Water Quality Trends at Selected

Monitoring Sites in British Columbia

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Prepared by:

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Introduction

The B.C. Ministry of Environment, Lands and Parks and Environment Canada recently released a series of “State of Water Quality” reports, which assessed the data from all long-term ambient water quality monitoring stations in the province. The reports outlined the state of water quality, guidelines/objectives exceedences, and apparent trends at each site, based on a graphical assessment of the data. To determine the significance of the apparent trends noted and provide input to the “British Columbia Water Quality Trend Report” to be published in 2000, further statistical analyses were required.

This report presents a summary of statistical tests for trends in selected water quality constituents at the following monitoring sites:

- Columbia River at Birchbank
- Columbia River at Waneta
- Elk River at Highway 93
- Fraser River at Hope
- Fraser River at Marguerite
- Fraser River at Stoner
- Kootenay River at Canal Flats
- Kootenay River at Creston
- Kootenay River at Fenwick
- Quinsam River
- Salmon River near Hyder, Alaska
- Similkameen River at US border
- South Thompson River at Kamloops
- Thompson River at Spences Bridge

The tests consisted of several non-parametric methods and regression modeling. Explanations of these methods are briefly presented in the report, followed by sections detailing the results of these tests.

Statistical Methods

Exploratory Data Analysis

Exploratory data analysis procedures are the ‘initial look’ at a data set, providing a researcher with tools to select appropriate statistical tests and modeling techniques. Apart from computing basic summary statistics (means, medians, minimums, maximums, number of observations), EDA procedures are best represented by graphical displays of the data. Time series and box and whisker plots (Tukey, 1977), blocked by both month and year, were used in the initial data explorations.

Non-parametric Analyses

Non-parametric tests to detect trends in water quality have been used by many others in the past (Yu and Zou, 1993; Walker, 1991; Gilbert, 1987; Hirsch and Slack, 1984). The relative simplicity and minimal data assumptions of these tests make them a popular choice for analysis of water quality time series. Four different non-parametric tests; the *seasonal Kendall’s Tau*, the *modified seasonal Kendall’s Tau*, the *Van Belle and Hughes* test for trends across time and the *Sen slope estimator*, were used to detect and determine magnitude of trends in the water quality data.

Seasonal Kendall’s Tau

A rank-order statistic that can be applied to time series exhibiting seasonal cycles, missing and censored data, and indications of non-normality (Yu and Zou, 1993). For computational details see Gilbert (1987), and Hirsch and Slack (1984).

Modified Seasonal Kendall’s Tau

The *Seasonal Kendall’s Tau* assumes that data are serially independent - i.e., that values are not determined in whole or in part on the previous state in the sequence. To compensate for serial dependence in a data series, Hirsch and Slack (1984) proposed a modification to the seasonal Kendall’s Tau that takes into account any covariation between seasons in a data set.

Either version of the *Seasonal Kendall’s* tests are most appropriate if trends are consistent throughout a year. For example, a negative trend for six months followed by a positive trend of six months would yield a test statistic indicating zero trend (the two tests do not measure the size of any trends, only the direction).

Van Belle and Hughes Statistic

Van Belle and Hughes (1984) presented a non-parametric test for trend across time. The test statistic uses parameters constructed from the Kendall tests described above. This test essentially indicates whether a trend exists. It does not indicate the direction or magnitude of any detected trend.

Sen Slope Estimator

This non-parametric statistic calculates the magnitude of any significant trends found. The Sen slope estimator (Sen, 1968) is calculated as follows:

$$D_{ijk} = \frac{Y_{ij} - Y_{kj}}{i - k} \qquad \text{for j = 1,…,12 ; } 1 \le k < i \le n_j \text{ .}$$

The slope estimate is the median of all D_{ijk} values. Hirsch *et al*. (1982) point out that this estimate is robust against extreme outliers and that since the D_{ijk} values are computed on values that are multiples of 12 months apart, confounding effects of serial correlation are unlikely. Confidence bounds for this slope estimator are calculated as a simple percentile of the total number of calculated slopes (Gilbert, 1987).

Parametric Statistics

This is a non-parametric statistics test for monotonic changes in a data series with minimal assumptions of normality and, in some instances, serial dependence. However, these methods are not very useful in constructing the forms of any detectable trends. Regression analysis has been used for this purpose and has been applied to water quality data (El-Shaarawi *et al*., 1983, Esterby *et al*., 1989).

Using these methods, many factors can be taken into account for explaining the variation in a water quality constituent over time, factors which include flow rates and seasonality. By accounting for flow and seasonality through functional approximation, their influence on the response constituent can be removed, revealing underlying trends.
The regression model used is as follows:

(1) $$y_{t_{ji}} = \beta_0 + \beta_1 x_{t_{ji}} + \beta_2 i + \alpha_1 \cos\omega t_{ji} + \alpha_2 \sin\omega t_{ji} + \varepsilon_{t_{ji}}$$

where :

- $y_{t_{ji}}$ = Observed value of water quality variable at time t_{ji} within year i;
- $x_{t_{ji}}$ = Flow rate at time t_{ji} within year i;
- α_1, α_2 = Unknown parameters representing the phase of the seasonal cycle;
- ω = Unknown parameter representing the frequency of the seasonal cycle;
- $\varepsilon_{t_{ji}}$ = Error term assumed to follow a normal distribution with mean 0 and variance σ^2.

This regression technique is an iterative process of parameter estimation and analyses of model residual and quantile plots.

The form in equation (1) above considers only a linear trend with slope β_2. The presence or absence of quadratic ($\cup$ or $\cap$ - shaped) trends may be determined by fitting the data to (1) with the addition of a quadratic term ($\beta_3 i^2$). ANOVA tables may then be used to determine if the quadratic models significantly improve the linear models. Significance of the model coefficients are tested at the 5 percent level.

Example

Results of the above described statistical analyses are tabulated and presented in Appendices 1 (non-parametric) and 2 (regression).

Using the results from the analysis of dissolved sodium in the Thompson River at Spences Bridge, Table 1 will be used to explain how the tests were interpreted.

Table 1. Statistical analyses of dissolved sodium data in the Thompson River at Spences Bridge.

NON-PARAMETRIC TESTS			REGRESSION MODELING		
Dissolved Sodium			Dissolved Sodium		
	statistic	p-value		parameter	value
VBT	16.567	0	intercept	b_0	2.406
SK	-4.056	0	flow	b_1	-0.219
MSK	-1.799	0.072	linear trend	b_2	-0.013
SSE	-0.033	NA	quadratic trend	b_3	-----
LCL	-0.08	NA	seasonality	α_1	0.003
UCL	0	NA	seasonality	α_2	0.323
			Fit	r^2	0.86

VBT Van Belle Trend test ;
SK Seasonal Kendall test;
MSK modified Seasonal Kendall test ;
SSE Sen Slope Estimator ;
LCL Lower Confidence Limit ;
UCL Upper Confidence Limit ;
NS not significant at the 0.05 level ;
----- quadratic term not used in model ;
NA not applicable ;

Non-parametric analyses

Table 1 presents three non-parametric tests, as well as an estimate for the slope with 95% confidence bounds. Beside each test name is the computed test statistic and it's associated p-value. P-values are the smallest level of significance at which the null hypothesis would be rejected (for our purposes, the null hypothesis is that there is no trend in the available data). Usually, a p-value of 5% (0.05) is used as a guideline level. The reason for using p-values as a way of reporting significance is to allow others to draw their own conclusions, particularly when a test statistic is marginally significant (e.g., $0.05 < p < 0.1$).

In Table 1, the *Van Belle and Hughes test for trend (VBT)* statistic of 16.567 is significant (p-value < 0.05), indicating that there is a linear trend in the data. What cannot be interpreted is the direction or the magnitude of the trend. The *Seasonal Kendall test (SK)* statistic of -4.056 is also significant (p-value < 0.05). As well as pointing to a trend, this statistic also indicates that the trend is decreasing over time. However, like the *VBT*, no conclusion can be made as to it's magnitude. The *Modified Seasonal Kendall test (MSK)* statistic of -1.799 is marginally significant ($0.05 < p < 0.1$). Again this indicates that a decreasing trend exists, but does not provide any information on it's magnitude. *The Sen Slope Estimate (SSE)* of -0.033 gives an estimate of the magnitude of the detected trend. The *lower and upper confidence limits (LCL & UCL)* indicate that the slope of the trend lies between -0.08 and 0 with 95% accuracy.

Regression analyses

To fully understand how to interpret these results, the reader is encouraged to read the section on regression analysis in the presentation of the statistical methods used within this report. What will be outlined here is a brief description of what one should look for.

The main coefficient to examine is b_2 (or b_3 when it is determined that a quadratic model best fits the data). Significance of this coefficient indicates a trend in the data. When b_3 is used in the model, significance of this coefficient indicates a quadratic trend. Note that the b_2 coefficient should not be used as a linear (or exponential if natural logarithms are used) test in a fitted quadratic model - i.e., a model with a significant positive quadratic term and a significant negative b_2 term should not be interpreted as a decreasing trend. The b_2 term in these models loses its customary meaning when a quadratic term is included.

From Table 1, it can be seen that the b_2 coefficient (-0.013) is significant at the 5% level (these regression tests are always based on this guideline level) and that it is decreasing. The size of this coefficient is meaningful here.

Unlike the non-parametric tests, the regression models include the flow rate as an explanatory variable. This can affect the size of any trend coefficients, and it is therefore not a concern when the non-parametric *Sen Slope estimate* and the regression trend coefficient indicate differing trend sizes. Additionally, as noted below, the regression slopes are sometimes in natural log units.

Variables analyzed in this report were transformed for regression modeling using natural logarithms. Thus for easier interpretation, the trend coefficient may be expressed as the percentage change from the beginning of a year to the end of that year by computing ($e^{\text{trend coefficient}}$ - 1) x 100. If original units are preferred, 100 may be substituted by some measure of central tendency such as the mean or median of the data set. For the example in Table 1, the regression model indicates that dissolved sodium is decreasing approximately 1% each year for the period of record, or using the overall median of the data (3.1 mg/L), the trend slope is -0.04 mg/L.

Results and Discussion

Of the 45 data sets selected for analysis for this report, only one was found unsuitable for the statistical techniques used. Total dissolved phosphorus data from the South Thompson River at Kamloops had too many values at or below the detection limit, and consequently was not statistically analyzed.

Another problem encountered was the lack of flow data for the Salmon River near Hyder, Alaska. This deficiency prevented the use of regression modeling techniques on the water quality data collected at this site, although non-parametric tests were conducted. There was also no hydrometric station on the Columbia River at Waneta; flow data collected at the Birchbank site was used in regression modeling for Waneta.

For those water quality constituents that were found to have different analytical results (i.e., forms of trends detected between non-parametric and regression methods were different), annual boxplots are provided to aid in interpreting the trends. Annual boxplots of all water quality constituents are provided in Appendix 3 of this report.

Results and discussion of the statistical findings for all sites analyzed are outlined below on a station-by-station basis. Tables of the statistical results are provided in Appendix 1 and 2 (non-parametric results and regression results, respectively). All water quality variables, with the exception of laboratory pH, were transformed using the natural logarithm before conducting regression modeling.

Columbia River at Birchbank

The station on the Columbia River at Birchbank is located about 24 km downstream from the community of Castlegar, and approximately 20 km north from the international boundary.

Water quality in this reach of the Columbia River is influenced by the Hugh Keenleyside dam, the Kootenay River, and several major effluent discharges (e.g., Celgar pulp mill, City of Castlegar).

A recent graphical assessment of the data indicated that total aluminum, total iron and total phosphorus concentrations were exhibiting environmentally significant declining trends (Holms, 1998.) Non-parametric and regression tests have confirmed that total aluminum data were indeed displaying significant decreasing trends. Non-parametric tests indicated that total iron exhibited a linear decreasing trend, while regression analysis indicated a negative quadratic (i.e. ∩-shaped trend). Total phosphorus was shown to have a marginally-significant linear decreasing trend, and a positive quadratic trend. The boxplot and graph for iron (Figures 1 and 5, respectively), indicate that iron values were elevated between 1988 and 1990 but have decreased since then, accounting for the quadratic trend. Potential iron contamination between 1986 and 1991 from preservative vials in use at the time may have contributed to this pattern. Figures 2 and 3 on the other hand, show that phosphorus decreased during the period from 1989 to 1993 but has increased since.

The causes of these trends are unknown, although entrainment of sediment (and thereby associated variables such as aluminum, iron and phosphorus) by upstream dams may be having an impact.

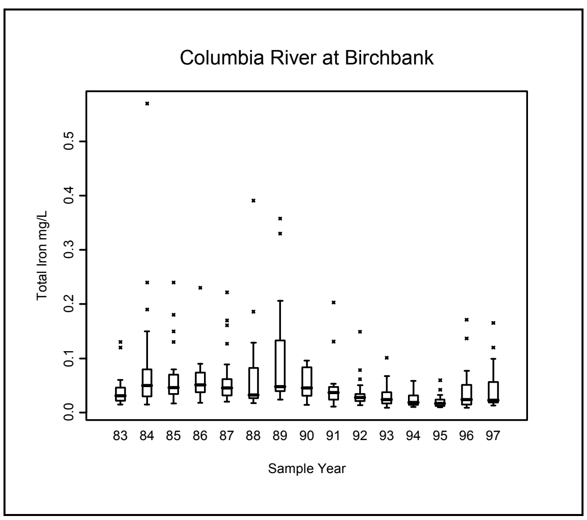

Figure 1. Annual summary of total iron in the Columbia River at Birchbank, 1983-1997.

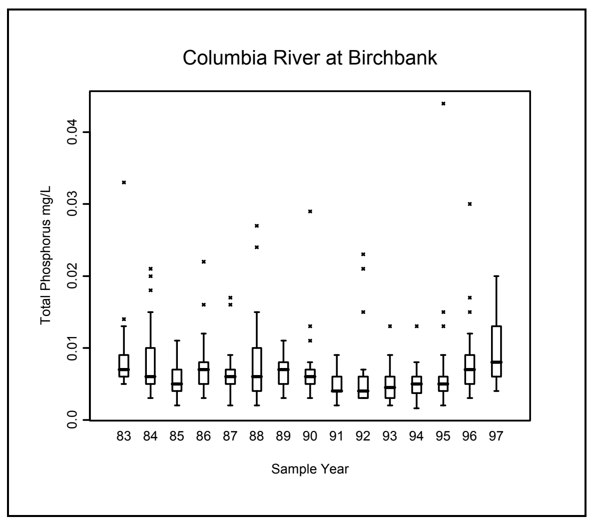

Figure 2. Annual summary of total phosphorus in the Columbia River at Birchbank, 1983-1997.

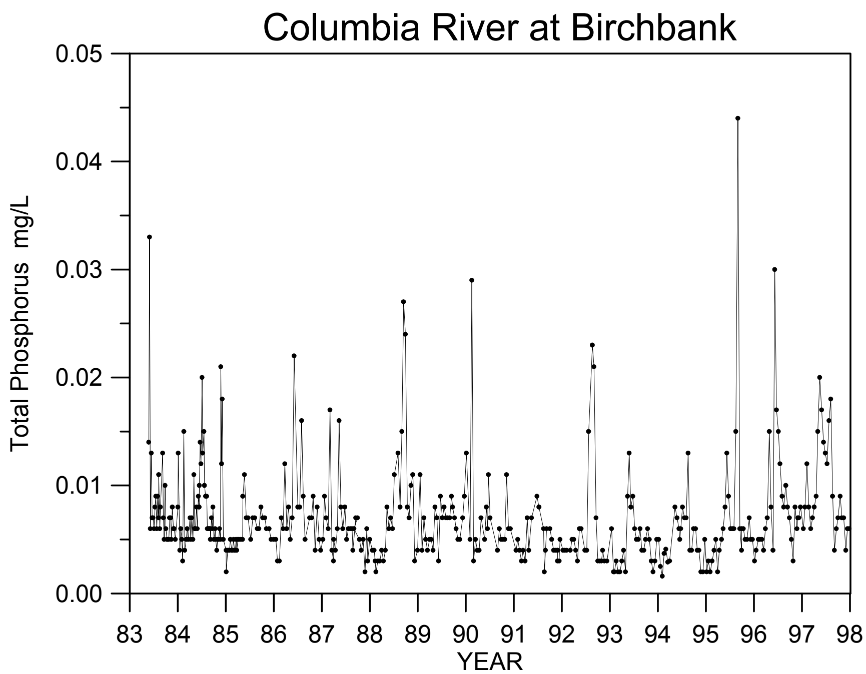

Figure 3. Time series plot of total phosphorus data in the Columbia River at Birchbank, 1983-1997.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**POSITIVE QUADRATIC TREND**

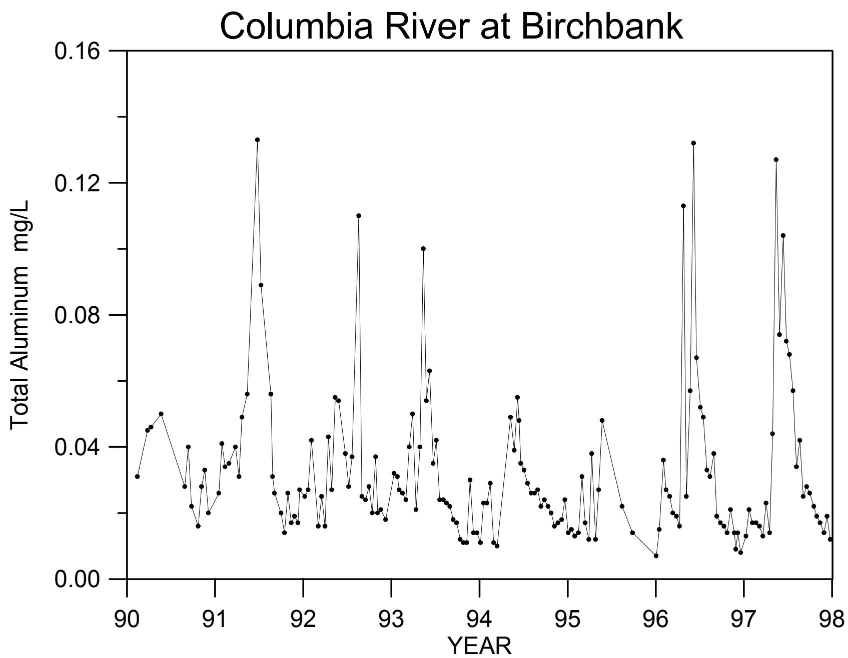

Figure 4. Time series plot of total aluminum data in the Columbia River at Birchbank, 1990-1997.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

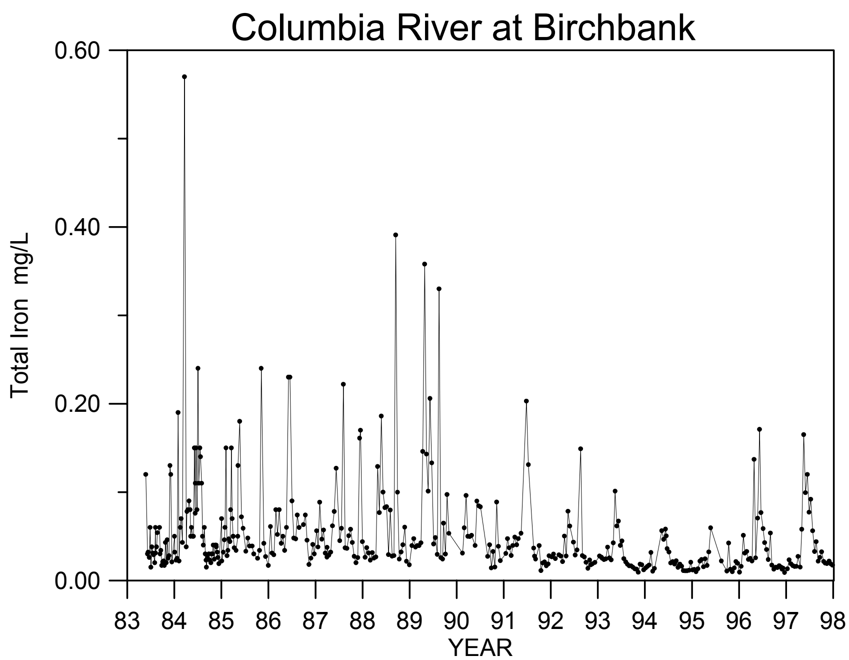

Figure 5. Time series plot of total iron data in the Columbia River at Birchbank, 1983-1997.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**NEGATIVE QUADRATIC TREND**

Columbia River at Waneta

The water quality site on the Columbia River at Waneta is 25 km downstream from Birchbank, and approximately 1.5 km upstream from the Pend d'Oreille River, which joins the Columbia at the international boundary.

Water quality in this reach of the river is impacted by effluent discharges from the Cominco Metal Smelter and Fertilizer Plant in Trail, primary-treated sewage from the Kootenay Boundary Sewage Treatment Plant (City of Trail), and secondary-treated sewage from Fruitvale and Montrose.

Recent graphical assessments of the data indicated declining trends for fluoride, sulphate, total phosphorus, ortho-phosphorus, cadmium, chromium, iron, manganese, lead and zinc (Holms, 1998.) Non-parametric tests confirmed that significant decreasing trends existed for all of these variables except coliforms, which did however show weak evidence of a linear decreasing trend. Regression analysis echoed these findings for all variables except total phosphorus, which was found to have a negative quadratic trend, and fecal coliforms, which were found to have a positive quadratic trend. The boxplots (Figures 6 and 7) and graphs (Figures 10 and 19) for these two constituents show these patterns to some extent.

Most of these improving trends in water quality can be attributed to modernized process changes and effluent abatement at the Cominco Smelter and Fertilizer Plant and the sewage treatment plant in Trail. Total iron exhibited a decreasing trend upstream at Birchbank as well, indicating that other factors are also having an impact on iron concentrations in the river. The detection limit for total manganese was lowered several times over the course of data collection, which likely contributed to the trend seen for this variable.

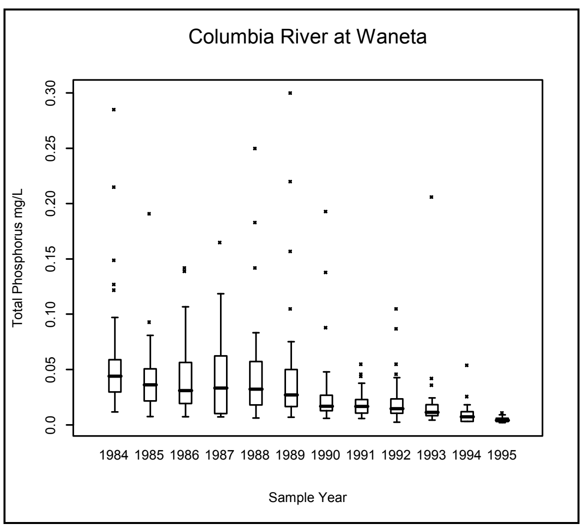

Figure 6. Annual summary of total phosphorus data from the Columbia River at Waneta, 1984-1995.

