

FRASER RIVER ACTION PLAN



Survey of Contaminants in Suspended Sediment and Water in the Fraser River Basin

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The Fraser River Basin

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ABSTRACT

Concentrations of trace organic contaminants (dioxins, furans, chlorophenolics, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, pesticides, fatty acids and resin acids), total trace metals and nutrients were measured in suspended sediments and/or water samples collected upstream and downstream of six pulp mills located in the Fraser River Basin. Sampling was conducted under fall low flow conditions over three consecutive years (1992 -1994) and under winter base flow conditions in February 1993. Concentrations of contaminants in both sediment and water were used to calculate log K_{oc} values for dioxins, furans, chlorophenolics and polycyclic aromatic hydrocarbons. Results indicate that (i) dioxins, furans, chlorophenolics, polycyclic aromatic hydrocarbons, fatty acids and resin acids, measured in suspended sediments, were found in higher concentrations downstream of pulp and paper mills than at reference sites upstream of the mills, (ii) these contaminants were generally found in higher concentrations during winter base flow periods than under fall flow conditions, (iii) estimated loadings of 2,3,7,8-T4CDD and 2,3,7,8-T4CDF in suspended sediments collected downstream of the pulp mills were generally lower than loads discharged to the receiving environment by the mills at approximately the same time, suggesting that deposition of contaminated sediment is likely occurring, (iv) concentrations of 2,3,7,8-T4CDD and 2,3,7,8-T4CDF in suspended sediments have decreased from levels measured in 1990 prior to implementation of pulp mill abatement measures, (v) phase partitioning of dioxins, furans, chlorophenolics and polycyclic aromatic hydrocarbons between sediment and water was highly variable and appeared to be influenced by site specific environmental conditions, (vi) none of the organic contaminants exceeded existing federal guidelines or provincial water quality criteria for the protection of aquatic life, however guidelines or criteria currently do not exist for many organic contaminants which were measured at elevated levels downstream of the mills, and (vii) total aluminum, lead, chromium, copper, iron and phosphorus measured in whole water exceeded federal guidelines and/or provincial water quality criteria for the protection of aquatic life, but these represent natural background levels.

RÉSUMÉ

Dans des sédiments en suspension et/ou des échantillons d'eau recueillis en amont ou en aval de six usines de pâtes situées dans le bassin du fleuve Fraser, on a mesuré les concentrations de contaminants organiques à l'état de traces (dioxines, furannes, composés chlorophénoliques, hydrocarbures aromatiques polycycliques, biphényles polychlorés, pesticides, acides gras et acides résiniques), les concentrations totales de métaux-traces et celles de nutriments. L'échantillonnage a été fait à l'automne dans des conditions de faible débit, pendant trois années consécutives (1992-1994), et dans des conditions d'écoulement de base d'hiver en février 1993. On a utilisé les concentrations de contaminants des sédiments et de l'eau pour le calcul des valeurs logarithmiques du K_{oc} des dioxines, des furannes, des composés chlorophénoliques et des hydrocarbures aromatiques polycycliques. D'après les résultats on a observé, (i) en aval des usines de pâtes et de papier, des concentrations supérieures, dans les sédiments en suspension, de dioxines, de furannes, de composés chlorophénoliques, d'hydrocarbures aromatiques polycycliques, d'acides gras et d'acides résiniques, par rapport à celles mesurées aux emplacements de référence situés en amont; (ii) on mesurait généralement, au cours des périodes d'écoulement de base d'hiver, des concentrations supérieures de ces contaminants à celles observées dans des conditions d'écoulement d'automne; (iii) les charges estimées de 2,3,7,8-T4CDD et de 2,3,7,8-T4CDF dans les sédiments en suspension étaient généralement inférieures à celles provenant des usines de pâtes en amont, mesurée environ au même temps; (iv) les concentrations de 2,3,7,8-T4CDD et de 2,3,7,8-T4CDF dans les sédiments en suspension ont diminué par rapport aux valeurs mesurées en 1990, avant l'application des mesures de lutte contre la pollution visant les usines de pâtes; (v) les résultats des séparations par phase, entre les sédiments et l'eau, des dioxines, des furannes, des composés chlorophénoliques et des hydrocarbures aromatiques polycycliques, étaient très variables et semblaient influencées par des conditions environnementales propres au site; (vi) même si aucune des valeurs des contaminants organiques mesurées ne dépassait les limites fixées par les lignes directives fédérales ou les critères provinciaux de qualité de l'eau pour la protection de la vie aquatique, des limites fixées n'existent pas pour plusieurs des contaminants organiques mesurées en concentrations élevées en aval des usines de pâtes, et (vii) les concentrations totales d'aluminium, de plomb, de chrome, de cuivre, de fer et de phosphore mesurées dans l'eau non traitée dépassaient les limites des lignes directrices fédérales et/ou celles des critères provinciaux de qualité de l'eau pour la protection de la vie aquatique, mais ces valeurs représentent des teneurs naturelles de fond.

