# FRASER RIVER ACTION PLAN

# PATTERNS IN WATER QUALITY AT SELECTED STATIONS IN THE FRASER RIVER BASIN (1985-1991)

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# Patterns in Water Quality at Selected Stations in the Fraser River Basin (1985-1991)

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# Abstract

Since the middle 1980's the two major environmental agencies in British Columbia, Environment Canada (EC) and the B.C. Ministry of Environment, Lands and Parks (BC MoELP), have monitored water quality at sites on the Fraser River and major tributaries. A number of sites are maintained through a Federal-Provincial water-quality monitoring agreement. These monitoring data were examined for spatial and temporal trends in the record from 1985-1991. Analytical methods included graphical analysis and summary and statistical analysis. Both non-parametric (Kendall's Tau, Van Belle statistics and Sen Slope estimation) and parametric (regression modelling) techniques were used in the statistical assessment of trend.

Sufficient data were available for seven sites within the Fraser River Basin; the mainstem Fraser River at Red Pass, Hansard, Marguerite and Hope; the Nechako River near Prince George; the Thompson River near Spences Bridge and the Salmon River near Salmon Arm. The suite of parameters being monitored include physical measurements (conductivity, colour, temperature, pH, residue), dissolved ions, dissolved nutrients, total metals and coliform bacteria. No data on organochlorine compounds were available for trend assessment. A total of 27 variables from the Environment Canada data and 15 from the BC MoELP data were studied for trend.

Comparison of upstream-downstream values of water quality variables on the mainstem Fraser River demonstrated the influence of surface geology on the composition of water at particular sites. In addition, the effect of major discharges such as pulp and paper mills and municipal sewage treatment facilities were evident as elevated concentrations of certain dissolved ions (chloride, sodium) and fecal coliform bacteria at downstream sites.

Statistical analyses of trend by non-parametric and parametric methods indicated a variety of patterns. Probably owing to the relatively short period of record (five years), results of the two methods differed somewhat. Instances of agreement of trend by both methods are considered to be relatively robust. Of particular interest are increasing trends in potassium, sulphate, arsenic, nitrate/nitrite and orthophosphorus on the Fraser at Marguerite which may be attributable to upstream discharges. A declining trend in fecal coliform numbers at Marguerite was also detected, suggesting a favourable effect of improvements in sewage treatment upstream of the site. Combined upstream discharges are probably responsible for a clear increasing trend in dissolved chloride in the Fraser River at Hope. Other trends not clearly attributable to anthropogenic cause are considered in the report.

This represents a first effort at summarizing the joint Federal-Provincial water quality information from the upper Fraser Basin, and results will provide direction for future efforts.

# RÉSUMÉ

Au milieu des années 1980, les deux principales autorités de la Colombie-Britannique en matière d'environnement - Environnement Canada et le ministère de l'Environnement, des Terres et des Parcs de la Colombie-Britannique - ont procédé à des campagnes de surveillance de la qualité de l'eau à divers endroits du fleuve Fraser et de ses principaux tributaires. Dans certains des sites étudiés, cette surveillance s'est opérée dans le cadre d'une entente fédérale-provinciale de surveillance de la qualité de l'eau. Les données recueillies ont été étudiées afin qu'on puisse dégager les tendances spatiales et temporelles des observations effectuées entre 1985 et 1991. Les méthodes employées ont consisté notamment dans l'analyse graphique et dans la simple analyse statistique des données recueillies. L'étude statistique des tendances a fait intervenir la modélisation non paramétrique (coefficient tau de Kendall, méthode statistique de Van Belle, étude de la pente Sen) et la modélisation paramétrique (modèle de régression).

On disposait d'une quantité suffisante de données pour sept des sites étudiés : l'artère principale du Fraser à la hauteur de Red Pass, de Hansard, de Marguerite et de Hope; la rivière Nechako, près de Prince George; la rivière Thompson près du pont Spences et la rivière Salmon près de Salmon Arm. La série des paramètres étudiés comprenait les caractéristiques physiques (conductivité, couleur, température, pH, résidus), les ions dissous, les nutriments dissous, les métaux totaux et les coliformes. On ne disposait pas de données sur les organochlorés. Un total de vingt-sept variables tirées des données d'Environnement Canada et de quinze variables tirées des données du ministère de l'Environnement, des Terres et des Parcs de la Colombie-Britannique ont été étudiées afin qu'on puisse en dégager les tendances.

Une comparaison des valeurs amont-aval des variables de la qualité de l'eau dans l'artère principale du Fraser a montré l'influence de la géologie de la surface sur la composition de l'eau à certains endroits. De plus, les taux relativement élevés d'ions dissous (chlorure, sodium) et de coliformes fécaux observés en aval témoignent de l'impact exercé par les principales sources d'effluents sur le milieu, notamment les usines de pâte et papier et les usines de traitement des eaux usées.

L'analyse statistique des tendances par des méthodes de modélisation non paramétrique et paramétrique nous a permis de dégager plusieurs tendances. Signalons toutefois qu'en raison de la durée relativement réduite du temps d'observation (cinq ans), les résultats des deux méthodes diffèrent quelque peu. Mais la concordance des résultats obtenus est relativement concluante. Citons notamment la tendance à la hausse des concentratins de potassium, de sulfates, d'arsenic, de nitrate/nitrite et d'orthophosphates à la hauteur de Marguerite, phénomène qu'on peut attribuer aux émissions d'effluents en amont. On constate par contre une tendance à la baisse des coliformes fécaux à la même hauteur, indiquant que les travaux d'amélioration des installations de traitement des eaux usées en amont ont donné de bons résultats. Les rejets émis en amont sont probablement responsables de l'augmentation manifeste du taux de chlorure dissous observé dans le Fraser, à la hauteur de Hope. Le rapport fait également état de diverses autres tendances qu'on ne peut attribuer positivement à des sources anthropiques.

Cette étude est un premier effort de synthèse des données dont disposent les autorités fédérales et provinciales sur la qualité de l'eau dans le cours supérieur du Fraser. Les résultats serviront de base aux études ultérieures.

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# 1.0 Introduction

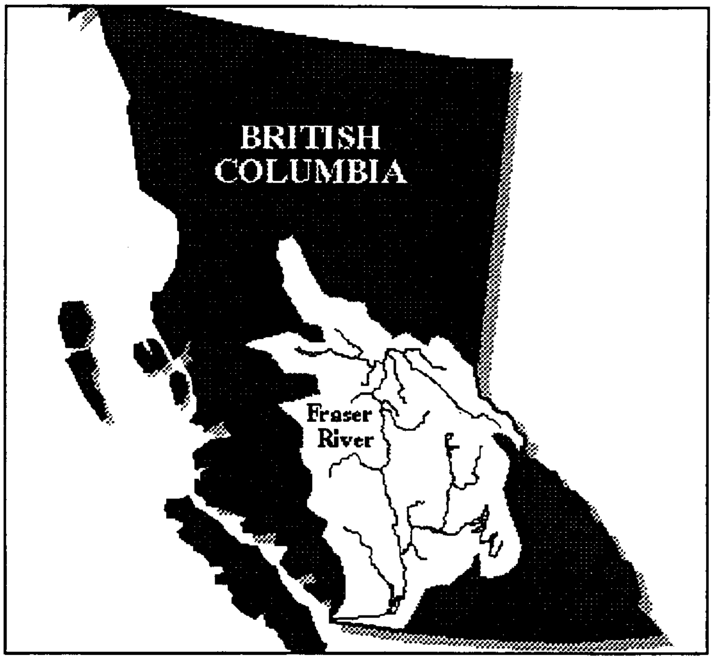



Figure 1.1 The province of British Columbia showing the extent of the Fraser River drainage basin.

Canada is a country with abundant and diverse natural resources which contribute significantly to the economic and social prosperity of its people. Since these resources are finite and some are non-renewable, they must be protected not only for our immediate needs but also for the wants of future generations. As a result Canada is changing its direction to the path of harmonizing economic development with the preservation of the environment. Fresh water is one of Canada's most valuable assets, both as a resource in itself and for the biological resources it supports.

Domestic, industrial and agricultural water uses are threatening the future use of the water resources and the health of their associated ecosystems. For this reason, Canada has initiated a series of flagship environmental programs with the ambitious objective of restoring the "natural" conditions of the major and most threatened lakes and rivers. The Fraser River Basin was included in these initiatives for many reasons, among them is its significant contribution to the BC economy. The Fraser drains some 25% of the total land area of British Columbia( Dorcey and Griggs 1991), and is home to about 63% of the total population of the province (1986 census, Boeckh *et al.* 1991). The river is the greatest producer of salmonids of any single large river in the world (Northcote and Larkin 1989) and clearly this resource will be threatened by over-utilization and pollution of the Fraser River and its tributaries.

The Fraser River arises in the snowcapped Rocky Mountains on the British Columbia - Alberta border. From its headwaters the river flows north and west through the Rocky Mountain trench to Prince George. Beyond this first major population centre, the flow is nearly due south through the central plateau of British Columbia to the rugged Fraser River Canyon beyond a confluence with the Thompson River. At Hope, the shallow slope and width of the Fraser River Valley encourages sedimentation of transported materials. Over millennia this has resulted in the rich deltaic deposits which have formed the basis of an important agricultural industry.

During this passage, the mainstem Fraser River passes through a wide range of physiographic settings and bedrock types, all of which influence water quality. Superimposed on the natural patterns are anthropogenic inputs such as discharges from pulp mills, sewage treatment plants, miscellaneous industrial activities, and agricultural and urban runoff, all of which the water quality to varying degrees. These factors are influenced strongly by seasonal patterns in climate - changes in temperature and precipitation - and seasonal activity patterns of the resident populations.

The strategic management of this important resource requires an understanding of the condition of the resource and the effects of management actions. A starting point should be an evaluation of the existing state of water quality in the basin. Using the available information for this analysis, gaps in knowledge can be

Long-term monitoring of water quality on the mainstem Fraser River and major tributaries has been conducted by Environment Canada (EC) and the British Columbia Ministry of Environment, Lands and Parks (BC MoELP) since the early 1980s. This report is concerned with statistical analyses of these data sets to evaluate temporal and spatial trends. Several simple statistical techniques are used to characterize the present condition, isolating seasonality and measuring trends in water quality. Both non-parametric and parametric statistical methods will be used, coupled with graphical techniques for data summary and model checking.

## 2.0 Factors Affecting Water Quality in the Upper Fraser Basin

Water quality in the mainstem and tributaries of the Fraser River is affected by both natural and anthropogenic factors. The major influences will be considered here to provide a background for interpreting later spatial patterns and trend analysis results. Other more comprehensive discussions have been presented elsewhere (Dorcey and Griggs 1991, Swain *et al.* 1994).

Bedrock geology is the major natural factor determining surface water quality (Hem 1985, Wetzel 1983, Muir and Johnson 1979). The headwaters of the Fraser and its tributaries (upstream of Prince George) pass through the massive marine sedimentary deposits of the Rocky Mountains. These are dominated by easily-erodable and soluble magnesium/calcium limestones, gypsum, sandstones and shales which contribute to the high ion load of waters draining this area. The middle Fraser and major tributary basins, such the Nechako and Thompson Rivers are underlain by mixed lavas and other volcanics (Hall *et al.* 1991), which tend to be both more resistant to weathering and somewhat acidic in nature (Wetzel 1983). As a consequence, waters from these areas tend to be of relatively lower hardness, total ion content and pH. Bedrock dissolution and weathering will also be affected by mediating factors such as water temperature, contact time, pH and flow rates (Hem 1985).

Surficial geology, in particular the presence of easily erodible drift deposits, will have a profound effect on not only the appearance but on the transport and load of materials. The Fraser River in particular carries very high suspended sediment loads, giving the water an obvious muddy appearance and has produced the rich deltaic sediments which form the basis for the extensive agricultural activity in the lower Fraser Valley. Suspended particles are rich in native metals and provide ready sites for binding and transport of many organic chemical contaminants and other water-borne constituents (Thomas and Meybeck 1992).

The major tributaries of the Fraser, such as the Nechako and Thompson Rivers arise in basins of very different geology and physiography to the mainstem and as such have very different water quality when compared with the mainstem. In a sense, these inputs function as large-volume point-source discharges. The Thompson and Nechako contribute significantly to the mainstem flow downstream of their confluence with the Fraser, and may have a marked influence on downstream water quality. For example, over the period 1979 to 1991, the Thompson River contributed an average of 27% of the Fraser River flow measured at the Hope water quantity gauging station.

Human activities have the potential to influence surface water quality in the basin, particularly when the development is in close proximity to the water body. Land uses such as agriculture, forestry, urban developments and industrial manufacturing and processing all have a characteristic suite of potential impacts, some of which may be imparted as changes in water quality parameters. Between the headwaters at Moose Lake and the monitoring site at Hope, there are at least 27 major permitted waste discharges to the mainstem Fraser River (Table 2.1).

Pulp and paper production is by far the most significant industrial activity in the upper basin, both in terms of total effluent volume and range of contaminants. Three kraft mills operate in Prince George and one kraft and one chemical-mechanical mill in Quesnel. Another kraft mill is located on the Thompson River at Kamloops. A slow but steady increase in pulp mill effluent discharges to the Fraser River from 1985 to 1992 is clearly evident (Figure 2.1), and may be detectable in the water quality monitoring record. The organochlorine contaminants found in kraft mill effluents have received particular attention due to their persistence and potential for bioaccumulation in tissues (ie: Mah *et al.* 1989). Although the long-term monitoring program did not address the organic water-borne contaminants until late 1990, the influence of the mill effluents may be evaluated indirectly through parameters such as dissolved ions (particularly chloride) and colour.

The urban centres in the upper basin release contaminants into surface waters through a number of routes. Sewage treatment plant discharges may include a wide range of metals, inorganic and organic chemicals and septic wastes, and constituents such as residual chlorine which have been added as part of the treatment process. Of particular concern are high concentrations of dissolved nutrients and bacteria. Permitted discharges from sewage treatment plants in the upper basin tend to be relatively small compared to the major industrial discharges, but their effects may be noticable and significant. Large areas of pavements in urban centres result in very high runoff rates after rainfall events, with associated transport of contaminants. Storm events may result in high transient loadings of a wide range of contaminants, including metals (both particulate and dissolved) and organic compounds, particularly oils and greases (Hall and Anderson 1988).

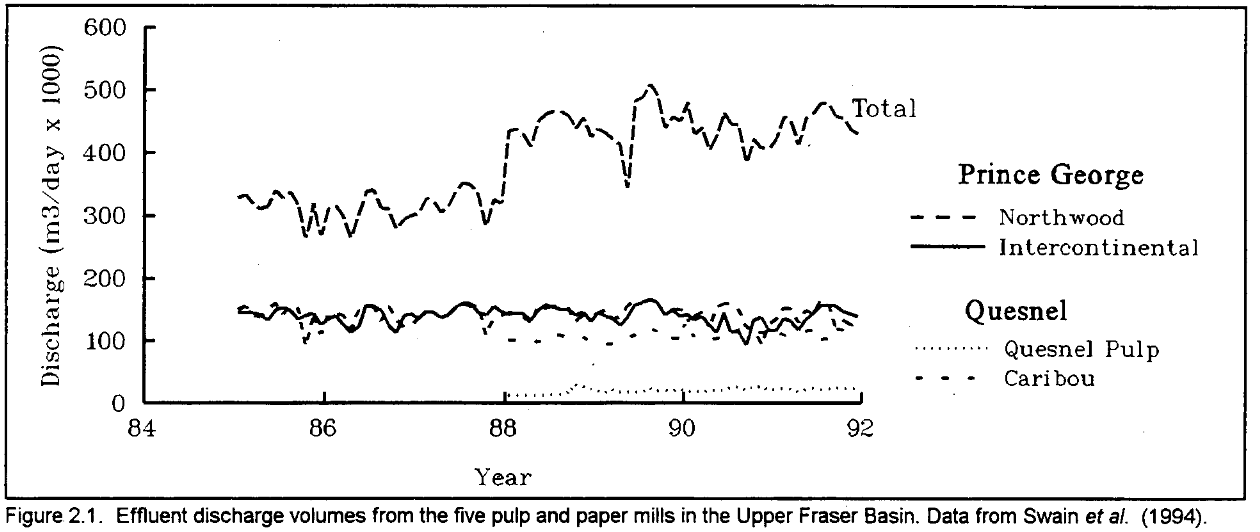



Figure 2.1. Effluent discharge volumes from the five pulp and paper mills in the Upper Fraser Basin. Data from Swain *et al.* (1994). Data for Intercontinental is a combined effluent from both the CanFor and Intercontinental mills.

Land-uses, such as agriculture and forestry have particular effects on water quality, but these are most evident in low-order tributaries. Slope destabilization, increased runoff, nutrient leaching and warming of water temperatures are water quality effects which have been associated with timber harvest (Campbell and Doeg 1989, MacDonald *et al.* 1991, Binkely and Brown 1993,). Similarly, cultivation and livestock agriculture have expected impacts related to waste disposal, soil destabilization, irrigation return flows and chemical applications (both fertilizers and pesticides) ( Branson *et al.* 1975).

Atmospheric transport of organic (Hoff *et al.* 1992, Cohen 1986), ionic (Gorham 1961) and metal pollutants (Alexander and Smith 1988) have been an increasing concern, and may be apparent in long-term water quality records. Precipitation in regions under maritime influence may have elevated levels of chloride and sodium . Deposition of a number of heavy metals, particularly lead (Alexander and Smith 1988) and mercury (Sorensen *et al.* 1990) has been studied, and here again, trends in levels of these constituents may be evident in analyses of long- term monitoring data.

**Table. 2.1** *Major permitted waste discharges in the Upper Fraser Basin. (from Swain 1994, unpublished and P. Wong, Environment Canada).*

| Location | Discharger | Type | Permitted Volume (m3/d) | Nearest D/S WQ Site |
|---|---|---|---|---|
| Burns Lake | Village of Burns Lake | Municipal Sewage | 4550 | Nechako |
| McBride | Village of McBride | Municipal Sewage | 750 | Hansard |
| Ft. St. James | Village of Ft. St. James | Municipal Sewage | 3200 | Nechako |
| Valemount | Village of Valemount | Municipal Sewage | 800 | Hansard |
| | Bulkley-Nechako Reg. District | Wastewater | 182 | Nechako |
| Vanderhoof | District of Vanderhoof | Municipal Sewage | 1640 | Nechako |
| Fraser Lake | Village of Fraser Lake | Municipal Sewage | 1180 | Nechako |
| Upper Fraser | Northwood Upper Fraser | Municipal Sewage | 273 | Hansard |
| Prince George | Northwood Pulp & Paper | Kraft Mill Effluent | 190,000 | Marguerite |
| Prince George | Northwood Prince George | Municipal Sewage | 145 | Marguerite |
| Prince George | City of Prince George | City Sewage Discharge | 1 250 | Marguerite |
| Prince George | CanFor and Intercontinental | Bleached Kraft Mill Effluent | 240,000 | Marguerite |
| Prince George | B.C. Chemicals | Chemical Plant: uncontaminated cooling water | 6 500 | Marguerite |
| Prince George | FMC Canada Ltd. | Chemical Plant | 7 700 | Marguerite |
| Prince George | B.C Buildings Corp | Municipal Sewage discharge | 31.5 | Marguerite |
| Prince George | School District 57 P.Geo. | Municipal Sewage | - | Marguerite |
| Prince George | City of Prince George: BCR Site | Municipal Sewage with Secondary treatment | 1 400 | Marguerite |
| Prince George | City of Prince George | Municipal Sewage with Secondary treatment | 45 000 | Marguerite |
| Prince George | Northwood Pulp and Timber | Landfill leachate Woodwaste | - | Marguerite |
| Prince George | Netherlands Overseas Mills | Landfill Leachate Woodwaste | - | Marguerite |
| Prince George | Woodland Lumber | Landfill Leachate Woodwaste | - | Marguerite |
| Prince George | City - Danson Lagoons | Municipal Sewage | 1 000 | Marguerite |
| Prince George | PG Wood Preserving | Landfill Leachate Woodwaste | - | Marguerite |
| Prince George | Carrier Lumber | Landfill Leachate Woodwaste | - | Marguerite |
| Prince George | Rustad Bros. World-wide storage | Landfill Leachate Woodwaste | - | Marguerite |
| Quesnel | Quesnel River Pulp/Paper | Mechanical Pulp Mill Effluent | 28 000 | Marguerite |
| Quesnel | Caribou Pulp and Paper | Kraft Mill Effluent | 118 200 | Marguerite |

# 3.0 Water Quality Monitoring Sites

Water quality measurements at Environment Canada long-term monitoring network sites commenced in 1979 (Ryan and McNaughton 1994). This monitoring program was restricted initially to measurements of transboundary (international and interprovincial) waters. Over time, the network has expanded to address other concerns such as fisheries habitat issues, water quality within national parks and water quality changes related to industrial development. Recognizing a common interest in preserving and protecting British Columbia water quality, EC and BC MoELP in 1985 entered into a joint monitoring program at a number of sites of mutual interest. At these locations, costs related to sample collection are shared, and each agency measures a suite of variables of particular concern.

Within the Fraser River Basin are a total of nine long-term water quality monitoring sites. Six of these sites are maintained as joint federal-provincial stations, two are of strictly federal concern and one is a provincial monitoring site.

On the mainstem Fraser River are four sites, which are (from upstream to downstream):

***Red Pass:*** a federal headwater site at the outlet of Moose Lake, in Mount Robson Provincial Park. Water quality data at this site is intended to represent conditions in the upper basin; monitoring at this site was suspended during 1986/1987.

***Hansard:*** this federal-provincial site is upstream of Prince George. Data at this location provides an indication of water quality in the Fraser River prior to the industrial and municipal discharges of the first major population centre.

***Marguerite Ferry:*** a federal-provincial site which integrates the effects of industrial and municipal discharges from both Prince George and Quesnel.

***Hope:*** water quality at this federal-provincial site represents the sum of all influences in the middle and upper Fraser, and provides a reference site for water quality entering the upper Fraser Valley and estuary; monitoring at this site was temporarily suspended during 1989/1990.

A provincial site at ***Stoner,*** downstream of Prince George, has been monitored sporadically for a number of years by BC MoELP. Data at this site were to sparse and of too short a duration for analysis, but should be considered carefully in the future. These data would be valuable in isolating the effect of Prince George discharges from those at Quesnel, and continued monitoring should be encouraged.

Three additional water quality sites on tributaries to the Fraser River were also considered:

***Nechako River:*** federal-provincial site upstream of the confluence of the Nechako and the Fraser Rivers. This site provides an indication of water quality entering the Fraser and was originally established to monitor water quality of the Nechako River downstream of the Kemano Hydroelectric Dam.

***Salmon River:*** A federal-provincial site at the mouth of the Salmon River at Salmon Arm established to address concerns about declining water quality. This particular site differs markedly from the other sites considered here because of the relatively low flow, the close proximity of agricultural activity and the high contribution of groundwater flows to the total discharge through much of the year (Obedkoff 1974).

***Thompson River:*** data from this federal-provincial monitoring site on the Thompson River at Spences Bridge represents the integrated effect of settlements and industrial discharges in the basin before confluence with the Fraser River at Lytton. The Thompson River is the largest tributary to the Fraser, contributing on average, 28% of the Fraser River flow at Hope.

Table 3.1 *Locations and site designations of federal and provincial water quality monitoring sites in the Fraser River Basin which were considered in this report.*

| Location | EC Designation ENVIRODAT | BC MoELP Designation SEAM |
|---|---|---|
| Fraser River at Red Pass | BC08KA0007 | - |
| Fraser River at Hansard | BC08KA0001 | E206580 |
| Fraser River at Marguerite | BC08MC0001 | 0600011 |
| Fraser River at Hope | BC08MF0001 | E206581 |
| Nechako River near Prince George | BC08KE0010 | E206583 |
| Thompson River at Spences Bridge | BC08LF0001 | E206586 |
| Salmon River at Highway 1 Crossing | BC08LE0004 | E206092 |

Data from one additional federal site, on the ***Sumas River*** in the upper Fraser Valley, were not included in the analyses owing to a relatively short and sporadic sampling. Site locations agency designations of the seven sites considered in this report are presented in Figure 3.1 and Table 3.1, respectively.

Water samples at these sites have collected at bi-weekly or monthly intervals since about 1985. Sampling is conducted by government or lay persons under the direction of government personnel. Some variables are measured on location, but bulk of the analyses are conducted at laboratories of the respective agencies using specified standard methods (IWD 1979). Water quality variables measured at sites in the Fraser River Basin are presented in Table 3.2. While there is some small overlap in the variable list, the suite is largely complimentary and the combined data provide a fairly complete picture of water quality conditions at the site.

A key component of the monitoring program are the quality assurance (QA) protocols implemented during field sampling, laboratory analysis and the data-entry stages of the monitoring program. The objectives of the QA program is: (1) to demonstrate the accuracy and precision of the analytical data generated by the monitoring program; (2) locate, estimate and control sources of error, and (3) adjust for bias and/or account for the natural variability in statistical analysis and interpretation of the data. There are three types of field QA data for the Fraser River:

(1) **Paired Samples**: refer to nearly simultaneous samples, one collected by an EC representative the other collected by the regular sampler.

(2) **Field Blank Samples**: are "samples" containing deionized water which have been transported to the field and treated with preservatives used for actual samples. The field blanks serve to detect contamination due to transport or sample treatment.

(3) **Replicate Samples:** samples collected simultaneously, using specially designed replicate samplers which hold six water sample bottles. Results of these analyses will provide information on the analytical variability for the particular water quality variable.

Standard QA protocols such as replicate analysis, quality control charting, reference standard analyses and laboratory blanks are followed in the laboratory analytical phase .

Analytical data are screened for suspect values, extreme outliers, known contamination problems and any other factors which could affect the quality of the data for interpretation. These data are not removed from the data record, but the "suspect" character of the data is indicated with a data flag indicating that future users of the data exercise caution. Monitoring data from both agencies are permanently archived in electronic form in major environmental databases of each agency. Data on which the present work is based were extracted from the EC (ENVIRODAT) and BC MoELP (SEAM) electronic databases. The available data were further screened for detailed trend analyses. Criteria included:

(1) the total number and temporal extent of the record
(2) number of flagged or suspect observations
(3) number of missing observations
(4) the number of samples below the analytical detection limit ("censored")

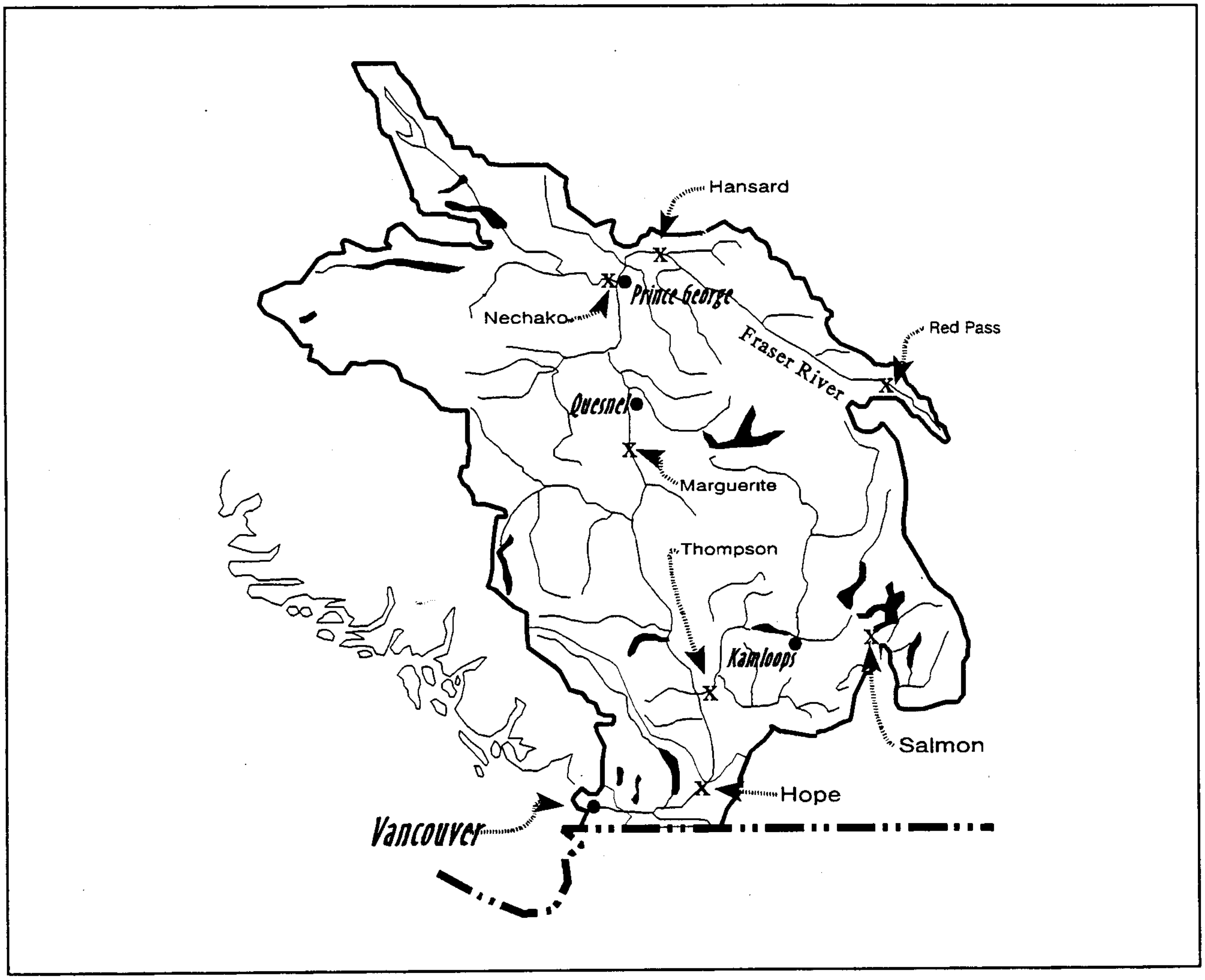



Figure 3.1. The Fraser River Basin showing the locations of water quality monitoring stations considered in this study.

*Table 3. 2 List of water quality parameters measured by EC and BC MoELP at monitoring stations in the Fraser River basin.*

| | Federal | Provincial |
|---|---|---|
| ***Physicals*** | Air Temp | |
| | Water Temp | |
| | Laboratory pH | Laboratory pH |
| | Specific Conductivity | Specific Conductivity |
| | | |
| | Turbidity | Turbidity |
| | Apparent Colour | Color TAC |
| | | Residue Filterable |
| | Alkalinity Total | |
| | | Residue Total |
| | Residue Non-Filterable | Residue Non-Filterable |
| | Residue Filterable | Residue Filterable |
| | Residue Fixed Non-Filterable | |
| | Residue Fixed Filterable | |
| ***Ions*** | Calcium | Calcium |
| | Chloride | Chloride |
| | Fluoride | |
| | Hardness | |
| | Magnesium | Magnesium |
| | Potassium | |
| | Silicon | |
| | Sodium | |
| | Sulphate | Sulfate |
| ***Nutrients*** | | Ammonia |
| | NOx (Nitrate + Nitrite) | NOx (Nitrate + Nitrite) |
| | Nitrogen Total Dissolved | |
| | | Nitrogen Total Kjeldahl |
| | Phosphorus, Total | Phosphorus, Total |
| | | Ortho-Phosphorus |
| | | Phosphorus, Dissolved |

| | Federal | Provincial |
|---|---|---|
| ***Metals*** | Aluminum Total | Aluminum Total |
| | Arsenic Total | |
| | Barium Total | |
| | Beryllium Total | |
| | Cadmium Total | Cadmium Total |
| | Chromium | Chromium |
| | Cobalt Total | Cobalt Total |
| | Copper Total | Copper Total |
| | Iron Total | Iron Total |
| | Lead Total | Lead Total |
| | Lithium Total | |
| | Manganese Total | Manganese Total |
| | Mercury Total | |
| | Molybdenum Total | Molybdenum Total |
| | Nickel Total | Nickel Total |
| | Selenium Total | |
| | Strontium Total | |
| | Vanadium Total | Vanadium Total |
| | Zinc Total | Zinc Total |
| ***Organics*** | | Phenols |
| | | Absorbable Organohalides |
| ***Microbial*** | | Fecal Coliform (CFU/cL) |
| | | Fecal Coliform (MPN/cL) |
| | | E. Coli |

# 4.0 Statistical Methods

## 4.1 *Non-Parametric Methods*

A variety of non-parametric tests have been used for evaluating trend in time series (Harcum *et al.* 1992, Hipel *et al.* 1988). Under the assumption of serial independence, these statistics offer relative simplicity, robustness and freedom from assumptions of normality in the data distributions. The most commonly used trend tests in water quality assessments are the Seasonal Kendall's Tau (Hirsch *et al.* 1982) and the modified Seasonal Kendall's Tau (Hirsch and Slack 1984). These are rank statistics which test for monotonic changes in a time series.

The available data are blocked by some time period within each year of the time series, whether it be by season or by month. Given that data are blocked by month during *m* years, the statistic is calculated as shown below. Let $Y_{ij}$ be the measurement made in the *i*th year ($i$ = 1,2,...,m) and *j*th ($j$ = 1,2,...,12) month, then Kendall's statistic for the *j*th month is defined by:

$$S_j = \sum_{i<k} sgn\ (Y_{kj} - Y_{ij})$$

where the function *sgn(x)* is defined by:

$$sgn(x) = \begin{cases} 1 & if\ \ x>0 \\ 0 & if\ \ x=0 \\ -1 & if\ \ x<0 \end{cases}$$

The variance of $S_j$ is:

$$var(S_j) = \frac{1}{18}(n_j(n_j-1)(2n_j+5) - \sum_t t(t-1)(2t+5))$$

where $n_j$ is the number of years out of $m$ without missing observations and $t$=number of $Y_{ij}$ values involved in a tie. The test of the null hypothesis of no trend is based upon:

$$Z_j = \begin{cases} \dfrac{S_j-1}{(var(S_j))^{1/2}} & S_j>0 \\ 0 & S_j=0 \\ \dfrac{S_j-1}{(var(S_j))^{1/2}} & S_j<0 \end{cases}$$

The distribution of $Z_j$ is approximately normal with mean 0 and variance 1.

The trends within each month are then combined into the seasonal Kendall statistic as :

$$S = \sum_{j=1}^{12} S_j$$

and

$$Var(S) = \sum_{j=1}^{12} Var(S_j)$$

which has approximately a normal distribution with zero mean and variance Var(S). In essence, the monthly statistic represents the number of increases less the number of decreases over years within a month. Similarly, the seasonal statistic is a sum of the number of months showing increase less the number showing decreases. For example, a data series showing increasing trends in 6 months and declining trends in 6 months would result in an overall result of no trend. Only the sign of the differences are important, and not the magnitude. As the originators point out, this test is robust against seasonal behaviour and non-normal data, but is affected by serial dependence.

In an effort to remove the effect of serial dependence, Hirsch and Slack (1984) introduced a modification to the Seasonal Kendall's Tau which takes into account the covariation between months. The variance of S is then:

$$Var(S) = \sum_{j=1}^{12} Var(S_j) + \sum_{\substack{j,h \\ j \neq h}} cov(S_j, S_h)$$

where the covariance estimator between months j and h, for $j \neq h$ is:

$$cov\ (S_j, S_h) = K_{jh}/3 + (n^3 - n)\ r_{jh}/9$$

where:

$$K_{jh} = \sum_{(i<l)} sgn[(X_{lj} - X_{ij})(X_{lh} - X_{ih})]$$

and:

$$r_{jh} = \sum_{i,l,k} sgn[(X_{lj}-X_{ij})(X_{lh}-X_{ih})]$$

The Seasonal Kendall and modified Seasonal Kendall Tau statistics are only strictly valid when the observed trend is consistent through the year since it is clear that the positive and negative terms corresponding to increases and decreases will tend to cancel one another. To test for uniformity of trend across time periods within a year, the Van Belle statistic (Van Belle and Hughes 1984) is used. Two tests are appropriate, the first is a test for trend across time and the second is the test for homogeneity of trend periods.

The statistics are calculated as:

$$\chi^2_{trend} = \frac{1}{12}\frac{\Sigma\, S_j}{\sqrt{var(S_j)}}$$

and

$$\chi^2_{homog} = \sum_{j=1}^{12} \frac{S_j^2}{var(S_j)} - \chi^2_{trend}$$

where $\chi^2_{trend}$ is measuring the trend, while $\chi^2_{homog}$ is used to test for the homogeneity of the trends from month to month. The distributions of $\chi^2_{trend}$ and $\chi^2_{homog}$ are well approximated by the Chi square distribution with 1 and 11 degrees of freedom, respectively with large values being evidence against trend or homogeneity of trend.

The tests discussed above provide no particular indication of the rate of change, only whether or not a monotonic change over time is happening. Sen's slope estimator (Sen 1968) was used to obtain a non-parametric estimate of the magnitude of change. The statistic is calculated as the median of all possible slopes between all points in the data series. To obtain the estimate, the $M_j=n_j(n_j-1)/2$ quantiles $Q_{ijk}$ are calculated as:

$$Q_{ijk} = \frac{Y_{ij}-Y_{kj}}{i-k} \qquad for\ i>k$$

The estimate is the median of the $Q_{ijk}$. Confidence bounds on the estimate may be calculated as percentiles of the distribution of possible slopes (Gilbert 1987).

## 4.2 Parametric Methods

Regression analysis is widely used for assessing trends, and has been applied to water quality data (El-Shaarawi *et al.* 1983, Esterby *et al.* 1989). The technique is very flexible, in that many forms of models representing the data series may be developed, including various terms to account for seasonality and other covariates (El-Shaarawi *et al.* 1991). By accounting for the effect of a particular covariate through functional approximation, its influence on the pattern over time may be removed and the presence and form of underlying trends become more apparent. For example, Esterby *et al.* (1989) found that although non-parametric seasonal statistics and regression models which included seasonality tended to produce similar results, that the regression models were more useful in elucidating the form of the trends. A brief outline of the methods used here is presented below, and the reader is referred to El-Shaarawi *et al.* (1991) for a more complete discussion.

As a simple model for trend in a water quality variable, when the data on a water quality variable are available at irregular time intervals with the influence of seasonality and a covariate such as the flow rate, we used:

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

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*

$\beta_o$, $\beta_1$, $\beta_2$ are unknown parameters
$\alpha_1$, $\alpha_2$ = unknown parameters representing the phase of the seasonal cycle
$\omega$ = unknown parameter representing the amplitude of the seasonal cycle

$\epsilon_{t_{ji}}$ = is the error term which is assumed to follow a normal distribution with mean 0 and variance $\sigma^2$.

and

(2) $\alpha_1 = R\cos(\phi)$ and $\alpha_2 = -R\sin(\phi)$.

where $\phi$ represents the phase angle and *R* is the amplitude of the seasonal cycle.

Informal graphical and numerical methods were used to evaluate the adequacy of the model in representing the observed data series. Graphical methods included plots of model residuals (difference between $Y_{tji}$ and its estimated value) against time and/or against the flow rate. Residuals showing non-random patterns indicate that the model is inadequate and may be improved through a data transformation or by inclusion of additional terms. In addition, the normality of the data distribution was evaluated using a quantile plot.

Fitting of the model to the available time series was an iterative process, with sequential evaluation of more complex possible trends. The form in equation (1) considers only a linear trend with slope, $\beta_2$. The presence or absence of a quadratic (∪ or ∩ - shaped) trends was tested by goodness of fit of the data to (1) with a quadratic term ($\beta_3 t^2$). Two issues are considered; the first is to determine the adequacy of the model (linear and quadratic), and the second is the significance testing of the coefficients.

### 4.2.1 Testing for Trend in the Presence of Censored Data

Censored values occur when measurements were recorded as below or above prespecified values such as the limits of measurements or detection associated with an analytical technique. In the case where we have many censored values, a contingency table approach is used to test for the trend by grouping the years into two periods and testing for an increase or a decrease in the proportion of values above the detection limit. This approach is described in detail in El-Shaarawi *et al.* (1991). Here we present a summary of the method.

Let $R_1$ and $R_2$ be the number of values above the detection limit out of $n_1$ and $n_2$ observations made in the first and second period, respectively. The difference on the log odd scale between the two periods is estimated as:

$$\tilde{\Delta} = log\frac{R_2}{n_2 - R_2} - log\frac{R_1}{n_1 - R_1}$$

with variance

$$V = \frac{1}{R_1} + \frac{1}{n_1 - R_1} + \frac{1}{R_2} + \frac{1}{n_2 - R_2} .$$

The estimated odd ratio is $exp(\tilde{\Delta})$ and its approximate 95% confidence interval is given by

$$[exp(\tilde{\Delta} - 1.96\sqrt{V}) \;,\; exp(\tilde{\Delta} + 1.96\sqrt{V})]$$

respectively. If the lower limit of the interval exceeds 1, then this indicates that a significant change to higher concentration has occurred in the second period. The opposite conclusion is reached if the upper limit falls below 1.

In the case where the number of censored values are small compared to the total number of observations, model (1) is used to analyze the data. The presence of censoring causes only computational difficulties since no closed-form solution exists, and iterative methods have to be used to estimate the parameters.

## Example

A practical application of the modelling approach using dissolved calcium data for the Fraser River at Hope is presented here for illustration. Data from the SEAM or ENVIRODAT databases were first screened for flagged (suspect) or extreme values. Preliminary plots were prepared to examine patterns in the data series, including relationship to probable covariates. For example, time series plots of calcium levels suggested that the amplitude of the seasonal cycle is dependent on the mean concentrations (e.g., high concentrations are associated with large seasonal cycles). This suggested that ln(x) transformation would result in an approximately constant seasonal cycle which could be more easily modelled by regression analysis (Figure 4.1). Also, as with most dissolved ion parameters in surface river waters (Wetzel 1983), there is a clear negative relationship between flow and calcium concentration (Figure 4.2).

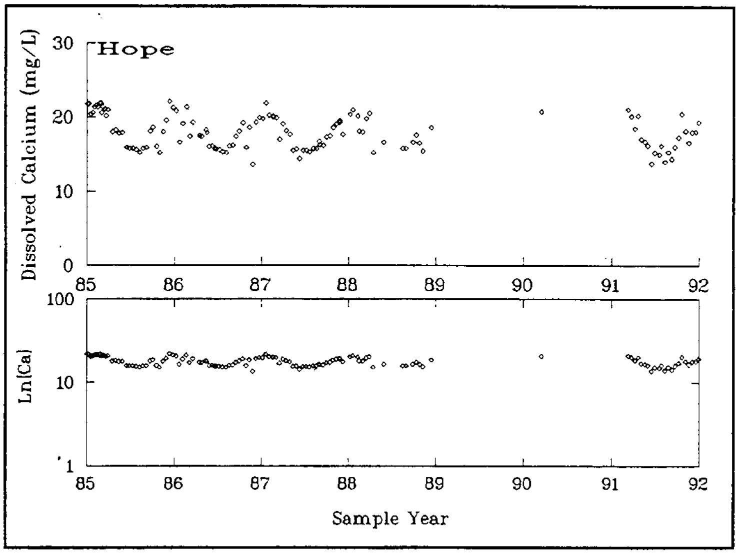



Figure 4.1 Stabilization of the seasonal cycle of EC dissolved calcium data from the Fraser River at Hope by ln transformation.

With a nearly stable seasonal cycle from the transformation and a known negative association between flow and calcium concentration, model (1) may be fitted to the data. The least-squares parameter estimation and model development is an interative process, and when this basic model is evaluated for fit to the original data, additional terms may be needed to better represent the data series. The goodness of fit is assessed using the calculated $r^2$ and plots of model residuals ($Y_{observed}$-$Y_{estimated}$). In the present example, a plot of residuals indicates an apparently random scatter (Figure 4.3), and the $r^2$ of 62.6% indicates that a high percentage of the variation in the data set is explained by the model. Parameter estimates for the calcium model for all sites are shown in Table 4.1. At Hope, the $\beta_1$ parameter was significant and negative, reinforcing the known negative association of dissolved calcium with flow. Further, significant contribution of the parameters $\alpha_1$ and $\alpha_2$ indicates seasonality in the variable. The linear trend component ($\beta_2$) is non-significant, showing that there is no trend indicated in the time series.

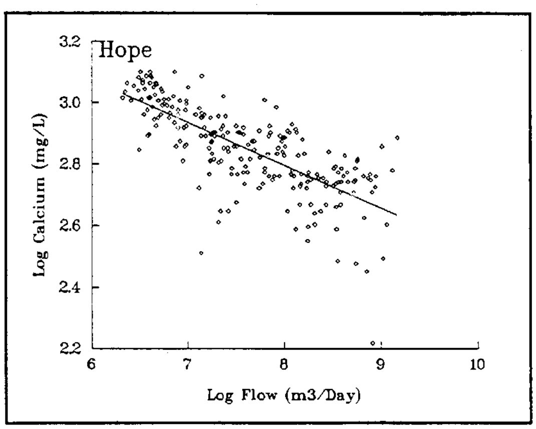



Figure 4.2 Relationship between calcium concentration and flow in the mainstem Fraser River at Hope.

Results of fitting this same model to data from other sites in the Fraser Basin indicated that, in some cases, addition of a second order term, $\beta_3 t^2$ to model (1) would better describe the time series. For example, at the Hansard, Nechako River and Thompson stations, the parameter $\beta_3$ is positive and significant, suggesting a U - shaped trend over the period of record (Table 4.1). When this term has a positive coefficient, the time series displays an initial declining trend followed by a increasing trend. Conversely, where a negative coefficient is indicated, early data in the time series have shown an increasing trend with a later declining trend. The coefficient of determination, $r^2$, indicates the proportion of the variation in the data series which is accounted for by the model.

Table 4.1 *Model parameter estimates for EC dissolved calcium data from sites in the Fraser River Basin.*

| Site | $\beta_0$ | $\beta_1$ | $\beta_2$ | $\beta_3$ | $\alpha_1$ | $\alpha_2$ | $\omega$ | $r^2$ | Conclusion |
|---|---|---|---|---|---|---|---|---|---|
| **Red Pass** | 2.86 | ns | -0.013 | - | 0.028 | 0.14 | 0.02 | 73.3 | |
| **Hansard** | 3.895 | -0.106 | -0.104 | 0.017 | 0.126 | 0.116 | 0.019 | 93.2 | U-shaped trend |
| **Marguerite** | 3.858 | -0.108 | -0.01 | - | 0.1 | 0.003 | 0.016 | 87 | Linear, ***decreasing*** trend |
| **Hope** | 3.49 | -0.084 | - | - | 0.06 | 0.043 | 0.017 | 62.6 | no trend |
| **Nechako** | 4.04 | -0.22 | -0.17 | 0.022 | -0.021 | 0.064 | 0.016 | 66.2 | U-shaped trend |
| **Salmon** | 3.86 | -0.396 | 0.102 | - | 0.031 | -0.045 | 0.017 | 92.2 | Linear ***increasing*** trend |
| **Thompson** | 3.188 | -0.078 | -0.091 | 0.014 | 0.007 | 0.106 | 0.019 | 88.6 | U-shaped trend |

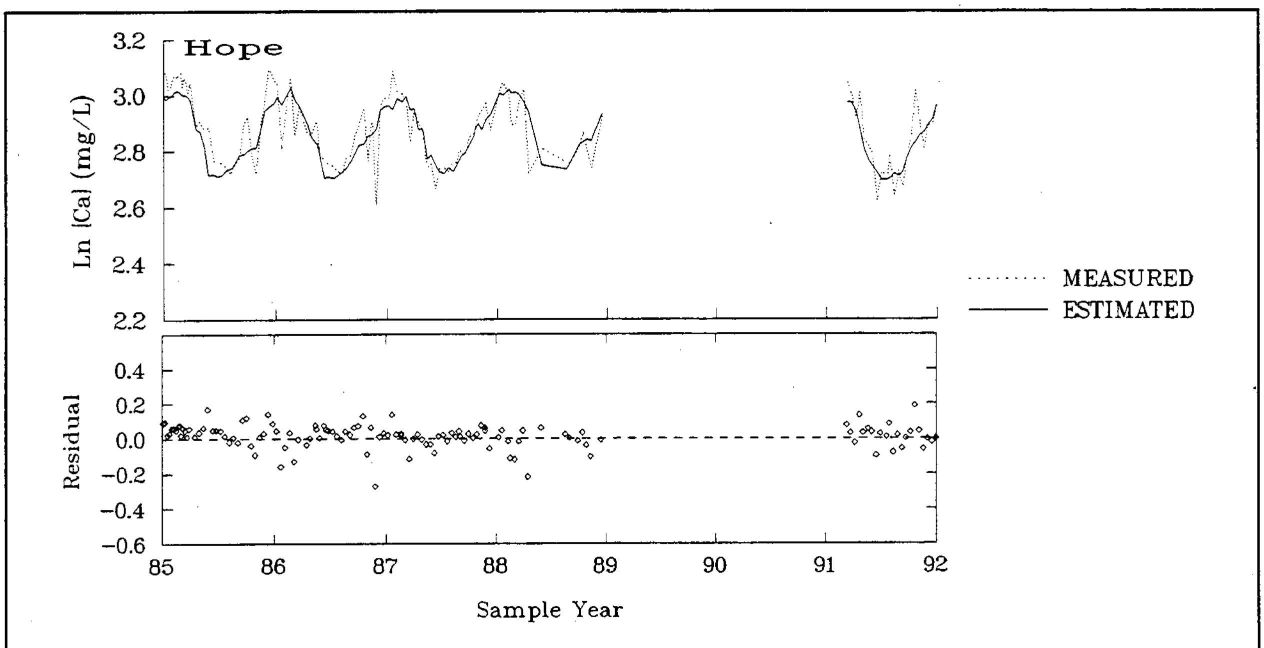



Figure 4.3. Goodness of fit of the regression model to the original data series for dissolved calcium concentrations in the mainstem Fraser River at Hope. The upper plot shows the original (Measured) time series and the estimated concentrations (Estimated). The lower plot shows the pattern of deviations of the model from the original time series (residuals).

# 5.0 Results and Discussion

Of the 43 water quality variables in the Environment Canada data set , 21 were judged to be adequate for detailed statistical analysis at all sampling stations. For an additional 6 variables, adequate data for further analysis were available at one or more sampling stations. In the Provincial data set there are a total of 52 variables, of which 15 variables have data from at least one sampling station which were adequate for statistical analysis. Details of the data, with counts of missing and censored observations are presented in Tables 5.1 and 5.2.

In the following sections, data from the EC monitoring program will provide a primary focus for discussion and summary plots. These data are typically more complete and of greater frequency than are the BC MoELP data. Trend analyses of both data sets were conducted, and results are presented. Similar variables are occasionally measured from a single site at the same time. Where possible, these data are integrated in an effort to provide a more complete picture of water quality at a site. Such variables include phosphorus, water colour, and conductivity. Time-series plots of the EC and BCMoELP data for which trend analyses were conducted are presented in Appendices 2 and 3.

In the following discussions, the water quality variables are consider as four related analytical groups:

- *Physical variables*: general water quality characteristics not attributable to a particular constituent. Included in this group are such measurements as flow, pH, conductivity, temperature and sediment-related parameters.
- *Dissolved Ions*: dissolved ion concentrations (for example calcium, magnesium).
- *Metals*: concentrations of total and dissolved metals (for example: iron, copper, manganese)
- *Nutrients:* dissolved nutrients used by plants (phosphorus and nitrogen forms)
- *Microbial:* microbial indicators of sewage pollution

In the following sections, the available water quality data are summarized using box and whisker plots (Tukey 1977). These figures provide a convenient visual image of the data distribution, the variability and non-parametric indicators of central tendency, such as the median and percentiles. Figure 5.1 shows the terminology of the plots and indicates the underlying data display for one representative data set. The bulk of the values in the distribution are contained within 1.5x the range between the 25th and 75th percentiles. For gross interpretation, values lying between 1.5x and 3x the range (marked with an asterisk) may be considered as "near outliers", and those more than 3x the range are "far outliers" (indicated with circles). The box plots indicate the mode of the data set, and the position of the median line within the box is an easy display of the skewness.

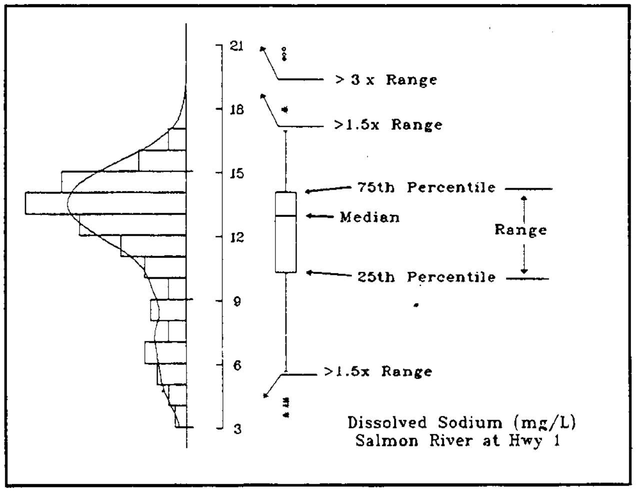



Figure 5.1. Box and Whisker plot (Tukey 1977) terminology. The plot on the left indicates the underlying data distribution displayed in the adjacent box plot.

The results presented here are for a relatively shorter time period than would be desirable for robust trend analyses, and as such, these analyses should be considered as a preliminary assessment - an indicator of particular variables or variable groups which should be followed in the future. While trend analyses are frequently reported using short time series of observations (i.e.:Bouchard and Haemmerli 1992), the chance of an incorrect assessment is probably relatively high. The tests used here are relatively robust, and commonly applied to time series of

Table 5.1. *Attributes of the Environment Canada water quality data set for sites in the Fraser River Basin.*

| | VARIABLE | Red Pass Total Values=109 | | | Hansard Total Values=134 | | | Marguerite Total Values=137 | | | Hope Total Values=186 | | | Nechako River Total Values=140 | | | Thompson River Total Values=144 | | | Salmon River Total Values=72 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | # Flagged | # Missing | Adequacy | # Flagged | # Missing | Adequacy | # Flagged | # Missing | Adequacy | # Flagged | # Missing | Adequacy | # Flagged | # Missing | Adequacy | # Flagged | # Missing | Adequacy | # Flagged | # Missing | Adequacy |
| | ***Physicals*** | | | | | | | | | | | | | | | | | | | | | |
| 1 | Air Temp | - | 2 | A | - | 5 | A | - | - | A | 1 | 9 | A | - | 2 | A | - | 2 | A | - | 4 | A |
| 2 | Water Temp | 1 | 1 | A | - | 7 | A | - | 1 | A | 1 | 6 | A | - | 9 | A | - | 1 | A | - | 2 | A |
| 3 | Apparent Colour | 24 | 1 | NA | 4 | - | A | 2 | - | A | 2 | 2 | A | - | - | A | 1 | - | A | 2 | - | A |
| 4 | Conductivity | - | 1 | A | - | - | A | - | - | A | - | - | A | - | - | A | - | - | A | - | - | A |
| 5 | Laboratory pH | - | 1 | A | 1 | - | A | 1 | - | A | - | 1 | A | 1 | - | A | - | 1 | A | 1 | 1 | A |
| 6 | Turbidity | 1 | 1 | A | 1 | - | A | 1 | - | A | - | 1 | A | 1 | - | A | 1 | 1 | A | 2 | - | A |
| 7 | Residue Non-Filterable | 37 | 68 | NA | 5 | 65 | A | 11 | 56 | A | 19 | 36 | A | 7 | 111 | NA | 4 | 132 | NA | 1 | 63 | NA |
| 8 | Residue Fixed Non-Filterable | 25 | 81 | NA | 9 | 65 | A | 18 | 56 | A | 36 | 38 | A | 11 | 113 | NA | 5 | 132 | NA | 2 | 63 | NA |
| 9 | Residue Filterable | 1 | 81 | NA | 1 | 65 | A | - | 56 | A | - | 38 | A | - | 113 | NA | - | 132 | NA | - | 63 | NA |
| 10 | Residue Fixed Filterable | 1 | 81 | NA | 2 | 65 | A | - | 56 | A | 1 | 38 | A | - | 113 | NA | - | 132 | NA | - | 63 | NA |
| 11 | Alkalinity (Total) | - | 1 | A | 1 | - | A | 1 | - | A | - | 1 | A | 1 | - | A | 1 | 2 | A | 1 | - | A |
| | ***Dissolved Ions*** | | | | | | | | | | | | | | | | | | | | | |
| 11 | Calcium | - | 1 | A | 1 | - | A | 1 | - | A | - | 1 | A | 1 | - | A | 1 | 2 | A | 2 | - | A |
| 12 | Chloride | - | 1 | A | 2 | - | A | 1 | - | A | - | 1 | A | 1 | - | A | 1 | 2 | A | 1 | - | A |
| 13 | Fluoride | 88 | 1 | NA | 100 | - | NA | 104 | - | NA | 146 | 1 | NA | 103 | - | NA | 89 | 2 | NA | 3 | - | A |
| 14 | Magnesium | - | 1 | A | 1 | - | A | 1 | - | A | - | 1 | A | 1 | - | A | 1 | 2 | A | 1 | - | A |
| 15 | Hardness | - | 1 | A | 1 | - | A | 1 | - | A | - | 1 | A | 1 | - | A | 1 | 2 | A | 1 | - | A |
| 16 | Potassium | 15 | 1 | A | 1 | - | A | 1 | - | A | - | 1 | A | 1 | - | A | 1 | 2 | A | 1 | - | A |
| 17 | Silicon Extr. | - | 91 | NA | 1 | 114 | NA | 1 | 116 | NA | - | 182 | NA | 1 | 124 | NA | 1 | 125 | NA | 1 | 52 | NA |
| 18 | Silicon | - | 19 | A | - | 20 | A | - | 21 | A | - | 6 | A | - | 16 | A | - | 21 | A | - | 19 | A |
| 19 | Sodium | - | 1 | A | 1 | - | A | 1 | - | A | - | 1 | A | 1 | - | A | 1 | 2 | A | 1 | - | A |
| 20 | Sulphate | - | 1 | A | 1 | - | A | - | - | A | - | 1 | A | 2 | - | A | - | 1 | A | - | - | A |
| | ***Nutrients*** | | | | | | | | | | | | | | | | | | | | | |
| 21 | Nitrogen: NO2/3 | - | 1 | A | - | - | A | - | 1 | A | 2 | 2 | A | 11 | - | A | - | 2 | A | 5 | - | A |
| 22 | Nitrogen: Total Dissolved | - | 2 | A | - | - | A | 1 | 1 | A | - | 33 | A | 1 | - | A | - | 3 | A | 3 | - | A |
| 23 | Phosphorus, Total | 18 | 1 | A | 3 | - | A | 1 | - | A | - | 33 | A | 1 | - | A | 1 | 2 | A | 1 | - | A |
| | ***Total Metals*** | | | | | | | | | | | | | | | | | | | | | |
| 24 | Aluminum | 14 | 83 | NA | 26 | 106 | NA | 28 | 107 | NA | 3 | 181 | NA | 19 | 116 | NA | 24 | 117 | NA | 24 | 46 | NA |
| 25 | Arsenic | 39 | 8 | NA | 2 | 8 | A | - | 8 | A | 1 | 4 | A | 1 | 8 | A | 16 | - | A | 1 | 7 | A |
| 26 | Barium | - | 83 | NA | - | 106 | NA | - | 107 | NA | - | 181 | NA | - | 116 | NA | - | 117 | NA | - | 46 | NA |
| 27 | Beryllium | 26 | 83 | NA | 21 | 106 | NA | 13 | 107 | NA | 3 | 181 | NA | 21 | 116 | NA | 25 | 117 | NA | 19 | 46 | NA |
| 28 | Cadmium | 84 | 8 | NA | 86 | 9 | NA | 72 | 7 | NA | 124 | 33 | NA | 100 | 7 | NA | 104 | 9 | NA | 38 | 7 | NA |
| 29 | Chromium | 3 | 82 | NA | 2 | 80 | NA | 2 | 79 | NA | - | 139 | NA | 1 | 88 | NA | 1 | 87 | NA | - | 46 | NA |
| 30 | Cobalt | 4 | 83 | NA | 1 | 106 | NA | 1 | 107 | NA | - | 181 | NA | 4 | 116 | NA | 6 | 117 | NA | - | 46 | NA |
| 31 | Copper | 1 | 8 | A | 5 | 9 | A | 4 | 7 | A | 1 | 33 | A | 3 | 7 | A | 3 | 9 | A | 2 | 7 | A |
| 32 | Iron | - | 8 | A | 5 | 9 | A | 4 | 7 | A | - | 33 | A | 2 | 7 | A | 1 | 9 | A | - | 7 | A |
| 33 | Lead | 59 | 8 | NA | 33 | 9 | NA | 25 | 7 | NA | 59 | 33 | NA | 69 | 7 | NA | 68 | 9 | NA | 29 | 7 | NA |
| 34 | Lithium | - | 83 | NA | 1 | 106 | NA | 1 | 107 | NA | - | 181 | NA | 1 | 116 | NA | 1 | 117 | NA | 1 | 46 | NA |
| 35 | Manganese | 17 | 8 | A | 5 | 8 | A | 5 | 7 | A | 1 | 33 | A | 5 | 7 | A | 13 | 9 | A | - | 7 | A |
| 36 | Mercury | 1 | 108 | NA | 1 | 133 | NA | 1 | 136 | NA | 18 | 168 | NA | 1 | 139 | NA | 1 | 143 | NA | - | ALL | NA |
| 37 | Molybdenum | 20 | 83 | NA | 16 | 106 | NA | 8 | 107 | NA | - | 181 | NA | 1 | 116 | NA | 1 | 117 | NA | 1 | 46 | NA |
| 38 | Nickel | - | 82 | NA | 5 | 81 | NA | 3 | 79 | NA | 1 | 139 | NA | - | 88 | NA | 8 | 88 | NA | - | 46 | NA |
| 39 | Selenium | 77 | 8 | NA | 67 | 8 | NA | 34 | 8 | NA | 49 | 4 | NA | 37 | 8 | NA | 34 | 9 | NA | 2 | 7 | A |
| 40 | Strontium | - | 83 | NA | - | 106 | NA | - | 107 | NA | - | 181 | NA | - | 116 | NA | - | 117 | NA | - | 46 | NA |
| 41 | Vanadium | 16 | 83 | NA | 1 | 106 | NA | 1 | 107 | NA | - | 181 | NA | 1 | 116 | NA | 2 | 117 | NA | 1 | 46 | NA |
| 42 | Zinc | 3 | 8 | A | 5 | 10 | A | 4 | 8 | A | 2 | 33 | A | 5 | 8 | A | 5 | 9 | A | - | 7 | A |

A: Adequate for further analysis NA: Not adequate for further analysis

*Table 5.2. Attributes of BC MoELP water quality data for sites in the Fraser River Basin.*

| | VARIABLE | Hansard | | | Marguerite | | | Hope | | | Nechako River | | | Salmon | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Number | Censored | Adequacy | Number | Censored | Adequacy | Number | Censored | Adequacy | Number | Censored | Adequacy | Number | Censored | Adequacy |
| | ***Physicals*** | | | | | | | | | | | | | | | |
| 1 | Specific Conductivity | 91 | -- | A | 102 | -- | A | 73 | -- | A | 91 | -- | A | 54 | -- | A |
| 2 | Color Tac | 129 | 6 | A | 100 | 2 | A | 4 | -- | NA | 2 | -- | NA | ND | -- | -- |
| 3 | pH | 71 | -- | A | 94 | -- | A | 76 | -- | A | 88 | -- | A | 63 | -- | A |
| 4 | Turbidity | 2 | -- | NA | 3 | -- | NA | 3 | -- | NA | 3 | -- | NA | 1 | -- | NA |
| 5 | Residue Non-Filterable | 131 | 4 | A | 134 | 5 | A | 71 | -- | A | 121 | 6 | A | 166 | -- | A |
| 6 | Residue Fixed Non-Filterable | ND | -- | -- | 2 | -- | NA | ND | -- | -- | 1 | -- | NA | ND | -- | -- |
| 7 | Residue Filterable | 134 | -- | A | 131 | -- | A | 70 | -- | A | 120 | -- | A | 125 | -- | A |
| 8 | Residue Fixed Filterable | 1 | -- | NA | ND | -- | NA | 1 | 1 | -- | ND | -- | -- | 3 | -- | NA |
| 9 | Residue Total | ND | -- | NA | ND | -- | NA | ND | -- | -- | ND | -- | -- | 35 | -- | NA |
| 10 | Alkalinity (phenolpht.) | 2 | 2 | NA | 3 | 3 | NA | 2 | 2 | NA | 3 | 3 | NA | ND | -- | -- |
| 11 | Alkalinity (Total) | 2 | -- | NA | 3 | -- | NA | 2 | -- | NA | 3 | -- | NA | 1 | -- | NA |
| 12 | Alkalinity 4.5/4.2 | 2 | -- | NA | 3 | -- | NA | 1 | -- | NA | 3 | -- | NA | ND | -- | -- |
| | ***Dissolved Ions*** | | | | | | | | | | | | | | | |
| 13 | Calcium | 44 | -- | A | 32 | -- | NA | 44 | -- | A | 38 | -- | NA | 16 | -- | NA |
| 14 | Chloride | 6 | 5 | NA | 39 | -- | NA | 3 | -- | NA | 3 | -- | NA | 17 | -- | NA |
| 15 | Fluoride, dissolved | 3 | 3 | NA | 3 | 3 | NA | 3 | 3 | NA | 3 | 3 | NA | 1 | -- | NA |
| 16 | Magnesium | 44 | -- | A | 32 | -- | A | 44 | -- | A | 38 | -- | A | 16 | -- | NA |
| 17 | Potassium,diss | 3 | -- | NA | 3 | -- | NA | 3 | -- | NA | 3 | -- | NA | 2 | -- | NA |
| 18 | Silica Reactive, diss | 2 | -- | NA | 3 | -- | NA | 3 | -- | NA | 3 | -- | NA | ND | -- | -- |
| 19 | Sodium, diss | 2 | -- | NA | 3 | -- | NA | 3 | -- | NA | 3 | -- | NA | 14 | -- | NA |
| 20 | Sulfate, diss | 2 | -- | NA | 3 | -- | NA | 3 | -- | NA | 3 | -- | NA | 29 | -- | NA |
| | ***Nutrients*** | | | | | | | | | | | | | | | |
| 21 | Nitrogen, Ammonia | 108 | 66 | A | 119 | 46 | A | 72 | 36 | NA | 120 | 68 | A | 164 | 44 | A |
| 22 | Nitrogen, NO2/3 Diss | 2 | -- | NA | 3 | 1 | NA | 2 | -- | NA | 33 | 1 | NA | 37 | 6 | NA |
| 23 | Nitrogen, Kjeldahl | 2 | -- | NA | 3 | 3 | NA | 2 | -- | NA | 3 | -- | NA | ND | -- | -- |
| 24 | Nitrogen Total Kjeldahl | ND | -- | NA | ND | -- | NA | ND | -- | -- | ND | -- | -- | 151 | -- | A |
| 25 | Nitrogen, dissolved | ND | -- | -- | ND | ND | -- | ND | -- | -- | ND | -- | -- | 11 | 10 | NA |
| 26 | Ortho-Phosphorus | 107 | 99 | NA | 115 | 49 | A | 71 | 36 | NA | 6 | 4 | NA | 184 | 2 | A |
| 27 | Phophorus, diss | 105 | 62 | A | 116 | 9 | A | 71 | 6 | A | 109 | 8 | A | 176 | 2 | A |
| 28 | Phosphorus, total | 2 | -- | NA | 3 | -- | NA | 3 | -- | NA | 3 | -- | NA | 74 | -- | A |
| | ***Metals*** | | | | | | | | | | | | | | | |
| 29 | Aluminum | 117 | -- | A | 125 | 2 | A | 65 | -- | A | 109 | 1 | A | 9 | -- | NA |
| 30 | Arsenic | 3 | 2 | NA | 4 | 3 | NA | 11 | 11 | NA | 5 | 4 | NA | 7 | 7 | NA |
| 31 | Barium | 1 | 1 | NA | ND | ND | -- | ND | -- | -- | ND | -- | -- | ND | -- | -- |
| 32 | Cadmium | 43 | 43 | NA | 31 | 31 | NA | 43 | 43 | NA | 37 | 37 | NA | 16 | 16 | NA |
| 33 | Chromium | 67 | 48 | NA | 47 | 17 | NA | 44 | 29 | NA | 40 | 37 | NA | 16 | 14 | NA |
| 34 | Cobalt | 44 | 44 | NA | 32 | 32 | NA | 44 | 44 | NA | 38 | 38 | NA | 16 | 16 | NA |
| 35 | Copper | 43 | 36 | NA | 32 | 26 | NA | 44 | 36 | NA | 38 | 33 | NA | 16 | 11 | NA |
| 36 | Iron | 44 | -- | A | 32 | -- | A | 44 | -- | A | 38 | -- | A | 16 | -- | NA |
| 37 | Lead | 44 | 42 | NA | 32 | 29 | NA | 44 | 41 | NA | 38 | 35 | NA | 16 | 16 | NA |
| 38 | Manganese | 44 | 6 | NA | 32 | 2 | NA | 44 | 3 | NA | 38 | 8 | NA | 16 | -- | NA |
| 39 | Mercury | 1 | 1 | NA | 2 | 2 | NA | 2 | 2 | NA | 2 | 2 | NA | ND | -- | -- |
| 40 | Molybdenum | 44 | 30 | NA | 32 | 20 | NA | 44 | 37 | NA | 38 | 32 | NA | 16 | -- | NA |
| 41 | Nickel | 44 | 44 | NA | 32 | 32 | NA | 44 | 43 | NA | 38 | 36 | NA | 16 | 16 | NA |
| 42 | Vanadium | 44 | 39 | NA | 32 | 28 | NA | 44 | 39 | NA | 38 | 33 | NA | 16 | 12 | NA |
| 43 | Zinc | 44 | 23 | NA | 32 | 14 | NA | 44 | 21 | NA | 38 | 25 | NA | 16 | 10 | NA |
| | ***Microbials*** | | | | | | | | | | | | | | | |
| 44 | Total Coliform (CFU/Cl) | ND | -- | -- | ND | ND | -- | ND | -- | -- | 1 | -- | NA | 2 | -- | NA |
| 45 | Total Coliform (MPN) | ND | -- | -- | ND | ND | -- | ND | -- | -- | ND | -- | -- | 27 | 6 | NA |
| 46 | Fecal Coliform (CFU/Cl) | 80 | 9 | A | 87 | 3 | A | 29 | -- | NA | 74 | 14 | A | 107 | 2 | A |
| 47 | Fecal Coliform (MPN) | 25 | 7 | NA | 21 | 3 | NA | 28 | 2 | NA | 31 | 11 | NA | 50 | 4 | NA |
| 48 | Fecal Streptococcus | ND | -- | -- | ND | ND | -- | ND | -- | -- | ND | -- | -- | 2 | -- | NA |
| 49 | E. Coli | ND | -- | -- | ND | ND | -- | ND | -- | -- | ND | -- | -- | 3 | -- | NA |
| 50 | Enterococcus | ND | -- | -- | ND | ND | -- | ND | -- | -- | ND | -- | -- | 9 | -- | NA |
| | ***Organics*** | | | | | | | | | | | | | | | |
| 51 | Phenols | 26 | 15 | NA | 31 | 16 | NA | ND | -- | -- | 56 | 24 | NA | 1 | -- | NA |
| 52 | Absorb Organohalides (AOX) | 29 | 22 | NA | 45 | 3 | NA | 42 | 3 | NA | ND | -- | -- | ND | -- | -- |

A: Adequate for further analysis NA: Not adequate for further analysis this type. Berryman *et al.* (1988) provided empirical power estimates and suggestions for minimal numbers of observations required in a time series for trend detection. The data series considered in this study, with 3 to 6 years of observations, are at the low end of the requisite minimum number of values for the Seasonal Kendall Tau and well below the minimum 10 years of data suggested for the modified Seasonal Kendall Tau. It is important to bear this in mind when interpreting results presented below. The results presented here should be considered to be a preliminary evaluation of Fraser River long-term monitoring data.

