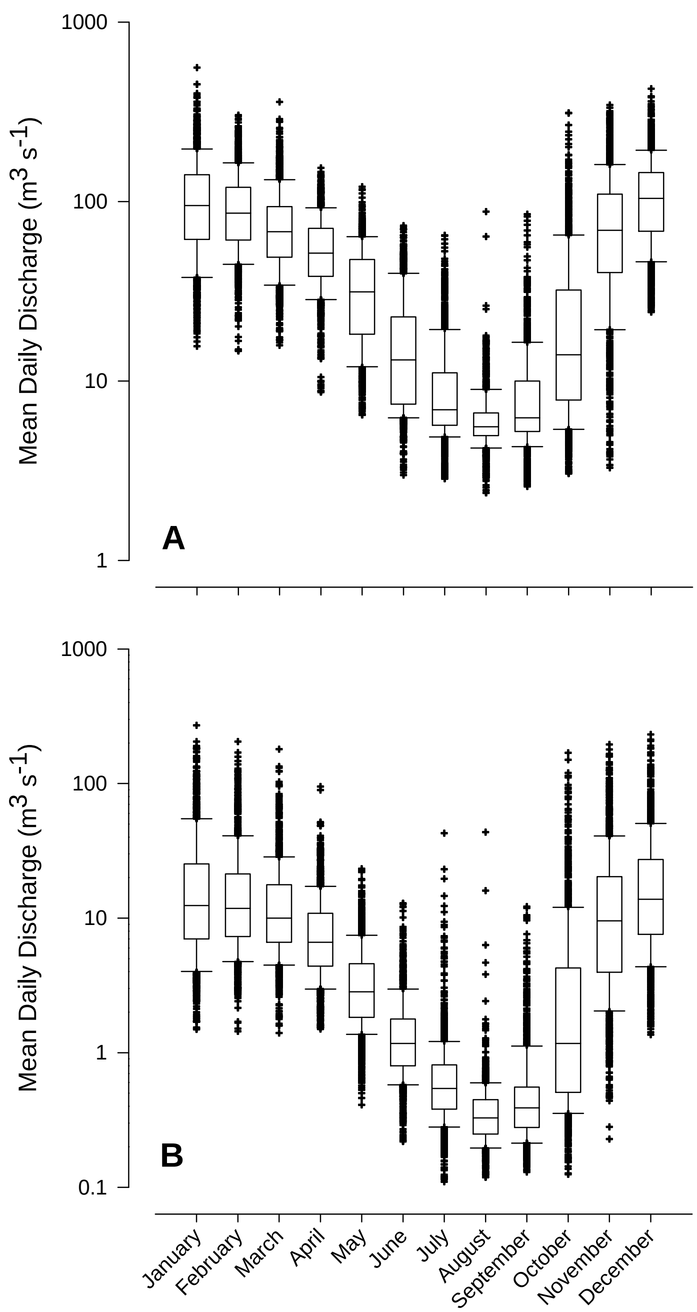
Non-parametric statistical tests were largely used since most water quality parameters are not normally distributed. Therefore, time-series trend analyses were conducted using the Mann-Kendall (MK) trend test (Helsel and Hirsh 1991) and Sen's slope estimate was used to approximate change over time.

### 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), the Canadian Council of Ministers of the Environment *Guidelines for the Protection of Aquatic Life Guidelines* (2007), and the water quality objectives developed for the Cowichan and Koksilah rivers (McKean 1989). This report only examines data from 1999 to 2008. Metals were assessed using data from 2005 to 2008 as this period includes low-level metal analyses. Statistical trends tests were conducted only on parameters which were sampled over the entire sample period (1999-2008).

**Figure 2:** Montly box-and-whisker plots of mean daily discharge from the Cowichan River near Duncan (A; 1965-2007) and the Koksilah River at Cowichan (B; 1960-2008).




Substances listed below are not discussed further since concentrations largely met guidelines or had no significant temporal trends. These substances include the following: ammonia, antimony, arsenic, barium, beryllium, bismuth, boron, bromide, chloride, cobalt, lithium, magnesium, molybdenum, nickel, nitrate plus nitrite, pH, potassium, filterable residue (TDS), selenium. silica and silicon, strontium, thallium, tin, uranium and vanadium. Median concentrations of total nitrogen were considered oligotrophic in both rivers (Kalff 2002). Benthic invertebrate bio-monitoring has been conducted and continuous temperature sensors have been installed in both watersheds. Results from biological and continuous monitoring will increase our ability to assess impacts on the aquatic biota and will be included in future assessment reports.

**FLOW:** Flow was measured at the Water Survey of Canada stations located at the Koksilah River at Cowichan (08HA003) and the Cowichan River near Duncan (08HA011). River flows in the Cowichan and Koksilah rivers were typical of coastal streams with little snow pack; maximum stream flows occur in the fall while baseflows occur in late-summer (Figure 2; McKean 1989). River flow is greatest in the Cowichan River, with greater peak flows and baseflows. Unlike the Cowichan River, the Koksilah River has very low baseflows primarily due to the absence of a large headwater lake (McKean 1989). Cowichan River flows have been regulated since 1965 by a weir at the mouth of Lake Cowichan. This weir was installed by BC Forest Products to ensure sufficient water storage capacity in Lake Cowichan to supply the pulp mill at Crofton (McKean 1989; Pommen Water Quality Consulting 2004).

River flow varies annually in both the Cowichan River at Duncan (Figure 3) and the Koksilah River at Cowichan (Figure 4). There was no trend in estimated total annual discharge in either river (linear regression: Cowichan River at Duncan, 1965-2007, $p > 0.05$; Koksilah River at Cowichan, 1960-2008, $p > 0.05$) which suggests that total annual discharge had not changed over the sample period. As the Koksilah and Cowichan watershed are adjacent to one another, there was a very strong correlation in estimated total annual discharge in both rivers (Pearson Correlation, $r = 0.91$). This suggests that they are affected by very similar weather patterns, as indicated by Rideout *et al*. (2000), resulting in high degree of coherence in certain water quality variables.

**Figure 3:** Annual box-and-whisker plots of mean daily discharge measured at the Water Survey of Canada hydrometric station located at the Cowichan River near Duncan (08HA011) from 1965 to 2007.

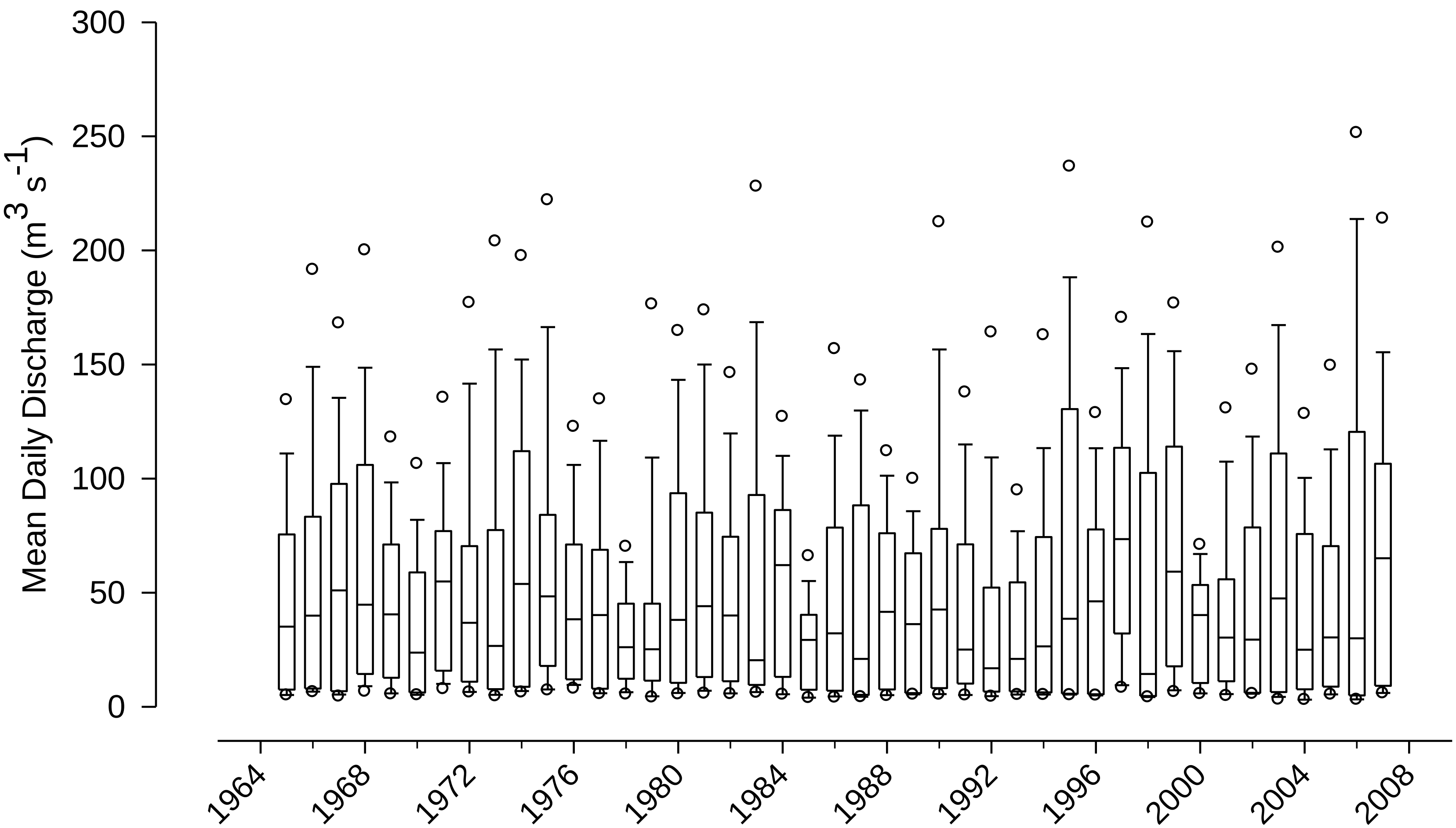
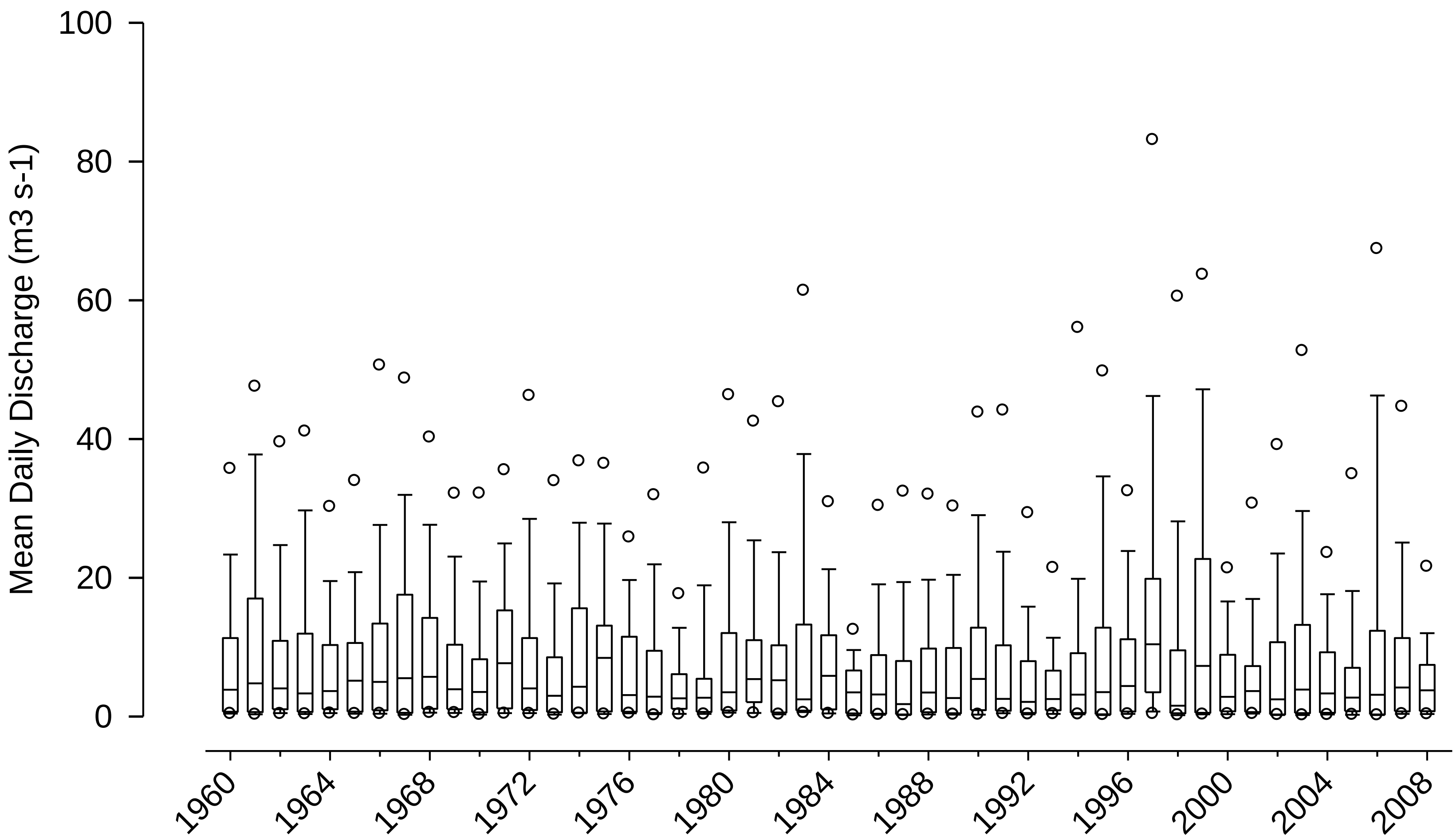