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1.0 INTRODUCTION

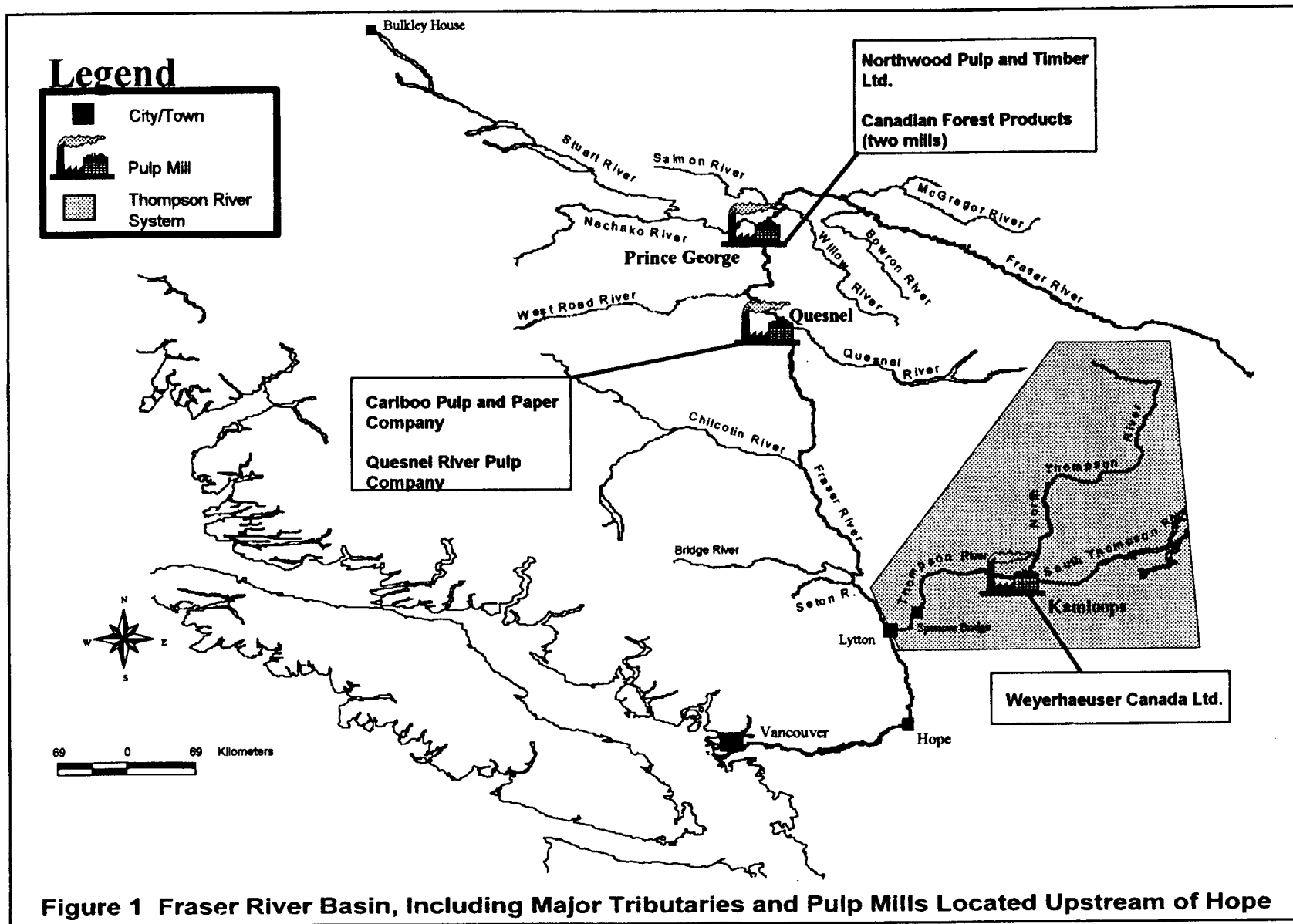
The Fraser River Basin has an area of 234,000 km² and extends north to Bulkley House on the Stuart River System and from the Coast Mountain Range to the west to the Rocky Mountains in the east (Dorcey and Griggs, 1991). It is composed of a vast network of lakes and tributaries which feed the Fraser River, 1375 km in length, lying at its heart.

The Fraser River is internationally renowned for the abundance and diversity of natural resources that rivals almost any other river in the world. The river and its tributaries drain diverse areas which include urban centres, industrial centres, agricultural land and pristine habitat. The largest tributary to the Fraser River is the Thompson River which joins the Fraser River at Lytton prior to entering Fraser River Canyon (Figure 1).

1.1 Water and Sediment Quality Issues

Pulp and paper mills represent one of the major pollution sources affecting the state of the aquatic environment in the Fraser River Basin, since they contribute the largest proportion of industrial effluents discharged to the basin (Schreier *et al.*, 1991). Contaminants related to pulp and paper mills have been of great concern, as a number of them have been shown to cause both acute and chronic effects in various organisms. Of primary concern is exposure of the general public to dioxins and furans through food intake (Gilman and Newhook, 1991). In 1988, Mah *et al.* (1989) identified dioxins and furans in Fraser and Thompson River bed sediments and fish thereby prompting the 1989 release of an advisory by National Health and Welfare Canada restricting the intake of muscle tissue from mountain whitefish, large-scale sucker, northern squawfish and peamouth chub. In April 1990, the advisory was expanded to include rainbow trout and Dolly Varden muscle and white sturgeon liver tissue.

In 1991, federal and provincial legislation was passed requiring bleached kraft pulp mills to make process changes in order to reduce emissions of dioxins and furans and other organochlorine compounds. These regulations resulted in the introduction of pulp mill technology which modified the previous bleaching methods from using 100% molecular chlorine with a method that employs 40 - 100% chlorine dioxide substitution. Following the implementation of pulp mill regulations and based on results of the 1990-1991 organochlorine trend monitoring program (Dwernychuk *et al.*, 1991), consumption advisories were revised by the British Columbia Ministry of Health. Revisions were made for quantities of mountain whitefish muscle which were deemed safe for consumption, and recommendations were made to avoid consumption of liver from largescale sucker, Dolly Varden, rainbow trout and mountain whitefish. In January 1994, the British Columbia Ministry of Health lifted its advisory on the consumption of mountain whitefish and trout muscle flesh (BCMELP, 1994b).



Although the pulp and paper industry has been regulated, and improvements have been made in the processing of wastes, toxic contaminants have been and continue to be found in main stem reaches of the Fraser River, particularly downstream of mill effluent discharges. In November 1991, following the implementation of pulp mill regulations, Derksen and Mitchell (in preparation[b]) found detectable levels of 2,3,7,8-tetrachlorodibenzofuran in suspended sediments collected from the Fraser River at Lillooet (downstream of five pulp and paper mills). These levels, however, represented an 86% reduction in concentration from March 1991 before the initiation of chlorine dioxide substitution. In addition, Dwernychuk *et al.* (1991) found measurable levels of chlorophenolics in bed sediments collected from the Fraser River in the vicinity of Prince George and Quesnel. Furthermore, Duncan (in preparation) found detectable levels of dioxins, furans and chlorophenolics in suspended sediments collected from Stoner (40 river kilometres (rkm) downstream of Prince George), Quesnel and Marguerite on the Fraser River. More recently, in 1993, Sekela *et al.* (1994) found detectable levels of dioxins/furans and chlorophenolics in suspended sediments and water at Marguerite, downstream of Quesnel.

In response to increasing public concern over the effects of growing urbanization and industry in the Fraser River Basin, in June 1991, the federal government announced the Fraser River Action Plan (FRAP). As part of FRAP, the Environmental Quality Program is responsible for providing a baseline of the environmental conditions in the aquatic environment and measuring the effects of major pollution sources on the aquatic environment.

1.2 Purpose and Scope

1.2.1 Purpose of Study

The purpose of this study was threefold:

1. To determine levels of contaminants, particularly those associated with pulp and paper mill effluents, in suspended sediments and water from sampling sites on the Fraser and Thompson Rivers;
2. To measure changes in contaminant levels over the 1992 - 1994 sampling period;
3. To relate changes in contaminants associated with pulp mill effluents to abatement measures implemented by the pulp mills in 1991.

1.2.2 Scope of Report

This report contains analyses of suspended sediment and water data collected at sampling sites on the Fraser and Thompson Rivers in October 1992, February 1993, November 1993 and November 1994. The data contain information on sediment and water concentrations of the

following contaminants: dioxins and furans, chlorophenolics, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, pesticides, fatty acids, resin acids, trace metals and nutrients. Levels of these substances are compared with the most recent federal, provincial and international guidelines and criteria. Information on phase partitioning is presented for dioxins and furans, chlorophenolics and polycyclic aromatic hydrocarbons.