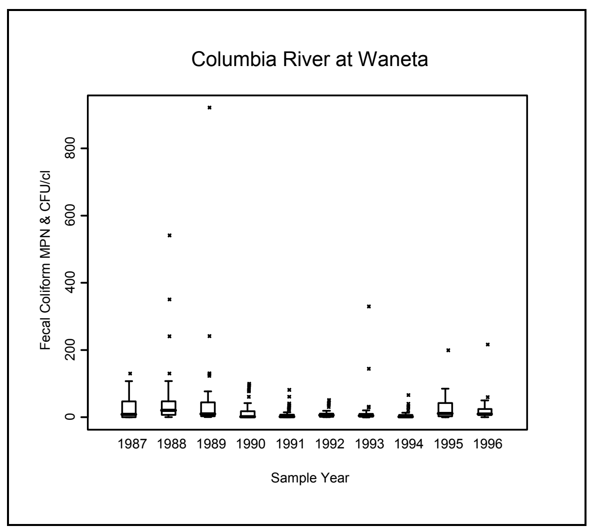

Figure 7. Annual summary of fecal coliform data from the Columbia River at Waneta, 1987-1996.

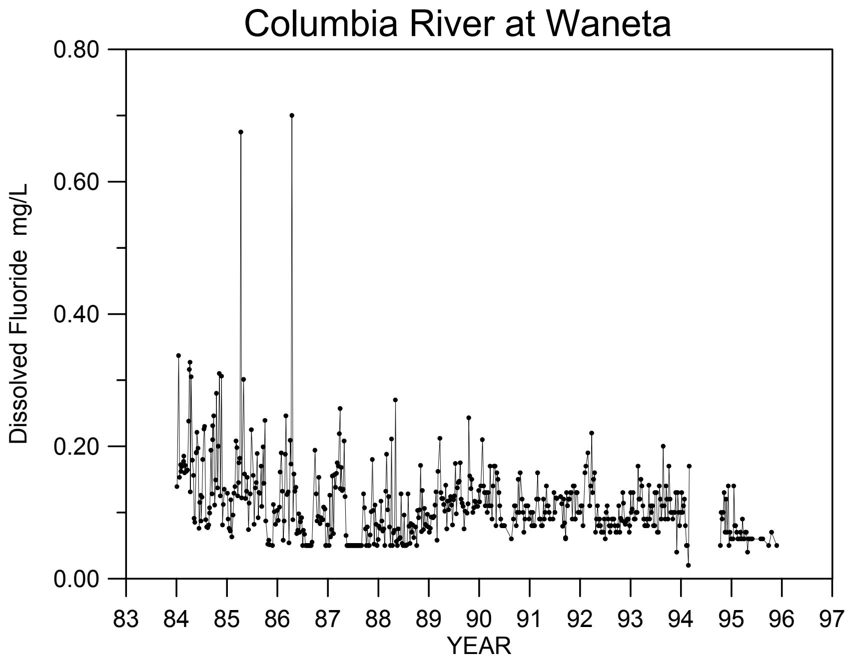

Figure 8. Time series plot of dissolved fluoride data from the Columbia River at Waneta, 1984-1995.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

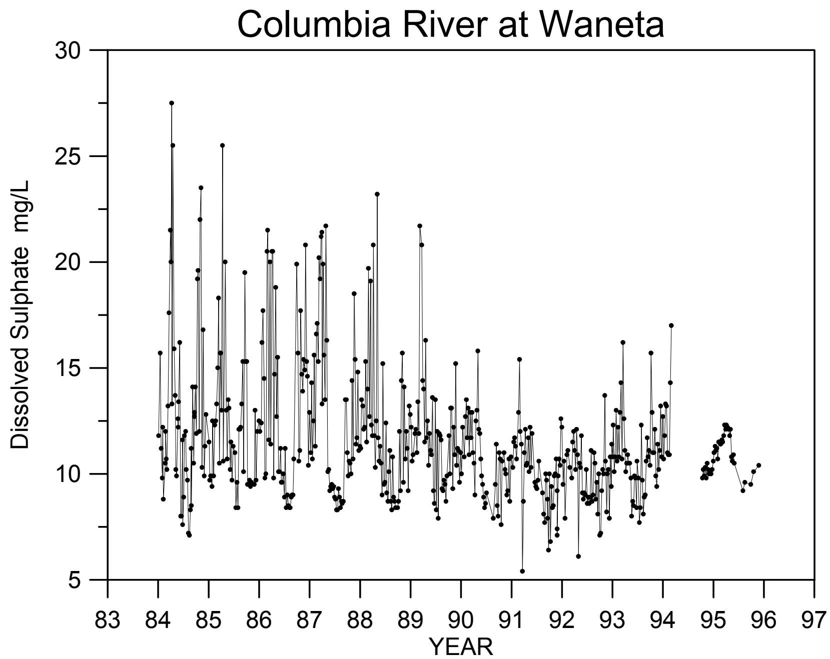

Figure 9. Time series plot of dissolved sulphate data from the Columbia River at Waneta, 1984-1995.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

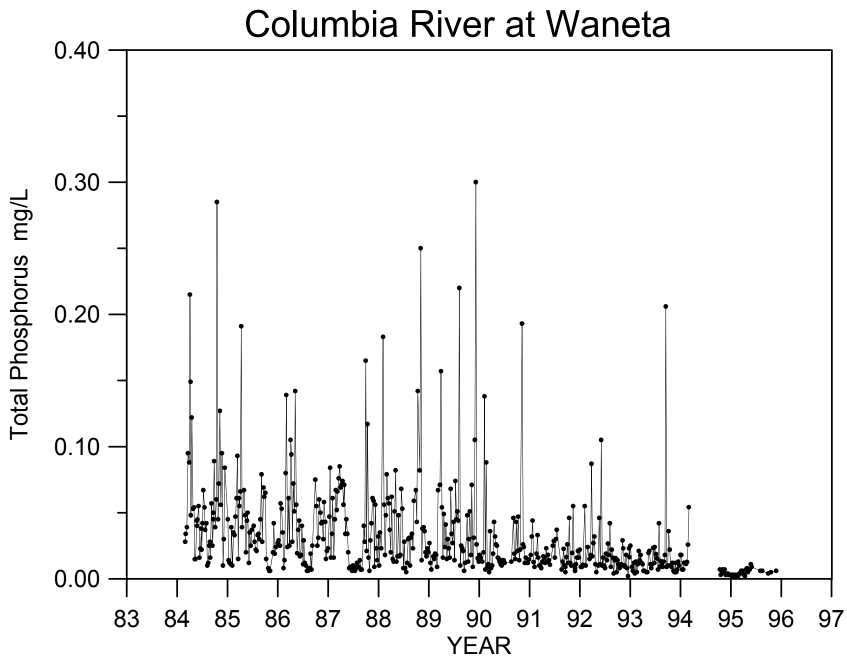

Figure 10. Time series plot of total phosphorus data from in the Columbia River at Waneta, 1984-1995.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**NEGATIVE QUADRATIC TREND**

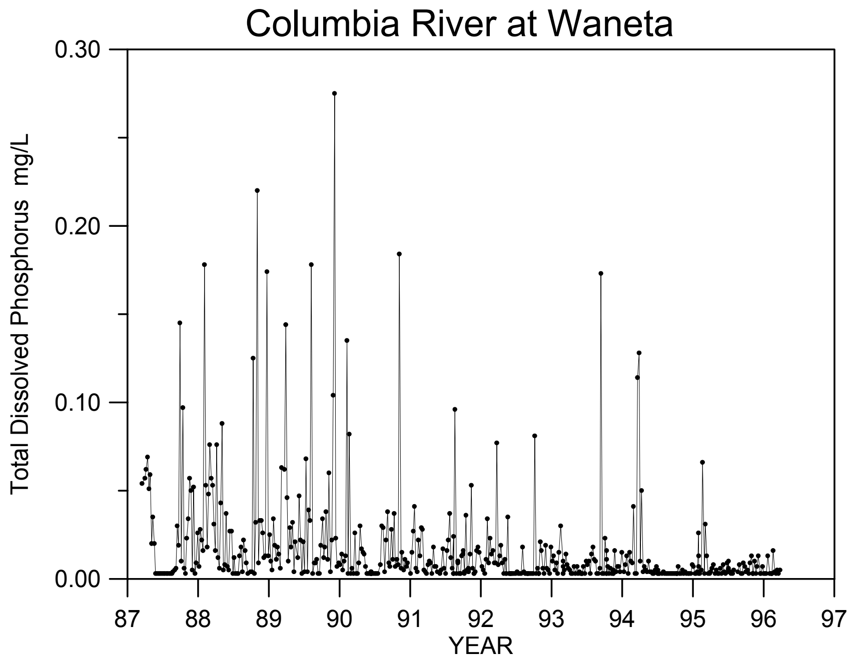

Figure 11. Time series plot of total dissolved phosphorus data from the Columbia River at Waneta, 1987-1996.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

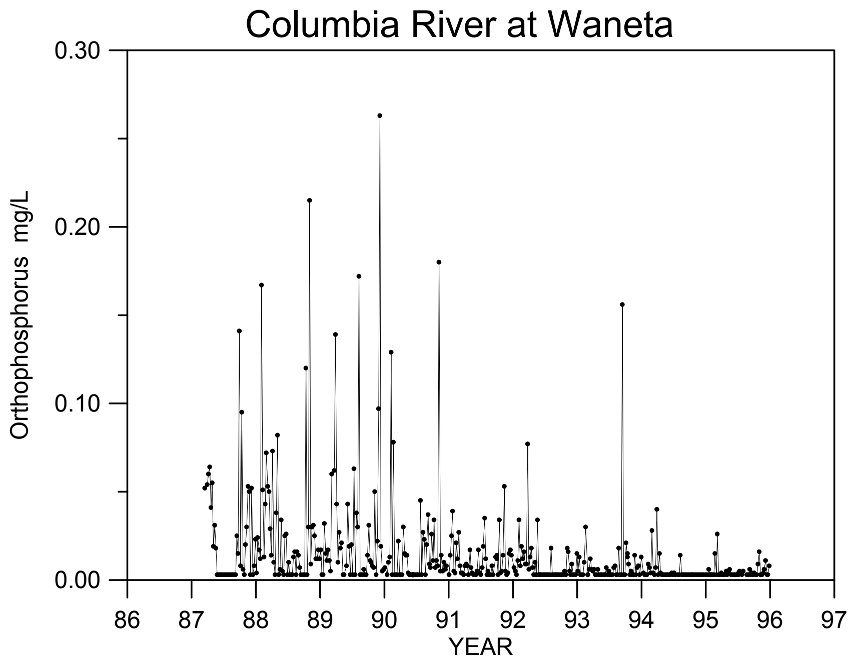

Figure 12. Time series plot of ortho-phosphorus data from the Columbia River at Waneta, 1987-1995.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

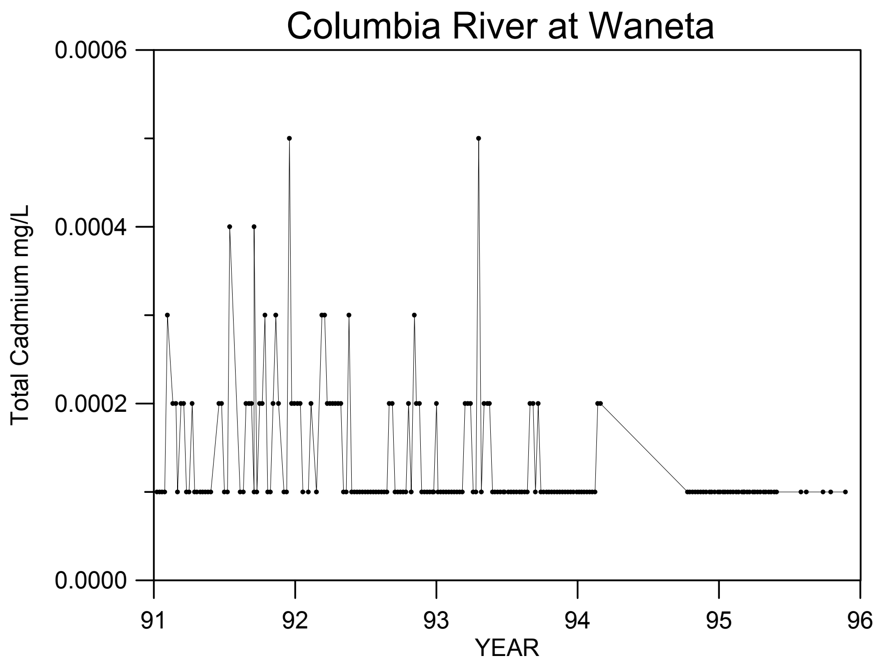

Figure 13. Time series plot of total cadmium data from the Columbia River at Waneta, 1991-1995.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

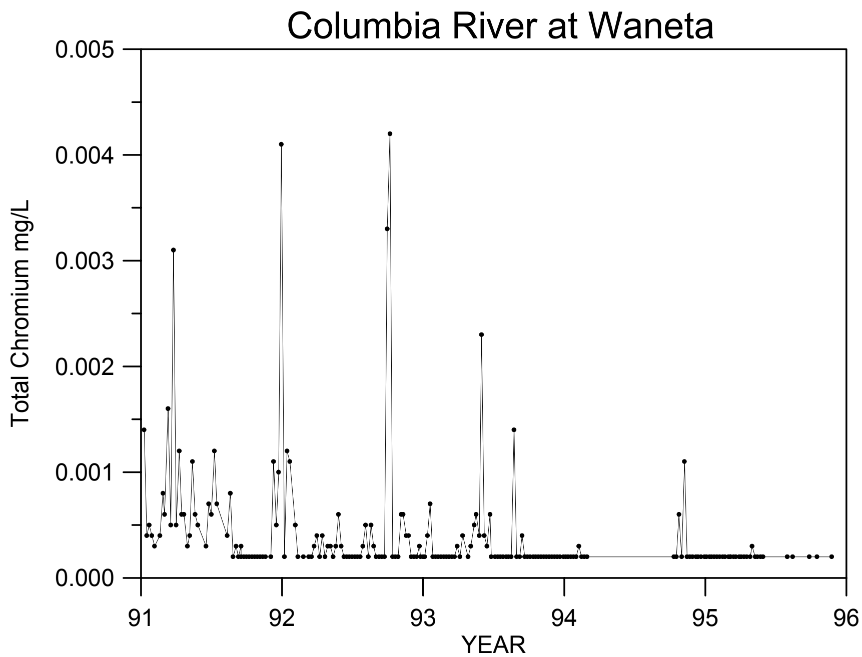

Figure 14. Time series plot of total chromium data from the Columbia River at Waneta, 1991-1995.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

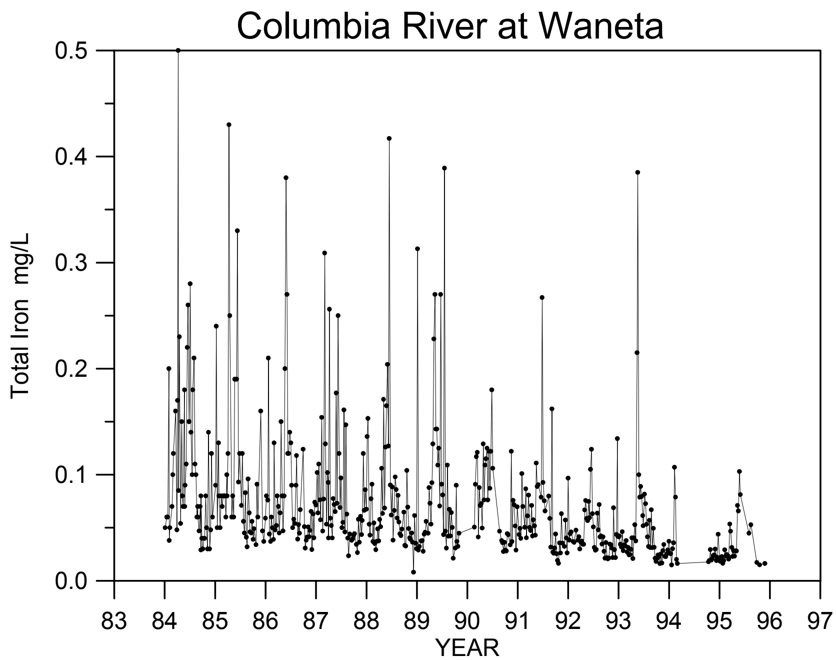

Figure 15. Time series plot of total iron data from the Columbia River at Waneta, 1984-1995.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

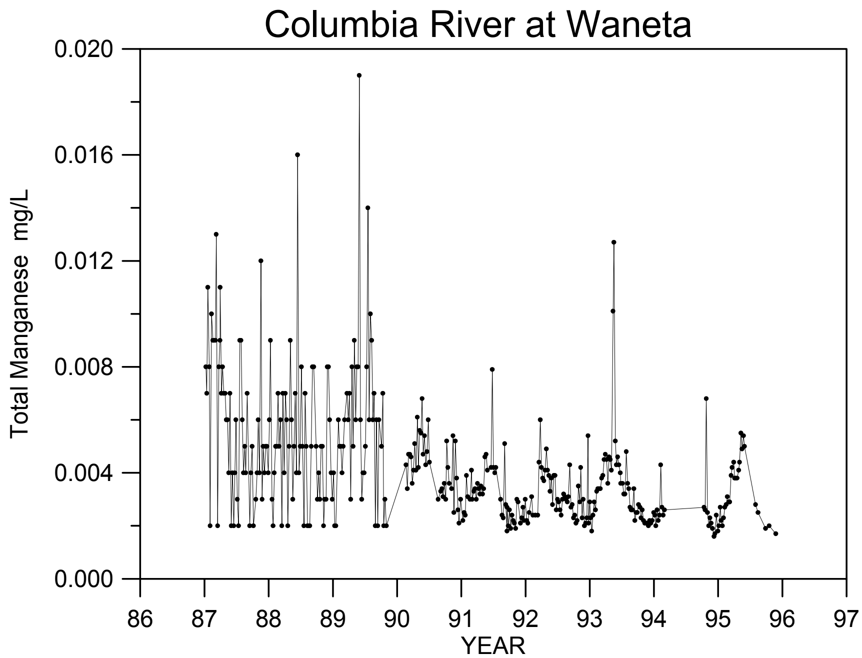

Figure 16. Time series plot of total manganese data from the Columbia River at Waneta, 1987-1995.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

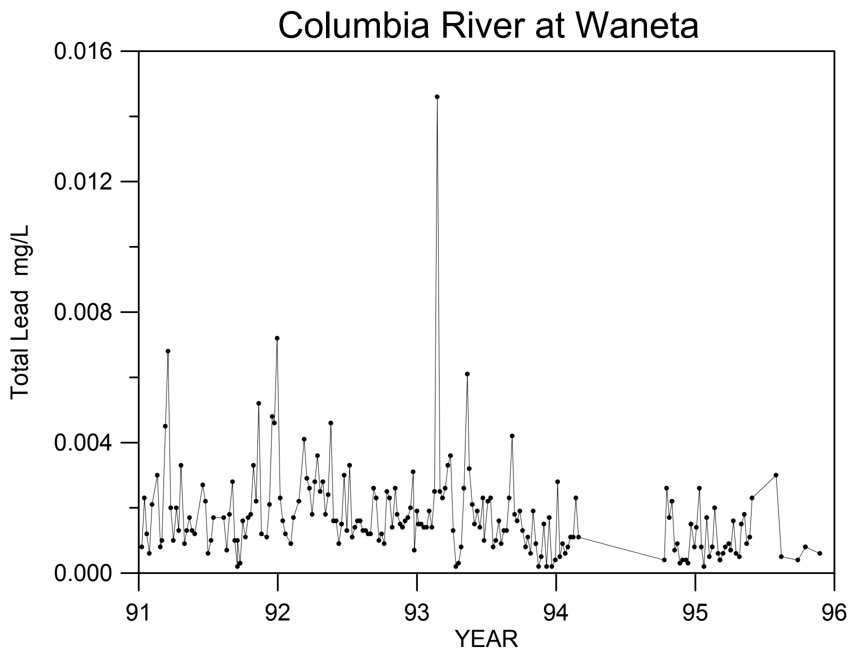

Figure 17. Time series plot of total lead data from the Columbia River at Waneta, 1991-1995.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

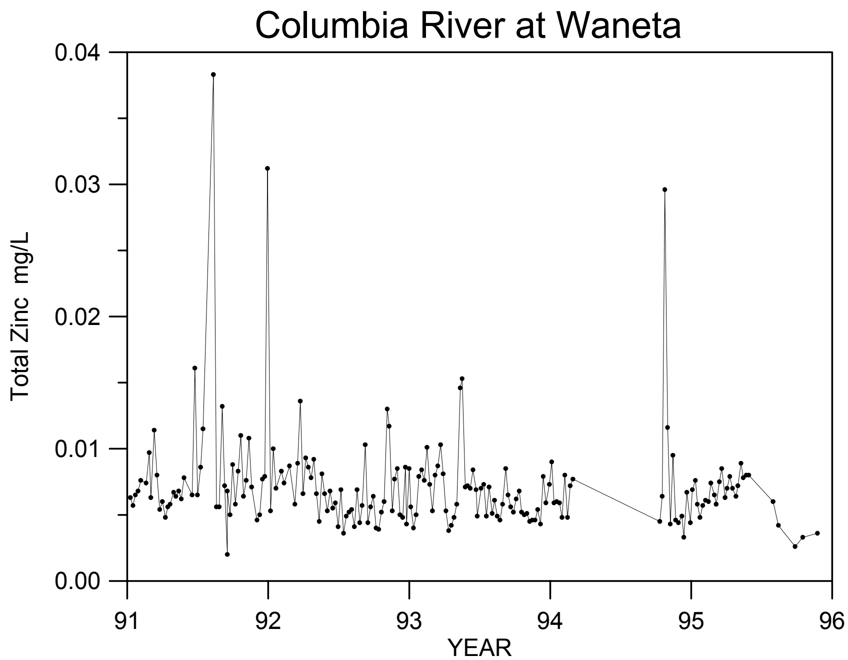

Figure 18. Time series plot of total zinc data from the Columbia River at Waneta, 1991-1995.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

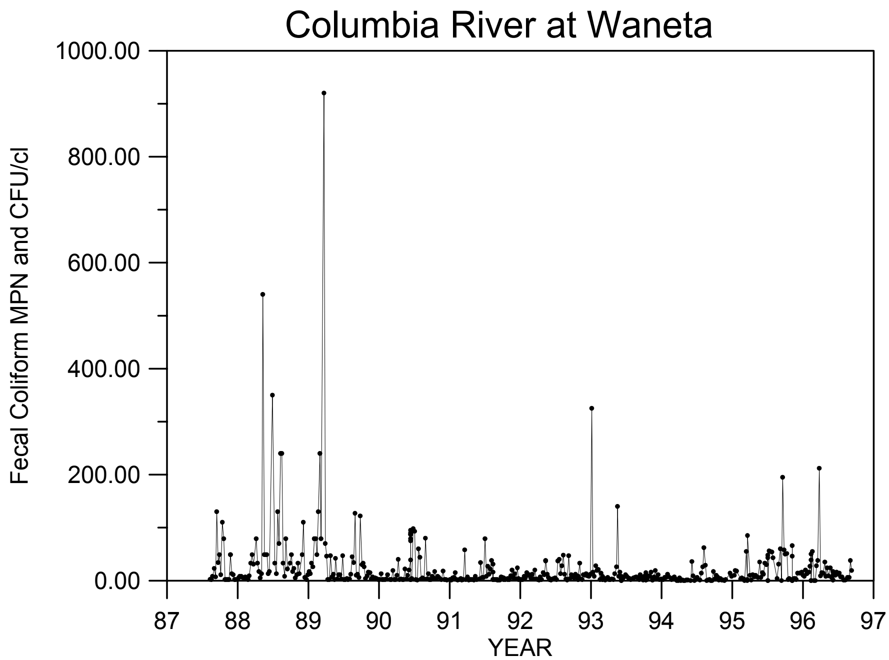

Figure 19. Time series plot of fecal coliform data from the Columbia River at Waneta, 1987-1996.

