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## WATER QUALITY IN THE FRASER RIVER BASIN

by D. Patrick Shaw and Taina Tuominen
Aquatic and Atmospheric Sciences Division
Environment Canada, Vancouver, B.C.

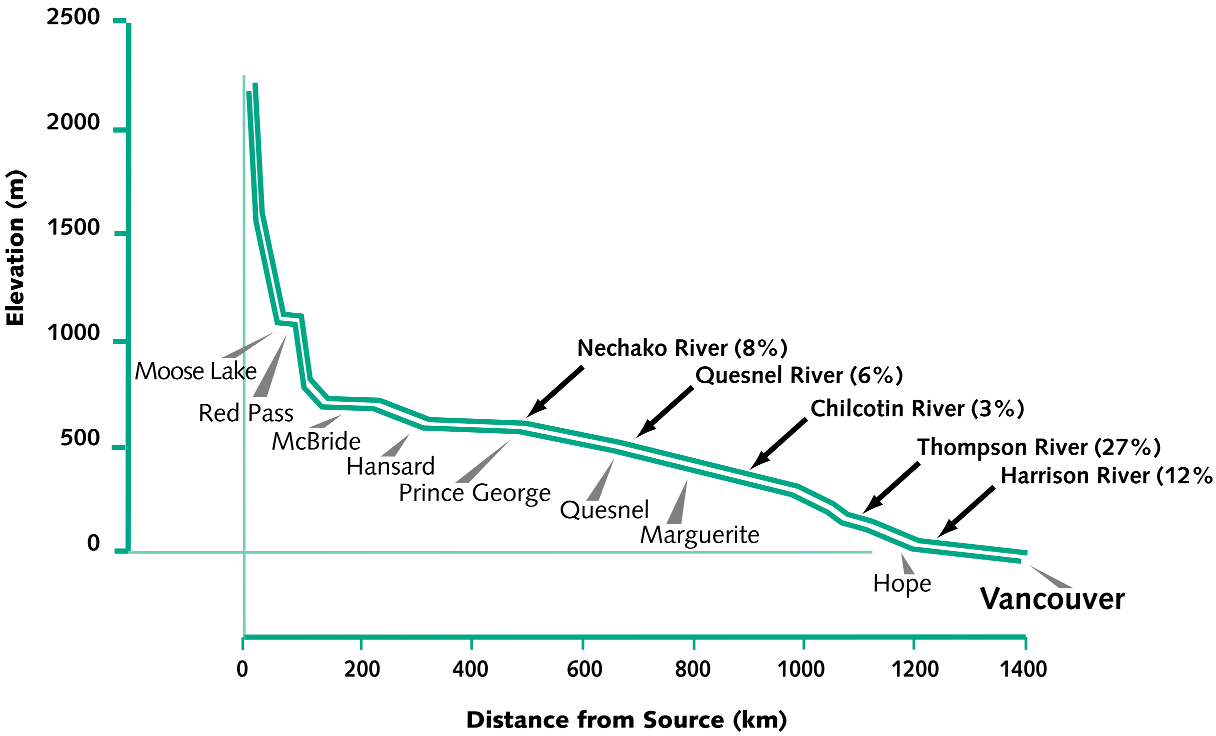
**Evaluation and study of water quality is fundamental to protection of both the aquatic ecosystem and human use of the Fraser River and its tributaries. Under the Fraser River Action Plan, three aspects of water quality in the Fraser River Basin were studied: an analysis of long-term trends; measurements of industry-specific contaminants related to major discharges in the upper basin and evaluation of water quality in the Fraser River Estuary area.**

### BACKGROUND

From the headwaters in the alpine glaciers of the Rocky Mountains above Moose Lake, the Fraser River drains north and west collecting drainage from the northern Rockies and the Cariboo Mountains. Between the first major population centre at Prince George and the town of Hope roughly 750 km downstream, the Fraser River is joined by its major tributaries—the Nechako, Quesnel, Chilcotin and Thompson rivers. These four tributaries constitute, on average, about 44 per cent of the mean annual flow at the river mouth (Figure 1).

Downstream of Hope, the Fraser enters the fertile Fraser Valley, a reach of relatively low gradient and high human activity, including extensive agriculture (cropping and livestock), dense residential housing and diverse industries.

The Fraser River tends to be turbid. In the distant headwaters, suspended sediment is supplied as a combination of glacial flour and insoluble silts and clays from bedrock dissolution. In passage through Moose Lake, these suspended particles are lost in the only major sedimentation basin in the entire river (Desloges and Gilbert 1995). Downstream, the river gradually reacquires its muddy appearance through erosion of fine glacial deposits near river banks, particularly through the middle Fraser upstream of Hope.




*Adapted from Cameron et al. 1995.*

***Figure 1.*** *Elevation profile of the Fraser River from the headwaters above Moose Lake to the mouth near Vancouver. (The contribution of the major tributaries is indicated as a percentage of the average mean annual flow at Hope).*

Longitudinal studies of water quality (Cameron 1996; Whitfield 1983; Whitfield and Clark 1992), particularly with respect to patterns in dissolved ion content, have demonstrated the primacy of bedrock dissolution in determining overall water quality in the Fraser River Basin (Hall *et al.* 1991). High concentrations of dissolved sulphate, calcium and magnesium are characteristic of headwaters where the underlying bedrock is dominated by evaporites and limestones. Mixing of the Fraser River with the generally softer and clearer water of major tributaries such as the Nechako, Quesnel, Chilcotin and Thompson rivers dilutes and alters significantly the character of the main stem water quality downstream. An example of this effect on water hardness is illustrated in Figure 2, where the addition of tributary waters either reduces or reverses the downstream trend toward increasing hardness in the main stem Fraser River. Dilution by the Thompson River, which comprises roughly one quarter of the flow downstream of its confluence, is particularly evident in the Fraser River at Hope (Figure 2).

Industrial and municipal discharges in the upper basin, particularly in the reach between Hansard and Marguerite on the main stem Fraser, and downstream of Kamloops on the Thompson River, have the potential to affect instream concentrations of common dissolved constituents. French and Chambers (1995) estimated total pulp and paper mill effluent volumes to the upper Fraser at $4.1 \times 10^5$ $m^3$/day, and domestic wastes at about $3.5 \times 10^4$ $m^3$/day—quantities which together can constitute as much as two per cent of the total winter in-river flow at Marguerite. In addition to the commonly measured water quality variables, pulp mills and municipal treatment plants also discharge a wide range of halogenated and non-halogenated organic compounds, metals, dissolved ions and dissolved nutrients (French and Chambers 1995; Norecol 1993). Some inexpensively measured variables are often used to assess the dilution and the extent of contamination by some effluents. For example, the principal tracers of pulp and paper mill effluents are levels of dissolved sodium and dissolved chloride, both of which are highly conservative and present in high concentrations in the discharges (Hall *et al.* 1991).