2.0 PULP MILL OPERATIONS

Of the six pulp and paper mills located in the Fraser River Basin upstream of Hope, five are located on the main stem of the Fraser River and one on the Thompson River (Figure 1). All six pulp mills release their effluents into either the Fraser or Thompson Rivers. The following information regarding pulp mill operations has been obtained from Dwernychuk (1994), and the reader is referred to that document for more detailed information.

Prince George Pulp and Paper Limited, Intercontinental Pulp Company Limited and Northwood Pulp and Timber Limited are located on the banks of the Fraser River at Prince George. In 1978, Prince George Pulp and Paper Limited and Intercontinental Pulp Company Limited combined to form Canadian Forest Products (Canfor). All three mills produce bleached softwood kraft pulp and release their effluents into the Fraser River.

Canfor's effluent treatment system consists of a primary clarifier and a primary and secondary aeration lagoon. The primary clarifier removes solids while the primary aeration lagoon is a one day system used for the treatment of bleached effluent and toxic streams. The secondary aeration lagoon has a six day retention time. Prior to 1991 molecular chlorine was employed in the bleaching process, but since July 1991 the installation of a chlorine dioxide generator has resulted in the production of bleached pulp with 70-100% chlorine dioxide substitution.

At Northwood Pulp and Timber Limited, effluent treatment consists of clarification through screening followed by biological treatment in aerated lagoons (which operate at an excess of 80% of BOD₅ reduction). Recent mill modifications now allow for 70-100% chlorine dioxide substitution.

Cariboo Pulp and Paper Company and Quesnel River Pulp Company are located on the banks of the Fraser River at Quesnel. Cariboo Pulp and Paper Company, also a producer of bleached softwood kraft pulp, employs 40-100% chlorine dioxide substitution in its bleaching process. Prior to discharging into the Fraser River, the effluent undergoes primary clarification followed by solids removal and then enters a series of aerated biological treatment lagoons where it is mixed with municipal sewage.

Quesnel River Pulp Company is a Thermal Mechanical Pulp and Bleached Chemical Thermal Mechanical Pulp mill which does not employ any form of chlorine in its bleaching process but instead uses a two stage hydrogen peroxide bleaching system. Effluent from the mill is clarified and then treated by an aerobic/anaerobic effluent treatment system. Effluent entering the anaerobic reactors undergoes degradation of small chain acids with resultant methane, carbon dioxide and hydrogen sulphide production which is processed through a gas scrubbing system.

The effluent from the anaerobic reactors is then transferred to the aerobic stabilization basin, which has a retention time of three days, and is then discharged into the Fraser River.

A single pulp mill, Weyerhaeuser Canada Limited located in Kamloops, is found on the Thompson River. Also a bleached kraft mill, Weyerhaeuser Canada Limited produces 100% chlorine dioxide bleached kraft pulp from sawdust and softwood chips. Before discharge into the Thompson River, the effluent is clarified, mixed with acid sewer, re-clarified in settling ponds and then biologically treated in aerated lagoons for a period of six days.

With the exception of Weyerhaeuser Canada Limited, all mills operated normally in the period between October 1992 and November 1994. According to information provided by Weyerhaeuser Canada Limited (Gordon Kerfoot, personal communication) the mill was temporarily shut down from October 13 to October 29, 1992 and again from January 20 to February 4, 1993. Moreover, the mill ran at 75 % of normal operations for the rest of February 1993. In September and October 1993, the mill was shut down for the purpose of dredging the effluent treatment ponds.

3.0 DESCRIPTION OF STUDY AREA

The study area was divided into two main regions. The Fraser River study region encompassed the mainstem of the Fraser River between Shelley and Yale, while the Thompson River study region encompassed the area between McLure on the North Thompson River and Savona on the Thompson River. Four sites were sampled on the mainstem of the Fraser River (Figure 2). These included the following: Shelley (reference site, 18 rkm upstream of Prince George), Woodpecker (59 rkm downstream of Prince George), Marguerite (65 rkm downstream of Quesnel) and Yale (450 rkm downstream of Marguerite). The two sites in the Thompson River study region included the reference site, McLure (41 rkm upstream of Kamloops), and Savona (61 rkm downstream of Kamloops).