NONPARAMETRIC	**:**	**Some evidence of a LINEAR DECREASING TREND**
REGRESSION	**:**	**POSITIVE QUADRATIC TREND**

Elk River at Highway 93 Bridge

The water quality monitoring station on the Elk River at Highway 93 is located south from Elko, B.C., just before the river enters Lake Koocanusa. This area - also known as Philips Canyon - is in the hotter, southern part of the Elk River basin. The river is a highly productive fisheries river, with some of the largest populations of westslope cutthroat trout, bull trout and whitefish in the Kootenay region.

There is widespread coal mining in the upper Elk basin - coal output from the Elk Valley almost doubled during the 1980's. Forestry and agriculture are also carried out in the basin. The primary contaminants discharged in the basin which may impact water quality are nitrogen (explosive residuals from mining), non-filterable residues and turbidity, along with related elements such as phosphorus.

The recent rapid assessment report on Elk River water quality indicated that nitrate/nitrite, total dissolved nitrogen, arsenic and selenium were all increasing over time; selenium values are among the highest measured at any of the stations within the B.C. monitoring network (Wipperman, 1997). Non-parametric statistical tests and regressions confirmed that significant increasing trends are occurring for nitrate/nitrite, total dissolved nitrogen and selenium. Total arsenic was found to exhibit no significant trend via non-parametric analysis, but a positive quadratic trend (i.e. a U-shaped trend) via regression analysis. A series of elevated peaks correlated with several periods of high flow and associated non-filterable residue appear to have contributed to this pattern.

Increasing nitrogen levels can likely be attributed to the nitrogen-based explosives utilized for coal mining in the Elk River basin. The increasing selenium trend is apparently also related to coal mines in the basin, and their expansion into the mining of seleniferous formations. The sources, concentrations and environmental effects of the selenium are presently under investigation by BC Environment and mining companies in the area.

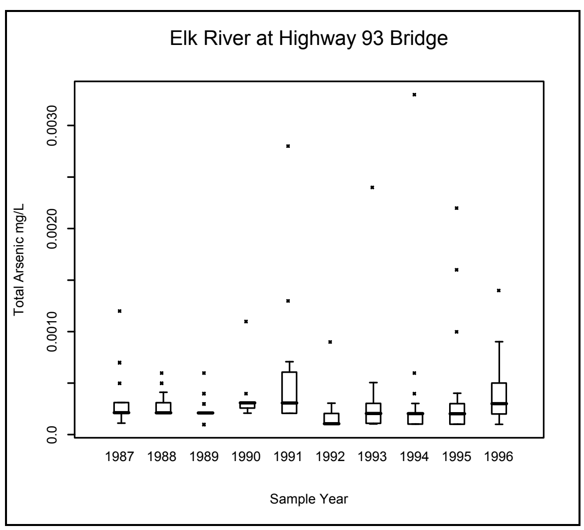

Figure 20. Annual summary of total arsenic data from the Elk River at Highway 93, 1987-1996. **(Note: high As value of 0.012 mg/Lin 1996 omitted from summary).**

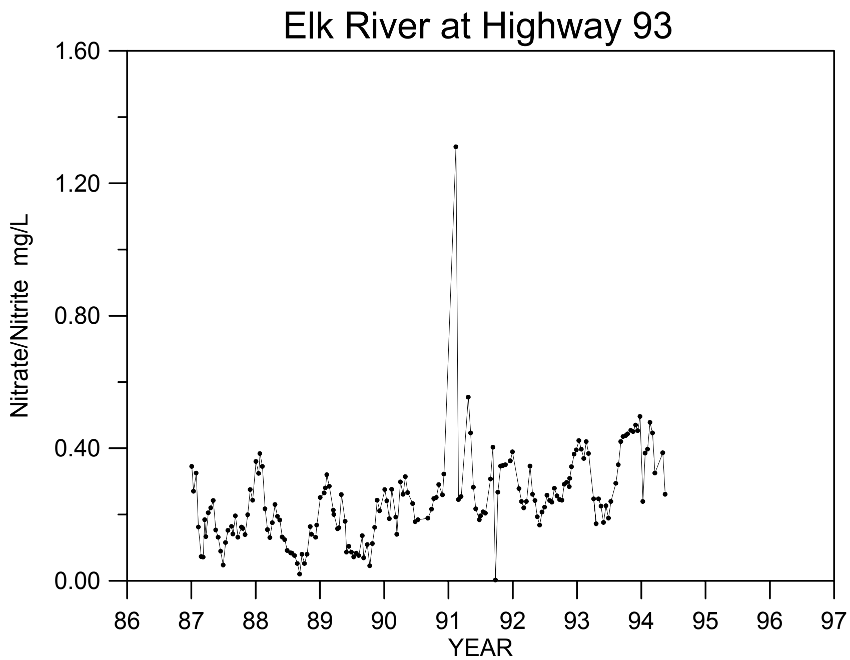

Figure 21. Time series plot of nitrate/nitrite data from the Elk River at Highway 93, 1987-1994.

NONPARAMETRIC	**:**	**LINEAR INCREASING TREND**
REGRESSION	**:**	**INCREASING TREND**

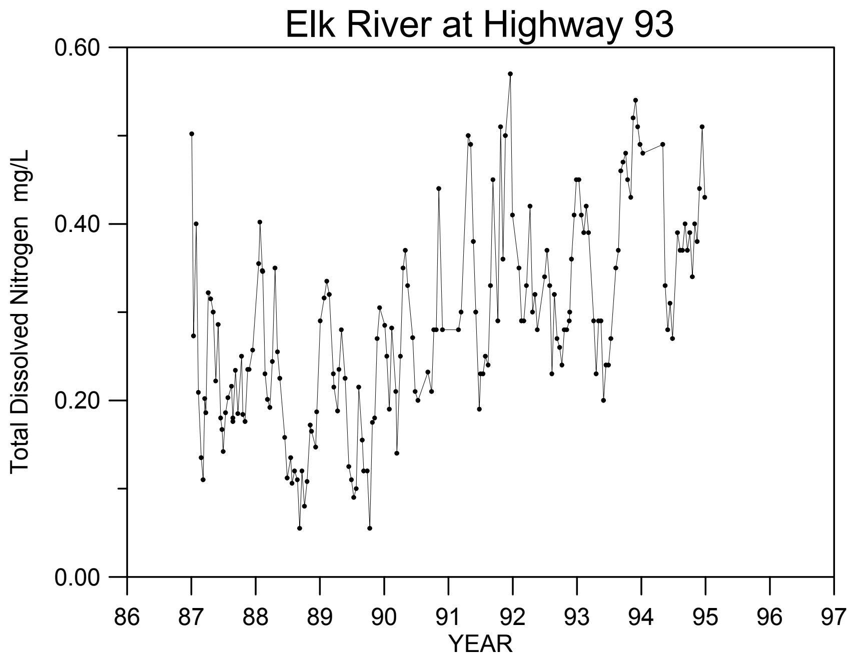

Figure 22. Time series plot of total dissolved nitrogen data from the Elk River at Highway 93, 1987-1994.

NONPARAMETRIC	**:**	**LINEAR INCREASING TREND**
REGRESSION	**:**	**INCREASING TREND**

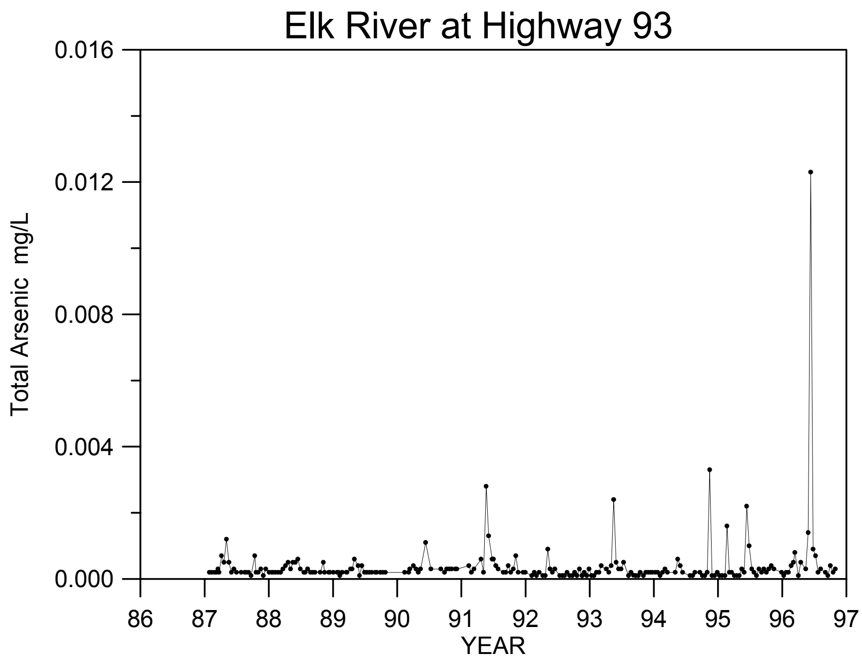

Figure 23. Time series plot of total arsenic data from the Elk River at Highway 93, 1987-1996.

NONPARAMETRIC	**:**	**NO TREND**
REGRESSION	**:**	**POSITIVE QUADRATIC TREND**

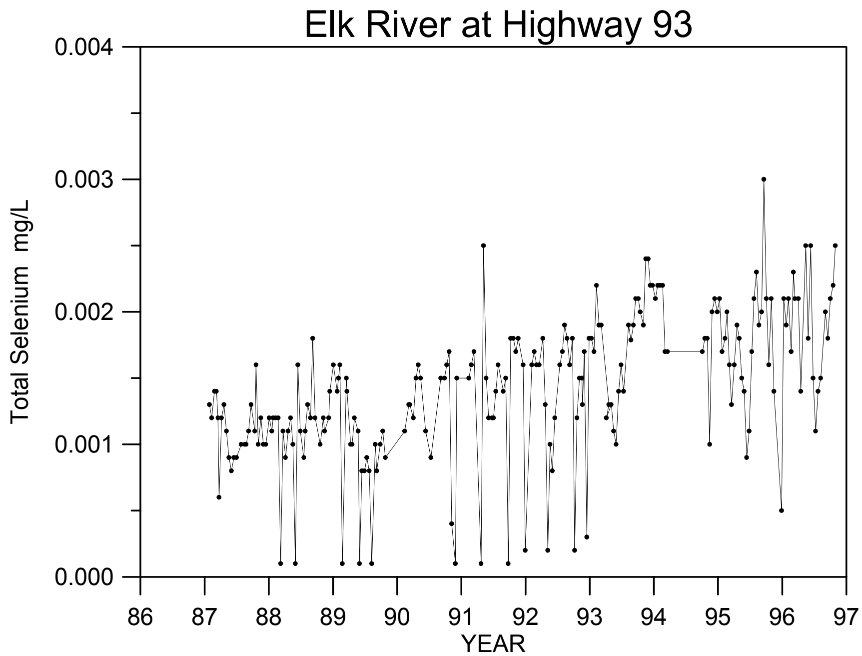

Figure 24. Time series plot of total selenium data from the Elk River at Highway 93, 1987-1996.

NONPARAMETRIC	**:**	**LINEAR INCREASING TREND**
REGRESSION	**:**	**INCREASING TREND**

Fraser River at Hope

The Fraser River at Hope station is used as a control for the upper Fraser Valley and the Fraser River estuary. Water quality at the site is influenced by inputs and tributaries (the Nechako and Thompson rivers, primarily) from the upper and middle reaches of the basin. Inputs include those from point sources such as upstream pulp mills and municipalities, as well as non-point sources including forestry and agriculture.

A recent assessment of Fraser River at Hope water quality indicated decreasing trends for both AOX and dissolved chloride (Holms, 1997). Both non-parametric and regression statistics indicated that significant decreasing trends existed for these variables. The decreases in AOX and chloride at the site can evidently be attributed to improved bleaching methods and reductions in AOX effluents from the upstream mills.

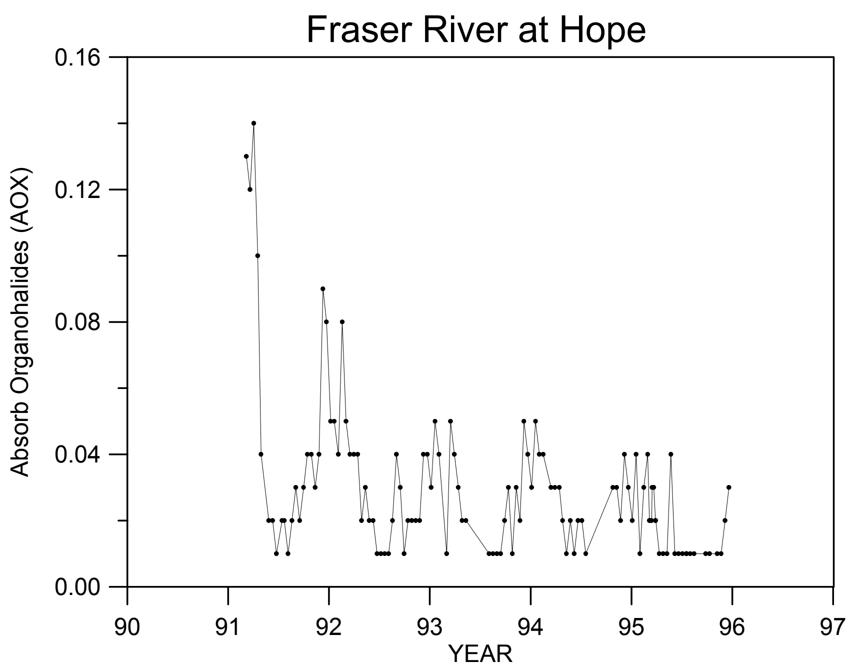

Figure 25. Time series plot of AOX data from the Fraser River at Hope, 1991-1995.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

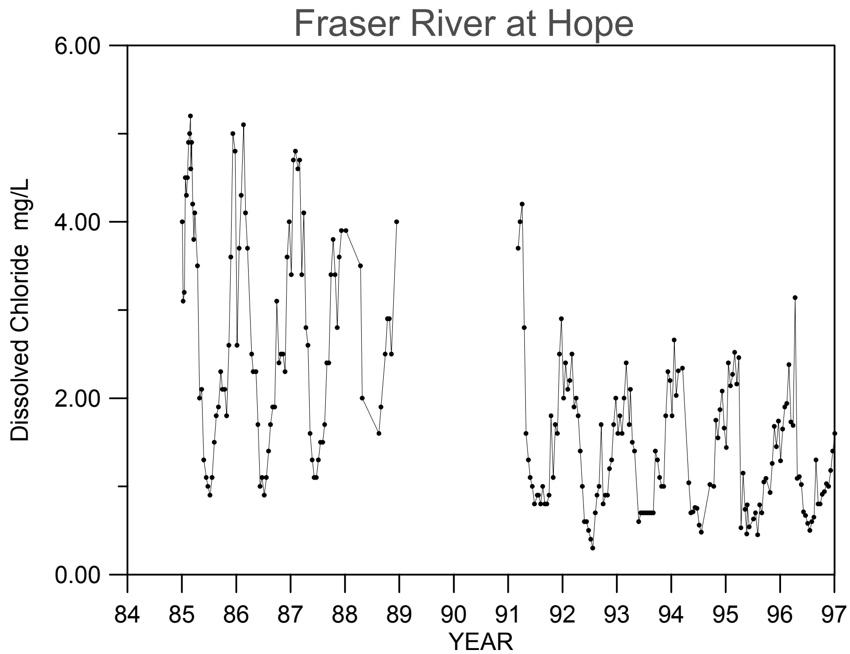

Figure 26. Time series plot of dissolved chloride data from the Fraser River at Hope, 1985-1996.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

Fraser River at Marguerite

The Marguerite monitoring station is located in central B.C., on the Fraser River mainstem approximately halfway between Williams Lake and Quesnel. Five upstream mills (pulp and/or paper) and municipal (sewage) inputs impact water quality at this location. Forestry and agriculture are also widespread in the basin.

A recent review of the water quality data from Marguerite (Wipperman, 1996) indicated that AOX and chloride have decreased over the period of record, while phosphorus (dissolved and ortho) and fecal coliforms were increasing. Both non-parametric statistics and regression analysis have confirmed that there are significant decreasing trends for both AOX and chloride at the site, again due to pollution abatement and improved effluent quality at upstream pulp mills.

Non-parametric analysis has shown that there is no significant trend for dissolved phosphorus, although the apparent increasing trend for ortho-phosphorus is marginally significant. Regression modeling indicated that a negative quadratic trend was occurring.

Fecal coliforms were shown to exhibit a marginally significant linear decreasing trend via non-parametric statistics, while regression analysis indicated a positive quadratic trend. Graphs of the data show that coliforms were high during 1988 - 1989, decreased somewhat from 1990 through 1993, and have again increased since then (Figure 40). Many of the values are above guidelines and objectives, although an increased sampling frequency is required to properly evaluate these exceedences. The elevated coliform levels seen are likely due to sewage discharges from Prince George and/or Quesnel. It is also possible that *klebsiella* bacteria, which are sometimes associated with pulp mill effluents, may be causing false positive readings during fecal coliform analysis.

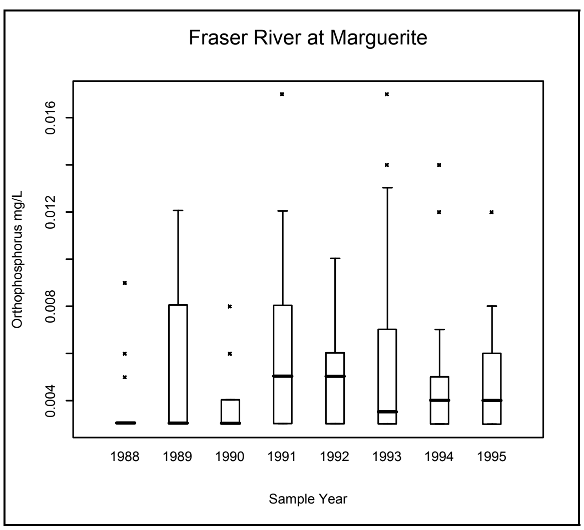

Figure 27. Annual summary of ortho-phosphorus from the Fraser River at Marguerite, 1988-1995.

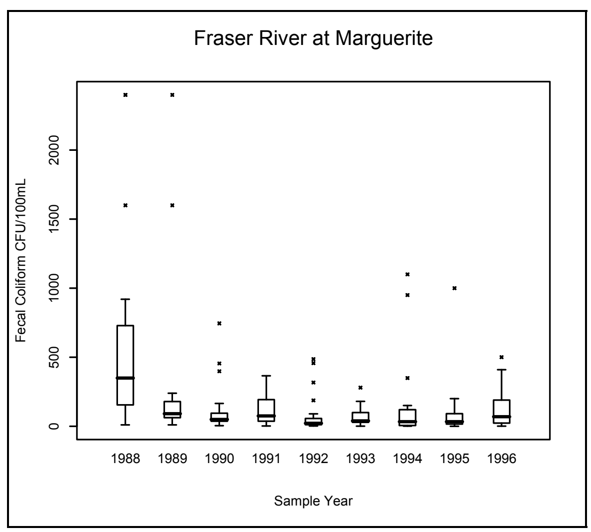

Figure 28. Annual summary of fecal coliform from the Fraser River at Marguerite, 1988-1996. (Note that 1988 and 1989 observations are in MPN/100mL, and that 3 values were greater than 2400 MPN/100mL).