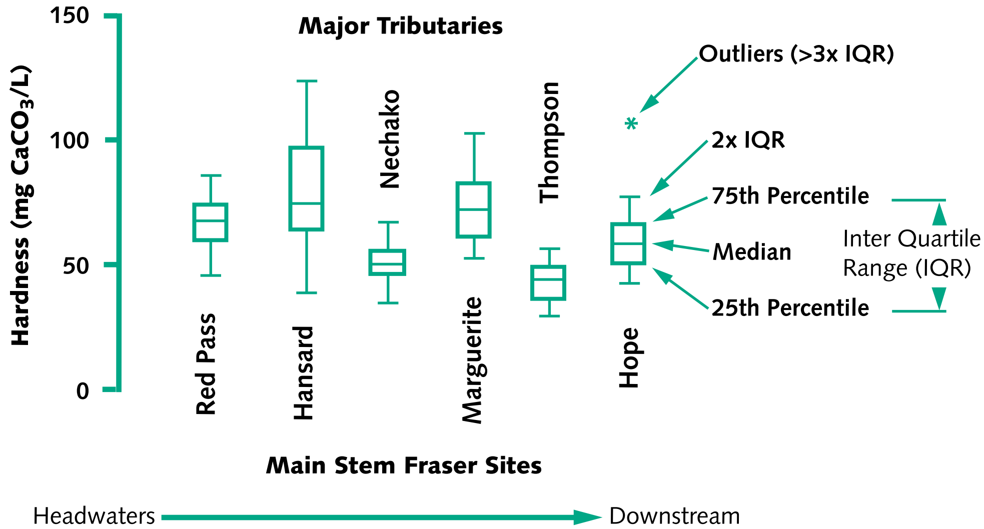



*Figure 2. Longitudinal pattern of water hardness in the Fraser River, showing the effect of dilution by confluence with water from major tributaries.*

The largest input of wastewater occurs in the Fraser River Estuary, largely through effluents discharged from the Vancouver area wastewater treatment facilities. Together, three plants in the region release roughly 4.29x$10^5$ $m^3$/day (FREMP 1996, Table 5.1). A wide variety of industrial discharges, including metal fabricating plants, sawmills, pulp and paper mills, chemical plants and other activities release a range of contaminants in relatively low-volume discharges to the Fraser River. Other more poorly characterized effluents are those released through the 20 combined sewer overflows (McGreer and Belzer 1999), which transmit an estimated volume of 6.27x$10^6$ $m^3$/yr to the North Arm and main stem of the Fraser (FREMP 1996). Evaluating the environmental effects, and even the measurement of ambient concentrations of these contaminants, is complex due to the array of inputs, the spectrum of contaminants and the physical interactions between the river flow and tidal intrusion (Ages 1988; Chapman and Brinkhurst 1981; Hall *et al.* 1991).

## LONG-TERM TREND ASSESSMENT

Water quality monitoring data have been collected since about 1985 at nine sites in the Fraser River Basin under the *Canada-BC Water Quality Monitoring Agreement*—on the main stem Fraser River at Red Pass, Hansard, Stoner (downstream of Prince George), Marguerite (downstream of Quesnel) and Hope; on the Nechako and Thompson rivers, the Fraser's major tributaries; on the Salmon River, near Salmon Arm; and on the Sumas River in the Fraser Valley (Figure 3).

Water samples have been collected and analyzed for dissolved ions, nutrients, trace metals and a range of other variables on a bi-weekly basis at many of the sites since the mid-1980s. Analyses of contaminants such as organochlorines (*e.g.* chlorophenols, guaiacols, catechols) are costly, and despite their release into the environment by industrial discharges, are generally excluded from the suite of monitoring variables. A relatively inexpensive indicator of organochlorine contamination, AOX (adsorbable organohalides), is being measured at the Stoner and Marguerite sites, which are downstream of pulp and paper mills. Preliminary graphical assessment and evaluation of these data relative to water quality guidelines, criteria and objectives have been reported jointly by BC Ministry of Environment, Lands and Parks (BC MELP) and Environment Canada as part of a "State of Water Quality" report series (*e.g.* Lilley and Webber 1997; Wipperman and

Holms 1997a; Wipperman and Holms 1997b). More comprehensive analyses have been conducted by Environment Canada under the Fraser River Action Plan (FRAP) and will be considered below.