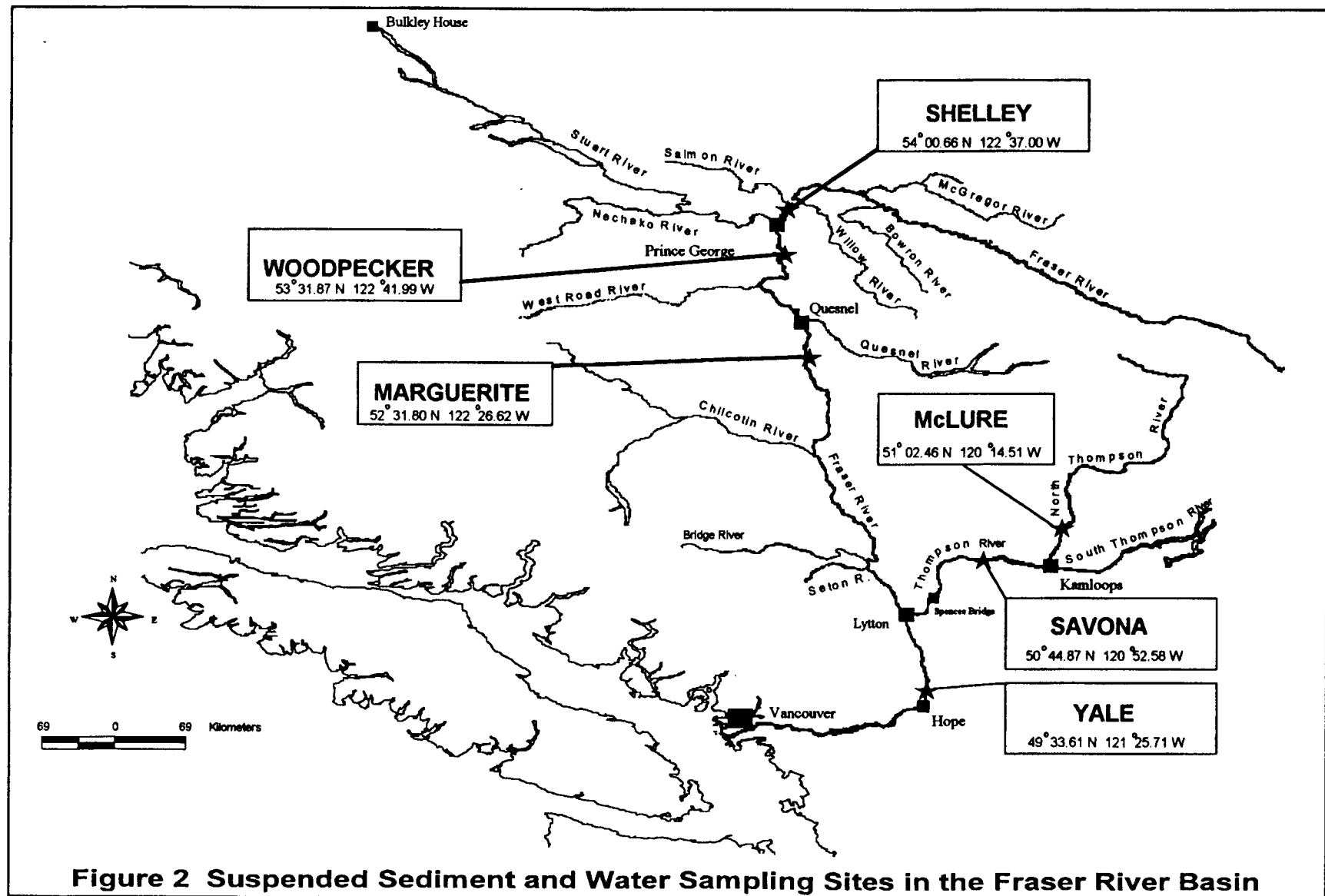
3.1 Fraser River Region

3.1.1 Geography

From its headwaters to Prince George, the Fraser River drains the Rocky Mountain trench. The trench is characterized by lacustrine silts interspersed with sand and gravel and flanked by steep valley walls comprising folded sedimentary rocks. The river valley is dominated by forested uplands and partially developed land. The predominant bed material is composed of sand with local gravel. The average gradient is of the order of 17 m per 100 km (Zrymiak and Tassone, 1988; Carson, 1988). The main tributaries entering the Fraser River north of Prince George are the McGregor River, draining the Rocky Mountains, the Salmon River flowing from the north and the Willow and Bowron Rivers, draining the Cariboo Mountains.

From Prince George to Marguerite, the Fraser River is joined from the north-west by waters from the Nechako and Stuart sub-basins. As it continues its southward flow, the river is further augmented with flows from the West Road and Quesnel sub-basins. In this reach, the river is characterized by narrow, weakly sinuous areas separated by wider multiple island stretches. It drains a landscape characterized by lowlands and late glacial lakes (Dorcey, 1991). The Fraser River near Marguerite is primarily a gravel-bed river, not sand-bedded, which is consistent with the increased river gradient of 64 m per 100 km (Carson, 1988).

From Marguerite to Hope, the Fraser River is further augmented by the Chilcotin and Bridge-Seton sub-basins. South of Lillooet the river drops rapidly, at a rate of 290 m per 100 km (Northwest Hydraulic, 1993), and enters a belt of extreme aridity. At Lytton the muddy waters of the Fraser are joined from the east by the clear waters of the Thompson River before entering into the long, narrow, Fraser River Canyon that cuts through the barrier of the Coast Range



(Dorcey and Griggs, 1991). The majority of the sediment in this region is derived from glacial and fluvial deposits (Dorcey and Griggs, 1991).

3.1.2 Hydrology and Suspended Sediment Characteristics

The hydrology of the Fraser River is predominantly determined by the melting of the snow pack in headwater tributaries, producing great variation between years. The quantity of glacial meltwater released each summer tends to vary inversely with the previous winter's snow accumulation and with summer precipitation (Fountain and Tanghorn, 1985). Since the mainstem of the Fraser River is unregulated, the flow regime of the river exhibits characteristic seasonal profiles. Discharge rises rapidly in April and May, peaks in June, declines rapidly in July and then more slowly through the rest of the year. Small isolated peaks can occur at any time of the open water period from rainstorms. Near its mouth, low flow can go down to around 450 m³/s and high flows can reach 20,000 m³/s (Dorcey and Griggs, 1991).

Glacial deposits exposed along the main river valleys are the major source of sediment load to the Fraser River. Erosion and transport of this sediment is accomplished primarily by the spring runoff. Approximately three-quarters of the annual suspended sediment load is transported during three months in late spring and early summer, corresponding to the period of greatest flows (Church *et al.*, 1989).

The suspended sediment load includes sand, silt and clay size particles as well as fine organic material. Suspended sand is mostly transported in the spring months and is only transported in small quantities throughout the year. A large part of the annual wash load (silts and clays) is also moved during snowmelt at freshet (Northwest Hydraulic, 1993).

Maximum suspended sediment concentrations at Fraser River sediment monitoring stations generally exceed 500 mg/L each year and often exceed 1,000 mg/L. Suspended sediment concentrations remain high from April through the end of June. Suspended sediment concentrations in the fall and late winter are much lower than during the snowmelt freshet and are often less than 100 mg/L. Annual minimum concentrations are usually less than 10 mg/L, and these typically occur around the time of minimum annual discharge. Rainstorm floods in October, November and December occasionally increase water levels and sediment concentrations (Northwest Hydraulic, 1993).

3.2 Thompson River Region

3.2.1 Geography

The Thompson River sub-basin is located in south-central British Columbia in the semi-arid rain shadow of the Coastal Mountain Range. With a drainage basin covering 55,000 km², the Thompson River is one of the larger rocky bottom rivers in the world (Bothwell *et al.*, 1992). The physiography of the Thompson River sub-basin is characterized by plateaus and highlands bounded on the east and west by mountain ranges. These plateaus are generally underlain by either basaltic, sedimentary or volcanic rock and are covered by a thick mantle of glacial drift. The mountain ranges forming the western boundary (Cascade Mountains, Clear Range and Marble Range) and eastern boundary (Monashee Mountains and Cariboo Mountains) are composed mainly of sedimentary and metamorphosed rock (Thompson River Basin Pre-Planning Task Force, 1981). The two major tributaries of the Thompson River are the North and South Thompson Rivers which come together to form the Thompson River at the city of Kamloops.

3.2.1.1 North Thompson River Study Reach

This reach extends from McLure, on the North Thompson River, to the confluence with the South Thompson River at Kamloops. This portion of the river is predominated by sand and cobble material with silt accumulations in backwater areas. The river gradient in this reach is 39.6 m per 100 km (Northwest Hydraulic, 1993).

3.2.1.2 Thompson River Study Reach

This reach extends from the confluence of the North and South Thompson Rivers at Kamloops to Savona. Downstream of Kamloops, the first 25 km this reach of the river is generally characterized by sand and boulders with fine silts accumulated in backwater areas (Northwest Hydraulic, 1993) whereas for the last 25 km of the reach the Thompson River flows through Kamloops Lake, which ends just upstream of Savona.

3.2.2 Hydrology and Suspended Sediment Characteristics

3.2.2.1 North Thompson River

With a drainage area of 19,600 km², the North Thompson River has a mean annual flow of 432 m³/s. Freshet generally peaks in June, corresponding to the period of maximal snow melt in its

headwater tributaries, and the lowest flows occur in late winter (January - March). Being a free flowing river without intervening lakes in its system, the hydrology of the North Thompson is greatly affected by heavy rains and sudden snow melt (Nordin and Holmes, 1992).

Suspended sediment concentrations of the North Thompson River range between 5 and 250 mg/L (Northwest Hydraulic, 1993).