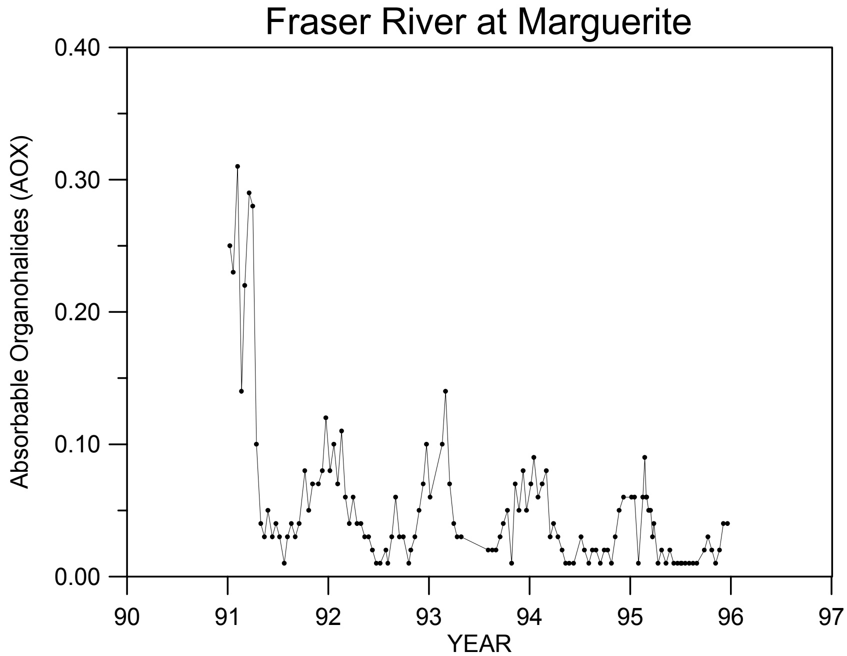

Figure 29. Time series plot of AOX data from the Fraser River at Marguerite, 1991-1995.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

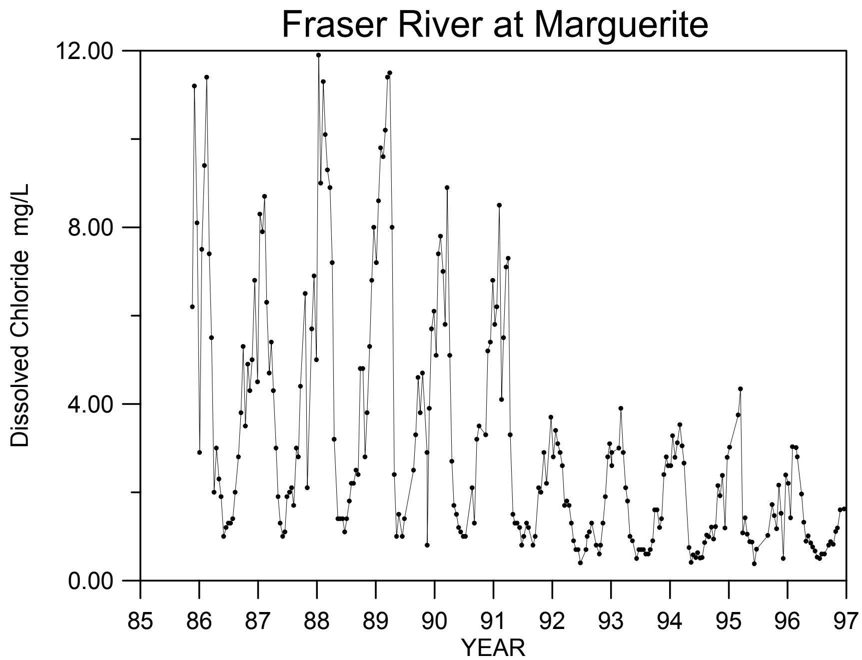

Figure 30. Time series plot of dissolved chloride data from the Fraser River at Marguerite, 1986-1996.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

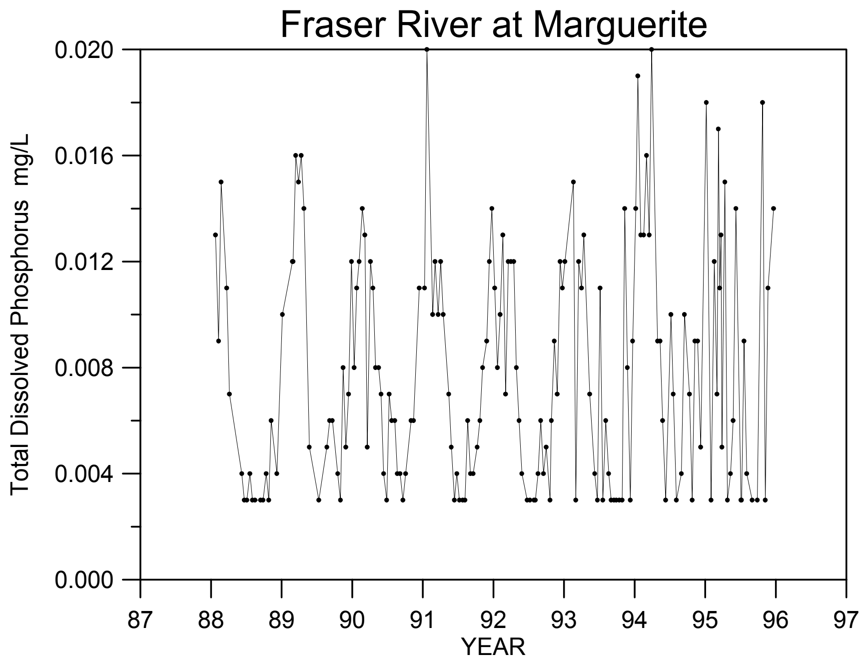

Figure 31. Time series plot of total dissolved phosphorus data from the Fraser River at Marguerite, 1988-1995.

NONPARAMETRIC	**:**	**NO TREND**
REGRESSION	**:**	**NO TREND**

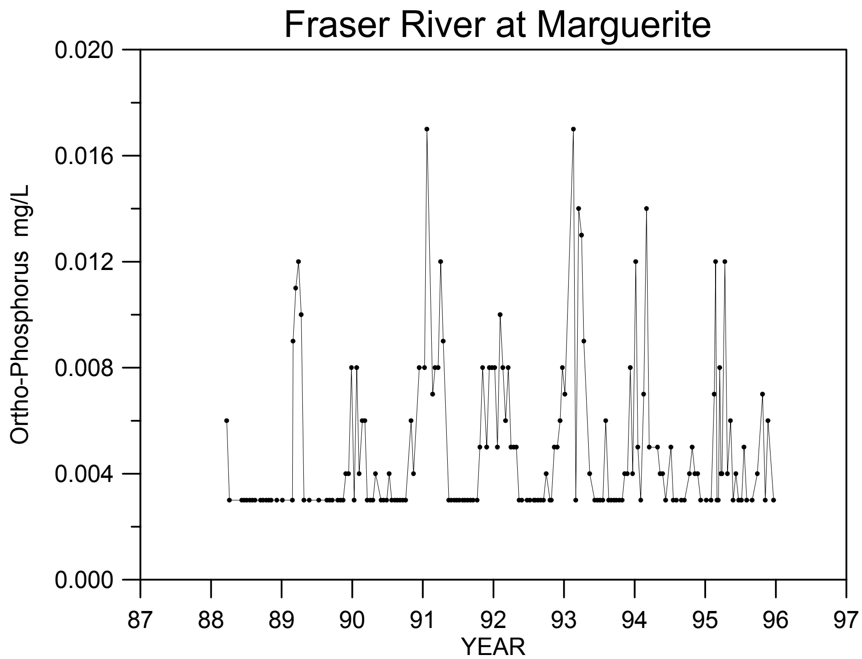

Figure 32. Time series plot of ortho-phosphorus data from the Fraser River at Marguerite, 1988-1995.

NONPARAMETRIC	**:**	**LINEAR INCREASING TREND (marginal)**
REGRESSION	**:**	**NEGATIVE QUADRATIC TREND**

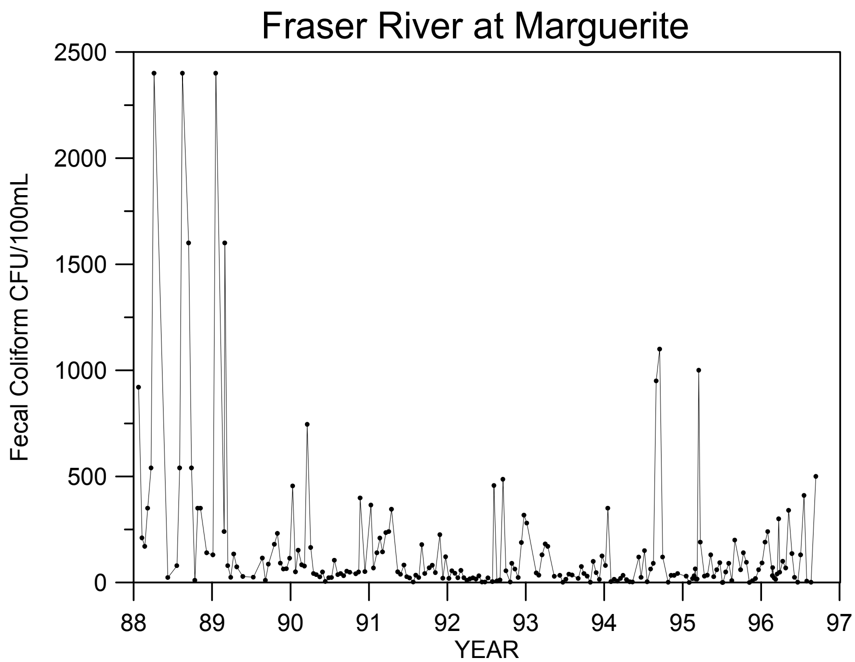

Figure 33. Time series plot of fecal coliform data from the Fraser River at Marguerite, 1988-1996. **(Note that 1988 and 1989 observations are in MPN/100mL, and that 3 values were greater than 2400 MPN/100mL during this period).**

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND (marginal)**
REGRESSION	**:**	**POSITIVE QUADRATIC TREND**

Fraser River at Stoner

The Stoner sampling site is located between Prince George and Marguerite. A limited number of variables have traditionally been measured at this site - it's primary purpose being to isolate the effects of effluent discharges from Prince George from those downstream towards Marguerite.

Graphical assessment of the data from Stoner indicated a decreasing trend in AOX at the site, again due to improved pulp mill effluent quality. Both non-parametric and regression analyses confirmed the significance of this trend.

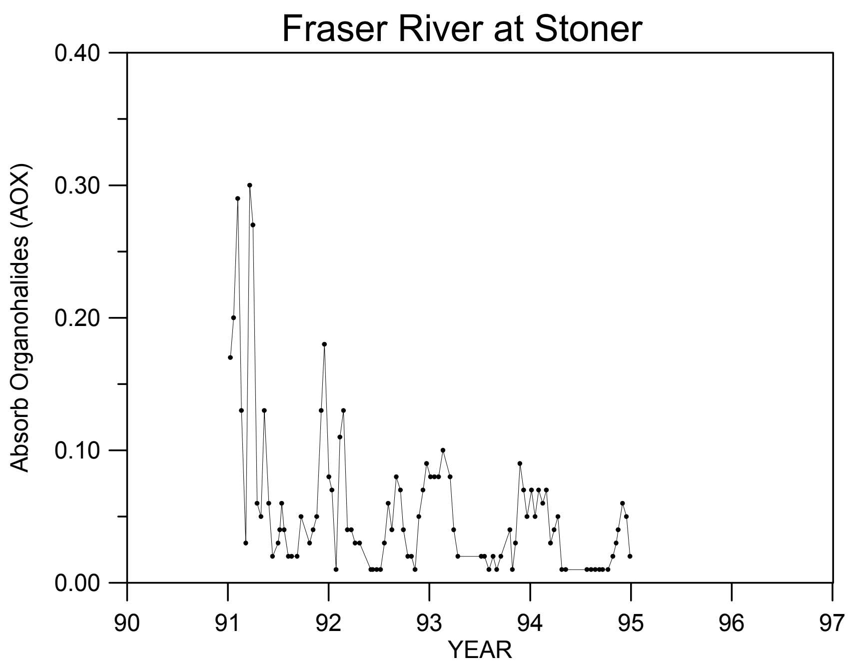

Figure 34. Time series plot of AOX data from the Fraser River at Stoner, 1991-1994.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

Kootenay River at Canal Flats

The water quality station on the Kootenay River at Canal Flats is located at the Highway 93/95 bridge at the south end of Canal Flats, B.C. Water quality at this site represents that from the upper portion of the basin; drainage from Kootenay National and Mount Assiniboine Parks, as well as from the Height of Rockies Park. There are no major point source discharges in this portion of the basin. Forestry and some agriculture are the only industries which could potentially impact water quality at this site.

The graphical review of the water quality data from Canal Flats has shown an apparent increase in specific conductivity over the period of record. Non-parametric and regression tests both confirmed a significantly increasing trend in specific conductivity at this site. While the cause of this increase is not known, continued monitoring of specific conductivity has indicated that values have decreased over the 1996 through 1998 period. Conductivity and related variables will continue to be sampled at Canal Flats over the next two years to monitor water quality changes at this site.

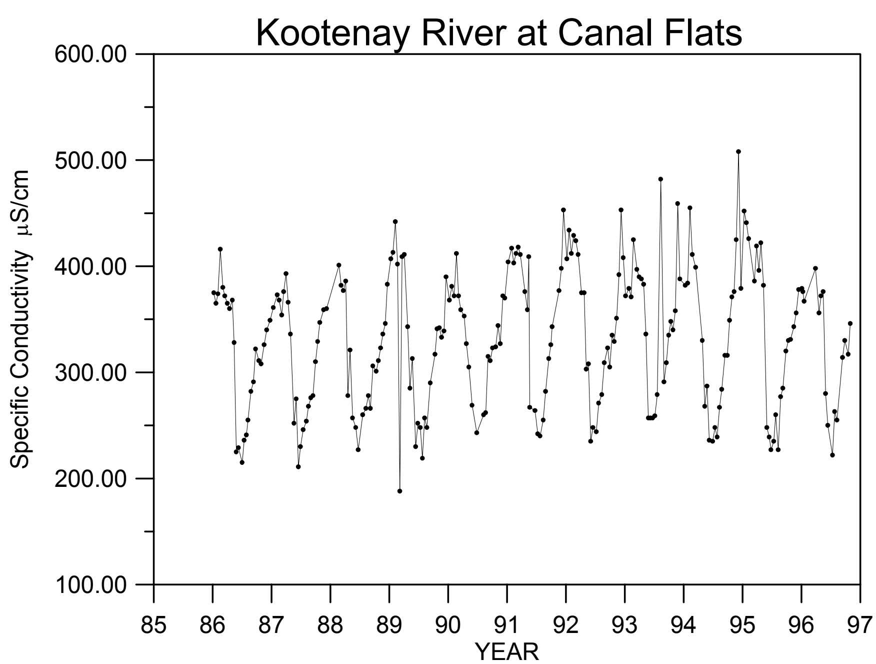

Figure 35. Time series plot of specific conductivity data from the Kootenay River at Canal Flats, 1986-1996.

(note that regression analysis only included data up to the end of 1995 due to lack of available flow data after this time period)

NONPARAMETRIC	**:**	**LINEAR INCREASING TREND**
REGRESSION	**:**	**INCREASING TREND**

Kootenay River at Creston

The water quality monitoring station on the Kootenay River at Creston is located just south from Creston at the Highway bridge, about 15 km north from the point where the Kootenay River re-enters Canada from the state of Idaho. The watershed upstream from the Creston site is impacted by agriculture, forestry, hydro-electric development, and some recreational uses. Major industrial discharges within the upper Kootenay basin include those from Crestbrook Forest Industries kraft pulp mill at Skookumchuk, Cominco Ltd.'s smelter and fertilizer plant at Kimberley, and a number of coal mines in the Elk River valley. Some municipal effluents, including those from the Creston sewage treatment plant, also have an impact on water quality at the site. Flow patterns at the station have undergone major changes due to the storage and release of water from the Libby Dam on Lake Koocanusa.

The rapid assessment report on water quality at this station indicated an apparent decreasing trend in total phosphorus (Webber, 1996.) Non-parametric statistics and regression analysis have indicated that this trend is marginally significant. The decline is most marked since 1992, which relates to a pattern of decreased flows and associated suspended sediments. The Libby impoundment (1972) and Cominco Kimberley's phosphorus abatement program (1975) caused subsequent declines in phosphorus in the Kootenay River at Creston (Clark, 1984). The decreases noted here may be a continuation of this earlier trend.

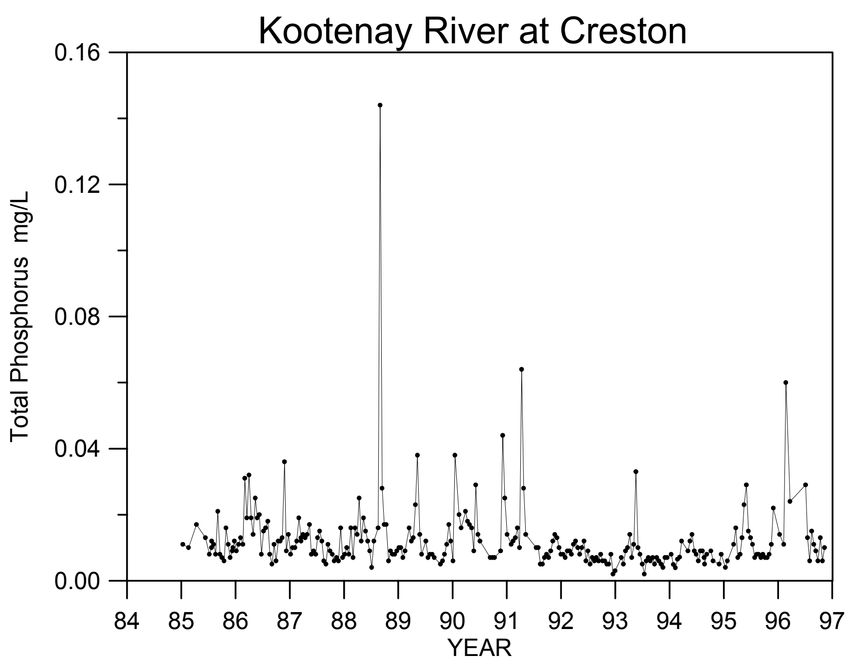

Figure 36. Time series plot of total phosphorus data from the Kootenay River at Creston, 1985-1996.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND (marginal)**
REGRESSION	**:**	**DECREASING TREND**

Kootenay River at Fenwick Station

The Fenwick Station monitoring site is located downstream from the St. Mary River and upstream from Koocanusa Lake, about 10 km south from Ft. Steele, B.C. The watershed upstream from Fenwick station is moderately impacted by forestry and agriculture, along with some mining and recreational uses. The only major industrial discharges within the upper Kootenay basin are Crestbrook Forest Industries kraft pulp mill at Skookumchuk, and Cominco Ltd.'s mining and fertilizer complex at Kimberley (located on the St. Mary River).

The rapid assessment report for this site noted an apparent decrease in zinc concentrations over the period of record at Fenwick Station (Webber, 1996.) Non-parametric and regression analyses echoed this, determining that a decreasing trend for zinc existed.

The decreasing trend noted for zinc is likely due to pollution abatement efforts at Cominco's Kimberley complex since 1990. It should be noted that sporadic zinc contamination from preservative vials in the late 1980's precluded the use of values from this period in the statistical analyses. Zinc values exceeding aquatic life guidelines continue to be noted occasionally at this site, indicating that zinc originating from Cominco's operations is still a contaminant of concern. Reclamation and pollution abatement programs are ongoing at the complex.

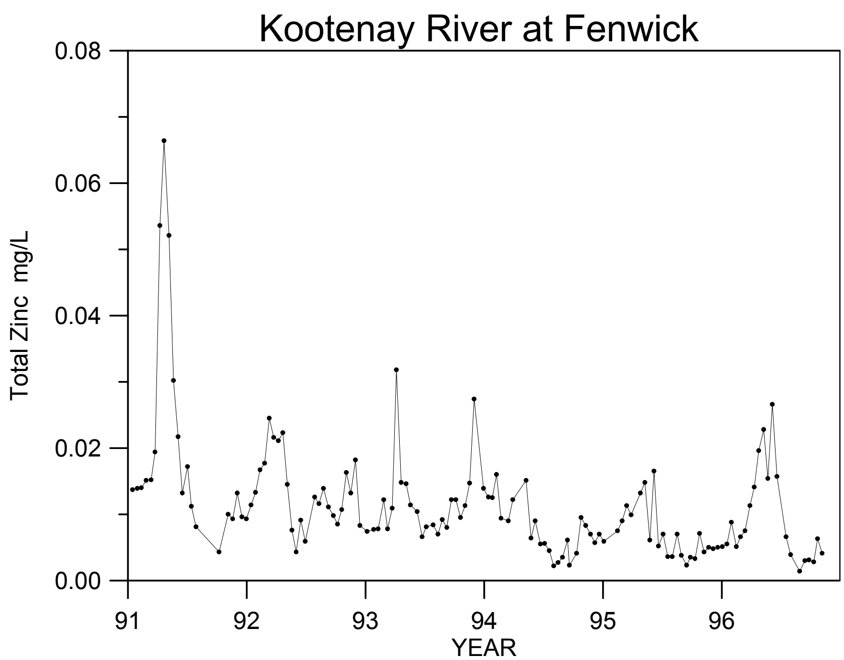

Figure 37. Time series plot of total zinc data from the Kootenay River at Fenwick Station, 1991-1996.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

Quinsam River near the Mouth

The Quinsam River is located on eastern Vancouver Island, west from Campbell River, B.C. It is a tributary of the Campbell River, which it joins 3 km inland from the Strait of Georgia. The water quality monitoring station on the Quinsam River is located just upstream from it's confluence with the Campbell River. The Quinsam River supports substantial populations of salmon (wild and hatchery-raised), steelhead and cutthroat trout; the Quinsam River Hatchery is located a short distance upstream from the monitoring site. The Quinsam River watershed is uninhabited. Logging and hydroelectric generation activities occur widely in the basin, and Quinsam Coal Ltd. began mining about 27 km upstream from the river mouth in December, 1987.

The graphical analysis of data from the Quinsam River site has shown apparent increasing trends in specific conductivity, hardness, dissolved calcium, magnesium, sodium and sulphate, and total strontium (Regnier *et al*., 1996.) Non-parametric analysis has confirmed significant linear increasing trends for all of these variables. Regression analysis also indicated that specific conductivity, sodium, sulphate and strontium were exhibiting increasing trends, but that hardness, calcium and magnesium exhibited positive quadratic trends. The shape of these trends can be noted in the boxplots and graphs (Figures 28-30 and 32-34, respectively) of these variables, and appears to be related to the flow pattern at this site (i.e., these constituents vary inversely with the flow pattern).

The increasing trends in water quality at the Quinsam River station coincide with the onset of coal mining in the basin, and would appear to be a result of these activities; the trends noted are indicative of neutralized acid drainage. Although concentrations of these variables are not yet of "environmental significance" at the site - i.e., they are well below guidelines - levels upstream at the mine are much higher, and the B.C. Ministry of Environment, Lands and Parks and the mining company are currently investigating potential upstream effects.