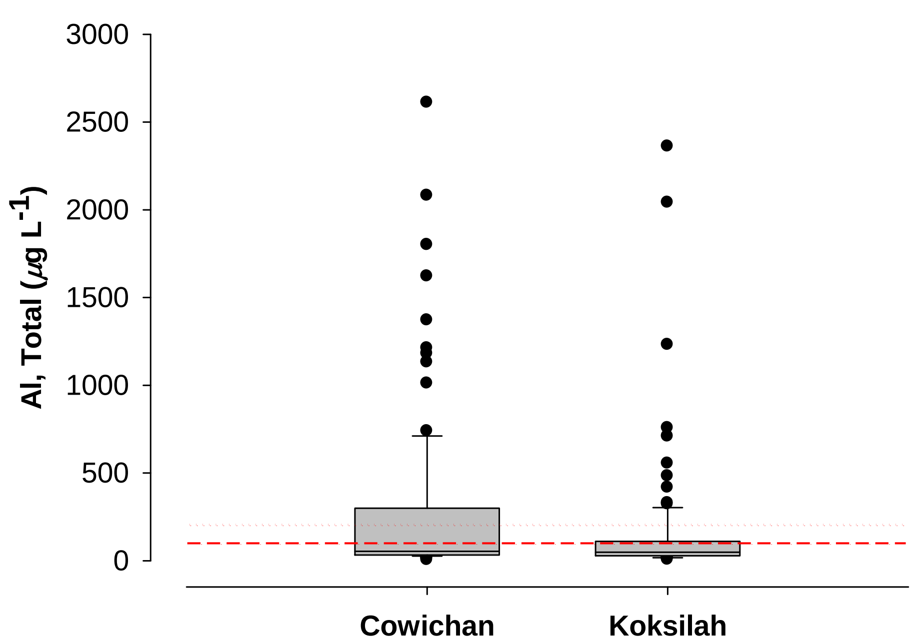
**Figure 4:** Annual box-and-whisker plots of mean daily discharge measured at the Water Survey of Canada hydrometric station located at the Koksilah River at Cowichan (08HA003) from 1960 to 2008.



**ALUMINUM:** Aluminum was measured as total aluminum in the Cowichan and Koksilah rivers over the sample period and was typically higher in the Cowichan River than in the Koksilah River (Figure 5). Total aluminum concentrations seasonally exceeded the B.C. aquatic life guideline established for dissolved Al and the CCME aquatic life guideline established for total Al, both set at 100 $\mu$g L$^{-1}$; total Al concentrations also seasonally exceeded the B.C. drinking water supply guideline established for dissolved Al at 200 $\mu$g L$^{-1}$ (Figure 5 and Figure 6; Butcher 1988).

Total aluminum concentrations were highly positively correlated with turbidity (Spearman Rank Order Correlation: Cowichan River, $r_s = 0.79$; Koksilah River, $r_s = 0.75$) and mean daily discharge (Spearman Rank Order Correlation: Cowichan River, $r_s = 0.88$; Koksilah River, $r_s = 0.73$). Thus, seasonal spikes in total aluminum concentrations were generally associated with precipitation events, higher water levels, and largely mirrored the seasonal pattern in turbidity (Figure 6); however, there were a few instances where total Al spikes did not appear to be associated with turbidity and may have been related to dissolved portions of the analyte. In general, total Al concentrations appear to be associated with suspended particulate matter

**Figure 5:** Box-and-whisker plots of total aluminum concentrations from the Cowichan and Koksilah rivers.

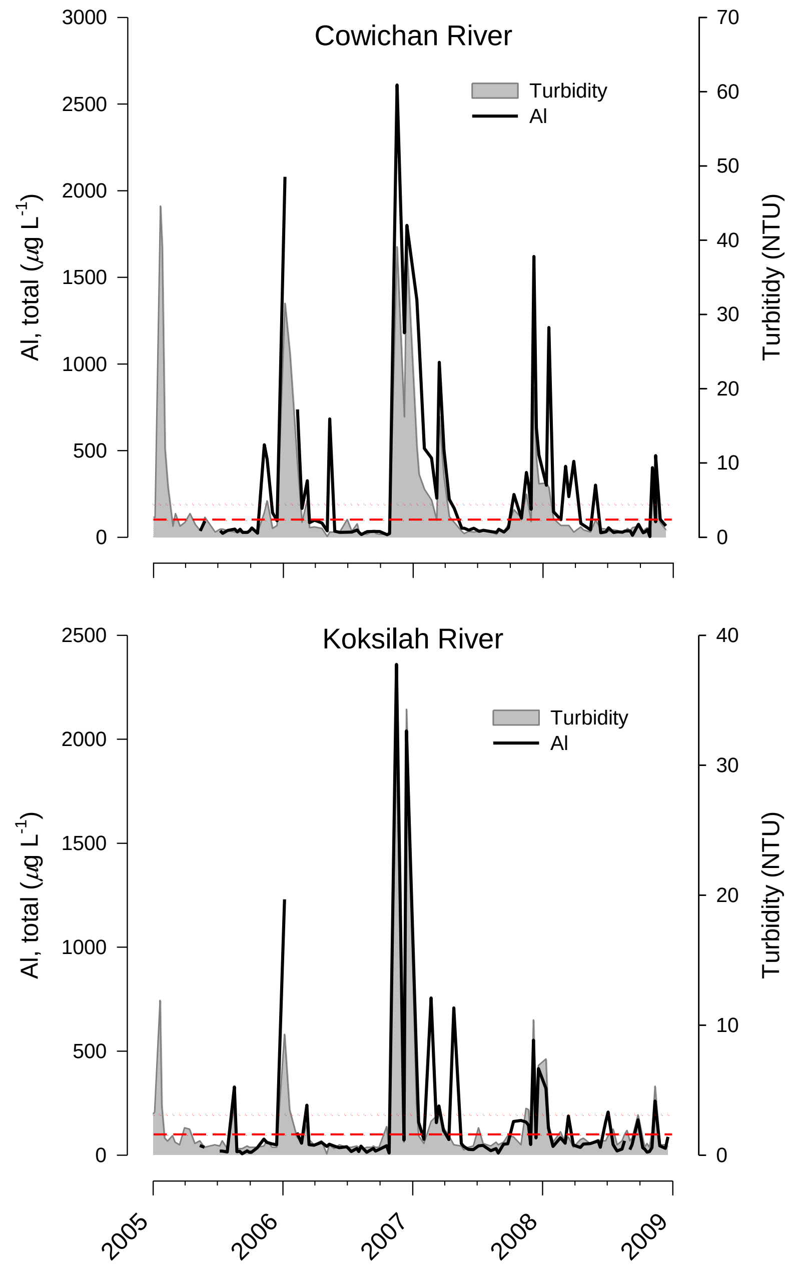



Note: dashed red line represents the B.C. aquatic life guideline for dissolved Al and the CCME guideline for total Al. The dotted red line represents the B.C. drinking water supply guideline for dissolved Al.

and not a concern to aquatic biota. It is recommended that dissolved Al be measured in addition to total Al to allow for direct comparisons to the B.C. guideline and to determine if non-turbidity related spikes are due to an increase in dissolved Al.

Interestingly, mean daily discharge measured in the Cowichan River was highly correlated with total Al concentrations in the Koksilah River (Spearman Rank Order Correlation, $r_s = 0.79$); similarly, mean daily discharge measured in the Koksilah River was highly correlated with total Al concentrations in the Cowichan River (Spearman Rank Order Correlation, $r_s = 0.83$). This suggests changes in flow in one river could potentially be used to estimate total Al concentrations in the other river.

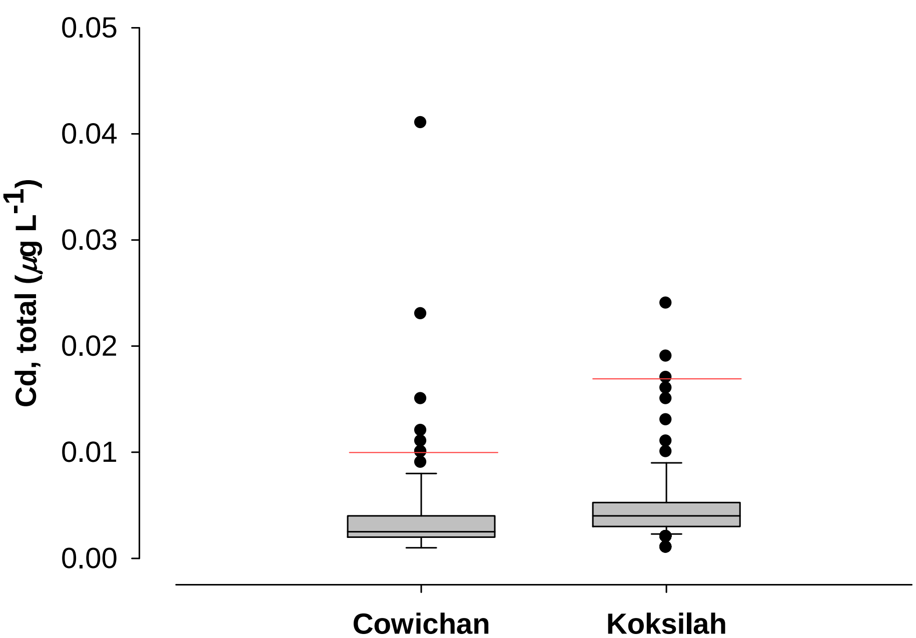
**Figure 6:** Total aluminum and turbidity measurement from the Cowichan and Koksilah rivers over the sample period.




Note: dashed red line represents the B.C. aquatic life guideline for dissolved Al and the CCME guideline for total Al. The dotted red line represents the B.C. drinking water supply guideline for dissolved Al.

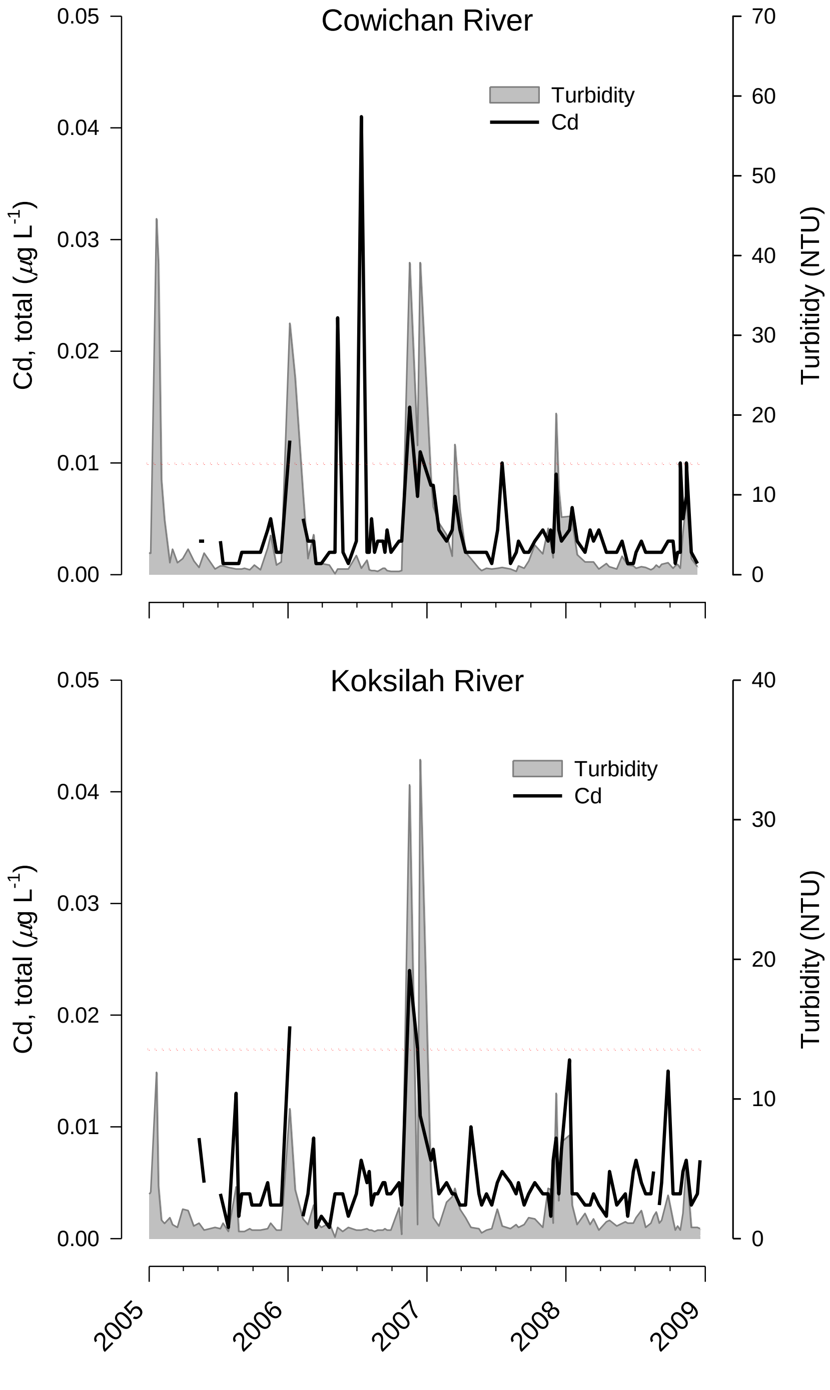
**CADMIUM:** Cadmium was measured in the total form in both the Cowichan and Koksilah rivers over the sample period. Total cadmium concentrations in the Koksilah River were typically greater than those in the Cowichan River (Figure 7), but concentrations rarely exceeded the hardness-dependant CCME aquatic life guideline (calculated using median hardness concentration for each site over the sample period; Figure 7 and Figure 8). Mean daily discharge and turbidity were positively correlated with total cadmium in the Cowichan River at Duncan (Spearman Rank Order Correlation: mean daily discharge, $r_s = 0.43$; turbidity, $r_s = 0.50$) while turbidity was positively correlated with total cadmium in the Koksilah River (Spearman Rank Order Correlation: turbidity, $r_s = 0.38$), suggesting that these parameters partly influence cadmium concentrations. Total cadmium exceedences in the Koksilah River were associated with turbidity spikes and not likely bioavailable; large exceedences in the Cowichan River were not associated with turbidity spikes (Figure 8) suggesting that these were potentially associated with increases in dissolved portions of the analyte (Figure 8). Although there were exceedences, they were rare and transient. It is recommended that dissolved cadmium be measured in addition to total to ensure that exceedences are not related to increases in dissolved concentrations.