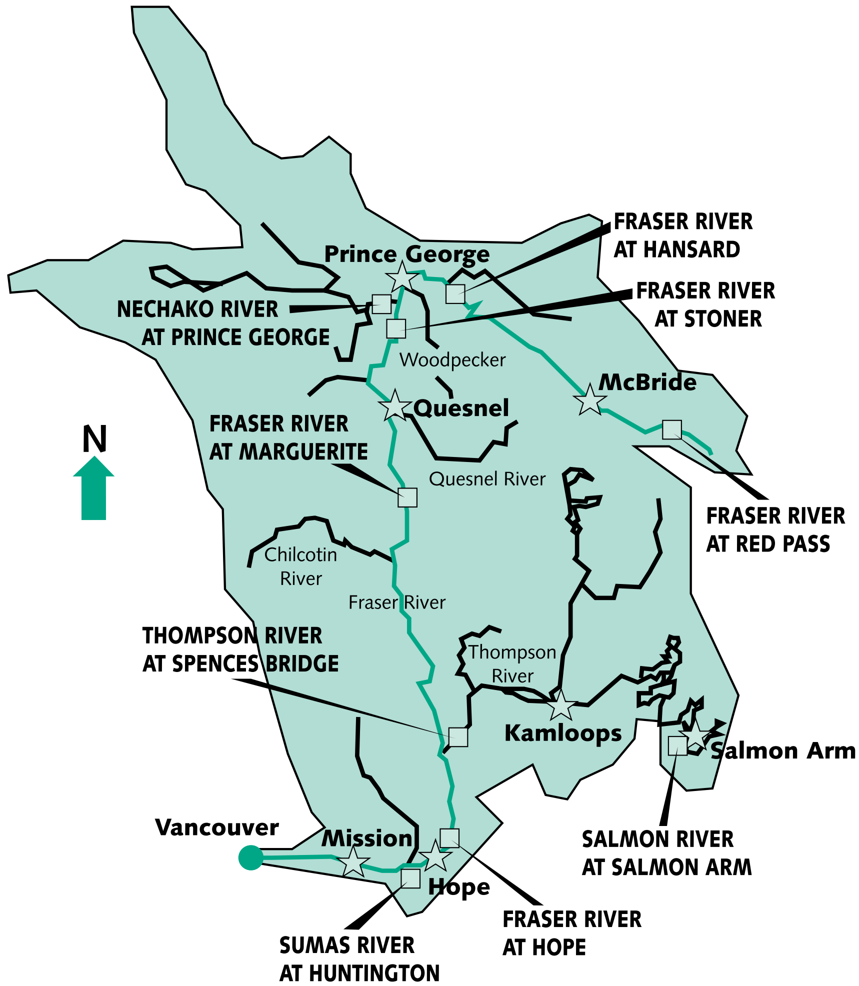



***Figure 3.*** *The Fraser River Basin showing locations of long-term water quality monitoring sites.*

In more than ten years of monitoring, measured concentrations of most variables in the main stem Fraser River have not exceeded levels which would compromise potential water uses. Some of the current water quality guidelines for total trace metals developed by the *Canadian Council of Ministers of the Environment* (CCME) were frequently exceeded, particularly the 0.3 mg/L guideline for protection of aquatic life from total iron. However, these high metal concentrations were related to native metal in suspended sediments and represent background levels in the river. In addition, despite major effluent improvement, the present stringent water quality objective for AOX (no significant increase from upstream to downstream of a discharge, Swain *et al.* 1997) was exceeded at locations downstream of pulp and paper mills for much of the period of record.

Most variables demonstrate a strong seasonal pattern, associated with seasonal changes in flow, as shown in Figure 4. Dissolved ion constituents and related variables, such as specific conductivity and hardness, show an inverse relationship with flow due to dilution on the rising hydrograph. Others, such as total metal variables (*e.g.* Al, Cr, Co, Fe, Pb, Mn), total phosphorus and turbidity have a strong association with suspended sediments which increase as bed sediment erodes with increasing flows. For many of these variables, the flow-discharge relationship depends on the previous flow state—that is, the relationship at the onset of freshet will often differ from that at the end. This produces a hysteresis (Figure 4) which is particularly common to sediment-related water quality variables, such as turbidity, non-filterable residues, and total metals (Whitfield and Clark 1992; Whitfield and Schreier 1981; Williams 1989). Other variables respond more quickly to changes in flow (*e.g.* conductivity, Figure 4) and show relatively little hysteresis.

Statistical analysis of trends in the Fraser Basin long-term water quality monitoring data has been the subject of two FRAP reports. The first (Shaw and El Shaarawi 1995) examined the available statistical techniques and presented an analysis of a five-year portion of the data set, and a second (Regnier and Shaw

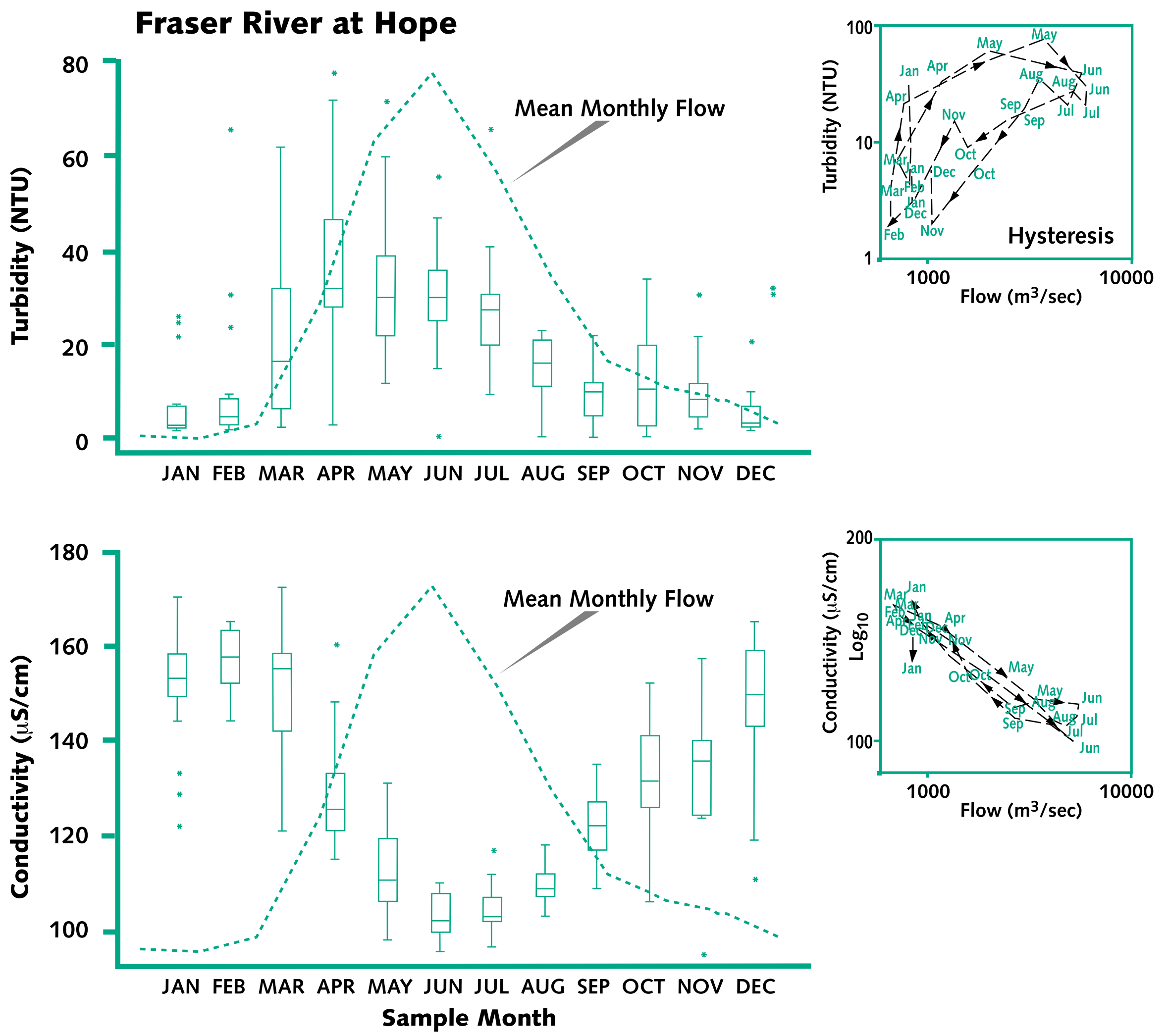



*Figure 4. Characteristic patterns in seasonality of water quality constituents as illustrated by data from the Fraser River at Hope.*

1998) re-applied these methods on a full 10-year time series. Methods included a variety of non-parametric statistical tests and regression modelling of the time series, in addition to graphical summary and presentation. The non-parametric statistical tests are particularly useful as robust indicators of monotonic trends, either increasing or decreasing, but are unable to detect more complex patterns. For example, a pattern in which a constituent showed an increase for some period (as from a new discharge) followed by a general decline (as from improvements in effluent quality) would be indicated as an overall non-changing trend. Regression modeling, while having a somewhat more rigid underlying set of assumptions, does permit elucidation and modeling of these more complex patterns.