3.2.2.2 Thompson River

Flow in the Thompson River is unregulated, so yearly discharge varies from 250 to 2,400 m³/s, and the mean annual flow is about 800 m³/s. Because flow in the Thompson River is largely driven by snow pack and glacier melt, the peak freshet occurs in spring and early summer (May - June), and the lowest flows are in the late winter (January - March) (Bothwell, 1992). The mainstem of the Thompson River begins at Kamloops, located at the confluence of its two primary tributaries, the North and South Thompson Rivers. Kamloops Lake, located 10 km downstream of Kamloops, is a long (25 km), narrow (mean width 2.1 km), and deep (mean depth 71 m) lake. The limnological conditions in Kamloops Lake are such that complete flushing of the lake occurs several times each year (Bothwell *et al.*, 1992). Furthermore, bulk residence time, defined as lake volume divided by river discharge, varies from less than 20 days to greater than 350 days, but the annual mean flushing time is only 60 days (Carmack *et al.*, 1979). Flow patterns of the Thompson River into Kamloops Lake, as described by St. John *et al.* (1976) and Carmack *et al.* (1979), have characteristic seasonal profiles. In the winter (January to March) colder less dense river water (0°C) flows over the warmer (4°C) more dense lake water, resulting in little intermixing within the lake. During much of the remainder of the year (April to December), the river water is denser than the lake surface, and the plume interflows at depth within the lake thereby enhancing mixing between the incoming river and the lake water.

As a result of the presence of Kamloops Lake, which acts as a sediment sink, suspended sediment concentrations in the Thompson River are typically low < 50 mg/L (Northwest Hydraulic, 1993).

4.0 METHODS

4.1 Sample Timing

Sampling in the Fraser Basin was conducted during the following hydrological periods: fall low flow (October 1992, November 1993, November 1994) and winter base flow (February 1993). Refer to Figure 3 for the mean monthly flow, relative to the annual hydrograph, of the North Thompson River at McLure and that of the Thompson River at Spences Bridge during each of the three sampling periods. Refer to Figure 4 for the mean monthly flow of the Fraser River at Marguerite, relative to the annual hydrograph, during each of the four sampling periods.

4.2 Field Methods

4.2.1 Sampling Equipment Cleaning Procedures

4.2.1.1 Field Equipment and Sediment Sample Containers

All field sampling equipment and sediment sample containers used for organic contaminants were made of stainless steel or Teflon and were cleaned as follows: (1) washed with tap water and laboratory detergent, (2) rinsed with tap water then deionized water (18 meg-ohm), (3) rinsed with pesticide grade acetone followed by hexane, (4) air dried. All cleaned field equipment was wrapped in heat treated (325° C) aluminum foil until used. Prior to use, all equipment was rinsed with water from the sample collection site.

4.2.1.2 Water Sample Containers

Four litre glass amber bottles with Teflon lined caps were used to collect river water samples for organics analyses. The bottles were cleaned as follows: (1) washed with tap water and laboratory detergent, (2) rinsed with tap water then deionized water (18 meg-ohm), (3) heat treated to 330°C for six hours.

Sample bottles used for trace metal analyses were made of non-pigmented, low density polyethylene and were cleaned as follows: (1) rinsed with tap water and laboratory detergent, (2) rinsed with tap water followed by deionized water (18 meg-ohm), (3) placed in an acid bath of 25 % v/v nitric acid for 2 hours, (4) rinsed three times with deionized water (18 meg-ohm) and (5) air dried. Prior to use, bottles and caps were rinsed three times with water from the sample collection site.

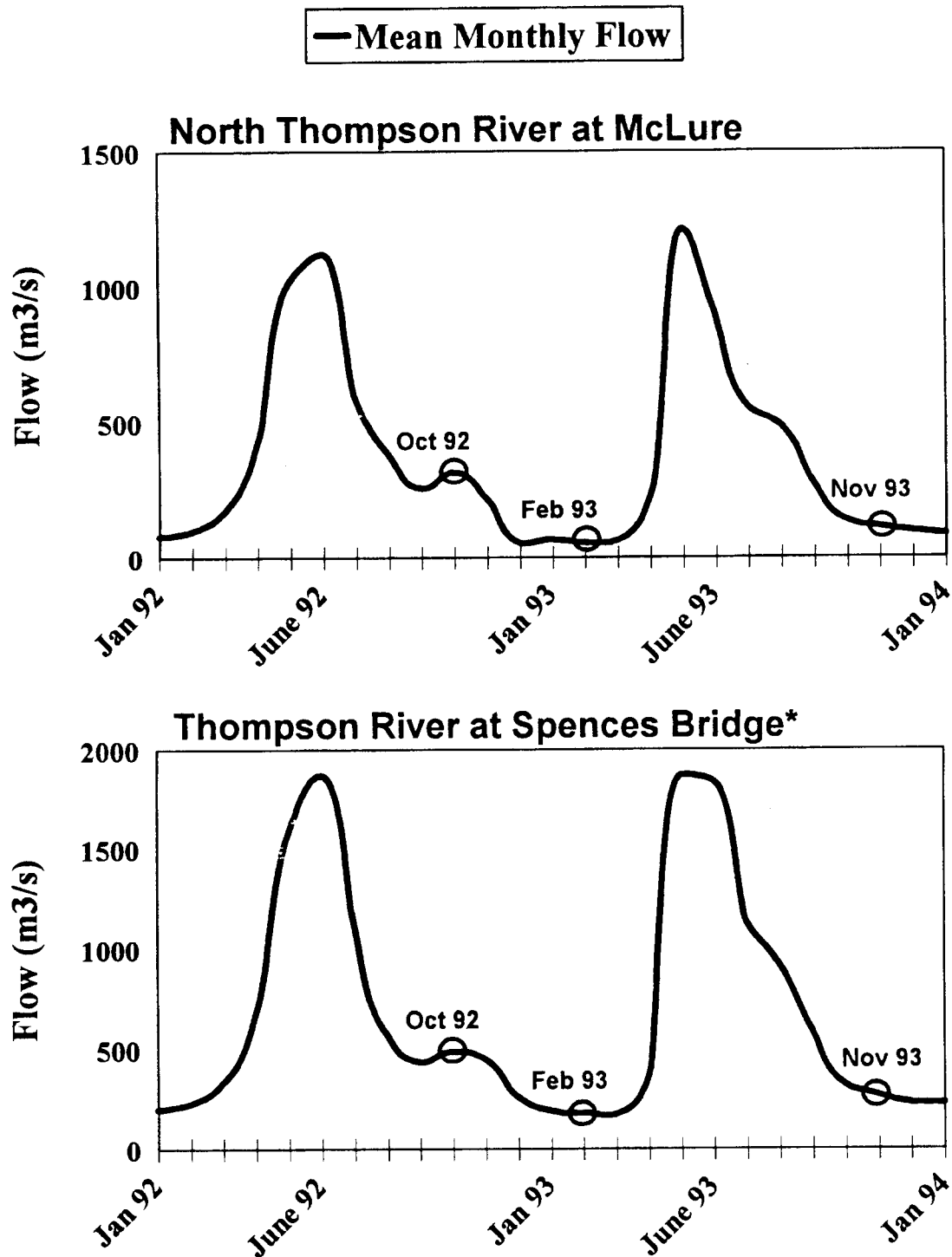


Figure 3 Mean Monthly Flow of the North Thompson River and the Thompson River During Sampling Periods

* Spences Bridge is the nearest Water Survey of Canada Hydrological Station located 70 km downstream of Savona.