**Figure 7:** Box-and-whisker plots of total cadmium concentrations from the Cowichan and Koksilah rivers.




Note: Solid red line represents the hardness-dependant CCME aquatic life guideline for total Cd.

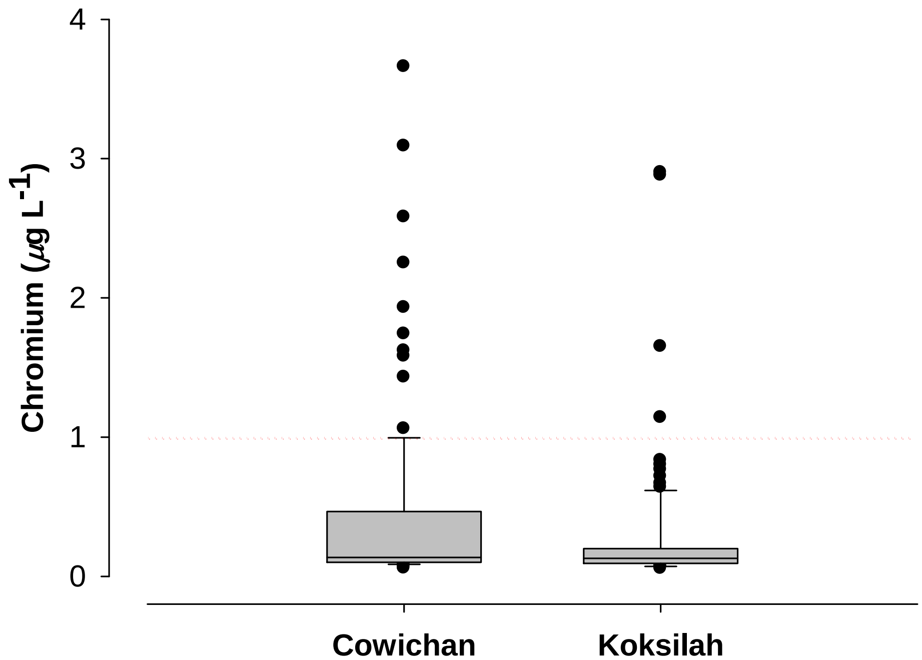
**Figure 8:** Total cadmium and turbidity measurement from the Cowichan and Koksilah rivers over the sample period.




Note: Solid red line represents the hardness-dependant CCME aquatic life guideline for total Cd.

**CHROMIUM:** Chromium was measured in the total form at both sites. Although median concentrations were similar in both rivers, maximum concentrations in the Cowichan River were typically greater than those in the Koksilah River (Figure 9 and Figure 10). CCME aquatic life guidelines are established for two different forms of chromium: trivalent chromium has guideline of 8.9 $\mu$g $L^{-1}$ and hexavalent chromium has a guideline of 1 $\mu$g $L^{-1}$. Generally, total chromium did not exceed the aquatic life guideline established for hexavalent chromium over the sample period in both rivers (Figure 9 and Figure 10).

**Figure 9:** Box-and-whisker plots of total chromium concentrations from the Cowichan and Koksilah rivers.

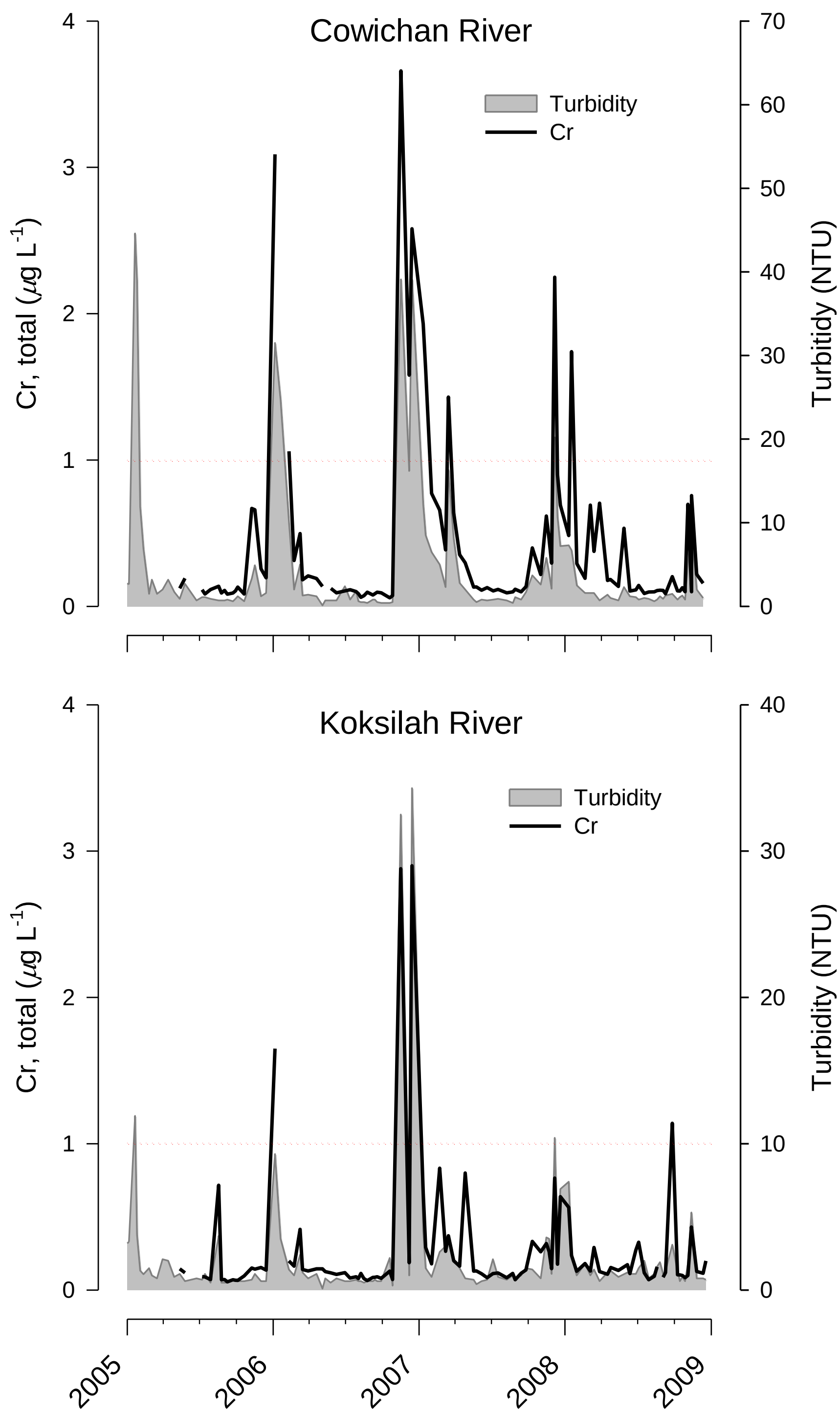



Note: the dotted red line represents the CCME and B.C. aquatic life guideline for hexavalent chromium.

Total chromium was highly positively correlated with mean daily discharge and turbidity in both the Cowichan (Spearman Rank Order Correlation: mean daily discharge, $r_s = 0.80$; turbidity, $r_s = 0.92$) and the Koksilah (Spearman Rank Order Correlation: mean daily discharge, $r_s = 0.76$; turbidity, $r_s = 0.73$) rivers. This suggests that total chromium closely follows the seasonal pattern of flow and turbidity, as demonstrated in Figure 10. As a result, spikes in total chromium are likely associated with increased suspended sediment during high flows and not considered a risk to aquatic life.

Similar to total aluminum, total chromium concentrations in the Koksilah River were highly positively correlated with mean daily discharge in the Cowichan River (Spearman Rank Order Correlation, $r_s$ = 0.84) and mean daily discharge from the Koksilah River was highly positively correlated with total chromium concentrations in the Cowichan River (Spearman Rank Order Correlation, $r_s$ = 0.87), suggesting that flow in one river might predict total chromium concentrations in the other river.

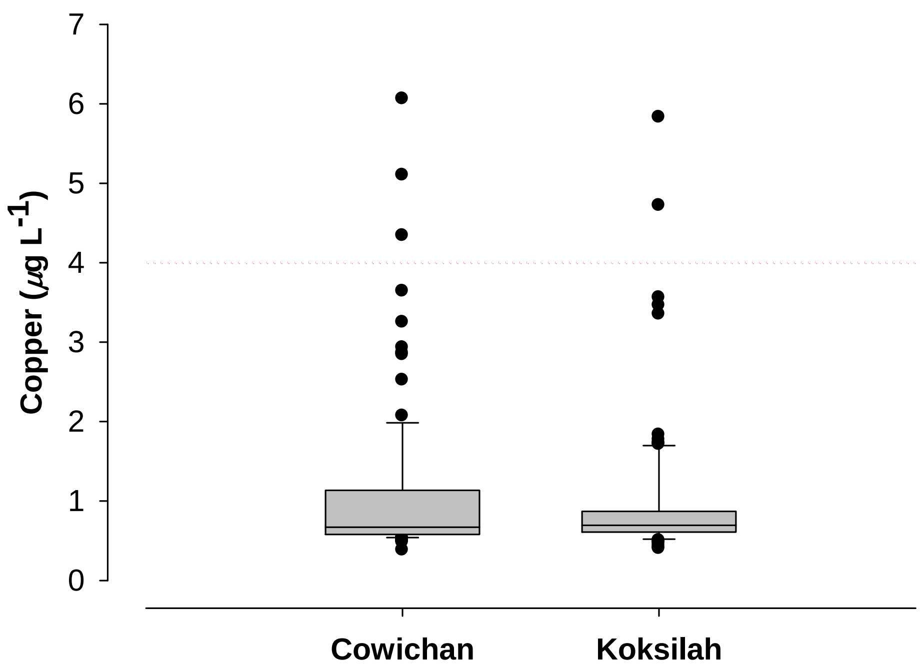
**Figure 10:** Total chromium and turbidity measurement from the Cowichan and Koksilah rivers over the sample period.




Note: the dotted red line represents the CCME and B.C. aquatic life guideline for hexavalent chromium.

**COPPER:** Copper was measured as total copper at both sampling stations. Median total copper concentrations were similar at both stations but tended to vary to a greater extent in the Cowichan River (Figure 11). A maximum water quality objective was established for dissolved copper concentrations in the Cowichan and Koksilah rivers at 4 $\mu$g L$^{-1}$ (McKean 1989). This objective was rarely exceeded over the sample period and median concentrations were below 1 $\mu$g L$^{-1}$ (Figure 11).