The results of the most robust of these trend analyses are summarized in Table 1. For economy of presentation, Table 1 shows: (1) the directions of trends without indication of magnitude, (2) only those variables where either an increasing or decreasing trend was indicated in data from at least one site, and (3) only those results where both non-parametric and parametric results showed similar trends. Trends in constituent concentrations, either increasing or decreasing, were relatively few and the strongest trends were most clearly

*Table 1. Summary of trend analyses of long-term water quality data from sites in the Fraser River Basin, 1985 to 1995.*

| CONSTITUENT | RED PASS | HANSARD | MARGUE-RITE | HOPE | NECHAKO RIVER | SALMON RIVER | THOMPSON RIVER |
|---|---|---|---|---|---|---|---|
| Specific Conductivity | ➚ ∩ | ➚ ↗ | ➔ ↗ | ➔ ↗ | ➚ ∪ | ➔ ↗ | ➚ ↗ |
| Turbidity | ➔ → | ➔ → | ➔ → | ➔ → | ➔ → | ➚ ↗ | ➔ ∪ |
| Total Alkalinity | ➔ ↗ | ➔ → | ➔ → | ➔ ↗ | ➔ ∪ | ➔ ↗ | ➚ ↗ |
| Chloride | ➚ ∩ | ➚ → | ➘ ↘ | ➘ ↘ | ➔ → | ➚ ↗ | ➘ ↘ |
| Magnesium | ➔ ↗ | ➔ ↗ | ➚ ↗ | ➚ ↗ | ➚ ∪ | ➔ ↗ | ➚ ↗ |
| Potassium | n/a | ➚ ↗ | ➚ ↗ | ➚ ↗ | ➚ ↗ | ➔ ↗ | ➚ ↗ |
| Sodium | ➚ ∩ | ➚ ↗ | ➔ → | ➔ ∪ | ➚ ∪ | ➔ ↗ | ➘ ↘ |
| Sulphate | ➚ ↗ | ➚ ↗ | ➚ ∩ | ➚ ∩ | ➔ ∩ | ➔ → | ➔ ↗ |

*Shaded cells indicate concordance between the non-parametric (Seasonal Kendall's Tau statistic) and the parametric (regression modeling) results. Results are significant at a p<0.10 for the non-parametric analysis and p<0.05 for regression analysis.*

➚ = *Increasing trend found by non-parametric tests*
➘ = *Decreasing trend found by non-parametric tests*
➔ = *No trend found by non-parametric tests*
n/a = *Constituent was not analyzed*

↗ = *Increasing linear trend found by regression methods*
↘ = *Decreasing linear trend found by regression methods*
→ = *No trend found by regression methods*
∩, ∪ = *Quadratic trends found*

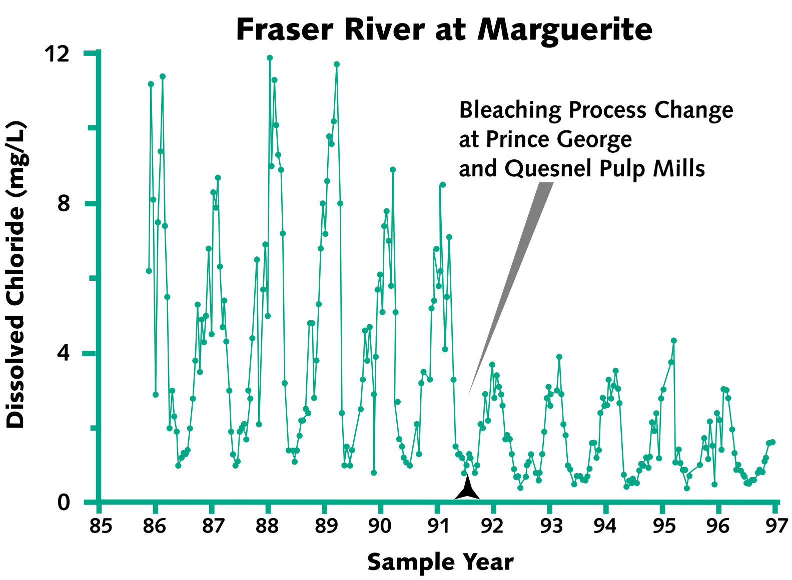



***Figure 5.*** *Time-series of dissolved chloride measurements from the Fraser River at Marguerite, showing the immediate effect of process changes in bleaching chemistry by upstream pulp and paper mills.*

related to changes in loadings from industrial or municipal effluents. For example, dramatic declines in dissolved chloride (Figure 5) and observable declines in adsorbable organohalides (AOX, Figure 6) at sites downstream of effluent discharges from Prince George and Quesnel are consequences of changes in the bleaching process implemented at most British Columbia kraft pulp mills in 1990–1991 (Krahn 1995; BC Ministry of Environment, Lands and Parks 1995).

Where trends in the main stem Fraser River and large tributaries were detected, none indicated rapid approaches to levels near existing water quality guidelines or criteria, or were at levels where potential water uses might be compromised. This result was not unexpected, since subtle changes in the levels of water quality constituents in the main stem Fraser River, resulting from either natural or anthropogenic causes, would be very difficult to discern over both the natural annual variability and the very high dilution. Smaller tributaries, which are rarely monitored for long-term water quality, are more sensitive to activities within the watershed. Relatively small changes in land-use, effluent discharges or land management practices translate to clear and rapid changes in downstream water quality because of the smaller potential for dilution and the close proximity of the activity to the watercourse. These small watersheds are a critical component in the total Fraser Basin aquatic ecosystem, particularly in their important role as critical spawning and rearing habitat for native salmonids.