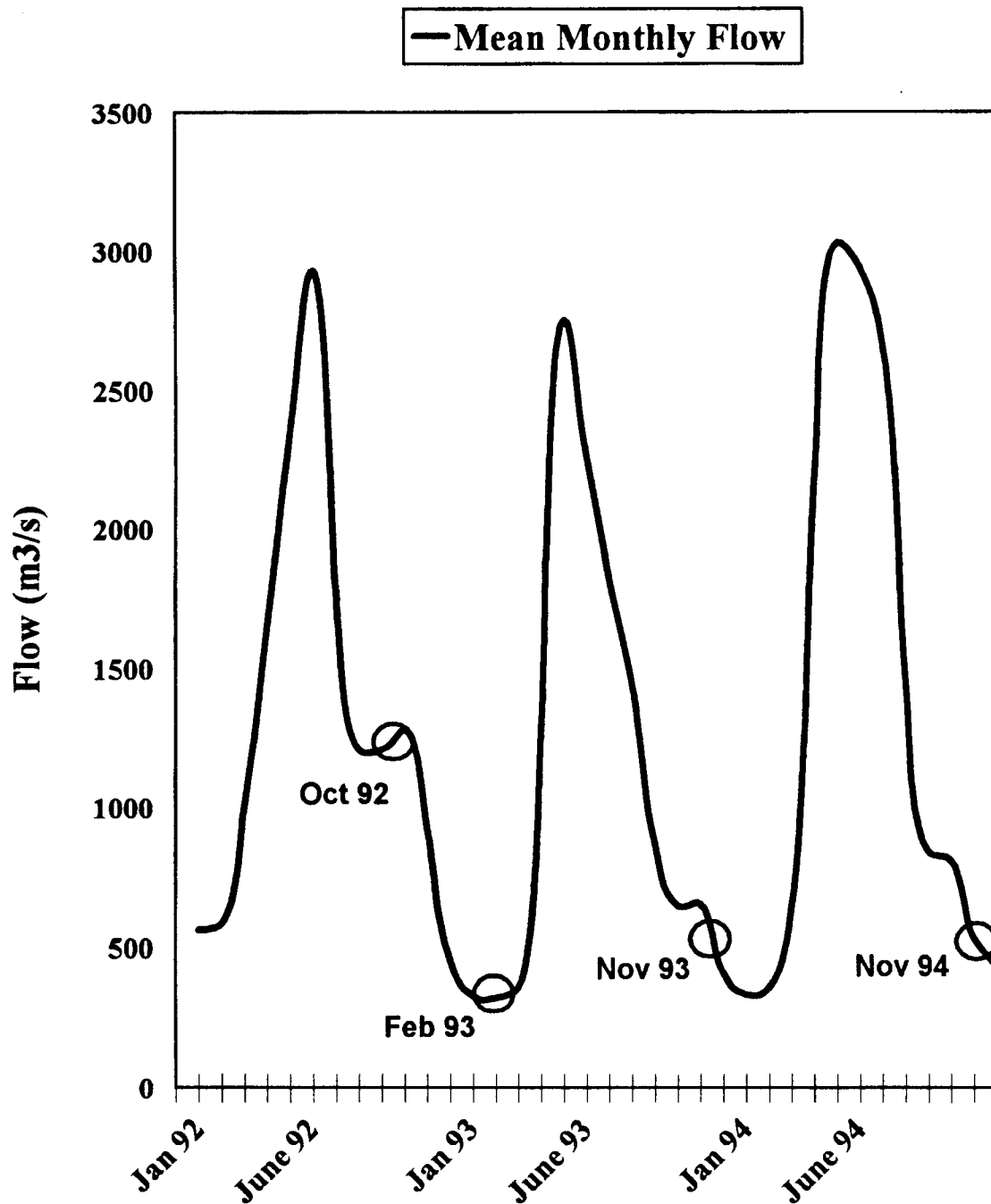


Figure 4 Mean Monthly Flow of the Fraser River at Marguerite During Sampling Periods

Sample bottles for phosphorus analyses were made of glass. Bottles and filters were cleaned as follows: (1) washed with tap water and detergent, (2) rinsed with deionized water (18 meg-ohm) and (3) oven dried for 2 hours.

Sample bottles for nitrogen analyses were made of non-pigmented, low density polyethylene and were cleaned in the same manner as the bottles used for phosphorus analysis.

4.2.1.3 XAD Column Preparation

Clarified water from the continuous flow centrifuge was sampled for dioxins, furans, polycyclic aromatic hydrocarbons (PAHs) and chlorophenolics using XAD-2 resin columns. These were pre-cleaned by AXYS Analytical (Sidney, B.C.) by eluting them with dichloromethane followed by a final rinse of methanol. The columns were left wet with methanol to prevent drying of the resin.

4.2.1.4 Liquid Phase Extractor Preparation

Two large volume liquid phase extractors were used to sample clarified water from the continuous flow centrifuge for dioxins and furans. The large volume liquid extractors are made entirely of glass and Teflon. Prior to use they were cleaned as follows: (1) washed with tap water followed by deionized water (18 meg-ohm), (2) rinsed with pesticide grade acetone, (3) filled with deionized water (18 meg-ohm) and pesticide grade dichloromethane and allowed to operate for 15 minutes, and (4) drained and air dried. All cleaned equipment was wrapped in heat treated (325 °C) aluminum foil until required.

4.2.2 Sample Collection

Refer to Figure 5 for a schematic diagram of sample collection.