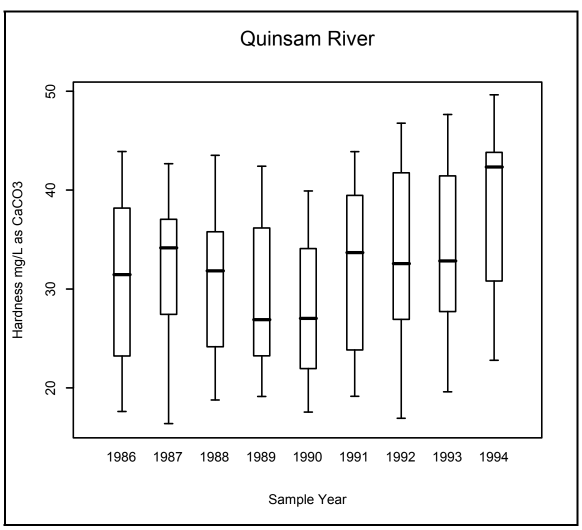

Figure 38. Annual summary of hardness data from the Quinsam River, 1986-1994.

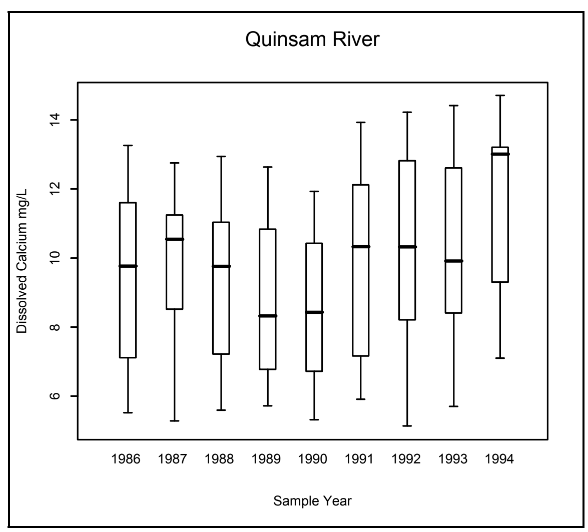

Figure 39. Annual summary of dissolved calcium data from the Quinsam River, 1986-1994.

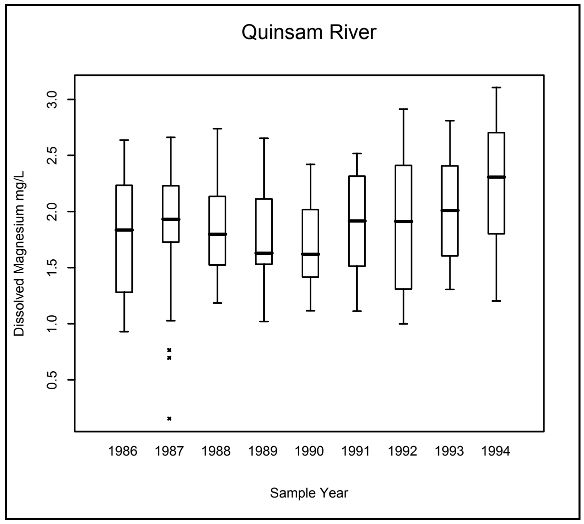

Figure 40. Annual summary of dissolved magnesium data from the Quinsam River, 1986-1994.

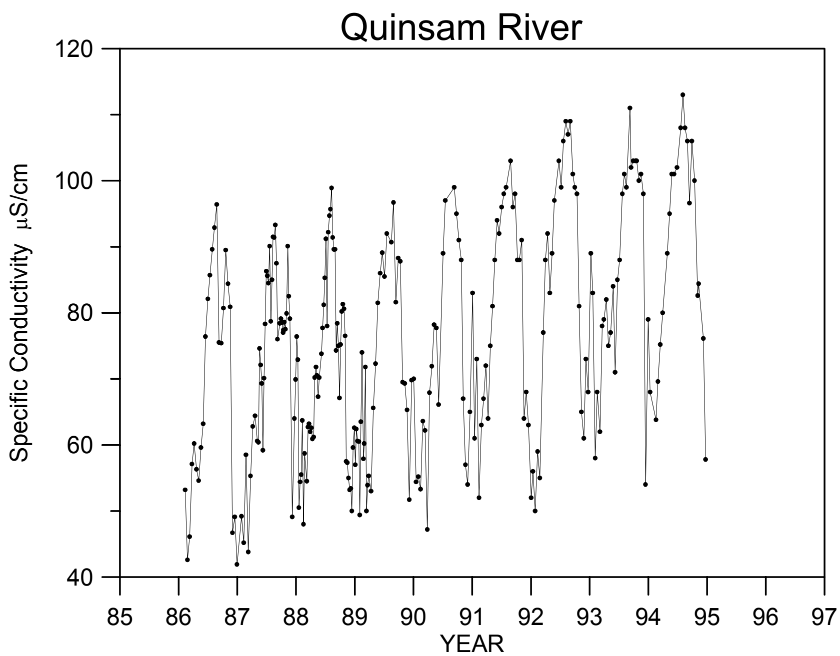

Figure 41. Time series plot of specific conductivity data from the Quinsam River, 1986-1994.

NONPARAMETRIC	**:**	**LINEAR INCREASING TREND**
REGRESSION	**:**	**INCREASING TREND**

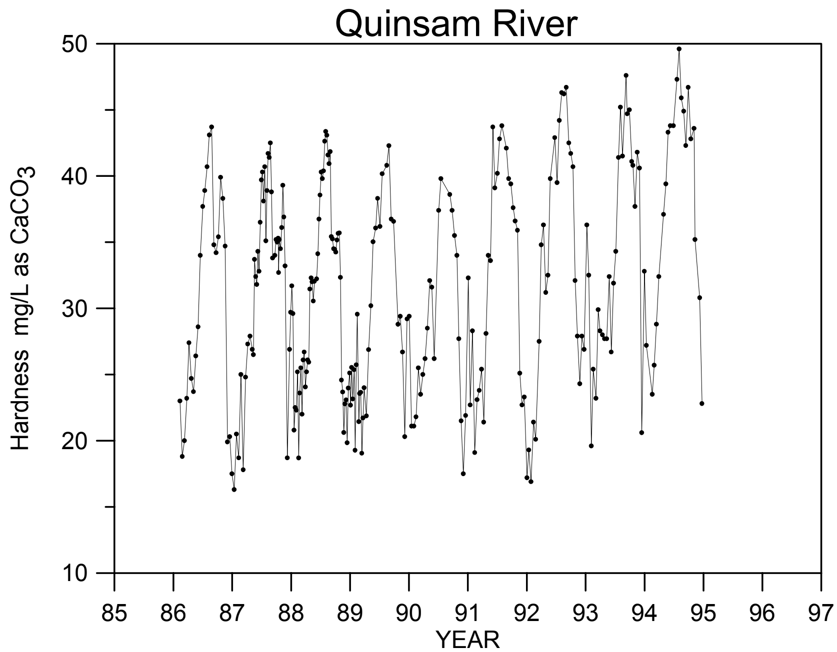

Figure 42. Time series plot of hardness data from the Quinsam River, 1986-1994.

NONPARAMETRIC	**:**	**LINEAR INCREASING TREND**
REGRESSION	**:**	**POSITIVE QUADRATIC TREND**

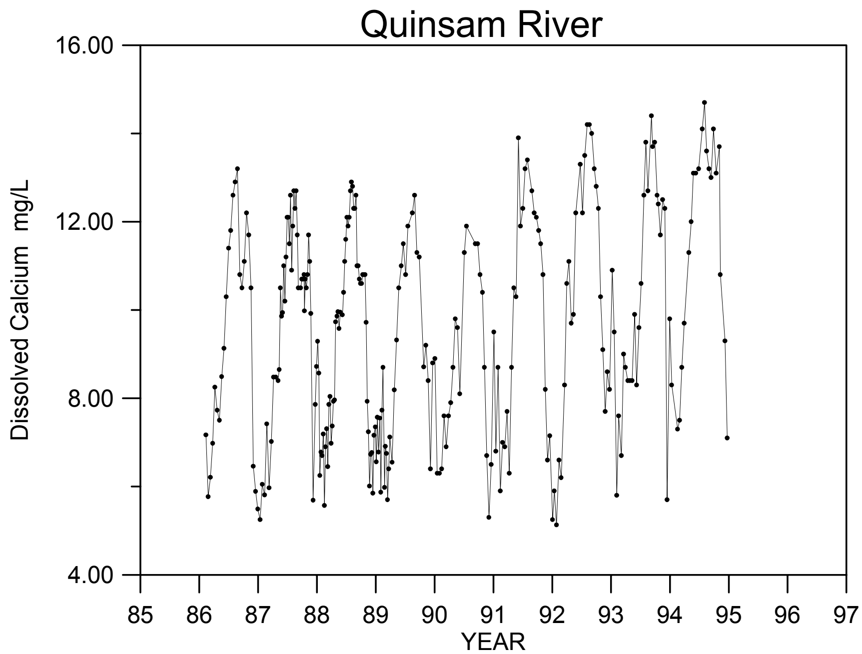

Figure 43. Time series plot of dissolved calcium data from the Quinsam River, 1986-1994.

NONPARAMETRIC	**:**	**LINEAR INCREASING TREND**
REGRESSION	**:**	**POSITIVE QUADRATIC TREND**

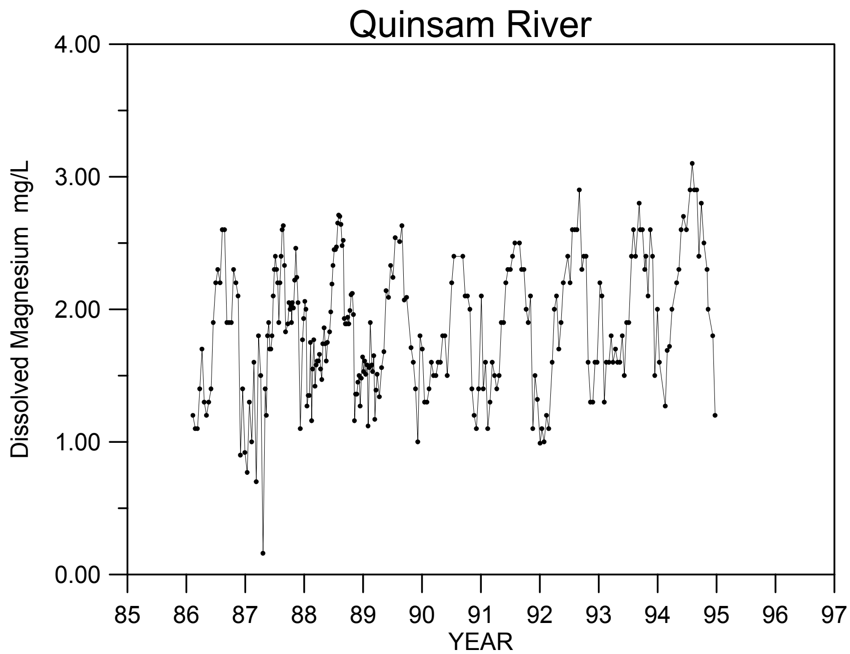

Figure 44. Time series plot of dissolved magnesium data from the Quinsam River, 1986-1994.

NONPARAMETRIC	**:**	**LINEAR INCREASING TREND**
REGRESSION	**:**	**POSITIVE QUADRATIC TREND**

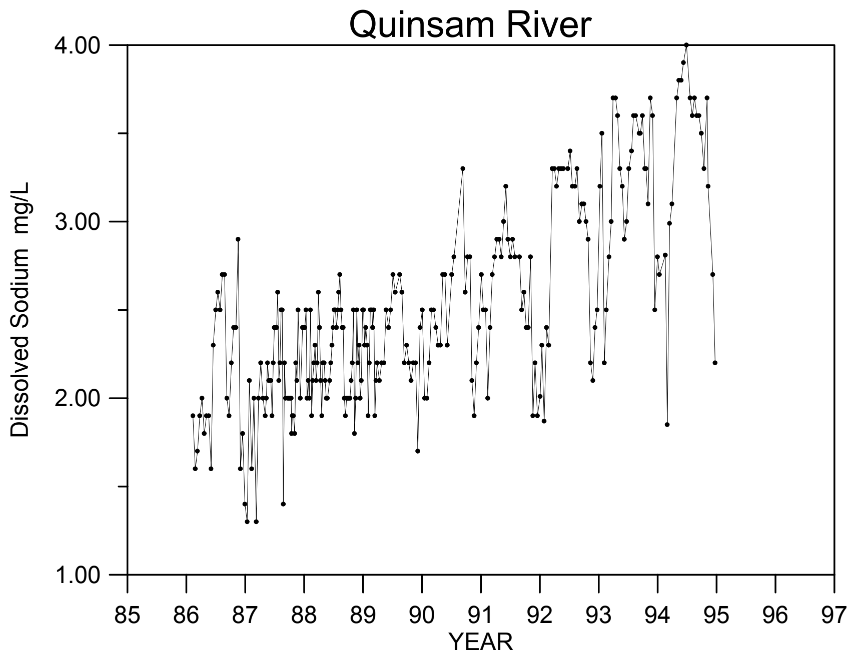

Figure45. Time series plot of dissolved sodium data from the Quinsam River, 1986-1994.

NONPARAMETRIC	**:**	**LINEAR INCREASING TREND**
REGRESSION	**:**	**INCREASING TREND**

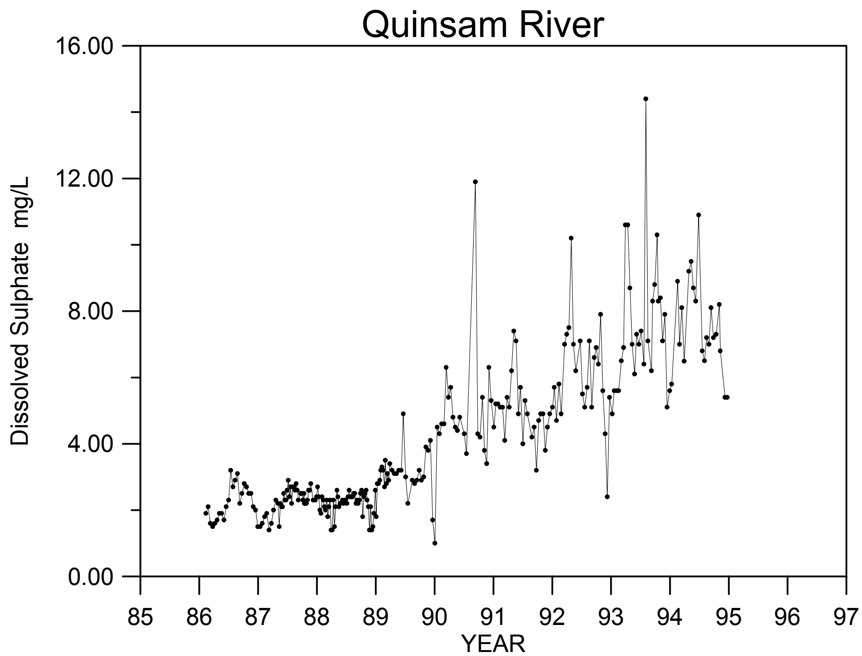

Figure 46. Time series plot of dissolved sulphate data from the Quinsam River, 1986-1994.

NONPARAMETRIC	**:**	**LINEAR INCREASING TREND**
REGRESSION	**:**	**INCREASING TREND**

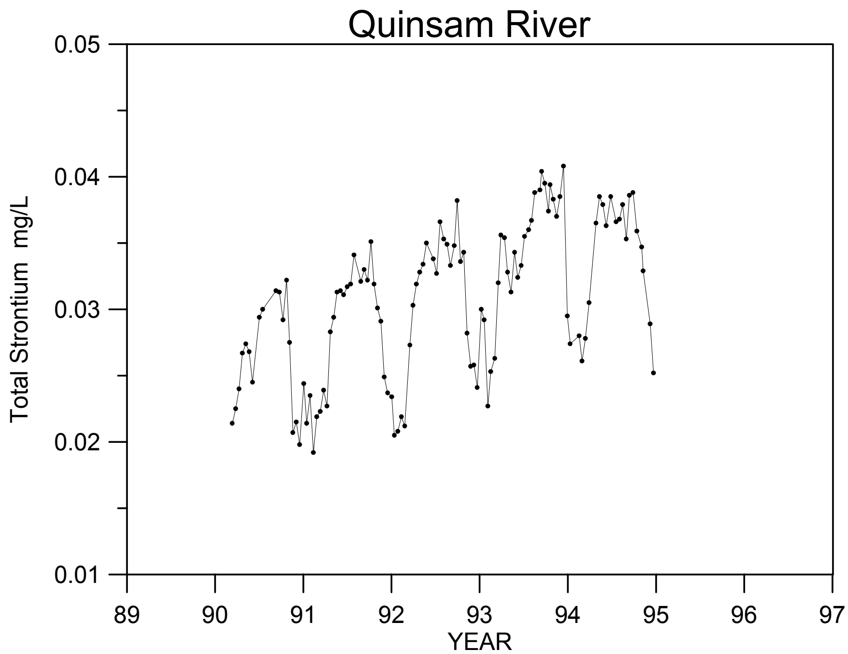

Figure 47. Time series plot of total strontium data from the Quinsam River, 1990-1994.

NONPARAMETRIC	**:**	**LINEAR INCREASING TREND**
REGRESSION	**:**	**INCREASING TREND**

Salmon River near Hyder, Alaska

The Salmon River near Hyder, Alaska is located in the North Coast region of B.C., just upstream from the town of Hyder. There is little human habitation in the upper watershed, but several operating and abandoned mines impart effluents and metal loadings to the river and it's tributaries.

The rapid assessment report on the data collected from this site indicated that total cyanide values have increased considerably since the early 1980's. Unfortunately, data collection at the station was suspended between 1985 and 1988, making data analysis during the 1980's virtually impossible. Non-parametric statistics carried out on data collected between 1989 and 1997 indicated that no trend existed at the 5% confidence level, but an increasing trend occurred at the 10% level. However, weak-acid dissociable cyanide has tended to decrease over the period of record, and remains at levels below guidelines.

Cyanide values between 1988 and 1991 are suspect, due to potential contamination from the preservative vials in use at that time. However, with the exception of the period between mid-1993 and mid-1994, values have continued to remain high despite the resolution of this problem, indicating that the measurements are real. Elevated cyanide levels may be attributable to effluent discharges from Westmin Premier Gold Mine, which began operation in 1989. Although the mine is currently not in operation due to the recent drop in gold prices, monitoring of both total and weak-acid dissociable cyanide will continue to track levels of this contaminant in the river.

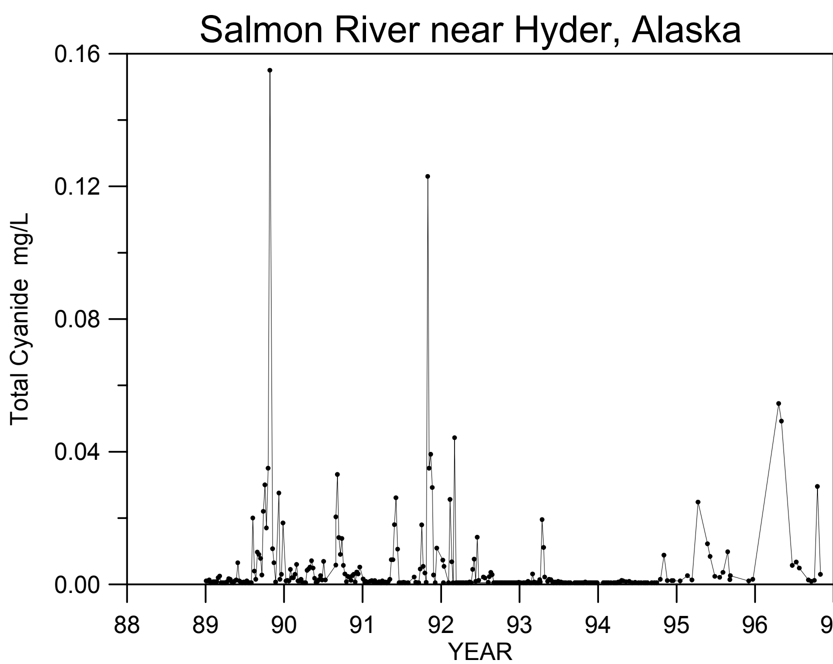

Figure 48. Time series plot of total cyanide data from the Salmon River near Hyder, Alaska, 1989-1996.

NONPARAMETRIC : NO TREND **(at the 5% level; increasing trend at the 10% level)**
REGRESSION : NA

Similkameen River at the US border

The Similkameen River drains about 9200 km^2 of the Cascade Mountains and the Interior Plateau of B.C. to the Okanagan River in Washington State, just downstream from Osoyoos Lake. The water quality monitoring station noted above is located approximately 10 km upstream from the international boundary.

Similkameen River water is used for drinking, irrigation, livestock and industry, and supports healthy populations of salmonids and a wide variety of other fish species. The river is also used for primary and secondary-contact recreation. The main impacts on water quality at the site include those from agriculture (fruit farming and cattle ranching), metal mining near Princeton and Hedley, forestry, and treated municipal waste water from Princeton and Keremeos.

Recent graphical review of the data from this station indicated that total arsenic and fecal coliforms had decreased over the period of record (Webber and Stewart, *in prep.)* Both trend and non-parametric analyses confirmed that arsenic levels have significantly decreased. However arsenic levels still occasionally exceed guidelines for aquatic life during freshet when turbidity levels are high. Erosion of tailings deposits at active and abandoned mines in the watershed may be the source of this arsenic; further studies are required to clarify the source(s) and environmental significance of the elevated levels measured.

Trend analyses indicated no significant trend for fecal coliforms, while non-parametric analyses indicated a decreasing trend. Despite the noted decrease, at times fecal coliform levels at this site still exceed the objective to protect raw drinking water receiving only disinfection. The elevated levels can be attributed to non-point sources - particularly cattle ranching in the watershed. Turbidity levels at the site are such that partial treatment (settling or filtration) is required before the water can be used for drinking, and such treatment would also remove fecal coliforms. The levels are nevertheless of concern, and will continue to be monitored on an ongoing basis.