**Figure 11:** Box-and-whisker plots of total copper concentrations from the Cowichan and Koksilah rivers.



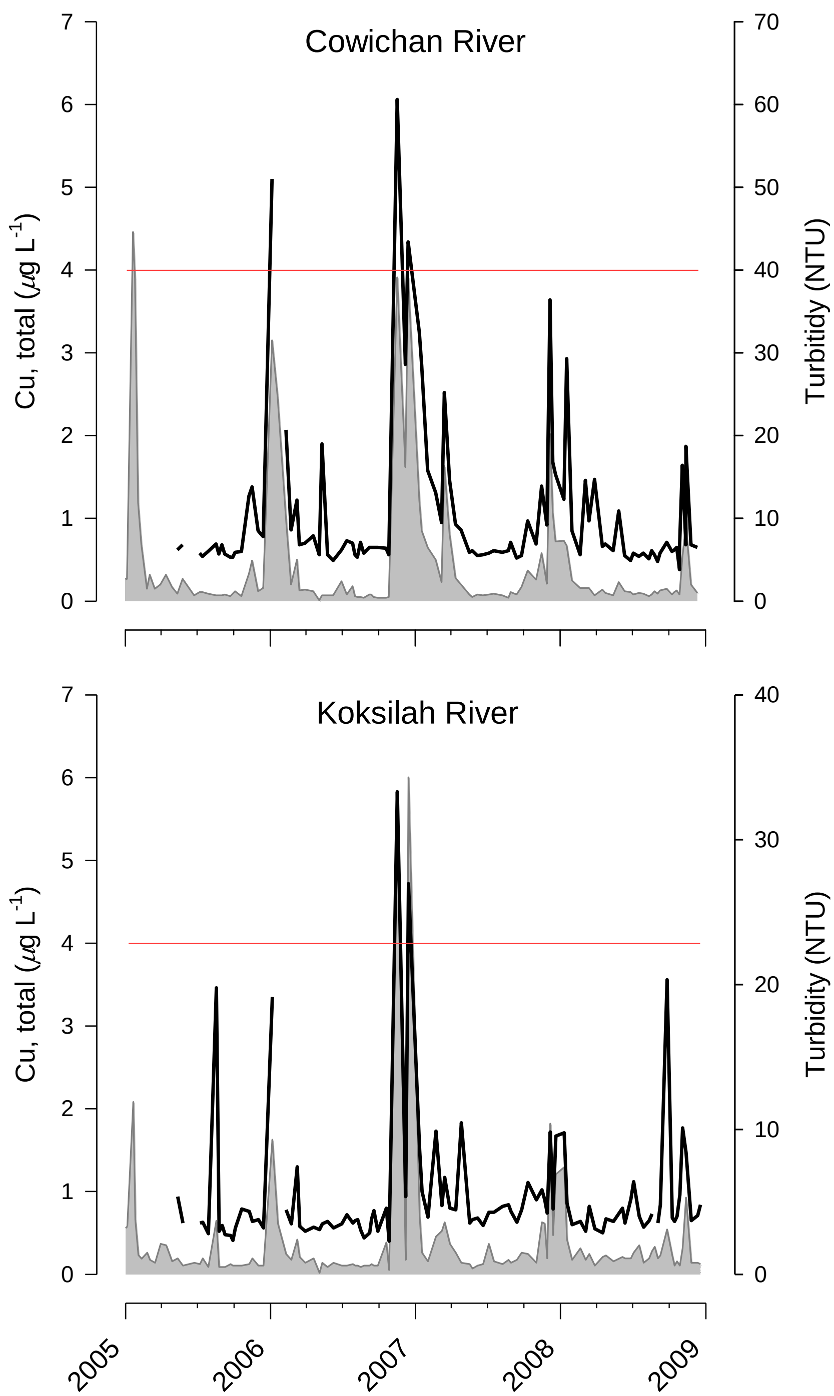

Note: the dotted red line represents the maximum objective for dissolved copper.

Total copper concentrations were highly positively correlated with mean daily discharge and turbidity in the Cowichan River (Spearman Rank Order Correlation: mean daily discharge, $r_s$ = 0.73; turbidity, $r_s$ = 0.71). These correlations also existed in the Koksilah River, although to a lesser extent than in the Cowichan River (Spearman Rank Order Correlation: mean daily discharge, $r_s$ = 0.47; turbidity, $r_s$ = 0.59). Since total copper concentrations varied with flow and turbidity, spikes in total copper concentrations were likely due to elevated levels of suspended particulate matter. For example, total copper exceedences in Figure 12 coincided with spikes in turbidity measurements.

Similar to other total metal measurements, mean daily discharges in the Cowichan River were positively correlated with total copper concentrations in the Koksilah River (spearman correlation, $r_s = 0.59$); the mean daily discharges measured in the Koksilah River were also positively correlated with total copper in the Cowichan River (Spearman Rank Order Correlation, $r_s = 0.72$).

It is recommended that the hardness-based B.C. aquatic life guideline be considered if the copper objective is updated since total copper concentrations are generally below the objectives established for dissolved copper. Dissolved copper should also be measured for trend detection.

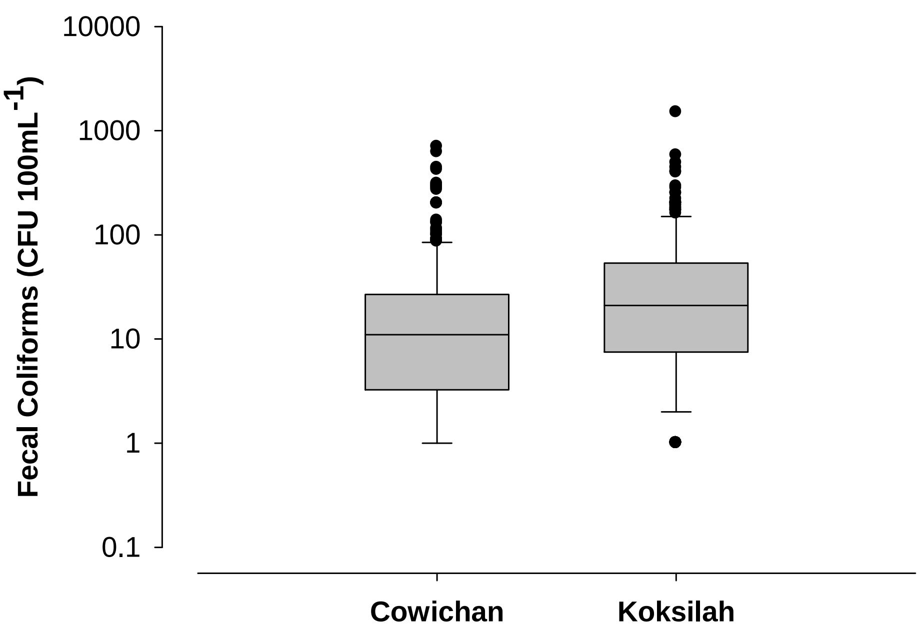
**Figure 12:** Total copper and turbidity measurement from the Cowichan and Koksilah rivers over the sample period.




Note: the dotted red line represents the maximum objective for dissolved copper.

**FECAL COLIFORMS:** B.C. guidelines for fecal coliforms are generally associated with human-related water uses (i.e. drinking water, irrigation and shellfish harvesting) and are reported as coliform forming units (CFU). Guideline comparisons are a result of a statistical derivation of a 5 sample in 30 day sampling frequency. Both the Cowichan and Koksilah rivers have numerous licenses for domestic water uses and depending on the level of treatment, result in differing fecal coliform guidelines (Warrington 1988). Specific fecal coliforms objectives were developed for sections of the Cowichan River and the entire Koksilah River (McKean 1989).

**Figure 13:** Box-and-whisker plots of fecal coliform measurements from the Cowichan and Koksilah rivers.




Fecal coliform measurements were generally greater in the Koksilah River than in the Cowichan River, although measurements varied greatly in both rivers over the sample period (Figure 13 and Figure 14). Sufficient samples were usually collected once a year for objectives comparison and attainment monitoring and these results are reported in Table 1. Objectives do not exist for the Cowichan River downstream of Highway 1; the objective for the Koksilah River is 10 CFU $100mL^{-1}$ (derived from the $90^{th}$ percentile of 5 samples in 30 days; McKean 1989). The fecal coliform measurements from the Koksilah River did not meet this objective during the sample period (Table 1).

There was a significant increasing trend in fecal coliform measurements from the Cowichan River over the sample period (Mann-Kendall, $p < 0.001$, slope = 0.9 CFU $100mL^{-1}$ $year^{-1}$). This trend may be due to a combination of the sewage treatment located upstream of the sample site, increased urbanization and agriculture. Further study is required to determine the source of the increasing trend in fecal coliform measurements in the Cowichan River. There were no trends in fecal coliform measurements in the Koksilah River over the sample period.

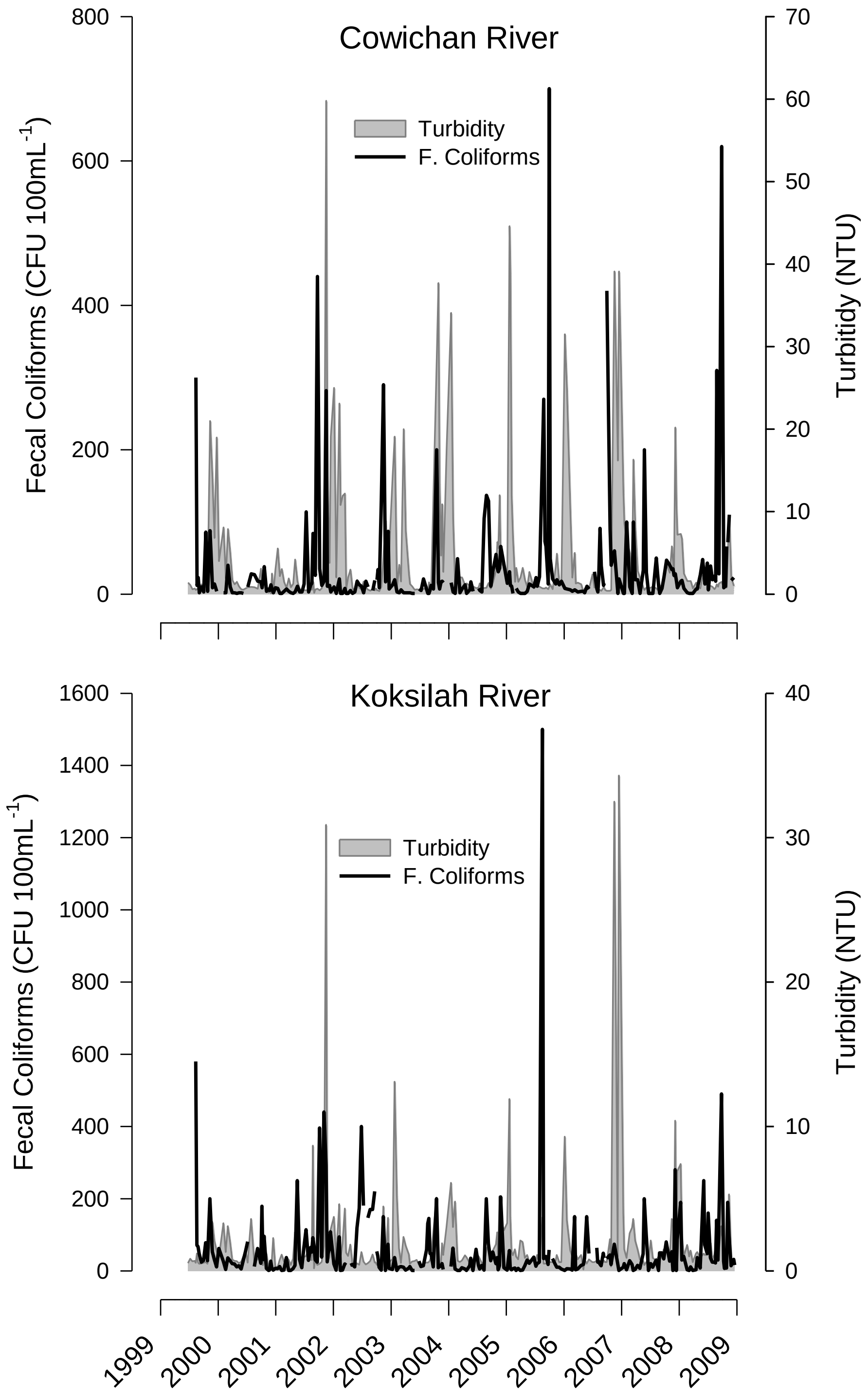
The Cowichan and Koksilah river monitoring stations are located near where they drain into the Cowichan Bay and may impact shellfish harvesting. The fecal coliform guideline for shellfish harvesting is a median of 14 and $90^{th}$ percentile of 43 CFU $100mL^{-1}$ based on the sampling frequency 5 samples in 30 days. This guideline was rarely met in the Cowichan and Koksilah rivers (Table 1). Although not a designated use in the Cowichan and Koksilah rivers, it is recommended that the shellfish harvesting activities in Cowichan Bay be considered when updating the microbiological indicator objectives for fecal coliforms and *E. coli* for both rivers. It is also recommended that water be treated appropriately prior to drinking water use.

**Table 1:** Fecal coliform measurements from the Cowichan and Koksilah rivers using the recommended guideline/ objective sampling frequency.

| | **Cowichan River*** | **Koksilah River*** |
|---|---|---|
| **2000** | 11 | 19 |
| **2001** | 65 | 83 |
| **2001** | 174 | 218 |
| **2003** | 18 | 17 |
| **2004** | 62 | 138 |
| **2006** | 70 | 49 |
| **2007** | 35 | 189 |
| **2008** | 70 | 125 |
| **2008** | 95 | N/A |

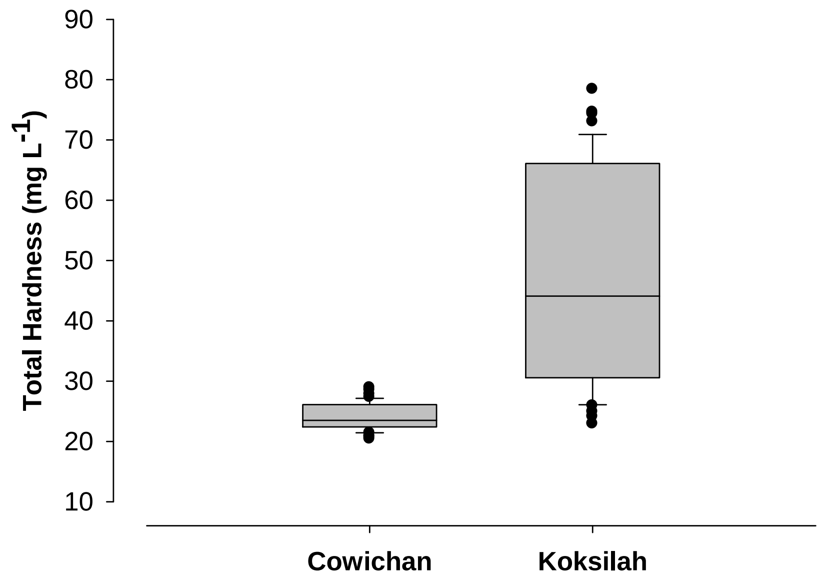
*$90^{th}$ percentile of 5 samples in 30 days.