Occasionally, trend assessment results from the non-parametric and parametric analyses differed somewhat. In most cases, the parametric methods indicated a trend which was not detected by the non-parametric analysis, and/or the parametric results indicated a different form (quadratic rather than linear) of the trend. There are two factors which might account for these apparent discrepancies. First, the non-parametric data were a subset of the entire data series, selected so that trends were evaluated using a single observation for each month of the data record. The parameter estimates in the regression modelling were based on the full data series, and included terms for both a seasonal component and a flow correction and thus may be more sensitive indicators of trends.

## 5.1 Physical Parameters

### 5.1.1 *Flow*

Most water quality parameters are influenced by flow in some manner. High flows increase stream-bed erosion with consequent increases in sediment-related parameters, such as turbidity, non- filterable residue and total metals. Parameters which result from slow dissolution of bedrock, particularly dissolved ions, show strong inverse correlations with flow due to simple dilution. The effects of flow regime must be considered carefully when interpreting water quality data. The present study is restricted to a relatively small subset of the number of hydrometric stations in the entire Environment Canada network. A comprehensive basin-wide analysis of flow, general hydrology and overall trend is presented by Moore (1991), and will not be covered here. Some general comments about flows at the different monitoring sites are presented below.

Flows in the mainstem and tributary rivers of the Fraser basin are derived from snowmelt with local contribution from other sources. Warming in the late spring and early summer produces a freshet, with peak discharges of several orders of magnitude over base flow. In the upper mainstem of the Fraser, late summer flows are sustained by glacial meltwaters. Monthly stream flows (cubic metres/second) over the period 1985-1991 at four monitoring stations on the mainstem Fraser River (Red Pass, Hansard, Marguerite, and Hope) are shown in Figure 5.1.1. Strong seasonality in flow and attenuation of downstream flows with the contribution of each major tributary are clearly evident.

Other basins with both water chemistry and flow measurements have somewhat different physiographic characteristics which are reflected in their annual discharge patterns. Flows in the Salmon River, Thompson River at Spences Bridge and in the Nechako near Prince George are shown in Figure 5.1.2. The Salmon River drains a relatively small area, and lacks high altitude water reserves necessary to sustain high flows through the year. As such, the freshet is short and flows through most of the year are near base-flows (Figure 5.1.2), with occasional elevated flows related to random precipitation events. Flows in the river are typically very low, compared to the other water quality sites, and instream water levels respond quickly to runoff from rainfall.

Flows in the Thompson River near Spences Bridge are moderated somewhat by passage through upstream Kamloops Lake. This is reflected in the discharge by a somewhat less steep ascending portion of the hydrograph and a generally smoother curve, with few excursions (Figure 5.1.2). The Nechako River flow is regulated at the Kemano Dam, operated by Alcan Aluminum. Although displaying some seasonality in discharge, the dramatic freshet and random excursions characteristic of a natural flow are lost (Figure 5.1.2).

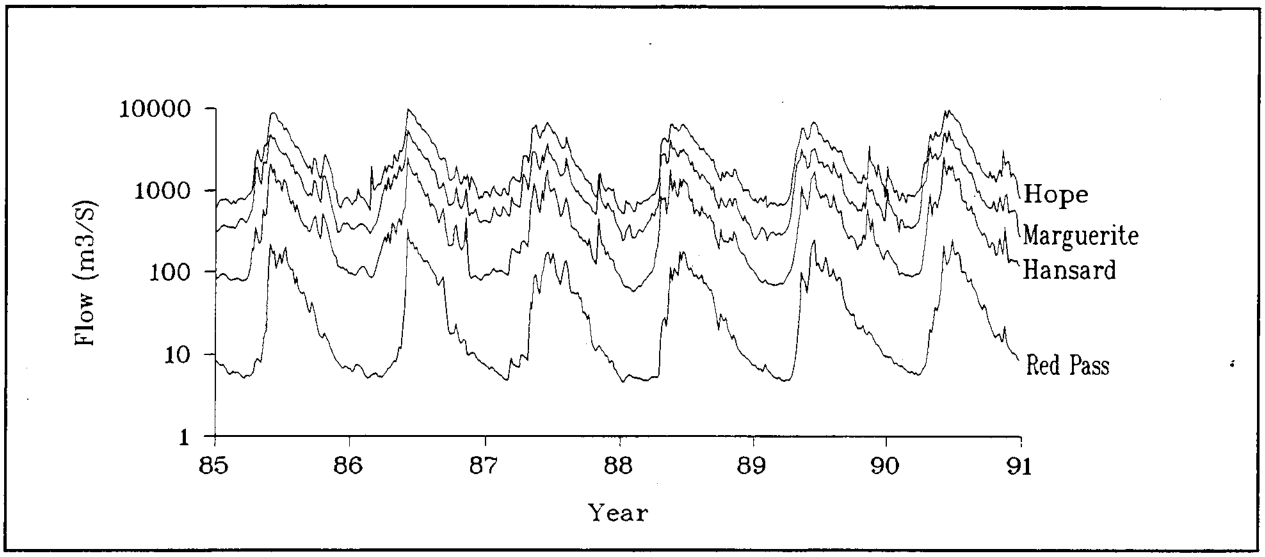



Figure 5.1.1. Discharge in the mainstem Fraser River for the period 1985-1991. Stations progress in a downstream sequence from Red Pass to Hope. Note that the Y-axis is presented as $Log_{10}$(Flow).

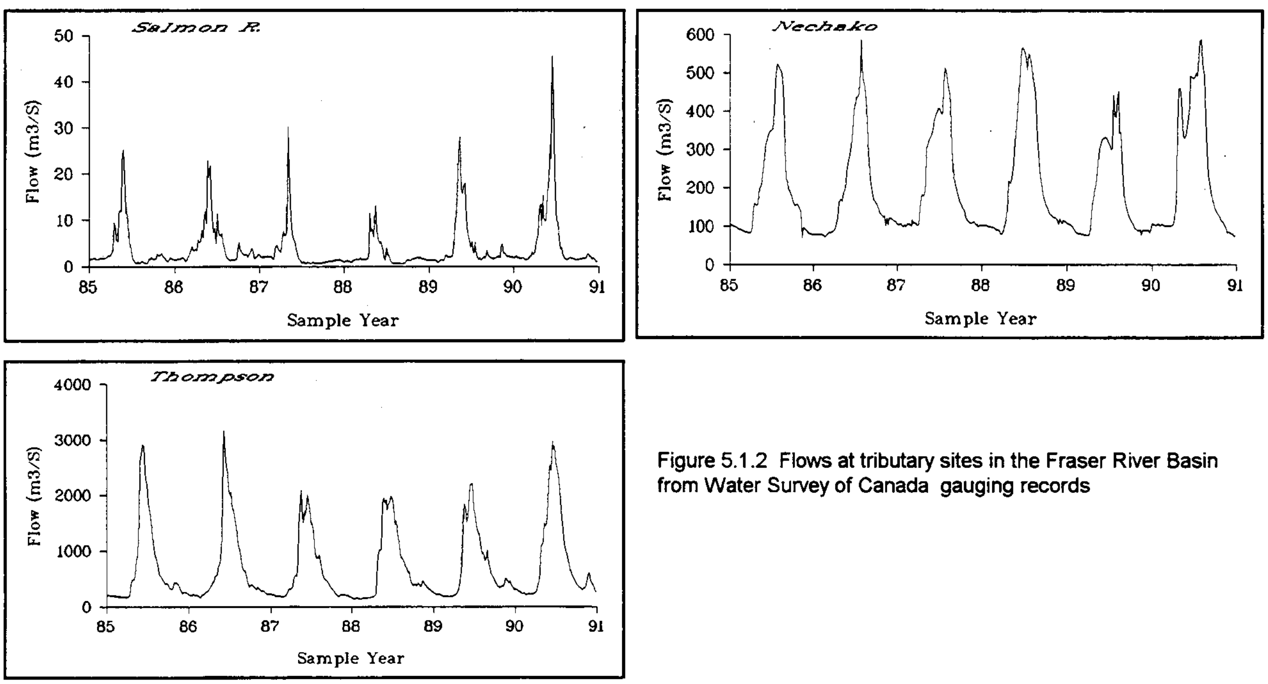



Figure 5.1.2 Flows at tributary sites in the Fraser River Basin from Water Survey of Canada gauging records

## 5.1.2 *Air Temperature*

The field air temperature is a record of local weather conditions at the sample time, which will strongly affect water discharge patterns and associated parameters and water temperatures. Local air and water temperatures are often highly correlated, and with some caveats, air temperature may be used to predict water temperature (Stefan and Preud'homme 1993). Air temperature will vary seasonally, and is strongly affected by geographic factors such as latitude and elevation and to a lesser extent, the immediate site physiography. In reviewing these air temperature data, it is important to remember that the data reflect conditions under which the samples were taken, and as such represent a non-random sample at the site. Values in the water quality data set will tend to underestimate the full range of temperature at a site, since water quality sampling may be suspended during periods of extreme cold. Plots of the air temperature record collected through the water quality sampling program against the local meteorological station measurements tends to support this possibility (e.g: Hansard, Figure 5.1.3). Analysis of these data, with recognition of this potential bias, is presented here for completeness.

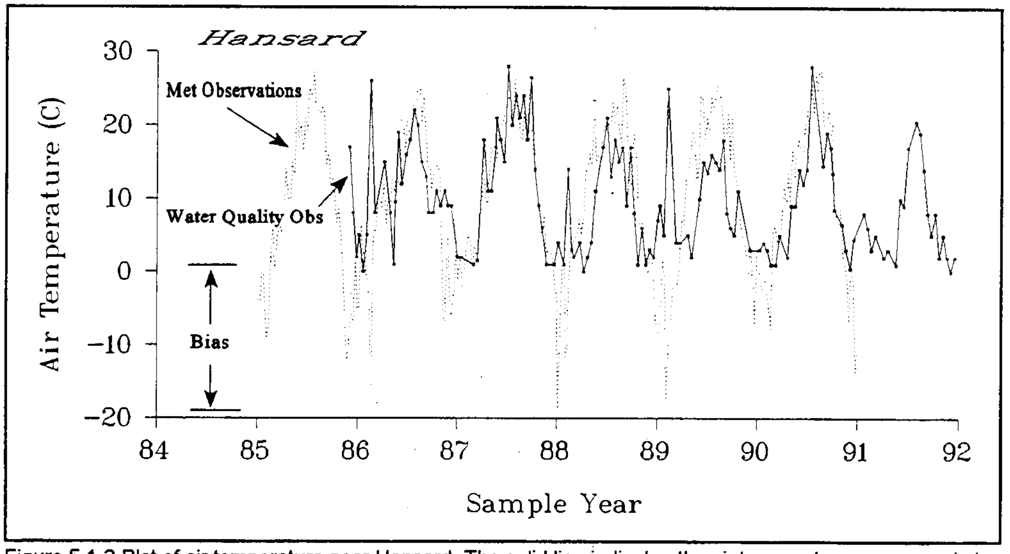



Figure 5.1.3 Plot of air temperature near Hansard. The solid line indicates the air temperatures measured at the time of water sampling, and the dashed line shows the temperature record from a local automated meteorological station. The extent of the difference between the two series is indicated as the bias.

Field air temperature data for the seven Fraser Basin sampling stations are summarized in Figure 5.1.4. Large spatial variation is readily apparent, with lower median temperatures at the northerly upstream stations (Red Pass, Hansard) compared to the southern, low-elevation down-stream stations (Hope, Thompson). As might be expected, there is a well defined and consistent seasonal cycle at all locations (e.g: Figure 5.1.3, above), although with considerable variation in amplitude between years and sites.

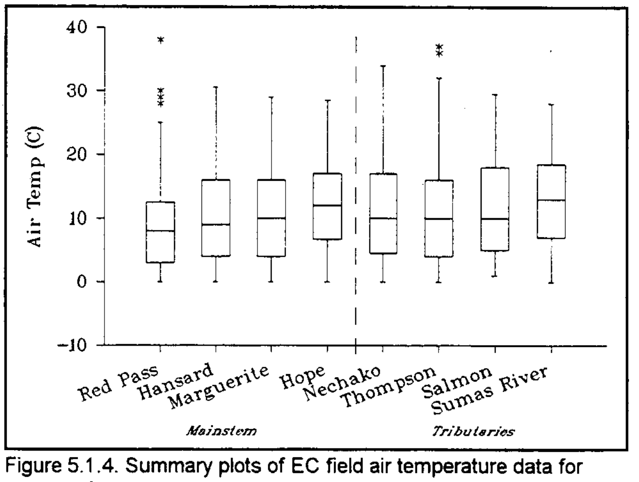



Figure 5.1.4. Summary plots of EC field air temperature data for selected Fraser Basin monitoring sites. These are incidental observations collected at the water sampling time, and not standard meteorological observations.

Non-parametric analysis of field air temperature measurements in the water quality data set indicate significant declining trends at the Hope and Red Pass stations and an increasing trend at the Marguerite site (Table 5.1.1). Recognizing the potential sampling bias in the measured air temperatures, these statistics were recalculated using data from the nearest meteorological monitoring station. When the meteorological data for the same period are summarized as mean monthly values, no trends were identified using the Seasonal Kendall's Tau. The sampling bias identified above is resulting in spurious trends. A detailed analysis of temperature data from meteorological sites in the basin should be conducted, particularly in light of global warming concerns.

**Table 5.1.1** *Summary of non-parametric tests for EC field air temperature data at sites in the Fraser River Basin, 1985-1991.*

| Test | Red Pass | Hansard | Marguerite | Hope | Nechako River | Thompson River | Salmon River |
|---|---|---|---|---|---|---|---|
| **Seasonal Kendall Tau Statistic** | -3.71 | ns | 3.61 | -2.67 | ns | ns | ns |
| **Modified Seasonal Kendall's Tau** | -2.35 | ns | ns | -2.11 | ns | ns | ns |
| **Van Belle Stat. For Homogeneity** | ns | ns | ns | ns | ns | ns | ns |
| **Van Belle Stat. For Trend** | 12.42 | ns | 12.2 | 7.0 | ns | ns | ns |
| **Sen's Slope** | -1.75 | ns | 1.5 | -0.50 | ns | ns | ns |

ns = not significant at 5% level

### 5.1.3 *Water Temperature*

Solubilities of most dissolved ions and gases are directly or indirectly influenced by water temperature. Dissolution of $CO_2$, an important determinant of pH, is inversely proportional to temperature (Wetzel 1983). Oxygen content of water is a critical factor for aquatic life, and the capacity decreases dramatically with increased temperature. Biological activity is also affected by temperature, and most species have fairly narrow optima, beyond which conditions may be fatal. For example, optimal temperatures for adult salmonids are in the range of 12-14°C and temperatures in excess of 25°C can be lethal. In British Columbia, maximum water temperature criteria of 13-15°C for salmonid embryo survival, and 22-24°C for adult salmon survival have been established (Nagpal *et al.* 1995).

River water temperature is affected by many factors, including (1) source water supplies (groundwater vs. lake vs. glacial melt), (2) latitude, (3) altitude, (4) season and (5) degree of shading. Low-dilution thermal effluent discharges, flow changes due to impoundment and water withdrawals, and reduced shading after removal of riparian vegetation are some of the factors affecting water temperatures in the Fraser River Basin. While changes in water flows and water depth in the mainstem Fraser River due to human activities are less likely to be detected, patterns in small rivers such as the Salmon provide insight into possible anthropogenic effects in upper tributaries.

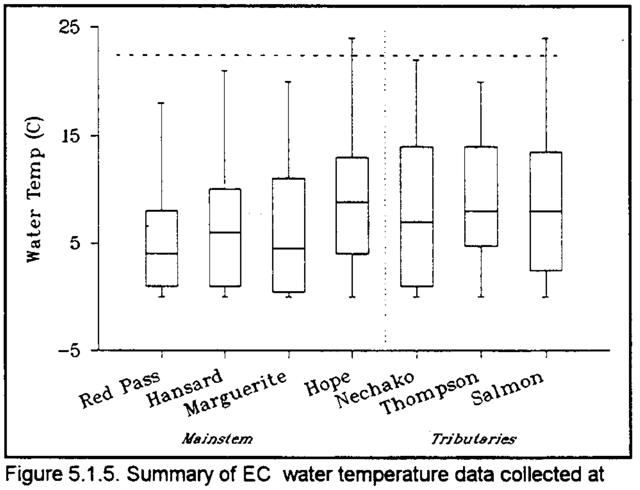



Figure 5.1.5. Summary of EC water temperature data collected at selected monitoring sites in the Fraser River Basin. The dashed line indicates the BC temperature criterion for protection of adult salmon.

EC water temperature data are summarized in Figure 5.1.5. There is a clear increase in water temperature from upstream to downstream which is probably related to both latitude and elevation. Conditions at the tributary sites are uniform, with a median temperatures of about 6.5°C. Surface water temperatures in excess of 15°C have been recorded at all sites, and occasional excursions in excess of the provincial criterion level of 24°C have occurred in the mainstem Fraser at Hope and on the Salmon River.

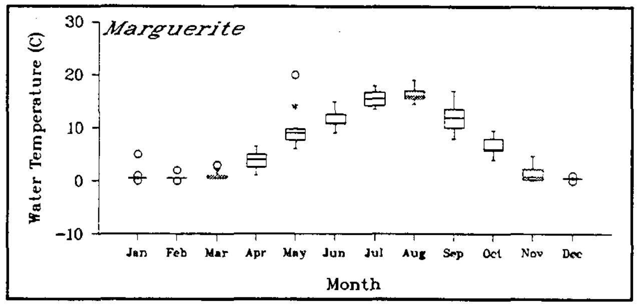


Figure 5.1. 6 Seasonal pattern in water temperature in the Fraser River at Marguerite, 1985-1991.

Seasonality in water temperature is strong and well defined at all sites (e.g: Figure 5.1.6).

Non-parametric analyses of trend using Kendall's Tau indicated a significant ($p<0.05$) decreasing trend at Red Pass (Table 5.1.2). Inspection of a yearly summary plot (Figure 5.1.7) shows that although the early record shows a decreasing trend, more recent data would indicate that temperatures are on the rise. Although it is difficult to establish a causal factor for these trends, it is interesting that this result agrees with a similar analysis of the field air temperature data at this same site. It is possible that the same sampling bias identified in the air temperature observations is present in the water temperature data. Parametric regression of the same data did not indicate trends at any sites.

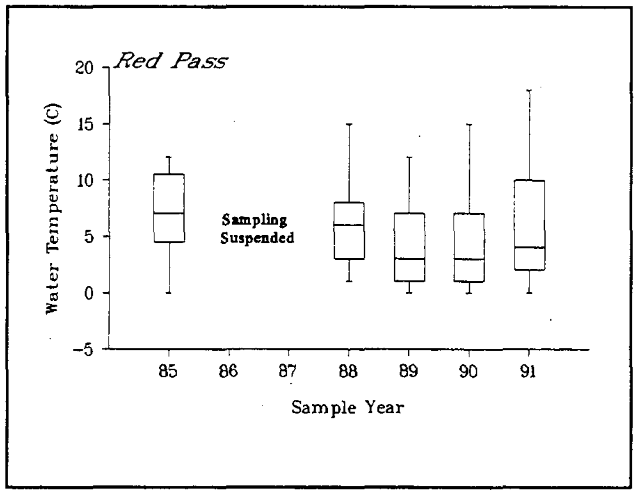


Figure 5.1.7. Summary of EC water temperature data at Red Pass. Non-parametric analysis of data at this site indicated an overall decreasing trend.

From a fisheries management perspective, temperature is an extremely important parameter. Elevated water temperatures have been implicated as contributing to the recent (1994) poor performance of several Fraser River salmon stocks, including runs in the Adams River and the Salmon River of the Shuswap system. During spawning runs, a small increase in temperature can increase the metabolic cost of migration such that successful returns may be impossible. Continued monitoring and assessment of water temperature is important, and application of continuous electronic monitoring might be considered to improve the temporal coverage and reduce possible sampling bias in the data record.

**Table 5.1.2** *Summary of non-parametric tests for the EC water temperature data at selected sites in the Fraser River Basin, 1985-1991.*

| Test | Red Pass | Hansard | Marguerite | Hope | Nechako River | Thompson River | Salmon River |
|---|---|---|---|---|---|---|---|
| Seasonal Kendall Tau Statistic | -1.97 | ns | ns | ns | ns | ns | ns |
| Modified Seasonal Kendall's Tau | ns | ns | ns | ns | ns | ns | ns |
| Van Belle Stat. For Homogeneity | ns | ns | ns | ns | ns | ns | ns |
| Van Belle Stat. For Trend | ns | ns | 4.22 | ns | ns | ns | ns |
| Sen's Slope | -0.25 | ns | ns | ns | ns | ns | ns |

ns = not significant at the 5% level

## 5.1.4 *Conductivity*

Specific conductivity refers to the ability of a substance to conduct an electrical current (APHA 1980). Conductivity is related to the concentration of dissolved ions, and is used in water quality monitoring as a simple, easily measured variable for estimating total dissolved solids. Conductivity is affected by any process which alters the ion content of water, be it natural (such as groundwater flows or freshet) or anthropogenic (such as waste discharges or road salts). Landscape changes, such as timber harvesting, may have an effect on conductivity through increased runoff and leaching of soils (Binkely and Brown 1993). High conductivity in surface water is of particular concern for agricultural irrigation and some industrial applications. High dissolved ion concentrations may accumulate in irrigated soils, resulting in undesirable salinization and loss of the land for crops. Neither the CCME nor the BC MoELP have designated conductivity criteria/guidelines for protection of aquatic life.

Both EC and BC MoELP determine conductivity at the joint federal/provincial sites on samples transported to the agency laboratory. Conductivity is a very stable parameter, as shown by the close agreement in paired measurements by the two agencies (Figure 5.1.8).

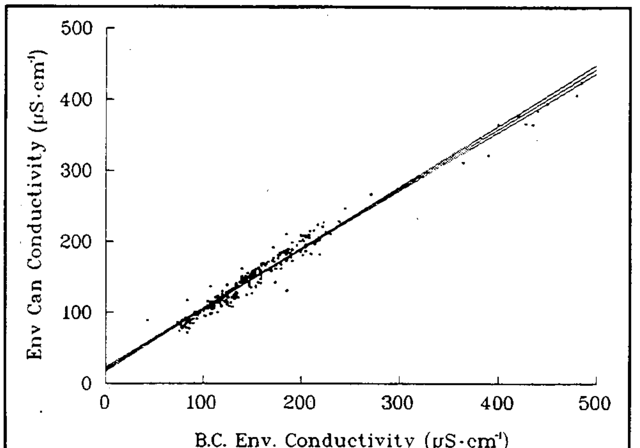



Figure 5.1.8. Comparison of EC and BC MoELP specific conductivity measurements at federal-provincial monitoring sites. Shown also is the least-squares regression line with 95% confidence bounds.

A small but steady increase in conductivity from the headwaters to Marguerite is found at sites on the mainstem Fraser River (Figure 5.1.9). Dilution of the mainstem flow by the Thompson River produces an obvious depression in the measurements at the Hope site. Levels in the Salmon River are high relative to the other sites considered here, with a median value for the period of record near 400 µS·cm[-1]. The BC MoELP conductivity data at these sites display the same pattern, with the highest conductivities being observed in the Salmon, followed by Hansard, Marguerite and Hope.

The high conductivities found in the Salmon River are due to several factors. This site differs markedly from the other Fraser Basin monitoring stations in that the river drains a relatively small catchment area in which agricultural irrigation returns and groundwater discharge constitute a large portion of the flow through much of the year (Obedkoff 1974). Relatively low in-stream flows and shallow water depth encourage high evaporative loss, further concentrating the already high total ion load.

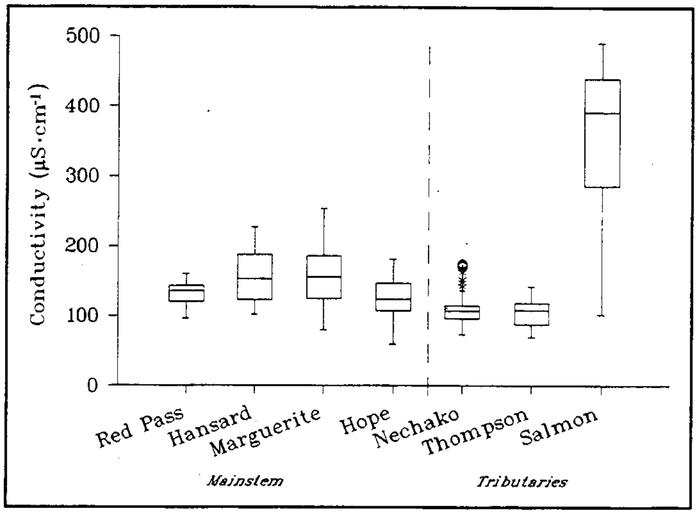



Figure 5.1.9. Summary of EC conductivity data for selected Fraser River water quality monitoring sites for the period 1985-91.

The seasonal pattern in conductivity at all sites is well-defined, with high values in the winter when groundwater contribution is high, and low values in the summer when flows are highest (ie: Figure 5.1.10). Conductivity is inversely correlated with flow, and is strongly depressed during freshet, slowly returning to peak values as flows diminish. Data from the Salmon River display a significant departure from the seasonal pattern at the "large-river" sites. In the Salmon River, the freshet period is of very short duration and the river rapidly returns to a low baseflow and corresponding high conductivity (Fig 5.1.10).

Non-parametric trend analyses of the Environment Canada data indicate an increasing trend in conductivity only at the Red Pass station (Table 5.1.3). Although this trend is clearly visible in a year to year summary plot of these same data (Figure 5.1.11), the cause is not readily apparent.

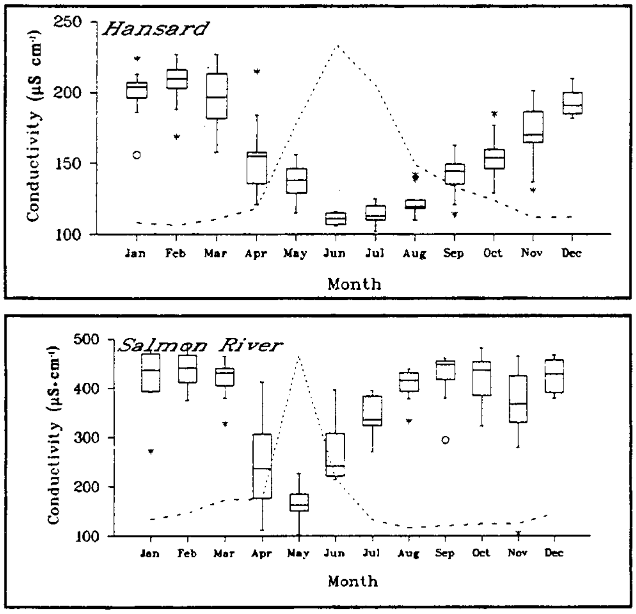



Figure 5.1.10 Seasonal conductivity pattern in the Fraser River at Hansard and the Salmon River from EC monitoring data, 1985-1991. The dashed line shows the mean monthly flow at each site for the same period.

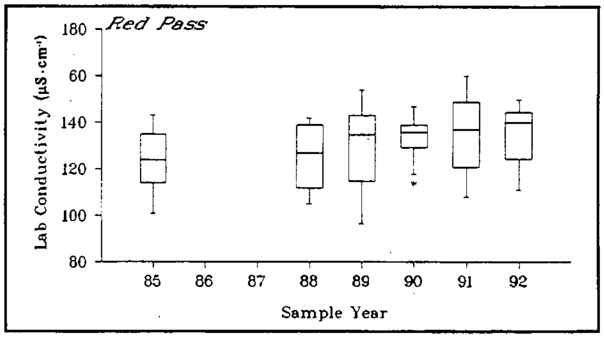



Figure 5.1.11 Summary by year of EC conductivity data for the mainstem Fraser River at Red Pass. Data for 1986 and 1987 are sporadic and were excluded from the plot

Regression analysis of the EC conductivity data reinforced the negative flow relationship ($\beta_1$ significant, negative) and indicated significant increasing ($\beta_2$ positive) linear trends in conductivity at the Hansard and Marguerite stations and a U - shaped quadratic trend ($\beta_3$ significantly different from zero) at the Nechako site (Table 5.1.4).

In contrast, a similar analysis of the BC MoELP conductivity data (Table 5.1.5) shows a significant increasing ($\beta_2$ significant and positive) trend in conductivity at the Hope station. Examination of annual summary plots from both agencies shows a clear increasing trend in the EC series at Marguerite (Figure 5.1.12), which is not evident in the BC MoELP data (Figure 5.1.13). The more complete data in the EC set suggests that this may be the "true" pattern, and future data should be carefully examined. Trends toward increasing conductivity at both Marguerite and Hope may be due to upstream releases from pulp mills and sewage treatment plants. Significant trends in the headwater sites, however, may suggest changes due to natural influences. It might be mentioned that the present levels of conductivity measured at the Fraser Basin sites, even in the Salmon River, are low relative to the 700 μS·cm$^{-1}$ criterion established by BC MoELP for protection of irrigation uses. While conductivity in most monitoring sites in the Fraser Basin is of little environmental concern, the increasing pressure for development and consequent rise in demand for water in the Salmon River Basin (Gormican and Cross 1995) could place water uses in that area at risk.

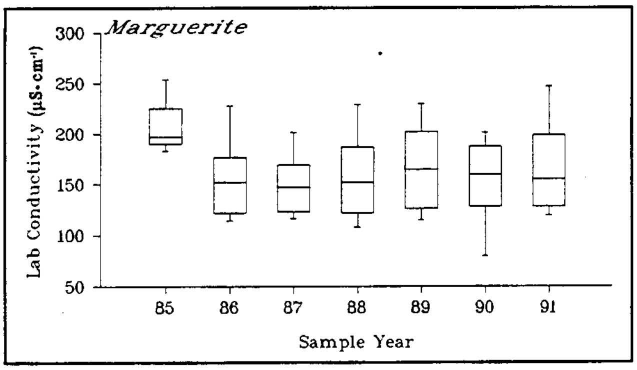


Figure 5.1.12 Annual summary of EC conductivity data from the Fraser River at Marguerite.

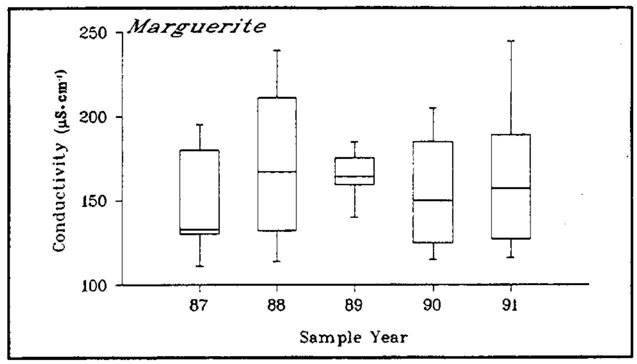


Figure 5.1.13 Annual summary of BC MoELP conductivity data from the Fraser River at Marguerite

Table 5.1.3 *Results of non-parametric tests on EC specific conductivity data for monitoring sites in the Fraser Basin, 1985-1991.*

| Test | Red Pass | Hansard | Marguerite | Hope | Nechako River | Thompson River | Salmon River |
|---|---|---|---|---|---|---|---|
| **Seasonal Kendall's Tau Statistic** | 2.55 | ns | ns | ns | ns | ns | ns |
| **Modified Seasonal Kendall's Tau** | ns | ns | ns | ns | ns | ns | ns |
| **Van Belle Stat. For Homogeneity** | ns | ns | ns | ns | ns | ns | ns |
| **Van Belle Stat. For Trend** | 5.44 | ns | ns | ns | ns | ns | ns |
| **Sen's Slope** | 1.60 | ns | ns | ns | ns | ns | ns |

ns = not significant at the 5% level

**Table 5.1.4** *Summary of fitted models for EC specific conductivity data from the Fraser Basin monitoring sites, 1985-1991.*

| Parameters | Sampling Stations | | | | | | |
|---|---|---|---|---|---|---|---|
| | Red Pass | Hansard | Marguerite | Hope | Nechako River | Thompson River | Salmon River |
| $\beta_0$ | 4.87 | 5.77 | 6.24 | 6.12 | 6.26 | 5.2 | 5.89 |
| $\beta_1$ | ns | -0.14 | -0.183 | -0.171 | -0.273 | -0.1 | -0.39 |
| $\beta_2$ | ns | 0.014 | 0.013 | ns | -0.137 | ns | 0.118 |
| $\beta_3$ | - | - | - | - | 0.021 | - | - |
| $\alpha_1$ | 0.016 | 0.1 | 0.093 | 0.038 | -0.072 | 0.016 | 0.063 |
| $\alpha_2$ | 0.135 | 0.067 | 0.023 | 0.052 | 0.053 | 0.146 | -0.061 |
| $\omega$ | 0.02 | 0.018 | 0.016 | 0.017 | 0.018 | 0.018 | -0.069 |
| $r^2$ | 74.09 | 89.85 | 89.89 | 84.05 | 68.64 | 88.38 | 90.95 |

ns = not significant at the 5% level

**Table 5.1.5** *Summary of the fitted models for BC MoELP specific conductivity data from monitoring sites in the Fraser Basin.*

| Parameters | Sampling Station | | | |
|---|---|---|---|---|
| | Hansard | Marguerite | Hope | Salmon River |
| $\beta_0$ | 5.86 | 6.36 | 6.42 | 5.90 |
| $\beta_1$ | -0.145 | -0.208 | -0.210 | -0.220 |
| $\beta_2$ | ns | ns | 0.014 | ns |
| $\alpha_1$ | 0.062 | 0.940 | -0.005 | -0.203 |
| $\alpha_2$ | 0.109 | 0.000 | 0.046 | 0.162 |
| $\bar{\omega}$ | 0.020 | 0.014 | 0.019 | 0.042 |
| $r^2$ | 93.44 | 93.42 | 95.64 | 68.95 |

## 5.1.5 *Colour*

The colour of surface waters results from the interaction of humic substances, dissolved ions, suspended materials and colloids and, where present, effluent discharges. For example, a high $CaCO_3$ concentration (such as in waters draining limestone terrains) will produce a green colour (CCREM 1987), while high levels of humic acid and tannins result in red-brown, "tea-coloured" waters (Chapman and Kimstach 1992). While of primarily aesthetic concern in drinking water and contact recreation, colour may also provide an easily-measured indicator of effluent plumes and dilution. Factors affecting colour in natural waters, with particular reference to waters in the Fraser Basin, have been recently discussed in Jerome *et al.* (1994 a,b).

Water colour data have been collected by EC at all 7 monitoring sites and by the BC MoELP at the Hansard and Marguerite sites. The federal colour data are expressed as *Apparent Colour*. This is a qualitative assessment of coloured particles and the refraction and reflection of light by suspended particles (Chapman and Kimstach 1992). The sample is first allowed to settle, then the water colour is visually compared against a series of platinum standard solutions. BC MoELP determines *Total Absorbance Colour* (TAC), which is measured as the integrated absorbance of the filtered sample (1 µm) over wavelengths from 400 to 700 nm. Both measures may be related to the original platinum (Pt) standard solution. Apparent colour units of 2 mg·l Pt is roughly equivalent to 1 TAC unit (Chapman and Kimstach 1992). Since colour is, in itself, not harmful to aquatic organisms, there are no water quality guidelines or criteria for protection of aquatic life.

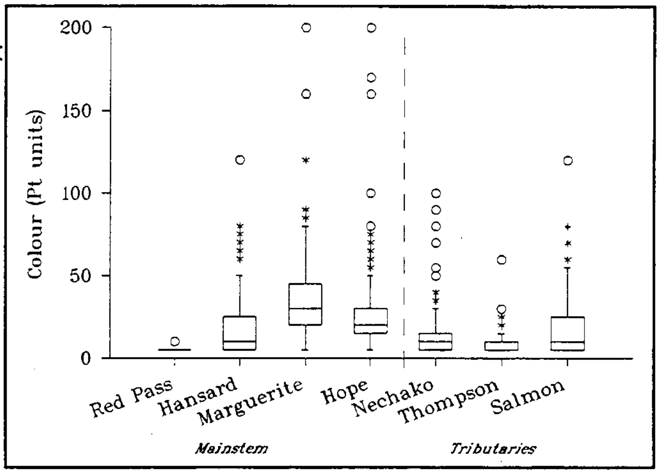



Figure 5.1.14 Summary of EC water colour data at monitoring sites on the Fraser and major tributaries for the period 1985 to 1991.

Silt and suspended sediments in the Fraser River contribute to colour, and factors which affect these parameters will likewise influence colour. Foremost among these is river discharge. Anthropogenic factors include land uses which will destabilize surficial and bed sediments, increasing turbidity and suspended sediment loads. Effluent discharges will also affect colour, depending on the type and degree of dilution of the waste. Pulp and paper mills, in particular, discharge a variety of highly coloured compounds which in some systems may be visible some distance downstream (pers. obs.).

Summary of the available EC data (Fig 5.1.14) shows a clear increase in apparent colour from near the detection limit in the headwaters at Red Pass downstream to Marguerite. The increase in colour from Hansard to Marguerite is probably due to both natural sediment loading and effluent discharges. A clear depression in values is evident at the Hope station. Major tributaries to the Fraser, the Nechako and Thompson Rivers, tend to be considerably less coloured than the mainstem, and it is probable that dilution of the mainstem by the Thompson produces the lower values at Hope. Excursions are common, as

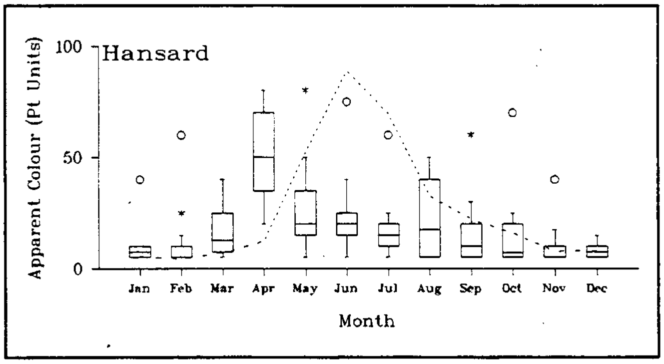



Figure 5.1.15 Seasonal pattern in EC apparent colour data from the Fraser River at Hansard for the period 1985-91. Overlain is a plot of the mean monthly flow at the site for the same period.

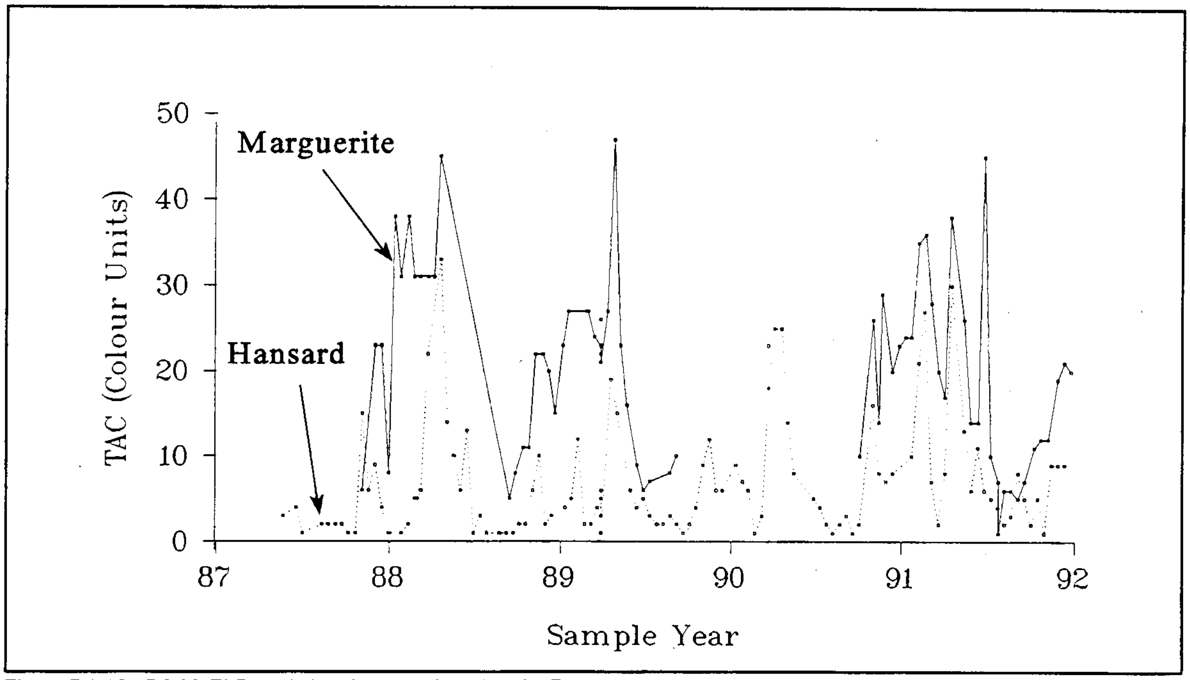


Figure 5.1.16 BC MoELP total absorbance colour data for Fraser River mainstem stations at Hansard and Marguerite.

evidenced by the number of outliers shown in Figure 5.1.14.

Seasonality in apparent colour is strong at most sites, with higher values being observed in the spring and lower values in the summer and early fall (e.g: Figure 5.1.15). Colour is weakly related to flow, increasing through the winter low-flow period and declining rapidly with the onset of freshet conditions in the late spring.

Provincial TAC data from the Fraser River at Hansard and Marguerite show patterns similar to the EC data (Figure 5.1.16). Relatively higher values are found at the downstream site, and time series plots of the data series indicate a regular seasonal pattern. Difference in colour between the Marguerite and Hansard sites is particularly pronounced during the winter period, probably related to low in-stream flows and consequent low dilution of pulp mill effluents.

Non-parametric analysis of the EC data suggests increasing trend in apparent colour at both Hansard and Marguerite (Table 5.1.6). Further analysis by parametric methods indicated a linear increasing trend only at Marguerite (Table 5.1.7). The trend at Marguerite is quite apparent in an annual summary plot (Figure 5.1.17), and a similar plot of data from Hansard would suggest a step-change at 1990 (Figure 5.1.18). Median values, the range and the frequency of excursions have been steadily increasing over the 1985 to 1991 period. Mill effluent volumes have been increasing over this same time period, and may be implicated in the observed trend.

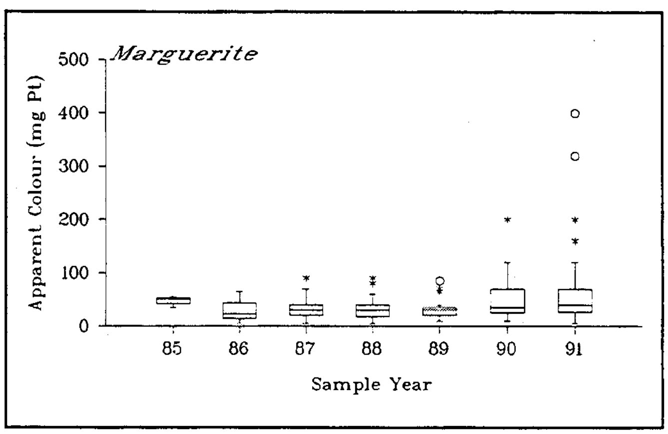


Figure 5.1.17 Annual summary of EC apparent colour data from the Fraser River at Marguerite.

In contrast to results of analysis of EC colour data, non-parametric analyses of the provincial data indicate an increasing trend in TAC at Hansard but not at Marguerite (Table 5.1.8). Regression analyses of these data further support this result (Table 5.1.9). A summary plot of these data shows this increasing trend very clearly (Figure 5.1.19).

Since colour may be affected by a number of factors, it is difficult to establish a definitive cause for the observed trends. The colour measures used by the two agencies differ greatly in analytical technique, and are affected by somewhat different water quality factors, as for example, turbidity. Conflicting results of these analyses suggest that there are subtle factors causing small increases in colour, and that the parameter should be followed carefully to monitor the degree of change.

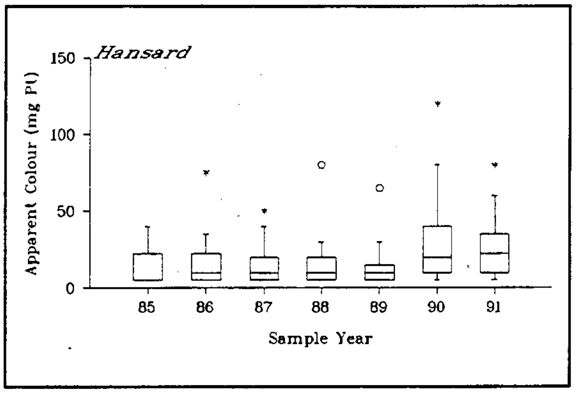



Figure 5.1.18 Annual summary of EC apparent colour data from the Fraser River at Hansard.

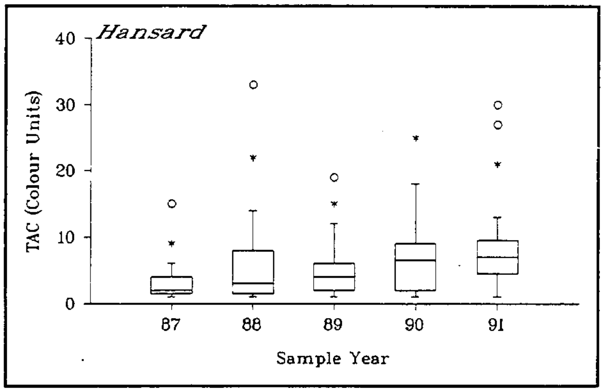



Figure 5.1.19. Annual summary of BC MoELP TAC data from the Fraser River at Hansard.

**Table 5.1.6** *Summary of non-parametric tests for EC apparent colour data at monitoring sites in the Fraser River Basin, 1985-1991*

| Test | Red Pass | Hansard | Marguerite | Hope | Nechako River | Thompson River | Salmon River |
|---|---|---|---|---|---|---|---|
| **Seasonal Kendall Tau Statistic** | ns | -2.79 | 2.42 | ns | ns | ns | ns |
| **Modified Seasonal Kendall's Tau** | ns | 2.40 | ns | ns | ns | ns | ns |
| **Van Belle Stat. For Homogeneity** | ns | ns | ns | ns | ns | ns | ns |
| **Van Belle Stat. For Trend** | ns | 8.65 | 6.60 | ns | ns | ns | ns |
| **Sen's Slope** | ns | .00017 | .00025 | ns | ns | ns | ns |

ns = not significant at the 5% level

**Table 5.1.7** *Summary of fitted models for EC apparent colour data at water quality monitoring sites in the Fraser River Basin, 1985-1991.*

| Parameters | Sampling Stations | | | | | |
|---|---|---|---|---|---|---|
| | Hansard | Marguerite | Thompson River | Hope | Salmon River | Nechako River |
| $\beta_0$ | ns | ns | ns | ns | 1.88 | ns |
| $\beta_1$ | 0.545 | 0.387 | 0.373 | 0.3698 | .88 | .61 |
| $\beta_2$ | ns | 0.104 | ns | ns | ns | ns |
| $\alpha_1$ | 0.304 | 0.471 | 0.413 | 0.489 | .028 | -.534 |
| $\alpha_2$ | 0.494 | 0.485 | 0.228 | 0.426 | -.22 | .491 |

ns = not significant at the 5% level

**Table 5.1.8** *Summary of non-parametric tests for BC MoELP total absorbance colour (TAC) for monitoring sites in the Fraser River Basin, 1985-1991.*

| Test | Hansard | Marguerite |
|---|---|---|
| **Seasonal Kendall's Tau Statistic** | 2.67 | ns |
| **Modified Seasonal Kendall Tau** | ns | ns |
| **Van Belle Stat. For Homogeneity** | ns | ns |
| **Van Belle Stat. For Trend** | 7.18 | ns |
| **Sen's Slope** | 0.50 | ns |

ns = not significant at the 5% level

**Table 5.1.9** *Model parameter estimates for BC MoELP total absorbance colour (TAC) for monitoring sites in the Fraser River Basin, 1985-1991.*

| Parameters | Sampling Stations | |
|---|---|---|
| | Hansard | Marguerite |
| $\beta_0$ | -4.27 | ns |
| $\beta_1$ | 0.949 | 0.387 |
| $\beta_2$ | 0.153 | ns |
| $\alpha_1$ | 1.427 | 0.771 |
| $\alpha_2$ | 0.757 | 0.745 |
| $\omega$ | -- | 0.018 |
| $r^2$ | -- | 77.75 |

ns= not significant at the 5% level

## 5.1.6 *pH*

pH is a measure of the acidity or alkalinity of a water. As a variable for water quality monitoring, pH is important as a direct and indirect mediator of water chemistry and habitat suitability for aquatic organisms. Most organisms can tolerate a pH range from 5 to 9, with signs of physiological stress (such as decreased growth, declining hatching success) beginning to occur at pH 6.5 (McNeeley *et al.* 1979). The toxicity of many chemicals, particularly metals, dissolved ammonia and some organic compounds (ie: cyanide, chlorophenols) is affected strongly by pH, and relatively small changes in pH have potential to cause large differences in toxic effect (Hoenicke *et al.*1991).

pH is affected strongly by dissolved ion composition, particularly through carbonate/bicarbonate equilibria (Hem 1985). In this respect, the bedrock geology, which determines the dissolved ion composition of surface waters, is an important determinant of basinwide pH. Waters draining carbonate terranes, such as the limestones of the upper Fraser River basin, tend to be well-buffered and of relatively high pH. Volcanic bedrocks tend to be sources of lower pH waters (Wetzel 1983). Dissolved $CO_2$, both from biological respiration and absorption from the atmosphere, produces carbonic acid which is also an important factor determining pH. Other low-pH sources are waters from bogs and bog lakes, which are typically of very low pH due to high levels of natural humic acids and tannins.

Many industrial processes produce low-pH waters, either directly or indirectly. Of particular environmental concern are atmospheric emissions of sulphur and nitrogen. These combine with atmospheric water to produce mineral acids which fall to the earth as "acid rain" - a serious environmental problem in many areas where surface waters have low buffering capacity. Another important source of acid waters is drainage from mining operations. Water combines with newly exposed sulphite minerals, resulting in waters of pH 2-3 flowing from these sites (Chapman and Kimstach 1992). Such drainage is of particularly serious environmental concern, since permanent mitigation is nearly impossible and the drainage may continue for centuries.

The EC pH data for the period of record demonstrates a common problem in long-term water quality data sets. Analytical errors, sample handling or consistent contamination problems may produce data bias which will result in precise but inaccurate determinations. When problems with the analysis are corrected, the data series will shift to a new level, as seen in Fig 5.1.20. Data in EC's, ENVIRODAT database which are clearly in error have been flagged as such, but the complete data set is presented here for illustration.

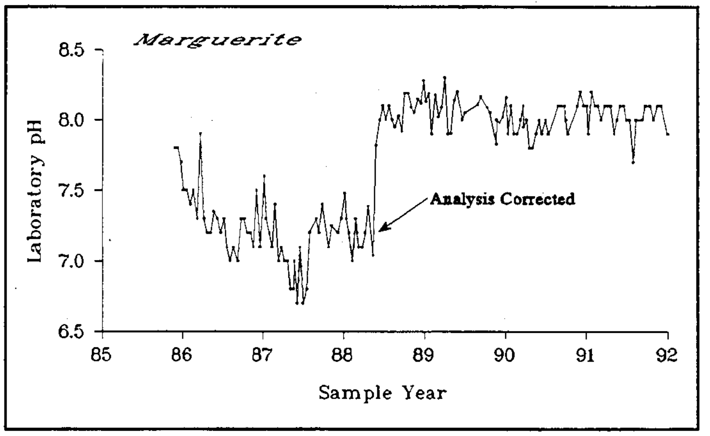



Figure 5.1.20. Time series of EC Laboratory pH data from the Fraser River at Marguerite showing the effect of a consistent analytical error. When the error was corrected in 1988, the record shows a marked "step-change" to the higher level. All other EC water quality stations show a similar pattern for this period.

Even when analyses are properly conducted, pH is a relatively unstable measurement. Both EC and BC MoELP measure pH in the laboratory from samples collected at federal-provincial sites. Although the two samples are collected at the same time and processed in a similar manner, the results may be slightly different owing to the unstable nature of the dissolved gas contribution to pH, temperature differences, factors related to sample storage and the control of instrumental conditions in the laboratory. Hoenicke *et al.* (1991) have reviewed the multitude of factors which can affect this very routine water quality measurement. The magnitude of this difference between the two methods is apparent when paired pH measurements (post-1988 EC data and BC MoELP data) are plotted (Figure 5.1.21).

In the mainstem Fraser, the median pH is a consistent 7.9-8.0 from the headwaters to Hope (Figure 5.1.22). Median values in the major tributaries are slightly more acidic than in the mainstem, being about 7.8 and 7.7 for the Nechako and Thompson Rivers respectively. Overall pH in the Salmon is the highest of all sites, with a median pH near 8.3.

Trend analyses were conducted only on the BC MoELP pH data. Non-parametric analyses suggested a declining pH at Marguerite, and no significant trends at the remaining sites (Table 5.1.10). Subsequent analysis using parametric methods also suggested the negative trend at Marguerite (Table 5.1.11). Fit of the model to the available data was poor at all sites (very low $r^2$). Both parametric and non-parametric methods suggest the same trend, although a time-series plot of these same data indicates only a very subtle decline (Figure 5.1.23).

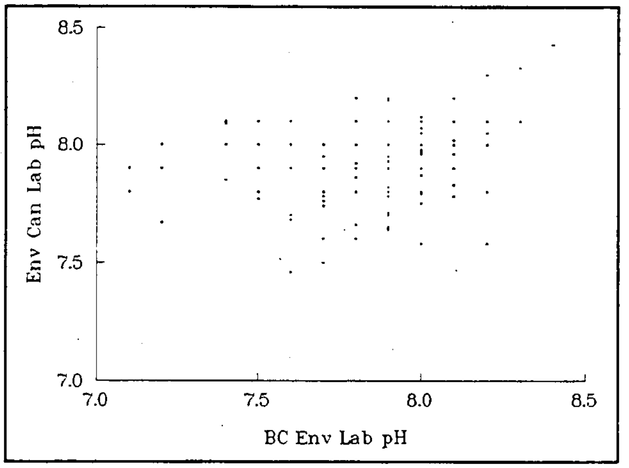


Figure 5.1.21 Paired pH measurements by EC and BC MoELP. Water samples were collected simultaneously and returned to the laboratory for determination by each agency.