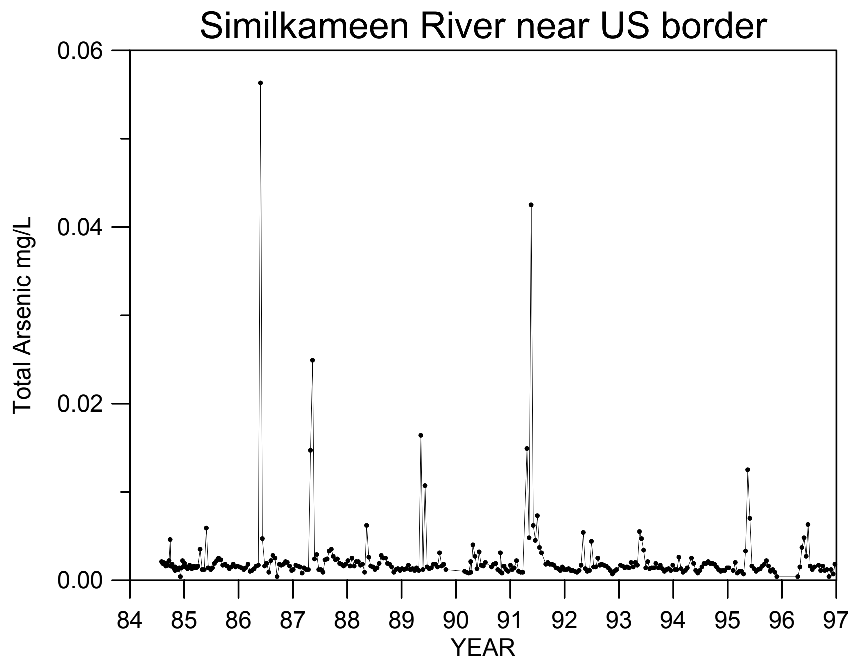

Figure 59. Time series plot of total arsenic data from the Similkameen River at the US border, 1984-1996.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

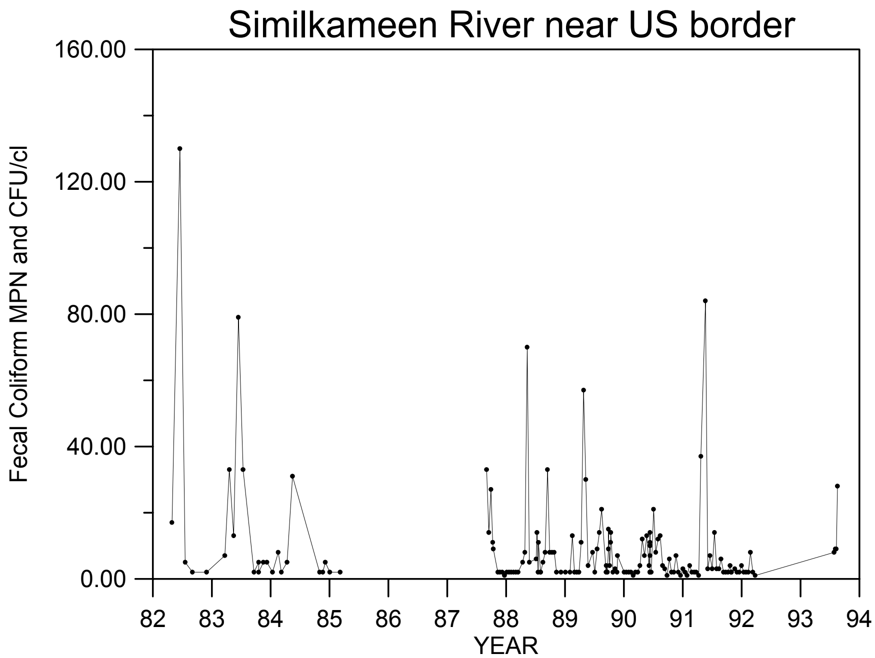

Figure 50. Time series plot of fecal coliform data from the Similkameen River at the US border, 1984-1996. **(Note that there was one value recorded on 11-FEB-85 of 20000 MPN that was not included in the analysis).**

NONPARAMETRIC	**:**	**NO TREND DETECTED**
REGRESSION	**:**	**DECREASING TREND**

South Thompson River at Kamloops

The South Thompson River is located in the southern interior of British Columbia. It arises from Little Shuswap Lake and flows in a southwesterly direction until it converges with the North Thompson River at Kamloops. The water quality monitoring station is located just above the river's confluence with the North Thompson River.

The South Thompson River provides important habitat for many fish species, supporting the well-known Adams River sockeye run each summer and fall, and many native species including steelhead, rainbow trout, and Rocky Mountain Whitefish year-round. Designated water uses of the South Thompson River include agricultural irrigation, livestock and wildlife watering, domestic water supply, industrial use, and a significant amount of outdoor recreation (Nordin and Holmes, 1992). The greatest impacts on river water quality occur from non-point discharges, with agriculture - primarily cattle operations - likely having the greatest effects.

The graphical assessment of the data from this station indicated decreasing trends for both total and dissolved phosphorus (Lilley *et al.,* 1998). Non-parametric and regression statistics confirmed that a decreasing trend existed for total phosphorus; the data set for dissolved phosphorus contained too many values at or below detection to allow statistical analyses via the methods being used (see Figure 52).

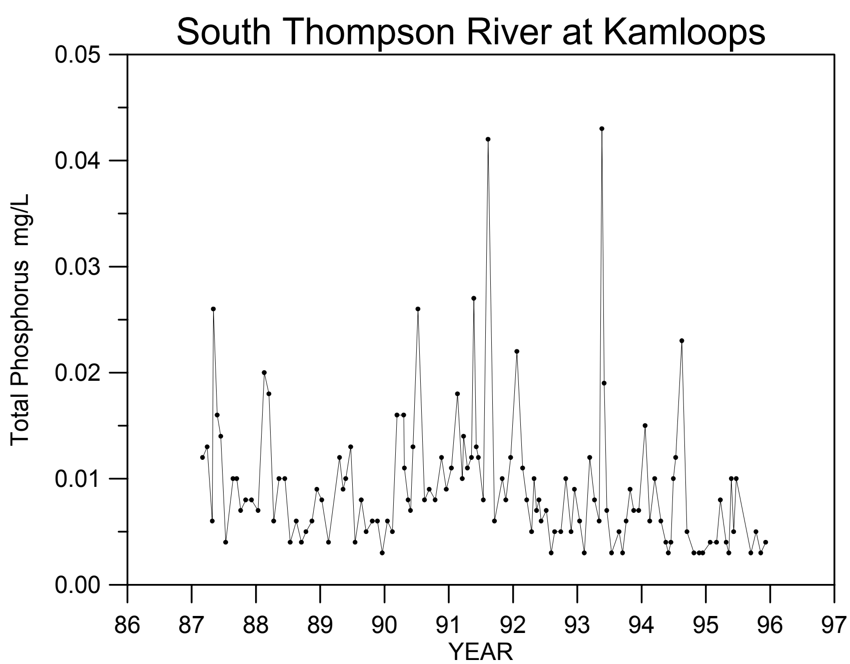

Figure 51. Time series plot of total phosphorus data from the South Thompson River at Kamloops, 1987-1995.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

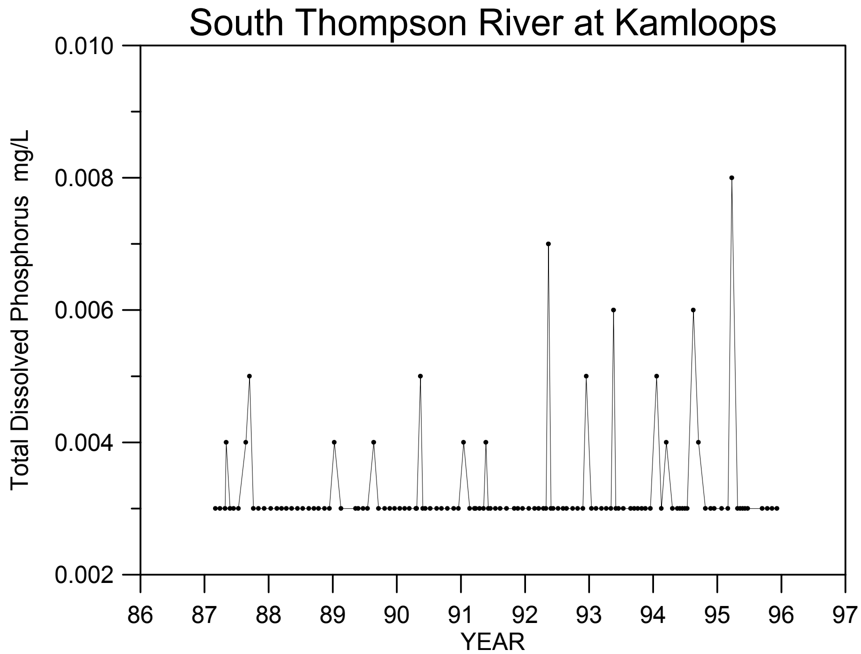

Figure 52. Time series plot of total dissolved phosphorus data from the South Thompson River at Kamloops, 1987-1995.

STATISTICAL ANALYSES NOT PERFORMED ON THIS DATA

Thompson River at Spences Bridge

The Thompson River is the largest tributary of the Fraser River, contributing up to 28% of the flow at Hope. The monitoring station at Spences Bridge provides representative water quality data from this major tributary. Impacts on water quality include upstream pulp mill and municipal discharges, as well as those from agriculture and forestry.

The recent assessment of water quality data from this site indicated that dissolved chloride, sodium and total phosphorus have decreased over time. Non-parametric and regression analyses confirmed that significant linear decreasing trends have occurred for these variables, although the trend for sodium is weak. These decreases can be attributed to improvements in upstream pulp mill operations.

Non-parametric analysis indicated that no trend existed for total phosphorus; however the analysis included 1996 data, which was considerably elevated over data from the previous years. Between 1986 and 1995 peak phosphorus values had clearly been decreasing over time (Figure 56). Regression analysis confirmed this pattern, indicating a positive quadratic trend. Continued data collection will indicate whether the trend will continue upward, or whether 1996 was an anomaly, and an overall downward trend in total phosphorus is dominant.

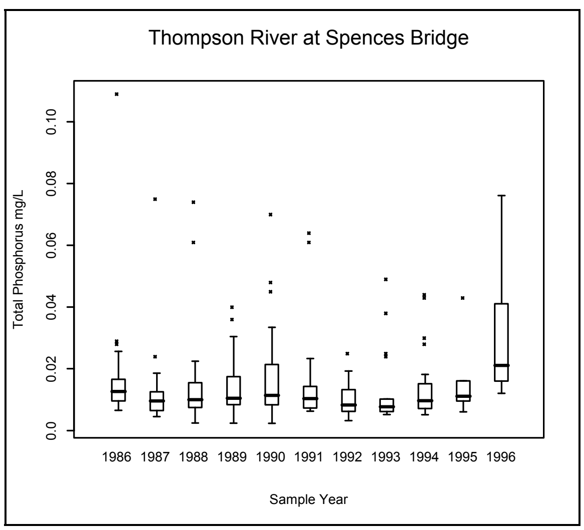

Figure 53. Annual summary of total phosphorus from the Thompson River at Spences Bridge, 1986-1996.

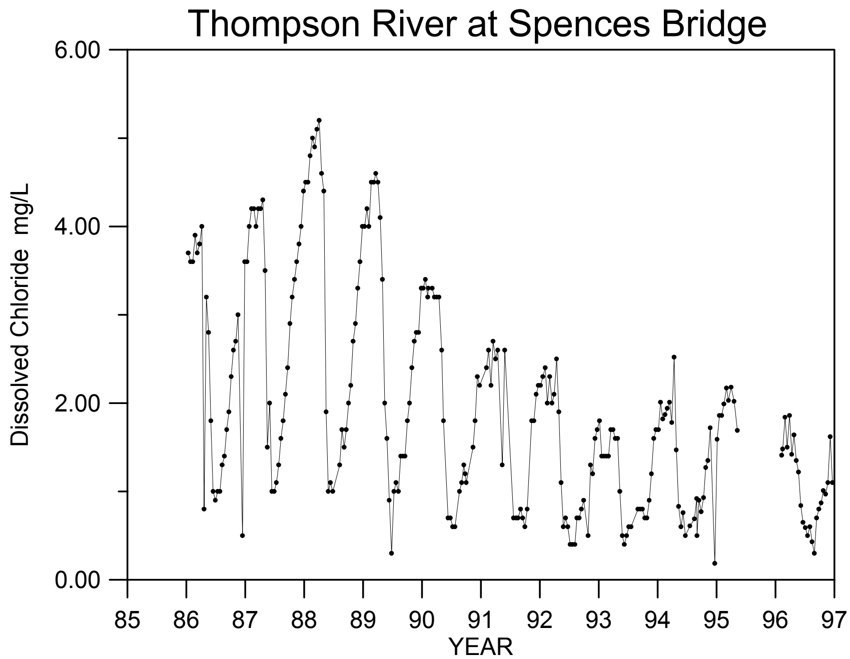

Figure 54. Time series plot of dissolved chloride data from the Thompson River at Spences Bridge, 1986-1996.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

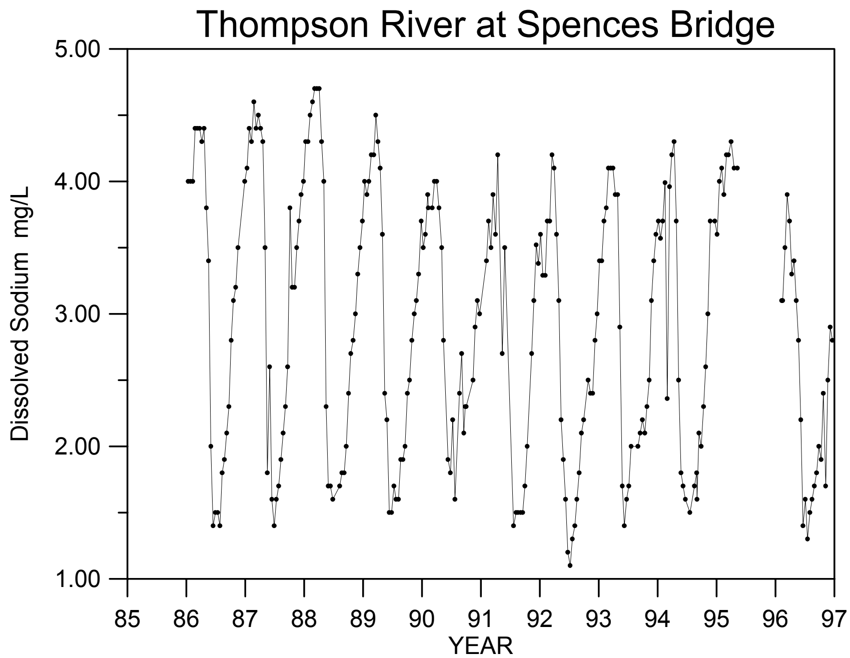

Figure 55. Time series plot of dissolved sodium data from the Thompson River at Spences Bridge, 1986-1996.

NONPARAMETRIC	**:**	**LINEAR DECREASING TREND**
REGRESSION	**:**	**DECREASING TREND**

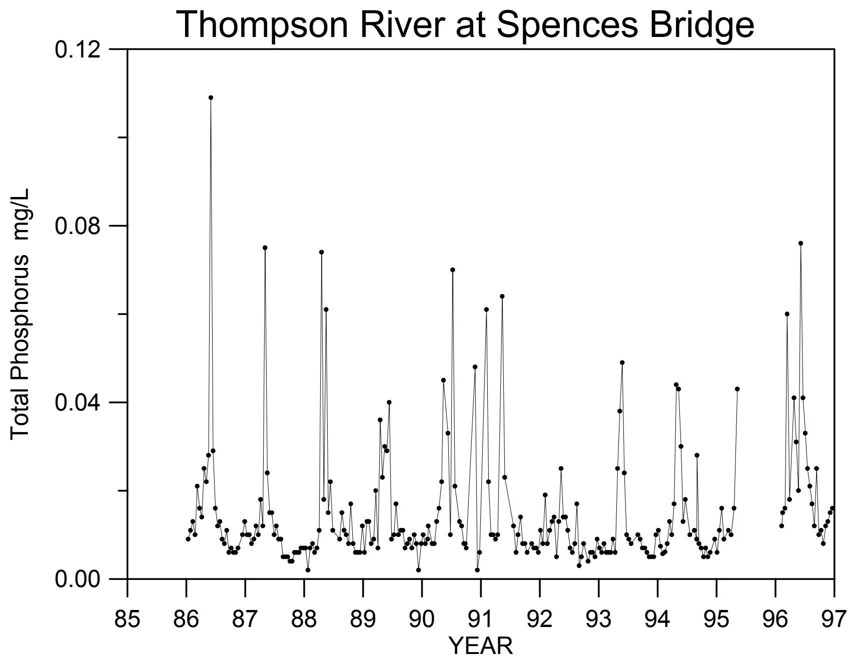

Figure 56. Time series plot of total phosphorus data from the Thompson River at Spences Bridge, 1986-1996.

NONPARAMETRIC	**:**	**NO TREND**
REGRESSION	**:**	**POSITIVE QUADRATIC TREND**

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APPENDIX 1

Non-parametric result tables

Statistics are significant at the 5% level unless otherwise indicated.

Columbia River at Birchbank

	Constituents		
	Total Phosphorus	Total Aluminum	Total Iron
VBT	3.035*	11.308	45.138
SK	-1.724*	-3.330	-6.704
MSK	NS	-1.891*	-3.003
SSE	-0.0001	-0.0015	-0.0021
LCL	-0.0002	-0.003	-0.0036
UCL	0.0001	0.00001	-0.0008

* - marginally significant (0.05 < p-value < 0.1)   NS - not significant at the 0.05 or 0.1 levels

Columbia River at Waneta

	Constituents		
	Dissolved Fluoride	Dissolved Sulphate	Total Phosphorus
VBT	15.831	22.389	53.943
SK	-3.961	-4.714	-7.326
MSK	-1.802*	-2.267	-3.217
SSE	-0.004	-0.167	-0.003
LCL	-0.007	-0.362	-0.005
UCL	0.0003	-0.025	-0.001
	Total Dissolved Phosphorus	Ortho-Phosphorus	Total Cadmium
VBT	22.132	41.352	13.414
SK	-4.680	-6.420	-3.570
MSK	-2.278	-2.766	-1.969
SSE	-0.007	-0.002	-1.1E-05
LCL	-0.004	-0.004	-2.78E-05
UCL	-0.0002	-0.0006	0
	Total Chromium	Fecal Coliforms	Total Iron
VBT	13.546	8.370	69.161
SK	-3.650	-2.868	-8.297
MSK	-1.805*	NS	-3.425
SSE	-0.00004	-1.274	-0.004
LCL	-0.0002	-3.844	-0.007
UCL	0	0.532	-0.002

* - marginally significant (0.05 < p-value < 0.1)   NS - not significant at the 0.05 or 0.1 levels

Columbia River at Waneta Continued

	Constituents		
	Total Manganese	Total Lead	Total Zinc
VBT	46.309	8.418	5.823
SK	-6.778	-2.836	-2.345
MSK	-2.607	-1.911*	-1.697*
SSE	-0.0003	-1.883E-04	-0.0004
LCL	-0.0005	-3.968E-04	-0.0008
UCL	-8.514E-05	5.173e-006	0.00006

* - marginally significant (0.05 < p-value < 0.1)

Elk River at Highway 93 Bridge

	Constituents			
	Nitrate/ Nitrite	Total Dissolved Nitrogen	Total Arsenic	Total Selenium
VBT	37.407	39.985	NS	41.587
SK	6.075	6.290	NS	6.418
MSK	2.280	2.478	NS	2.789
SSE	0.031	0.0295	NA	0.00009
LCL	0.007	0.008	NA	3.305E-05
UCL	0.060	0.048	NA	0.0001

NS - not significant at the 0.05 or 0.1 levels NA - not applicable

Kootenay River at Canal Flats

	Constituent
	Specific Conductivity
VBT	23.606
SK	4.837
MSK	2.357
SSE	2.500
LCL	0.478
UCL	4.610

Kootenay River at Fenwick

	Constituent
	Total Zinc
VBT	17.488
SK	-4.128
MSK	-2.081
SSE	-0.001425
LCL	-0.003
UCL	-0.0002

Kootenay River at Creston

	Constituent
	Total Phosphorus
VBT	5.424
SK	-2.308
MSK	NS
SSE	-0.0003
LCL	-0.0006
UCL	0.0001

NS - not significant at the 0.05 or 0.1 levels

Quinsam River near the mouth

	Constituents			
	Specific Conductivity	Hardness	Dissolved Calcium	Dissolved Magnesium
VBT	65.750	33.077	31.084	24.793
SK	8.077	5.721	5.545	4.956
MSK	3.027	2.746	2.629	2.640
SSE	2.903	0.818	0.241	0.059
LCL	1.382	0.269	0.076	0.011
UCL	4.543	1.549	0.425	0.096

Quinsam River at the mouth Continued

	Constituents		
	Dissolved Sodium	Dissolved Sulphate	Total Strontium
VBT	81.499	104.193	36.980
SK	9.008	10.177	6.010
MSK	3.188	3.182	2.033
SSE	0.175	0.734	0.002
LCL	0.081	0.437	0.0002
UCL	0.250	1.067	0.004

Salmon River near Hyder, Alaska

	Constituent
	Total Cyanide
VBT	3.797*
SK	1.913*
MSK	1.776*
SSE	0
LCL	0
UCL	5.479E-05

* - marginally significant (0.05 < p-value < 0.1)

Fraser River at Marguerite

	Constituents			
	Absorbable Organohalides	Dissolved Chloride	Total Dissolved Phosphorus	Ortho-Phosphorus
VBT	36.290	75.046	NS	10.605
SK	-5.959	-8.641	NS	3.178
MSK	-5.959	-2.954	NS	3.178
SSE	-0.008	-0.217	NA	0
LCL	-0.013	-0.509	NA	0
UCL	-0.006	-0.083	NA	0.0002

NS - not significant at the 0.05 or 0.1 levels NA - not applicable

Fraser River at Marguerite Continued

	Constituent
	Fecal Coliform
VBT	9.797
SK	-3.100
MSK	-1.783*
SSE	-8.708
LCL	-24.083
UCL	0.750

* - marginally significant (0.05 < p-value < 0.1)

Fraser River at Stoner

	Constituent
	Absorbable Organohalides
VBT	19.372
SK	-4.300
MSK	-1.665*
SSE	-0.011
LCL	-0.048
UCL	0.003

* - marginally significant (0.05 < p-value < 0.1)

Fraser River at Hope

	Constituents	
	Absorbable Organohalides	Dissolved Chloride
VBT	23.848	48.204
SK	-4.835	-6.918
MSK	-1.961	-2.345
SSE	-0.003	-0.120
LCL	-0.010	-0.236
UCL	0	-0.027

Thompson River at Spences Bridge

	Constituents		
	Dissolved Chloride	Dissolved Sodium	Total Phosphorus
VBT	62.832	16.567	NS
SK	-7.908	-4.056	NS
MSK	-2.687	-1.799*	NS
SSE	-0.148	-0.033	NA
LCL	-0.300	-0.080	NA
UCL	-0.051	0	NA

* - marginally significant (0.05 < p-value < 0.1)
NS - not significant at the 0.05 or 0.1 levels
NA - not applicable

South Thompson River at Kamloops

	Constituent
	Total Phosphorus
VBT	11.265
SK	-3.328
MSK	-1.877*
SSE	-0.0005
LCL	-0.001
UCL	0

* - marginally significant (0.05 < p-value < 0.1)

Similkameen River at the US border

	Constituents	
	Total Arsenic	Fecal Coliform
VBT	18.624	NS
SK	-4.297	NS
MSK	-2.663	NS
SSE	-3.333e-05	NA
LCL	-6.271e-05	NA
UCL	-5.62e-06	NA

NS - not significant at the 0.05 or 0.1 levels
NA - not applicable

APPENDIX 2

Regression result tables

Note that some seasonal coefficients were not significant but are included in these tables. Removing one seasonal coefficient (sine or cosine) is not sensible as it forces the periodic term to have a completely arbitrary phase shift, rather than one determined by the data. If both terms are insignificant then they may be dropped.