**Figure 14:** Fecal coliform and turbidity measurement from the Cowichan and Koksilah rivers over the sample period.



**HARDNESS:** Total hardness is largely a measure of calcium and magnesium and measurements are often a calculated result derived using the following equation: [Hardness, mg equivalent $CaCO_3$ mg $L^{-1}$ = 2.497(Ca, mg $L^{-1}$) + 4.118 (Mg, mg $L^{-1}$)] (Eaton *et al.* 2005). Total hardness is an important component of water quality, affecting the toxicity of a variety of metals but is generally not considered a parameter of concern for drinking water or aquatic life. Total hardness measurements began in August of 2007 in the Cowichan and Koksilah rivers.

**Figure 15:** Box-and-whisker plots of fecal coliform measurements from the Cowichan and Koksilah rivers.

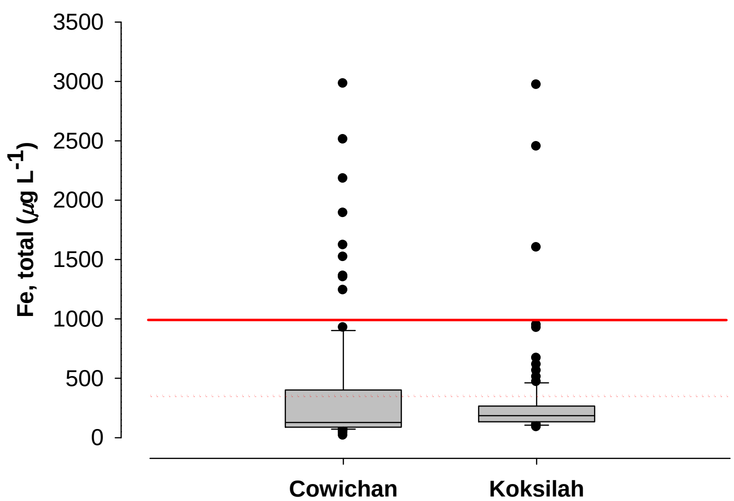



Hardness measurements in the two rivers are very different (Figure 15). Total hardness measurements in the Cowichan River are likely influenced by the presence of an upstream lake, and differences in the geology and exposure in both watersheds might also contribute to the differences in total hardness measurements. These hardness measurements suggest that the Cowichan River may be more sensitive to changes in certain metal concentrations than the Koksilah River.

Spearman Rank Order Correlations suggest that hardness concentrations are highly negatively correlated with mean daily discharge in both rivers over the sample period (Cowichan River, $r_s$ = -0.92; Koksilah River, $r_s$ = -0.94). Similar to other parameters, mean daily discharge in the Cowichan River was highly negatively correlated with total hardness in the Koksilah River ($r_s$ = -0.88), and mean daily discharge measured in the Koksilah River was highly negatively correlated with total hardness in the Cowichan River ($r_s$ = -0.80). This suggests that shared weather patterns are effecting total hardness measurements in a similar manner.

**IRON:** Iron was measured as total iron in both the Cowichan and Koksilah rivers. Median concentrations were similar in both rivers over the sample period but varied to a larger degree in the Cowichan River (Figure 16). B.C. aquatic life guidelines are established for dissolved and total iron and 350 $\mu$g L$^{-1}$ and 1000 $\mu$g L$^{-1}$ (Phippen *et al.* 2008), respectively; the CCME aquatic life guideline is 300 $\mu$g L$^{-1}$ for total iron. Total iron generally does not exceed the B.C. aquatic life guideline (Figure 16) and exceedences were associated with turbidity spikes (Figure 17).

**Figure 16:** Box-and-whisker plots of total iron concentrations from the Cowichan and Koksilah rivers.

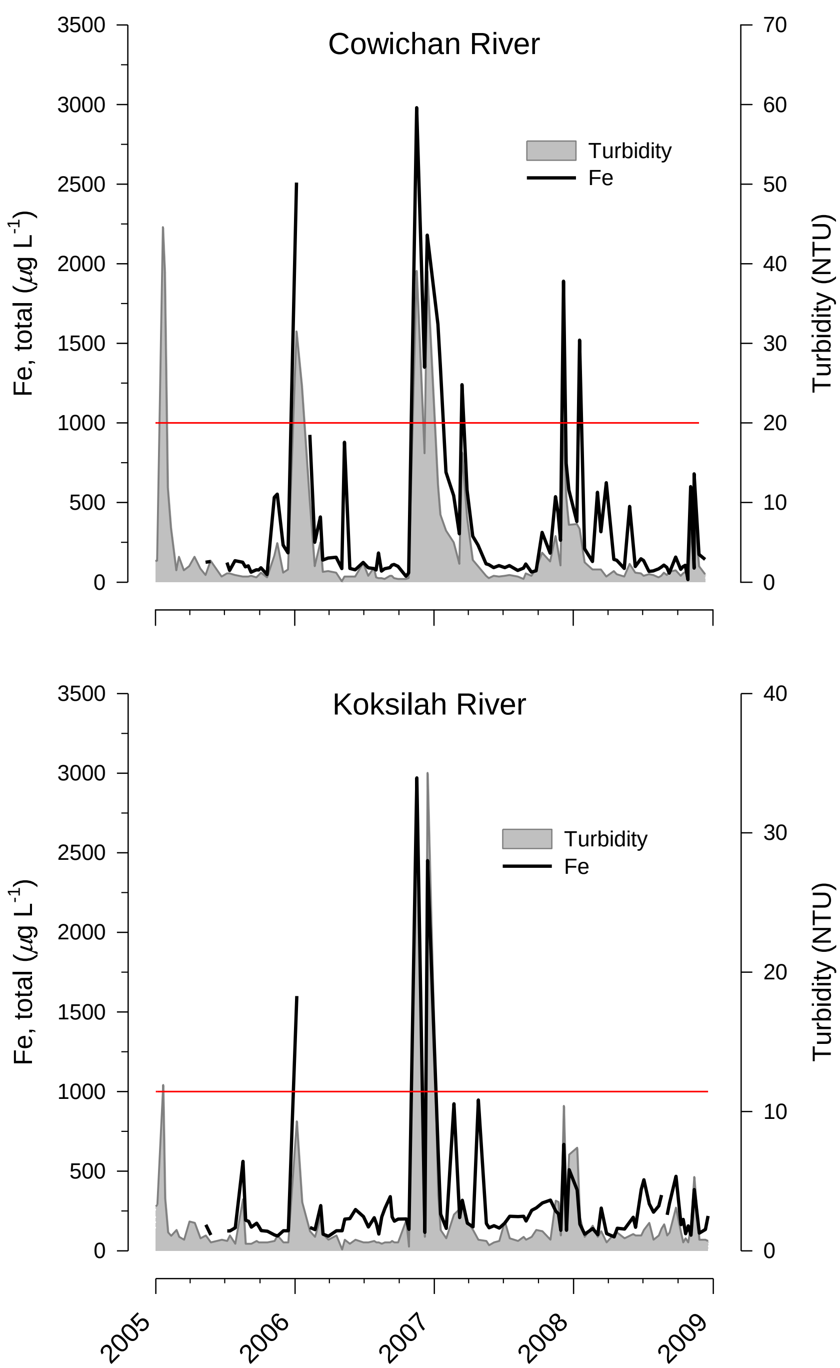



Note: the dotted red line represents the B.C. aquatic life guideline for

Total iron was highly correlated with mean daily discharge and turbidity in the Cowichan River (Spearman Rank Order Correlation: mean daily discharge, $r_s$ = 0.81; turbidity, $r_s$ = 0.74). Interestingly, total iron was not correlated with mean daily discharge in the Koksilah River, but was positively correlated with turbidity (Spearman Rank Order Correlation, $r_s$ = 0.44), although to a lesser extent than the Cowichan River. Total iron is more closely associated with suspended solids and increasing flow in the Cowichan River; iron concentrations in the Koksilah River seem to be partly driven by dissolved concentrations of the analyte. Nevertheless, spikes in total iron were associated with elevated turbidity levels in both rivers and suggest that suspended sediment were the sources of these exceedences (Figure 17).

It is recommended that dissolved iron be measured in addition to total iron in to compare against provincial aquatic life guidelines and to monitor dissolved iron concentrations in the Koksilah River to determine if this is an issue of concern.

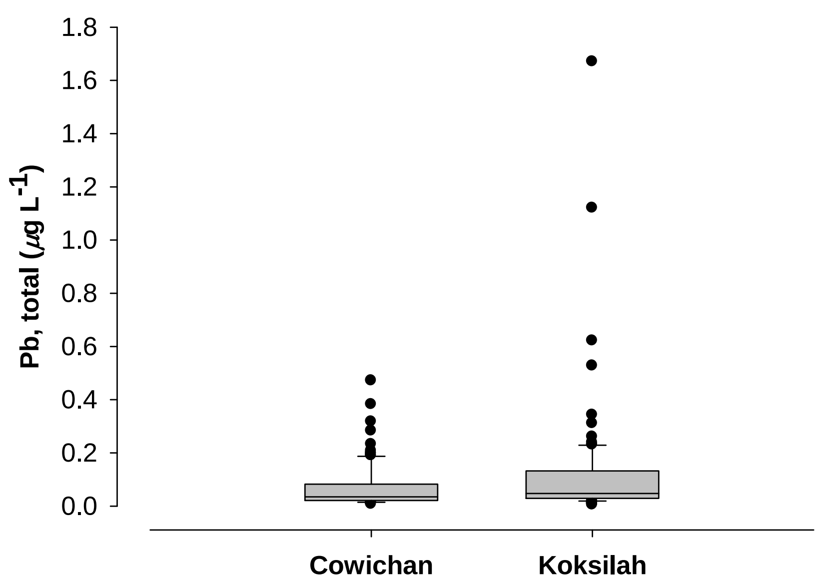
**Figure 17:** Total iron and turbidity measurement from the Cowichan and Koksilah rivers over the sample period.




Note: the solid red line represents the B.C. aquatic life guideline for total Fe.

**LEAD:** Lead was measured as total lead in the Cowichan and Koksilah rivers. Water quality objectives were developed for dissolved lead for the Cowichan and Koksilah rivers as an average concentration of 3 $\mu g\ L^{-1}$ and a maximum concentration of 8 $\mu g\ L^{-1}$ (McKean 1989). At no time over the sample period were total lead concentrations near either the average or maximum objectives for dissolved lead and total lead concentrations were very low in both systems (Figure 18 and Figure 19).