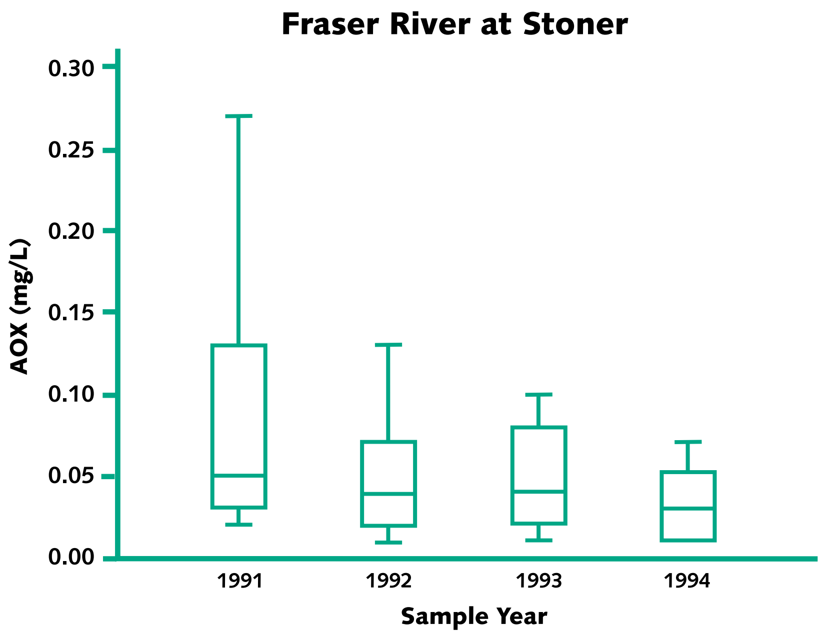



*Figure 6. Time-series in concentration of adsorbable organohalides from the Fraser River at Stoner showing the effect of bleaching process changes by upstream pulp and paper mills.*

Two Fraser Basin long-term monitoring sites, the Salmon River at Salmon Arm and the Sumas River near Huntington, are within smaller watersheds. Data from the Sumas River are of relatively short duration and sporadic, but the analysis of the nearly ten years of data from the Salmon River illustrates some effects of development in a rural setting on basin water quality. Recent human history of the Salmon River basin includes a range of land-altering activities, such as clearing for agriculture, cattle production, timber harvesting and residential development, which have affected the instream flows through increasing water withdrawal and changing hydrologic conditions. Removal of riparian vegetation and resulting siltation from increasing sediment movement have also resulted in loss of critical salmonid spawning habitat (McPhee *et al.* 1996). These changes in land-use were reflected in the analyses of water quality data from the Salmon River. Increasing trends in concentration of many of the dissolved ions (Figure 7) and in turbidity were detected in trend analyses (Table 1). Parametric analyses revealed an increasing trend in all dissolved ions in the Salmon River, supported by non-parametric statistics in some, though not all, cases (Table 1). This pattern is likely caused by over-allocation of instream water withdrawals (McPhee *et al.* 1996) resulting in low instream water level and movement of ion-rich groundwaters into the stream channel.  In addition, groundwater used for irriga-

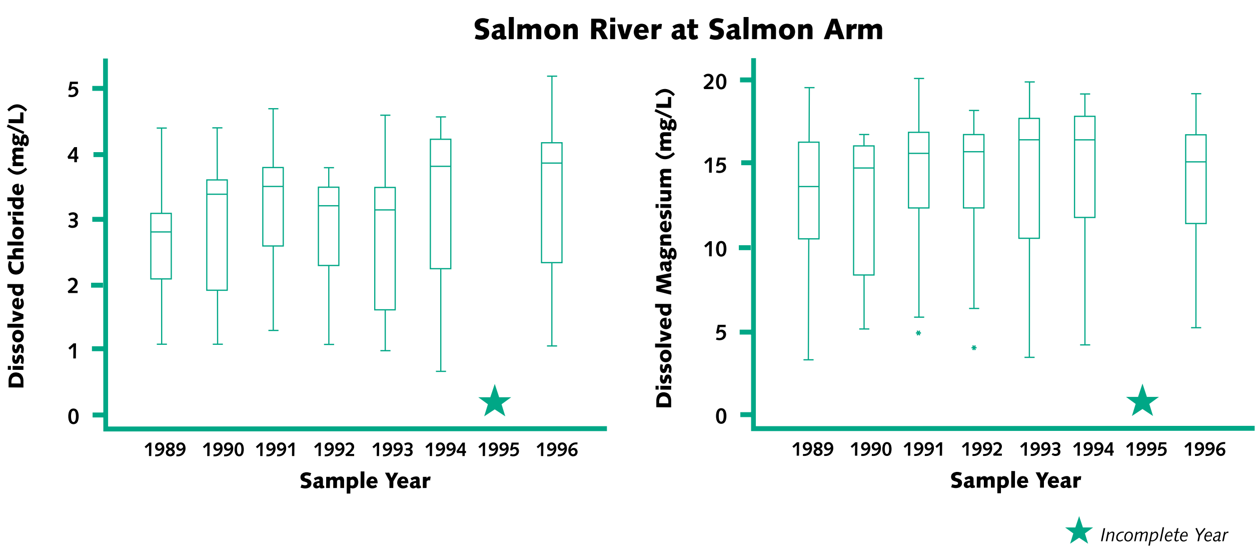



*Figure 7. Box and whisker plots of representative dissolved ion measurements from the Salmon River at Salmon Arm. Non-parametric statistical analyses indicated a significant increasing trend in dissolved chloride, but no trend in dissolved magnesium. Regression analyses indicated a significant increasing trend in both.*

tion returns to the river through surface runoff. These processes are probably contributing to the overall increase in concentration of most dissolved ions evident in both the trend analyses and summary plots (Figure 7). Accelerated soil erosion and transport to the river, as results from removal of riparian vegetation or from timber harvesting, are probably responsible for the observed increasing trend in turbidity.

These measured increases in dissolved ion concentrations, while not toxic to wildlife or humans and not approaching water quality guideline or criterion levels, are reflecting important and continuing changes in the aquatic ecosystem. Water resource and environmental managers too often confuse “environmental significance” of a water quality trend with proximity of a concentration to an accepted water quality guideline or criterion. Instead, significant changes, however subtle, should be considered as indicative of a process change in some aspect of the ecosystem and deserving of further investigation (Whitfield 1997).