Regression modeling results of water quality constituents at selected sites in British Columbia

	Regression Coefficients							
	b_0	b_1	b_2	b_3	α_1	α_2	ω	r^2
Columbia River at Birchbank								
Total Phosphorus	-8.095	0.452	-0.129	0.0073	0.015	-0.145	0.041	0.21
Total Aluminum	-7.378	0.544	-0.067	---	-0.473	0.174	0.018	0.57
Total Iron	-7.328	0.572	0.030	-0.0061	-0.001	-0.147	0.039	0.21
Columbia River at Waneta								
Dissolved Fluoride	1.556	-0.472	-0.038	---	0.083	-0.144	0.009	0.26
Dissolved Sulphate	5.042	-0.331	-0.025	---	0.113	0.079	0.016	0.52
Total Phosphorus	2.486	-0.808	0.131	-0.024	NS	NS	0.054	0.44
Total Dissolved Phosphorus	NS	-0.685	-0.177	---	0.4	0.065	0.015	0.28
Ortho-phosphorus	NS	-0.710	-0.186	---	0.266	0.200	0.019	0.30
Total Cadmium	-5.772	-0.375	-0.160	---	NS	NS	0.017	0.26
Total Chromium	-8.764	NS	-0.194	---	-0.011	0.141	0.017	0.20
Total Iron	-5.628	0.445	-0.088	---	-0.427	0.189	0.020	0.51
Total Manganese	-3.157	-0.27	-0.088	---	-0.182	-0.184	0.018	0.41
Total Lead	-4.689	NS	-0.215	---	-0.027	0.200	0.016	0.15
Total Zinc	-3.929	NS	-0.059	---	NS	NS	0.488	0.04
Fecal Coliforms	5.863	NS	-0.748	0.061	0.209	0.227	-0.027	0.11
Elk River at Highway 93 Bridge								
Nitrate/Nitrite	-1.520	-0.178	0.155	---	0.103	-0.134	0.036	0.40
Total Dissolved Nitrogen	-2.082	0.105	0.111	---	0.342	-0.221	0.013	0.48
Total Arsenic	-10.882	0.751	-0.157	0.012	0.299	0.432	0.022	0.42
Total Selenium	-6.705	-0.116	0.085	---	-0.058	0.111	0.203	0.18
Kootenay River at Canal Flats								
Specific Conductivity	6.165	-0.116	0.014	---	0.038	0.087	0.020	0.80
Kootenay River at Fenwick								
Total Zinc	-4.862	NS	-0.171	---	-0.064	0.596	0.020	0.55
Kootenay River at Creston								
Total Phosphorus	-6.100	0.306	-0.045	---	-0.129	0.278	0.018	0.38
Quinsam River at the mouth								
Specific Conductivity	4.552	-0.253	0.036	---	0.021	-0.022	0.037	0.84
Hardness	3.930	-0.303	-0.036	0.006	0.031	-0.029	0.037	0.83
Dissolved Calcium	2.747	-0.299	-0.044	0.006	0.037	-0.041	0.038	0.81
Dissolved Magnesium	1.055	-0.312	NS	0.003	0.002	-0.036	0.053	0.82
Dissolved Sodium	0.801	-0.124	0.065	---	-0.016	-0.025	0.027	0.74
Dissolved Sulphate	1.085	NS	0.180	---	-0.106	-0.059	0.035	0.63
Total Strontium	-3.513	-0.143	0.078	---	0.008	-0.086	0.038	0.67

NS - not significant at the 0.05 level --- - quadratic term not included in model

Regression modeling results continued

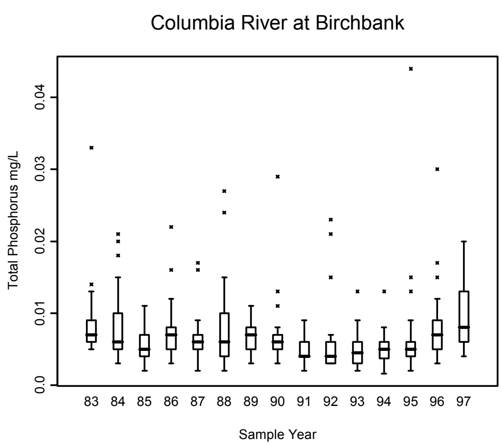
	Regression Coefficients							
	b_0	b_1	b_2	b_3	α_1	α_2	ω	r^2
Salmon River near Hyder, Alaska								
Total Cyanide	*Not analyzed by regression methods*							
Fraser River at Marguerite								
Absorbable Organohalides	3.078	-0.802	-0.306	---	NS	NS	0.040	0.67
Dissolved Chloride	7.036	-0.805	-0.124	---	NS	NS	0.039	0.82
Total Dissolved Phosphorus	-2.762	-0.348	NS	---	NS	NS	0.055	0.22
Ortho-phosphorus	-3.989	-0.278	0.202	-0.019	-0.091	-0.030	0.047	0.27
Fecal Coliform	10.318	-0.589	-0.886	0.072	0.358	-0.272	0.049	0.25
Fraser River at Stoner								
Absorbable Organohalides	2.317	-0.766	-0.383	---	-0.010	0.200	0.038	0.57
Fraser River at Hope								
Absorbable Organohalides	NS	-0.500	-0.223	---	NS	NS	0.052	0.47
Dissolved Chloride	4.018	-0.396	-0.107	---	0.086	0.315	0.020	0.84
Thompson River at Spences Bridge								
Dissolved Chloride	2.686	-0.264	-0.111	---	0.168	0.434	0.018	0.73
Dissolved Sodium	2.406	-0.219	-0.013	---	0.003	0.323	0.020	0.86
Total Phosphorus	-6.192	0.145	-0.182	0.021	0.254	0.058	0.016	0.22
South Thompson River at Kamloops								
Total Phosphorus	-5.476	NS	-0.065	---	0.184	0.218	0.016	0.18
Total Dissolved Phosphorus	*Not analyzed by regression methods*							
Similkameen River at the US border								
Total Arsenic	-6.828	0.200	-0.026	---	0.163	0.213	0.052	0.28
Fecal Coliforms	1.278	0.365	-0.125	---	0.066	-0.477	0.043	0.29

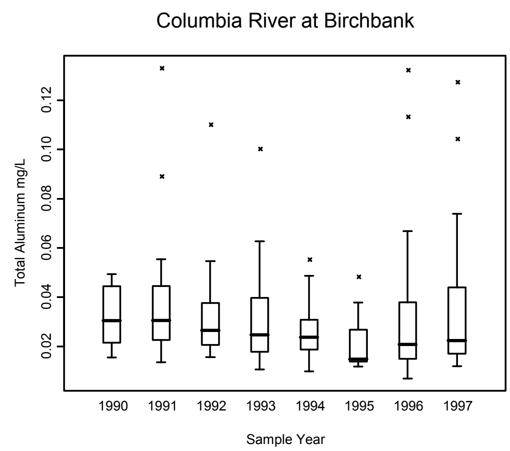
NS - not significant at the 0.05 level   --- - quadratic term not included in model

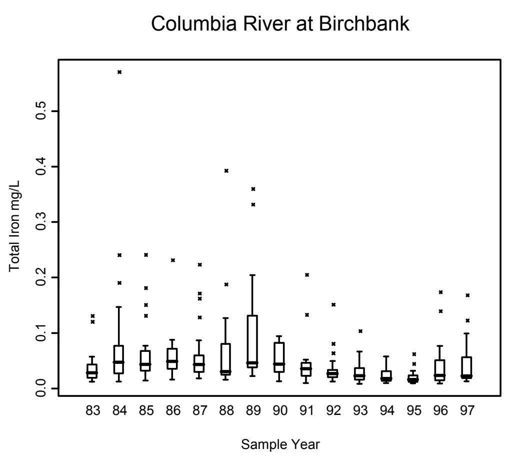
APPENDIX 3

Annual boxplots

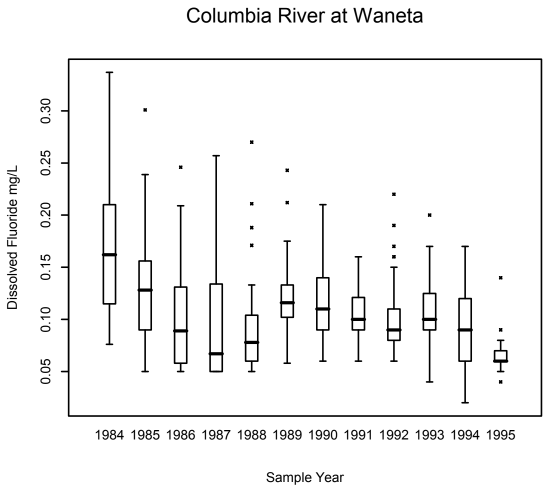
Columbia River at Birchbank

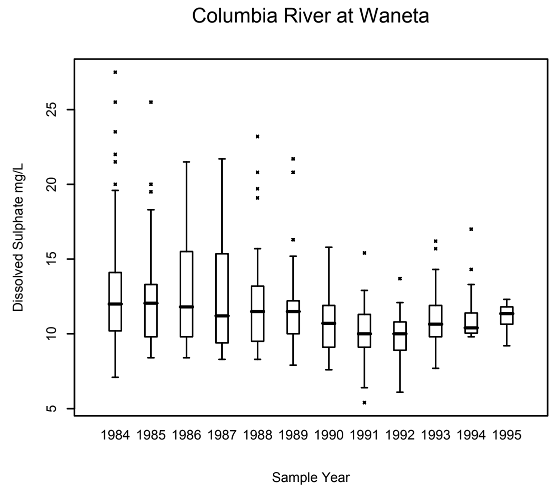


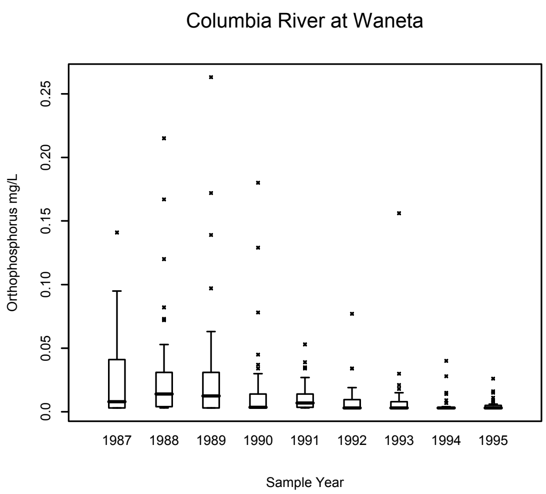


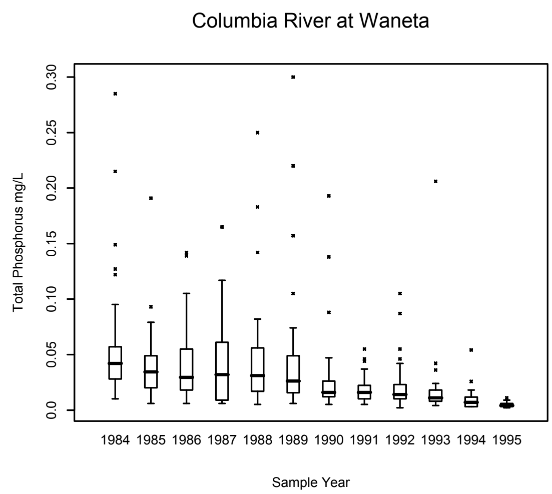


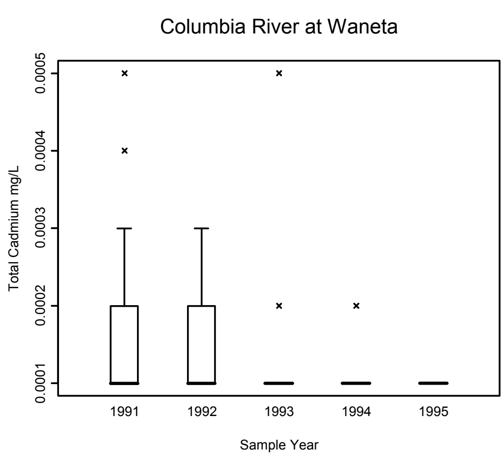
Columbia River at Waneta

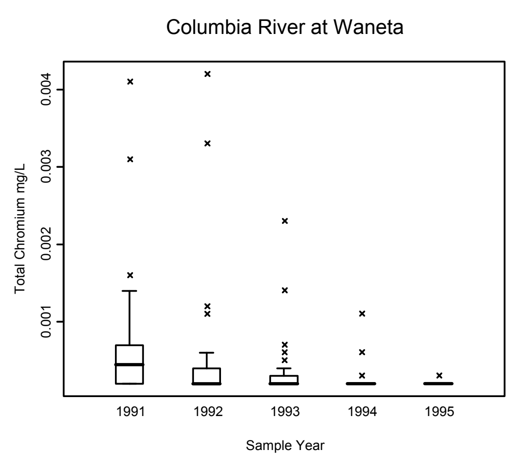


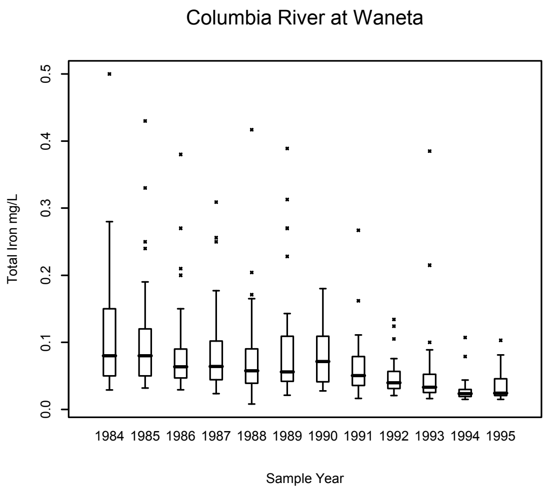


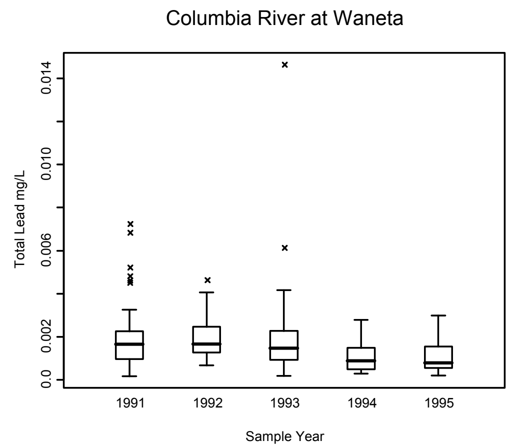


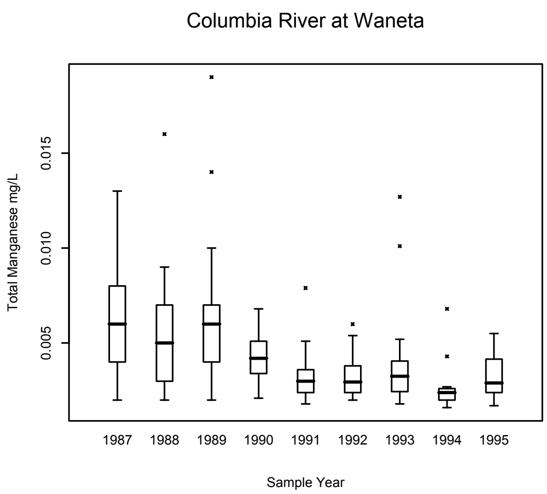


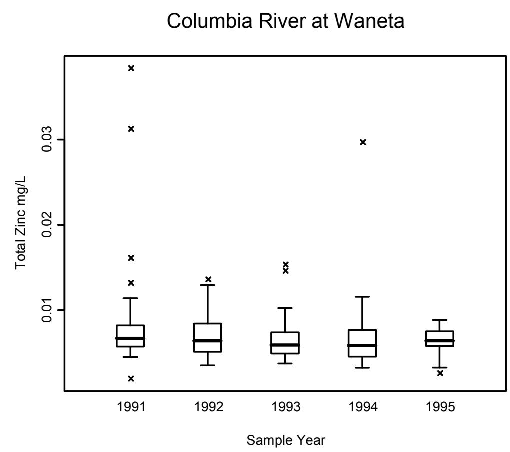


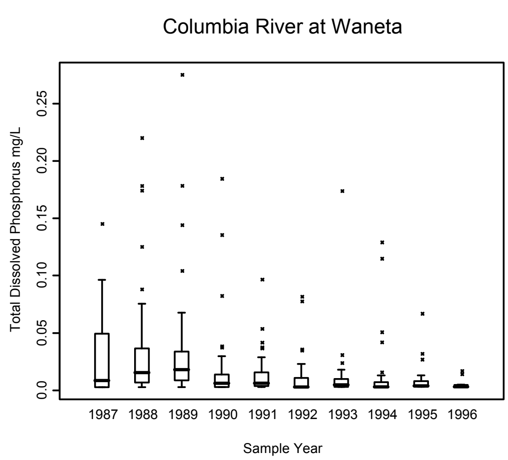


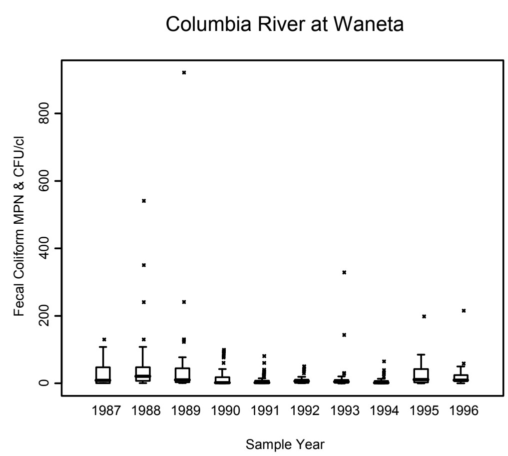

Columbia River at Waneta
Total Iron mg/L
0.0 0.1 0.2 0.3 0.4 0.5
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995
Sample Year


Columbia River at Waneta
Total Lead mg/L
0.0 0.002 0.006 0.010 0.014
1991 1992 1993 1994 1995
Sample Year

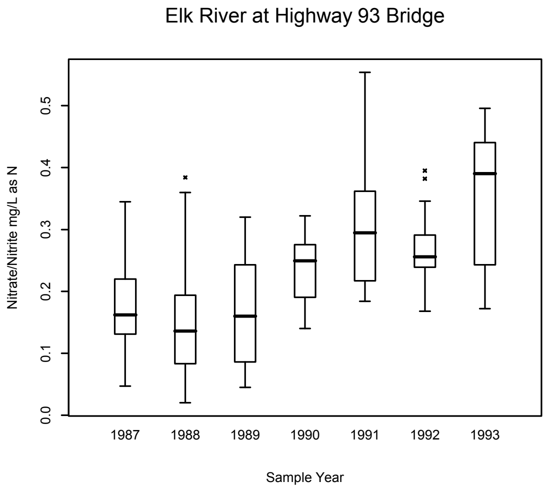

Columbia River at Waneta
Total Manganese mg/L
0.005 0.010 0.015
1987 1988 1989 1990 1991 1992 1993 1994 1995
Sample Year

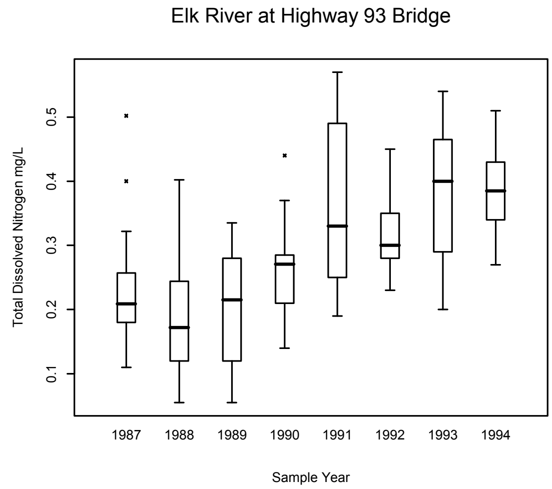

Columbia River at Waneta
Total Zinc mg/L
0.01 0.02 0.03
1991 1992 1993 1994 1995
Sample Year

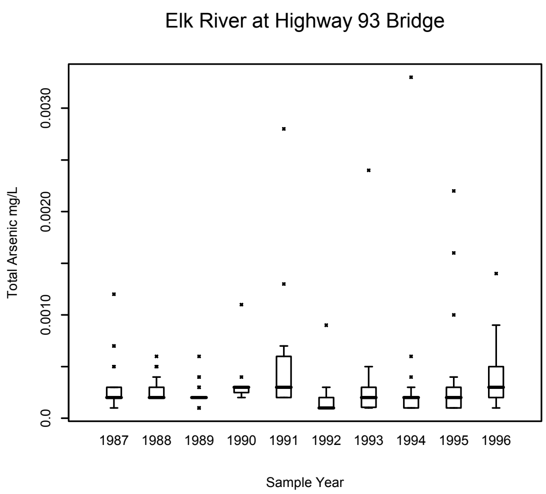

Columbia River at Waneta
Total Dissolved Phosphorus mg/L
0.0 0.05 0.10 0.15 0.20 0.25
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996
Sample Year