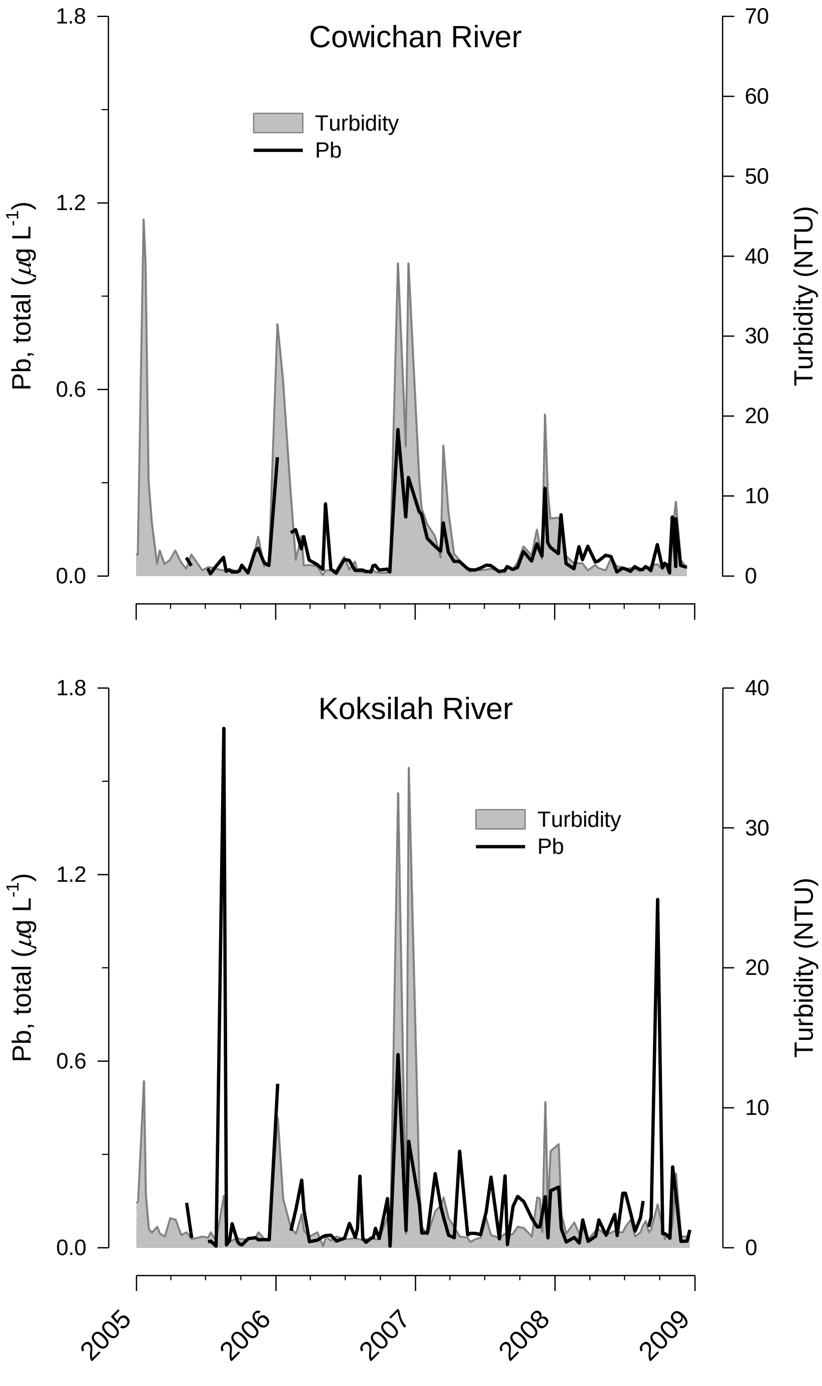
**Figure 18:** Box-and-whisker plots of total lead concentrations from the Cowichan and Koksilah rivers.




Total lead was highly correlated with mean daily discharge in the Cowichan River (Spearman Rank Order Correlation: mean daily discharge, $r_s = 0.78$; turbidity, $r_s = 0.73$). Total lead was weakly correlated with mean daily discharge (Spearman Rank Order Correlation: $r_s = 0.24$) but more strongly correlated with turbidity (Spearman Rank Order Correlation: $r_s = 0.64$). This suggests that flow was not a major driver in total lead concentrations in the Koksilah River, but turbidity was still related to total lead; perhaps total lead concentrations in the Koksilah River are driven by dissolved concentrations of the analyte, especially during low (base) flow periods. As both watersheds share essentially the same weather patterns, mean daily discharge and turbidity measurements from the Koksilah River were highly correlated with total lead concentrations in the Cowichan River (Spearman Rank Order Correlation: mean daily discharge, $r_s = 0.77$; turbidity, $r_s = 0.57$).

It is recommended that dissolved lead be measured in addition to total to determine the contribution of the dissolved portion to total lead and for trend detection. It is also recommended that the hardness-based B.C. aquatic life guideline for total lead be considered when the water quality objectives are updated to better assess current concentrations.

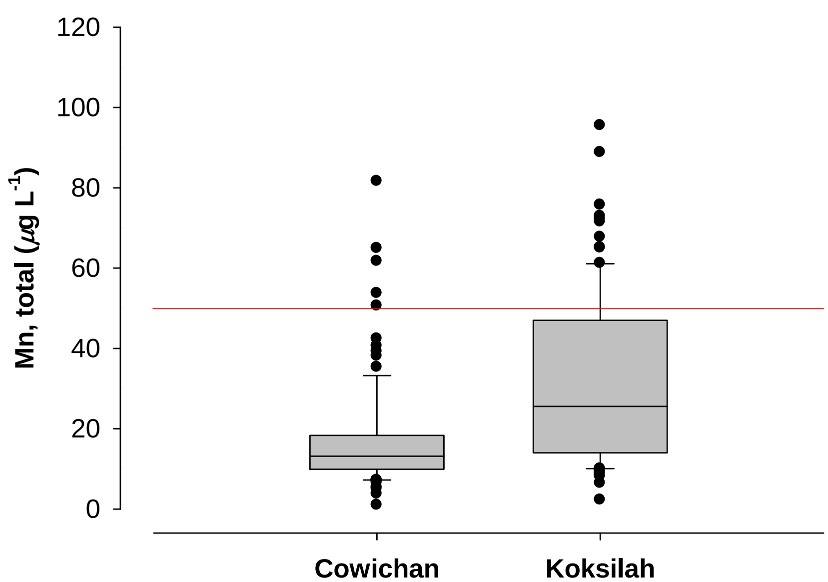
**Figure 19:** Total lead and turbidity measurement from the Cowichan and Koksilah rivers over the sample period.



**MANGANESE:** Manganese was measured as total manganese in the Cowichan and Koksilah rivers, and was significantly greater in concentration in the Koksilah River over the sample period (Mann-Whitney Rank Sum Test, $p < 0.001$; Figure 20). The provincial aquatic life guidelines established for the manganese concentrations (Nagpal 2001) are much higher than concentrations over the sample period. The most appropriate guideline is the Canadian drinking water aesthetic objective related to odour, taste and staining which is set at 50 $\mu g\ L^{-1}$.

The drinking water objective was seasonally exceeded in the Cowichan River (Figure 21), and peaks were generally related to increases in turbidity. In general total manganese concentrations did not seem to be related to suspended sediment beyond major turbidity spikes and may be related to groundwater inputs (Figure 21). Total manganese concentrations in the Koksilah River seemed to follow a similar pattern to those in the Cowichan River – turbidity spikes resulted in increased total manganese concentrations, but concentrations generally increased in the summer; in fact, mean daily discharge was negatively correlated with total manganese in the Koksilah River (Spearman Rank Order Correlation, $r_s = -0.68$) while specific conductivity was positively correlated with total manganese (Spearman Rank Order Correlation, $r_s = 0.67$). This suggests that total manganese concentrations were largely a result of groundwater inputs except for the high flow spikes related to turbidity. Since the Cowichan River has a large upstream lake that provides higher summer flows, the contributions of groundwater

**Figure 20:** Box-and-whisker plots of total manganese concentrations from the Cowichan and Koksilah rivers.

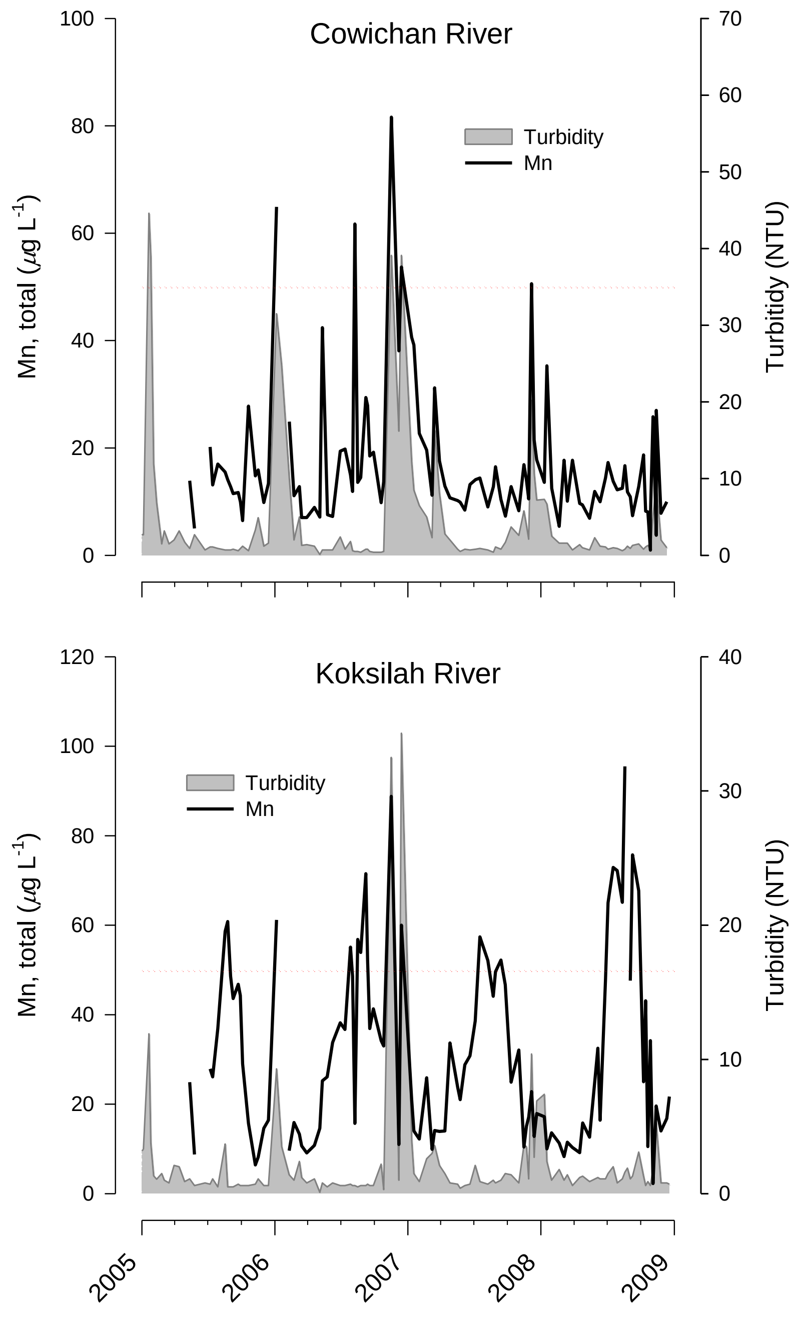



Note: the solid red line represents the drinking water aesthetic objective.

are less apparent in this river.

It is recommended that dissolved manganese be measured in addition to total to monitor for trends in concentrations.

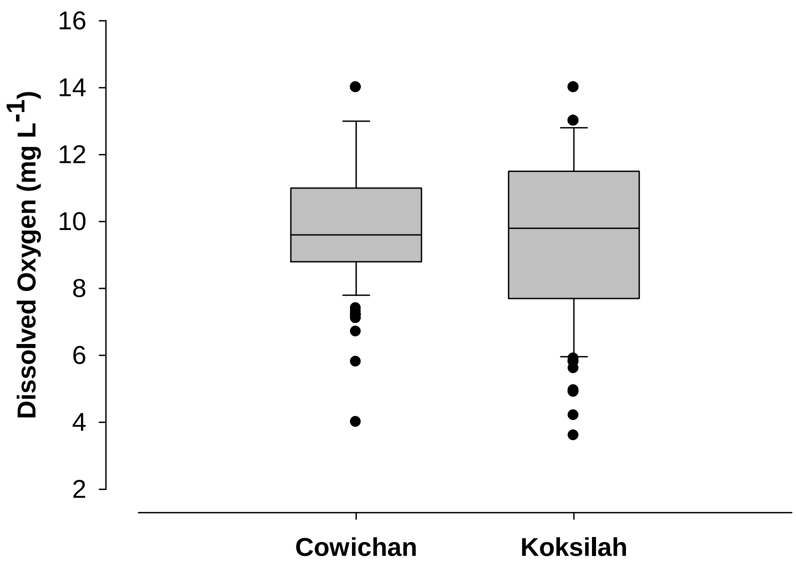
**Figure 21:** Total manganese and turbidity measurements from the Cowichan and Koksilah rivers over the sample period.




Note: the solid red line represents the drinking water aesthetic objective.

**OXYGEN, DISSOLVED:** Seasonal dissolved oxygen objectives have been established for the Cowichan and Koksilah rivers; the minimum dissolved oxygen objective from October to May is set at 11.2 mg $L^{-1}$ and the minimum dissolved oxygen objective from June to September is set at 8.0 mg $L^{-1}$. Median dissolved oxygen measurements were similar in both rivers but measurements tended to vary more in the Koksilah River (Figure 22). Fall and winter dissolved oxygen measurements tended to be below the minimum objective in the Cowichan River and the Koksilah; summer measurements were often below the minimum objective in both rivers (Figure 23).