## INDUSTRY-SPECIFIC CONTAMINANTS

As part of the FRAP environmental programs, a number of industry-specific contaminants in water have been measured at intervals over the life of FRAP. Pulp and paper-related contaminants including chlorophenolics, dioxins and furans, and resin and fatty acids were measured in the vicinity of pulp and paper mills in the upper basin (Sekela *et al.* 1995; Sylvestre *et al.* 1998a). Water samples were collected on the main stem Fraser River upstream of Prince George (Fraser “reference” area), at Woodpecker (approximately 60 km downstream of Prince George), at Marguerite and in the Thompson River system, upstream and downstream of the pulp mill at Kamloops. Samples were collected as whole-water grab samples as well as through pre-concentration of organic contaminants from centrifuged water with XAD-2 resin columns. A wide range of compounds, including polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and organochlorine pesticides, were measured in addition to pulp and paper mill-related compounds. In addition, occasional samples were collected for nutrient analyses and determination of total and fecal coliform numbers.

Chlorophenolics, resin acids and chlorinated resin acids were elevated downstream of pulp and paper mills on the main stem Fraser River. In the Thompson River system, including the North and South Thompson and Thompson River downstream of Kamloops Lake, values tended to be near or below detection and there were no differences between upstream and downstream sites. Effluent dilution is lowest during the winter low-flow period as reflected clearly in chlorophenol concentrations which varied as much as 40-fold between low- and high-flow sampling periods. Concentrations of these variables in the associated suspended sediment component of the water are presented in Brewer *et al.* (1999). Between 1990 and 1993, mills in the upper Fraser (at Prince George and Quesnel) shifted from 40–60 per cent to 100 per cent chlorine dioxide in the bleaching process. This has had the desired effect of reducing levels of both polychlorinated dioxins and furans (PCDD/F) in the effluents (BC Ministry of Environment, Lands and Parks 1995; Krahn 1995). PCDD/F concentrations in ambient waters were below detection (<1 pg/L) in nearly all analyses, despite sample pre-concentration on resin columns. These frequent non-detections are probably a consequence of both low levels in effluents and very low solubility of these compounds, which will tend to be scavenged from the water column through absorption to suspended sediments.

Dissolved nutrients and microbial variables were also higher in samples downstream of major industrial and municipal effluent sources. While total phosphorus levels at sites downstream of Prince George tend to be higher than at upstream reaches, at least some of the increase is due to natural increases in suspended sediment load. French and Chambers (1995) estimate that only about five (high flow) to 13 per cent (low flow) of the total phosphorus carried in the Fraser River at Marguerite is due to direct effluent sources. However, much (60–95%) of the phosphorus from the major point sources is released in a dissolved form, and more readily available for plant growth than is the sediment-associated phosphorus (French and Chambers 1995).

Cameron *et al.* (1995) identified several other influences of land practices and effluent discharges on water quality. They drew a tentative link between logging activity and elevated dissolved organic carbon levels in waters draining the McGregor and Nechako watersheds, which, as they suggest, requires additional study. They also found very high dissolved carbon dioxide in waters of the Fraser River main stem—levels rivaling those of the Rhine River in Europe. Since high carbon dioxide tension often results from bacterial respiration of organic carbon, a likely cause may be input of organic materials from forestry activities, both timber harvesting and pulp and paper production. Ratios of $^{13}C$ and $^{12}C$ in the dissolved organic carbon suggest much of the excess $CO_2$ in the Fraser may result from organic decomposition in soils and subsequent transport to the river in groundwater. Further work will be necessary to evaluate the significance of these results.

## FRASER ESTUARY

Water quality in the lower Fraser Valley is of particular concern, due to the large number and diversity of point and non-point source inputs, coupled with a rapidly increasing population. The population in southwestern B.C. is predicted to grow by 50 per cent over the next 20 years (GVRD 1997), with accompanying increases in the volume of both point and non-point source discharges to the river. Compared to the upper Fraser reaches, the river downstream of Hope has a much lower gradient (*e.g.* Figure 1), receives multiple effluents from both point and non-point sources (such as agricultural runoff), receives a high volume of precipitation seasonally, and is affected strongly by salt water intrusion seaward of New Westminster.

Over the past 20–25 years most data on water quality in the estuary have resulted from short-term, issue-specific sampling campaigns. A compilation of such data from the 1970s (Drinnan and Clark 1980) showed that water quality in the main river channel of the estuary was not degraded. However, in the poorly circulated bottom water of sloughs in the estuary, low oxygen levels, low pH and high organic matter content were common. Although most metals in water were at levels below analytical detection, a few were present at concentrations above existing water quality criteria. Until recently (1993) BC MELP conducted short-term sampling to evaluate attainment of established water quality objectives (BC Ministry of Environment, Lands and Parks 1992; 1993). Water quality objectives were attained in most areas of the lower Fraser River. Exceptions include fecal coliforms in the vicinity of sewage treatment plants in the Main Arm and objectives for dissolved oxygen in some sloughs in the Main Arm. The sloughs are generally poorly flushed and stagnant, and will preferentially accumulate fine particulates and organic materials from the main river flow—the combination of which results in poor water quality.

A recent comprehensive assessment of water quality in the estuary was conducted by the Fraser River Estuary Management Program (FREMP) with funding from FRAP (Drinnan and Humphrey 1997; FREMP 1996). A broad suite of variables was analyzed in this program including physical variables (*e.g.* temperature, conductivity, pH), major dissolved ions, trace metals and a variety of organic compounds. Bi-weekly sampling was conducted for a total of 15 months at three locations; North Arm at Oak Street Bridge, South Arm at Tilbury Island, and in the Main Arm at Mission (Figure 8). Samples were also taken in sloughs on two occasions during low-flow conditions.

Intrusion of marine waters into the estuary during high tide is an important factor in evaluations of water quality in the lower Fraser. The influence is greatest during the winter low-flow period, when the salt water wedge can penetrate as far upstream as New Westminster (Ages 1988; Chapman and Brinkhurst 1981; Drinnan and Clark 1980). In the recent FREMP study, the influence of salt water was evident in all samples collected at low-flow despite measures taken, such as sampling during low slack tide, to avoid this interference.