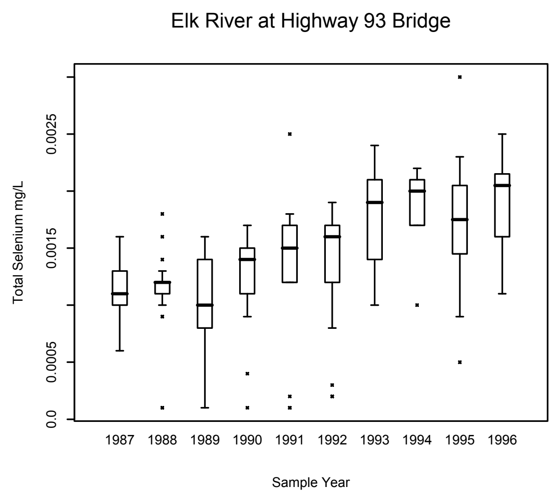

Columbia River at Waneta
Fecal Coliform MPN & CFU/cl
0 200 400 600 800
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996
Sample Year

Elk River at Highway 93 Bridge

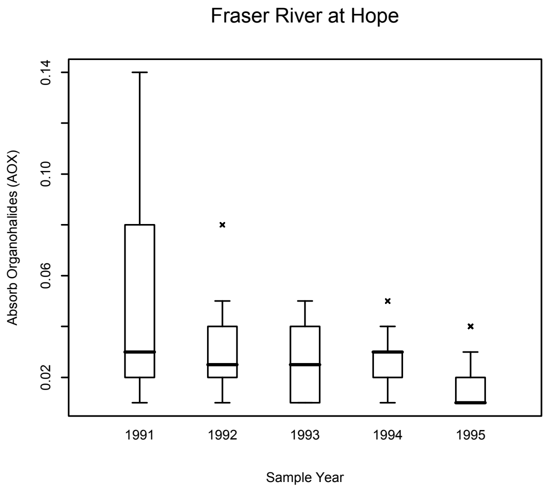


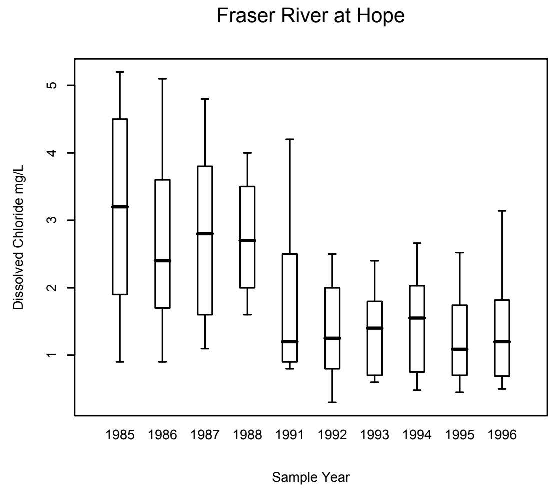




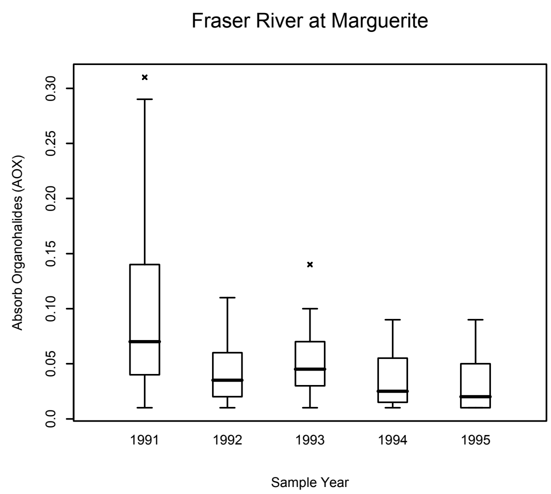


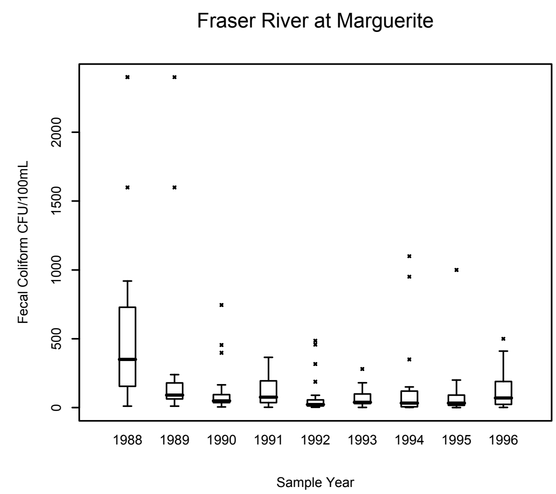
Fraser River at Hope

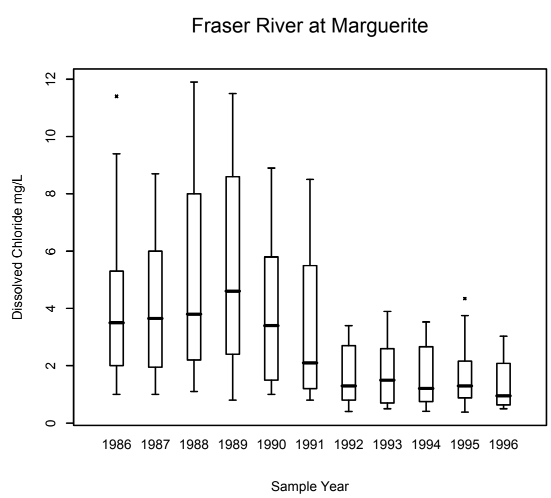


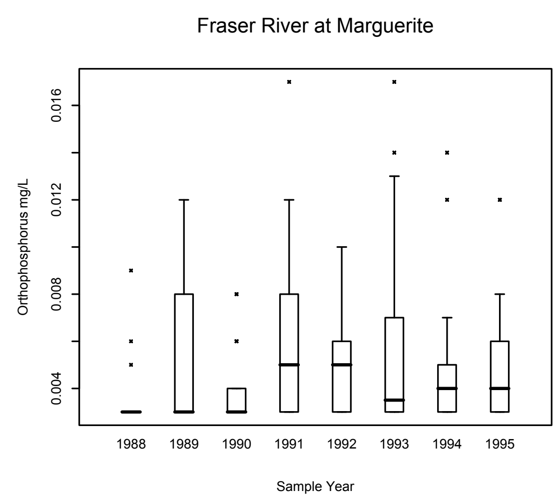


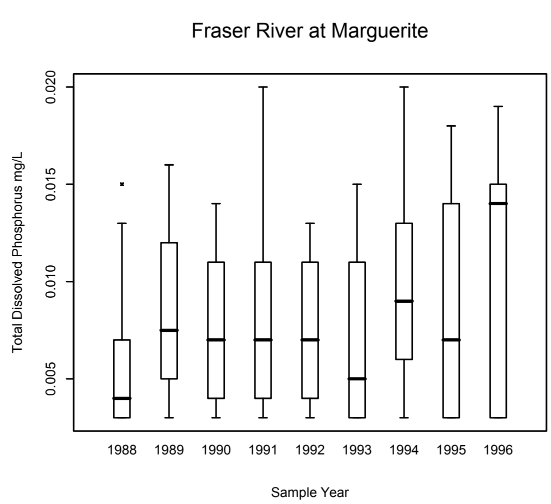
Fraser River at Marguerite

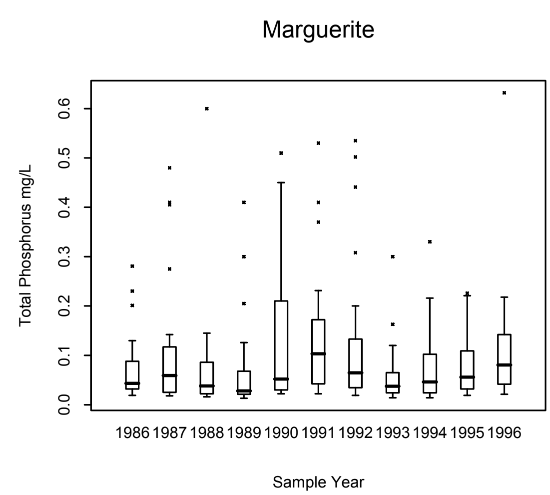




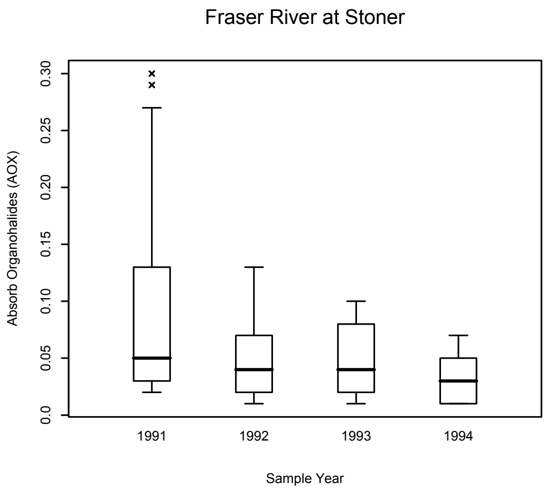




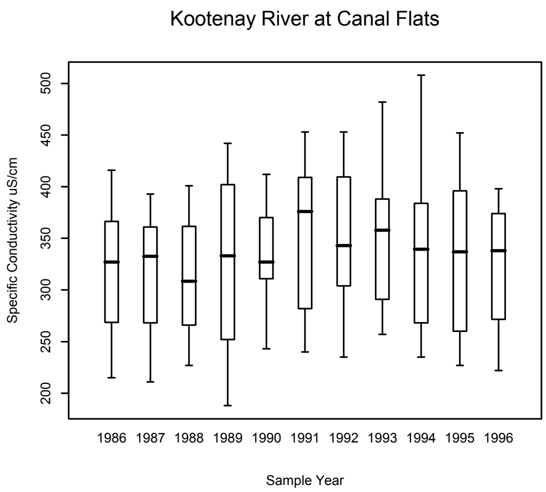




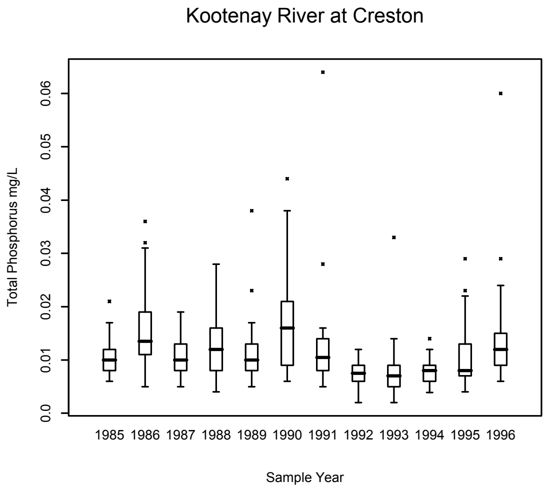
Fraser River at Stoner



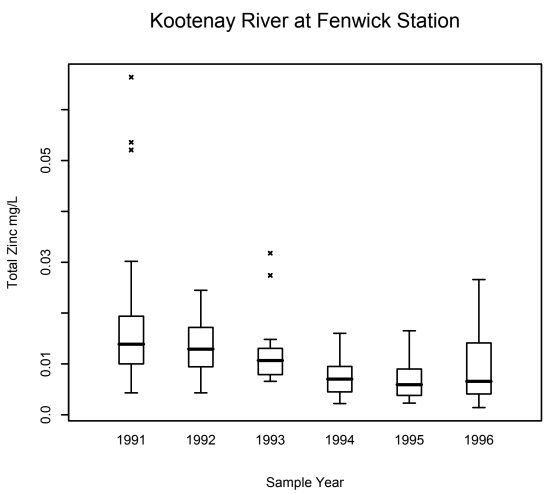
Kootenay River at Canal Flats



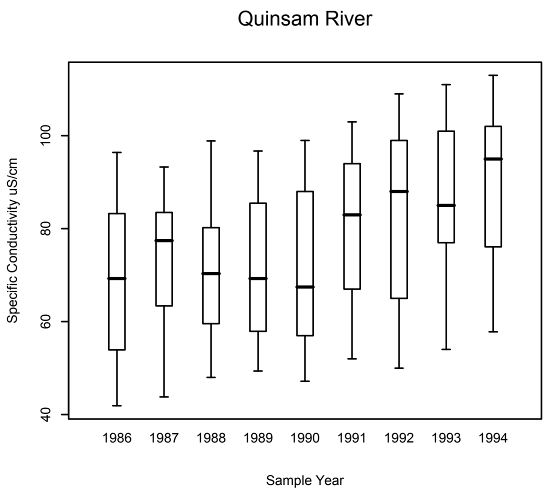
Kootenay River at Creston

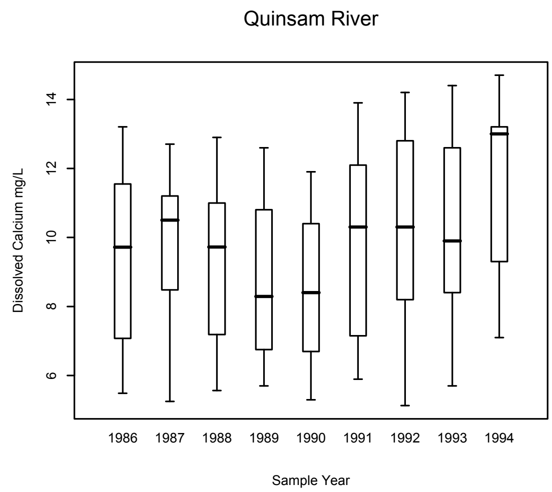


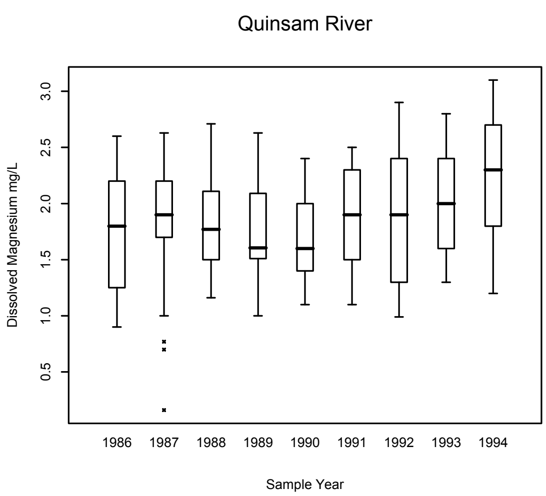
Kootenay River at Fenwick Station

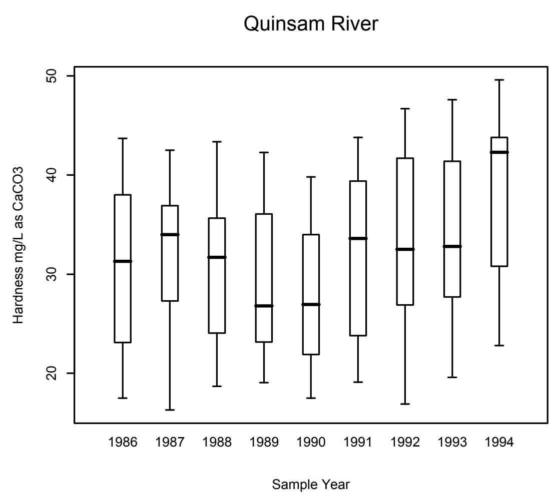


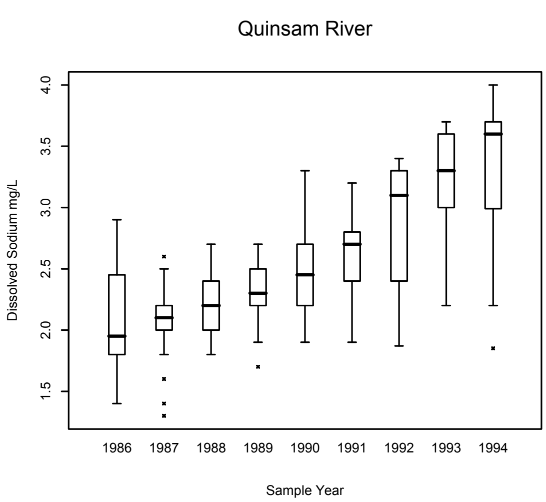
Quinsam River near the mouth

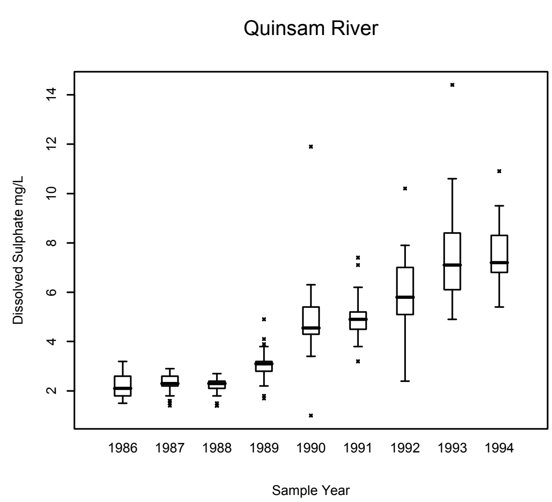


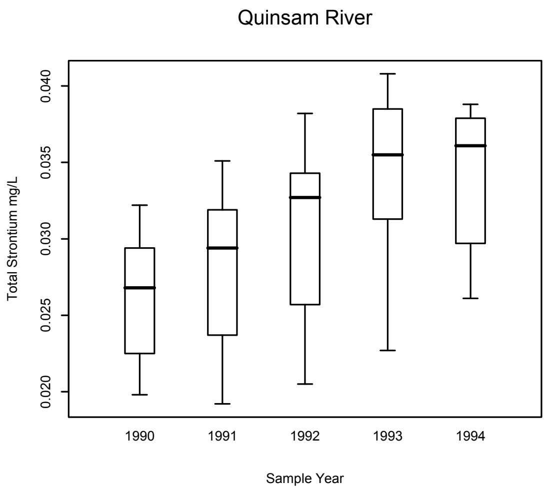




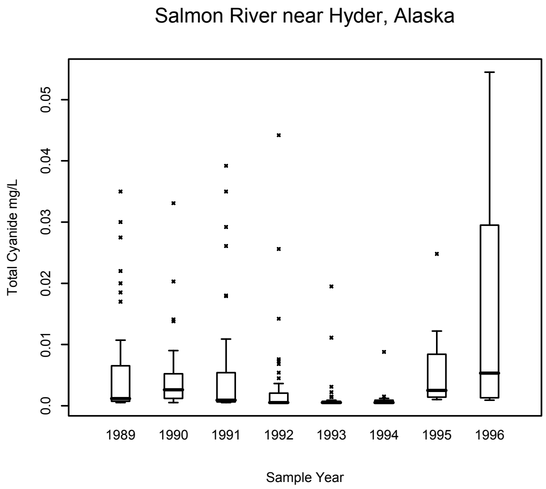




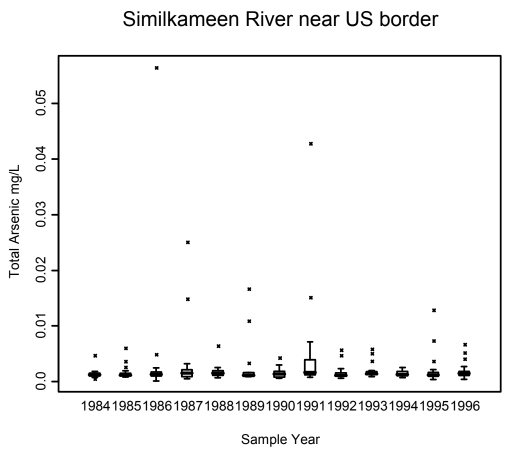


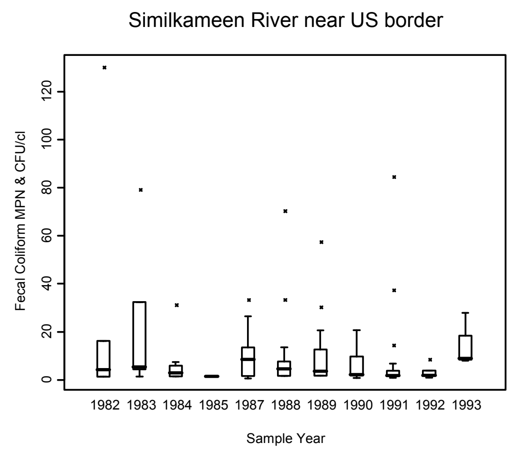

Quinsam River
Total Strontium mg/L
0.020
0.025
0.030
0.035
0.040
1990
1991
1992
1993
1994
Sample Year

Salmon River near Hyder, Alaska

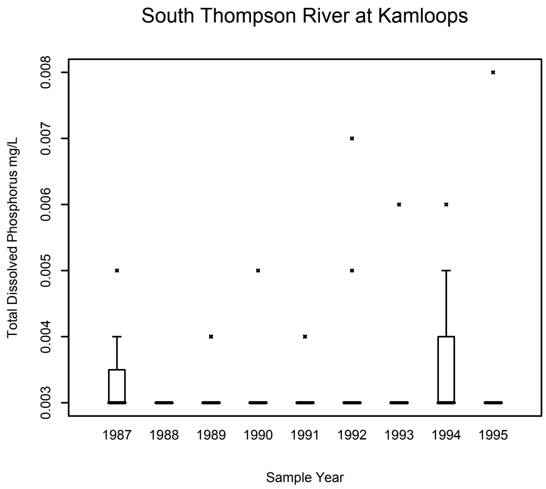


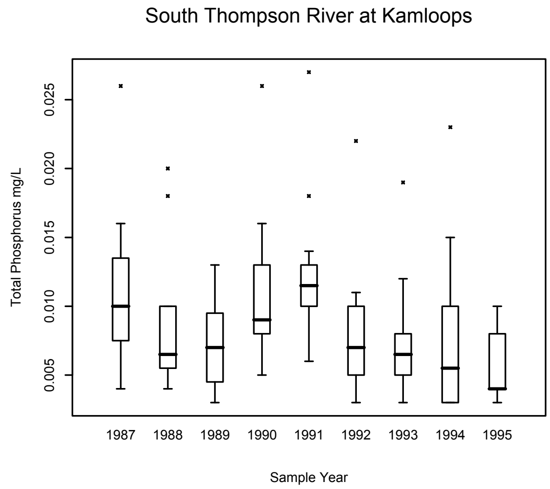
Similkameen River at the US border





South Thompson River at Kamloops





Thompson River at Spences Bridge