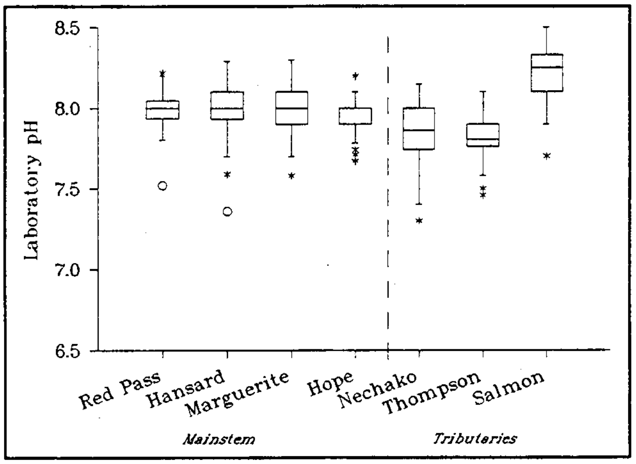


Figure 5.1.22. Summary plots of EC pH data at monitoring sites in the Fraser River Basin for the period 1988 to 1991. The y-axis represents the range of pH values in the provincial criterion for protection of aquatic life.

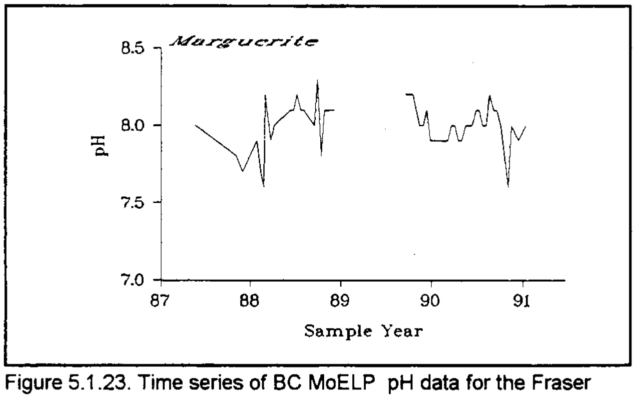


Figure 5.1.23. Time series of BC MoELP pH data for the Fraser River at Marguerite. Non-parametric analysis of these data indicate a declining trend in pH at this site.

**Table 5.1.10** *Results of non-parametric tests for BC MoELP pH data from monitoring sites in the Fraser River Basin, 1985-1991*

| Test | Hansard | Marguerite | Nechako River | Salmon River |
|---|---|---|---|---|
| **Seasonal Kendall's Tau** | ns | -2.42 | ns | ns |
| **Modified Seasonal Kendall's Tau** | ns | ns | ns | ns |
| **Van Belle Stat. For Homogeneity** | ns | ns | ns | ns |
| **Van Belle Stat. For Trend** | ns | 6.99 | ns | ns |
| **Sen's Slope** | ns | -0.031 | ns | ns |

ns = not significant at the 5% level

**Table 5.1.11** *Summary of parameter estimates for BC MoELP pH data from monitoring sites in the Fraser River Basin.*

| Parameter | Sampling Stations | | | | |
|---|---|---|---|---|---|
| | Hansard | Marguerite | Hope | Nechako River | Salmon River |
| $\beta_0$ | 2.03 | 2.13 | 20.17 | 2.10 | 2.11 |
| $\beta_1$ | 0.006 | ns | ns | ns | -0.012 |
| $\beta_2$ | ns | ns | ns | ns | ns |
| $\alpha_1$ | ns | -0.018 | 0.010 | -0.010 | -0.007 |
| $\alpha_2$ | ns | -0.004 | 0.005 | -0.011 | -0.009 |
| $\omega$ | 0.043 | 0.016 | 0.027 | 0.017 | 0.015 |
| $r^2$ | 10.92 | 25.53 | 19.31 | 24.39 | 50.61 |

ns = not significant at the 5% level

## 5.1.7 *Turbidity*

Turbidity is a measure of the scattering or absorption of light by a fluid (APHA 1980). Highly turbid waters appear "cloudy", while waters of low turbidity are "clear". Clays and suspended silts are the primary cause of turbidity of surface waters, although other factors, such as organic matter, plankton and bacteria may contribute. From a human perspective, turbidity is primarily of aesthetic concern, since very cloudy waters may not be appealing for either drinking or recreational contact. Turbidity can, however, interfere with disinfection of water for consumption, so is of some concern for municipal treatment facilities. Biological effects are related to the decreased penetration of light with increasing turbidity. Photosynthetic activity and feeding of visual-feeding fish may be affected by turbid waters (MacDonald *et al.* 1991). The ease of measurement and the close relationship between turbidity and suspended solids concentration makes turbidity a common parameter in water quality monitoring.

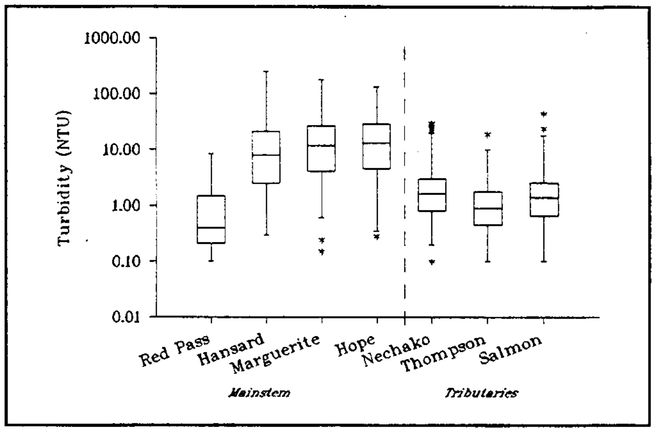


Figure 5.1.24 Summary of EC turbidity data for monitoring sites on the mainstem Fraser and major tributaries for the period 1985 to 1991. Note that the y-axis is represented as $Log_{10}$(turbidity).

Turbidity is affected by two key factors: river discharge, which will resuspend bed sediments, and general surficial geology. Erosion of stream beds and banks, particularly during high-flow periods, and glacial scouring are key natural sources in the Fraser River. Activities which destabilize stream-side sediments and enhance runoff will cause increases in turbidity. Road construction, timber harvesting and runoff from some agricultural settings are few such activities (Binkely and Brown 1993).

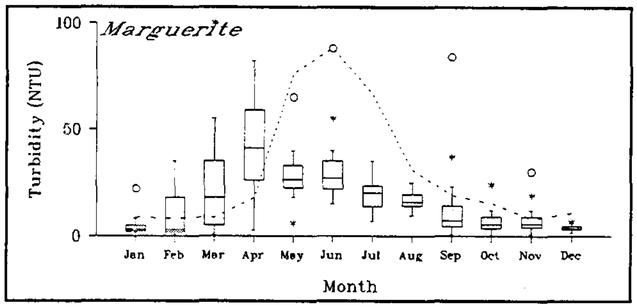


Figure 5.1.25 Annual summary of EC turbidity data from the Fraser River at Marguerite, 1985-1991. The dashed line shows the mean monthly flow at the site for the same period.

At the mainstem Fraser River monitoring sites, the lowest turbidity is in the headwaters at Red Pass (Figure 5.1.24). The Red Pass site is situated at the outlet of a large lake (Moose Lake) which functions as a large settling basin for more turbid influent waters entering at the eastern end. As such, data from this location probably under-represent the true turbidity of the upper Fraser, upstream of the lake. Turbidity increases from Red Pass to Hansard, and is similar at the remainder of the mainstem sites. Tributary stations in the Nechako, Thompson and Salmon Rivers have similar distributions of medians and ranges of turbidity values. Median values at these sites are well below that of the mainstem Fraser, but show occasional excursions to very high levels (e.g.: Figure 5.1.24).

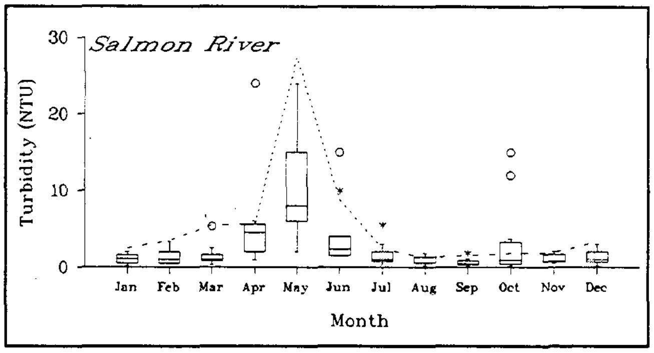


Figure 5.1.26 Monthly summary of EC turbidity data from the Salmon River, 1985-1991. The dashed line shows the mean monthly flow at the site for the same period.

Turbidity is affected by silt and sediment load, and seasonality in the parameter is closely related to discharge. Resuspension and erosion during the extreme freshet flows results in very high spring values. These quickly decline with declining flows through the late summer and winter (Figure 5.1.25). The seasonal pattern in the Salmon River is somewhat more dramatic, owing to the short, intense freshet period in the basin (Figure 5.1.26).

Non-parametric analysis of the data series using Kendall's Tau revealed no significant trends at any of the sites. Regression modelling suggested decreasing (negative $\beta_2$) trends in turbidity at the Hansard and Salmon River stations (Table 5.1.12) The overall fit of the model to the data is relatively poor, as indicated by the relatively low $r^2$ values, the indicated trends may be quite weak. Declining trends in turbidity at both sites are clearly visible in annual summary box plots (Figures 5.1.27,28)

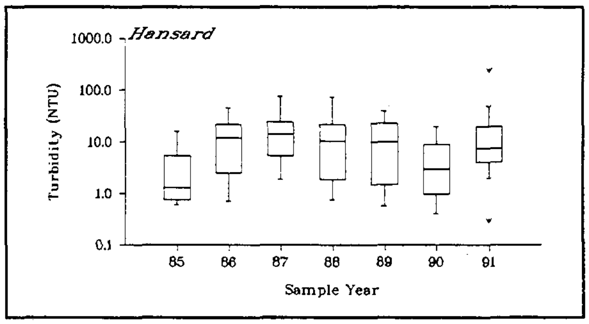


Figure 5.1.27 Annual summary of EC turbidity data in the Fraser River at Hansard. Regression modelling of these data indicates a declining trend in turbidity over this period.

Turbidity is a highly variable measure,

being affected by factors such as discharge, chance events such as log jams, debris flows and time since last runoff event (MacDonald *et al.* 1991). While there is a general increase in turbidity with increasing discharge, the relationship does not lend itself to simple modelling (Figure 5.1.29). Whitfield and Schreier (1981) and Whitfield and Clark (1992) have shown that hysteresis is common in many frequently measured water quality variables. These characteristics produce unpredictability in temporal patterns of turbidity and account for the poor fit of the regression model to the data series.

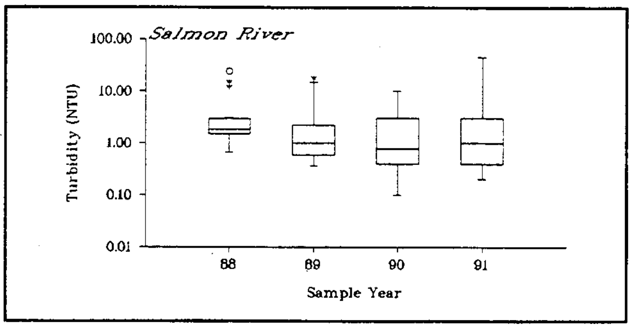


Figure 5.1.28 Annual summary of EC turbidity data from the Salmon River. Regression modelling from these data suggest a declining trend at this site.

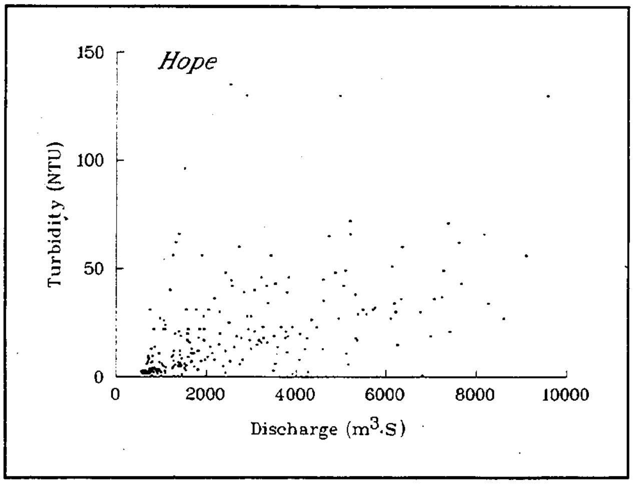


Figure 5.1.29. Turbidity and flow scatter from EC data at Hope, 1985-1991.

**Table 5.1.12** *Model parameter estimates for EC turbidity data from sites in the Fraser River Basin, 1985-1991*

| Parameters | Sampling Stations | | | | |
|---|---|---|---|---|---|
| | **Hansard** | **Marguerite** | **Hope** | **Nechako River** | **Salmon River** |
| $\beta_0$ | 12.89 | 16.84 | 7.79 | 2.95 | 1.32 |
| $\beta_1$ | 0.01 | ns | 0.004 | ns | 0.54 |
| $\beta_2$ | -1.41 | ns | ns | ns | -0.57 |
| $\alpha_1$ | -9.35 | -12.36 | -5.84 | -1.69 | -0.75 |
| $\alpha_2$ | 2.06 | 7.50 | 4.63 | 0.35 | -0.26 |
| $\omega$ | 0.016 | 0.019 | 0.019 | 0.020 | 0.042 |
| $r^2$ | 53.67 | 47.07 | 52.55 | 45.53 | 81.86 |

ns = not significant at the 5% level

### 5.1.8 *Residue Variables*

The somewhat unspecific term "residue" refers to any solid matter either dissolved or suspended in water (APHA 1980). Included are such components as dissolved ions, organic matter, suspended sediments and organic debris. In water quality monitoring, water-borne residues are divided into four operational categories:

*Non-Filterable Residue* (NFR) : the component of a water sample retained by a 0.45μm filter after drying.

*Filterable Residue* (FR) : the component passing through a 0.45μm filter and evaporated to dryness.

*Fixed Non-Filterable Residue* (FNFR): that portion of the NFR remaining after combustion at 550°C

*Fixed Filterable Residue* (FFR): that portion of the FR remaining after combustion at 550°C

The sum of the NFR and FR should be an estimate of the total solids content of the water. Ashing at 550°C will drive off much, if not all, of the organic fraction so that which remains as the "fixed" residue will represent the total inorganic portion. Non-filterable residue will be related closely to other water quality parameters such as turbidity and suspended sediment measurements, since all are affected by the same components and factors. Filterable residue will likewise be correlated with both conductivity and total ion content.

Residue in surface waters will be affected by natural factors such as water flow, geology and general topography. The dominant factor determining residue, both NFR and FR, is discharge. High flows, such as freshet, will produce high NFR through increased bank and bed-sediment erosion. Low flows, as during typical winter conditions, will result in elevated FR due to the increased contribution of groundwater to instream flows. Forested areas will tend to have a higher organic residue component than, for example, open desert areas.

Effluent discharges may, depending on the type of discharge, have significant effects on both filterable and non-filterable residues. Sewage treatment plants, pulp mills and saw mills will all contribute NFR with a high organic proportion. Effluent discharges containing high concentrations of dissolved ions, such as those of many pulp mills, will likewise increase the inorganic FR (FFR).

In the mainstem Fraser River, the lowest concentrations of both NFR and FNFR are found at Red Pass, where most available data are at or near the detection limit (Figure 5.1.30). The EC data summary (Figure 5.1.30) shows that concentrations of both parameters increase downstream to Hansard, and decline gradually to the monitoring station at Hope. A similar pattern is evident in the BC MoELP data (Figure 5.1.31). The downstream decrease in concentration is probably attributable to the influence of very low-NFR waters from tributaries, since most observations of NFR and FNFR from both the Nechako and Thompson are near-detection. The number of outliers shown in the plot is a clear indication of the typically high variability of NFR measurements.

In the Fraser River basin, from 85 to 100% of the non-filterable residue measured in the EC monitoring from all sites was present as fixed NFR. Fixed and total NFR are very closely related (Figure 5.1.32), a factor which reflects the relatively low concentration of particulate organic matter in the mainstem and tributaries relative to the suspended sediment load.

Seasonality of both NFR and FNFR is driven by changes in discharge, with extreme values being associated with freshet flows (eg: Figures 5.1.33).

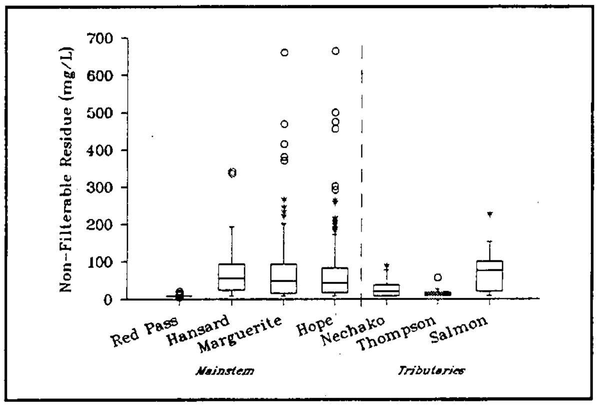



Figure 5.1.30. Summary of EC non-filterable residue data from selected water quality monitoring sites in the Fraser River Basin, 1985-1991

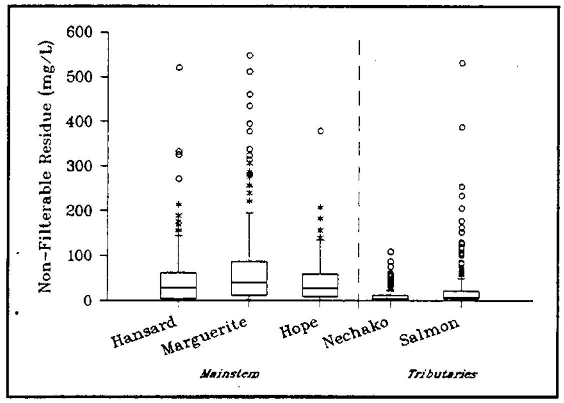



Figure 5.1.31. Summary of BC MoELP non-filterable residue data for selected water quality sites in the Fraser River Basin, 1985-1991

Levels of NFR are lowest in the fall and winter, when in-stream flows are tending to base flow.

Non-parametric analysis of both the available EC and BC MoELP total and fixed NFR data indicated no trends in either fixed or total NFR. Subsequent analyses using the parametric methods suggested some trends. Since a high proportion of the EC NFR data were missing or flagged, the analyses were restricted to data from the Hansard, Marguerite and Hope sites on the Fraser River. The BC MoELP data were more complete, and modelling was completed on all 5 stations. At all sites, there is a clear positive association with flow as indicated by a significant value of $\beta_1$ (Tables 5.1.13-16). Of the data from the three federal data sets, an increasing trend in NFR was indicated only at Hope. The provincial data suggested a linear increase in NFR at both Hansard and Marguerite (Table 5.1.15).

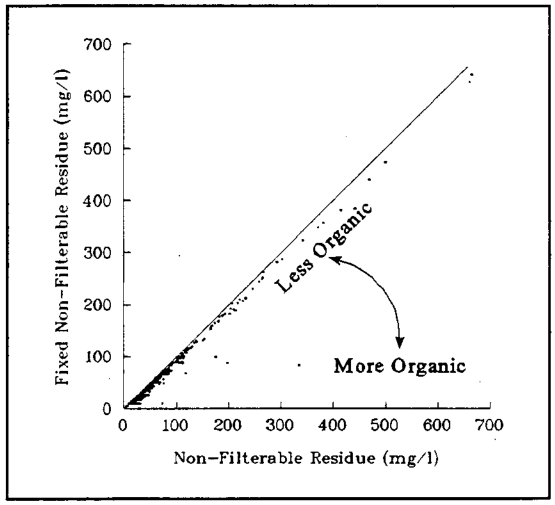



Figure 5.1.32 Relationship of non-filterable residue to fixed non-filterable residue (EC monitoring data for paired analyses).

**Table 5.1.13** *Summary of fitted models for EC non-filterable residue data from sites in the Fraser River Basin, 1985-1991.*

| Parameters | Sampling Stations | | |
|---|---|---|---|
| | Hansard | Marguerite | Hope |
| $\beta_0$ | ns | ns | -6.787 |
| $\beta_1$ | 0.6413 | 0.7423 | 1.299 |
| $\beta_2$ | ns | ns | 0.0722 |
| $\alpha_1$ | ns | -0.369 | 0.337 |
| $\alpha_2$ | ns | 0.573 | 0.551 |

ns = not significant at the 5% level

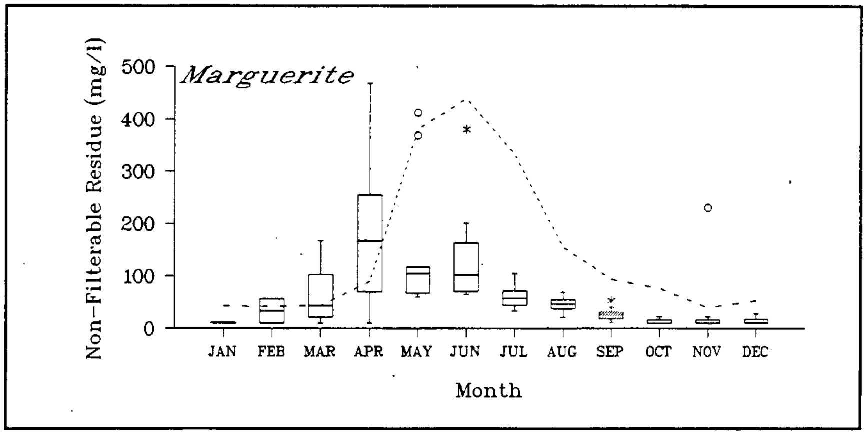



Figure 5.1.33 Annual pattern of non-filterable residue observations on the Fraser River at Marguerite from EC data for 1985-1991. The overlain line indicates the mean monthly flow at the site for the same period.

**Table 5.1.14** *Summary of fitted models for EC fixed non-filterable residue data from sites in the Fraser River Basin, 1985-1991.*

| Parameters | Sampling Stations | | |
|---|---|---|---|
| | Hansard | Marguerite | Hope |
| $\beta_0$ | ns | ns | -8.14 |
| $\beta_1$ | 0.6959 | 0.9211 | 1.4262 |
| $\beta_2$ | ns | ns | ns |
| $\alpha_1$ | ns | -0.266 | 0.631 |
| $\alpha_2$ | ns | 0.746 | 0.0671 |

ns = not significant at the 5% level

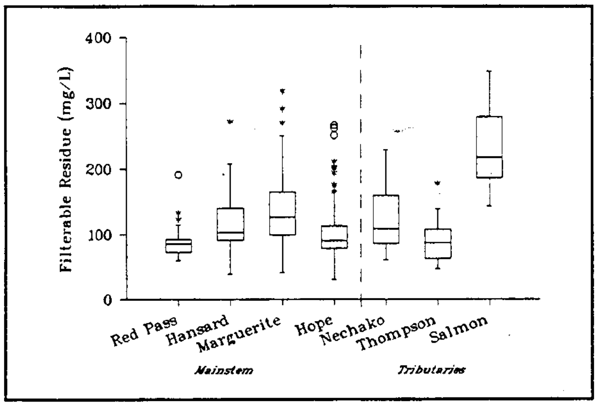



Figure 5.1.34. Summary of EC filterable residue data from selected water quality monitoring sites in the Fraser River Basin, 1985-1991

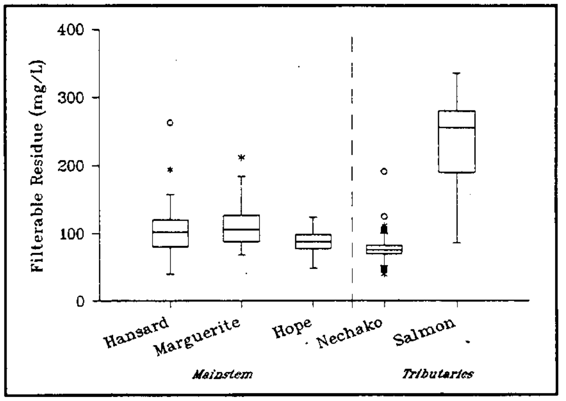



Figure 5.1.35. Summary of BC MoELP filterable residue data for selected water quality monitoring sites in the Fraser River Basin, 1985-1991

Filterable residue data are relatively more complete in the BC MoELP data when compared to the EC data set and as a result will form the principal basis for discussion. Summary plots of both the EC and BC MoELP data show similar spatial patterns (Figures 5.1.34,35). Both show a common longitudinal trend in concentrations in the mainstem, from low values in the headwaters, increasing to Marguerite, and lower at Hope due to the influence of the Thompson River water. Filterable residues in the Nechako are low. In the Salmon FRs are relatively higher due to a combination of groundwater influences, low flow and agricultural activities. Filterable residue tends to be a somewhat less erratic measure than NFR, since the dissolved components of the water column tend to be more homogeneous and therefore less subject to the vagaries of sampling (such as chance capture of a large suspended particle). As a result, the summary plots show fewer excursions (Figures 5.1.34,35).

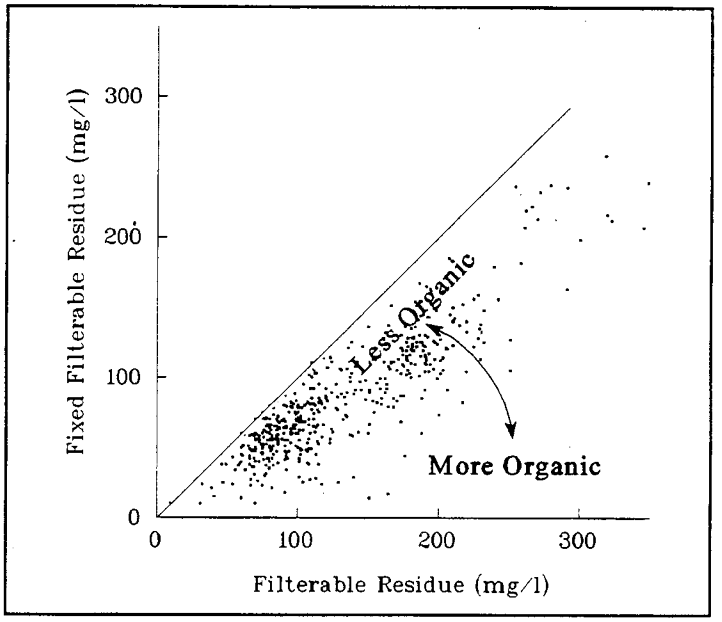


Figure 5.1.36 Relationship of filterable to fixed filterable residue (EC monitoring data from paired analyses).

The proportion of filterable residue present as fixed (that is, mostly inorganic) is much more variable than in the case of NFR (Figure 5.1.36) The fixed fraction ranged from 8 to 100% of the filterable residue (EC data, all sites). In general, as the total filterable residue increases the fixed proportion tends to increase.

Regression analyses of the BC MoELP filterable residue data indicated linear increases in at all sites except the Nechako River (Table 5.1.16). The $r^2$ values in Table 5.1.16 suggest the fit of the models to the data series are generally very good.

**Table 5.1.15** *Summary of fitted models for BC MoELP non-filterable residue data from sites in the Fraser River Basin, 1985-1991.*

| Parameter | Sampling Stations | | | | |
|---|---|---|---|---|---|
| | Hansard | Marguerite | Hope | Nechako River | Salmon River |
| $\beta_o$ | -4.52 | ns | -10.22 | ns | 1.39 |
| $\beta_1$ | 1.21 | 0.912 | 1.74 | 0.723 | 0.680 |
| $\beta_2$ | 0.141 | 0.477 | ns | ns | ns |
| $\alpha_1$ | -0.518 | -0.345 | 0.051 | -0.36 | -0.58 |
| $\alpha_2$ | -0.286 | 0.477 | 0.46 | 1.077 | 0.33 |
| $\varpi$ | 0.017 | 0.017 | 0.020 | 0.097 | 0.021 |
| $r^2$ | -- | -- | 78.19 | -- | 70.68 |

ns = not significant at the 5% level

**Table 5.1.16** *Summary of fitted models for BC MoELP filterable residue data from sites in the Fraser River Basin, 1985-1991.*

| Parameters | Sampling Stations | | | | |
|---|---|---|---|---|---|
| | Hansard | Marguerite | Hope | Nechako River | Salmon River |
| $\beta_0$ | 5.10 | 5.70 | 4.90 | 4.90 | 5.51 |
| $\beta_1$ | -0.110 | -0.164 | ns | -0.124 | -0.286 |
| $\beta_2$ | 0.023 | 0.028 | 0.035 | ns | 0.080 |
| $\alpha_1$ | 0.030 | 0.063 | 0.086 | ns | -0.040 |
| $\alpha_2$ | 0.160 | 0.130 | 0.099 | ns | -0.029 |
| $\omega$ | 0.021 | 0.018 | 0.018 | 0.021 | 0.052 |
| $r^2$ | 90.67 | 81.55 | 69.93 | 43.89 | 87.42 |

ns = not significant at the 5% level

## 5.1.9 *Alkalinity*

Alkalinity refers to the buffering capacity of a water body (APHA 1980), and is related to concentrations of carbonates, bicarbonates and hydroxide ions in solution. Alkalinity (like acidity) is a measure of the potential of the water for interaction with other water-borne or contact material (Hem 1985). Several ionic speciès contribute to alkalinity, and since each of these is not explicitly identified in the analyses, the measurement is typically expressed in terms of $CaCO_3$ equivalents. The buffering action and ionic species involved are dependent on pH, temperature and ionic source strengths, largely through carbonate-bicarbonate equilibria (Hem 1985, Wetzel 1983).

Alkalinity will be affected by any of the factors which will determine dissolved ion load, with bedrock geology and discharge being particularly important. Limestones produce waters of high alkalinity, since the source rock is rich in carbonate. Uptake and dissolution of carbon dioxide, both from the atmosphere and through metabolic or photosynthetic activity will also influence the alkalinity. Measurement of alkalinity has been important in evaluating the susceptibility of surface waters to alterations in pH, as for example, from acid deposition or effluent discharges (Chapman and Kimstach 1992).

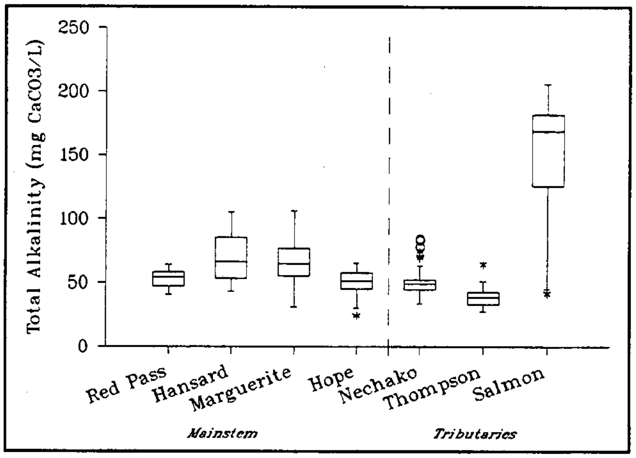



Figure 5.1.37 Summary of EC total alkalinity data for water quality monitoring sites in the Fraser River Basin, 1985-1991.

Detrimental effects of highly alkaline waters are due to the high dissolved ion content. When used in irrigation, highly alkaline waters may produce undesirable salinization of soils (CCREM 1987). Scale formation is a particular problem in industrial uses (McNeeley *et al.* 1979). In the BC-Yukon area, analysis of 1500 samples collected from 1980 to 1985 showed a range of values from 0.5 to 162 mg $CaCO_3 \cdot L^{-1}$ (CCREM 1987). Since alkalinity is in itself of little toxicological concern, there are presently no designated British Columbia or Federal criteria or guidelines for protection of aquatic life. BC has established criteria for the sensitivity of waters to acid inputs, with waters of alkalinity greater than 20 mg $CaCO_3 \cdot L^{-1}$ being considered to be of "low" sensitivity (Nagpal *et al.* 1995).

Total alkalinity increases from the headwaters near Red Pass to Hansard, and declines downstream to Marguerite (Figure 5.1.37). Levels in the Nechako River are somewhat higher than the

Thompson, but both are far less than measurements from the Salmon River. The large groundwater contribution to the river results in high concentrations of most dissolved ions, resulting in a median alkalinity at the Salmon River site of more than 160 mg $CaCO_3 \cdot L^{-1}$, and occasional excursions in excess of 200 mg $CaCO_3 \cdot l^{-1}$.

Alkalinity is affected strongly by discharge through simple dilution of the active ionic species. The seasonal pattern shows an inverse relationship with flow, with very low values during freshet and high values during the winter low-flow period when groundwater contribution to instream flow is highest (Figure 5.1.38).

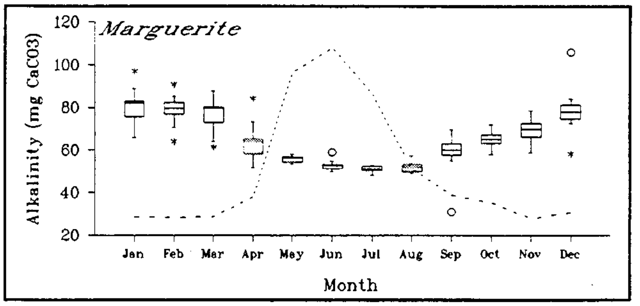


Figure 5.1.38 Monthly summary of EC alkalinity data from the Fraser River at Marguerite, 1985-1991.

Non-parametric trend analysis of the Environment Canada data sets indicated a monotonic increase at the Red Pass site (Table 5.1.17). Further study of these data using regression modelling suggested U - shaped trends at Hansard, Nechako River and Thompson River, a linear increase in alkalinity in the Salmon, but interestingly, no trend at the Red Pass site (Table 5.1.18). With the exception of Red Pass, there was a clear negative association between alkalinity and flow ($\beta_1$ significant and negative).

**Table 5.1.17** *Summary of non-parametric tests for EC total alkalinity data for selected monitoring sites in the Fraser River Basin, 1985-91.*

| Test | Red Pass | Hansard | Marguerite | Hope | Nechako River | Thompson River | Salmon River |
|---|---|---|---|---|---|---|---|
| Seasonal Kendall's Tau Statistic | 2.17 | ns | ns | ns | ns | ns | ns |
| Modified Seasonal Kendall's Tau | ns | ns | ns | ns | ns | ns | ns |
| Van Belle Stat. For Homogeneity | ns | ns | ns | ns | ns | ns | ns |
| Van Belle Stat. For Trend | 5.16 | ns | ns | ns | ns | ns | ns |
| Sen's Slope | 0.32 | ns | ns | ns | ns | ns | ns |

ns = not significant at the 5% level

**Table 5.1.18** *Model parameter estimates for EC total alkalinity data from sites in the Fraser River Basin, 1985-1991*

| Parameters | Sampling Stations | | | | | | |
|---|---|---|---|---|---|---|---|
| | Red Pass | Hansard | Marguerite | Hope | Nechako River | Thompson River | Salmon River |
| $\beta_0$ | 3.97 | 5.04 | 4.99 | 4.8 | 5.51 | 4.28 | 5.04 |
| $\beta_1$ | ns | -0.131 | -0.12 | -0.114 | -0.27 | -0.091 | -0.41 |
| $\beta_2$ | ns | -0.095 | ns | ns | -0.15 | -0.121 | 0.12 |
| $\beta_3$ | - | 0.017 | - | - | 0.021 | 0.022 | - |
| $\alpha_1$ | 0.0159 | 0.116 | 0.108 | 0.031 | -0.059 | -0.011 | -0.083 |
| $\alpha_2$ | 0.134 | 0.137 | 0.039 | 0.074 | 0.064 | 0.114 | 0.051 |
| $\bar{\omega}$ | 0.019 | 0.019 | 0.017 | 0.019 | 0.017 | 0.02 | 0.048 |
| $r^2$ | 87.07 | 93.39 | 90.15 | 68.03 | 71.54 | 87.49 | 89.99 |

ns = not significant at the 5% level

## 5.2 Dissolved Ions

The concentration and proportional representation of ions in surface water is determined to a large extent by the underlying bedrock composition. Water from basins rich in carbonates, such as the Fraser River headwaters, tend to be well-buffered and hard, rich in calcium and magnesium ions. Bedrock of volcanic basalts produce sulphate-rich, low-pH waters which are relatively poorly buffered (Wetzel 1983). The total dissolved solid load of a river will depend on the relative contribution of solute-rich groundwaters and precipitation, either as direct rain or snow fall or runoff. Seasonal changes in precipitation, with consequent changes in dilution, drive the characteristic temporal pattern of dissolved ion concentrations.

The composition and load of dissolved ions in surface waters may be altered by both direct discharges and some landscape-level changes. In the Fraser Basin, sewage treatment plants and pulp mills contribute a range of high-ion effluents to the mainstem Fraser River. Agricultural sources, particularly return flows of ion-rich water from irrigation, can contribute significantly to ion loads of surface waters.

Most aquatic organisms are tolerant to relatively high levels of particular dissolved ions, and detrimental effects would be a result of general osmotic stress rather than a direct toxic response. Toxicity of many dissolved metals is related to water hardness, so changes in total solutes levels (particularly magnesium and calcium) will result in indirect effects when high metal levels are also present. Agricultural water uses, such as livestock watering and crop irrigation may be compromised by high ion concentrations and for these water-uses the CCME have developed safe guideline levels. For irrigation, the maximal dissolved solids concentration for safe use is 500-3500 $mg \cdot l^{-1}$. For livestock watering, a maximum level of 3000 $mg \cdot l^{-1}$ is permissible.

### 5.2.1 *Calcium*

Calcium is the predominant cation of surface waters (Wetzel 1983). The primary source of water-borne calcium is from weathering of carbonate bedrocks, particularly limestones. High calcium concentrations, particularly in conjunction with dissolved magnesium, is the primary cause of water hardness (McNeely *et al.* 1979). Calcium is essential for biota, being intimately involved in many physiological processes and a primary component of skeletal structures. Aquatic organisms are highly tolerant of dissolved calcium, and no guidelines for protection of aquatic life have been established.

Anthropogenic sources of dissolved calcium are related to weathering of concrete, production of cement and concrete from limestones, and from the use of calcium salts on road surfaces. Calcium oxide used in pulp and paper production forms one component of the effluent discharge.

Passage of the upper Fraser through the massive limestones of the Rocky Mountain trench produces the elevated calcium levels observed at Hansard (Figure 5.2.1). Subsequent dilution by relatively low-calcium tributaries, such as waters of the Nechako and Thompson Rivers, produces a decline in concentration downstream of Hansard. The highest dissolved calcium

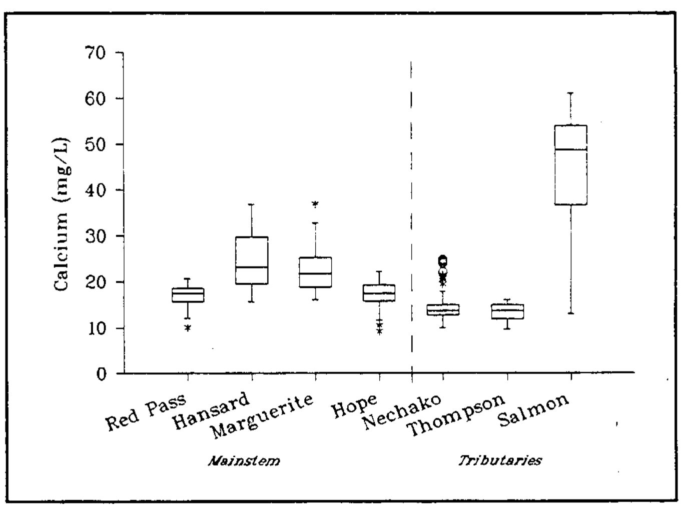


Figure 5.2.1 Summary of EC dissolved calcium data from selected water quality monitoring sites in the Fraser River Basin, 1985-1991.

values are found in the Salmon River, with an overall median concentration of 48.8 $mg \cdot l^{-1}$.

Seasonality of dissolved calcium concentration is strong, with high values occurring in the winter when the groundwater contribution to instream flow is high. Low concentration occurs in the summer when instream flows and loadings are diluted at the onset of freshet and remain low in the mainstem due to summer meltwater flow (Figure 5.2.2).

Analysis of the EC data using Seasonal Kendall's Tau (Table 5.2.1) indicated significant declining trends in calcium concentrations in the Fraser River at the Hansard and Marguerite and in the Nechako and Thompson River stations. Annual summary plots of these data show clear declining trends in most cases (Figure 5.2.3).

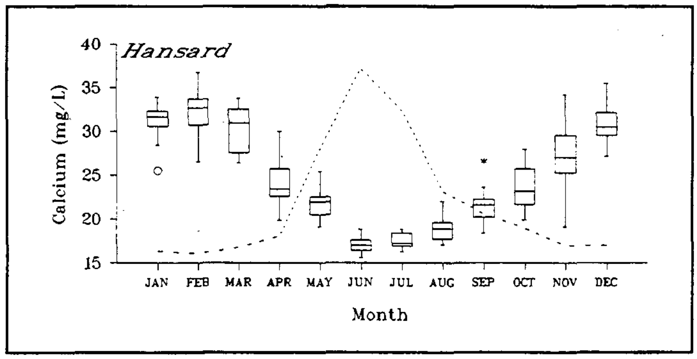



Figure 5.2.2 Seasonal summary of EC dissolved calcium data from the Fraser River at Hansard, 1985-1991. The dashed line indicates the mean monthly flow at the site over the same period.

Parametric analyses of these data indicated declining calcium concentration at the Red Pass and Marguerite sites, an increasing trend in the Salmon River and a U -shaped trend at the Hansard, Nechako River and Thompson stations.

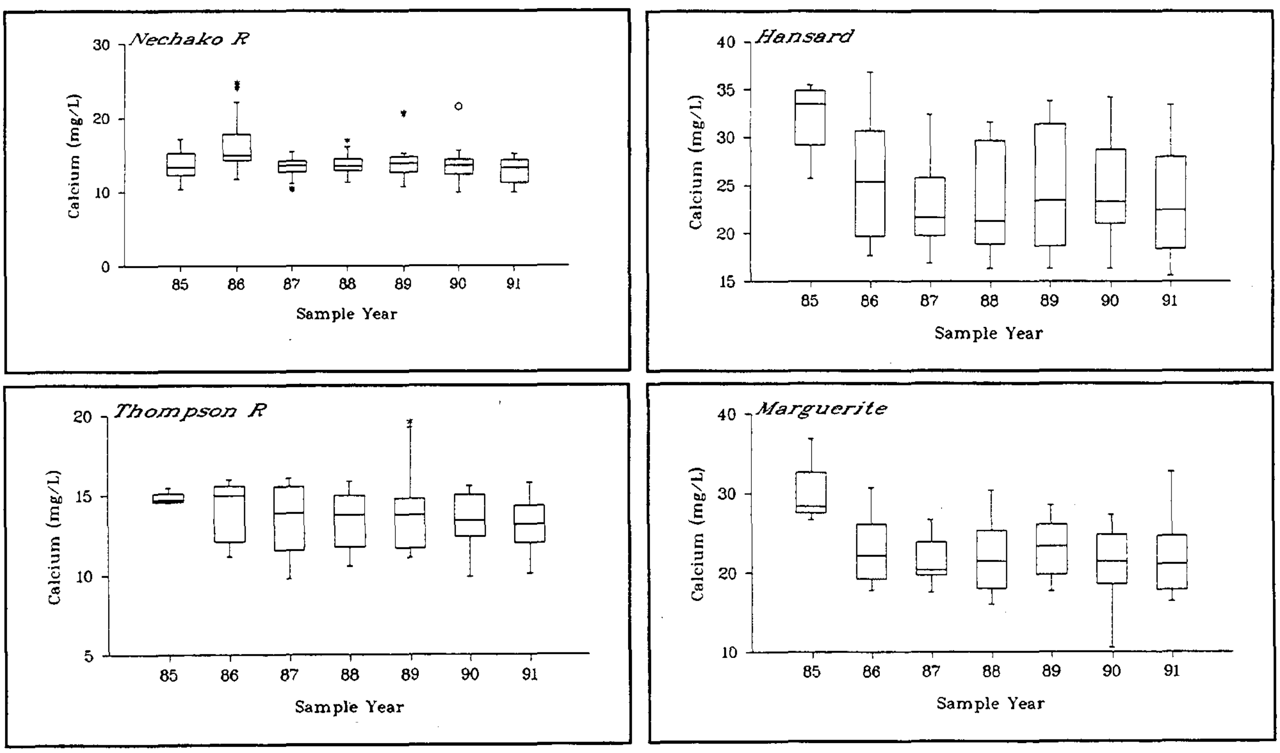



Figure 5.2.3 Annual plots of EC dissolved calcium data from selected sites in the Fraser River Basin for the period 1985-1991. Non-parametric analyses of these time series indicated declining trends in all cases.

Table 5.2.1. Results of non-parametric analyses of Environment Canada dissolved ion data (1985-1991) for monitoring sites in the Fraser River Basin.

| Parameter | Site | Seasonal Kendall's Tau | Modified Seasonal Kendall's Tau | Van Belle Test for Homogeneity | Van Belle Test for Trend | Sen Slope |
|---|---|---|---|---|---|---|
| ***Calcium*** | Red Pass | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Hansard | **-2.10** | - n.s. - | **6.09** | - n.s. - | **-0.36** |
| | Marguerite | **-2.60** | - n.s. - | - n.s. - | **7.67** | - n.s. - |
| | Hope | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Nechako | **-3.56** | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Salmon | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Thompson | **-3.98** | **-1.99** | - n.s. - | **15.22** | **-0.23** |
| | | | | | | |
| ***Magnesium*** | Red Pass | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Hansard | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Marguerite | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Hope | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Nechako | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Salmon | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Thompson | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | | | | | | |
| ***Hardness*** | Red Pass | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Hansard | **-2.28** | - n.s. - | - n.s. - | **6.65** | **-0.96** |
| | Marguerite | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Hope | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Nechako | - n.s. - | - n.s. - | - n.s. - | **3.88** | **-0.61** |
| | Salmon | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Thompson | **-2.65** | - n.s. - | - n.s. - | **6.68** | **-0.48** |
| | | | | | | |
| ***Potassium*** | Red Pass | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Hansard | **3.94** | **6.05** | - n.s. - | **16.00** | **0.30** |
| | Marguerite | **3.14** | - n.s. - | - n.s. - | **9.42** | **0.03** |
| | Hope | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Nechako | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Salmon | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Thompson | **3.38** | **1.98** | - n.s. - | **11.39** | **0.03** |
| | | | | | | |
| ***Sodium*** | Red Pass | **3.43** | - n.s. - | - n.s. - | **12.13** | **0.03** |
| | Hansard | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Marguerite | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Hope | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Nechako | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Salmon | - n.s. - | - n.s. - | **20.84** | - n.s. - | **0.03** |
| | Thompson | **-3.01** | - n.s. - | - n.s. - | **9.05** | **-0.11** |
| | | | | | | |
| ***Chloride*** | Red Pass | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Hansard | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Marguerite | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Hope | **3.32** | - n.s. - | - n.s. - | **13.14** | **0.10** |
| | Nechako | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Salmon | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Thompson | **-3.42** | - n.s. - | - n.s. - | **11.79** | **-0.20** |
| | | | | | | |
| ***Silicate*** | Red Pass | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Hansard | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Marguerite | **-4.27** | **-2.24** | - n.s. - | **18.64** | **-0.15** |
| | Hope | **-4.46** | **-2.12** | - n.s. - | **20.34** | **-0.83** |
| | Nechako | **-3.56** | - n.s. - | - n.s. - | **15.07** | **-0.13** |
| | Salmon | **2.16** | - n.s. - | - n.s. - | **4.24** | **0.80** |
| | Thompson | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | | | | | | |
| ***Sulphate*** | Red Pass | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Hansard | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Marguerite | **2.46** | - n.s. - | - n.s. - | **6.11** | **0.20** |
| | Hope | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Nechako | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Salmon | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | Thompson | - n.s. - | - n.s. - | - n.s. - | - n.s. - | - n.s. - |
| | | | | | | |

Table 5.2.2. *Model parameter estimates for Environment Canada dissolved ion data from sites in the Fraser River Basin, 1985-1991.*

| Parameter | Site | $\beta_0$ | $\beta_1$ | $\beta_2$ | $\beta_3$ | $\alpha_1$ | $\alpha_2$ | $\omega$ | $r^2$ | *Conclusion* |
|---|---|---|---|---|---|---|---|---|---|---|
| ***Calcium*** | **Red Pass** | 2.86 | ns | -0.013 | - | 0.028 | 0.14 | 0.02 | 73.3 | |
| | **Hansard** | 3.895 | -0.106 | -0.104 | 0.017 | 0.126 | 0.116 | 0.019 | 93.2 | U-shaped trend |
| | **Marguerite** | 3.858 | -0.108 | -0.01 | - | 0.1 | 0.003 | 0.016 | 87 | Linear, ***decreasing*** trend |
| | **Hope** | 3.49 | -0.084 | - | - | 0.06 | 0.043 | 0.017 | 62.6 | |
| | **Nechako** | 4.04 | -0.22 | -0.17 | 0.022 | -0.021 | 0.064 | 0.016 | 66.2 | U-shaped trend |
| | **Salmon** | 3.86 | -0.396 | 0.102 | - | 0.031 | -0.045 | 0.017 | 92.2 | Linear ***increasing*** trend |
| | **Thompson** | 3.188 | -0.078 | -0.091 | 0.014 | 0.007 | 0.106 | 0.019 | 88.6 | U-shaped trend |
| ***Magnesium*** | **Red Pass** | 1.77 | -0.039 | ns | - | 0.005 | 0.136 | 0.019 | 75.4 | |
| | **Hansard** | 2.93 | -0.279 | 0.025 | - | 0.037 | 0.046 | 0.042 | 86.6 | Linear ***increasing*** trend |
| | **Marguerite** | 2.95 | -0.23 | 0.017 | - | 0.031 | 0.098 | 0.019 | 92.3 | Linear ***increasing*** trend |
| | **Hope** | 3.054 | -0.236 | -0.013 | - | -0.003 | 0.098 | 0.02 | 69.1 | Linear, ***decreasing*** trend |
| | **Nechako** | 3.33 | -0.36 | -0.096 | 0.015 | -0.11 | 0.084 | 0.018 | 71.3 | U-shaped trend |
| | **Salmon** | 2.68 | -0.45 | 0.104 | - | -0.084 | 0.069 | 0.048 | 90.3 | Linear ***Increasing*** trend |
| | **Thompson** | 1.63 | -0.127 | -0.084 | 0.018 | 0.044 | 0.182 | 0.019 | 87.4 | U-shaped trend |
| ***Hardness (Ca+Mg)*** | **Red Pass** | 4.22 | ns | -0.01 | - | 0.017 | 0.134 | 0.02 | 79.4 | Linear, ***decreasing*** trend |
| | **Hansard** | 5.2 | -0.134 | -0.086 | 0.014 | 0.127 | 0.073 | 0.018 | 88.1 | U-shaped trend |
| | **Marguerite** | 5.5 | -0.134 | ns | - | 0.09 | 0.039 | 0.017 | 91.2 | |
| | **Hope** | 4.97 | -0.121 | ns | - | 0.045 | 0.058 | 0.018 | 73.3 | |
| | **Nechako** | 5.53 | -0.27 | -0.14 | 0.019 | -0.057 | 0.072 | 0.017 | 70.1 | U-shaped trend |
| | **Salmon** | 5.19 | -0.43 | 0.104 | - | -0.076 | 0.04 | 0.048 | 92.5 | Linear ***Increasing*** trend |
| | **Thompson** | 4.41 | -0.09 | -0.091 | 0.015 | 0.014 | 0.122 | 0.019 | 90 | U-shaped trend |

**Table 5.2.2 Continued**

| Parameter | Site | $\beta_0$ | $\beta_1$ | $\beta_2$ | $\beta_3$ | $\alpha_1$ | $\alpha_2$ | $\omega$ | $r^2$ | Conclusion |
|---|---|---|---|---|---|---|---|---|---|---|
| ***Silicate*** | Red Pass | 0.94 | ns | ns | - | 0.061 | 0.153 | 0.018 | 77.3 | |
| | Hansard | 1.88 | -0.111 | ns | - | 0.089 | 0.332 | 0.02 | 92 | |
| | Marguerite | 2.07 | -0.075 | -0.022 | - | 0.137 | 0.293 | 0.018 | 86.5 | Linear, ***decreasing*** trend |
| | Hope | 1.84 | ns | -0.014 | - | 0.097 | 0.24 | 0.018 | 85.9 | Linear, ***decreasing*** trend |
| | Nechako | 2.61 | -0.135 | -0.142 | 0.017 | -0.007 | 0.18 | 0.018 | 80.1 | U-shaped trend |
| | Salmon | 2.79 | -0.096 | 0.24 | -0.05 | 0.037 | 0.049 | 0.042 | 78.8 | ∩-shaped |
| | Thompson | 0.87 | 0.122 | ns | - | 0.15 | 0.201 | 0.018 | 82 | |
| ***Potassium*** | Red Pass | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | |
| | Hansard | -0.831 | ns | 0.058 | - | -0.085 | 0.106 | 0.031 | 36.7 | Increasing ***linear*** trend |
| | Marguerite | 0.135 | -0.115 | 0.038 | - | -0.023 | 0.195 | 0.02 | 50.2 | Increasing ***linear*** trend |
| | Hope | 0.415 | -0.106 | ns | - | -0.014 | 0.13 | 0.02 | 49.9 | |
| | Nechako | 1.98 | -0.42 | -0.18 | 0.032 | -0.33 | 0.051 | 0.021 | 70 | U-shaped trend |
| | Salmon | 1.08 | -0.26 | 0.106 | - | -0.009 | -0.063 | 0.019 | 78.9 | Increasing ***linear*** trend |
| | Thompson | -0.067 | ns | 0.035 | - | 0.011 | 0.104 | 0.022 | 60.5 | Increasing ***linear*** trend |
| ***Sodium*** | Red Pass | -0.18 | ns | ns | - | -0.075 | 0.213 | 0.021 | 62 | |
| | Hansard | 1.51 | -0.278 | 0.027 | - | 0.116 | 0.243 | 0.02 | 90.7 | Increasing ***linear*** trend |
| | Marguerite | 5.87 | -0.68 | 0.018 | - | 0.087 | 0.091 | 0.015 | 96 | Increasing ***linear*** trend |
| | Hope | 4.48 | -0.463 | 0.011 | - | -0.001 | 0.162 | 0.019 | 91.8 | Increasing ***linear*** trend |
| | Nechako | 2.41 | -0.27 | -0.12 | 0.02 | -0.128 | 0.05 | 0.02 | 81 | U-shaped trend |
| | Thompson | 2.53 | -0.238 | ns | - | -0.002 | 0.306 | 0.02 | 89.6 | |
| | Salmon | 2.39 | -0.35 | 0.141 | - | -0.076 | 0.073 | 0.047 | 88.4 | Increasing ***linear*** trend |

Table 5.2.2 Continued

| Parameter | Site | $\beta_0$ | $\beta_1$ | $\beta_2$ | $\beta_3$ | $\alpha_1$ | $\alpha_2$ | $\omega$ | $r^2$ | Conclusion |
|---|---|---|---|---|---|---|---|---|---|---|
| ***Chloride*** | Red Pass | -0.889 | ns | ns | - | 0.041 | 0.27 | 0.018 | 40.3 | |
| | Hansard | -0.33 | ns | -0.3 | 0.048 | 0.157 | 0.549 | 0.02 | 73.7 | U-shaped trend |
| | Marguerite | 6.8 | -0.807 | ns | - | 0.137 | 0.105 | 0.015 | 93.1 | |
| | Hope | 4.51 | -0.53 | 0.047 | - | 0.033 | 0.211 | 0.02 | 87.5 | Increasing ***linear*** trend |
| | Nechako | 3.065 | -0.56 | -0.62 | 0.101 | -0.322 | -0.373 | 0.017 | 62.6 | U-shaped trend |
| | Salmon | 0.87 | -0.36 | 0.18 | - | 0.11 | 0.019 | 0.019 | 85.4 | Increasing ***linear*** trend |
| | Thompson | 2.81 | -0.352 | 0.245 | -0.05 | 0.018 | 0.415 | 0.02 | 89.6 | ∩-shaped trend |
| ***Sulphate*** | Red Pass | 2.86 | -0.12 | ns | - | 0.067 | 0.034 | 0.048 | 72.2 | |
| | Hansard | 3.64 | -0.226 | ns | - | 0.1 | -0.097 | 0.022 | 76.9 | |
| | Marguerite | 4.19 | -0.321 | 0.041 | - | 0.054 | -0.039 | 0.024 | 85.5 | Increasing ***linear*** trend |
| | Hope | 4.84 | -0.372 | 0.009 | - | 0.037 | -0.052 | 0.023 | 88.5 | Increasing ***linear*** trend |
| | Nechako | 2.98 | -0.244 | -0.26 | 0.05 | 0.007 | 0.056 | 0.015 | 65.9 | U-shaped trend |
| | Salmon | 3.84 | -0.523 | 0.058 | - | -0.078 | 0.036 | 0.049 | 90.9 | Increasing ***linear*** trend |
| | Thompson | 3.27 | -0.188 | ns | - | 0.026 | 0.119 | 0.02 | 90.5 | |

**Table 5.2.3**. *Model parameter estimates for BC MoELP dissolved ion data from sites in the Fraser River Basin, 1985-1991.*

| Parameter | Site | $\beta_0$ | $\beta_1$ | $\beta_2$ | $\beta_3$ | $\alpha_1$ | $\alpha_2$ | $\omega$ | $r^2$ | Conclusion |
|---|---|---|---|---|---|---|---|---|---|---|
| ***Calcium*** | Hansard | 3.68 | -0.096 | ns | - | 0.065 | 0.114 | 0.021 | 86.2 | |
| | Hope | 3.096 | ns | ns | - | 0.096 | -0.025 | 0.014 | 58.3 | |
| | Nechako | 3.036 | -0.106 | 0.063 | - | 0.009 | 0.073 | 0.046 | 68.8 | increasing linear trend |
| ***Magnesium*** | Hansard | 1.94 | ns | ns | - | 0.143 | 0.067 | 0.016 | 61.1 | |
| | Marguerite | 1.92 | ns | ns | - | 0.007 | 0.243 | 0.019 | 62.4 | |
| | Hope | 1.84 | ns | ns | - | 0.111 | 0.096 | 0.015 | 46.1 | |
| | Nechako | 2.36 | -0.213 | 0.070 | - | -0.075 | 0.078 | 0.019 | 83.5 | increasing linear trend |

BC MoELP also measures calcium in their monitoring program, but the extent and number of observations were sufficient for regression analysis only at Hansard, Hope and the Nechako River (Table 5.2.3). A significant increasing trend was indicated in the Nechako River. Spatial and seasonal patterns were identical to those found in the EC data.

### *5.2.2 Magnesium*

Dissolved magnesium is a common component of surface waters. Although magnesium is used in a number of industrial and agricultural applications, the loading from anthropogenic sources is thought to be insignificant compared to natural contributions (CCME 1987). Magnesium is an essential element for organisms, and is one of the principal cations of soft tissues. High concentrations pose no harm to aquatic organisms, apart from possible osmotic stress at very high levels. As such there are no existing guidelines for protection of aquatic life.

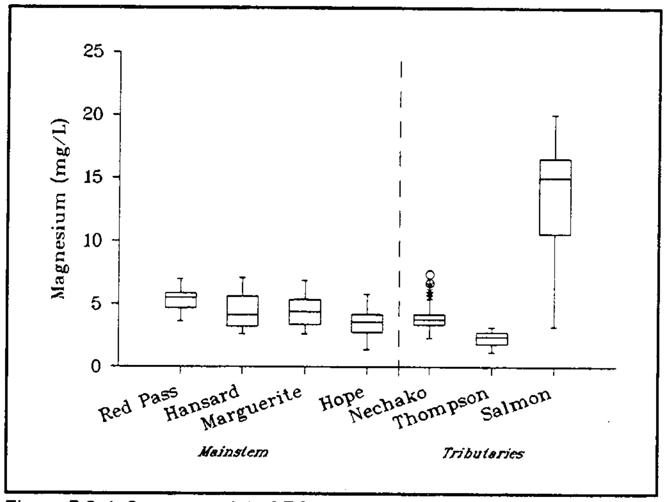



Figure 5.2.4. Summary plot of EC dissolved magnesium data from selected water quality monitoring sites in the Fraser River Basin, 1985-1991.

In the mainstem Fraser River, the highest overall magnesium concentrations are found in the upper basin at Red Pass (Figure 5.2.4). Concentration declines with distance downstream, from a median value at Red Pass of 5.5 mg·L$^{-1}$ to 3.6 mg·L$^{-1}$ at Hope. Levels in the Nechako and Thompson rivers are low, and the concentrations at all sites are dwarfed by the high magnesium levels in the Salmon River.

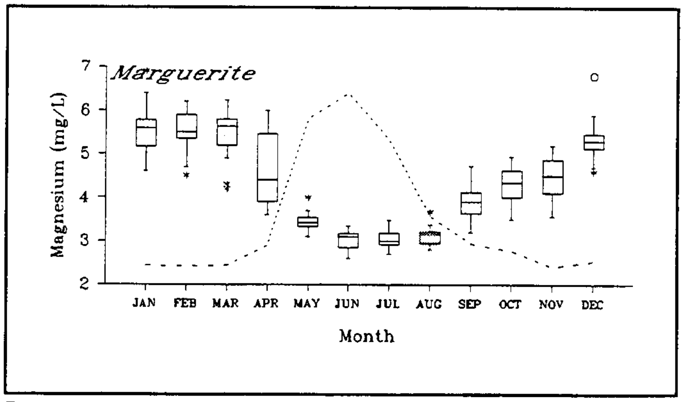


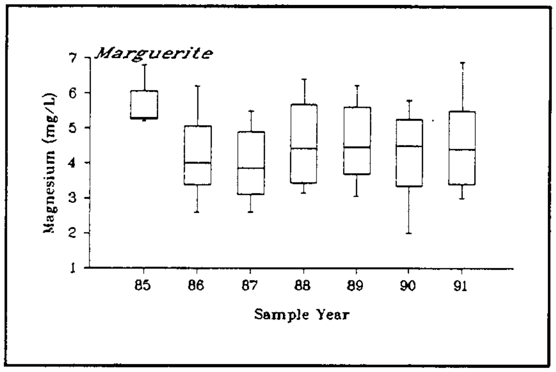

Figure 5.2.5. Seasonal pattern of dissolved magnesium in the Fraser River at Marguerite from EC data, 1985-1991. The dashed line indicates the mean monthly flow at the site over the same time period.