4.2.2.1 Suspended Sediment Collection

Suspended sediment samples were collected using two or three Westfalia Separator model KA-2-06-175 continuous flow centrifuges. Each centrifuge operates by delivering sample water continuously to a four chambered bowl assembly where it is evenly distributed by means of a vane insert. The bowl assembly rests on a spindle which rotates the bowl assembly at a rate of 11,000 rpm. The centrifugally separated solids accumulate in the four chambers of the bowl while the clarified water is pressure discharged by means of a centripetal pump. For a detailed description

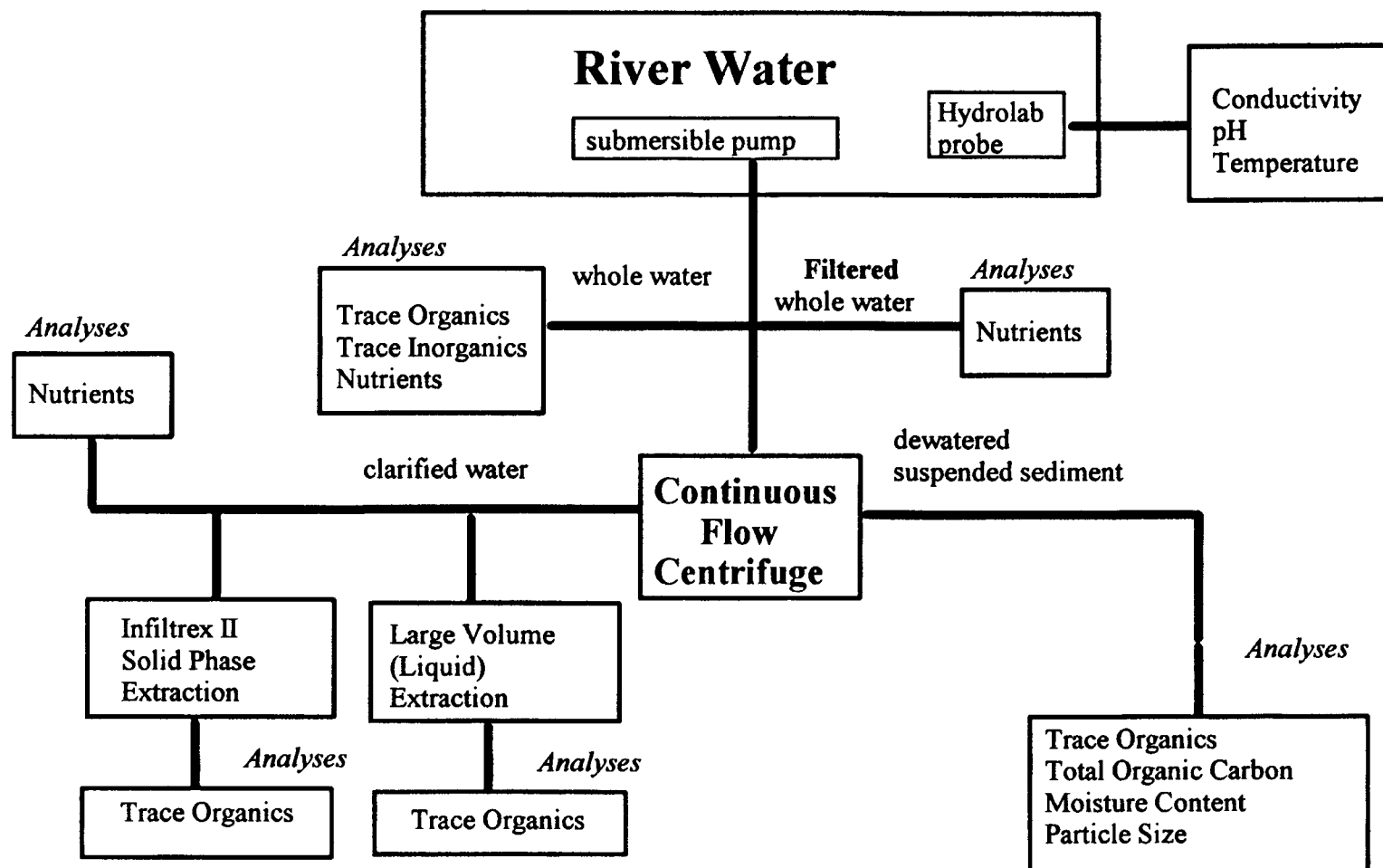


Figure 5 Schematic Flow Diagram of Suspended Sediment and Water Sample Collection

of the operation of the Westfalia centrifuge refer to Horowitz *et al.* (1989).

Sample water was delivered from the river with a submersible pump (March model 5C-MD). All wetted plastic parts of the pump assembly are made of glass filled polypropylene with ceramic spindles and Vitron gaskets. The pump intake was suspended in the river approximately 3 m from shore and 1 m below the surface. Stainless steel encased Teflon tubing was used to deliver the sample water from the pump to the centrifuge.

The centrifuges were positioned onshore and power was supplied to them and the submersible pump by a 5000 watt generator. The generator was located approximately 30 m from the centrifuge to reduce the possibility of contamination from fuel and exhaust. Except for February 1993, the centrifuges were operated at 4 L/min, as this flow velocity was found to be ideal for efficient recovery of suspended sediment (90-99%), and because loss of particles is restricted to those < 1 μm in diameter (Churchland *et al.*, 1987). Due to the low suspended sediment concentrations in February 1993, the centrifuge was operated at 5.5 L/min in order to collect sufficient sample for analyses. The sampling periods ranged from a maximum of 95 hours at Savona in February 1993 to a minimum of 6.5 hours at Woodpecker in October 1992. The duration of the sampling periods was dependent on the suspended sediment concentration in the river water at each site. Once sufficient sample water was clarified, the centrifuges were stopped. The entire bowl assembly from each centrifuge was removed intact and taken to the on site mobile field laboratory for sediment removal. Sediments removed from each centrifuge were combined and placed into a pre-weighed Teflon jar, and total sample weight was recorded. The sample was mixed thoroughly, and subsamples for analytical splits and particle size determination were removed prior to freezing.

4.2.2.2 River Water Collection

4.2.2.2.1 Organic Contaminants

Whole water samples for chlorophenolics, PAHs and resin/fatty acid analyses were collected as discrete samples in 4 L amber glass bottles from an in-line T-valve placed in the stainless steel encased Teflon tubing prior to entering the centrifuge (Figure 5). Sample bottles and Teflon lined caps were rinsed three times with sample water before filling. Sample bottles were filled so that no air space remained under the cap. Once filled, samples were kept cool (4 °C) until shipped to the laboratory for analysis.

4.2.2.2.2 *Trace Metals*

Three whole water samples were collected sequentially in polyethylene bottles from the in-line T-valve. Sample bottles and caps were rinsed three times with sample water before filling.

4.2.2.2.3 *Nutrients*

Three whole water samples were collected sequentially in glass bottles with Teflon liners (for phosphorus analysis) and in polyethylene bottles (for nitrogen analysis) from the in-line T-valve. Three clarified water samples were collected sequentially from the centrifuge outflow tube. Whole water samples were filtered by suction filtration using 0.45 µm cellulose-acetate filters. Sample bottles and caps were rinsed three times with sample water prior to filling.

4.2.2.3 *Clarified Water Extraction*

4.2.2.3.1 *Solid Phase Extraction*

Clarified water was collected from the centrifuge outflow tube in 4 L amber glass bottles and taken to the mobile field laboratory for solid phase extraction. The clarified water was passed through an Infiltrax II *in situ* water sampler (AXYS Environmental Systems Ltd., Sydney, B.C.) for dioxin/furan, PAH and chlorophenolic analyses. The Infiltrax II uses a resin column (solid phase extraction) filled with XAD-2 resin to extract organic contaminants from sample water. The resin column is sent to the laboratory to be eluted, and the eluate is then analysed. A detailed description of the operation of the Infiltrax II is provided in AXYS (1991).