The three sampling sites in the estuary were similar with respect to most of the physical and inorganic parameters. Significant exceptions were dissolved ion levels and conductivity, which were highest at the Oak St. and Tilbury Island sampling sites due to salt water intrusion. Many trace metals were below limits of

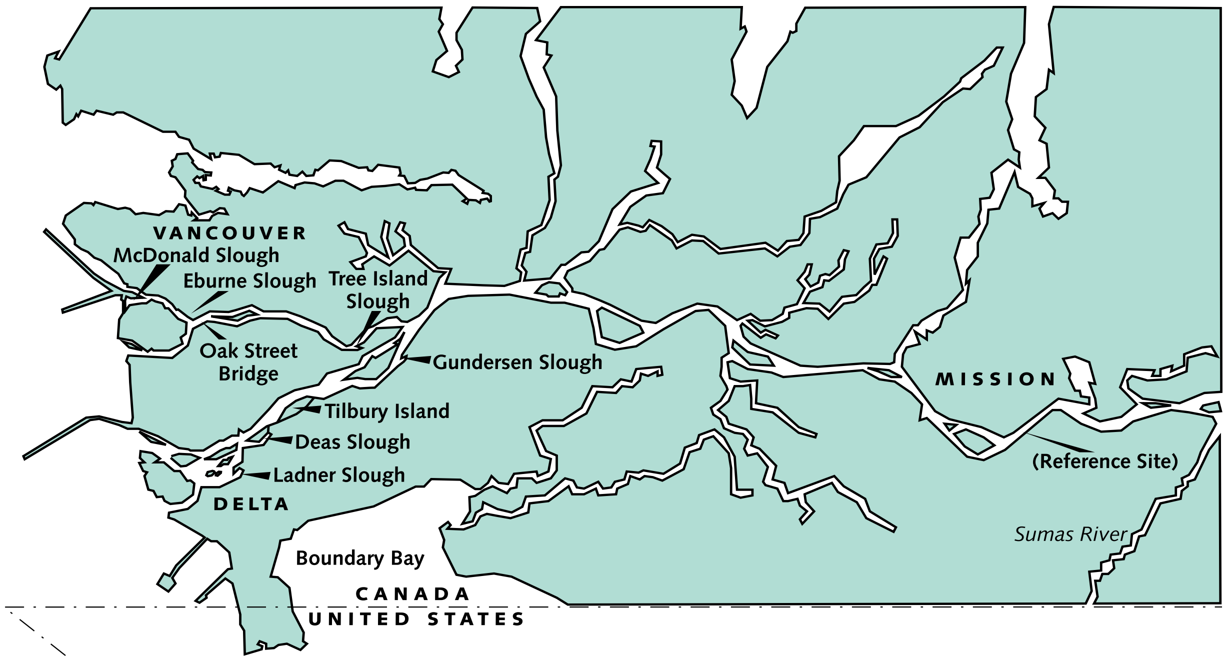



***Figure 8.*** *The Fraser River Estuary area showing sampling sites for the FREMP water quality study (from Drinnan and Humphrey 1994).*

analytical detection, and for those variables that were detected, most were within present British Columbia water quality criteria and Canadian water quality guidelines for the protection of freshwater aquatic life. Concentrations of total aluminum, total copper and total iron did exceed these guidelines frequently, but the measured values were not significantly different from levels in the Fraser River at Hope, upstream of the estuary (Figure 9). This suggests that most of the metals are resulting from upstream erosion of natural bedrock, and that the relative contribution of local effluent sources to the total metal levels in the lower Fraser may be minor. In further support, both total iron and total copper were correlated with suspended sediment concentration, and many of the other trace metals (arsenic, chromium, nickel and zinc) showed peaks in concentration during periods of high flow. Most values did not exceed the established provincial water quality objectives for copper, lead and zinc in the lower Fraser (Swain *et al.* Draft 1995). It should be remembered that the toxicologically important dissolved component of the total metal analysis is generally small relative to particulate metals in natural waters, but may be a large proportion of the total in many industrial and municipal effluents.

Both municipal wastewater treatment plants and stormwater runoff contribute to fecal coliform levels in water in the lower Fraser. Bacterial numbers vary widely over a seasonal cycle, being highest (up to 17,000 fecal coliforms/100ml) in the winter when rainfall is highest and regional treatment plants suspend chlorination of effluent waters (Drinnan and Humphrey 1997). Coliform density in the estuary declines through the summer as a consequence of drier weather and increased disinfection (Figure 10). During this period, levels of fecal coliforms were considerably less than the maximum value for the existing provincial water quality objective (4,000 fecal coliforms/100ml: Swain and Holms 1985) and most single samples were less than the objective for the geometric mean of five samples collected over 30 days (1000 fecal coliforms/100 ml), which apply from April to October. The new objective for the estuary is 200 colony forming units/100 ml (Swain 1998).

Most of the measured organic contaminants were near or below detection and where measurable were many times lower than historical levels. Chlorophenolics, in particular, have dropped nearly an order of magnitude from levels measured in the 1980s (Drinnan *et al.* 1991), attributable to de-registration of chlorophenate