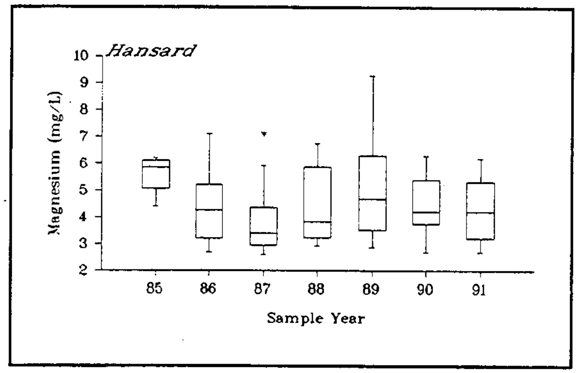
As with other dissolved ion parameters, strong flow-mediated seasonality is evident. Dilution of groundwater flows during freshet, and subsequent summer melt of alpine ice produces low concentrations in early summer to fall (Figure 5.2.5).

Non-parametric analyses of the Environment Canada time series data indicate no increasing or decreasing trends in concentration at any site (Table 5.2.1).

Further analysis of the data using the modelling approach suggested some trends not apparent in the non-parametric results (Table 5.2.2). Significant increasing linear trends were detected for Hansard, Marguerite and Salmon River and a linear decreasing trend is indicated for data from the Hope site. In the Thompson and Nechako Rivers, U-shaped trends are indicated. The negative association of magnesium concentration with flow is confirmed in the model parameter estimation since all the values of $\beta_1$ in Table 5.2. 2 are significant.

Although increasing trends are evident in the data, ambient magnesium concentrations remain well below levels which could affect either organisms or possible water uses.



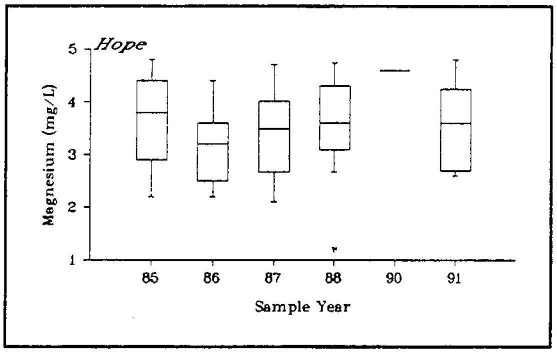




Figure 5.2.6. Annual summary plots of dissolved magnesium data for selected sites in the Fraser River Basin from EC monitoring data, 1985-1991. Parametric analysis of data from each of these sites indicated linear trends - declining at Hope, and increasing at Hansard and Marguerite.

### 5.2.3 *Hardness (Calcium + Magnesium)*

Hardness is an indication of the utility of water for domestic uses. Simply stated, hard water will not produce a lather from soap. Water hardness is related to the summed concentration of magnesium and calcium ions, and is expressed as a total calcium carbonate equivalent (McNeeley *et al.* 1979). In itself, hardness has little effect on aquatic life but is an important mediator of the toxicity of other chemicals in water, particularly dissolved metals (Chapman and Kimstach 1992). Water hardness has consequences for consumptive water use by humans. Very hard water will produce scaling in boilers and kettles, and will result in increased use of soaps for cleaning. Water is considered "hard" when the $CaCO_3$ equivalent concentration exceeds 120 mg·l$^{-1}$ (McNeeley *et al.* 1979).

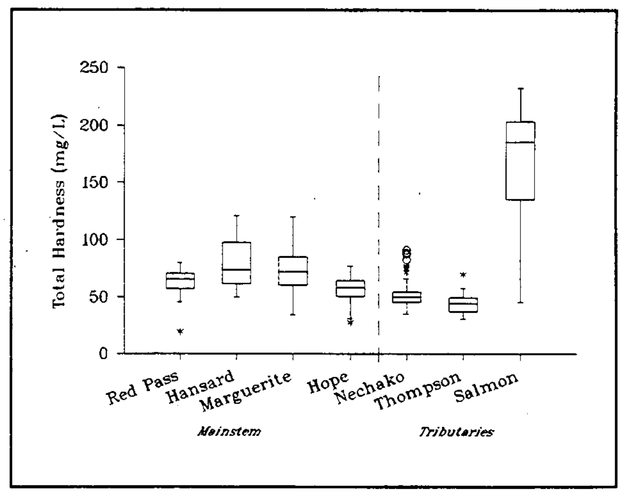



Figure 5.2.7. Summary of EC water hardness data from selected monitoring sites in the Fraser River Basin, 1985-1991.

Since hardness is determined by both calcium and magnesium concentrations, it is not surprising that the spatial pattern of the parameter mirrors that of the constituent ions. In the mainstem, the highest measured hardness is at the Hansard site, and declines downstream to Hope (Figure 5.2.7). Consistent with the high dissolved ion levels in the Salmon River, this site has the hardest water of all sites. The median hardness at this site, at 185.7 mg·l$^{-1}$, is in the "very hard" category.

Analysis of the EC data by Seasonal Kendall's Tau shows decreasing trends in water hardness at both the Hansard and Thompson River sampling stations (Table 5.2.1). Regression modelling of the data set suggested other patterns. As shown in Table 5.2.2, a significant decreasing trend ($\beta_2$<0) in hardness is suggested in the Fraser River at Red Pass station and an increasing trend at the Salmon River station. The results of the model fitting further indicate a U-shape trend at the Hansard, Nechako River and Thompson River stations.

### 5.2.4 *Silicate*

Silicon is second only to oxygen as the most abundant element in the earth's crust (Hem 1985). The dissolved silica in natural waters is derived from weathering of bedrock, and as with other dissolved ion parameters is highest in groundwaters. Silica is very important for planktonic diatom algae, which have an absolute requirement for production of frustules. In some circumstances, concentrations of dissolved silica can be a determining factor in algal production (Wetzel 1983). High concentrations of dissolved silica are, apart from certain industrial water uses, of little consequence. As such there are no existing criteria or guidelines.

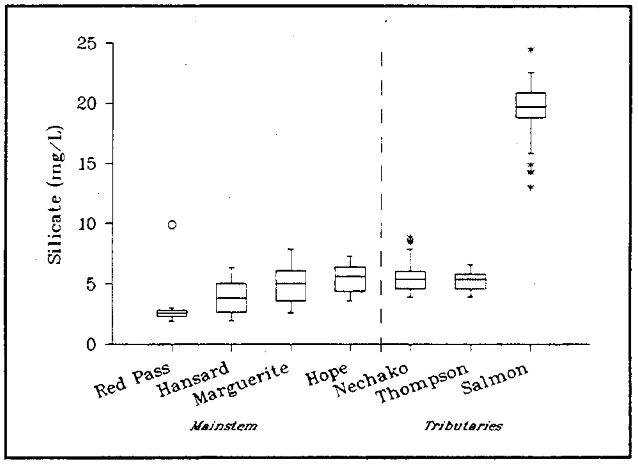



Figure 5.2.8. Summary of EC dissolved silicate data for selected sites in the Fraser River Basin, 1985-1991.

In the mainstem Fraser River, the overall concentration of dissolved silica increases downstream from the headwaters at Red Pass (median 2.5 $mg \cdot l^{-1}$) to Hope (median 5.1 $mg \cdot l^{-1}$) (Figure 5.2.8). Groundwater contribution to the instream flows in the Salmon River have produced relatively high concentrations of dissolved silica, with a median value about 4 times (19.7 $mg \cdot l^{-1}$) the highest value in the mainstem Fraser.

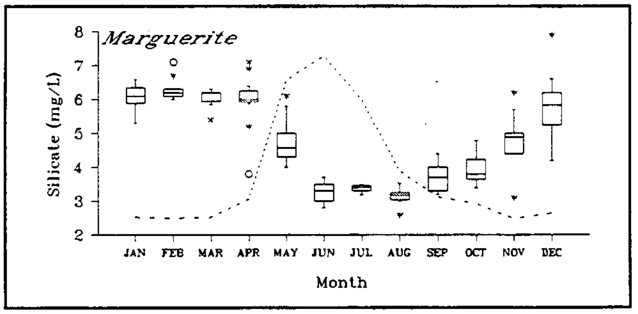



Figure 5.2.9. Annual pattern of dissolved silica in the mainstem Fraser River at Marguerite from EC monitoring data, 1985-1991. The dotted line shows the mean monthly flow at the site over the same period.

Edwards and Liss (1973) have suggested that dissolved silica is little affected by discharge. Data from all sites in the Fraser basin, however, show a strong negative association of flow and silica (eg:Figure 5.2.9). It is possible that the pattern reflects the seasonal growth and silica uptake by aquatic algae, and would require additional study for confirmation.

Seasonal Kendall's Tau (Table 5.2.1) indicates significant declining trends in dissolved silicate values in the Nechako River, in the Fraser at Marguerite and Hope, and an increasing trend at the Salmon River station. Regression analysis of these data support the trends at the Marguerite and Hope stations (Figures 5.1.10,11), and further suggest that the Nechako and Salmon River patterns would be better represented by quadratic U - and ∩ - shaped trends, respectively (Table 5.2.2).

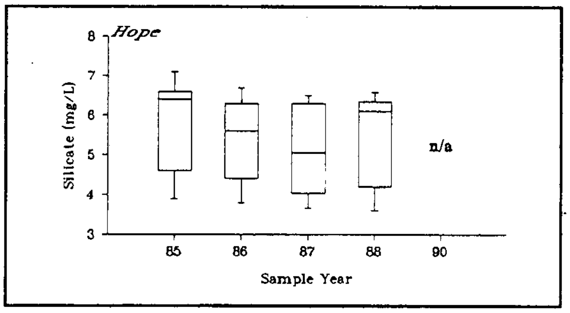



Figure 5.2.10 Annual summary of dissolved silicate concentration in the Fraser River at Hope from EC data, 1985-1991. Trend analyses indicate a decreasing concentration at this site.

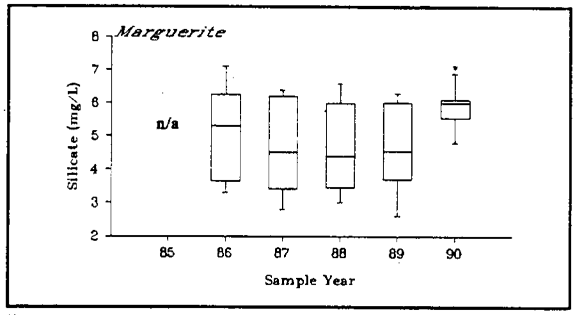



Figure 5.2.11. Annual summary of dissolved silicate concentration in the Fraser River at Marguerite, 1985-1991. Trend analyses indicate a decreasing concentration at this site.

## 5.2.5 *Potassium*

Potassium is an essential element for plants and animals, and is a key component of soil fertility and plant production in agriculture. Despite the abundance of potassium in the earth's crust, levels in surface water are typically quite low since principal potassium-containing minerals, such as feldspars, are very resistant to weathering. Potassium in solution shows a strong tendency to be incorporated into resistant clay minerals (Hem 1985), which further contributes to the low concentrations. Potassium salts are widely used in industry and agriculture (CCME 1987), and may be introduced to surface waters through effluent discharges or runoff.

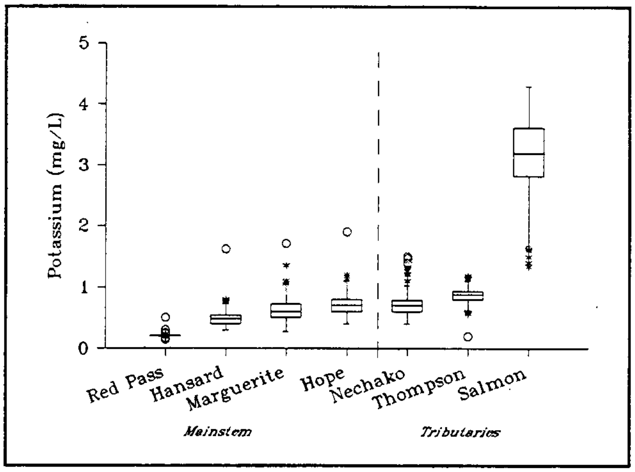



Figure 5.2.12 Summary of EC dissolved potassium data from sites in the Fraser River Basin, 1985-1991.

Dissolved potassium in the mainstem Fraser River increased from the headwaters to Hope, but rarely exceeds 1 $mg{\cdot}l^{-1}$ even at the most southerly sites (Figure 5.2.12). All but 9 values at Red Pass are below the detection limit of <0.2 $mg{\cdot}l^{-1}$. Potassium concentrations in the tributaries are similar to levels in the lower Fraser, with median concentrations near 0.9 $mg{\cdot}l^{-1}$. In the Salmon River, levels are relatively high compared to other sites, reflecting the contribution of groundwater and agricultural activity in this watershed.

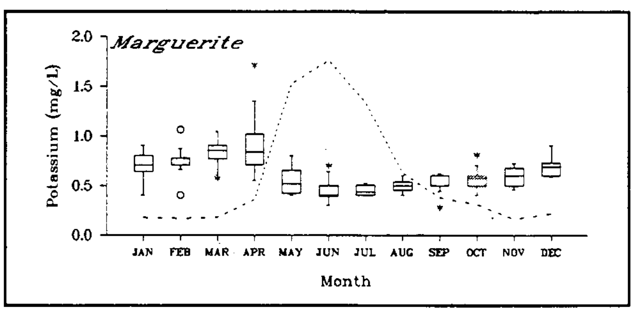



Figure 5.2.13 Annual pattern of dissolved potassium in the Fraser River at Marguerite from EC monitoring data at the site, 1985-1991. The dashed line shows the mean monthly flow at the site for the same period.

Seasonality in dissolved potassium concentration is evident, but the pattern is less dramatic than that seen with other ions (Figure 5.2.13). Some dilution due to freshet and summer flow is apparent.

Non-parametric analyses indicated increasing trends in the mainstem Fraser at Hansard and Marguerite, and in the Thompson River (Table 5.2.1). Parameter estimates for the fitted models (Table 5.2.2) reinforce results of the non-parametric analyses, showing linear increasing trends at Hansard, Marguerite, Salmon and Thompson River sampling stations, and a U-shaped trend for Nechako River.

## 5.2.6 *Sodium*

All surface waters contain some amount of dissolved sodium. Because of the high solubility of nearly all sodium salts, dissolved sodium is exclusively present in water in ionic form. Sodium salts are used in a many industrial processes and other anthropogenic activities which result in environmental releases. The use of sodium sulphate (salt cake) in pulp and paper production is of particular relevance to water quality patterns In the Fraser Basin (CCME 1987). Sodium is required by all animals, and many plants and microorganisms (McNeeley *et al.* 1979), being only of concern at very high concentrations. Irrigation uses are particularly sensitive because of the tendency for sodium to adsorb and accumulate in soils, resulting in undesirable salinization. Criteria for irrigation are not specified, but the suitability of water for this use is evaluated with respect to concentrations of other ions (such as calcium and magnesium) and soil characteristics (CCREM 1987). Drinking water criteria of 20 mg·l$^{-1}$ for sodium-restricted individuals and 200 mg·l$^{-1}$ for others have been established by BC MoELP (Nagpal *et al.* 1995).

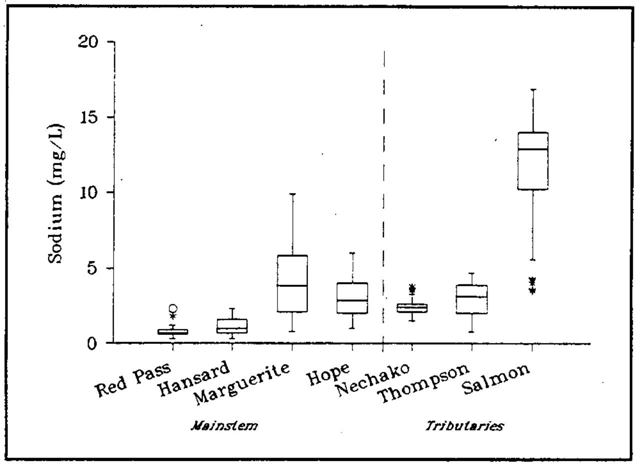
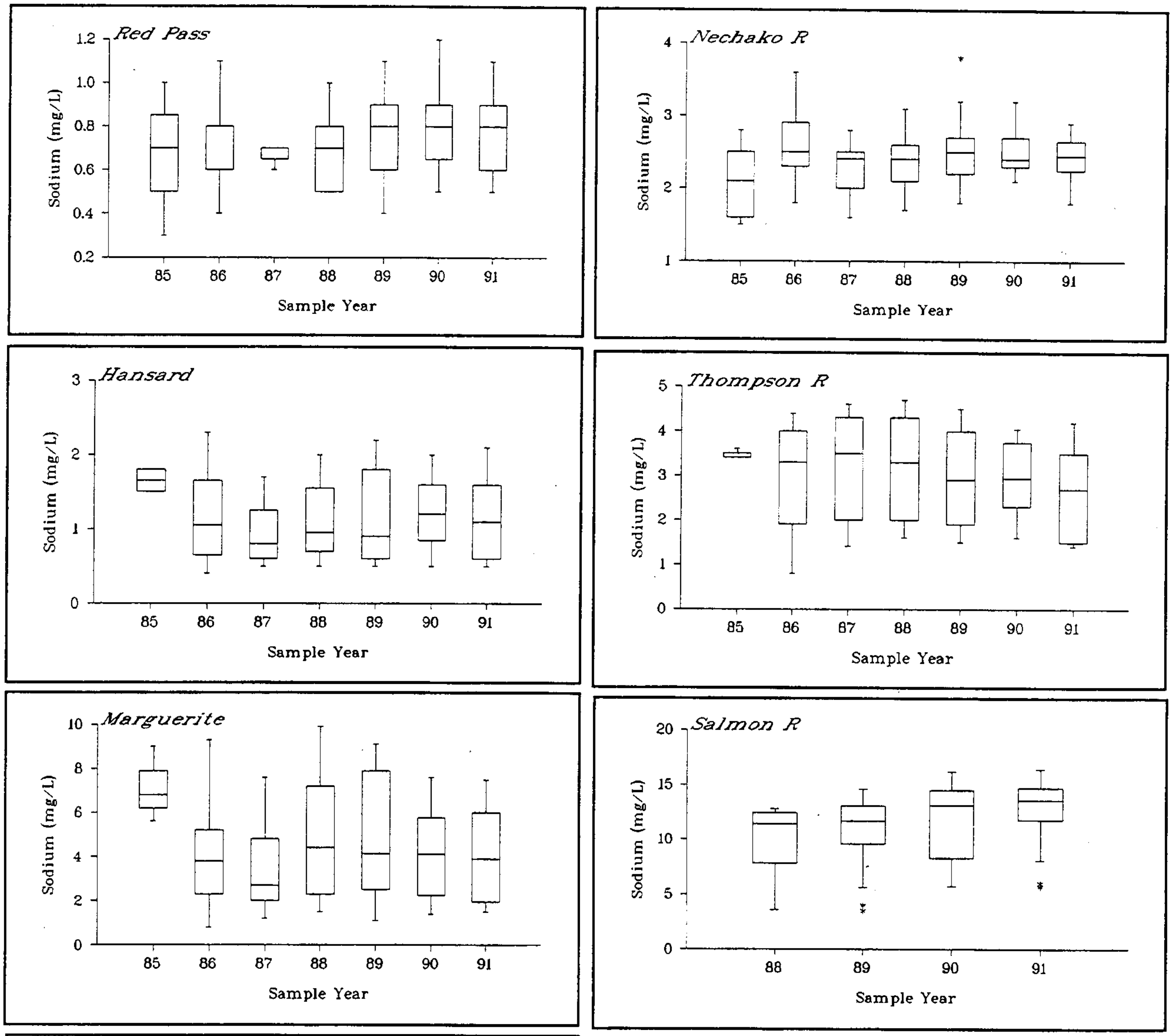


Figure 5.2.14. Summary of EC dissolved sodium data from monitoring sites in the Fraser River Basin, 1985-1991.

Sodium levels in the mainstem Fraser River are very low in the headwaters, and increase sharply downstream of Hansard (Figure 5.2.14). While elevated sodium levels at Marguerite may be due to natural factors, it is probable that the municipal and pulp/paper effluent discharges from both Prince George and Quesnel are major contributors. Sodium levels are also elevated in the Thompson River relative to the Nechako, a pattern which again is probably related to both municipal and pulp and paper mill effluents from Kamloops. Groundwater inputs to the Salmon River result in sodium concentrations which far exceed other sites, the median level being near 13 mg·l$^{-1}$.

Non-parametric analysis using Seasonal Kendall's Tau suggests an increasing trend in sodium concentrations at Red Pass and a decreasing trend at the Thompson River stations (Table 5.2.1). Regression analysis, in contrast, indicated significant increasing trends in sodium at the Hansard, Marguerite, Hope and the Salmon River stations, and a quadratic U-shaped trend at Nechako River station (Table 5.2.2). The unusual and marked discrepancy between the two methods is both interesting and problematic. Visual inspection of annual summaries of the data from each site (Figure 5.2.17) would support the trend results from both methods. The difference between the non-parametric and parametric analyses may be attributed to the inclusion of the flow as a covariate in the parametric model.

Although sodium levels appear to be increasing at several sites, all are well below guideline levels for the most sensitive use. Concentrations in the Salmon River are of most concern, since median levels are approaching the BC MoELP drinking water criterion for sodium-sensitive individuals.



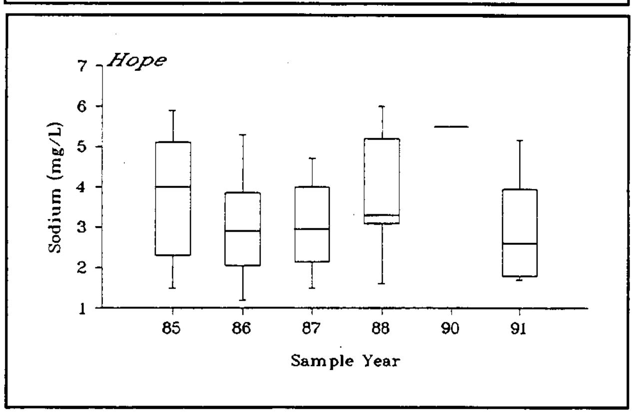




Figure 5.2.15 Annual summaries of EC dissolved sodium data from sites in the Fraser River Basin.

## 5.2.7 *Chloride*

Chloride is a particularly valuable marker of human development because of its very conservative nature, being relatively inert chemically and uninvolved in most biological processes (Sherwood 1989, Feth 1981). The clearest pattern in the ion data which might be attributed to human influence is seen in dissolved chloride levels of the mainstem Fraser and Thompson Rivers.

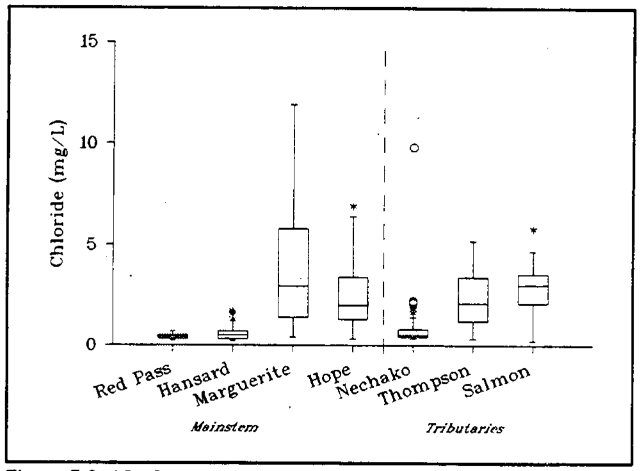


Figure 5.2. 16. Summary of EC dissolved chloride data from selected monitoring sites in the Fraser River Basin, 1985-1991.

Although there are a number of possible chloride sources to the basin, such as municipal runoff, sewage treatment plants and agricultural fertilizers, the principal source is discharge from pulp and paper mills. High chloride levels are of particular concern in irrigation, since sensitive crops may be damaged by both absorption and direct contact (CCREM 1987). Irrigation criteria of 200-700 mg·l$^{-1}$ chloride have been designated by BC MoELP (Nagpal *et al.* 1995).

Dissolved chloride concentrations in the upper basin are consistently low, with median concentrations at Red Pass and Hansard for the period of record of 0.40 and 0.50 mg·l$^{-1}$ respectively (Figure 5.2.16). Downstream of Prince George on the mainstem Fraser, chloride levels rise to a median concentration at Marguerite of about 3 mg·l$^{-1}$. Water quality at this location integrates the combined effluents from five pulp mills, (three at Prince George and two at Quesnel) and the municipal effluents of both Prince George and Quesnel, and as such, the increase might be expected. Chloride in the Thompson River, which receives effluent from a kraft mill at Kamloops, appears to be elevated relative to the concentrations of other ion variables. The overall effect of the mill effluent is put into perspective when these downstream sites are compared with summary values from the Salmon River. For all other ions, groundwater inputs to the Salmon produce values far exceeding those of all other sites, but for this parameter alone, values at this site are similar to sites on the mainstem and Thompson (Figure 5.1.16).

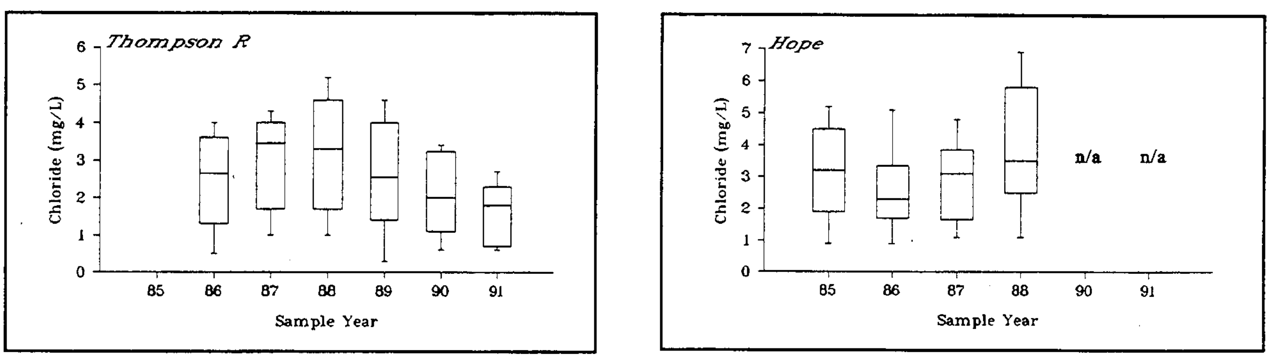



Figure 5.2.17 Annual summaries of EC dissolved chloride data from the Fraser River at Hope and on the Thompson River at Spences Bridge. Non-parametric analysis of these data indicated a linear declining trend in the Thompson and an increasing trend at Hope.

Analysis of the EC data using non-parametric statistics indicated a significant increasing trend in chloride at Hope, and declining trend in the Thompson River (Table 5.2.1). Results of regression analysis reinforced a linear increasing trend in chloride at Hope, and further identified an increasing trend in the Salmon River. The declining pattern on the Thompson River was found to be best modelled as a ∩-shaped trend, while data from sites on the Fraser at Hansard and on the Nechako showed a U-shaped trend. Annual summary plots of data from the Thompson River and Hope sites (Figure 5.2.17) show clear indication of decreasing and increasing trends respectively.

While the elevated chloride downstream of the pulp mills poses little threat to water uses in the basin, the levels indicate the extent of surface-water contamination from these effluent sources. Associated contaminants in the mill effluents, particularly organochlorine components, have only recently been added to the BC MoELP monitoring program. Some estimate of in-stream organochlorine concentrations may be possible using dissolved chloride as a surrogate parameter. For example, a general organochlorine measure, Adsorbable Organic Halides (AOX) is highly correlated with dissolved chloride concentration downstream of Prince George (Figure 5.2.18).

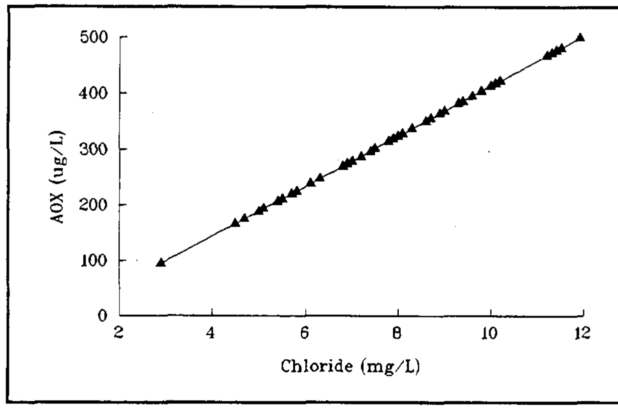


Figure 5.2.18. Relationship between AOX and dissolved chloride in the Fraser River at Marguerite, 1985-1990. Data from G. Derksen, Environmental Protection, Environment Canada

## 5.2.8 *Sulphate*

The principal source of dissolved sulphate in surface waters is the erosion of sedimentary deposits, particularly gypsum (Hem 1985). In many parts of North America, the burning of sulphur-rich fossil fuels has produced serious increases in atmospheric sulphur. When combined with rainwater, a low pH solution results in "acid rain." Under anoxic conditions, many bacteria are capable of reducing sedimentary and dissolved sulphur compounds to sulphide, producing the sour, bad-egg smell of stagnant waters.

Dissolved sulphate poses little threat to most water uses, except at high concentrations. BC MoELP have established a tentative criterion for protection of aquatic life of 100 $mg \cdot l^{-1}$ (Nagpal *et al.* 1995).

In the Fraser River basin, localized gypsum deposits in a few areas are sufficiently extensive as to be commercially exploitable. Sulphate-containing compounds are used in manufacturing and processing industries, including pulp and paper, agriculture (fertilizers) and some sewage treatment processes (CCME 1987).

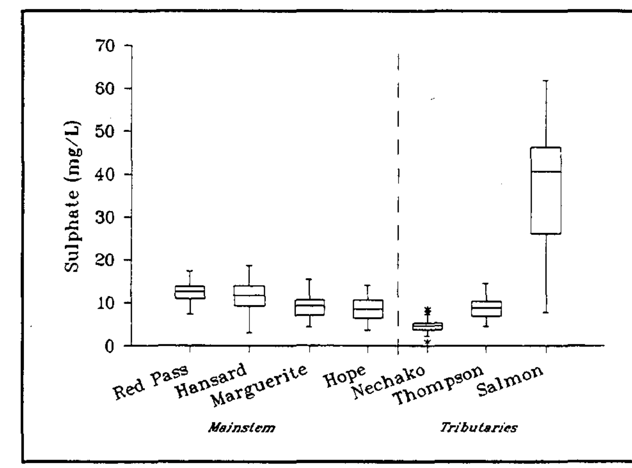


Figure 5.2.19 Summary plot of EC dissolved sulphate concentrations at selected water quality monitoring sites in the Fraser River Basin, 1985-1991.

The spatial pattern of sulphate concentration in the mainstem Fraser River (Figure 5.2.19) reflects the influence of the geology in the upper Fraser Basin. The highest levels are found at Red Pass, and sulphate concentrations decline downstream towards to the monitoring station at Hope. This pattern has been previously noted in the basin by Whitfield (1983). The highest sulphate levels are found in the Salmon River, reflecting again, the high contribution of groundwater to the instream flows.

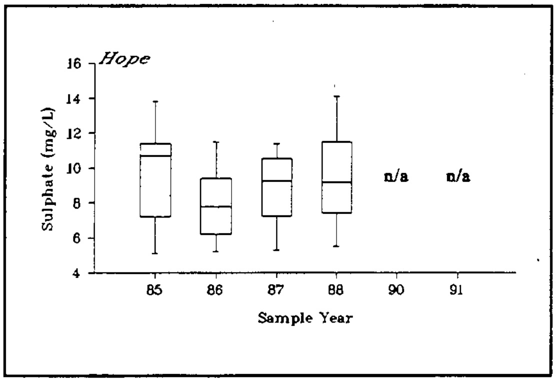



Figure 5.2.20. Annual summary plot of EC dissolved sulphate data from the Fraser River at Hope.

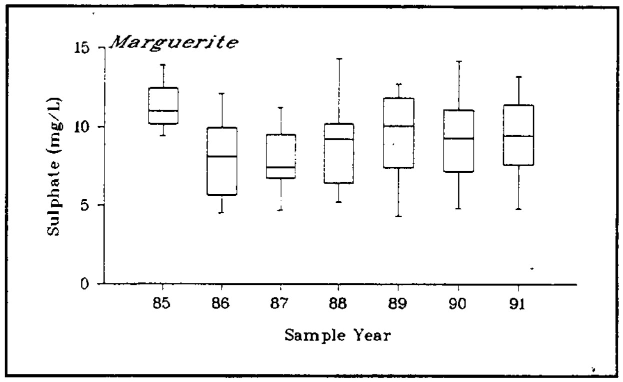



Figure 5.2.21. Annual summary plot of EC dissolved sulphate data from the Fraser River at Marguerite.

Non-parametric analyses suggest an increasing trend in dissolved sulphate at Marguerite (Table 5.2.1), a result which was further reinforced by regression modelling (Table 5.2.2). In addition, the regression analysis indicated a linear increasing trend at the Hope and Salmon River station, and a quadratic U-shaped trend for dissolved sulphate in the Nechako River. The trend at Hope may be due to the effect of upstream effluent discharges, particularly pulp and paper waste waters. Increases in dissolved sulphate are evident in annual summary plots of the data (Figure 5.2.20, 21), and should be carefully examined for the consistency of trend in more recent monitoring data.

### *5.2.9 General Spatial Patterns in Dissolved Ions*

Environment Canada dissolved ion data at the four monitoring sites on the mainstem Fraser River show three patterns. Concentrations of dissolved potassium and silicate increase with river distance from the headwaters, probably due to natural weathering of underlying bedrock. Dissolved sulphate and magnesium decline in concentration from headwater sites, a pattern observed in previous water quality studies on the Fraser (Whitfield 1983). Other ions, such as sodium and chloride, increase in concentration to the Marguerite sampling station and decline in concentration to the Hope water quality station. The pattern in concentration of these ions is probably due to anthropogenic factors, such as industrial and municipal discharges from the population centres of Prince George and Quesnel. The relatively clear, low-ion water of the Thompson functions as a point-source discharge to the Fraser, contributing on average 28% of the mainstem flow at Hope. The resulting dilution of the Fraser River water by the Thompson River produces a depression in levels of nearly all dissolved ion variables at the Hope monitoring site, when compared with the upstream site at Marguerite.

Concentrations of dissolved ions in the Salmon River are consistently the highest of all monitored stations. Three factors account for the observed pattern. First, the watershed has no high alpine water reserves which produce the prolonged elevated flows both the Fraser and Thompson Rivers. As a result, the spring freshet is derived of snowmelt, and is intense and of short duration with the river soon returning to a normal base flow. Secondly, through a much of the year, most of the instream flow of the Salmon is groundwater-derived. Under non-freshet conditions, the entire river in the upper Salmon River Valley flows underground about 3 km before resurging into the main river channel (Obedkoff 1974, Gormican and Cross 1995). The slow and close contact with the surrounding rock during this passage produces elevated levels of most measured ions. A third factor is the extensive irrigation in the basin, with runoff and irrigation return flows further contributing to the total ion load.

# 5.3 Dissolved Nutrients

Water-borne nutrients (phosphorus and nitrogen) are chemicals used by aquatic plants and bacteria for growth. While low levels of these chemicals are essential for proper functioning of the aquatic ecosystem, excess nutrients can lead to unusually luxuriant, and often undesirable, algal and macrophyte growth. In extreme cases, this can lead to choking of waterways, low oxygen levels resulting from plant decay, toxic blue-green algal blooms and other "symptoms" of eutrophication.

## 5.3.1 *Phosphorus*

Natural phosphorus in surface water results primarily from erosion and dissolution of bedrock, and secondarily from breakdown of phosphorus-rich organic tissues. Phosphorus in water is separable into dissolved and particulate fractions, each of which have organic and inorganic components. Dissolved phosphorus is found almost exclusively as phosphate ions ($PO_4^{-3}$) which bind readily to particulates and other chemicals (Hem 1985). The particulate component is primarily mineral phosphate, most of which is unavailable biologically, but has the potential to enter the phosphorus cycle under certain conditions (Wetzel 1983). The movement of phosphorus through the ecosystem is complex, with a number of possible pathways depending upon both chemical conditions and biological activity (Wetzel 1983).

Phosphorus is the nutrient most commonly limiting the growth of algal populations in freshwater. Eutrophication of surface water is almost invariably associated with high phosphorus levels. High concentrations of phosphorus in water may occur naturally, particularly in areas with high sediment apatite and other phosphorus-rich minerals. There are some areas of the Fraser River Basin in which natural background levels of phosphorus are high. Such is the case in the headwaters of the Salmon River, where dissolution of apatite-rich sediments produces nearly eutrophic conditions in lakes in the upper basin (Gormican and Cross 1995). Phosphate is an important component of many domestic and industrial cleaning compounds, and waste water releases from municipal sewage treatment plants are a very significant and important source of biologically available dissolved phosphate.

In the EC monitoring program, phosphorus in water is measured as *total phosphorus*, which is a sum of both particulate and dissolved fractions. Although it is a useful correlate of dissolved phosphorus concentration, the total phosphorus measure may include a good portion which is not immediately available biologically. The ratio of particulate to dissolved forms will vary seasonally, being lowest in the winter and highest during freshet when the high flows cause erosion and resuspension of mineral phosphorus in sediments. Total phosphorus data were available from all seven federal sites for the period of record.

BC MoELP measures two phosphorus forms in addition to total phosphorus. Available data include *dissolved phosphorus*, which is a sum of both organic and inorganic dissolved forms, and *orthophosphorus*, which is the dissolved form most available to biological activity. The provincial data set includes measurements of all three analytical forms, but sufficient data for trend assessments were available for: dissolved phosphorus at all sites, total phosphorus at the Salmon River site and orthophosphate at Marguerite and Salmon River sites.

Total phosphorus concentrations are strongly affected by discharge-related suspended sediment

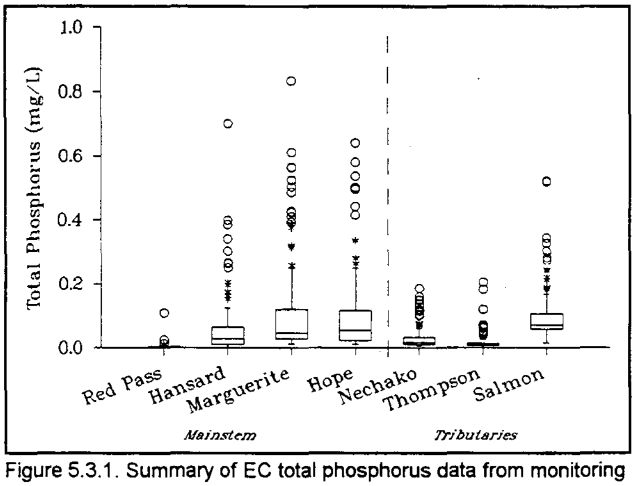


Figure 5.3.1. Summary of EC total phosphorus data from monitoring sites in the Fraser River Basin, 1985-1991.

loads. As a result, concentrations are highly variable and excursions are frequent at most sites (Figure 5.3.1). Probably owing to the site location downstream of a large lake, excursions at Red Pass are relatively infrequent and concentrations are consistently at or below the analytical detection limit. Concentrations in the mainstem Fraser River are somewhat more variable, but do display an increasing concentration downstream to Hope. This trend is probably due to both a natural increase in sediment load and the contribution of municipal and industrial effluents from Prince George and Quesnel. The major tributaries of the Nechako and Thompson have very low total phosphorus levels. Concentrations in the Salmon River are slightly higher, on average, than those at Hope. As noted in previous sections, the Salmon River drains headwaters which are high in dissolved phosphorus, then flows through agricultural and residential areas which would further contribute to the load. Phosphorus loading from the Salmon River is thought to be a significant contributing factor to the growing eutrophication of the receiving water in Tappen Bay of Shuswap Lake (Gormican and Cross 1994).

Non-parametric and parametric analyses of both the EC data from the 7 monitoring sites and the BC MoELP data available from the Salmon River showed no trends in total phosphorus (Table 5.3.1).

Data on dissolved phosphorus concentrations indicated increasing trends in the Fraser River. Parametric analyses of the provincial dissolved phosphorus data indicated a linear increasing trend at the Marguerite site (Table 5.3.2), a pattern which is evident in a summary plot of the same data (Figure 5.3.2). An increasing trend is also indicated in both parametric and non-parametric analyses of the BC MoELP orthophosphorus data (Tables 5.3.3,.4). Although eutrophication of the Fraser River in the vicinity of Marguerite is unlikely, this trend should be followed closely since it probably represents the effect of upstream municipal and industrial effluent discharges.

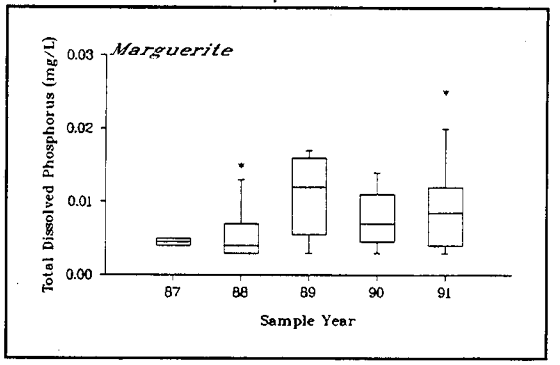



Figure 5.3.2 Annual summary of BC MoELP total dissolved phosphorus data from the Fraser River at Marguerite. Non-parametric analysis of these data indicated an increasing trend at this site.

**Table 5.3.1** *Parameter estimates of fitted models for EC total phosphorus data from sites in the Fraser River Basin, 1985-1991.*

| Parameter | Sampling Stations | | | | | | |
|---|---|---|---|---|---|---|---|
| | Red Pass | Hansard | Marguerite | Hope | Nechako River | Thompson River | Salmon River |
| $\beta_0$ | -6.05 | -9.79 | -9.13 | -12.64 | -4.32 | -8.38 | -2.72 |
| $\beta_1$ | ns | 1.102 | 0.918 | 1.26 | ns | 0.635 | 0.412 |
| $\beta_2$ | ns | ns | ns | ns | ns | ns | ns |
| $\alpha_1$ | 0.261 | -0.188 | -0.064 | 0.023 | -0.71 | 0.049 | ns |
| $\alpha_2$ | -0.367 | -0.308 | 0.714 | 0.74 | 0.39 | 0.538 | ns |
| $\omega$ | - | 0.041 | 0.019 | 0.02 | 0.02 | 0.019 | 0.017 |
| $r^2$ | - | 79.3 | 69.11 | 66.59 | 68.08 | 61.59 | 68.86 |

**Table 5.3.2** *Summary of the fitted models for BC MoELP dissolved phosphorus data from water quality sites in the Fraser River Basin, 1985-1991.*

| Parameter | Sampling Stations | | | | |
|---|---|---|---|---|---|
| | Hansard | Marguerite | Hope | Nechako River | Salmon River |
| $\beta_o$ | -7.43 | -4.56 | -3.21 | -4.28 | -3.34 |
| $\beta_1$ | 0.30 | ns | -0.295 | ns | 0.041 |
| $\beta_2$ | ns | 0.127 | ns | ns | ns |
| $\alpha_1$ | 0.416 | 0.311 | -0.009 | -0.24 | -0.074 |
| $\alpha_2$ | 0.261 | 0.452 | 0.322 | 0.22 | 0.102 |

ns = not significant at the 5% level

**Table 5.3.3** *Summary of non-parametric tests for BC MoELP orthophosphorus data from sites in the Fraser River Basin, 1985-1991.*

| Test | Marguerite | Salmon River |
|---|---|---|
| **Seasonal Kendall Tau Statistic** | 2.49 | ns |
| **Modified Seasonal Kendall Tau** | ns | ns |
| **Van Belle Stat. For Homogeneity** | ns | ns |
| **Van Belle Stat. For Trend** | 5.29 | ns |
| **Sen's Slope** | 0.00 | ns |

ns = not significant at the 5% level

**Table 5.3.4** *Summary of the fitted models for BC MoELP orthophosphorus data from sites in the Fraser River Basin, 1985-1991.*

| Parameters | Sampling Stations | |
|---|---|---|
| | Marguerite | Salmon River |
| $\beta_o$ | -4.4 | -3.35 |
| $\beta_1$ | ns | ns |
| $\beta_2$ | 0.013 | ns |
| $\alpha_1$ | 0.276 | -0.11 |
| $\alpha_2$ | 0.332 | 0.15 |

ns = not significant at the 5% level

## 5.3.2 *Nitrogen*

Nitrogen is found in a number of forms in surface waters, each playing a part in its cycling in the environment (Wetzel 1983). Inorganic nitrogen in freshwater systems is present as dissolved atmospheric nitrogen ($N_2$), nitrite ($NO_2^-$), nitrate($NO_3^-$) and ammonia ($NH_3$+$NH_4^+$). Nitrite is a unstable intermediate in the oxidation of ammonia in the nitrogen cycle, and is typically found at very low concentration (~0.001 $mg \cdot l^{-1}$) in surface waters. High levels are often indicative of industrial discharges or unsanitary water conditions (Chapman and Kimstach 1992).

Nitrate is the stable end product of nitrogen oxidation. Nitrate is readily assimilated by aquatic plants (Wetzl 1983) and is of low toxicity to invertebrates and fish (McNeely *et al.* 1979). Nitrate is, however, a considerable health concern in human and livestock drinking water. Major sources of nitrate are human and animal wastes, both from sewage treatment plant discharges and runoff from livestock ranges and feedlots, and chemical fertilizers (Chapman and Kimstach 1992). Leaching of nitrates from these sources into groundwater supplies is a considerable problem in agricultural areas, such as Abbotsford region of the Lower Fraser Basin (Leibscher *et al.* 1992). Nitrate is the predominant nitrogen form in pristine waters, but concentrations in excess of 5 mg·l$^{-1}$ may be an indication of unsanitary conditions ( McNeeley *et al.* 1979). The current BC MoELP criterion for nitrate in drinking water is 10 mg·l$^{-1}$ (Nagpal *et al.* 1995).

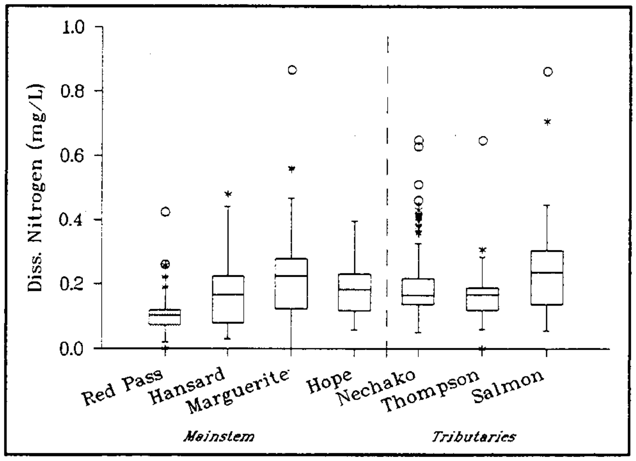



Figure 5.3.3. Summary of EC data for total dissolved nitrogen at monitoring sites in the Fraser River Basin, 1985-1991.

Ammonia is produced through bacterial decomposition of organic nitrogen. Levels are highest under reducing conditions, such as under-ice or other low-oxygen situations. Under most conditions, ammonia is present as dissociated ammonium ion ($NH_4^+$). However, under certain combinations of pH and temperature it may be present as undissociated ammonia ($NH_3$), a form which is highly toxic to fish.

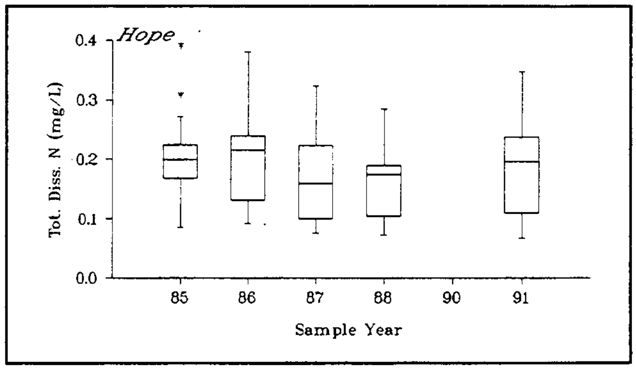



Figure 5.3.4. Annual summary of EC total dissolved nitrogen data from the the mainstem Fraser River at Hope, 1985-1991.

Natural sources of dissolved and particulate nitrogen are many, including bedrock (particularly waters draining limestones, Wetzl 1983), nitrogen fixation by plants, dry fallout and rainwater. Rainwater itself may contain up to 0.20 mg·l$^{-1}$ $NO_3$ (McNeeley *et al.* 1979). The major anthropogenic sources are related to animal and human waste disposal, such as from livestock ranching and sewage treatment, and to fertilizer application in agriculture.

Nitrate/nitrite and total dissolved nitrogen ($NH_4^+/NH_3+NO_X$+organic N) has been measured by Environment Canada at all 7 sites, ammonia by BC MoELP at five sites, and Kjeldahl nitrogen has been measured by BC MoELP at the Salmon River only.

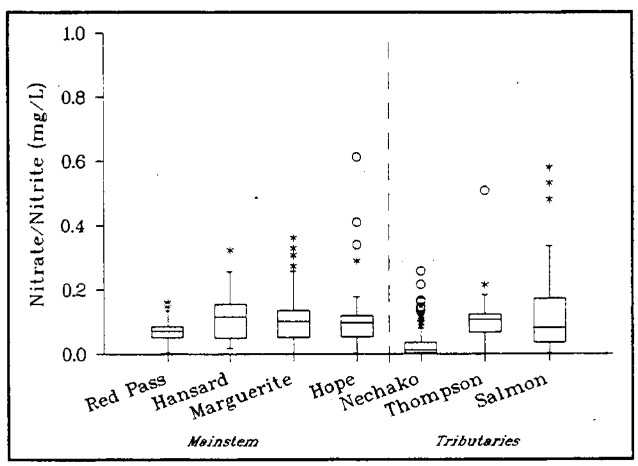



Figure 5.3.5 Summary of EC nitrate+nitrite data from selected sites in the Fraser River Basin, 1985-1991.

Total dissolved nitrogen (TDN) data from the seven EC sites are summarized in Figure 5.3.3. In the Fraser River mainstem, there is a clear increase in TDN from the low values at Red Pass to Marguerite. Much of the accumulated load from the headwaters to Hansard may be due to natural processes, but values at Marguerite reflect the contribution of effluent discharges from Prince George and Quesnel. The effect of dilution of the Fraser by the Thompson is seen in the somewhat lower values at Hope. The highest median levels are those in the Salmon River, probably indicating the combined effects of agricultural activities, low in-stream flows, and groundwater contribution. In all cases, median values are well below the current drinking water guideline.

Non-parametric analysis of the TDN data indicates only one trend, a declining concentration at the Hope site (Table 5.3.5). Further analysis of the data using parametric methods reinforced this result, with the fitted parameters suggesting a declining trend in TDN at Hope. In addition, U-shaped trends were indicated at Marguerite, Nechako, Salmon and Thompson Rivers (Table 5.3.6). An annual summary plot shows that the pattern at Hope site may be somewhat biased by a downward trend in TDN through the early years of the monitoring program, since the 1991 summary would suggest an increase (Figure 5.3.4). Analysis of more recent data may show quite a different pattern.

The spatial pattern of EC nitrate/nitrite at sites in the Fraser Basin (Figure 5.3.5) differs from that of TDN. Levels in the Nechako are near detection for much of the data record, while the remaining sites show median concentrations of roughly 0.1 mg·l$^{-1}$ (Figure 5.3.5) with occasional excursions in excess of 0.6 mg·l$^{-1}$. In the mainstem Fraser, the highest median concentration is Hansard, with values declining downstream to Hope. Environmental levels of nitrate/nitrite are quite low, from 1/10 to 1/100th the guideline values for human and livestock consumption (Nagpal *et al.* 1995, CCREM 1987).

Seasonality in nitrate/nitrite is driven by both discharge relations and biological uptake. The typical seasonal pattern at sites in the basin is shown in Figure 5.3.6. Nitrate levels increase through the winter, due to low discharge and low biological uptake. Concentrations decline rapidly with the onset of freshet, remaining low through the summer months due to dilution and biological uptake.

All sites, except Nechako River, showed a monotonic increasing trend when analysed using non-parametric methods (Table 5.3.7). Subsequent analysis using parametric methods indicated a positive increasing trend in nitrate/nitrite at Red Pass, Marguerite and Hope sites (Table 5.3.8). The very low $r^2$ of the Red Pass model suggests a poor fit, and casts some doubt on the significance of the trend at this particular site. Increases at the Hope and Marguerite sites may be an indication of the effects of effluent discharges, although it is important to keep in mind that the measured levels are presently far below guidelines for sensitive water uses.

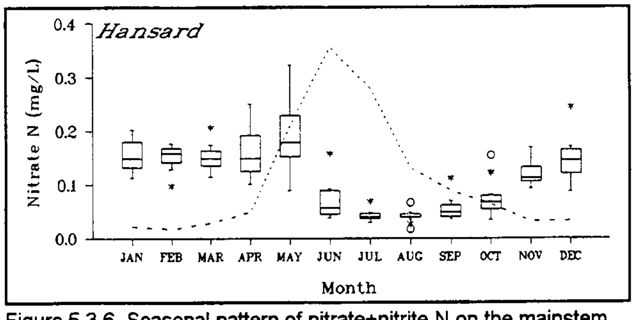



Figure 5.3.6. Seasonal pattern of nitrate+nitrite N on the mainstem Fraser River at Hansard from EC water quality data, 1985-1991. The dsahed line shows the mean monthly flow at the site for the same period.

Ammonia is measured by BC MoELP at all sites of provincial interest. In the mainstem Fraser River, high dissolved ammonia levels are unlikely because of the very high flow volumes and high dilution. In the smaller tributaries, particularly the Salmon River, backwater areas and low flows may result in elevated dissolved ammonia. No temporal trends were indicated at any sites using either non-parametric or parametric statistics.

**Table 5.3.5** *Results of non-parametric analysis of EC total dissolved nitrogen data from water quality sites in the Fraser River Basin, 1985-1991.*

| Test | Red Pass | Hansard | Marguerite | Hope | Nechako River | Thompson River | Salmon River |
|---|---|---|---|---|---|---|---|
| **Seasonal Kendall's Tau Statistic** | ns | ns | ns | -3.65 | ns | ns | ns |
| **Modified Seasonal Kendall's Tau** | ns | ns | ns | ns | ns | ns | ns |
| **Van Belle Stat. For Homogeneity** | ns | ns | ns | ns | ns | ns | ns |
| **Van Belle Stat. For Trend** | ns | ns | ns | 14.84 | ns | ns | ns |
| **Sen's Slope** | ns | ns | ns | -.0095 | ns | ns | ns |

ns = not significant at the 5% level

**Table 5.3.6** *Summary of fitted models for EC total dissolved nitrogen data from sites in the Fraser River Basin, 1985-1991.*

| Parameters | Sampling Stations | | | | | | |
|---|---|---|---|---|---|---|---|
| | Red Pass | Hansard | Marguerite | Hope | Nechako River | Thompson River | Salmon River |
| $\beta_0$ | -1.57 | -3.75 | -3.55 | -1.84 | -1.033 | -3.61 | -1.23 |
| $\beta_1$ | -0.229 | 0.318 | 0.32 | ns | ns | 0.301 | 0.22 |
| $\beta_2$ | ns | ns | -0.356 | -0.05 | -0.703 | -0.168 | -0.91 |
| $\beta_3$ | - | - | 0.054 | - | 0.098 | 0.025 | 0.26 |
| $\alpha_1$ | 0.267 | 0.312 | 0.328 | 0.000 | -0.214 | 0.346 | 0.55 |
| $\alpha_2$ | -0.263 | 1.008 | 0.734 | 0.494 | 0.43 | 0.474 | 0.171 |
| $\omega$ | 0.032 | 0.020 | 0.020 | 0.020 | 0.020 | 0.019 | 0.015 |
| $r^2$ | 38.64 | 79.03 | 79.76 | 61.62 | 55.35 | 78.67 | 74.44 |

ns = not significant at the 5% level

**Table 5.3.7** *Summary of non-parametric tests for EC nitrate+nitrite data from water quality sites in the Fraser River Basin, 1985-1991.*

| Test | Red Pass | Hansard | Marguerite | Hope | Nechako River | Thompson River | Salmon River |
|---|---|---|---|---|---|---|---|
| **Seasonal Kendall's Tau Statistic** | 3.145 | 3.539 | 2.90 | 2.0 | ns | 2.91 | 2.12 |
| **Modified Seasonal Kendall's Tau** | ns | 2.044 | ns | ns | ns | 2.02 | ns |
| **Van Belle Stat. For Homogeneity** | ns | ns | ns | ns | ns | ns | ns |
| **Van Belle Stat. For Trend** | 9.02 | 12.45 | 7.525 | 3.99 | ns | 8.35 | 5.60 |
| **Sen's Slope** | .039 | .0048 | .0051 | .0021 | ns | .0041 | 0.018 |

ns = not significant at the 5% level

**Table 5.3.8** *Summary of fitted models for EC nitrate+nitrite data from water quality sites in the Fraser River basin, 1985-1991*

| Parameters | Sampling Stations | | | | | | |
|---|---|---|---|---|---|---|---|
| | Red Pass | Hansard | Marguerite | Hope | Nechako River | Thompson River | Salmon River |
| $\beta_0$ | -2.21 | -3.85 | -6.22 | -5.54 | ns | -4.69 | -3.13 |
| $\beta_1$ | -0.255 | 0.230 | 0.499 | 0.358 | ns | 0.326 | 0.280 |
| $\beta_2$ | 0.048 | ns | 0.059 | 0.046 | ns | ns | ns |
| $\alpha_1$ | 0.010 | 0.320 | 0.634 | 0.484 | 0.380 | 0.518 | 1.220 |
| $\alpha_2$ | -0.440 | 0.911 | 0.851 | 0.718 | 0.840 | 0.592 | 0.024 |
| $\omega$ | 0.030 | 0.020 | 0.019 | 0.019 | 0.017 | 0.018 | 0.015 |
| $r^2$ | 50.49 | 78.00 | 80.05 | 63.73 | - | 80.85 | 70.12 |

ns = not significant at the 5% level

## 5.4 Metals

Trace levels of dissolved metals in surface water are essential for proper biological functioning. Many are important in basic physiological functions in both plants and animals, as blood components or cofactors in enzyme reactions (CCME 1987). Natural weathering of metal-bearing soils and rocks typically produces the necessary background levels. Many industrial activities discharge dissolved metals in waste waters, and may raise concentrations to potentially harmful levels. In the Fraser River Basin are many such sources of metal contamination, such as metal plating plants, sewage treatment plants and atmospheric deposition. Other sources, such as drainage from mines and tailings piles may be of considerable concern. A number of metals are highly toxic to both biota and humans, and as such, the measurement of this component of the solute load in surface water is an important aspect of most water quality monitoring programs.

Toxicity of metals to aquatic biota is complex, being affected by such factors as water hardness, temperature, oxygen levels, pH (Foulkes 1989, 1990) and the presence or absence of other metal ions (Enserink *et al.* 1991). In addition, a number of metals may be concentrated in tissues through direct absorption and bioaccumulation, either as a naked ion or complexed with an organic ligand (Bloom 1992). The heavy metals, such as lead, mercury and cadmium, readily accumulate in the food chain, and even low concentrations in the lower trophic levels may translate into high and potentially harmful levels in the uppermost trophic levels (Watras and Bloom 1992).

Metals in water may be present in a native form as colloids or suspended particles, or in a truly dissolved state (Chapman and Kimstach 1992). Measurements in monitoring programs are typically either the dissolved fraction or the total metal content of a water sample. For operational purposes, the dissolved fraction is that portion of the water-borne metal which passes through a 0.45 µm filter. In determining the total metal concentration, the raw water sample is digested vigorously with strong mineral acids in order to dissolve all metals in the sample before analysis. If the analyses are done correctly, and without error or contamination, the total metal concentration less the dissolved amount will equal the particulate metal total. In practice, it is only with absolute attention to cleanliness that truly uncontaminated dissolved metal samples are obtained. Contamination by filters, glassware, sample bottles, sampling equipment and preservatives added to the raw samples are but a few of the routes of contamination. In view of the difficulty in ensuring uncontaminated dissolved metals data, most monitoring agencies have opted for determinations of total metal concentrations.

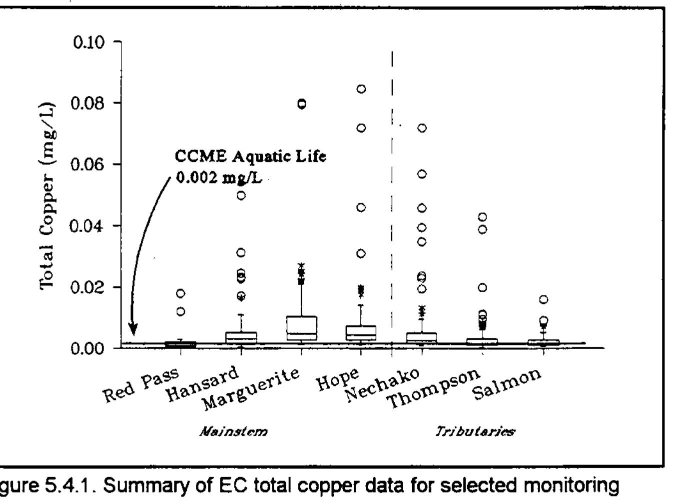



Figure 5.4.1. Summary of EC total copper data for selected monitoring sites in the Fraser River Basin, 1985-1991. The horizontal line indicates the CCME water quality guideline for protection of aquatic life. The plot excludes data from 1988-1990 because of suspected contamination problems.

Both the EC and BC MoELP measure the total metal content of water samples at monitoring sites in the Fraser River basin. A total suite of 15 to 19 metals are analyzed in the BC MoELP and EC monitoring programs (see Table 3.2). Concentrations of most metals in water were less than the method detection limits (see Appendix 1). A final set of parameters for trend assessment was narrowed to six; total aluminum from the BC MoELP data and total arsenic, iron, manganese, copper and zinc from the EC data series.