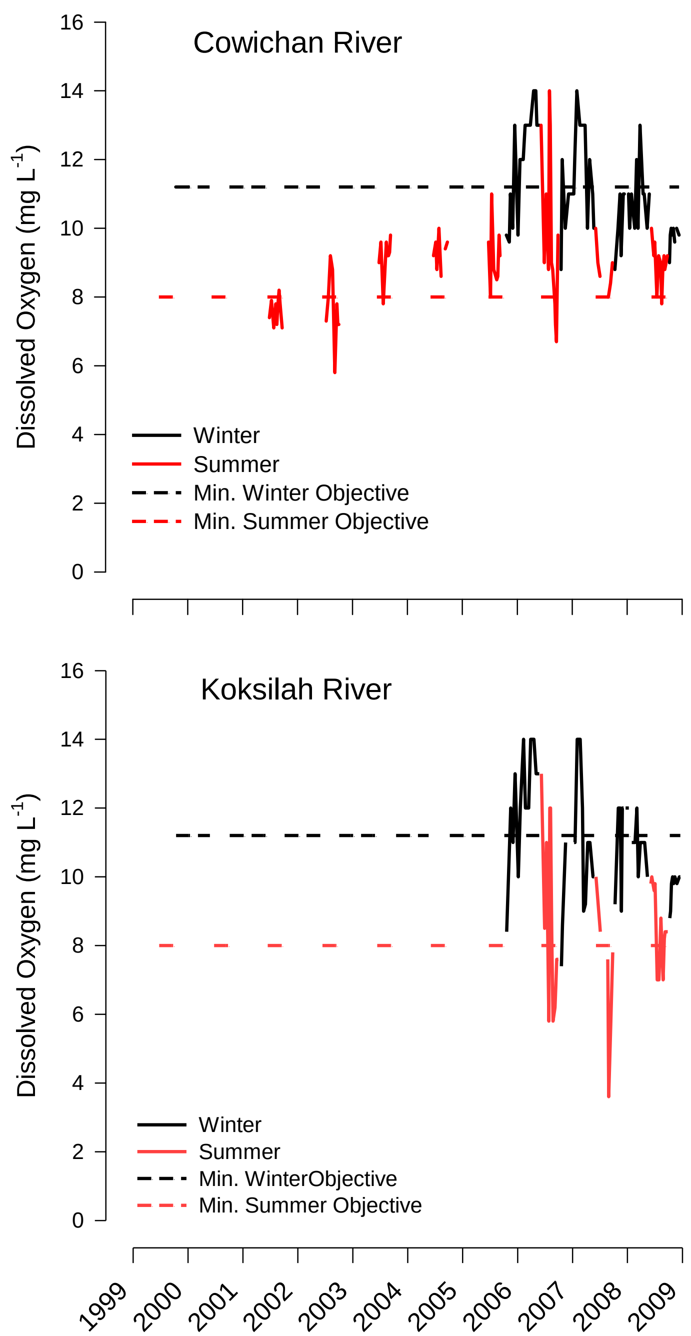
**Figure 22:** Box-and-whisker plots of dissolved oxygen measurements from the Cowichan and Koksilah rivers.




The solubility of dissolved oxygen is primarily affected by temperature, with dissolved oxygen content decreasing with increasing water temperature. Dissolved oxygen was negatively correlated with water temperature in the Cowichan River (Spearman Rank Order Correlation, $r_s$ = -0.60) and the Koksilah River (Spearman Rank Order Correlation, $r_s$ = -0.65). Dissolved oxygen was highly correlated with mean daily discharge in both rivers (Spearman Rank Order Correlation: Cowichan River, $r_s$ = 0.52; Koksilah River, $r_s$ = 0.71) with minimum dissolved oxygen concentrations occurring during baseflows. As temperatures and flows change, this may further reduce dissolved oxygen concentrations in both rivers.

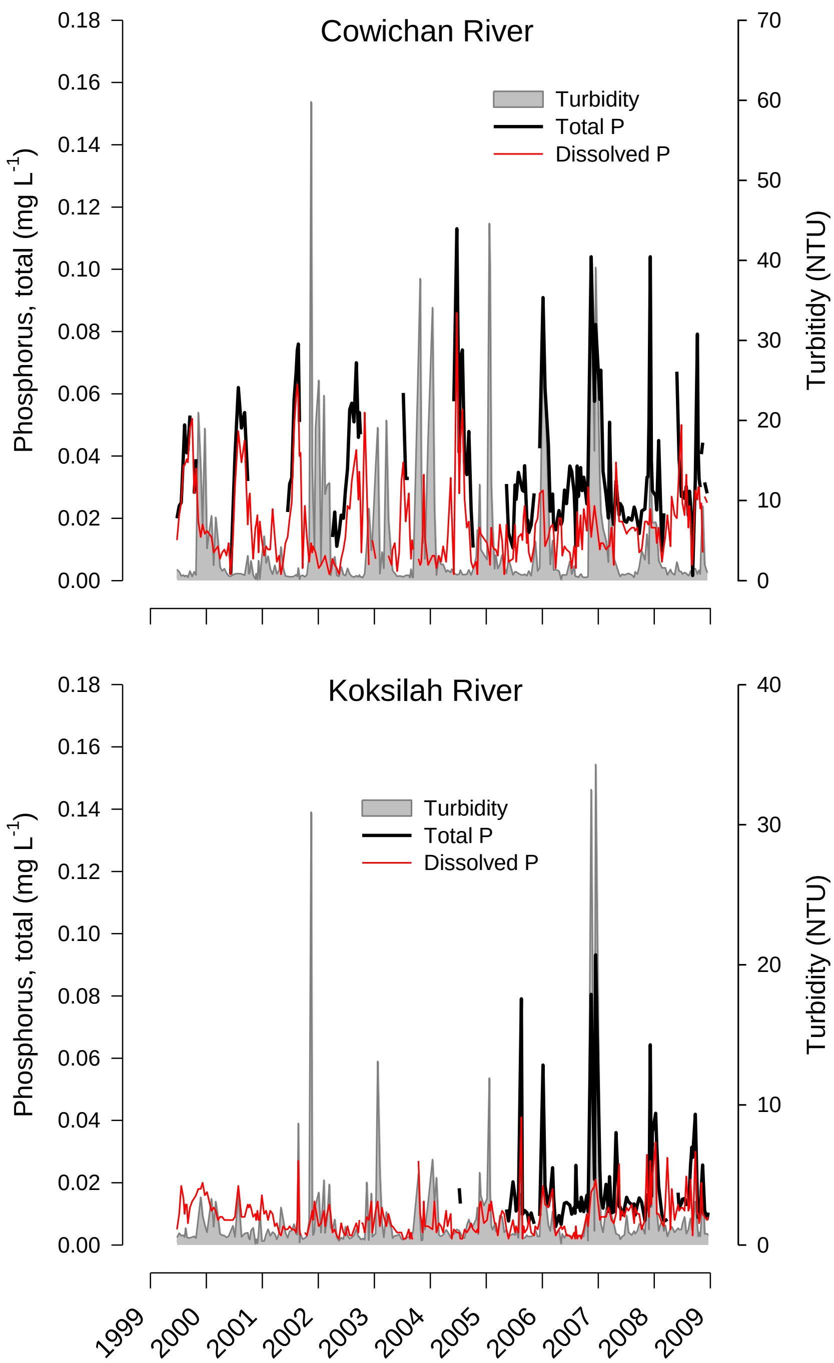
Since dissolved oxygen measurements often are below seasonal objectives, this constituent should continue to be monitored. Assessment of fish communities may be considered to determine if there are impacts due to low dissolved oxygen.

**Figure 23:** Dissolved oxygen measurements from the Cowichan and Koksilah rivers over the sample period.



**PHOSPHORUS:**

Figure 24: Total phosphorus, dissolved phosphorus and turbidity measurements from the Cowichan and Koksilah rivers over the sample period.




Phosphorus was measured as both dissolved and total phosphorus in the Cowichan and Koksilah rivers (Figure 24). Phosphorus is an essential and often limiting macronutrient in aquatic systems. Median phosphorus concentrations in the Cowichan River were 31 $\mu g\ L^{-1}$ (max. = 154 $\mu g\ L^{-1}$) for total phosphorus and 14 $\mu g\ L^{-1}$ (max. = 86 $\mu g\ L^{-1}$) for dissolved over the sample period, suggesting that the Cowichan River is mesotrophic (Kalff 2002). Median phosphorus concentrations in the Koksilah River were 12 $\mu g\ L^{-1}$ (max. = 93 $\mu g\ L^{-1}$) for total phosphorus and 8 $\mu g\ L^{-1}$ (max. = 41 $\mu g\ L^{-1}$) for dissolved over the sample period, suggesting that it is olighotrophic and would support less algal growth than the Cowichan River.

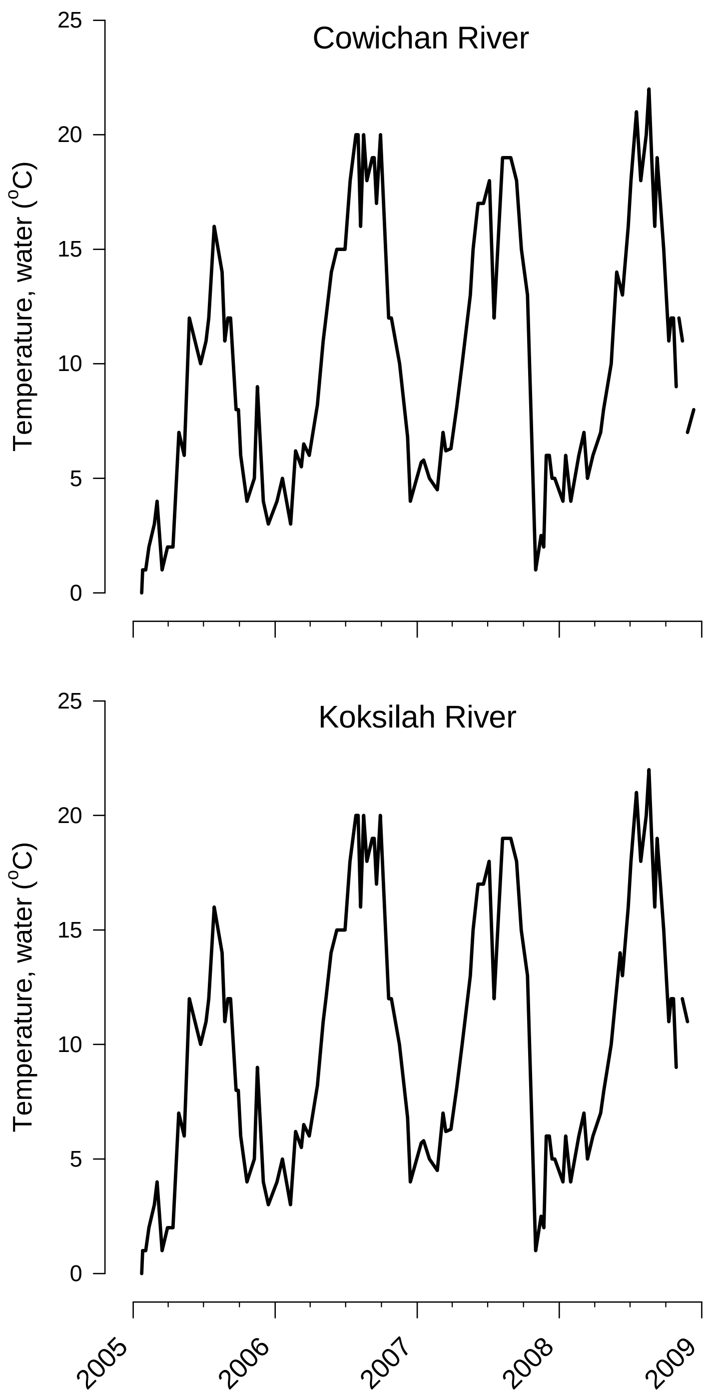
Interestingly, dissolved phosphorus measurements in the Cowichan River were negatively correlated with mean daily discharge and turbidity (Spearman Rank Order Correlation: mean daily discharge, $r_s$ = -0.40; turbidity, $r_s$ = -0.32) and often increased in the summer. This may be indicative of the stronger influence of effluent from the sewage treatment plant and fish hatchery upstream of the water quality monitoring site during summer low flows; winter high flows would dilute the effluent from these sources to a much greater degree. Total dissolved phosphorus concentrations in the Koksilah River were positively correlated with mean daily discharge and turbidity (Spearman Rank Order Correlation: mean daily discharge, $r_s$ = 0.38; turbidity, $r_s$ = 0.42), and generally followed the seasonal pattern of flow.

Previous reports suggest that the available nutrients in both rivers have supported substantial algal growth in the past (Pommen Water Quality Consulting 2004a and 2004b; Rideout *et al*. 2000). Pommen Water Quality Consulting (2004a) suggests that phosphorus concentrations may have declined from 2000 to 2003, possibly due to the addition of alum at the Duncan-North Cowichan sewage treatment plant. Indeed, dissolved phosphorus concentrations seemed to be stable throughout much of the sample period; however, samples from 2007 onwards seem to be increasing in concentration in both rivers (Figure 24) although there were no statistically significant trends. Phosphorus loadings from the Duncan-North Cowichan sewage treatment plant have been regulated in since 2005 during the summer months (between July 1st and September 30th) with maximum daily loadings set at 18 kg total P. Although these reductions in total phosphorus loadings are not readily apparent in the data, hopefully this will assist in the management of phosphorus concentrations in the Cowichan River.

It is recommended that total and dissolved phosphorus continue to be measured to gain sufficient data to determine if a statistically significant trend in phosphorus exists in both rivers. It is also recommended that chlorophyll *a* be monitored during summer months as a measure of algal growth.

**TEMPERATURE:** Aquatic life guidelines for water temperature vary by species and life stages of fish. The Cowichan and Koksilah rivers provides habitat for a variety of sport fish including salmon, and resident and anadromous trout. Water temperature varied greatly in the Cowichan and Koksilah rivers over the sample period and throughout the year (Figure 25) with maximum values near or above 20°C which may impact fish species and reduced the solubility of oxygen in water.