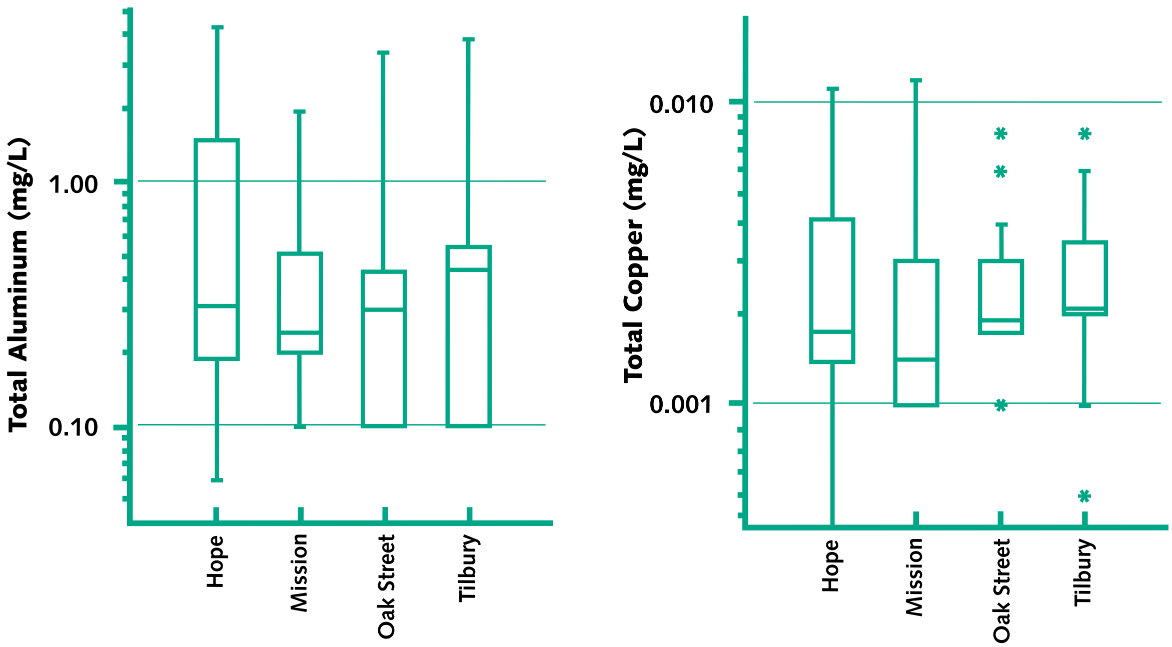
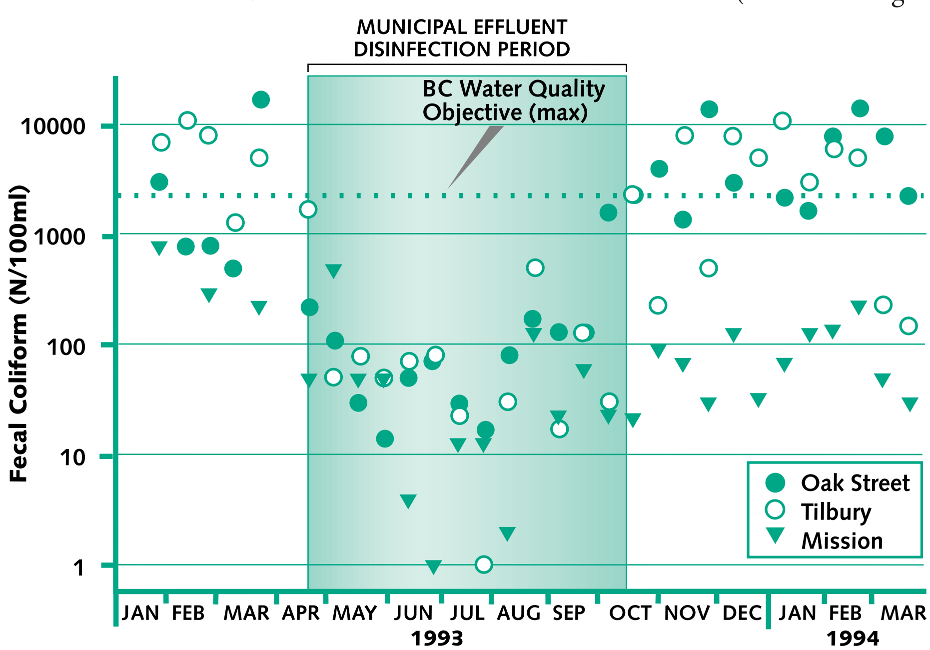



*Figure 9. Total aluminum and total copper data summaries for the upstream "control" site at Hope and at the FREMP sampling sites in the estuary.*

wood preservatives for general antisapstain treatment. Other compounds continue to be of some concern. For example, concentrations of the PAHs, pyrene, benzo(a)pyrene and phenanthrene exceeded provincial water quality criteria in some sloughs. Elevated levels of PAHs in the estuary, relative to upstream locations, were also measured in bed sediments (Brewer *et al.* 1999) and in fish tissues (Raymond *et al.* 1999)—indicative of point and non-point contaminant sources in this increasingly urbanized estuary. Localized areas of concern remain, particularly in the main stem and Main Arm where levels of total PCBs (0.16–0.26 ng/L) exceeded the B.C. Water Quality criterion of 0.10 ng /L and in the North Arm where measured dioxin TEQs (0.06 ng/L) reached the CCME draft interim water quality guideline for protection of aquatic life (0.06 ng/L) (Sylvestre *et al.* 1998a).

With the successful reduction in environmental releases of bioaccumulative organochlorine compounds, focus has shifted to the effects and levels of other contaminants. An example is nonylphenol, a common component of household chemicals, which causes




*The summer depression in numbers reflects a combination of both disinfection of municipal effluents and lower rainfall and stormwater flows.*

*Figure 10. Seasonal pattern in fecal coliform numbers in the Fraser River near Vancouver.*

hormonal disruption in fish (Arukwe *et al.* 1997; Jobling *et al.* 1996; Jobling and Sumpter 1993). Nonylphenol entering the domestic wastewater system in the Vancouver area is released to the environment in sewage effluents in the Fraser River Estuary. Total daily loadings of nonylphenol from the Annacis Island plant alone are in the order of 1.2 (GVRD 1999) to 9 kg/day (Supervisory Coordinating Committee 1987), and ambient levels of 32–130 ng/L and 6.7–7.4 ng/lL have been measured downstream and upstream, respectively, of the effluent discharges (Sylvestre *et al.* 1998b).

## CONCLUSION

Trend analyses of water quality at most sites in the basin showed few strong trends. Particularly dramatic increases or decreases were related to changes in the effluent character of major upstream discharges. Subtle trends in particular constituents were seen at a number of sites, and may be an indication of incremental change in some environmental component. Small watersheds, where human activities will have the most effect, are poorly represented in the long-term water quality record.

Water sampling revealed generally low levels of industry-related contaminants. Improvements in industrial wastewater treatment, changes in industrial processes and regulatory action related particularly to wood treatment and preservation have had a favourable effect in reducing organochlorine contamination of waters in the Fraser Basin. Current concentrations of many water-borne contaminants of concern, such as chlorophenolics released from pulp and paper mills and washed from lumber treatment areas, have declined to a fraction of historical levels. The significance of contaminants from other sources, particularly from municipal wastewater treatment plants, will perhaps increase in the future with anticipated population growth throughout the basin.

Despite the relatively high population densities in the Fraser Valley, water quality in the estuary is generally good. Concentrations of a wide range of chlorophenolic compounds, insecticides and other chemical pesticides, and the PAHs are also much lower than historical levels. Areas of some concern do remain, particularly in sloughs near the main channels and in areas of dense effluent and stormwater runoff. Some contaminants, such as the PAHs benzo(a)pyrene and naphthalene associated with urban non-point sources, are of continuing concern in the populated lower reaches of the river. Other less well-known contaminants, such as nonylphenol, prove to be of more concern as information accumulates on both ambient levels and environmental effects.

Future monitoring efforts should address the effects of specific events or activities, including the consequences of active development, on water and general environmental quality in small watersheds. Effects-based monitoring will likely become a trend in the future of water quality assessment in the Fraser River Basin. Concurrent evaluation of both ambient levels of contaminants and effects on biota (through biomarkers, sentinel species or study of aquatic communities) should be a focus of future monitoring programs.

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