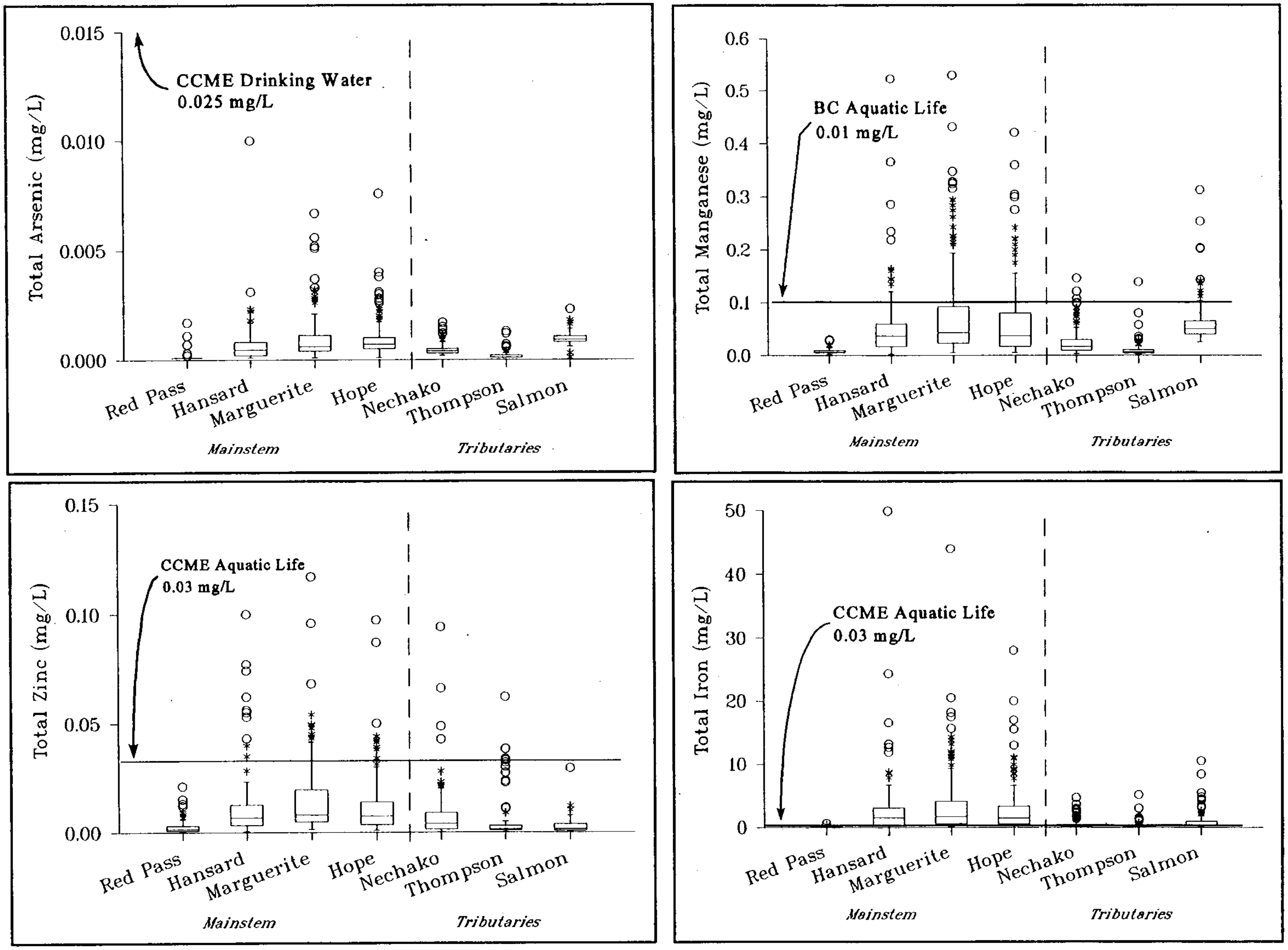



Figure 5.4.2. Summary plots of EC total arsenic, manganese, zinc and iron data from selected Fraser River Basin monitoring sites for the period 1985-1991. Relevant guideline levels are shown for comparison. The plot of total zinc excludes data from 1988-1990 because of suspected contamination problems.

Spatial summary of the available Environment Canada data for arsenic, copper, iron, manganese and zinc are presented in Figures 5.4.1 and 5.4.2. The record is punctuated by a high frequency of extreme values (indicated by the number of asterisks and circles in the box and whisker diagrams). These data represent *total* metal concentrations, and a high suspended sediment load (such as during freshet) will increase the chance of a metal-rich particle being captured during sampling. Only a relatively small particle rich in the analyte need be included in the sample in order to produce a high value. These spikes in the time series reflect the highly variable nature of total metal measurements (eg: Figure 5.4.3, Appendix 2). *Dissolved* metal concentrations are somewhat more stable, since the metals in solution have a much more homogeneous distribution in the water column and sampling is less affected by chance events. However, as noted above, samples collected and processed for dissolved metal determinations are far more prone to contamination problems.

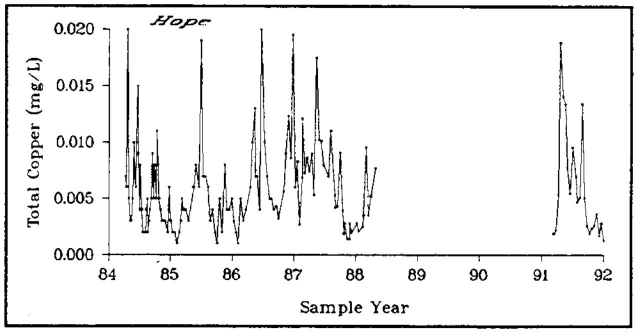


Figure 5.4.3 Total copper concentrations in the Fraser River at Hope measured by Environment Canada. The plot illustrates the erratic nature of total metal determinations overlain on seasonal the seasonal cycle.

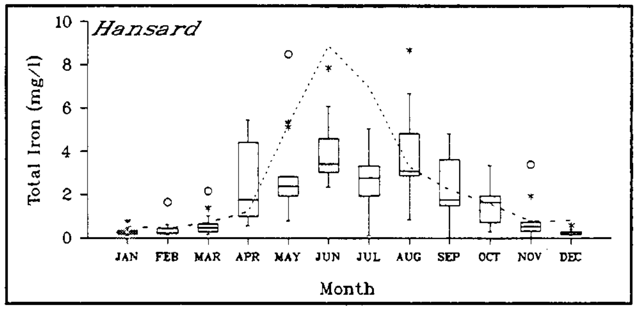


Figure 5.4.4. Seasonal pattern of total iron in the Fraser River at Harsard, 1985-1991. The dashed line indicates the pattern of mean monthly flow at the site for the same period.

Seasonality in the metal parameters is driven by the pattern of flow, since the total concentration of metals is so closely linked to the suspended sediment load. The typical seasonal pattern of the total metal level is illustrated in Figure 5.4.4. Concentrations are consistently low through the winter, while in-stream flows are minimal. Measured levels rise dramatically with the onset of freshet. Peak metal levels occur through the early summer while flows are highest, and decline with decreasing flows through the fall and winter.

### 5.4.1 *Aluminum*

Total aluminum data of sufficient number and extent were available from the BC MoELP monitoring program for all sites but the Salmon River at Salmon Arm. Concentrations in the mainstem are very similar, but do show a slight increase from upstream to downstream (Figure 5.4.5). Levels in the Nechako River are uniformly low, which probably is a reflection of the low suspended sediment load. As Hem (1985) notes, aluminum is only soluble in low pH waters, and concentrations in neutral pH waters in excess of 1 mg·l$^{-1}$ are almost certainly due to particulate material.

Non-parametric analyses suggested a linear trend in total aluminum at Marguerite (Table 5.4.3).

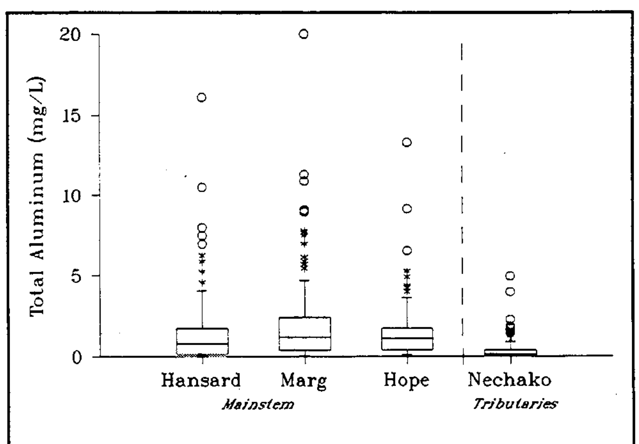


Figure 5.4.5. Summary of BC MoELP total aluminum data at monitorng sites in the Fraser River basin, 1985-1991.

Table 5.4.1. *Model parameter estimates for Environment Canada total metals data for monitoring sites in the Fraser River Basin, 1985-1991*

| Parameter | Site | $\beta_0$ | $\beta_1$ | $\beta_2$ | $\beta_3$ | $\alpha_1$ | $\alpha_2$ | $\omega$ | Conclusion |
|---|---|---|---|---|---|---|---|---|---|
| ***Total Arsenic*** | Red Pass | - | - | - | - | - | - | - | |
| | Hansard | -10.480 | 0.441 | 0.078 | - | ns | ns | - | linear increase; positive flow association |
| | Marguerite | -11.810 | 0.610 | 0.097 | - | -0.070 | 0.360 | - | linear increase; positive flow association |
| | Hope | -10.760 | 0.445 | ns | - | 0.170 | 0.343 | - | positive flow association |
| | Nechako | -7.930 | ns | 0.051 | - | -0.240 | -0.041 | - | linear increase |
| | Salmon | -7.150 | ns | ns | - | 0.115 | -0.143 | - | |
| | Thompson | -10.550 | ns | 0.085 | - | 0.210 | 0.257 | - | linear increase |
| ***Total Iron*** | Red Pass | -3.430 | ns | ns | -- | -0.715 | -0.609 | - | positive flow association |
| | Hansard | -6.180 | 1.140 | ns | - | -0.414 | -0.310 | 0.039 | positive flow association |
| | Marguerite | -10.150 | 1.520 | ns | - | -0.602 | 0.644 | 0.028 | positive flow association |
| | Hope | -10.770 | 1.440 | ns | -- | -0.145 | 0.682 | 0.023 | positive flow association |
| | Nechako | -3.900 | ns | ns | - | -0.930 | 0.480 | 0.022 | |
| | Salmon | -1.310 | 0.880 | ns | - | -0.260 | 0.223 | 0.021 | positive flow association |
| | Thompson | -6.070 | 0.673 | ns | - | -0.153 | 0.398 | 0.019 | positive flow association |
| ***Total Manganese*** | Red Pass | - - | - | - | - | - | - | - | |
| | Hansard | -8.210 | 0.887 | -0.078 | - | 0.155 | 0.225 | - | linear decrease; positive flow association |
| | Marguerite | -9.860 | 0.991 | ns | - | 0.341 | 0.508 | - | positive flow association |
| | Hope | -11.540 | 1.095 | ns | - | 0.238 | 0.483 | - | positive flow association |
| | Nechako | -5.060 | ns | ns | - | -0.416 | 2.700 | - | |
| | Salmon | -2.850 | 0.350 | -0.170 | - | ns | ns | - | linear decrease; positive flow association |
| | Thompson | -9.000 | 0.699 | ns | - | -0.420 | 0.598 | - | positive flow association |

Table 5.4.2 . *Model parameter estimates for BC MoELP total metals data for monitoring sites in the Fraser River Basin, 1985-1991.*

| **Parameter** | **Site** | $\beta_0$ | $\beta_1$ | $\beta_2$ | $\beta_3$ | $\alpha_1$ | $\alpha_2$ | $\omega$ | $r^2$ | ***Conclusion*** |
|---|---|---|---|---|---|---|---|---|---|---|
| ***Aluminium*** | Hansard | -7.520 | 1.250 | ns | - | -0.443 | -0.586 | 0.040 | 71.060 | |
| | Marguerite | -8.240 | 1.097 | 0.371 | - | -0.506 | -0.475 | 0.040 | 60.770 | linear increase |
| | Hope | -6.280 | 0.750 | 0.211 | | ns | ns | 0.018 | 61.230 | linear increase |
| | Nechako | ns | ns | ns | - | -1.270 | 0.059 | 0.020 | 54.160 | |
| ***Iron*** | Hansard | -6.730 | 1.230 | - | - | -0.540 | 0.009 | 0.036 | 89.060 | |
| | Marguerite | -7.590 | 1.150 | - | - | -0.530 | -0.244 | 0.037 | 72.900 | |
| | Hope | -8.800 | 1.194 | - | - | -0.308 | -0.072 | 0.036 | 74.260 | |
| | Nechako | ns | ns | 0.660 | | -0.854 | -0.250 | 0.021 | 47.800 | linear increase |

This result was reinforced by regression analysis, and this method further suggested a linear trend at Hope (Table 5.4.2).

Table 5.4.3 *Summary of non-parametric tests for BC MoELP total aluminum data from selected sites in the Fraser Basin, 1985-1991.*

| Test | Hansard | Marguerite | Nechako |
|---|---|---|---|
| **Seasonal Kendall Tau** | ns | 3.01 | ns |
| **Modified Seasonal Kendall Tau** | ns | 1.98 | ns |
| **Van Belle Stat for Homogeneity** | ns | ns | ns |
| **Van Belle Stat for Trend** | ns | 8.96 | ns |
| **Sen's Slope** | ns | 0.21 | ns |

ns=not significant at the 5% level

## 5.4.2 *Arsenic*

Non-parametric trend analysis of the total arsenic data suggest an increasing trend in the Fraser River at Marguerite. Further evaluation of the data set using parametric analyses further indicated a positive linear increase at Marguerite, in addition to sites at Hansard, Thompson River and the Nechako River. The increasing trend is clearly evident in an annual summary plot of data from the site at Marguerite (Figure 5.4.6), though

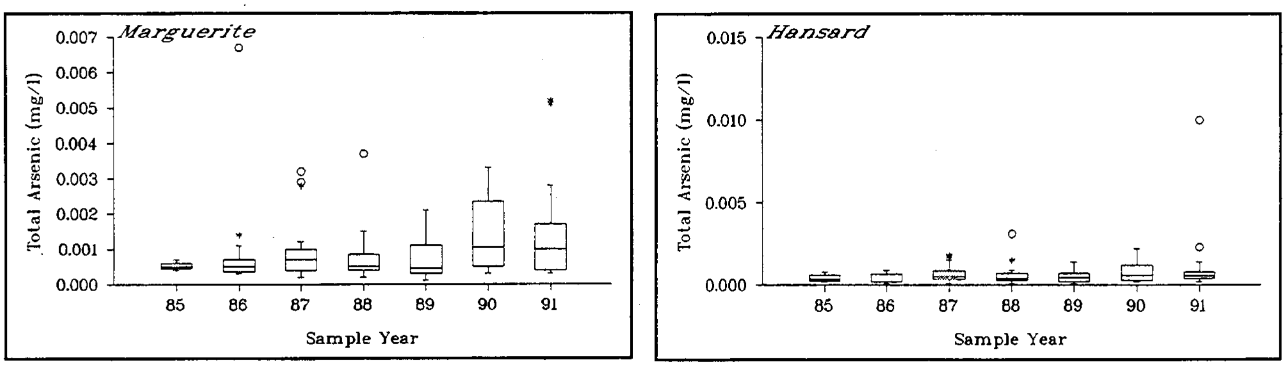



Figure 5.4.6 Annual summary of EC total arsenic measurements from monitoring sites on the mainstem Fraser River at Marguerite and Hansard.

less so at Hansard. Arsenic is released in municipal effluents in the basin (Norecol 1993), and it is possible that the observed trend at Marguerite is attributable to upstream discharges from Prince George and Quesnel. A possible cause for the increase at Hansard is not readily apparent. Even though arsenic was measurable and increasing at these sites, the concentrations measured by Environment Canada were well below the 0.05 $mg \cdot l^{-1}$ CCME water quality guideline for protection of aquatic life.

**Table 5.4.4** *Summary of non-parametric tests for EC total arsenic data for sites in the Fraser River Basin, 1985-1991.*

| Test | Red Pass | Hansard | Marguerite | Hope | Nechako River | Thompson River | Salmon River |
|---|---|---|---|---|---|---|---|
| **Seasonal Kendall's Tau Statistic** | ns | ns | 1.99 | ns | ns | ns | ns |
| **Modified Seasonal Kendall's Tau** | ns | ns | ns | ns | ns | ns | ns |
| **Van Belle Stat. For Homogeneity** | ns | ns | ns | ns | ns | ns | ns |
| **Van Belle Stat. For Trend** | ns | ns | ns | ns | ns | ns | ns |
| **Sen's Slope** | ns | ns | .0006 | ns | ns | ns | ns |

ns = not significant at the 5% level

## 5.4.3 *Iron*

Total iron levels are high thoughout the mainstem Fraser River, with natural levels frequently exceeding the current 0.3 $mg \cdot l^{-1}$ CCME guideline for protection of aquatic life. Like most of the other total metal variables, high levels are likely due to native ore being carried as suspended sediment, as the close relationship between non-filterable residue and total iron concentration would indicate (Figure 5.4.7). The highest median concentrations are found at sites where the suspended sediments are highest - the three downstream sites on the Fraser River (Figure 5.4.2).

Non-parametric analysis suggested an increasing trend at three sites, the Fraser River at Red Pass and Marguerite, and in the Nechako River (Table 5.4.5). In contrast, there were no trends at any site indicated by parametric analysis (Table 5.4.2), although a clear association between flow and total iron is indicated.

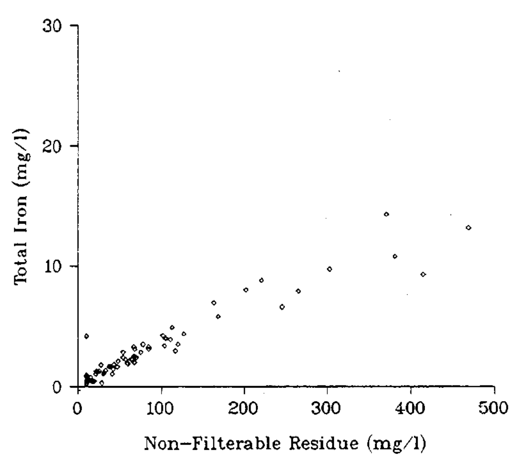



Figure 5.4.7 Relationship between total iron and non-filterable residue in the Fraser River at Marguerite.

**Table 5.4.5** *Summary of non-parametric tests for EC total iron data for sites in the Fraser River Basin, 1985-1991.*

| Test | Red Pass | Hansard | Marguerite | Hope | Nechako River | Thompson River | Salmon River |
|---|---|---|---|---|---|---|---|
| **Seasonal Kendall's Tau Statistic** | 2.09 | ns | 2.63 | ns | 2.19 | ns | ns |
| **Modified Seasonal Kendall's Tau** | ns | ns | ns | ns | ns | ns | ns |
| **Van Belle Stat. For Homogeneity** | ns | ns | ns | ns | ns | 21.34 | ns |
| **Van Belle Stat. For Trend** | ns | ns | 6.86 | ns | 4.39 | ns | ns |
| **Sen's Slope** | 0.0045 | ns | 0.171 | ns | 0.0125 | - | ns |

ns = not significant at the 5% level

## 5.4.4. *Manganese*

As with the total iron data from the mainstem Fraser, concentrations of total manganese frequently exceed the current CCME water quality quideline (0.20 $mg \cdot l^{-1}$) for protection of irrigation water uses. There are presently no CCME guidelines for protection of aquatic life, but BC MoELP has adopted criterion of 0.1-1.0 $mg \cdot l^{-1}$. Hem (1985) notes that manganese is common at low levels in most limestones, where it substitutes for calcium in the mineral matrix.

Non-parametric analysis showed no trends in total manganese in any of the available EC data. However, additional examination of the series using parametric analyses suggest declining trends in the Fraser River at Hansard and in the Salmon River at Salmon Arm (Table 5.4.1). Summary plots of yearly data as these two sites show no compelling trends (Figure 5.4.8)). The apparent lack of consensus between the two methods suggests that the trend may not be strong, but the parameter should be evaluated at intervals. This is particularly important since manganese has replaced lead as an anti-knock ingredient in automobile fuel, and concentrations in bottom sediments of urban lakes in the lower Fraser River have been increasing in recent years (Ken Hall, Civil Engineering, UBC).

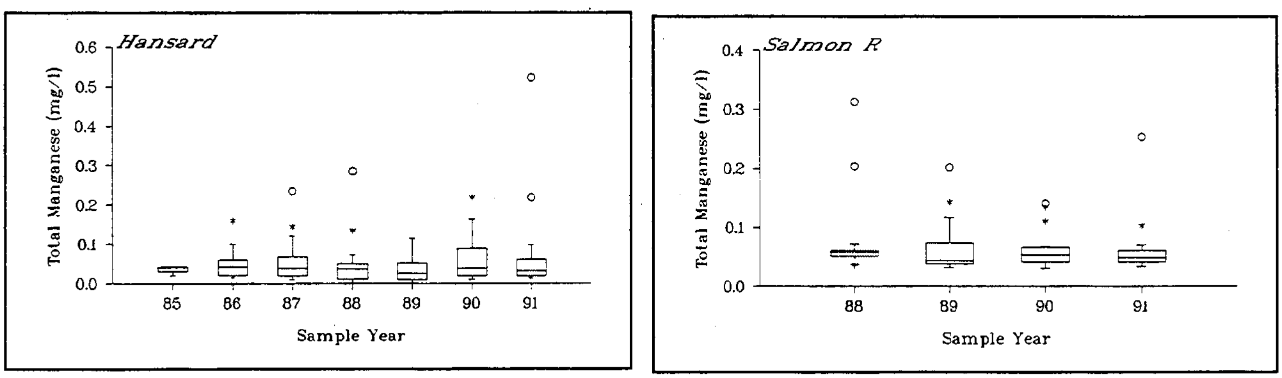



Figure 5.4 8. Annual summary of EC total manganese data from the Fraser River at Hansard and the Salmon River at Salmon Arm.

## 5.4.5 *Copper*

Copper is a common heavy-metal constituent of surface waters, and is particularly soluble in slightly acidic waters (McNeely *et al.* 1979). Copper is very widely used in many aspects of manufacturing, industry and agriculture in addition to important uses in domestic piping. Toxicicity of copper to aquatic life is high, and is determined by a number of water quality factors including pH and water hardness. The current CCME guideline for total copper for protection of aquatic life is 0.002 to 0.004 $mg \cdot l^{-1}$ (CCME 1987).

Because of the ubiquity of copper in human activity, preventing contamination of water samples is a particular problem even in total metal analyses. The EC monitoring program suffered the effects of suspected contamination of water samples through leaching of copper from bottle caps (A. Ryan, Environment Canada) in a number of samples from 1988 to 1990. Occasional failure of teflon liners of preservative containers resulted in leaching of copper and zinc into the preservative. Clearly anomalous and questionable records in the data series have been flagged as such in the database but all data from 1988 to 1990 is suspect (A. Ryan, Environment Canada; L. Pommen, BC MoELP) and is presented here for completeness.

Detection of sporadic contamination in a highly variable measurement, such as any of the total metal determinations, is difficult. However, the problem is apparent in annual box and whisker plots as a period of both unusually high median levels and an increased frequency of extreme values (Figure 5.4.9). Results of trend analyses of these data would be incorrect and misleading, and as such, are not presented here. Data outside of the 1988-90 period are summarized in Figure 5.4.1.

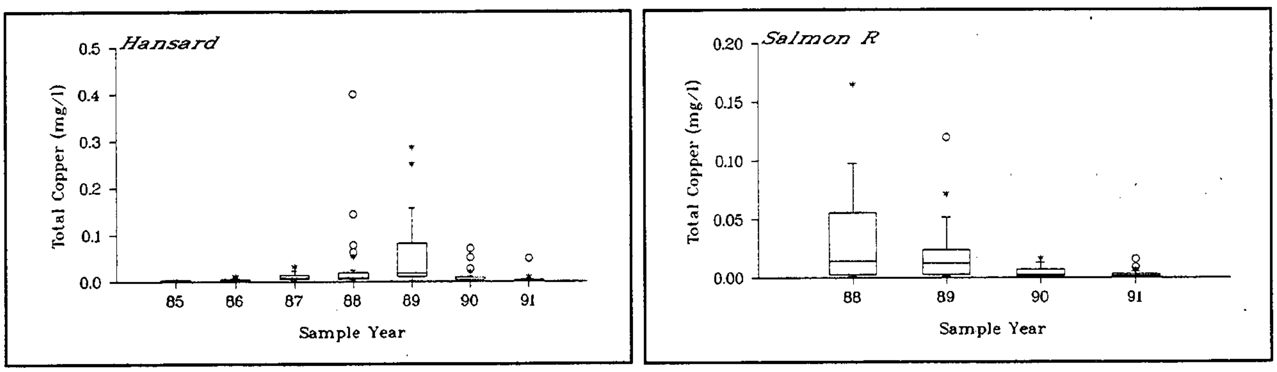



Figure 5.4.9 Annual summary plots of EC total copper data from sites in the Fraser River Basin.

## 5.4.6 *Zinc*

Zinc, in terms of use, toxicity and general behavior, is similar to copper. It is common in the environment, and has a multitude of applications in human activity, many of which would result in environmental contamination. Zinc is quite toxic to aquatic life, and the current CCME guideline specifies that total concentrations in water not exceed 0.03 $mg \cdot l^{-1}$.

As with total copper, zinc contamination of water samples was suspected in 1988 -1990 samples through leaching from cap liners in sample preservative bottles. As discussed above, trend analyses of these data are not presented here, but the values (after removing the suspect data) are summarized in Figure 5.4.2.

## 5.5 Microbial Variables

Microbial evaluation of surface waters is related to human health concerns from recreational contact and drinking. High levels of bacteria and other micro-organisms are associated with gastrointestinal disorders, and may be correlated with transmission of other water-borne diseases. In water quality monitoring programs, four groups of bacteria are monitored (MacDonald *et al.* 1991):

*Total coliforms*: comprises a wide range of bacteria, both harmless and pathogenic, not specifically related to sewage waste; distinguished by their ability to ferment lactose and produce gas

*Fecal coliforms*: coliform bacteria from warm-blooded animals; generally short-lived in the environment; ferment lactose and produce gas at 44.5°C

*Fecal streptococci* : also found in warm-blooded animals, but less common in man than are the coliforms; the ratio of coliform to streptococcal bacterial numbers has been used as an indicator of sewage pollution (Sherer *et al.* 1992, but see Warrington (1988) for a critique)

*Enterococci* : fecal streptococcal bacteria which seem to be better predictors of gastrointestinal illness than are the other bacterial categories

While the presence of coliform and streptococcal bacteria in surface water may be due to wildlife, the most significant source in the Fraser Basin is probably discharge from municipal sewage treatment plants (Swain *et al.* 1994). Leaking septic tanks and runoff from agricultural lands (Baxter-Potter and Gilliland 1988) can produce localized increases in water-borne bacteria, and have a significant impact on human water use in smaller tributaries. Bacterial measurements are notoriously variable in time, and time series observations typically show frequent excursions from background levels. Recognizing this variability, guidelines and criteria are usually based on a summary statistic from a number of analyses. BC MoELP uses medians, geometric means and percentiles of 5-10 samples collected over some time period (typically 30 days) to evaluate the coliform contamination of a waterbody (Warrington 1988).

Coliform bacteria in water pose no hazard to either aquatic life or most industrial uses, but may be of concern to human health through ingestion, recreational contact or irrigation of food crops. Canadian drinking water guidelines for water after treatment require a complete absence of fecal coliform bacteria. Ambient criteria for drinking water are somewhat more complicated. Three levels are recognized, each with a separate criterion:

*1 - 10 cfu·100 ml$^{-1}$* (90th percentile) - disinfection only;

*11- 100 cfu·100 ml$^{-1}$* (90th percentile) - partial treatment and disinfection

*>100 cfu·100 ml$^{-1}$* (90th percentile) - full treatment and disinfection

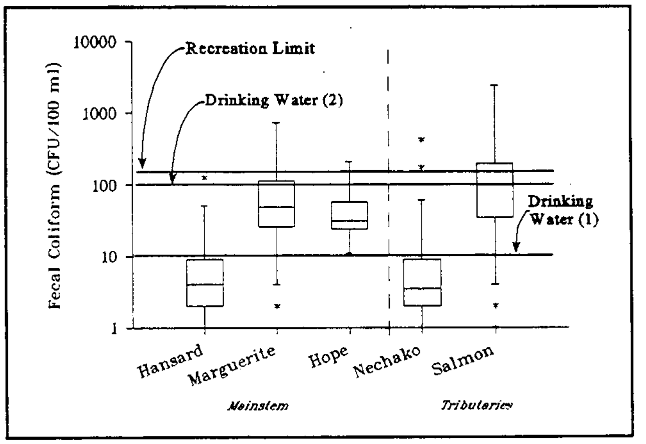



Figure 5.5.1. Summary of BC MoELP fecal colifom data for monitoring sites in the Fraser River Basin, 1985-1991. Three BC MoELP criterion levels are shown: "Drinking water (1)" - level at which disinfection only is needed, "Drinking water (2)" - level requiring both partial treatment and disinfection and "Recreation" - limit for contact recreation (swimming, etc.).

Contact recreational guidelines are set at a maximum level of 200 colony forming units/100 ml (CFU/100ml). For irrigation waters, guidelines limit fecal coliform levels to a maximum of 100 cfu per 100ml.

Bacterial parameters are not part of the EC monitoring program, but all four microbial indicators have been measured by BC MoELP at all stations at some point in the period of record. Data on fecal coliform numbers were of sufficient sampling and detection frequency to permit trend analyses, and are considered here.

The highest numbers of fecal coliform bacteria at the five provincial monitoring sites were measured in the Salmon River, where the median value for the 1985-1991 period exceeds 100 cfu/100 ml (Figure 5.5.1). Lower median values are found in the Fraser River mainstem sites at Marguerite and Hope. Both of these locations show elevated values compared to the low numbers in the Nechako River and in the Fraser River at Hansard.

Non-parametric analysis indicated a declining trend in fecal coliform numbers at Marguerite, and non-significant trends at the remaining sites (Table 5.5.1). Further parametric analysis of these data, without flow correction, also suggested a declining trend in fecal coliform numbers at Marguerite (Table 5.5.2). While this may be a significant trend at this site, the low proportion of explained variation ($r^2$=22.7) and the absence of a trend when flow is included, makes the result somewhat suspect. However, data from these sites should be examined closely in the future for bacterial trends.

The 200 cfu/100ml recreational guideline is exceeded regularly in single samples from the Salmon River, and occasionally at Marguerite. On average, about 13% of samples at Marguerite (n=96, 1989-92) and 27% of the Salmon River samples (n=102, 1989-1992) exceeded the present guideline. At all other sites, the frequency is less than 1%.

The mainstem Fraser River receives sewage effluents from a number of major population centres in the upper basin, and as such, elevated fecal coliform numbers might be expected. In addition, pulp mills are known to discharge *Klebsiella sp.*, an enteric coliform bacterium (Bell *et al.* 1979), and may be contributing to results from Marguerite and Hope. The high fecal coliform numbers recorded in the Salmon River are due to two factors. The first key factor is the contribution from cattle in the basin. At a number of ranches, cattle are permitted free access to the river and deposit and track fecal matter into the main flow. Also, through the winter and early spring, cattle are maintained on open pastures in the upper Salmon River valley. The accumulated manures are released into the watercourse when these fields flood in late spring, the consequence of which is very high fecal coliform numbers (to 2450 cfu/100ml: 1990) (R. Grace, BC MoELP, pers. comm.). The second key factor is the number of near-field septic systems in the basin, many of which probably leach into the in-stream flow and further contribute to the bacterial load.

**Table 5.5.1** *Summary of non-parametric tests for BC MoELP fecal coliform data from monitoring sites in the Fraser River Basin, 1985-1991.*

| Test | Hansard | Marguerite | Nechako River | Salmon River |
|---|---|---|---|---|
| **Seasonal Kendall Tau Statistic** | ns | -3.47 | ns | ns |
| **Modified Seasonal Kendall Tau** | ns | ns | ns | ns |
| **Van Belle Statistic For Homogeneity** | ns | ns | ns | ns |
| **Van Belle Statistic For Trend** | ns | 11.67 | ns | ns |
| **Sen's Slope** | ns | -33.08 | ns | ns |

ns = not significant at the 5% level

**Table 5.5.2** *Summary of the fitted models for BC MoELP fecal coliform data from monitoring sites in the Fraser River basin.*

| Parameters | Sampling Stations | | | |
|---|---|---|---|---|
| | Hansard | Marguerite | Hope | Salmon River |
| $\beta_o$ | -1.9 | -9.17 | - | -4.49 |
| $\beta_1$ | 0.566 | -0.775 | - | ns |
| $\beta_2$ | ns | ns | - | ns |
| $\alpha_1$ | ns | 0.435 | - | 0.17 |
| $\alpha_2$ | ns | -0.200 | - | -0.61 |
| $\omega$ | 0.07 | 0.06 | - | 0.047 |
| $r^2$ | - | 47.34 | - | 27.96 |

ns = not significant at the 5% level

# 6.0 General Summary and Recommendations

## 6.1 Spatial Trends

Natural factors, such as stream flow and bedrock geology, are primarily responsible for the water quality in the upper Fraser River. With occasional exceptions, dissolved constituents and suspended sediments tend to increase from the headwaters downstream to Hope. Exceptions arise when the bedrock geology of the upper basin contributes constituents not common in the rest of the study area. Dissolved sulphate and magnesium, derived of the sedimentary deposits in the Rocky Mountain Trench, are good examples.

Anthopogenic factors are also evident. The high flow volumes of the mainstem Fraser River ensure that all but the largest discharges are diluted to near detection or near background levels. Pulp mills and municipal water treatment plants are among this category, and the influence of these effluents are apparent at monitoring sites downstream. Elevated chloride levels in the Fraser River at Marguerite and in Thompson River at Spences Bridge may be attributed to upstream release of pulp and paper mill effluents.

Monitoring stations on the major tributaries such as the Thompson and Nechako Rivers indicate very different water quality to that of the mainstem Fraser River. Typically, these rivers have a far lower sediment load and lower concentrations of most dissolved ions compared to even the headwaters of the Fraser River. As a consequence, their confluence with the mainstem Fraser produces an effect which is clearly visible at sites downstream. For example, concentrations of nearly all dissolved ion variables are lower at Hope than at Marguerite, an effect attributable to the influence of the Thompson River.

Water in the Salmon River is hard, nutrient and ion rich and very well buffered. These qualities are a consequence of the small size of the watershed, the close proximity of agricultural activities and developments and the high contribution of groundwater to in-stream flows throughout the year.

## 6.2 Temporal Trends

Results of trend analyses on the Environment Canada and BC Ministry of Environment, Lands and Parks data sets are summarized in Tables 6.1 and 6.2, respectively. The 1985-1991 time period of this study is a relatively short record from which to draw firm conclusions regarding water quality trends. Occasional inconsistencies in the trends indicated by the non-parametric and parametric statistical analyses reinforce the unstability of the patterns, which would probably become more pronounced given a longer time series. There are some patterns which emerge and will bear some particularly careful consideration in future analyses. The site at Marguerite, as has been noted on several occasions, represents the most seriously affected water quality monitoring site of the seven considered in this report. Water flowing past this location has received effluents from two major population centres (Prince George and Quesnel) and five pulp and paper mills upstream and it is at this site that four chemical variables in the EC (potassium, sulphate, arsenic and nitrates/nitrites) and one in the BC MoELP set (orthophosphorus) show consistent increasing trends. Further study, including evaluation of a longer data series and full effluent characterization, will be needed to attribute cause.

Pulp mills discharge the highest effluent volumes of any industrial activity in the basin , and discharges have increased over the 1985-1991 period of this study. Effect of these effluents on water quality is seen in a number of parameters, such as total absorbance colour (BC MoELP Hansard/Marguerite), chloride, sodium, sulphate and possibly potassium. That the measured levels are not presently exceeding existing guidelines for these variables should not imply that these effluents are having no detrimental effect on the environment. As noted earlier, the monitoring program considers a limited number of chemical variables which may not be of highest environmental concern. Chlorinated compounds in the effluent, such as dioxins and furans, are of special importance but are not addressed in the present program. BC MoELP has recently added AOX to the monitoring program as a relatively inexpensive measure of organochlorine concentration.

The effects of municipal discharges are apparent in the fecal coliform and phosphorus records. In data from Marguerite, the trends are favourable and indicate some improvement in upstream treatment. Rising levels of othophosphorus and nitrate-nitrate at the site suggest that additional improvement in treatment is still needed. Unfortunately, the site locations do not allow the relative contributions of discharges from Quesnel and Prince George to be isolated, but it is clear that these variables should be followed in the future.

Interesting patterns are seen in the Nechako and Salmon Rivers. The Nechako River shows a striking preponderance of quadratic increasing trends in the parametric trend analyses of the EC data (Table 6.1), which may be attributed to flow-regulation of the river. Water-supply issues in the Salmon River present quite a different pattern. Human activity coupled with the naturally high contribution of groundwater to in-stream flows have produced high concentrations of nearly all solutes which have been increasing over the relatively short monitoring period. Water quality in the Salmon River has been of concern for some time (Gormican and Cross 1995), owing to low flows, high irrigation withdrawal and return flows and cattle ranching. Parametric trend analysis of the EC dissolved ion data from the Salmon River, while not showing the strong trends, did show a consistent increasing pattern (Table 6.1). These results might be expected, given the background information, but were not apparent in the non-parametric analyses. A number of factors might be contributing to the non-significant results in the non-parametric methods, but these examples demonstrate the sensitivity of the regression methods.

## 6.3 Recommendations

The results of this study demonstrate the application and utility of trend analyses in reviewing the data series from monitoring sites in the Fraser River Basin. The information presented here is a first effort, and should be a starting point for future studies and new projects. A few recommendations are appropriate in this regard.

1) *Review and statistical analysis of water quality trends should be repeated at regular intervals, perhaps every five years.*

   The analysis would be conducted on a 10 year data set at that point, and results would be considerably more robust. Some attention should be given to comparing blocked time periods, such as pre-1991 versus post-1991, or comparison before and after process changes at pulp mills. Some form of routine data screening, such as regular trend assessment using non-parametric analysis should be considered for all the existing monitoring sites, and not just those within the Fraser River Basin.

2) *Monitoring programs at the existing sites should be maintained.*

   Long-term data series are very important in evaluating changes in environmental conditions, and the utility of the data set for detecting change increases with each additional year of sampling.

3) *Monitoring at some additional sites should be enhanced.*

   The BC MoELP monitoring site at Stoner, downstream of Prince George, has had a relatively short sampling history with a limited number of parameters. This site is particularly important for determining the effect on the mainstem Fraser River of discharges from Prince George. Changes in the values of water quality variables from Hansard to Marguerite may be attributed to a mixture of natural processes and combined effluents from both upstream population and industrial discharges, but the relative contributions cannot be properly assessed without data from a site upstream of Quesnel.

4) *Correlate water quality trends with effluent characterization.*

While some of the trends described here may be easily attributed to particular obvious sources, others (such as total arsenic), may not. A similar analysis should be conducted to examine the covariance of effluent components and measured water quality constituents.

Table 6.1 *Overall summary of trend analyses on Environment Canada water quality data. Shaded boxes indicate concordance between non-parametric and parametric analyses*

| Parameter | Red Pass | Hansard | Marguerite | Hope | Nechako | Thompson | Salmon R |
|---|---|---|---|---|---|---|---|
| Flow | → ⇒ | → ⇒ | → ⇒ | → ⇒ | → ⇒ | → ⇒ | → ⇒ |
| Air Temp | — | — | — | — | — | — | — |
| Water Temp | ↘ ⇒ | → ⇒ | → ⇒ | → ⇒ | → ⇒ | → ⇒ | → ⇒ |
| Conductivity | ↗ ⇒ | → ⇗ | → ⇗ | → ⇒ | → U | → ⇒ | → ⇒ |
| App. Colour | → ⇒ | ↗ ⇒ | ↗ ⇒ | → ⇒ | → ⇒ | → ⇒ | → ⇒ |
| pH | — | — | — | — | — | — | — |
| Turbidity | → ⇒ | → ⇘ | → ⇒ | → ⇒ | → ⇒ | → ⇒ | → ⇘ |
| Alkalinity | ↗ ⇒ | → U | → ⇒ | → ⇒ | → ⇒ | → U | → ⇒ |
| NFR | → ⇒ | → ⇒ | → ⇒ | → ⇒ | → ⇒ | → ⇒ | → ⇒ |
| FNFR | → ⇒ | → ⇒ | → ⇒ | → ⇒ | → ⇒ | → ⇒ | → ⇒ |
| Ca | → ⇒ | ↘ U | **↘ ⇘** | → ⇘ | ↘ U | ↘ U | → ⇗ |
| Mg | → ⇒ | → ⇗ | → ⇗ | → ⇒ | → U | → U | → ⇗ |
| K | → ⇒ | **↗ ⇗** | **↗ ⇗** | → ⇒ | → U | **↗ ⇗** | → ⇗ |
| Na | ↗ ⇒ | → ⇗ | → ⇗ | → ⇗ | → U | ↘ ⇒ | → ⇗ |
| Cl | → ⇒ | → U | → ⇒ | **↗ ⇗** | → U | ↘ ∩ | → ⇗ |
| SO4 | → ⇒ | → ⇒ | **↗ ⇗** | → ⇗ | → U | → ⇒ | → ⇗ |
| SiO2 | → ⇒ | → ⇒ | **↘ ⇘** | → ↘ | ↘ ⇒ | → ⇒ | ↗ ⇒ |
| Hardness | → ⇘ | ↘ U | → ⇒ | → ⇒ | → ⇒ | ↘ U | → ⇗ |
| Arsenic | → ⇒ | → ⇗ | **↗ ⇗** | → ⇒ | → ⇗ | → ⇗ | → ⇒ |
| Iron | ↗ ⇒ | → ⇒ | ↗ ⇒ | → ⇒ | ↗ ⇒ | → ⇒ | → ⇒ |
| Manganese | → ⇒ | → ⇘ | → ⇒ | → ⇒ | → ⇒ | → ⇒ | → ⇘ |
| Copper | → ⇗ | → ⇗ | → ⇒ | **↗ ⇗** | → ∩ | → ⇒ | ↘ ⇒ |
| Zinc | **↘ ⇘** | → ⇗ | → ⇘ | → ⇘ | ↘ ⇒ | → ⇒ | → ⇒ |
| Total P | → ⇒ | → ⇒ | → ⇒ | → ⇒ | → ⇒ | → ⇒ | → ⇒ |
| DN | → ⇒ | → ⇒ | → ⇒ | **↘ ⇘** | → U | → U | → U |
| NOx | **↗ ⇗** | ↗ ⇒ | **↗ ⇗** | ↗ ⇒ | → ⇒ | ↗ ⇒ | ↗ ⇒ |

↗ - Increasing trend indicated by non-parametric analysis ⇗ - Increasing linear trend indicated by parametric analysis
↘ - Decreasing trend indicated by non-parametric analysis ⇘ - Decreasing linear trend indicated by parametric analysis
→ - No trend indicated ⇒ - No trend indicated ∩,U - quadratic trend indicated

Table 6.2 *Overall summary of trend analyses of BC MoELP water quality data. Shaded boxes indicate concordance between non-parametric and parametric analyses*

| Parameter | Hansard | Marguerite | Hope | Nechako | Salmon |
|---|---|---|---|---|---|
| Specific Conductivity | → ➸ | ↘ ➸ | → ➸ | → ➸ | → ➸ |
| Colour TAC | ↗ ➚ | → ➸ | -X- | -X- | -X- |
| pH | → ➸ | ↘ ➘ | → ➸ | → ➸ | → ➸ |
| Non-Filterable Residues | → ➚ | → ➚ | → ➸ | → ➸ | → ➸ |
| Filterable Residues | → ➚ | → ➚ | → ➚ | -X- | → ➚ |
| Total Ammonia | → ➸ | → ➸ | -X- | → ➸ | → ➸ |
| Kjeldahl Nitrogen | -X- | -X- | -X- | -X- | → ➸ |
| Orthophosphorus | -X- | ↗ ➚ | -X- | -X- | → ➸ |
| Dissolved Phosphorus | → ➸ | → ➚ | → ➸ | → ➸ | → ➸ |
| Total Phosphorus | -X- | -X- | -X- | -X- | → ➸ |
| Total Aluminum | → ➸ | → ➚ | → ➚ | → ➸ | -X- |
| Total Iron | → ➸ | → ➸ | - X - | - X - | -X- |
| Fecal Coliform | → ➸ | ↘ ➘ | -X- | → ➸ | → ➸ |

↗ - Increasing trend indicated by non-parametric analysis ➚ - Increasing linear trend indicated by parametric analysis
↘ - Decreasing trend indicated by non-parametric analysis ➘ - Decreasing linear trend indicated by parametric analysis
→ - No trend indicated ➸ - No trend indicated ∩,∪ - quadratic trend indicated
-X- variable not measured at this site

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Appendix 1.

Parameter codes and detection limits for Environment Canada and B.C. Ministry of Environment, Lands and Parks water chemistry analyses

# Environment Canada Parameter Codes and Associated Detection Limits

## Physicals

| | Method Code | Detection Limit | Units |
|---|---|---|---|
| Air Temp | 97060S | - | |
| Water Temp | 02061S | - | |
| Apparent Colour | 02011L | - | |
| Conductivity | 02041L | 0.2 | uS/cm |
| Labratory pH | 10301L | - | |
| Turbidity | 02073L | - | |
| Residue Non-Filterable | 10401L | 10 | mg/l |
| Residue Fixed Non-Filterable | 10501L | 10 | mg/l |
| Alkalinity | 10101L | 0.5 | mg/l |

## Dissolved Ions

| | *< Aug 1, 1987* | | | *Aug 1, 1987 -Jan 31, 1990* | | | *> = Feb 1, 1990* | | |
|---|---|---|---|---|---|---|---|---|---|
| | Method Code | Detection Limit | units | Method Code | Detection Limit | units | Method Code | Detection Limit | units |
| Calcium | 20103L | 0.05 | mg/l | 20103L | 0.05 | mg/l | 20321L | 100 | ug/l |
| Magnesium | 12101E | calculated (a)* | - | 12102L | 0.01 | mg/l | 12321L | 100 | ug/l |
| Hardness | 10603L | 1 | mg/l | 10602E | calculated (b)* | - | 10602E | calculated (b)* | |

| | *< Nov 1, 1989* | | | *> = Nov 1, 1989* | | |
|---|---|---|---|---|---|---|
| | Method Code | Detection Limit | units | Method Code | Detection Limit | units |
| Potassium | 19103L | 0.02 | mg/l | 19301L | 0.001 | mg/l |
| Sodium | 11103L | 0.02 | mg/l | 11321L | 200 | ug/l |

| | Method Code | Detection Limit | units |
|---|---|---|---|
| Chloride | 17206L | 0.05 | mg/l |
| Fluoride | 09105L | 0.05 | mg/l |
| Silicon Extr. | 14111L | 8 | ug/l |
| Silicon | 14105L | 0.02 | mg/l |
| Sulphate | 16306L | 0.02 | mg/l |

## Nutrients

| | Method Code | Detection Limit | units |
|---|---|---|---|
| Nitrogen: NO2/3 | 07110L | 0.005 | mg/l |
| Nitrogen: Total Dissolved | 07651L | 25 | ug/l |
| Phosphorus, Total | 15406L | 2 | ug/l |

## Total Metals

| | *Aug 1, 1984-Feb 13 1990* (AA TOTAL) | | | *> Feb 13, 1990* (ICP TOTAL) | | |
|---|---|---|---|---|---|---|
| | Method Code | Detection Limit | units | Method Code | Detection Limit | units |
| Aluminum | 13003P | 50 | ug/l | 13009P | 0.001 | mg/l |
| Arsenic | 33008L | 0.0 | ug/l | 33008L | 0.02 | ug/l |
| Barium | 56001P | 0.1 | mg/l | 56009P | 0.001 | mg/l |
| Beryllium | - | - | - | 04010P | 0.05 | ug/l |
| Cadmium | 48002P | 1 | ug/l | 48009P | 0.001 | mg/l |
| Chromium | 24003P | 2 | ug/l | 24009P | 0.002 | mg/l |
| Cobalt | - | - | - | 27009P | 0.002 | mg/l |
| Copper | 29005P | 1 | ug/l | 29009P | 0.001 | mg/l |
| Iron | 26004P | 50 | ug/l | 26009P | 0.002 | mg/l |
| Lead | 82002P | 1 | ug/l | 82009P | 0.010 | mg/l |
| Lithium | - | - | - | 03009P | 0.1 | mg/l |
| Manganese | 25004P | 1 | ug/l | 25010P | 0.001 | mg/l |
| Mercury | 80011P | 0.05 | ug/l | 80011P | 0.05 | ug/l |
| Molybdenum | 42002P | 0.2 | ug/l | 42009P | 0.004 | mg/l |
| Nickel | 28002P | 1 | ug/l | 28009P | 0.002 | mg/l |
| Selenium | 34008P | 0.03 | ug/l | 34008P | 0.03 | ug/l |
| Strontium | - | - | - | 38009P | 0.002 | mg/l |
| Vanadium | - | - | - | 23009P | 0.002 | mg/l |
| Zinc | 30005P | 1 | ug/l | 30009P | 0.002 | mg/l |

(a) - Calculated from the values of the total hardness (determined by EDTA titration) and dissolved calcium dissolved :

$$Mg = (Total\ Hardness*0.01998 - Ca*0.0499) * 12.16$$

(b) - Calculated from concentrations of dissolved calcium and magnesium dissolved :

$$Mg = Ca*2.497 - Mg*4.117$$

**BC Environment Parameter Codes and Associated Detection Limits**

## Physicals

| Physicals | Parameter Code | Work Route | Detection Limit | Units |
|---|---|---|---|---|
| Specific Conductivity | 0011 | 1160 | 1 | µS/cm |
| Color Tac | 1310 | 1310 | 1 | TAC |
| pH | 0004 | 1220 | 0.1 | pH units |
| Turbidity | 0015 | 1150 | 0.1 | NTU |
| Residue Non-Filterable | 0008 | 1070/1072 | 4 | mg/L |
| Residue Fixed Non-Filterable | 0009 | 1050 | 4 | mg/L |
| Residue Filterable | 7 | 1030 | 4 | mg/L |
| Residue Fixed Filterable | 0006 | 1020 | 4 | mg/L |
| Residue Total | 0005 | 1031 | 14 | mg/L |
| Alkalinity (Total) | 0102 | 1210 | 0.5 | mg/L |
| Alkalinity 4.5/4.2 | D102 | 1212 | 0.5 | mg/L |

## Dissolved Ions

| Dissolved Ions | Parameter Code | Work Route | Detection Limit | Units |
|---|---|---|---|---|
| Calcium | Ca-D | 0031 | 0.01 | mg/L |
| Chloride | 1104 | 1330 | 0.5 | mg/L |
| Fluoride, dissolved | 1106 | 1341 | 0.1 | mg/L |
| Magnesium | Mg-D | 0031 | 0.02 | mg/L |
| Potassium,diss | K-D | 0031 | 0.4 | mg/L |
| Silica Reactive, diss | Si-D | 0031 | 0.03 | mg/L |
| Sodium, diss | Na-D | 0031 | 0.01 | mg/L |
| Sulfate, diss | 1121 | 1400 | 1 | mg/L |

## Nutrients

| Nutrients | Parameter Code | Work Route | Detection Limit | Units |
|---|---|---|---|---|
| Nitrogen, Ammonia | 1108 | 1351 | 0.005 | mg/L |
| Nitrogen, NO2/3 Diss | 1109 | 1350 | 0.02 | mg/L |
| Nitrogen, Kjeldahl Diss | 1113 | 136A | 0.04 | mg/L |
| Nitrogen Total Kjeldahl | 0113 | 136A | 0.04 | mg/L |
| Nitrogen, dissolved | 1114 | CALC | 0.04 | mg/L |
| Ortho-Phosphorus | 1118 | 1380 | 0.003 | mg/L |
| Phophorus, Diss | P--D | 139A | 0.003 | mg/L |
| Phosphorus, total | P--T | 139A | 0.003 | mg/L |

## Metals

| Metals | Parameter Code | Work Route | Detection Limit | Units |
|---|---|---|---|---|
| Aluminum | Al-T | 0040 | 0.02 | mg/L |
| Arsenic | As-T | 0181 | 0.001 | mg/L |
| Barium | Ba-T | 0042 | 0.001 | mg/L |
| Cadmium | Cd-T | 0040 | 0.01 | mg/L |
| Chromium | Cr-T | 0040 | 0.01 | mg/L |
| Cobalt | Co-T | 0040 | 0.10 | mg/L |
| Copper | Cu-T | 0040 | 0.01 | mg/L |
| Iron | Fe-T | 0040 | 0.01 | mg/L |
| Lead | Pb-T | 0040 | 0.10 | mg/L |
| Manganese | Mn-T | 0040 | 0.01 | mg/L |
| Molybdenum | Mo-T | 0040 | 0.01 | mg/L |
| Nickel | Ni-T | 0040 | 0.05 | mg/L |
| Vanadium | V-T | 0040 | 0.01 | mg/L |
| Zinc | Zn-T | 0040 | 0.01 | mg/L |

## Microbials

| Microbials | Parameter Code | Work Route | Detection Limit | Units |
|---|---|---|---|---|
| Total Coliform (CFU/Cl) | 0451 | 2480 | 0 | CFU/cL |
| Total Coliform (MPN) | 0451 | 2492 | 0 | MPN/cL |
| Fecal Coliform (CFU/Cl) | 0450 | 2480 | 0 | CFU/cL |
| Fecal Coliform (MPN) | 0450 | 2492 | 0 | MPN/cL |
| Fecal Streptococcus | 0454 | 2480 | 0 | CFU/cL |
| E. Coli | 0147 | 6013 | 2 | CFU/cL |
| Enterococcus | 0148 | 6014 | 2 | CFU/cL |

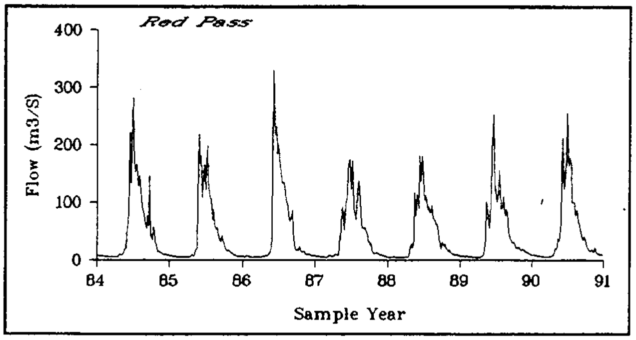
## Organics

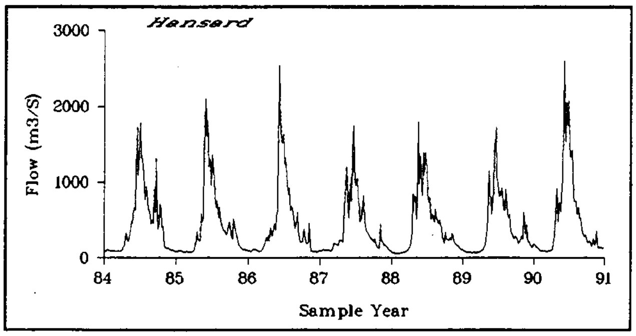
| Organics | Parameter Code | Work Route | Detection Limit | Units |
|---|---|---|---|---|
| Phenols | 0117 | 0550 | 0.002 | mg/L |
| Absorb Organohalides | AOX- | DM01 | 0.01 | mg/L |

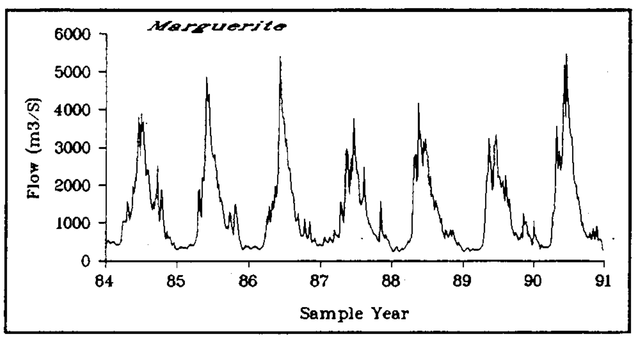
## Appendix 2.

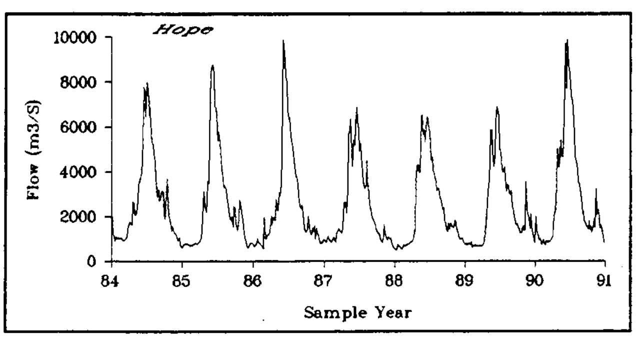
Time series plots of Environment Canada water quality monitoring data for variables considered in this report at selected sites in the Fraser River Basin

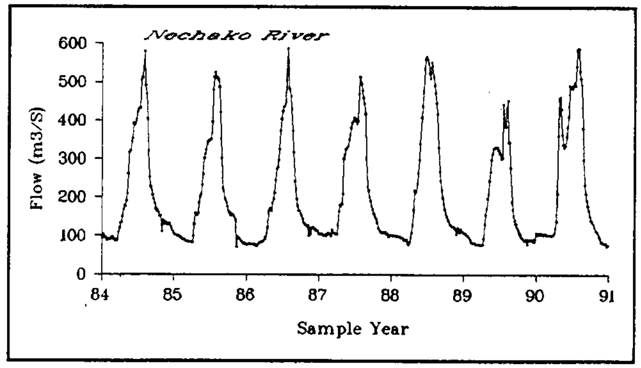
| Page | Variable |
|---|---|
| 1 | Flow |
| 2 | Air Temperature |
| 3 | Water Temperature |
| 4 | Laboratory Conductivity |
| 5 | Apparent Colour |
| 6 | Laboratory pH |
| 7 | Turbidity |
| 8 | Non-filterable residue |
| 9 | Fixed non-filterable residue |
| 10 | Filterable residue |
| 11 | Fixed filterable residue |
| 12 | Total Alkalinity |
| 13 | Calcium |
| 14 | Magnesium |
| 15 | Hardness |
| 16 | Silicate |
| 17 | Potassium |
| 18 | Sodium |
| 19 | Chloride |
| 20 | Sulphate |
| 21 | Total phosphorus |
| 22 | Dissolved nitrogen |
| 23 | Nitrate-nitrite nitrogen |
| 24 | Total arsenic |
| 25 | Total iron |
| 26 | Total manganese |
| 27 | Total copper |
| 28 | Total zinc |

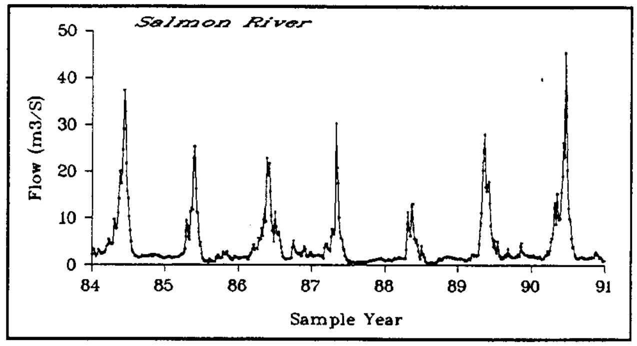


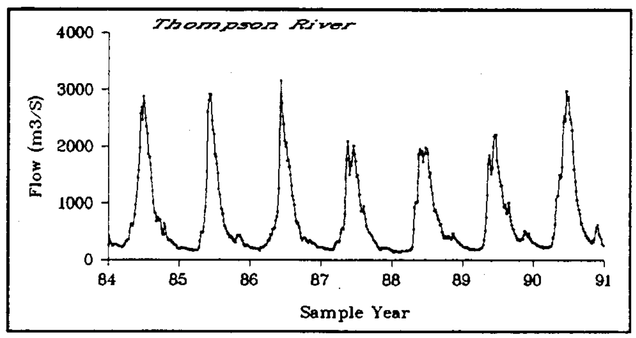



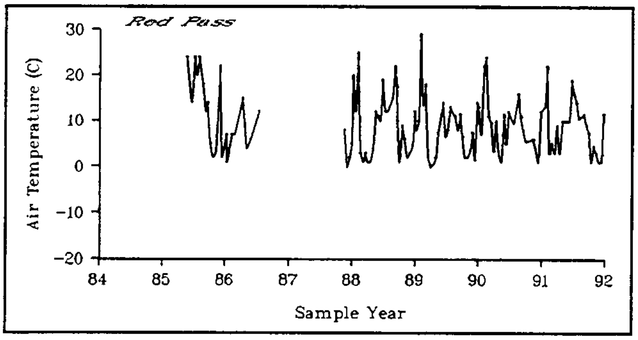



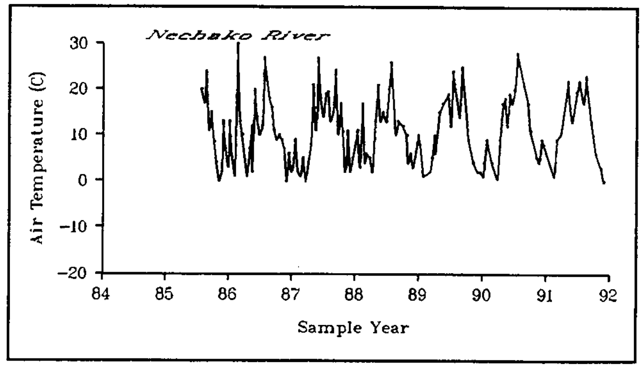



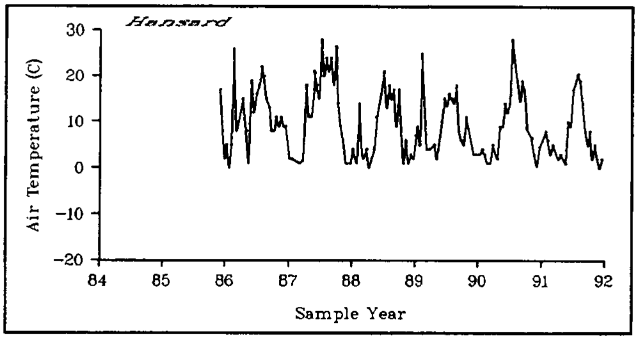



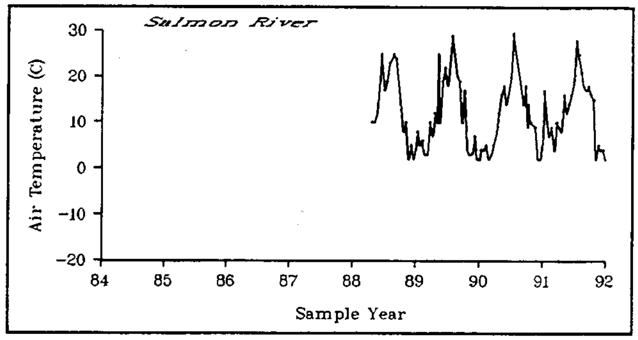



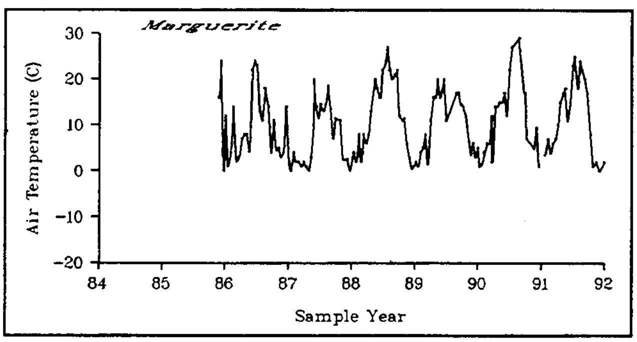

Time Series plots of Water Flow Data for the period 1984-1992 at selected sites in the Fraser River basin.