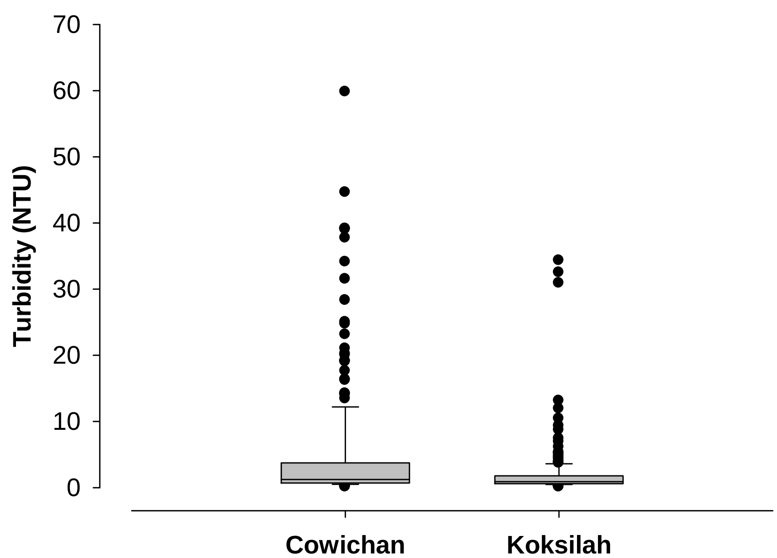
**Figure 25:** Water Temperature measurements from the Cowichan and Koksilah rivers over the sample period.




Automated water temperature loggers were recently installed at both sites to assess the duration and extent of summer water temperature maximums and seasonal objective exceedences. It is recommended that this data be assessed when available and that water temperature continue to be monitored at these active stations to determine how temperature may be changing with the availability of water and weather patterns 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), and it is often associated with increased suspended particulate matter since it is usually consists of soil erosion and run off in catchment basins (Wetzel 2001). Median turbidity measurements were relatively similar in both rivers over the sample period although maximum measurements were greater in the Cowichan River (Figure 26). Turbidity was positively correlated with mean daily discharge in the Cowichan (Spearman Rank Order Correlation, $r_s = 0.80$) and the Koksilah rivers (Spearman Rank Order Correlation, $r_s = 0.59$), and typically mirrored the seasonal pattern of flow in both rivers (Figure 27).

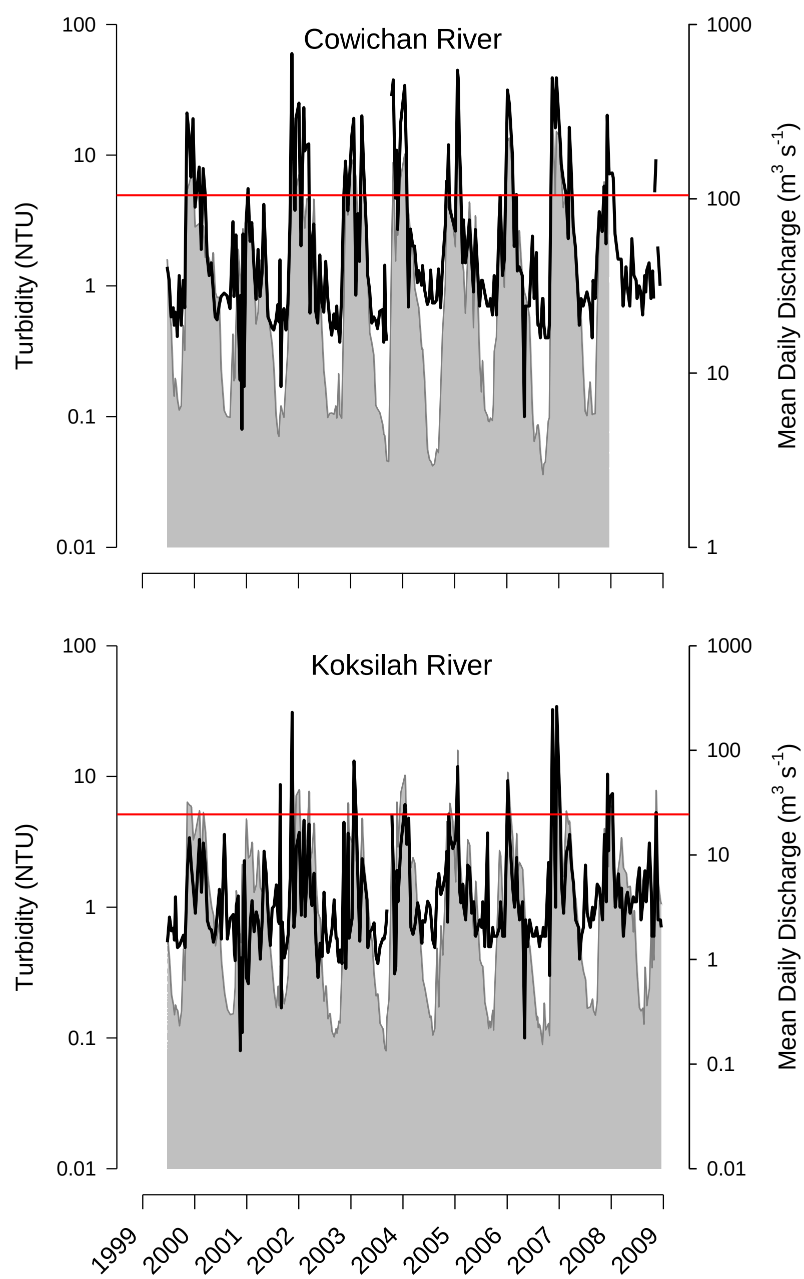
**Figure 26:** Box-and-whisker plots of turbidity measurements from the Cowichan and Koksilah rivers.




Turbidity was significantly increasing in the Koksilah River over the sample period (Mann-Kendall trend test, $p < 0.001$, slope = 0.04 NTU year$^{-1}$). Due to its close relationship with suspended sediment, turbidity is often positively correlated with nutrients and metals, thus an increase in turbidity often results in increased loadings in these associated parameters. The estimated slope suggests that turbidity is increasing at a small rate and increases in associated constituents may not be apparent nor an immediate cause for concern. Since turbidity is correlated with flow in both the

Cowichan and Koksilah rivers, changes in flow may results in corresponding changes in turbidity and other associated patterns. It is recommended that flow and turbidity continue to be measured at both these sites.

**Figure 27:** Turbidity measurements from the Cowichan and Koksilah rivers over the sample period.

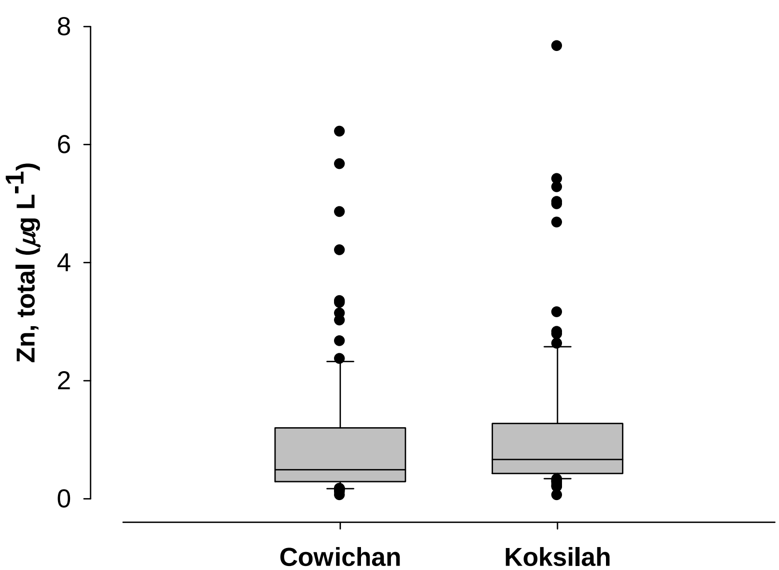



Note: red line represents maximum objective for turbidity in the Englishman River for comparison.

Vancouver Island applies the ecoregion approach to water quality objectives whereby objectives established for one watershed can be applied on an interim basis to other watersheds in the same ecoregion (Deniseger *et al.* 2009). A maximum objective for turbidity of 5 NTU is being developed for the Englishman River, a watershed in the same ecoregion as the Cowichan and Koksilah rivers. Turbidity measurements in the Cowichan and Koksilah rivers seasonally exceeded the turbidity objective for the Englishman River (Figure 27). If the increasing turbidity trend continues in the Koksilah River, then this objective will be exceeded with greater frequency and magnitude.

**ZINC:** Zinc was measured as total zinc in the Cowichan and Koksilah rivers over the sample period. Water quality objectives are established for dissolved zinc in both rivers as a 30-day mean maximum concentration of 30 $\mu$g $L^{-1}$ and a maximum instantaneous concentration of 180 $\mu$g $L^{-1}$ (McKean 1989). Total zinc concentrations were low relative to the established water quality objectives with median concentrations of < 1 $\mu$g $L^{-1}$ in both rivers and maximum concentrations of 6.2 $\mu$g $L^{-1}$ in the Cowichan River and 7.7 $\mu$g $L^{-1}$ in the Koksilah River (Figure 28).

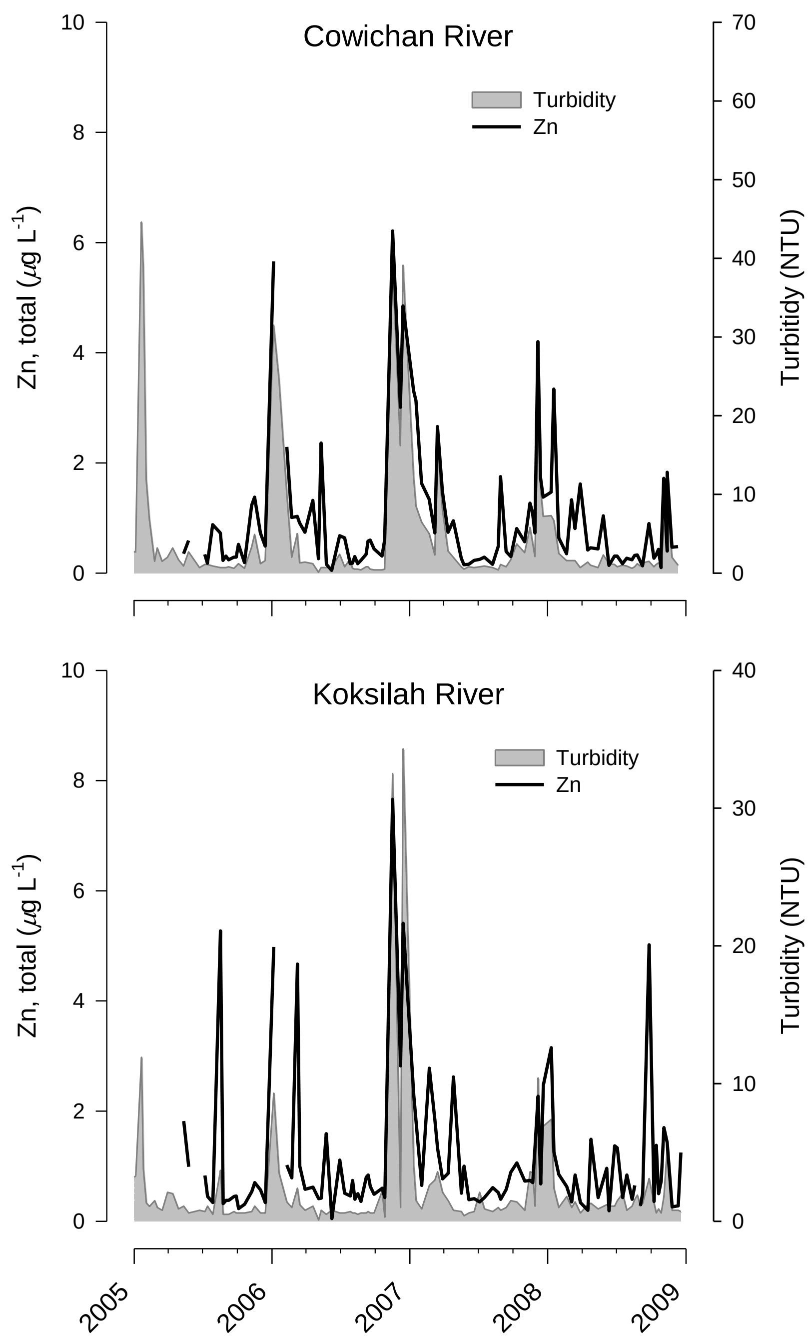
**Figure 28:** Box-and-whisker plots of total zinc measurements from the Cowichan and Koksilah rivers.




Total zinc was positively correlated with mean daily discharge and turbidity in the Cowichan River (Spearman Rank Order Correlation: mean daily discharge, $r_s = 0.71$; turbidity, $r_s = 0.70$) and the Koksilah River (Spearman Rank Order Correlation: mean daily discharge, $r_s = 0.46$; turbidity, $r_s = 0.53$). As a result, spikes in total zinc were generally associated with increased flow and turbidity in both rivers (Figure 29). However, there were periodic summer increases in total zinc concentrations which did not seem to be associated with increased turbidity (Figure 29) and may be a result of increased dissolved zinc concentrations, possibly due to groundwater inputs.

It is recommended that dissolved zinc be measured in addition to total to determine its seasonal contribution and to determine if there are trends related to the dissolved zinc. It is also recommended that the B.C. aquatic life guideline for total zinc be considered when the water quality objectives are updated since current zinc concentrations are orders of magnitude below the maximum objective for the analyte.

**Figure 29:** Total zinc measurements from the Cowichan and Koksilah rivers over the sample period.



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