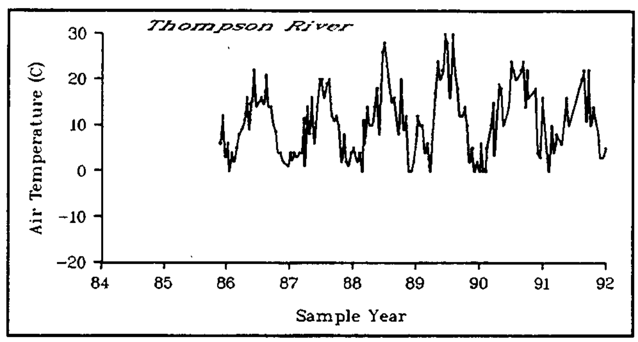


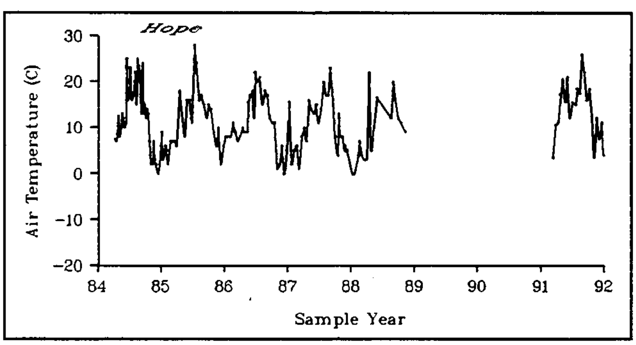



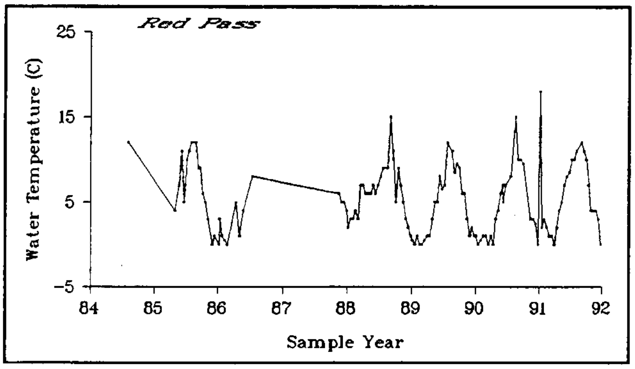



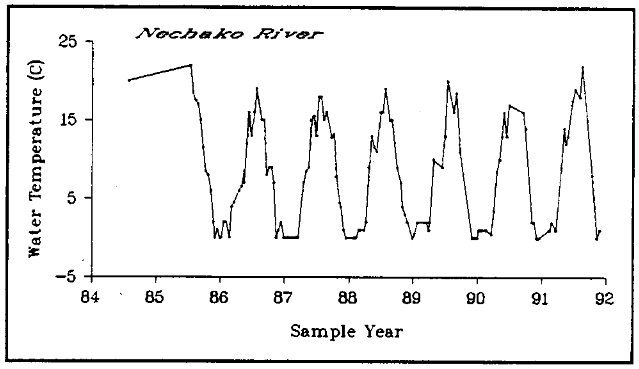



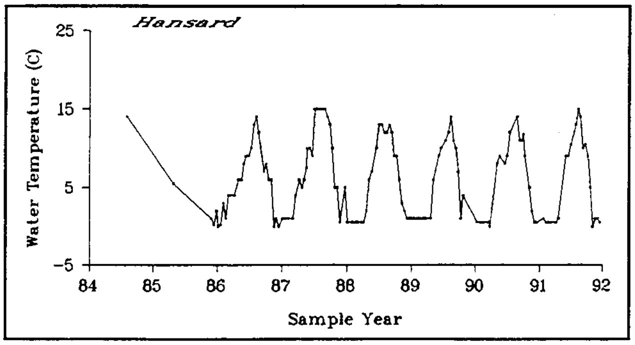



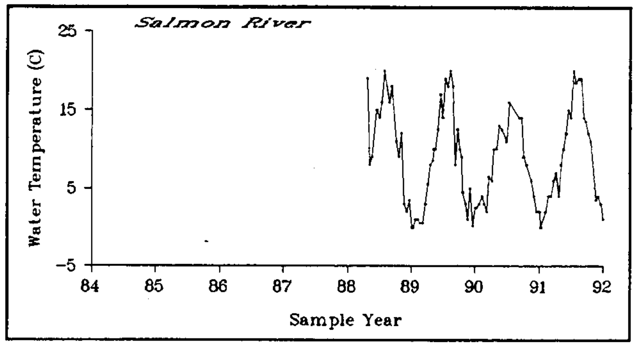



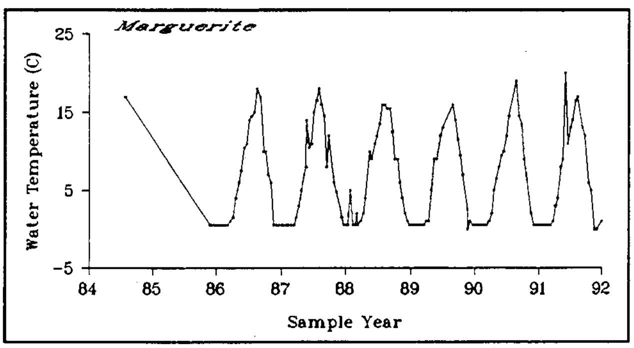

Time Series plots of Air Temperature Data for the period 1984-1992 at selected sites in the Fraser River basin. These are measurements taken during water sampling, and are not standard meteorological data.

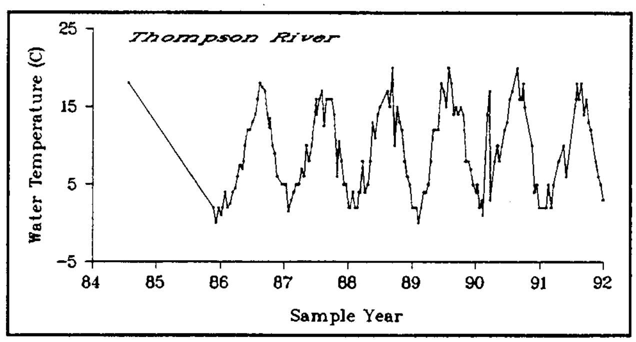


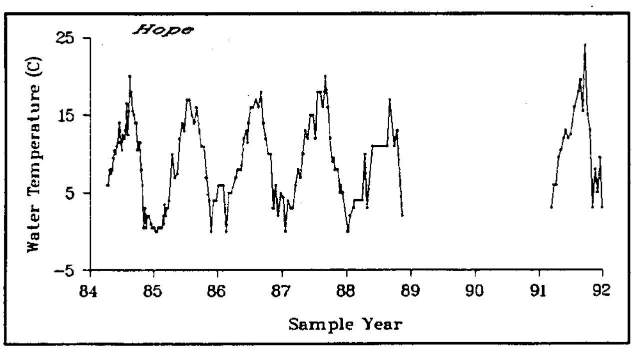



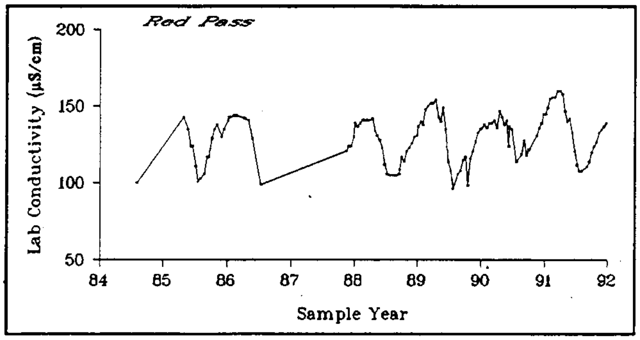



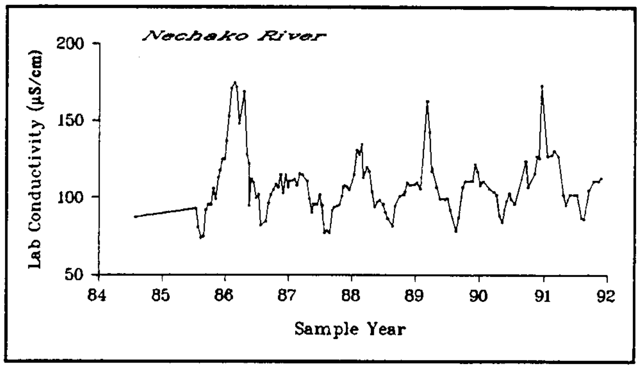



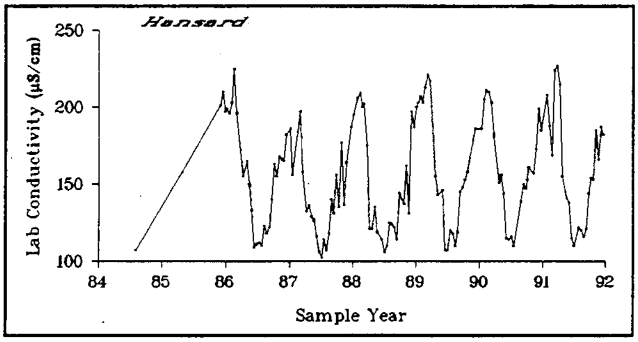



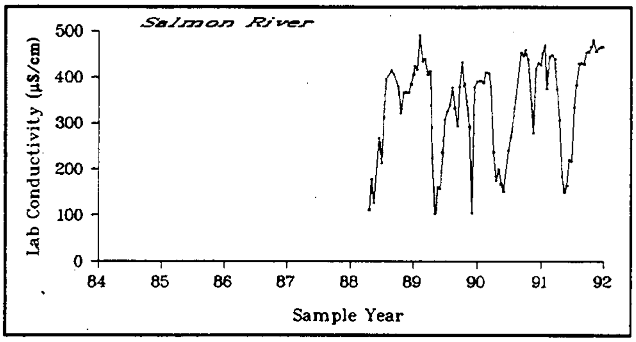



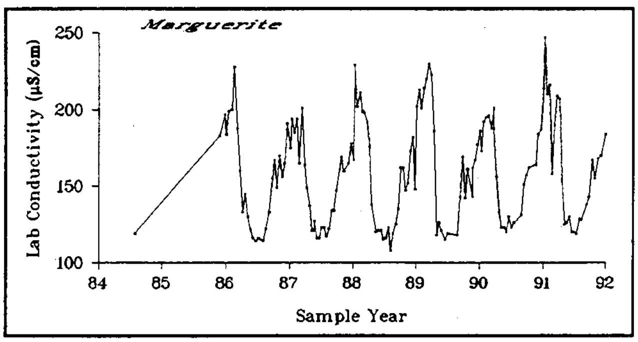

Time Series plots of Environment Canada Water Temperature data for the period 1984-1992 at selected sites in the Fraser River basin.

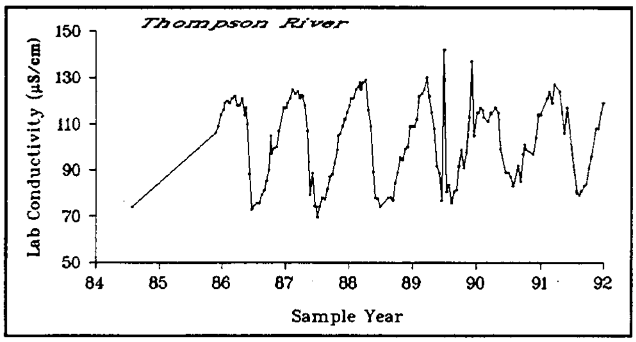


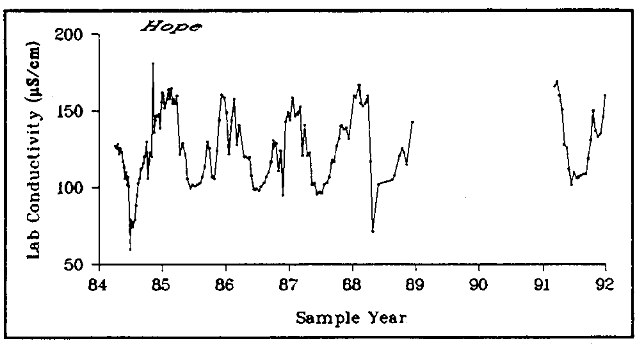



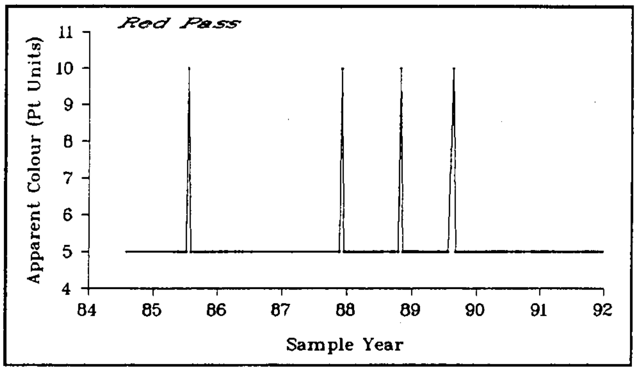



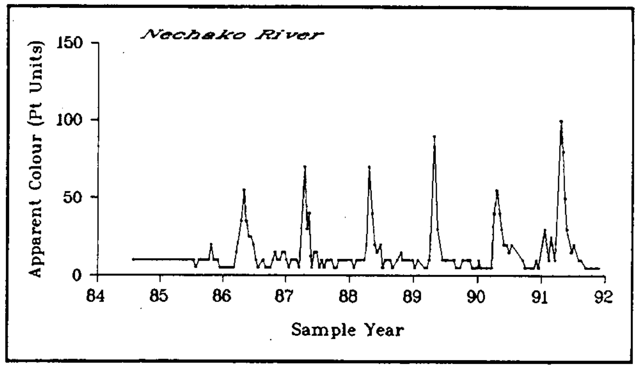



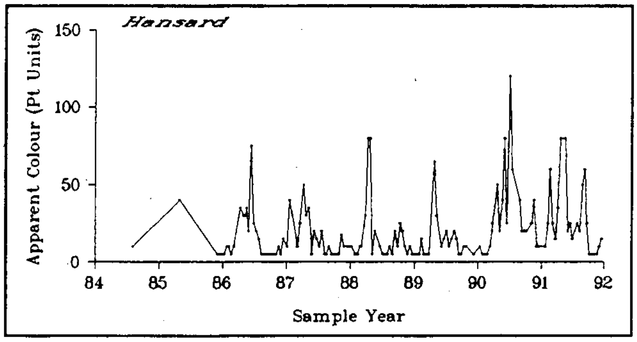



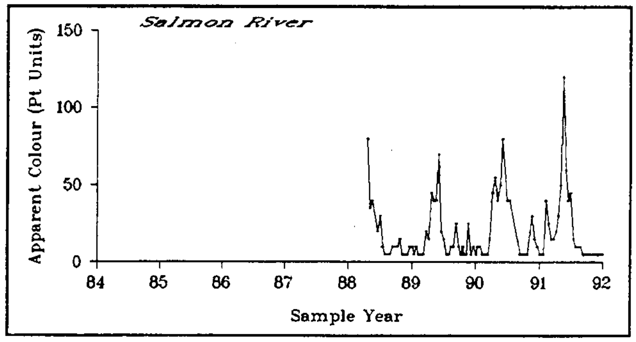



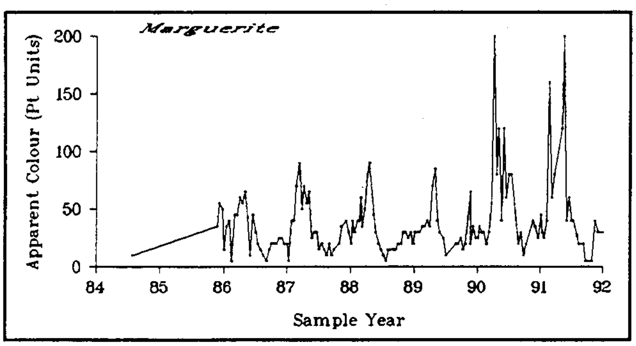

Time Series plots of Laboratory Specific Conductivity Data for the period 1984-1992 at selected sites in the Fraser River basin.

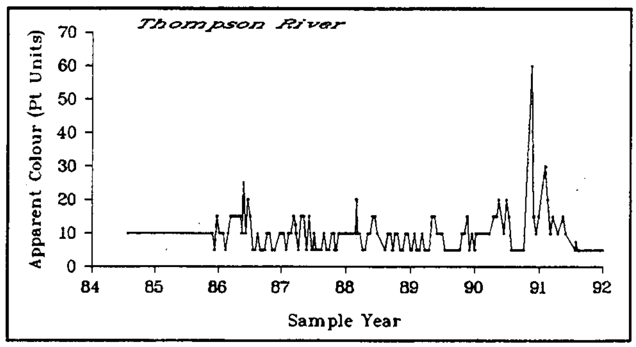


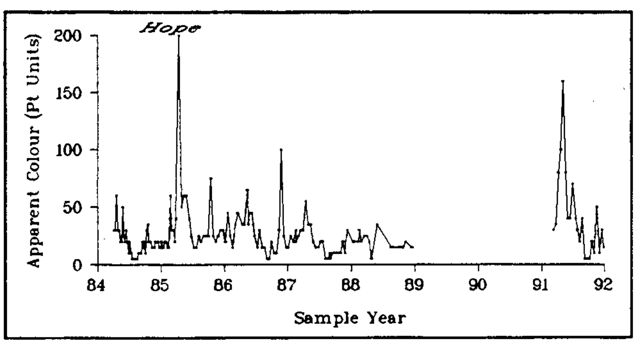



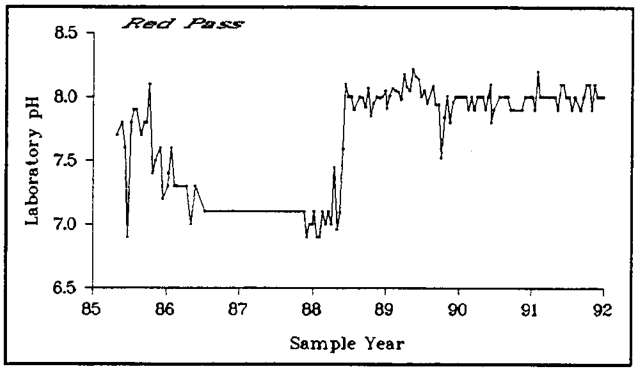



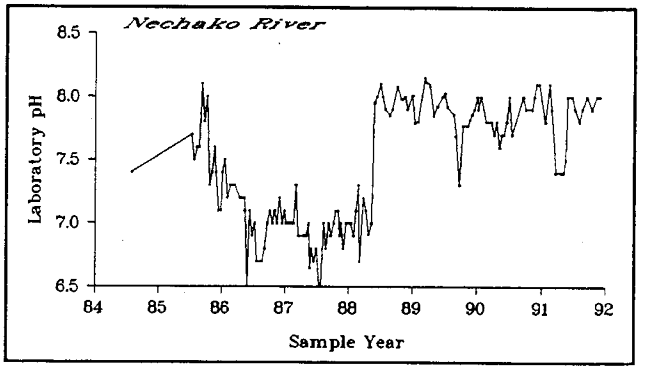



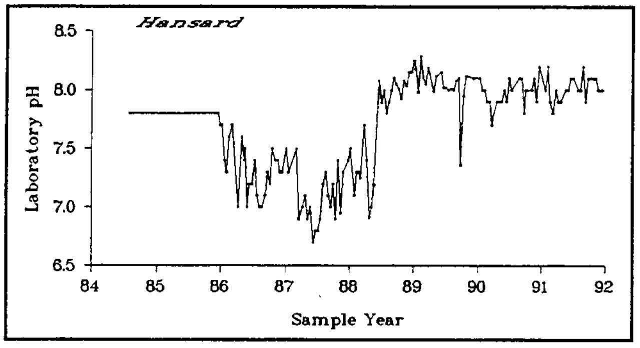



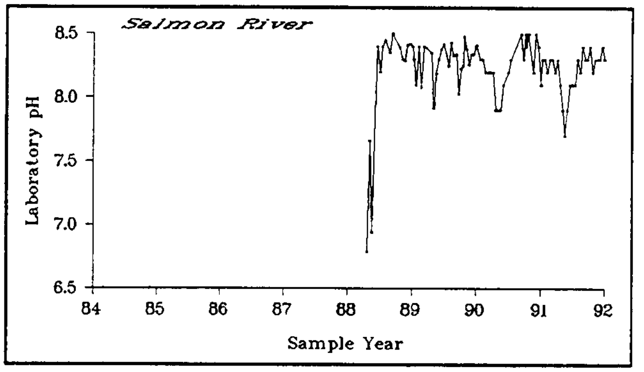



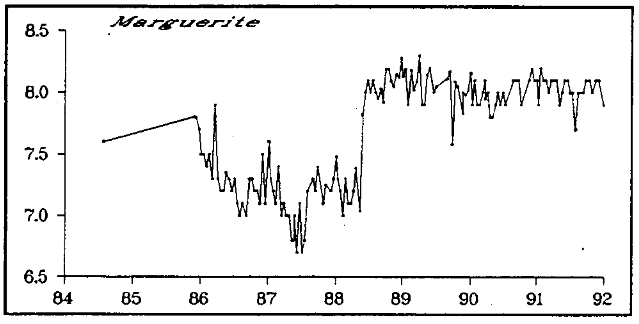

Time Series plots of Environment Canada Apparent Colour Data for the period 1984-1992 at selected sites in the Fraser River basin.

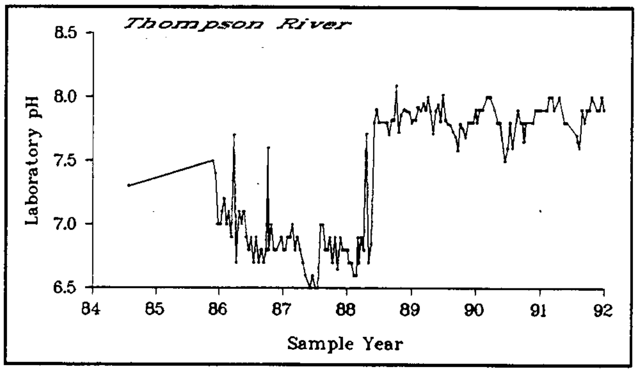


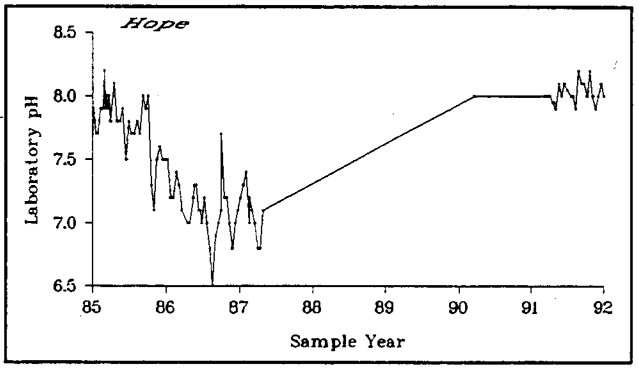



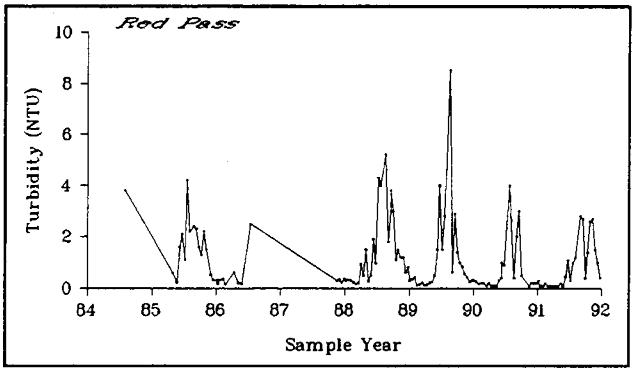



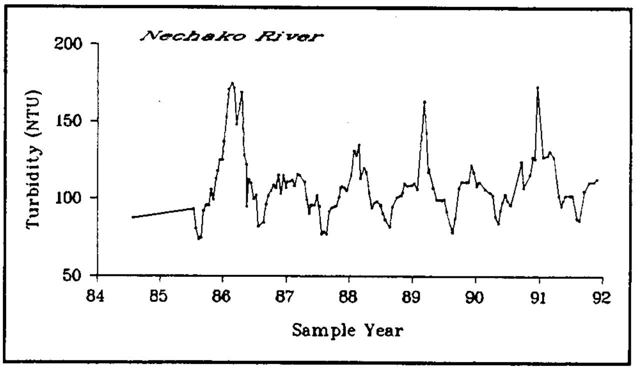



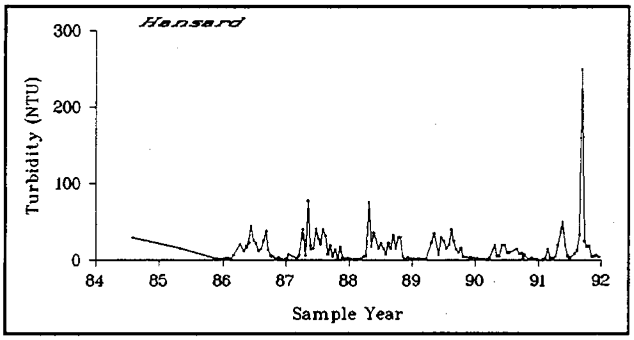



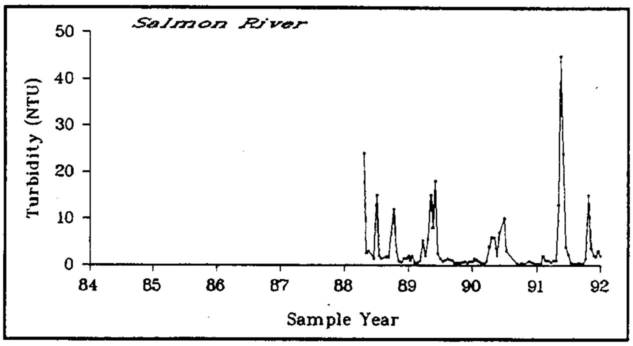



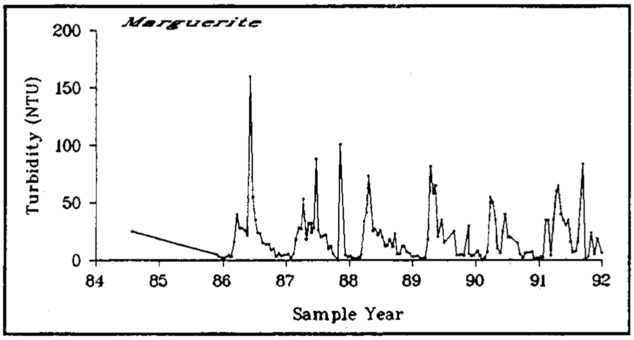

Time Series plots of Environment Canada Laboratory pH data for the period 1984-1992 at selected sites in the Fraser River basin.

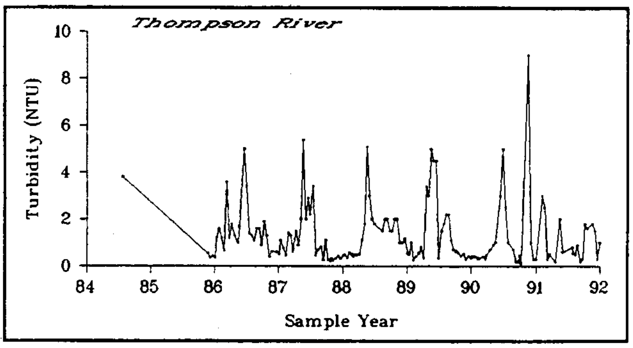


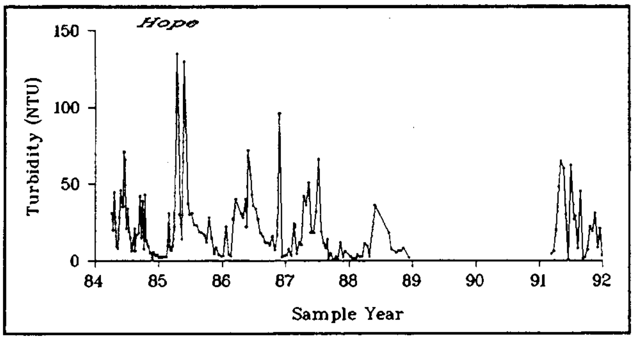



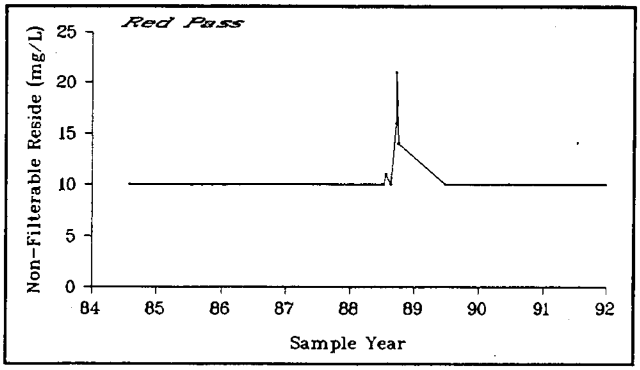



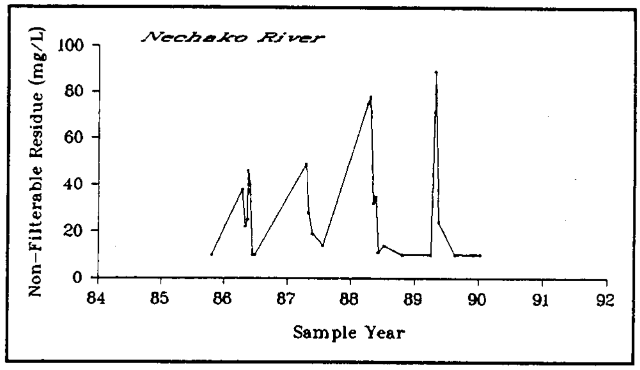



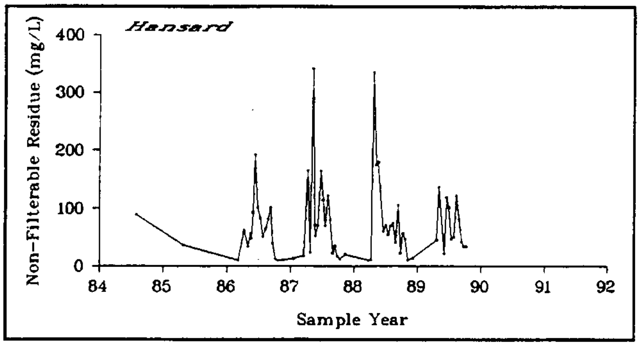



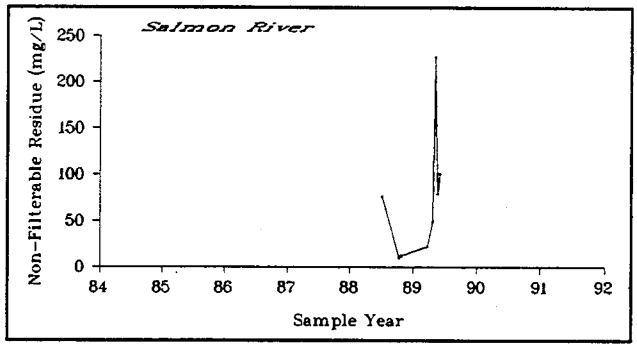



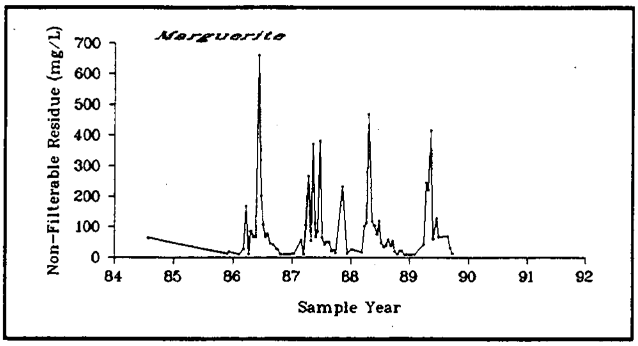

Time Series plots of Environment Canada Turbidity Data for the period 1984-1992 at selected sites in the Fraser River basin.

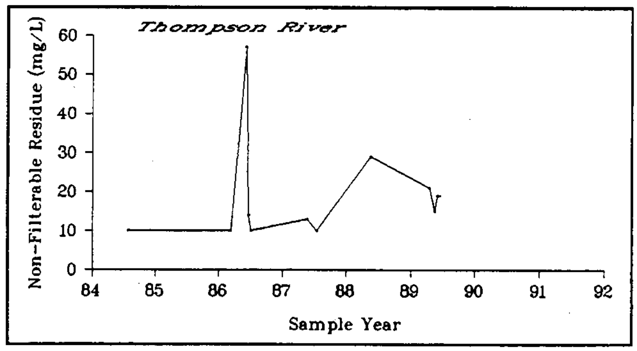


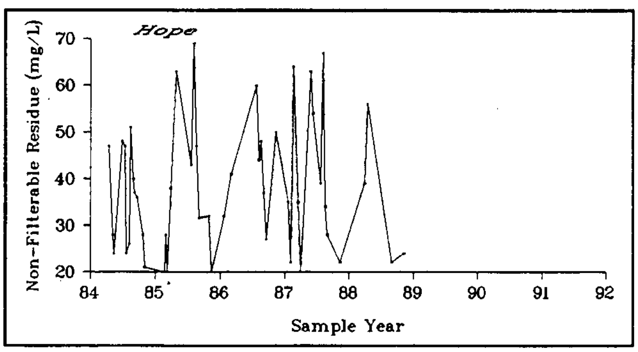



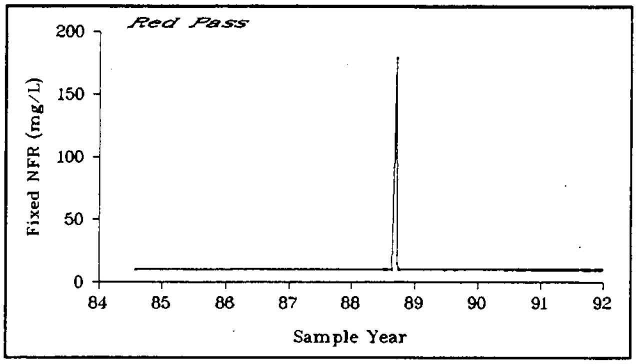



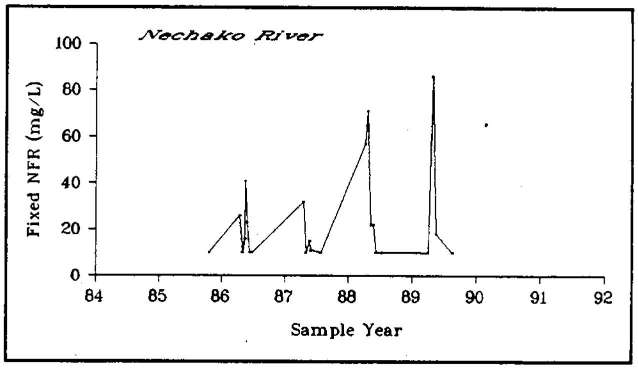



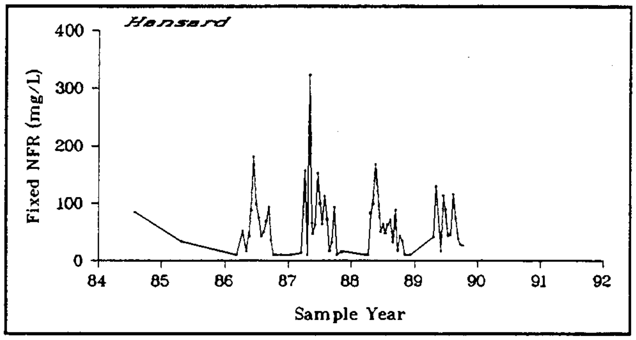



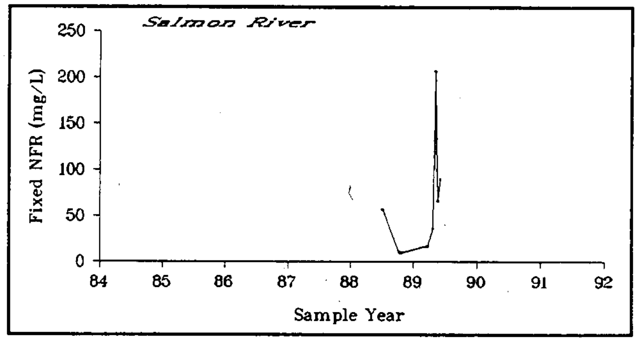



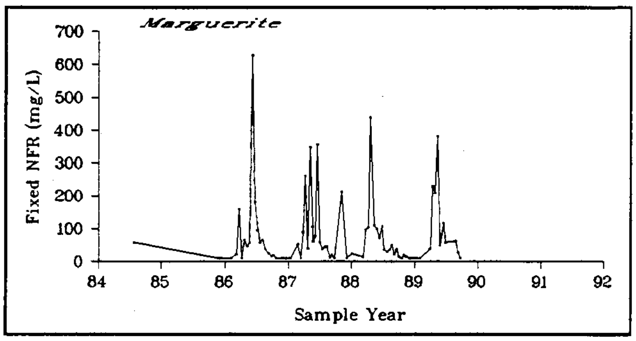

Time Series plots of Environment Canada Non-Filterable Residue Data for the period 1984-1992 at selected sites the Fraser River basin.

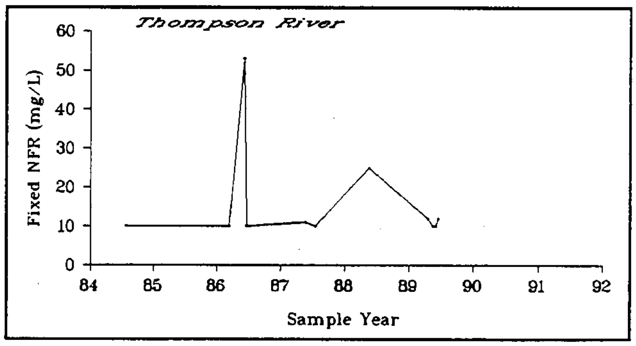


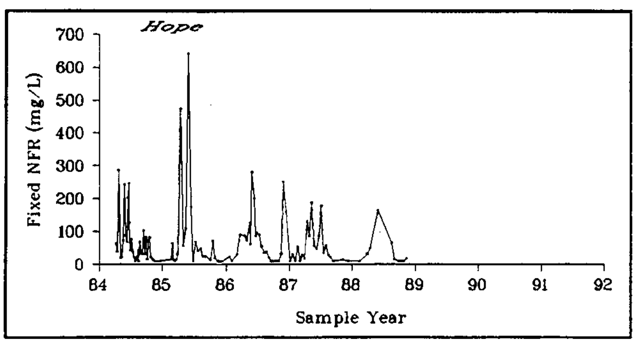



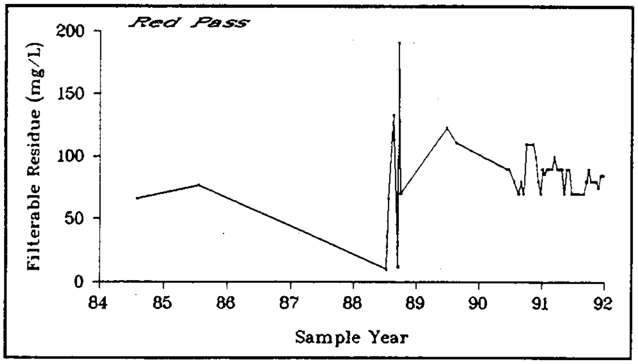



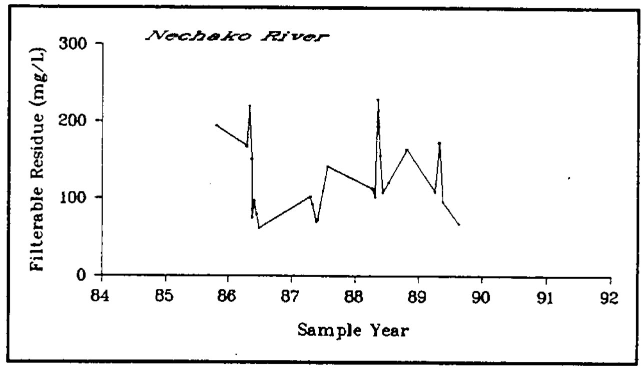



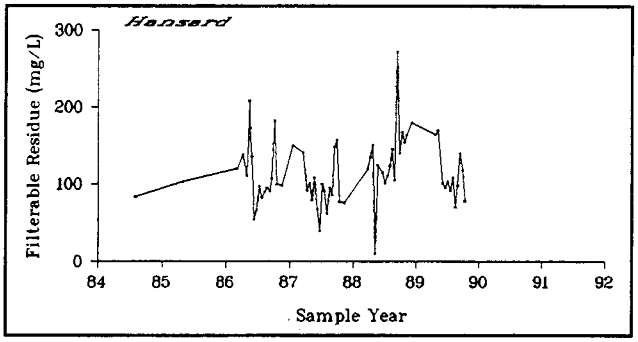



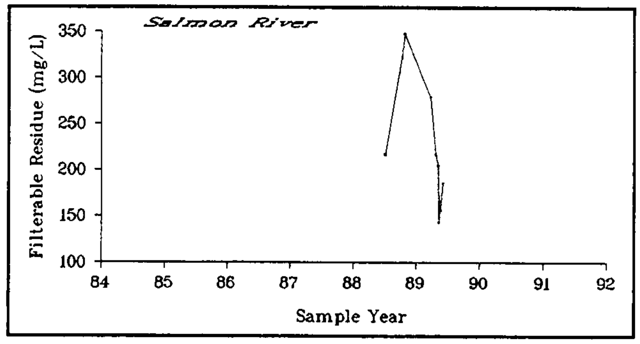



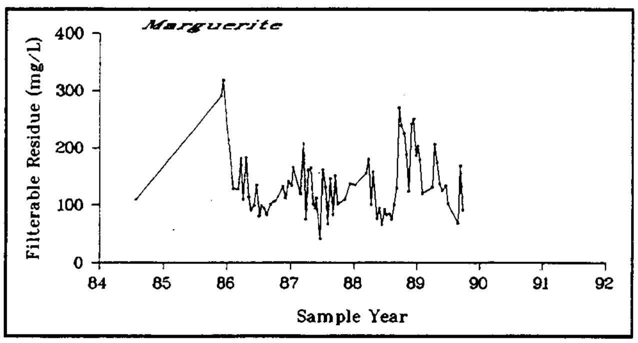

Time Series plots of Environment Canada Fixed Non-Filterable Residue Data for the period 1984-1992 at selected sites in the Fraser River basin.

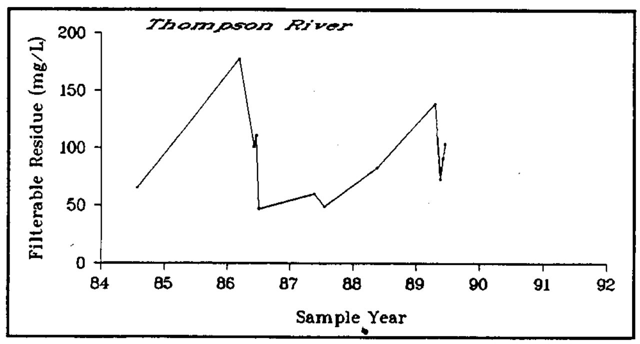


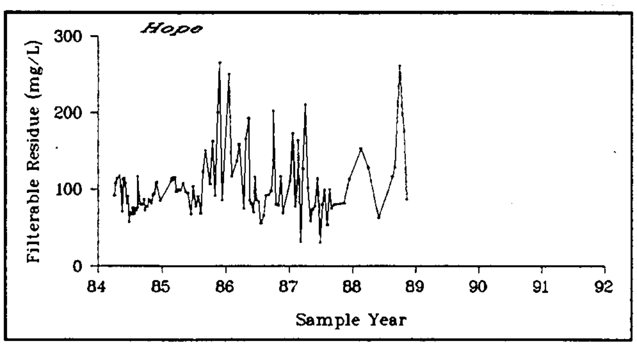



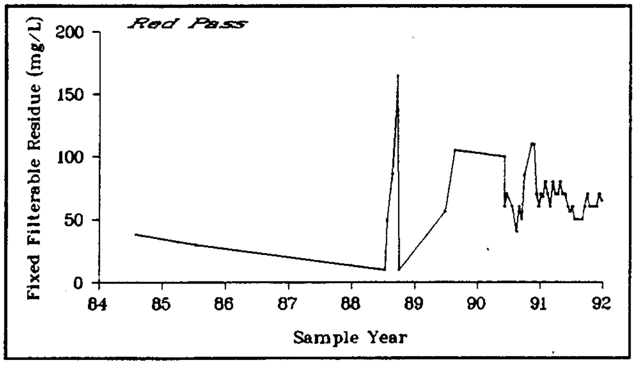



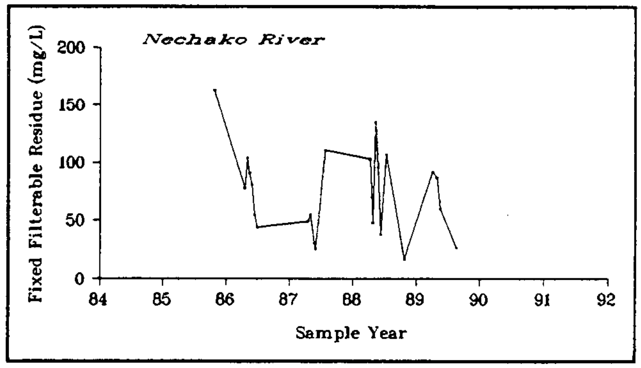



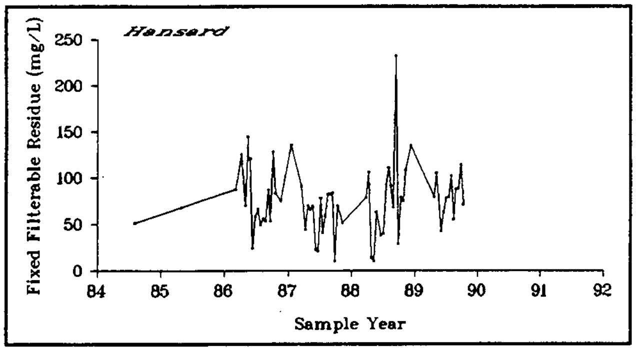



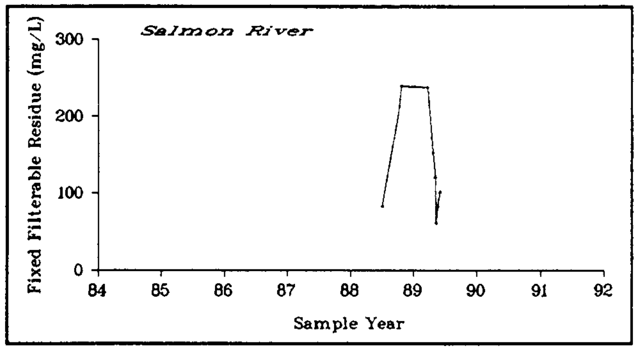



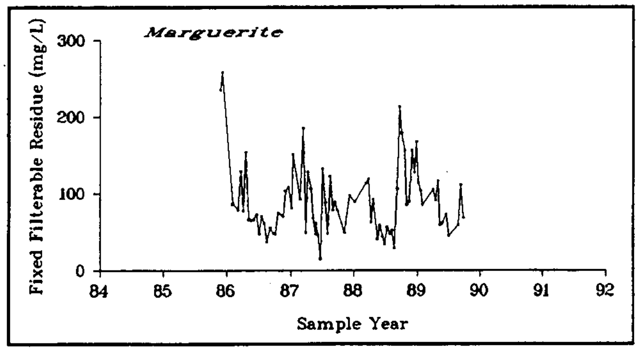

Time Series plots of Environment Canada Filterable Residue Data for the period 1984- 1992 at selected sites in the Fraser River basin.

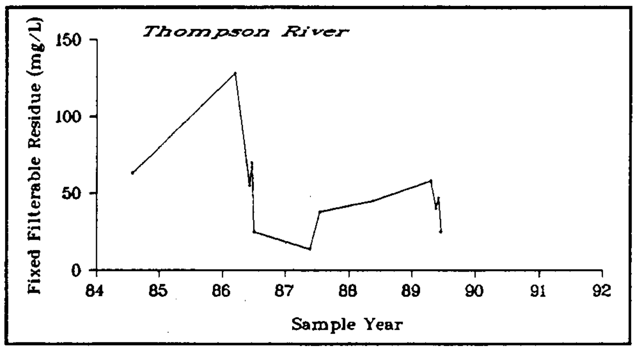


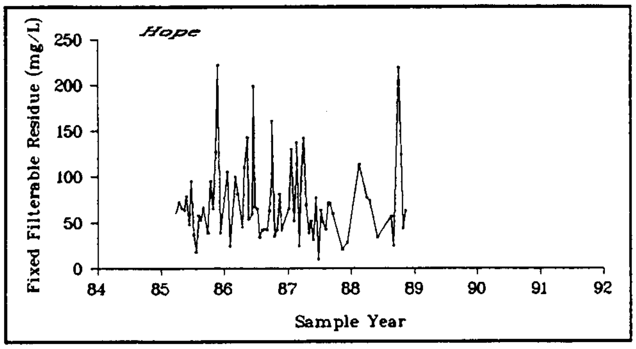



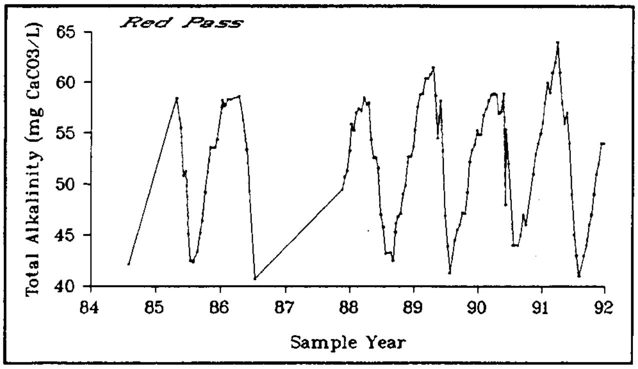



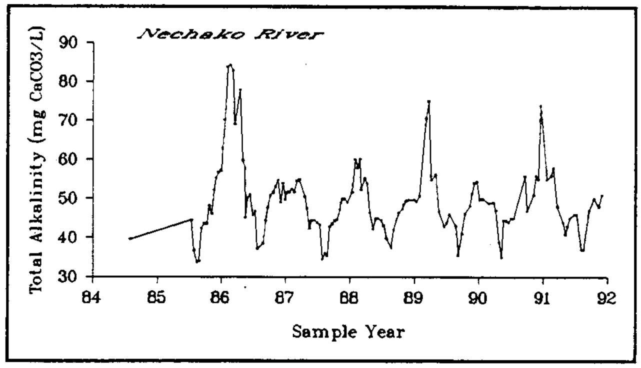



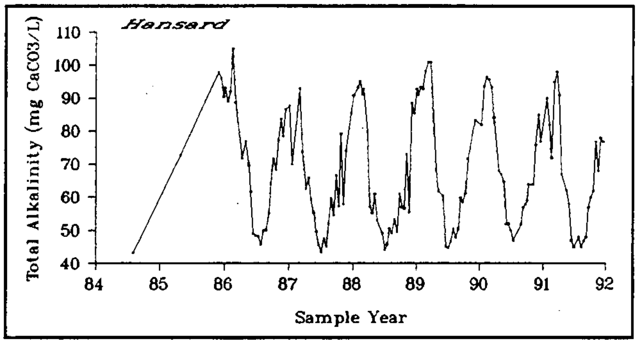



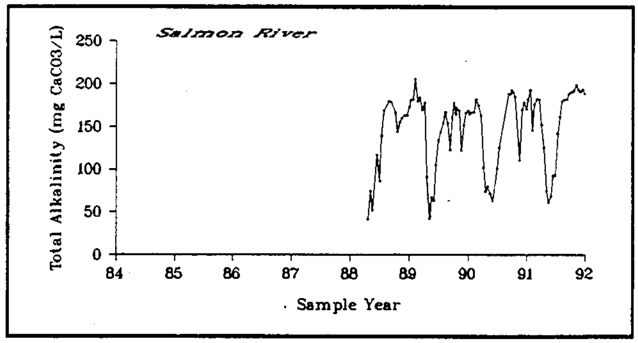



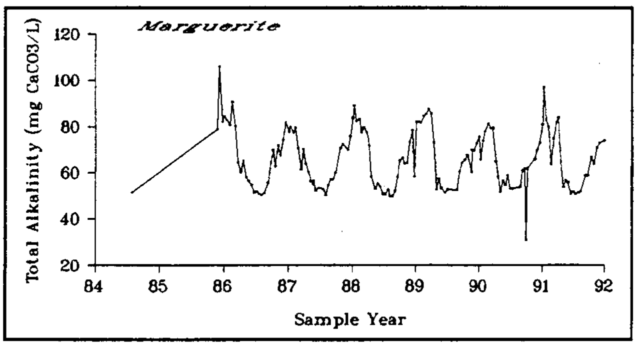

Time Series plots of Fixed Filterable Residue Data for the period 1984-1992 at selected sites in the Fraser River Basin.

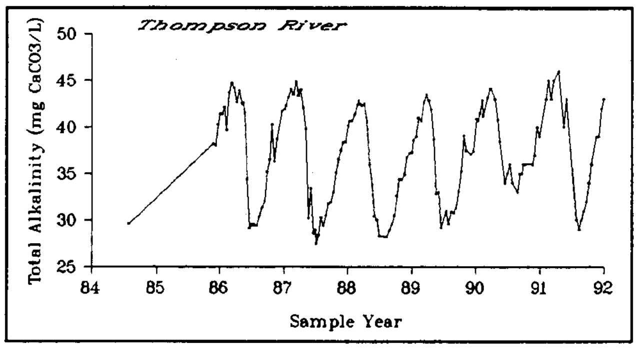


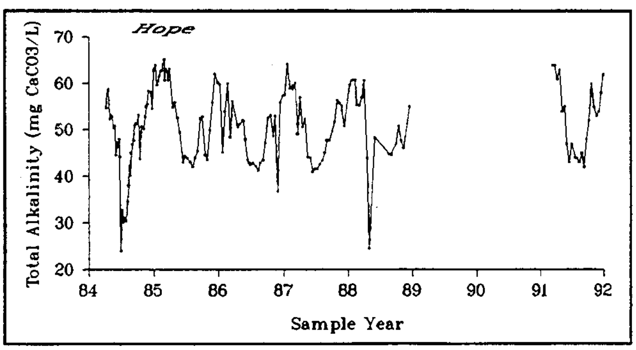



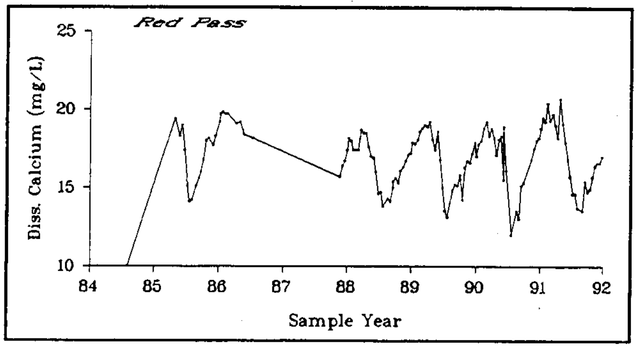



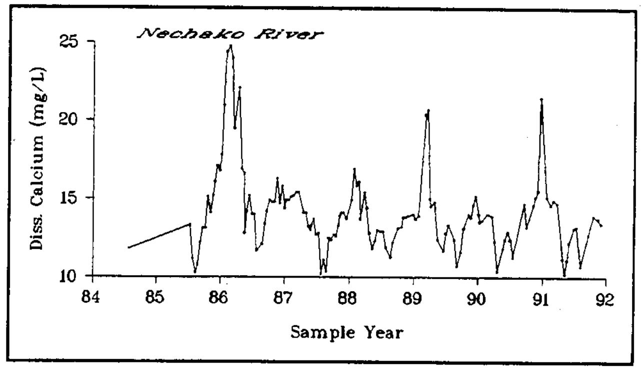



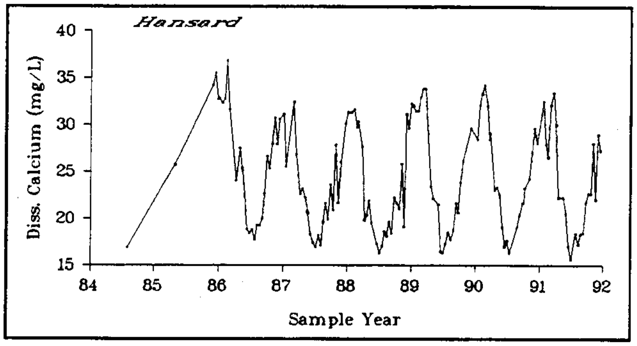



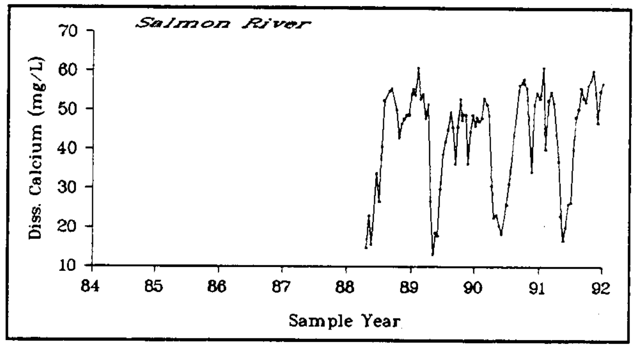



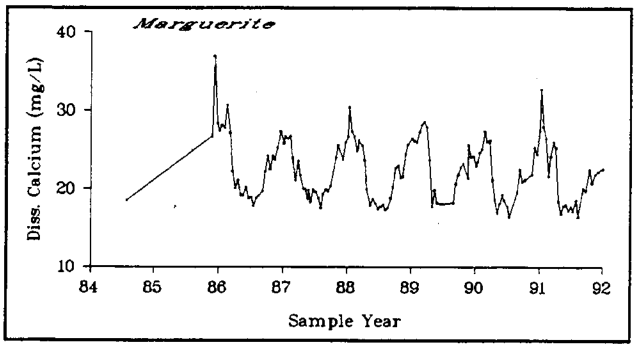

Time Series plots of Environment Canada Total Alkalinity Data for the period 1984-1992 at selected sites in the Fraser River basin.

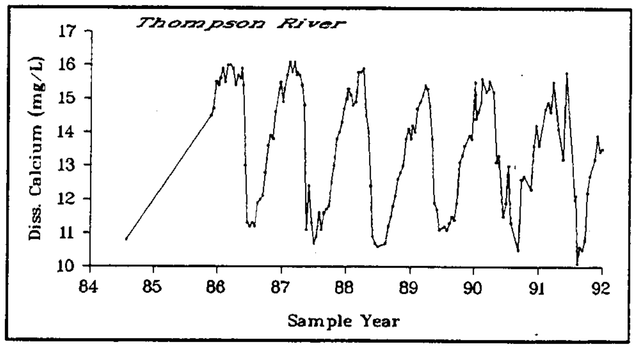


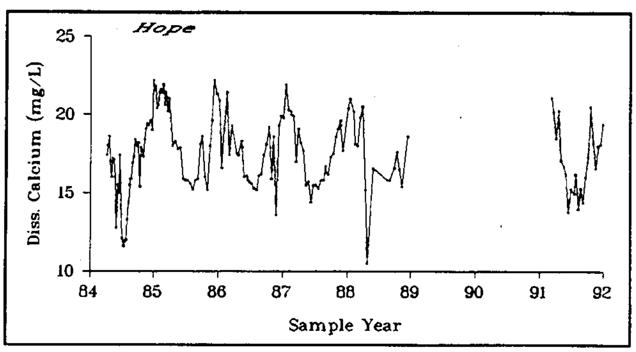



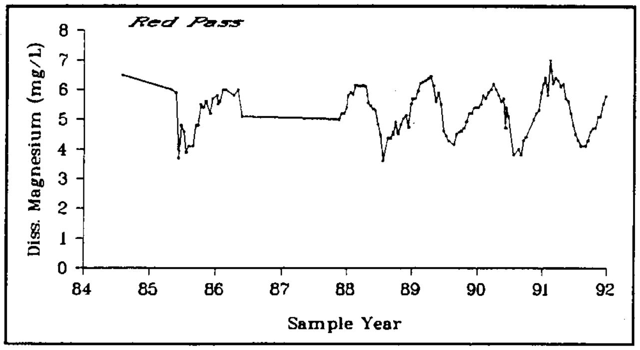



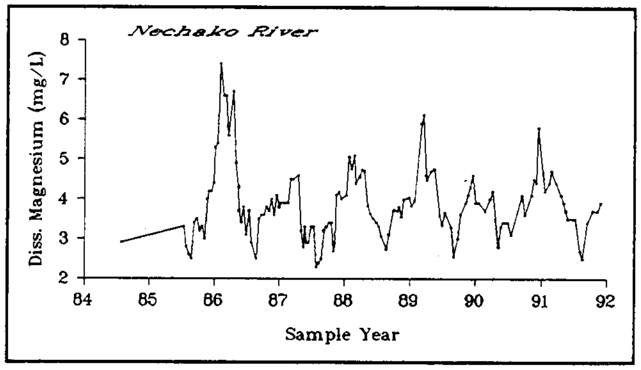



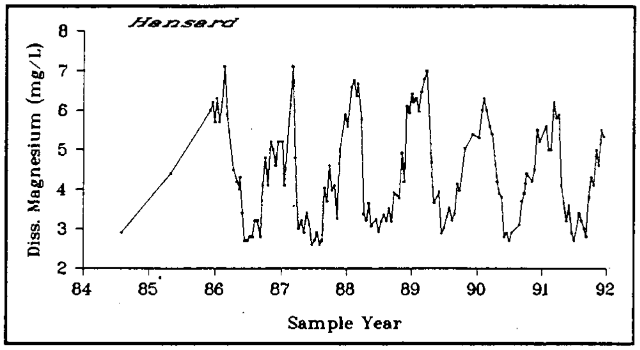



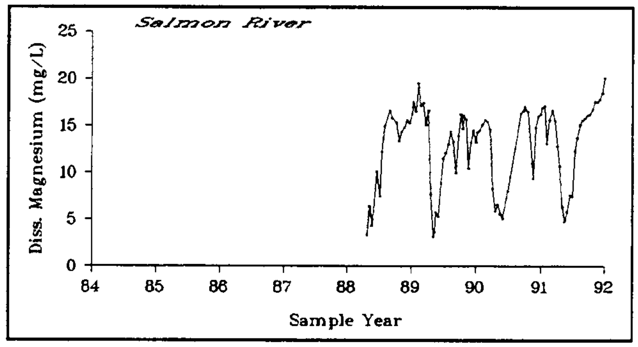



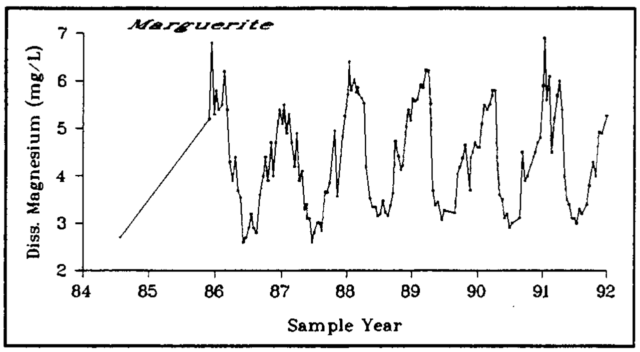

Time Series plots of Environment Canada Dissolved Calcium Data for the period 1984-1992 at selected sites in the Fraser River basin.

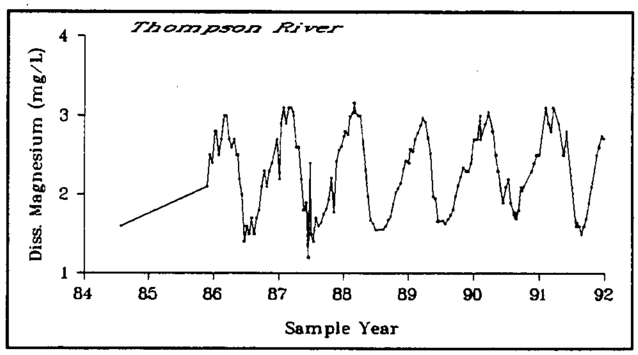


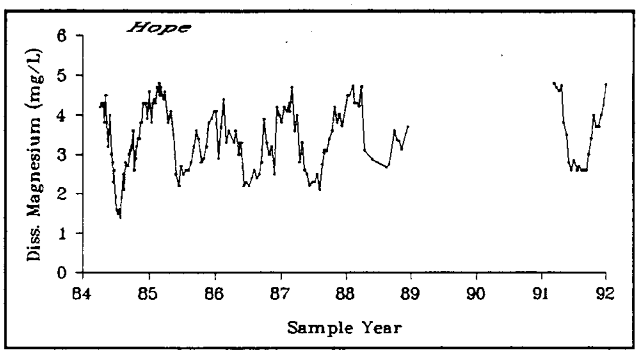



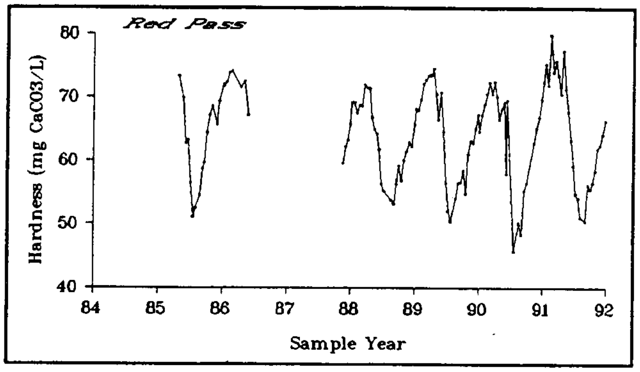



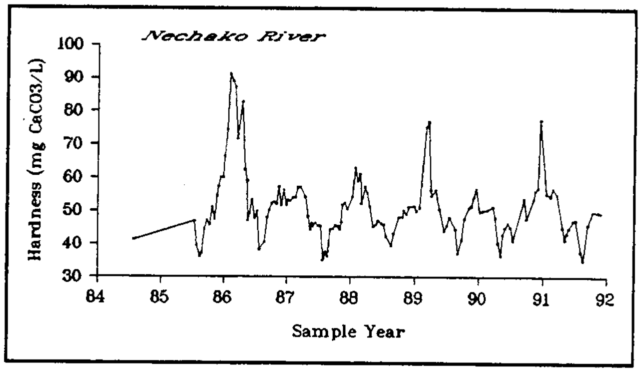



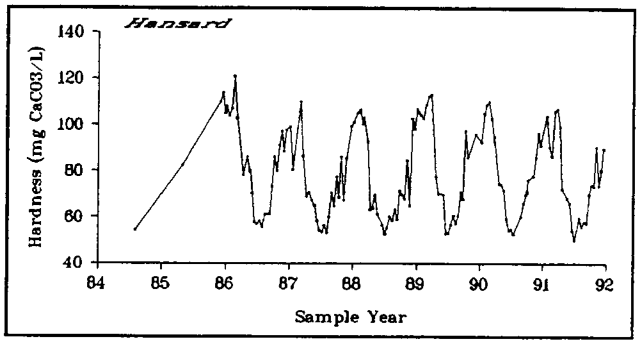



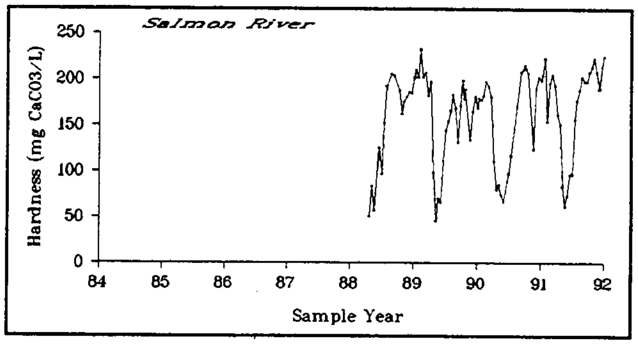



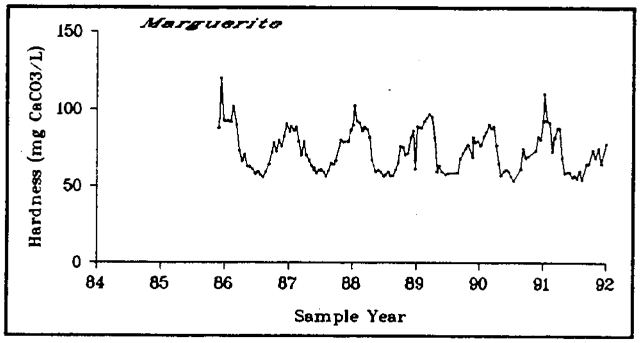

Time Series plots of Dissolved Magnesium Data for the period 1984-1992 at selected sites in the Fraser River basin.

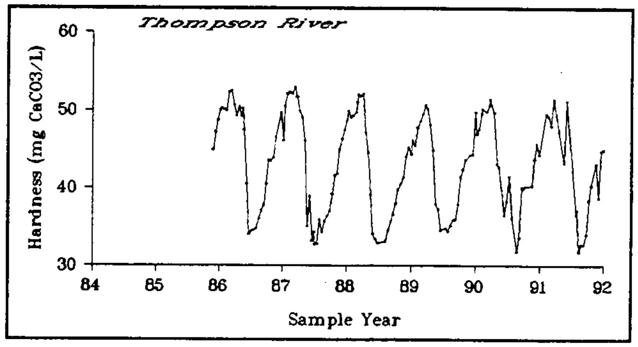


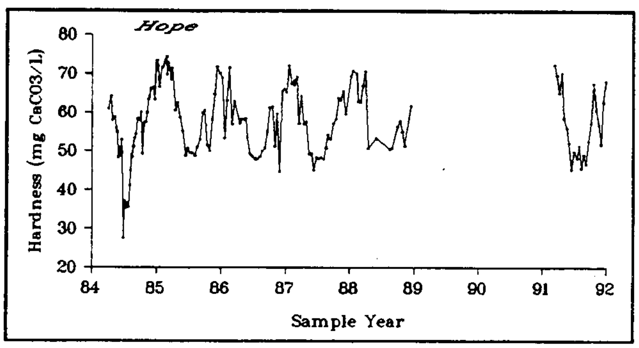



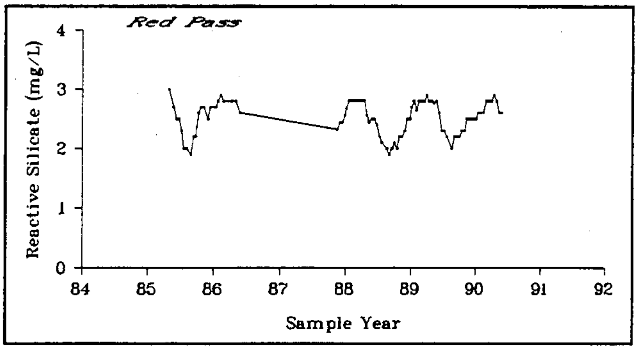



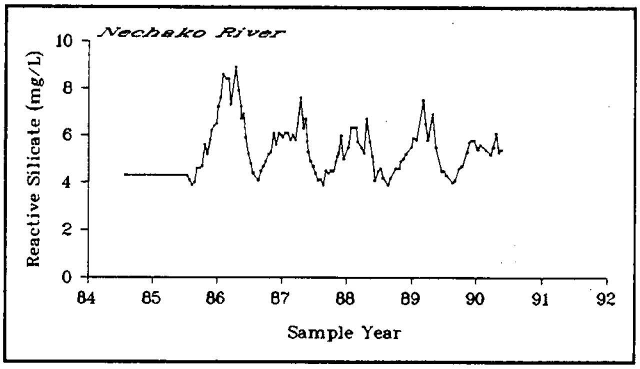



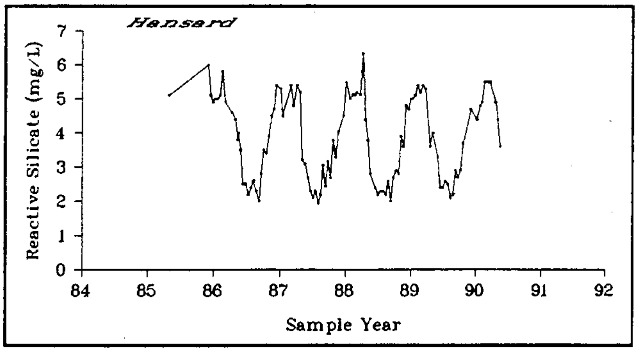



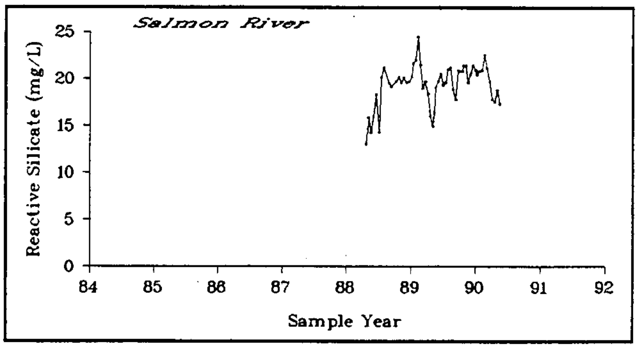



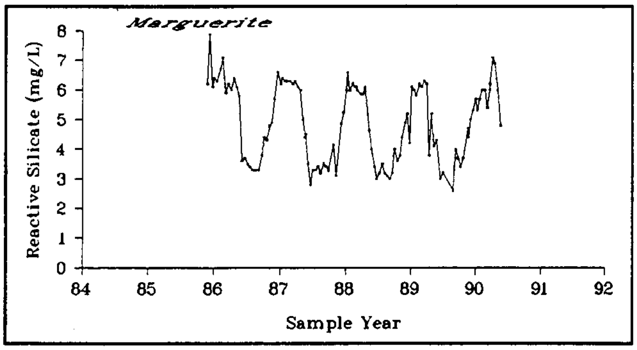

Time Series plots of Total Hardness data for the period 1984-1992 at selected sites in the Fraser River Basin.

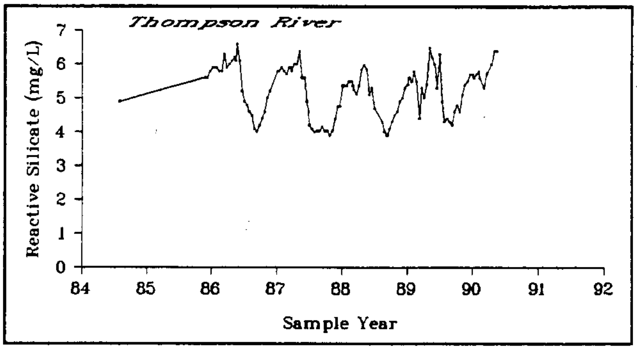


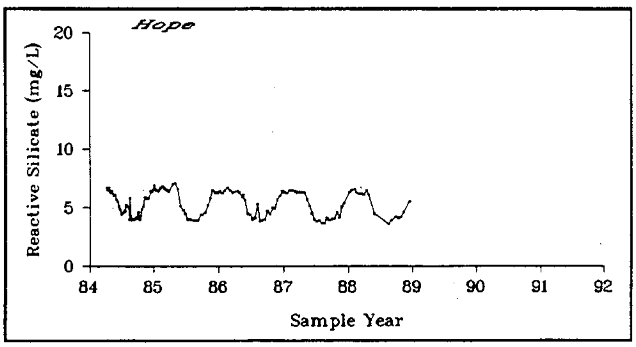



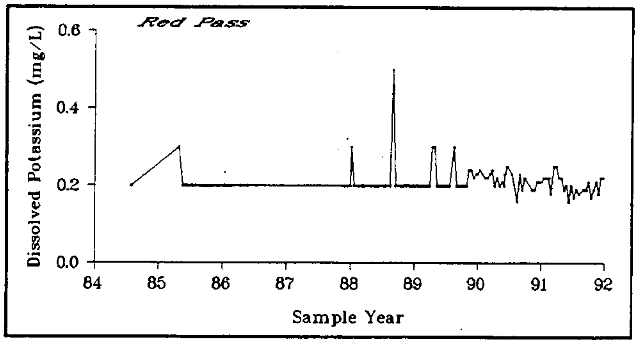



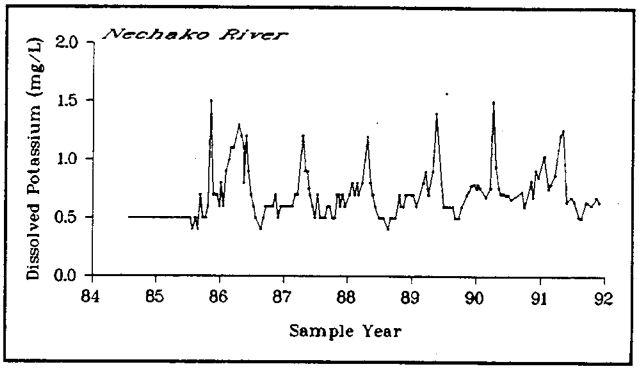



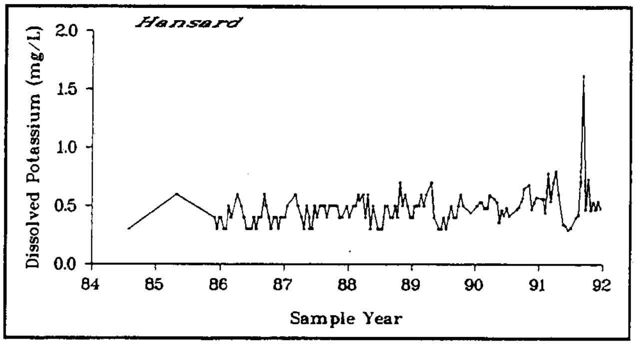



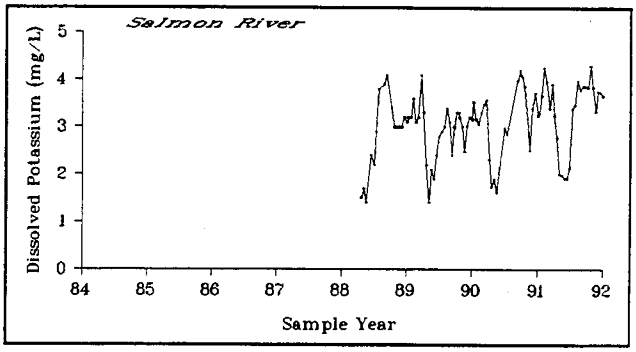



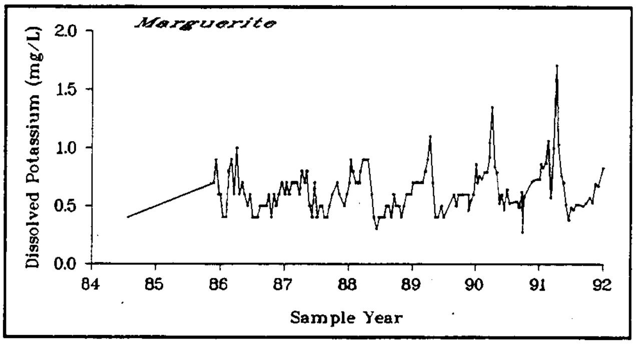

Time Series plots of Environment Canada Laboratory Dissolved Silicate for the period 1984-1992 at selected sites in the Fraser River basin.

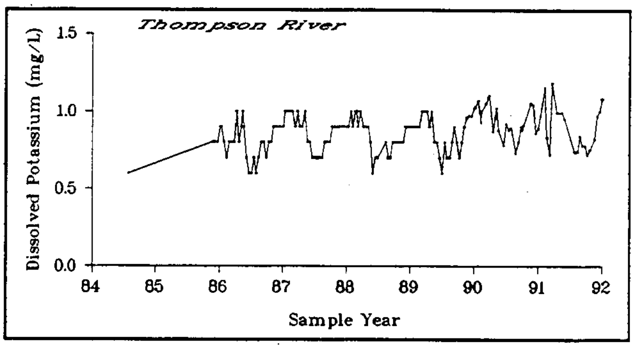


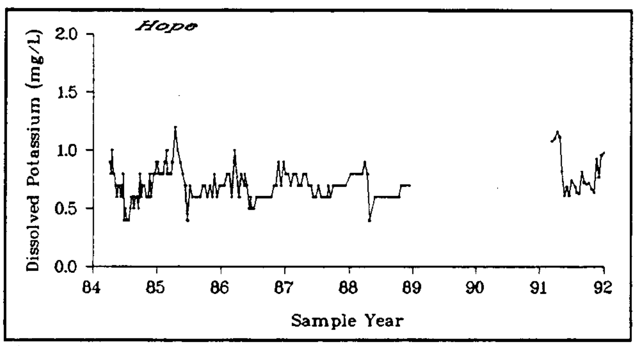



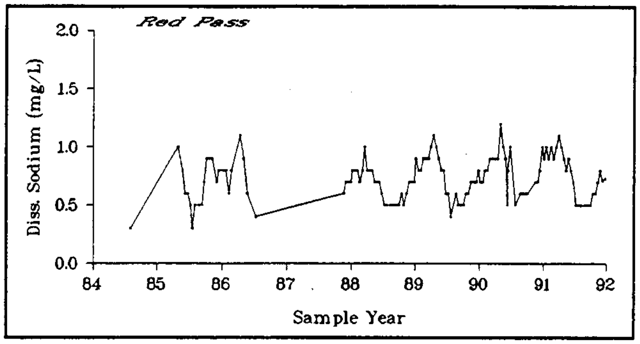



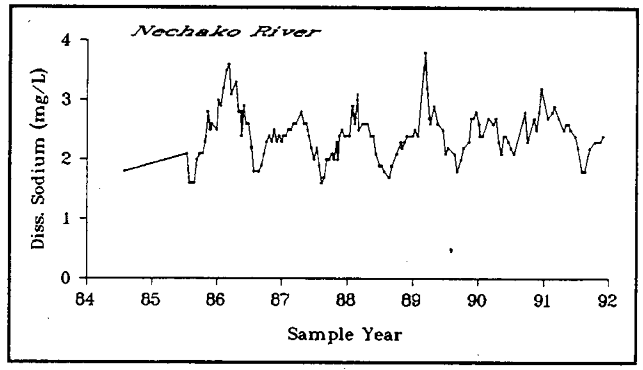



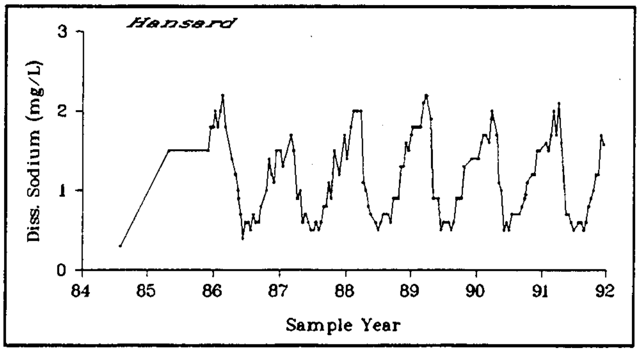



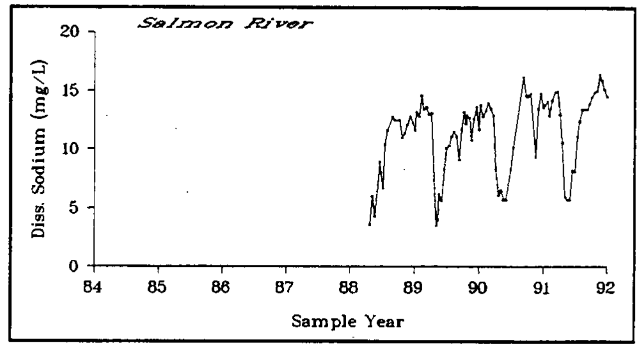



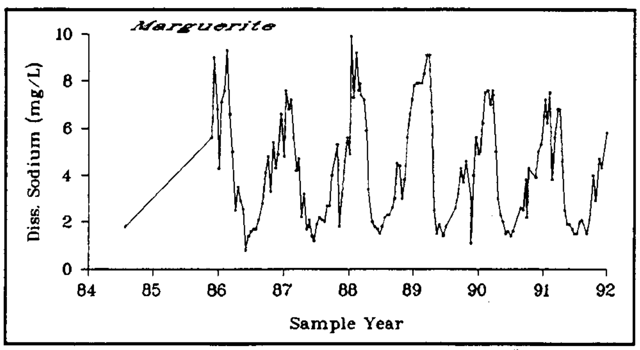

Time Series plots of Environment Canada Dissolved Potassium Data for the period 1984-1992 at selected sites in the Fraser River basin.

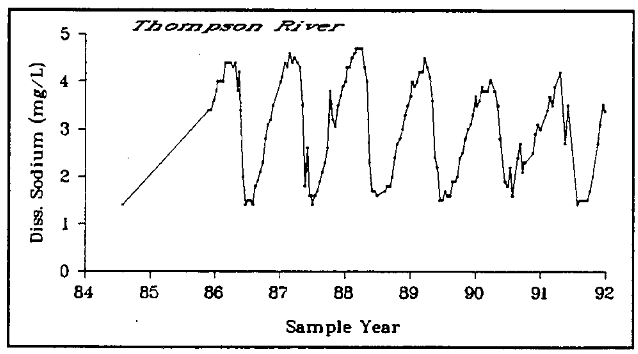


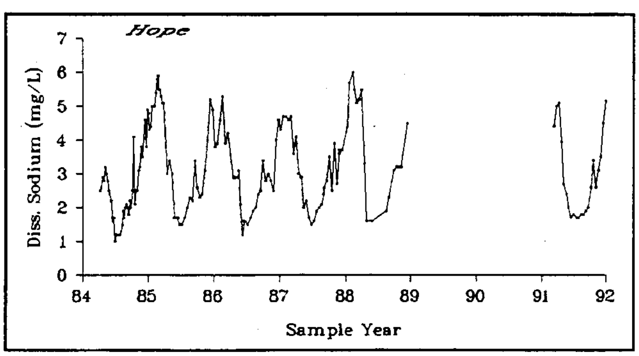



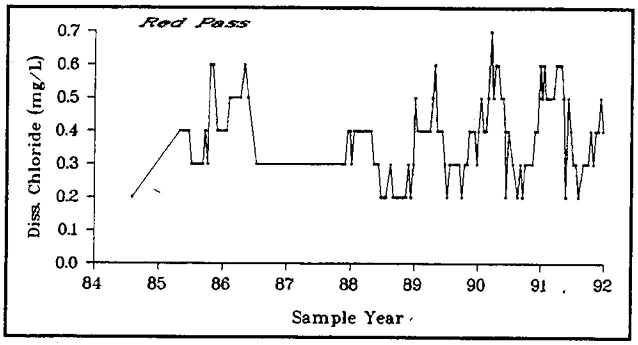



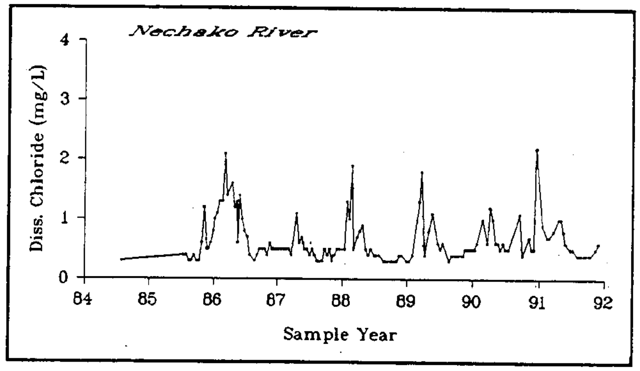



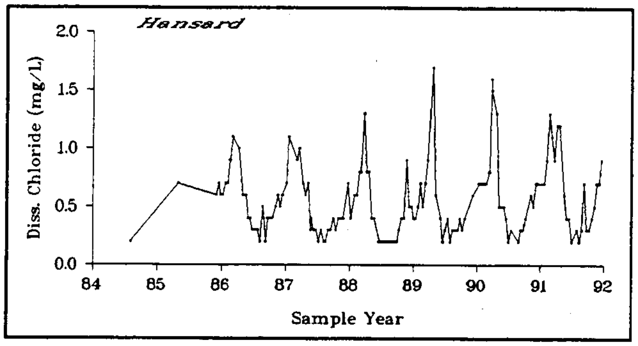



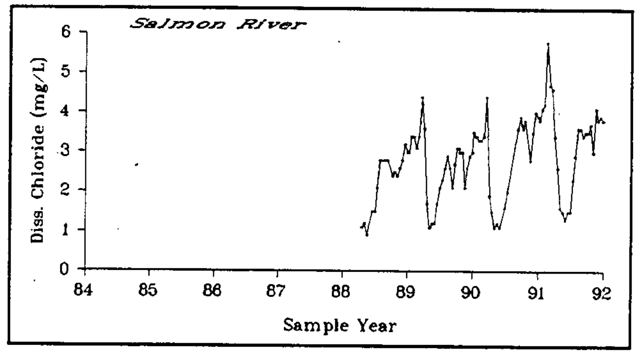



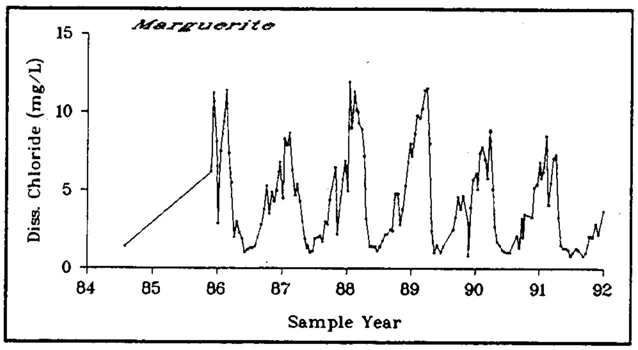

Time Series plots of Environment Canada Dissolved Sodium Data for the period 1984-1992 at selected sites in the Fraser River basin.

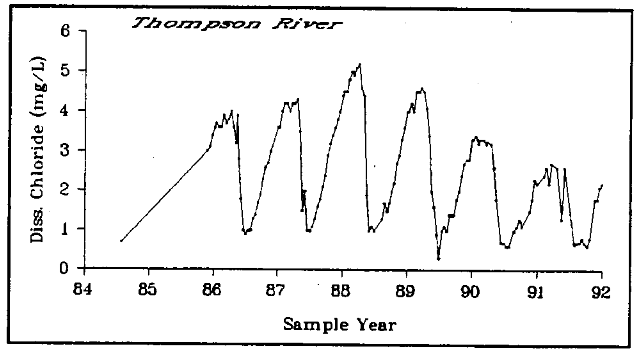


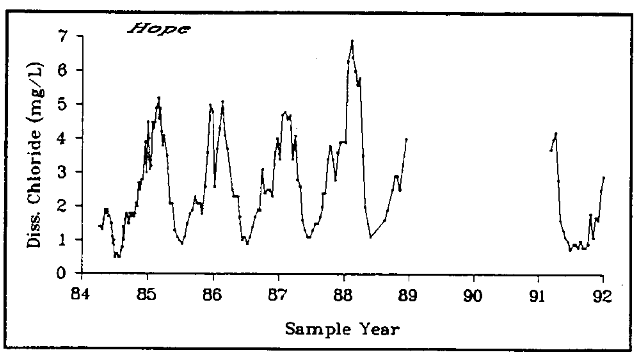



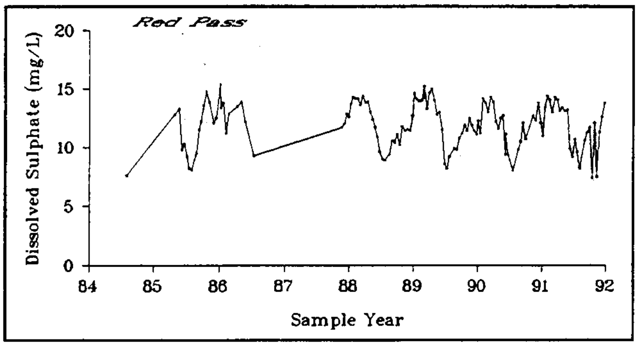



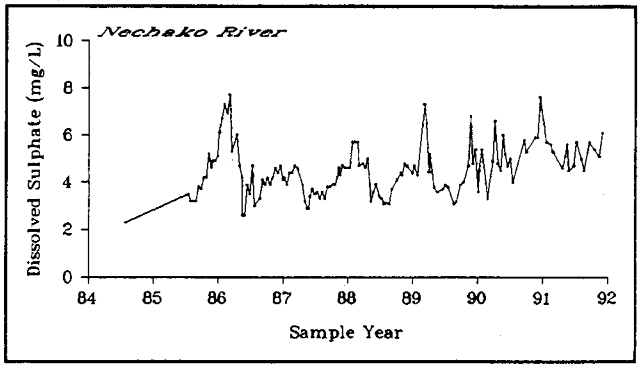



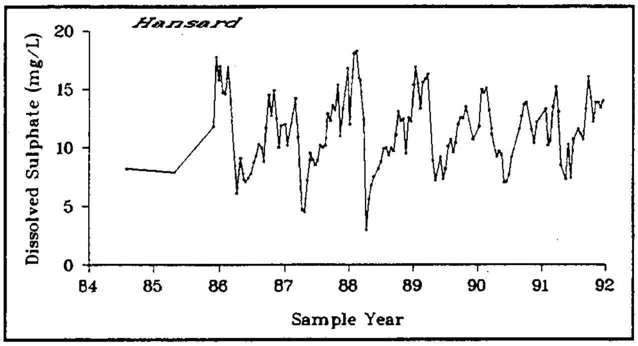



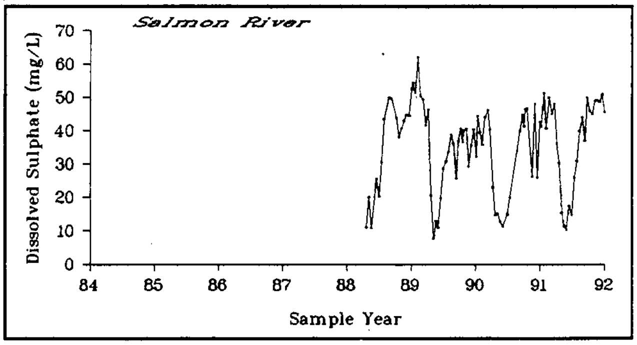



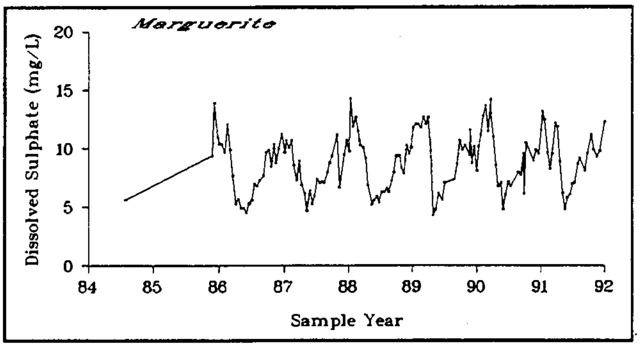

Time Series plots of Environment Canada Dissolved Chloride Data for the period 1984-1992 at selected sites in the Fraser River basin.

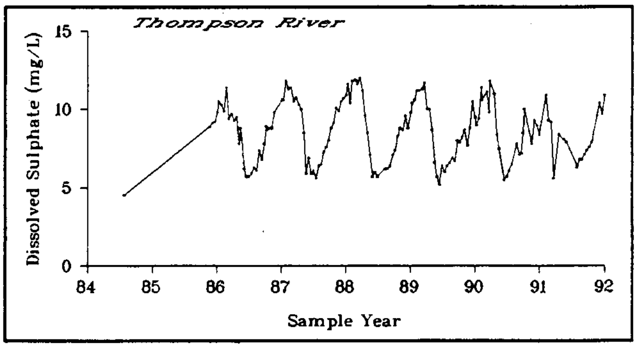


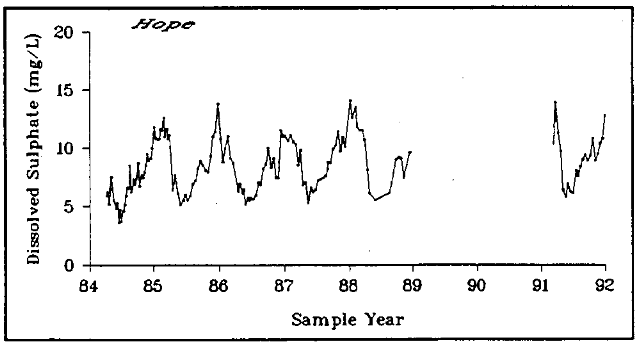



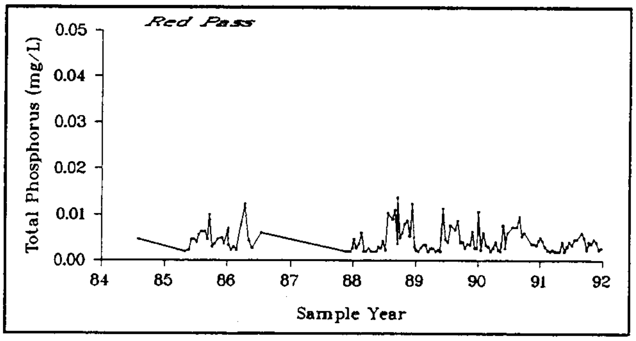



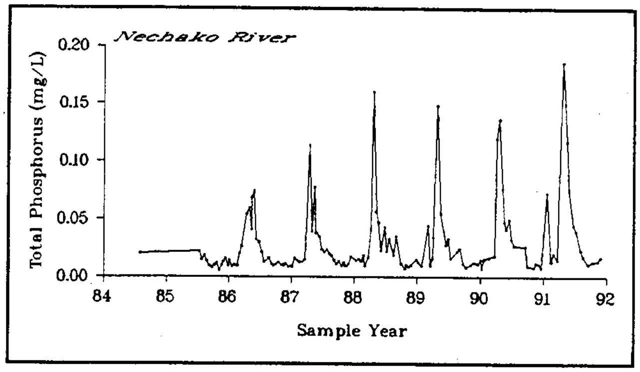



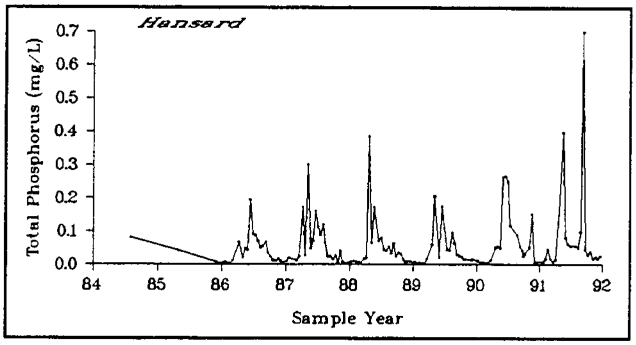



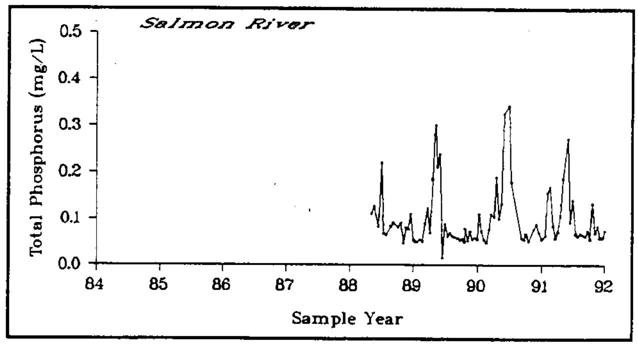



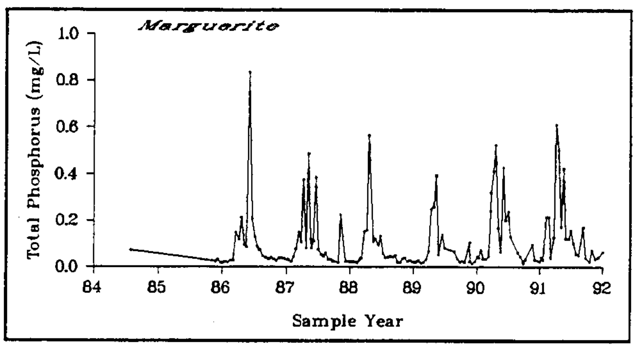

Time Series plots of Environment Canada Dissolved Sulphate Data for the period 1984-1992 at selected sites in the Fraser River basin.

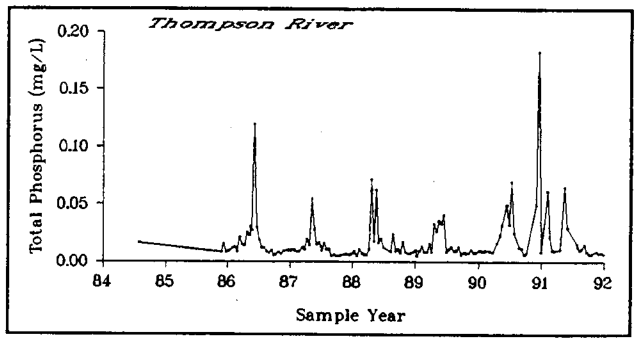


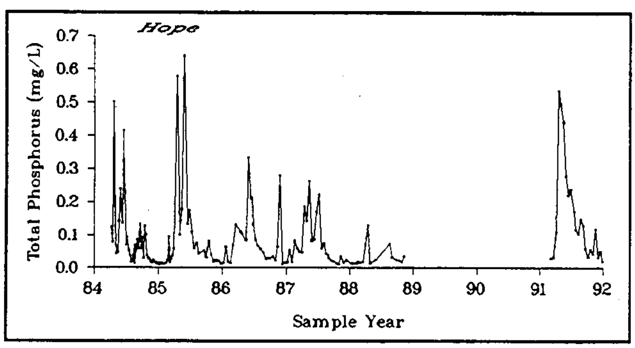



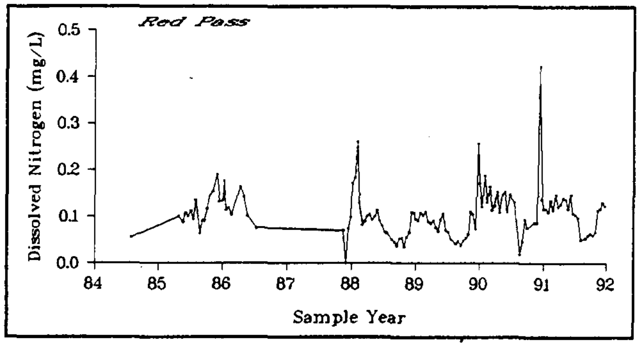



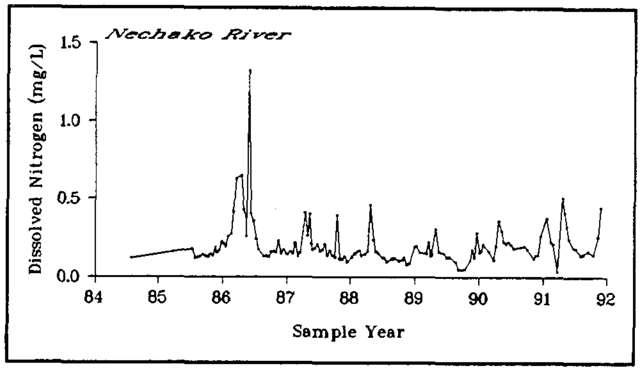



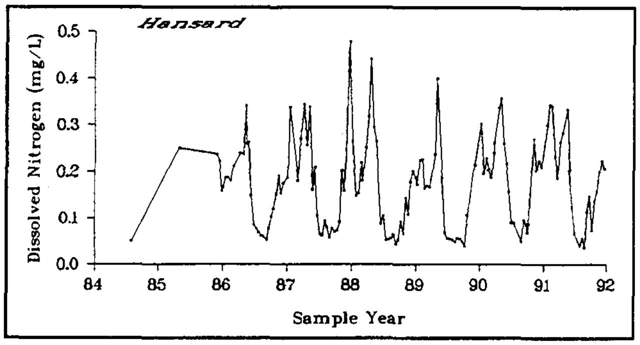



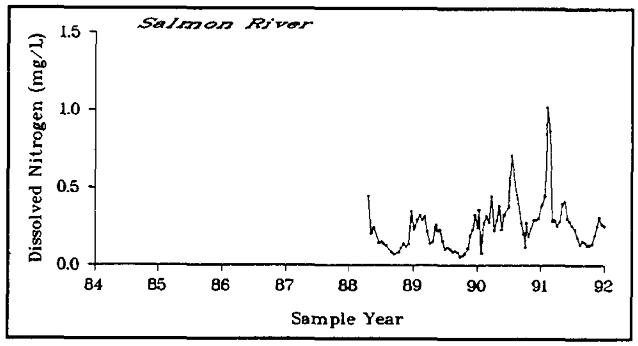



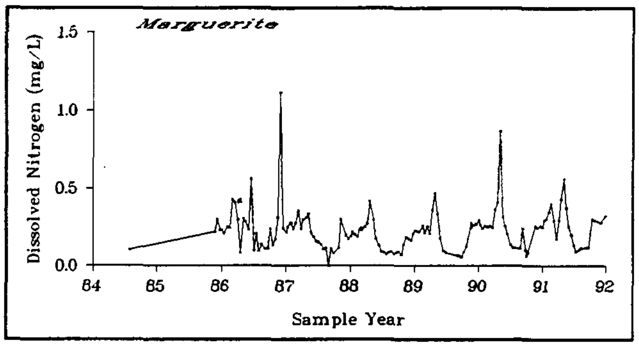

Time Series plots of Environment Canada Total Phosphorus Data for the period 1984-1992 at selected sites in the Fraser River basin.

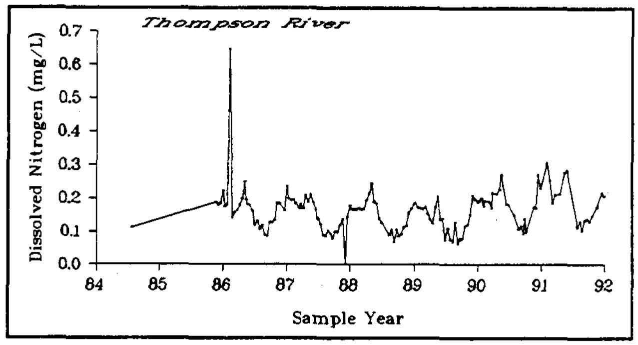


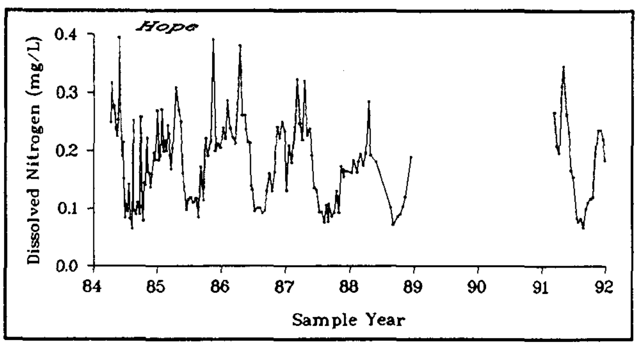



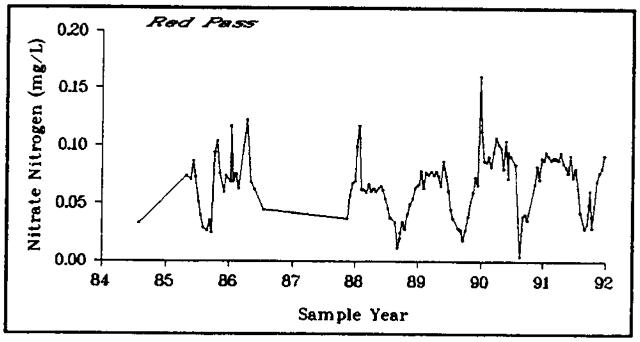



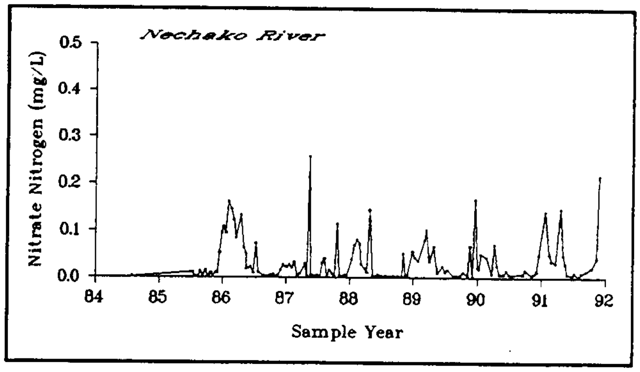



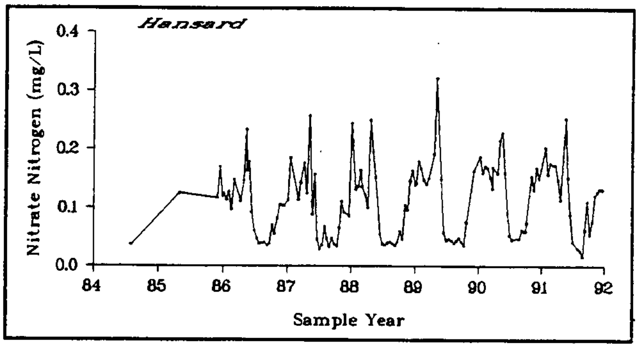



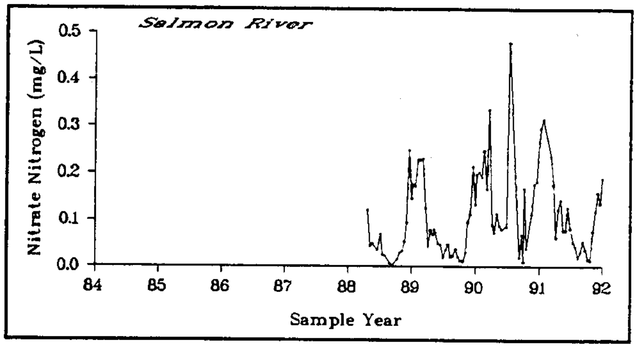



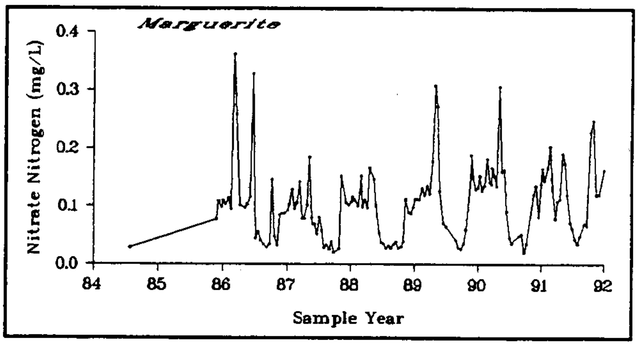

Time Series plots of Environment Canada Laboratory Dissolved Nitrogen for the period 1984-1992 at selected sites in the Fraser River basin.

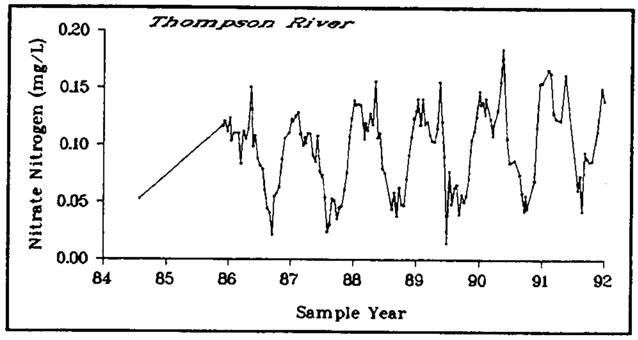


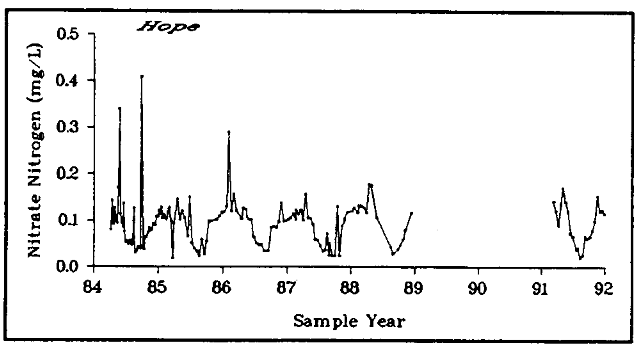



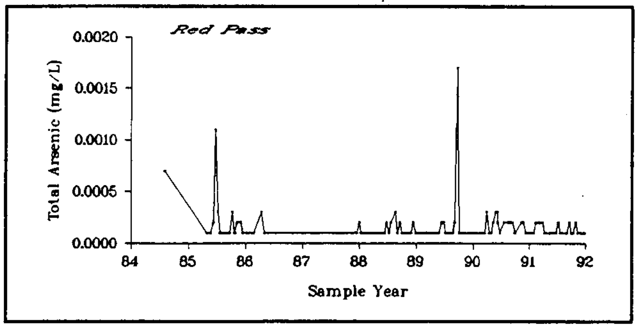



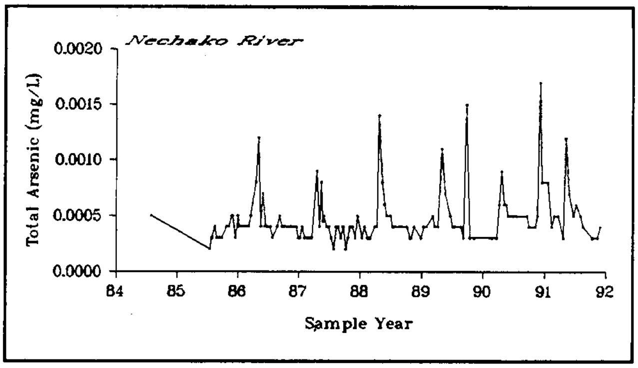



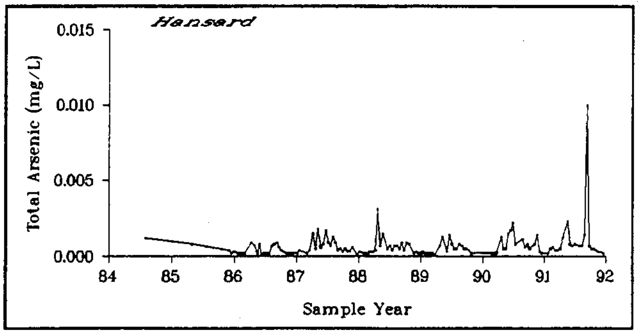



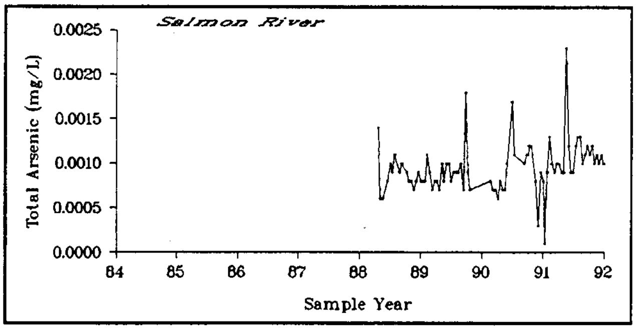



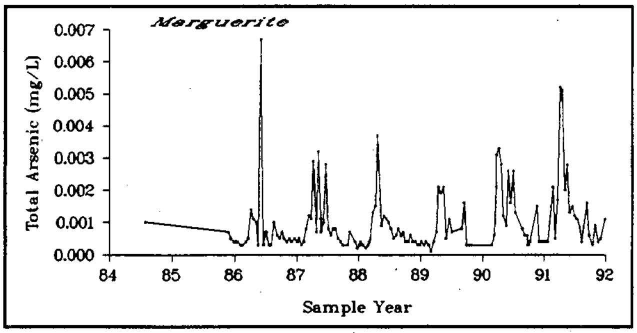

Time Series plots of Environment Canada Nitrate Nitrogen Data for the period 1984-1992 at selected sites in the Fraser River basin.

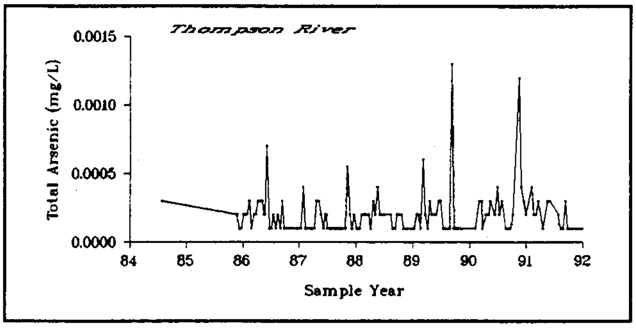


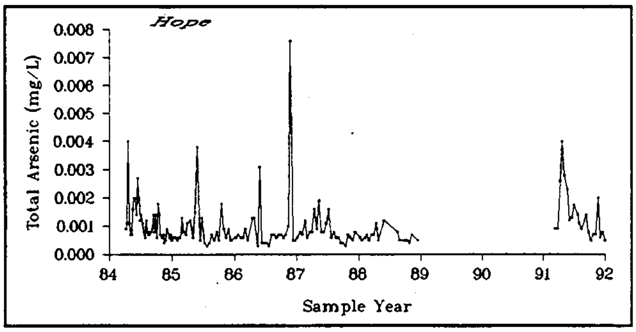



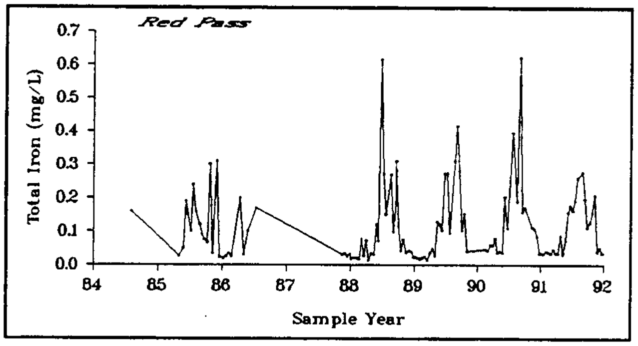



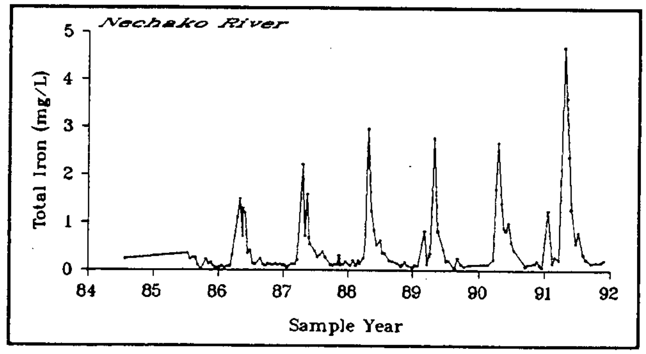



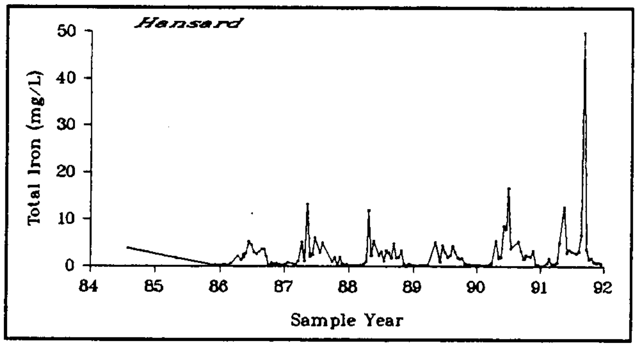



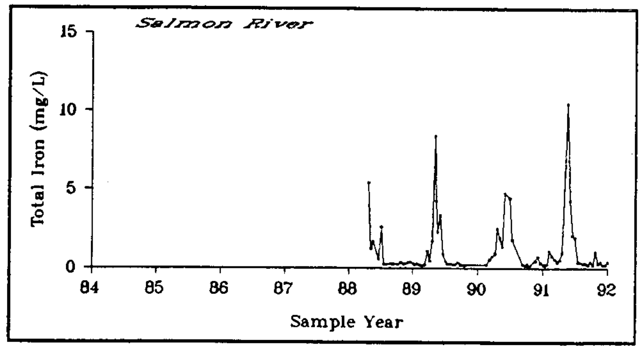



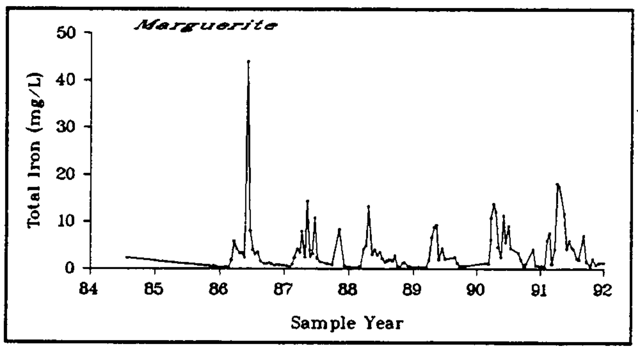

Time Series plots of Environment Canada Laboratory Total Arsenic for the period 1984-1992 at selected sites in the Fraser River basin.

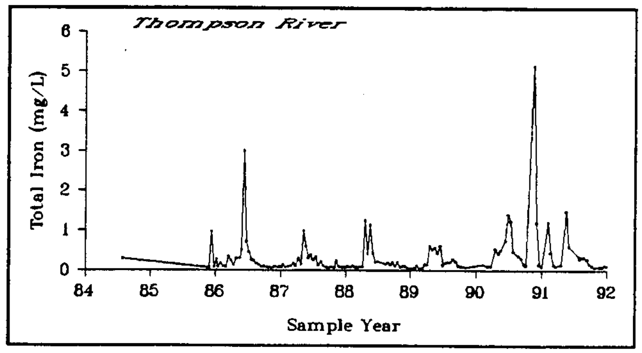


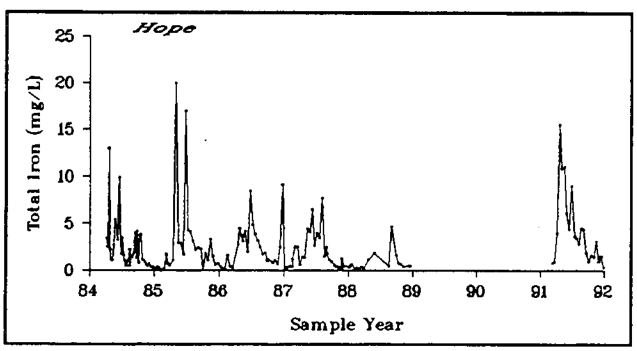



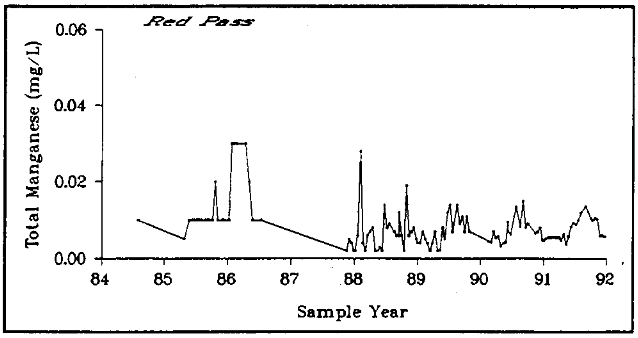



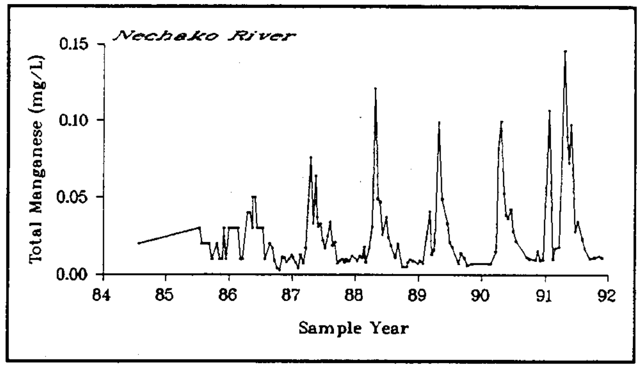



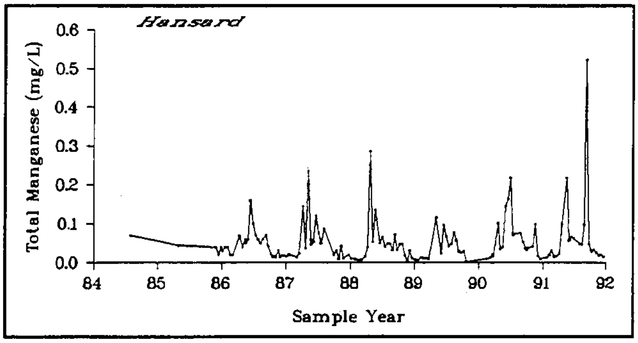



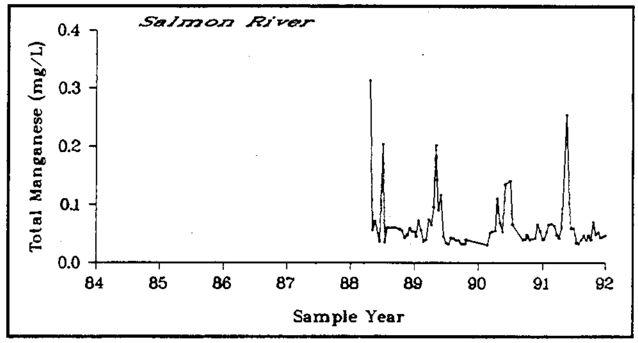



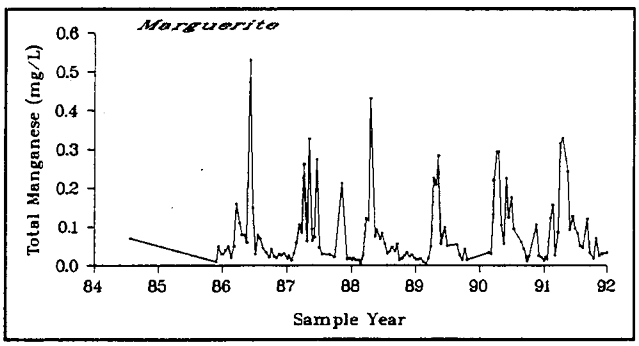

Time Series plots of Environment Canada Laboratory Total Iron for the period 1984-1992 at selected sites in the Fraser River basin.

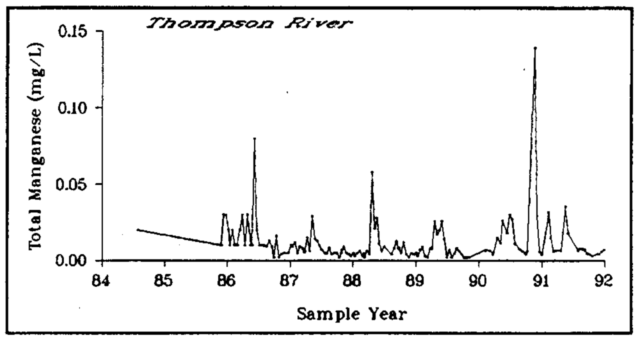


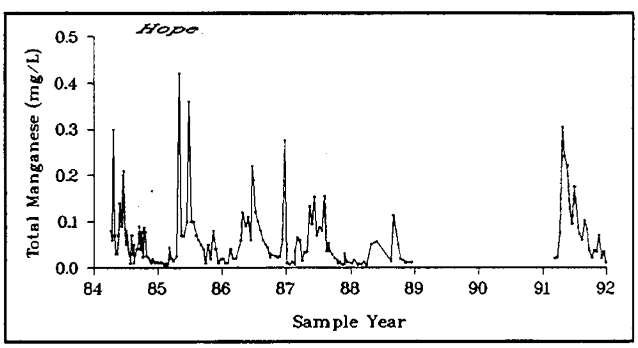



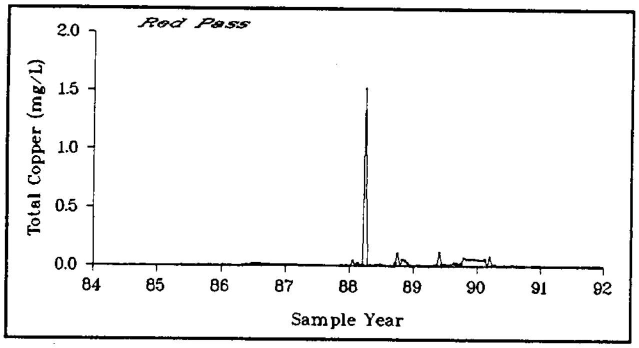



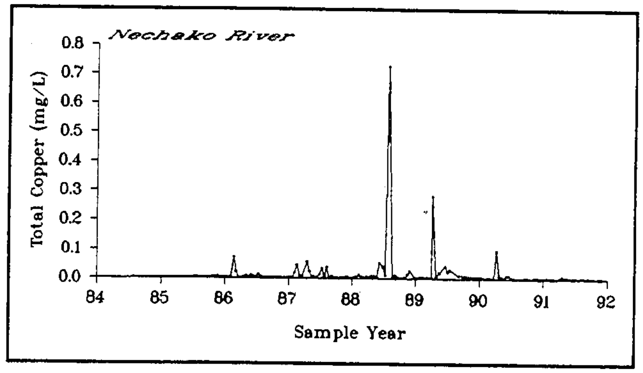



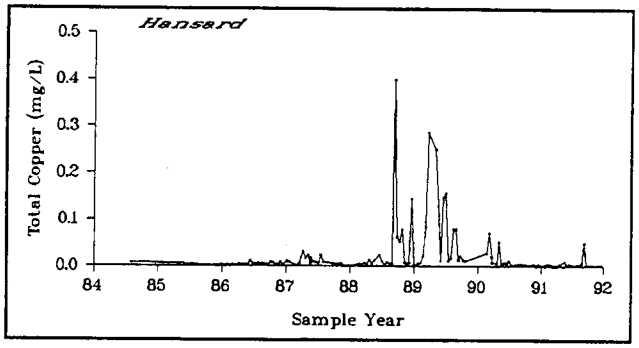



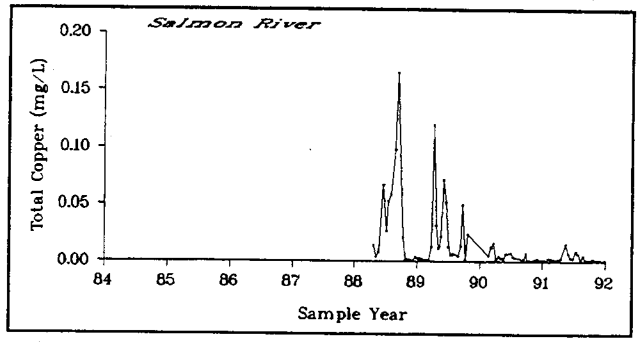



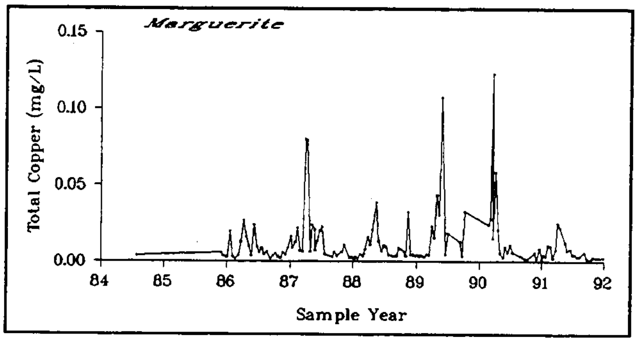

Time Series plots of Environment Canada Laboratory Total Manganese for the period 1984-1992 at selected sites in the Fraser River basin.

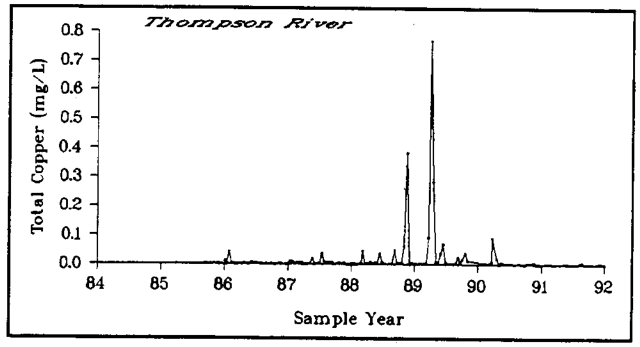


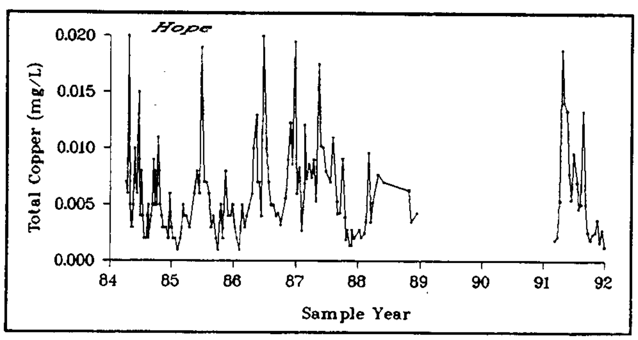



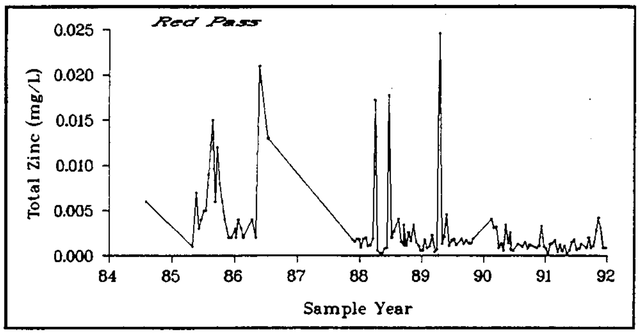



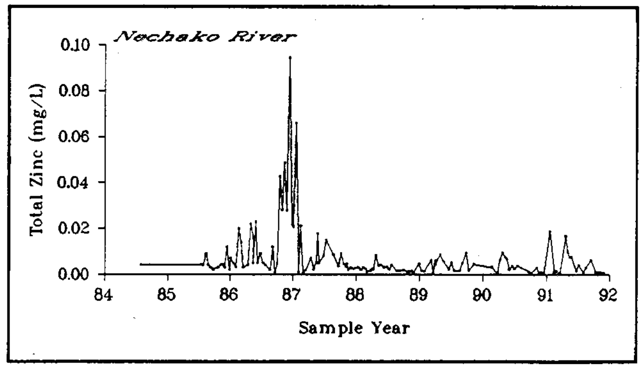



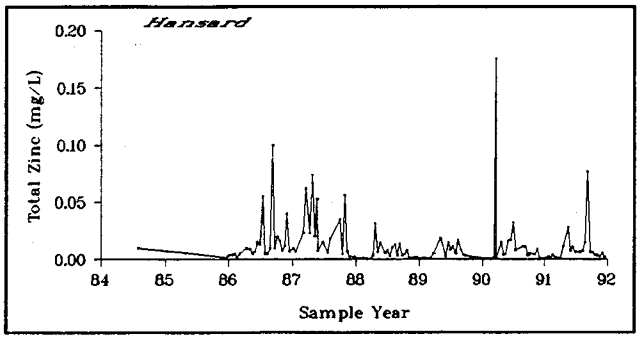



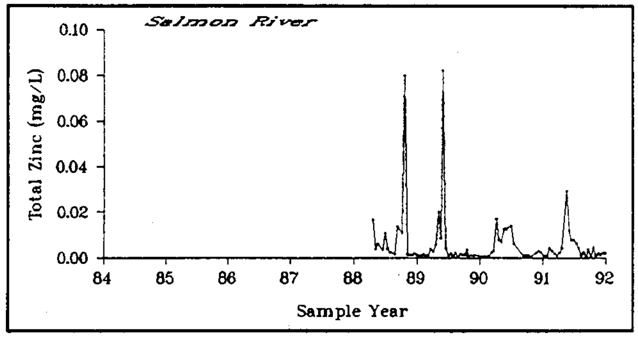



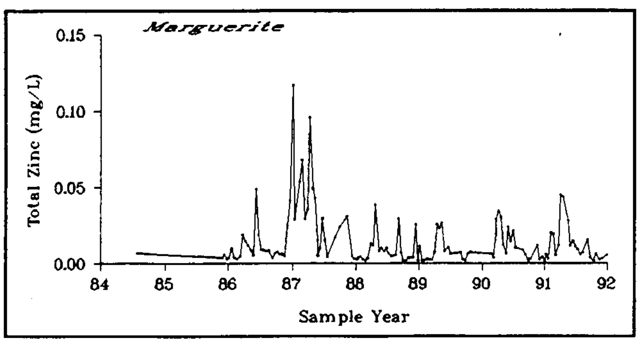

Time Series plots of Environment Canada Laboratory Total Copper for the period 1984-1992 at selected sites in the Fraser River basin.

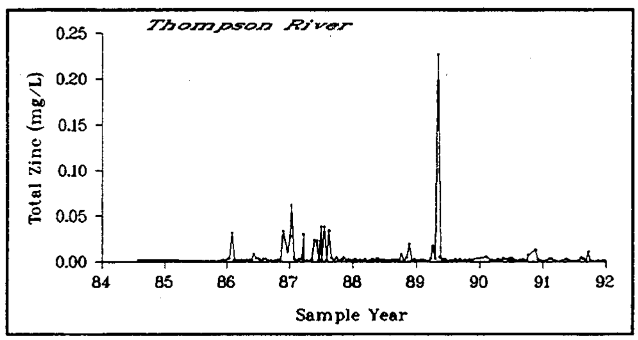


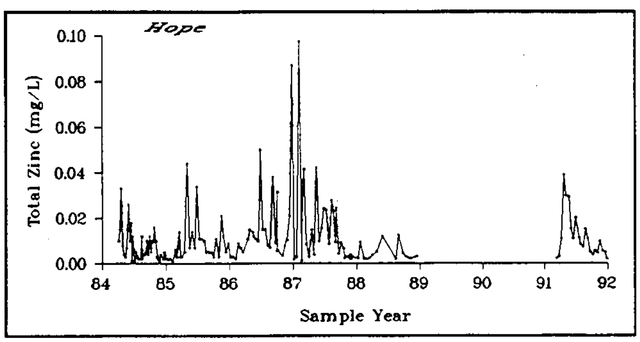




Time Series plots of Environment Canada Laboratory Total Zinc for the period 1984-1992 at selected sites in the Fraser River basin.

**Appendix 3.**

Time series plots of B.C. Ministry of Environment, Lands and Parks water quality monitoring data for variables considered in this report at selected sites in the Fraser River Basin

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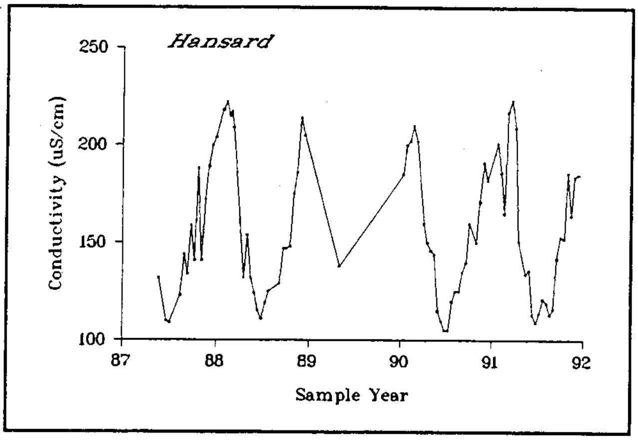
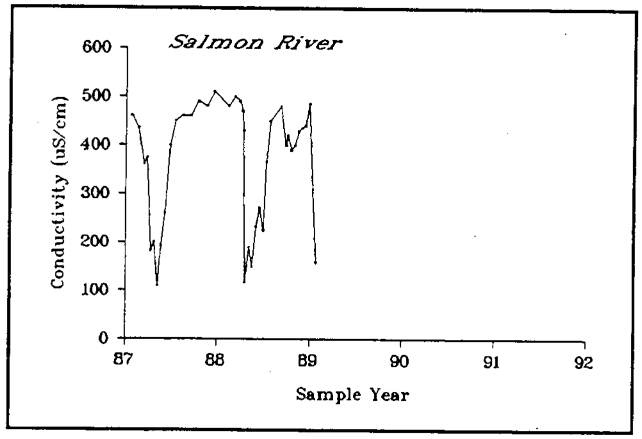
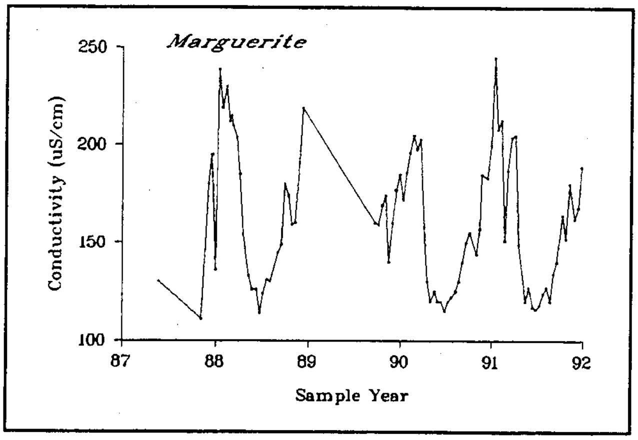
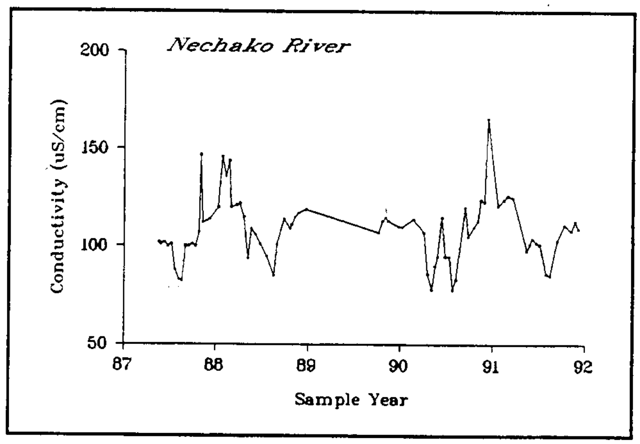
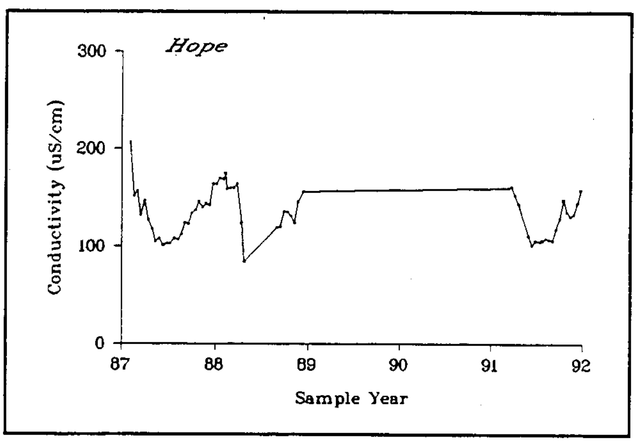


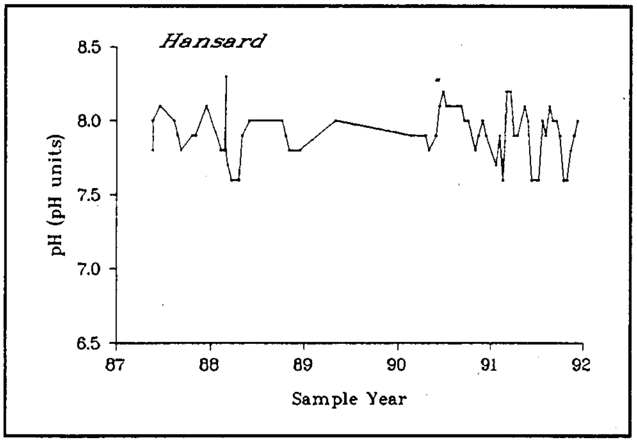



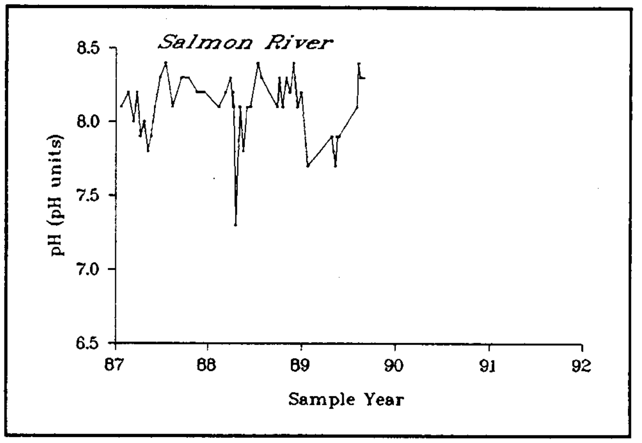



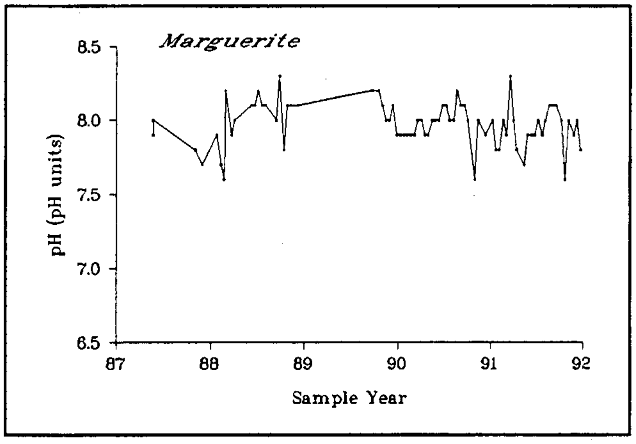



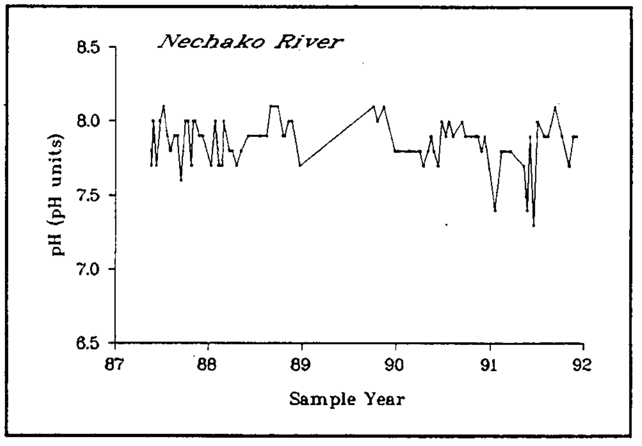



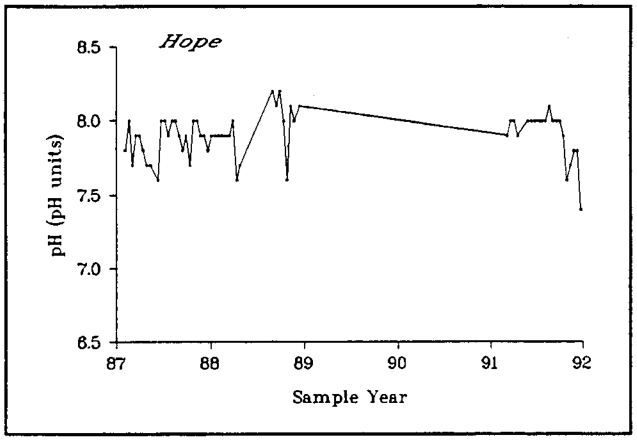

Time Series Plots of B.C. Environment Field Conductivity Data from Selected Sites in the Fraser River Basin 1987-1991



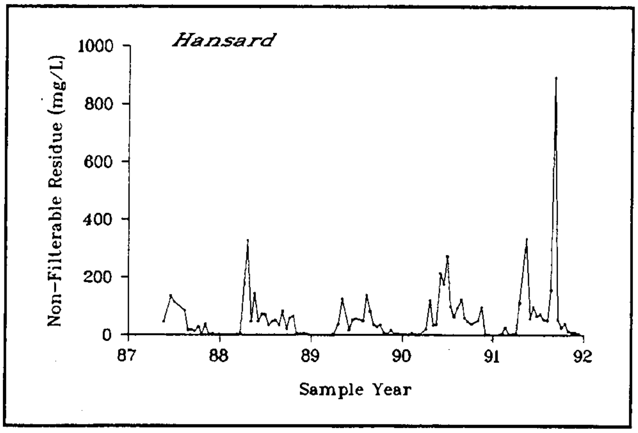



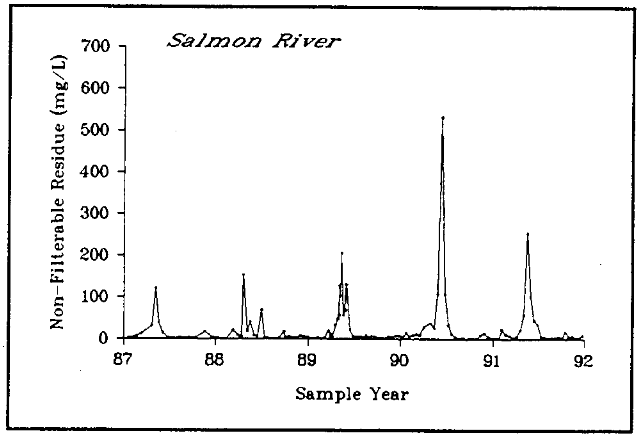



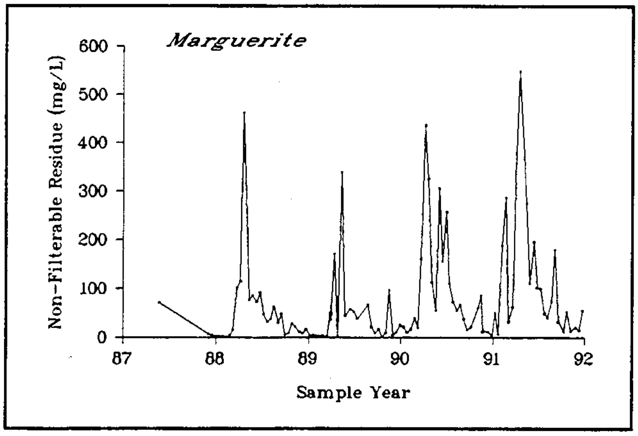



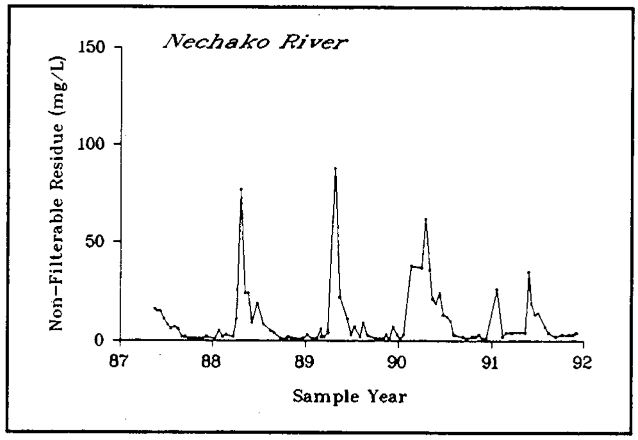



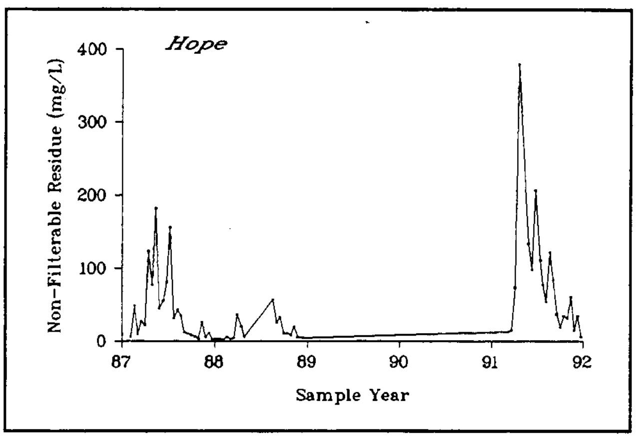

Time Series Plots of B.C. Environment pH Data from Selected Sites in the Fraser River Basin 1987-1991



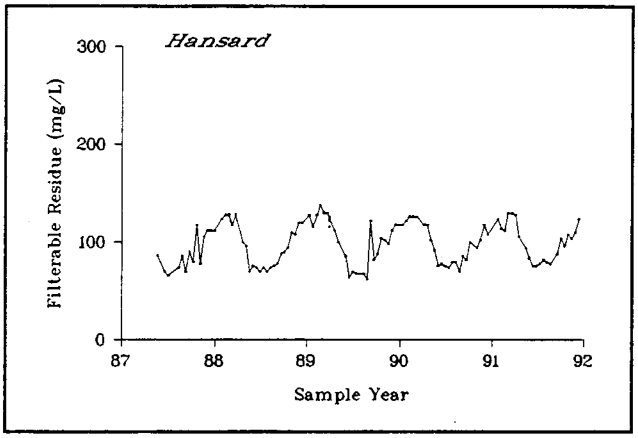



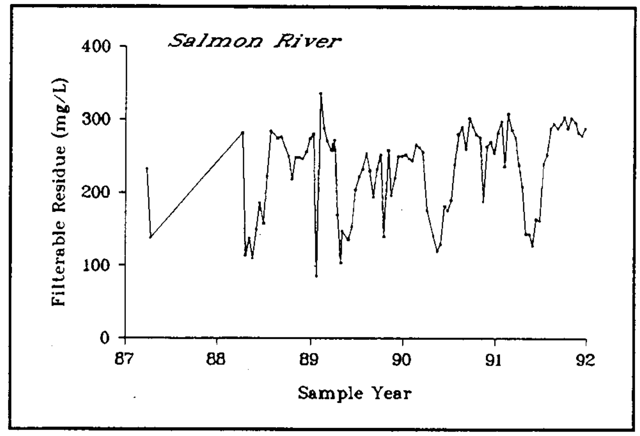



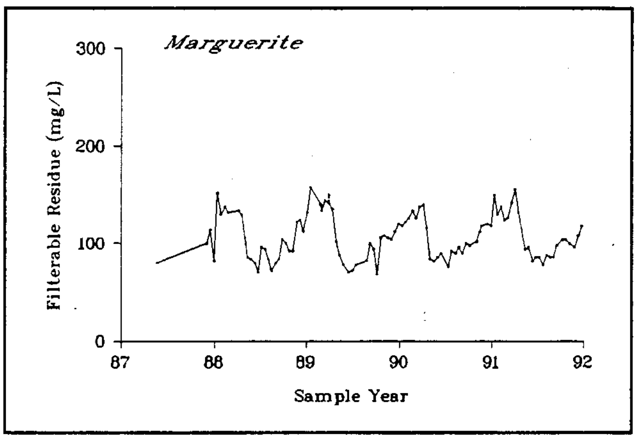



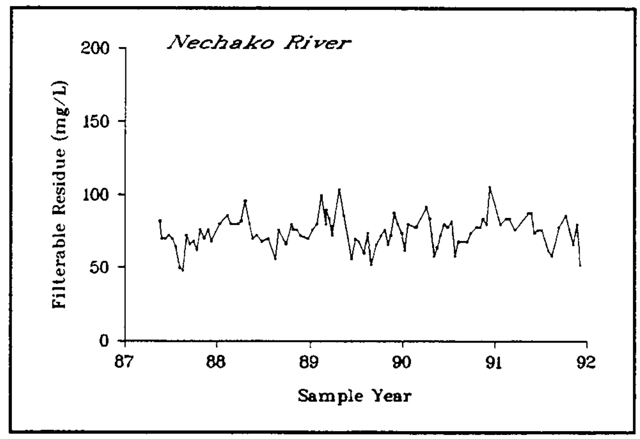



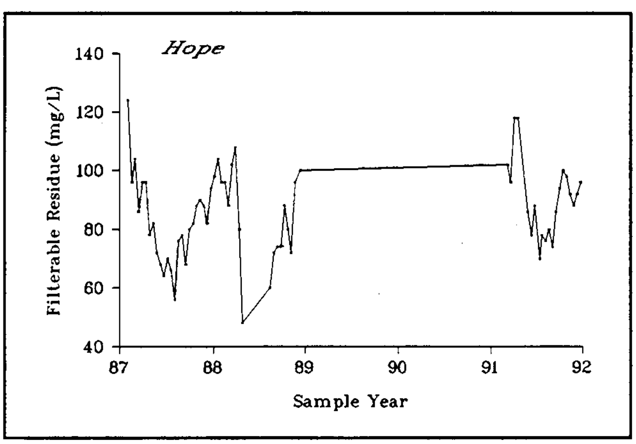

Time Series Plots of B.C. Environment Non-Filterable Residue Data from Selected Sites in the Fraser River Basin 1987-1991



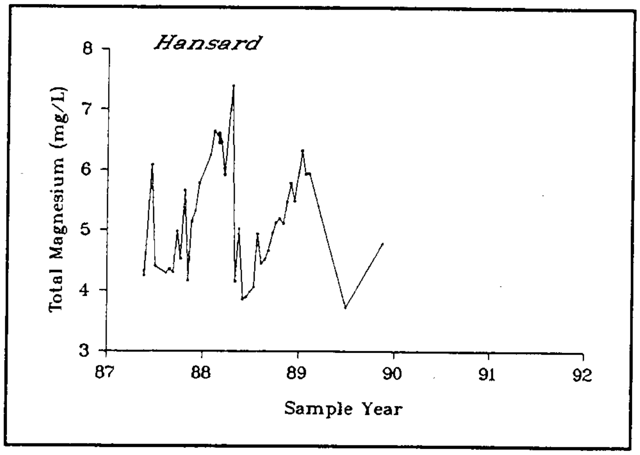



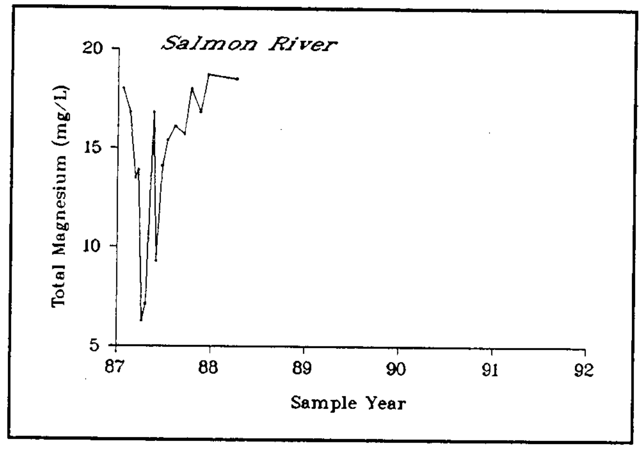



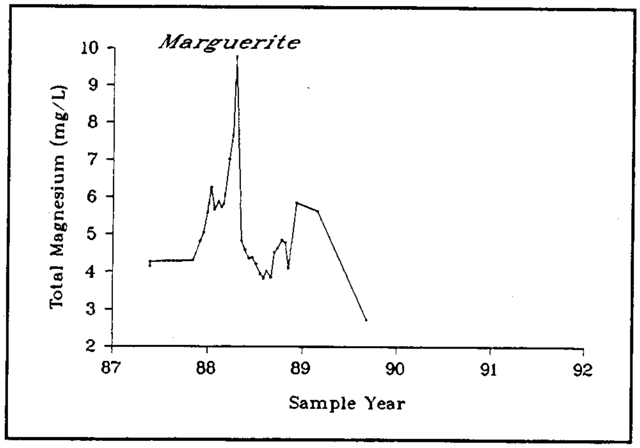



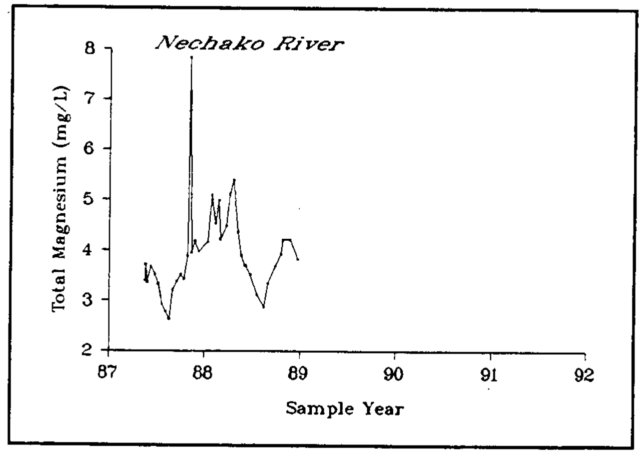



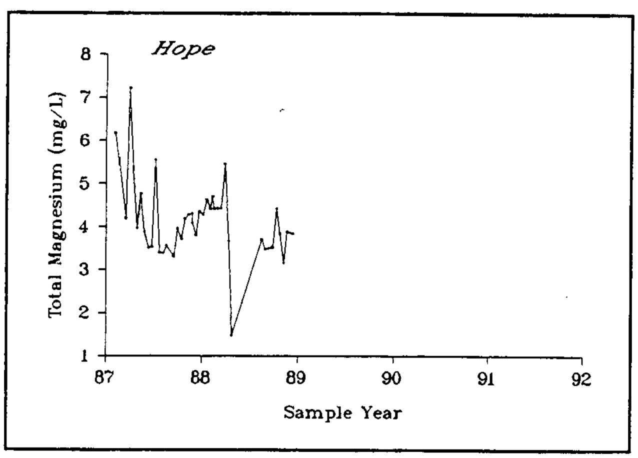

Time Series Plots of B.C. Environment Filterable Residue Data from Selected Sites in the Fraser River Basin 1987-1991



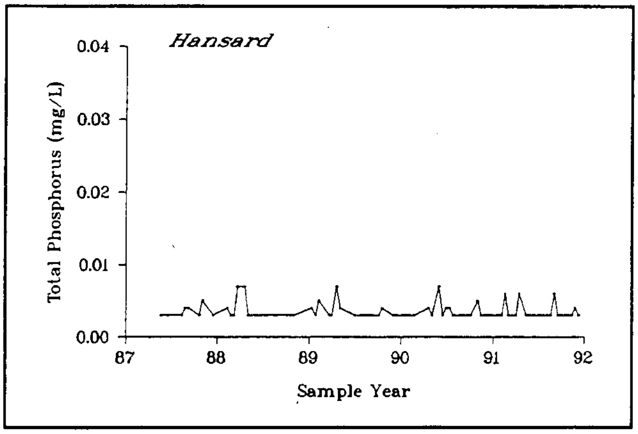



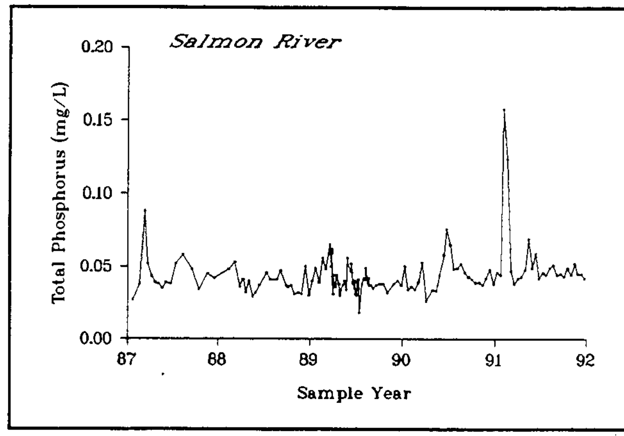



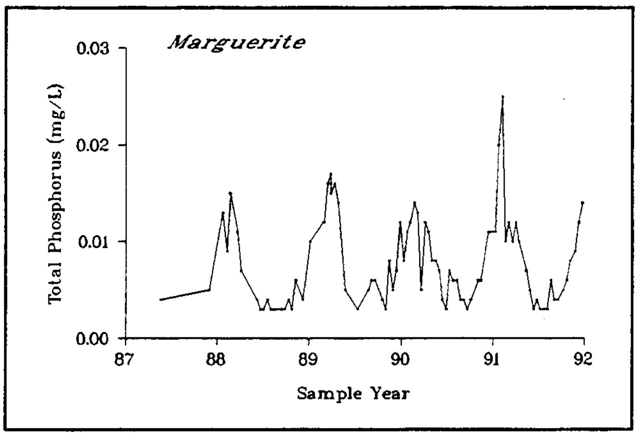



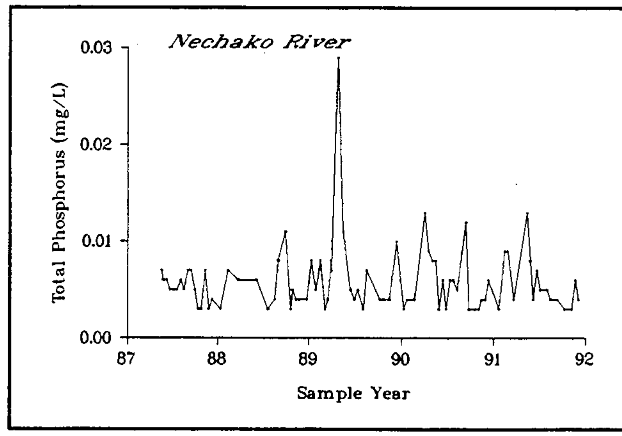



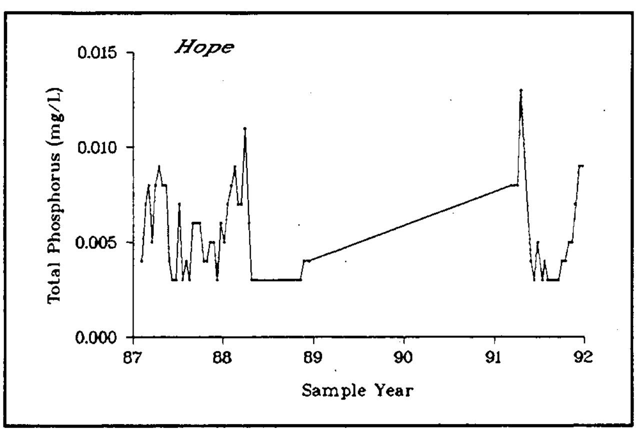

Time Series Plots of B.C. Environment Total Magnesium Data from Selected Sites in the Fraser River Basin 1987-1991



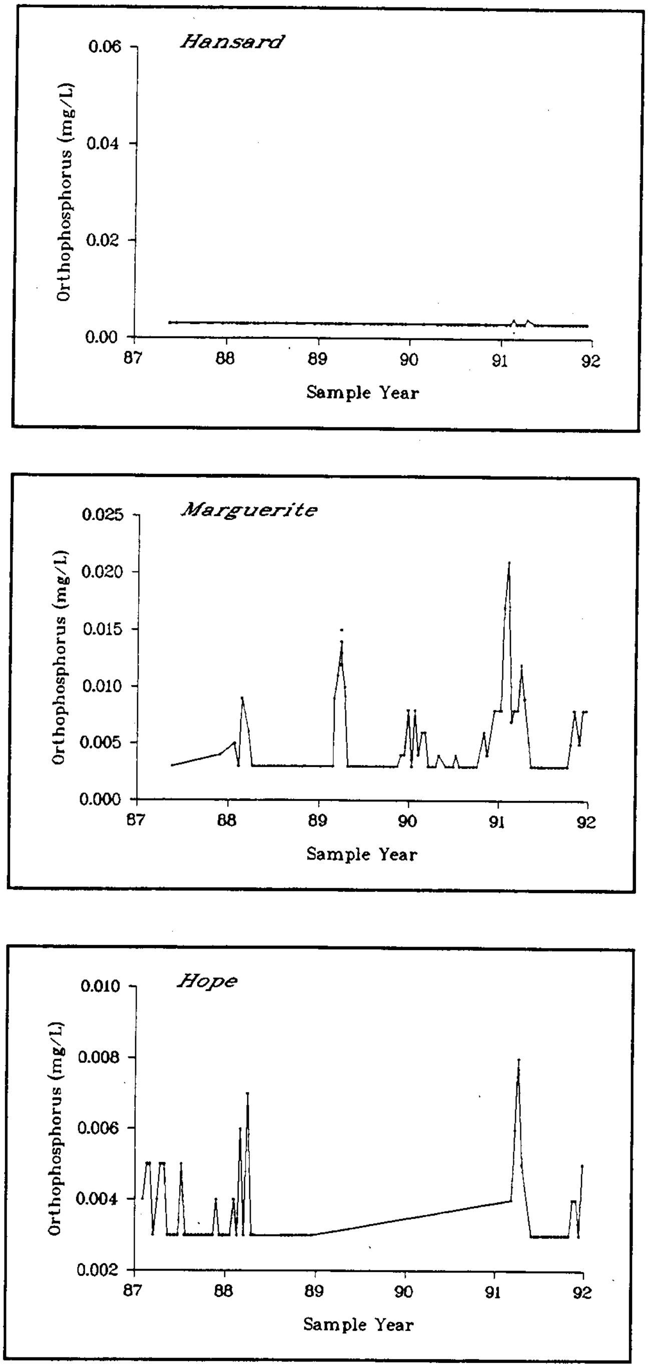



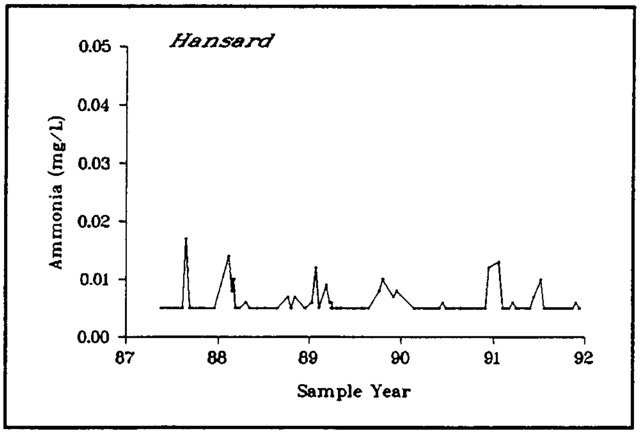



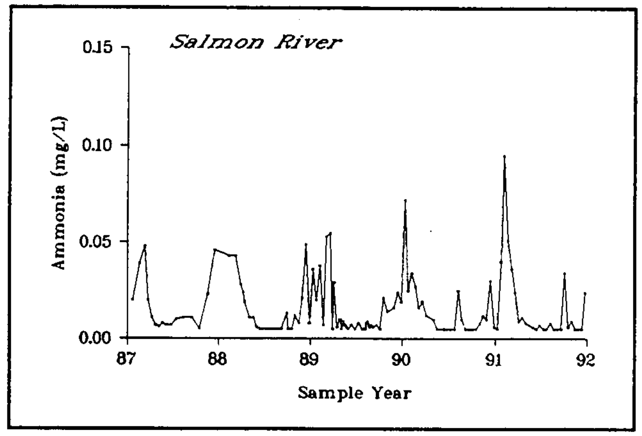



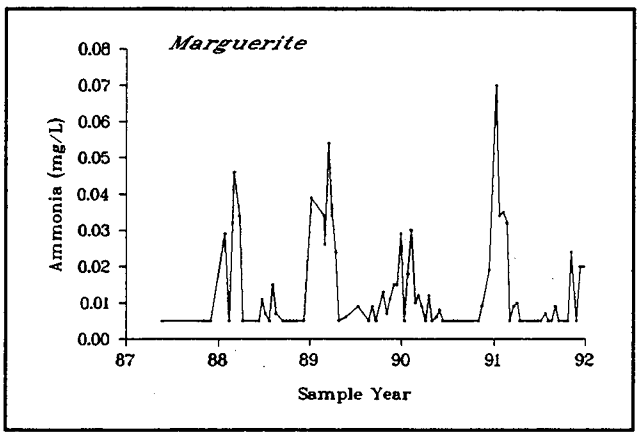

Time Series Plots of B.C. Environment Total Dissolved Phosphorus Data from Selected Sites in the Fraser River Basin 1987-1991

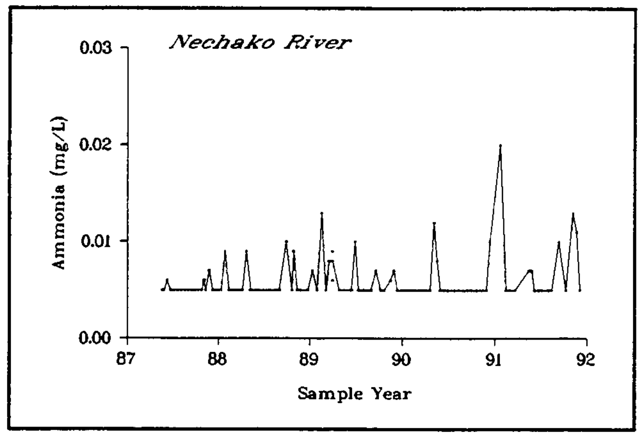


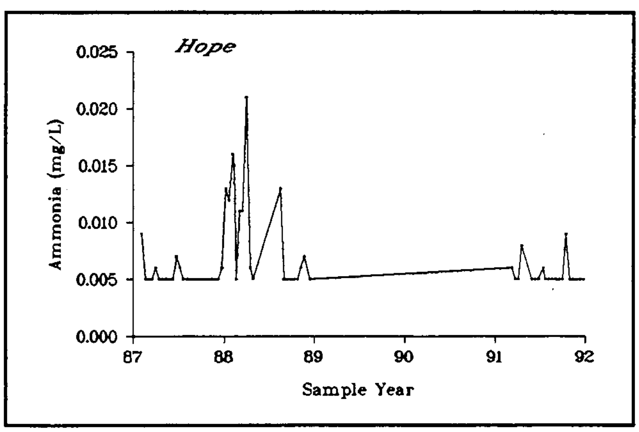

Time Series Plots of B.C. Environment orthophosphorus Data from Selected Sites in the Fraser River Basin 1987-1991



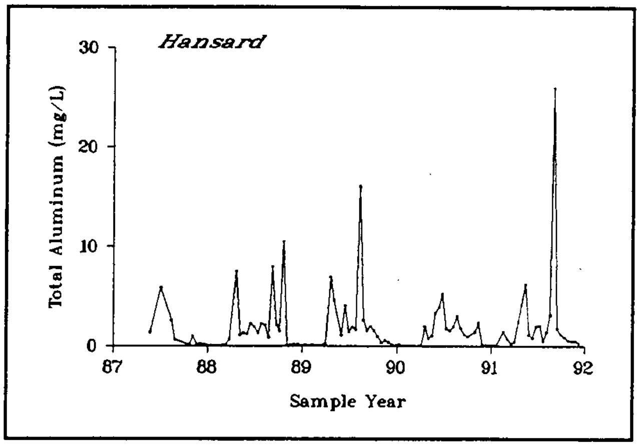



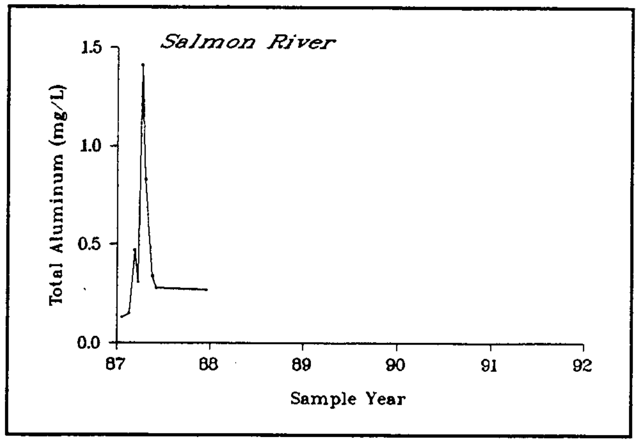



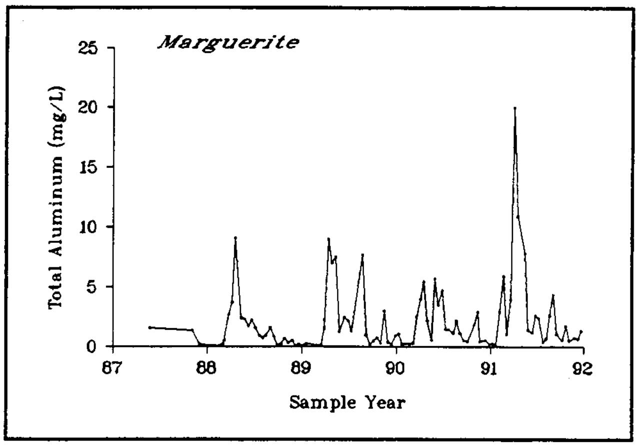



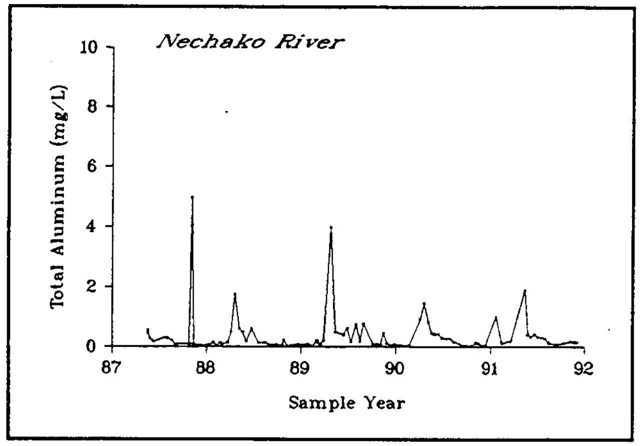



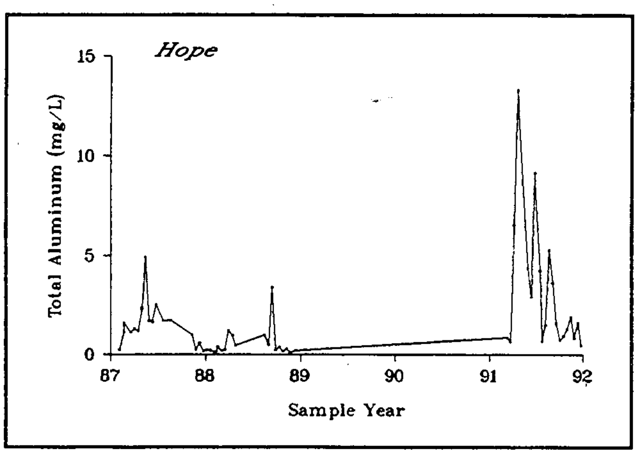

Time Series Plots of B.C. Environment Ammonia Data from Selected Sites in the Fraser River Basin 1987-1991



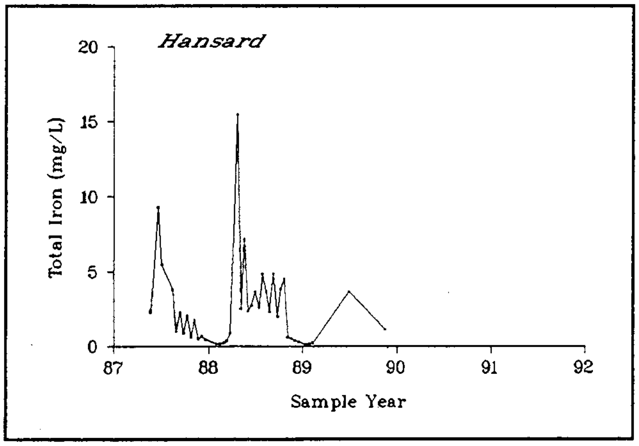



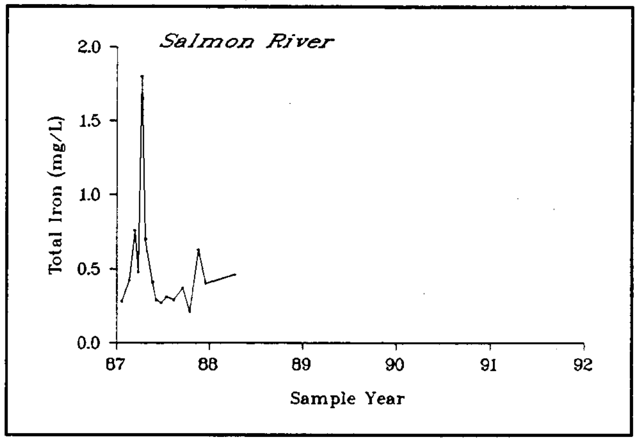



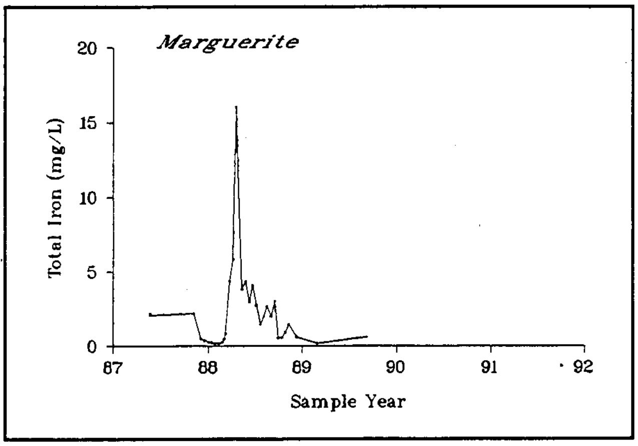



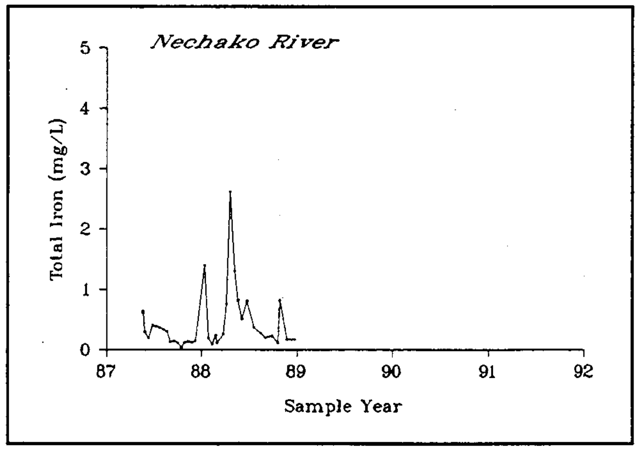



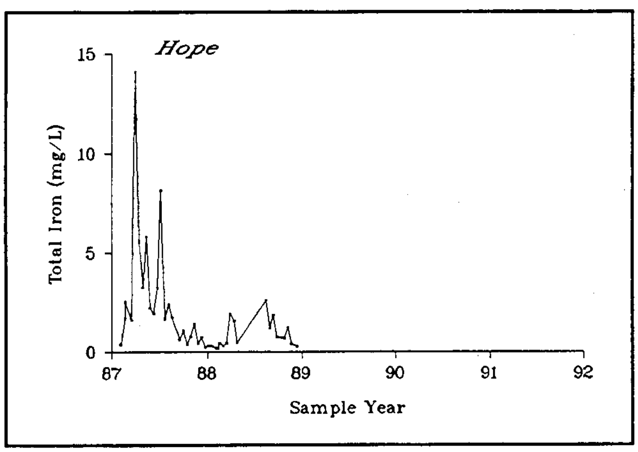

Time Series Plots of B.C. Environment Total Aluminum Data from Selected Sites in the Fraser River Basin 1987-1991



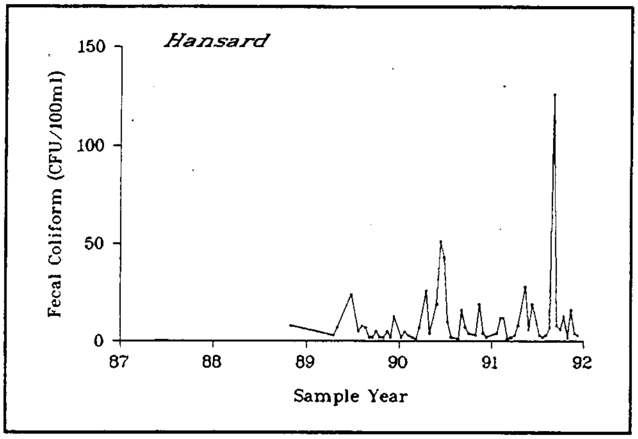



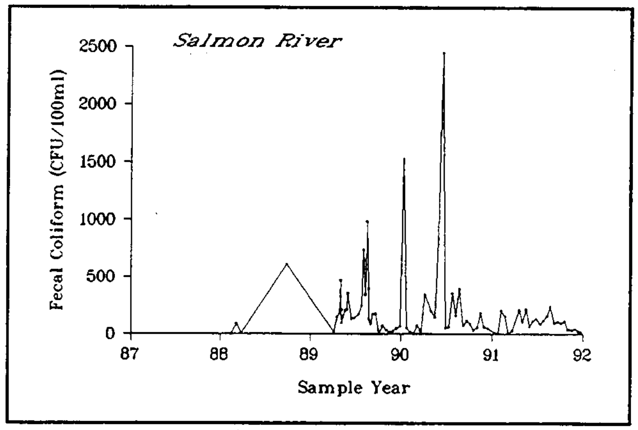



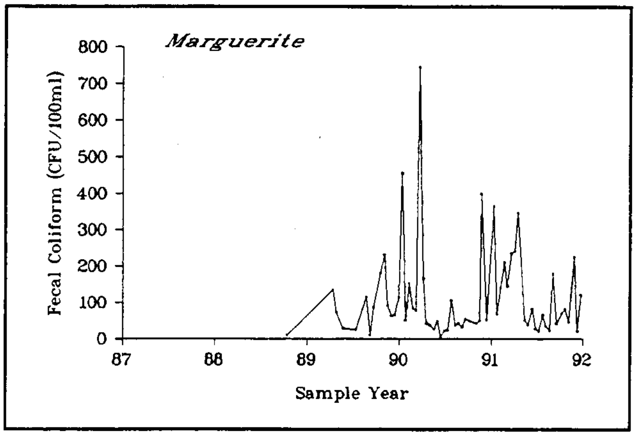



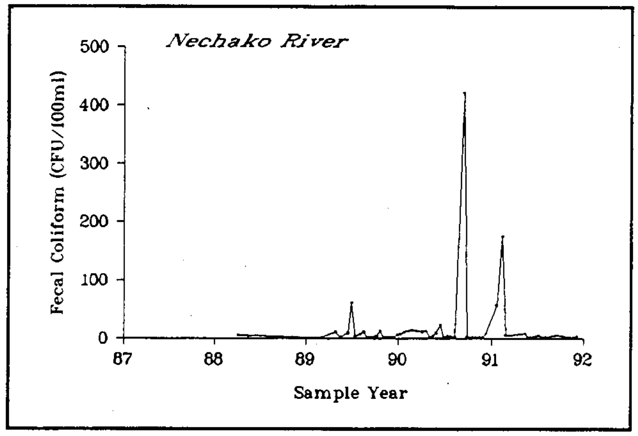



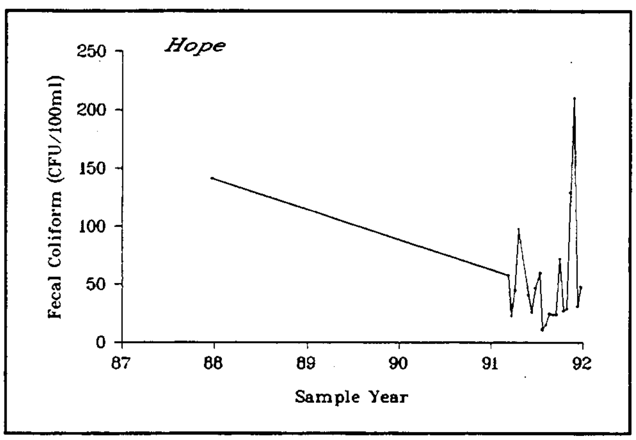

Time Series Plots of B.C. Environment Total Iron Data from Selected Sites in the Fraser River Basin 1987-1991




Time Series Plots of B.C. Environment Fecal Coliform Data from Selected Sites in the Fraser River Basin 1987-1991