For all samples, 50 L of clarified sample water were passed through the column at 250 mL/min. In order to determine the recovery of dioxins by the XAD-2 resin, field surrogates were added to the sample water prior to extraction. Two dioxin field surrogates (Cambridge Isotope Laboratories, Massachusetts) were added to the sample at a rate of 0.7 mL/min over the entire extraction period. The two internal surrogates added to the sample were: 50 nanograms per millilitre (ng/mL) of ¹³C labelled 1,2,3,4-tetrachlorodibenzo-para-dioxin and 100 ng/mL of ¹³C labelled 1,2,3,7,8,9-hexachlorodibenzo-para-dioxin.

In order to determine the recovery of chlorophenolics by the XAD-2 resin, a phenolic field surrogate (AXYS Analytical Laboratories, Sydney, B.C.) was added to the sample at a rate of 0.7 mL/min over the entire extraction period. The internal surrogate added to the sample was: 7.56 ng/L of carbon thirteen (¹³C) labelled 2,6-dibromophenol. Due to their ionic nature at ambient pH (approximately 7.4), chlorophenolic compounds do not readily adsorb to XAD-2 resin. Therefore,

it was necessary to lower the pH of the sample water to an approximate pH of 2 (by adding 0.8 mL of concentrated sulphuric acid to each 4 L of sample) before passing it through the resin column. Once acidified, the sample was extracted. All extractions were conducted on site in the mobile field laboratory.

4.2.2.3.2 Liquid Phase Extraction

Clarified water was collected from the centrifuge outflow tube in 4 L amber glass bottles and taken to the mobile field laboratory for liquid phase extraction. Water extraction was conducted using a large volume liquid extractor developed by Goulden and Anthony (1985). The extractor operates as a mixer-settler. Sample water continuously passes through the extractor where it is mixed with a strong solvent (dichloromethane). The same surrogates as in solid phase extraction were added to the sample water prior to extraction in order to determine recovery. For all samples, 50 L of clarified sample water was passed through the extractor at a rate of 250 mL/min. Once the 50 L of sample water was passed through the large volume liquid extractor, the dichloromethane was removed and placed in a 1 L amber glass bottle which was sent to the laboratory for analyses.

4.2.3 Temperature, pH and Conductivity Data Collection

Water temperature, pH and conductivity were measured *in situ* with a Hydrolab DataSonde 3 transmitter (HYDROLAB Corporation, Texas). The transmitter was suspended 1 m below the surface at approximately the same distance from shore as the submersible pump intake for the centrifuge. Readings of pH, temperature and conductivity were taken every hour during each centrifuge sampling period.

4.3 Analytical Methods

4.3.1 Sample Analysis

All trace organics were analysed by AXYS Analytical Laboratories, located in Sidney, B.C. Dioxins and furans in suspended sediment and clarified river water were analysed by high resolution gas chromatography and high resolution mass spectrometric detection (HRGC/HRMS). Refer to Table 1 for a list of dioxins and furans analysed.

Chlorophenolics and PAHs were measured in suspended sediment, whole river water and clarified river water and were analysed by high resolution gas chromatography with low resolution

Table 1 Dioxins and Furans Analysed in Suspended Sediment and Clarified Water*

Dioxins	Furans
M1CDD - Total	M1CDF - Total
2	2
1	4
D2CDD - Total	D2CDF- Total
2,7/2,8	2,4
2,3	2,8
T3CDD - Total	2,6
1,2,4	T3CDF - Total
2,3,7	2,4,6/2,4,8
1,2,3	2,3,8
T4CDD - Total	T4CDF - Total
2,3,7,8	2,3,7,8
P5CDD - Total	P5CDF - Total
1,2,3,7,8	1,2,3,7,8
H6CDD - Total	2,3,4,7,8
1,2,3,4,7,8	H6CDF - Total
1,2,3,6,7,8	1,2,3,4,7,8
1,2,3,7,8,9	1,2,3,6,7,8
H7CDD - Total	2,3,4,6,7,8
1,2,3,4,6,7,8	1,2,3,7,8,9
O8CDD	H7CDF -Total
	1,2,3,4,6,7,8
	1,2,3,4,7,8,9
	O8CDF

*Detection limits vary with sample size and matrix heterogeneity (for sediment)

Note: Refer to Table 15 for full nomenclature

(quadrupole) mass spectrometric detection (HRGC/LRMS). Refer to Table 2 for chlorophenolics and to Table 3 for PAHs.

Polychlorinated biphenyls (PCBs) and pesticides were measured in suspended sediments and were analysed by HRGC/LRMS. Refer to Table 4 for PCB congeners, Table 5 for PCB aroclors and coplanars and Table 6 for pesticides analysed in suspended sediments.

Fatty acids and resin acids were measured in suspended sediment and whole water and were analysed by HRGC/LRMS. Refer to Table 7 for fatty and resin acids analysed in these media.

Total organic carbon (TOC) was determined by Pacific Soils Ltd. in Vancouver, B.C. using the Walkley-Black wet oxidation method. Particle size was determined by Geo-Sea Consultants in Cambridge, U.K. with a Malvern 2600l laser particle size analyser. Total trace metals were analysed in whole water by Elemental Research in North Vancouver, B.C. by ICP Mass Spectrometry and Atomic Absorption. Refer to Table 8 for total trace metals analysed and method detection limits.

Total and dissolved phosphate, ammonia, nitrite, nitrate and total nitrogen were measured in whole, clarified and filtered river water and were analysed by the Environment Canada Laboratory, Pacific and Yukon Region, by colorimetric methods. Refer to Table 9 for the nutrients analysed, method detection limits and corresponding ENVIRODAT method codes.

Refer to Appendix I for a detailed description of analytical methods for trace organics, total trace metals and nutrients.

Table 2 Chlorophenolics Analysed in Suspended Sediment, Whole Water and Clarified Water*

Chlorophenolic	Chlorophenolic	Chlorophenolic
4-chlorophenol	3-chlorocatechol	6-chlorovanillin
2,6-dichlorophenol	4-chlorocatechol	3,5-dichlorosyringol
2,4/2,5-dichlorophenol	3,4-dichloroguaiacol	3,4,6-trichloroguaiacol
3,5-dichlorophenol	4,6-dichloroguaiacol	3,4,5-trichloroguaiacol
2,3-dichlorophenol	3,4/4,6-dichloroguaiacol	4,5,6-trichloroguaiacol
3,4-dichlorophenol	4,5-dichloroguaiacol	3,4,6-trichlorocatechol
6-chloroguaiacol	3-chlorosyringol	3,4,5-trichlorocatechol
4-chloroguaiacol	3,4-dichlorocatechol	5,6-dichlorovanillin
5-chloroguaiacol	3,6-dichlorocatechol	pentachlorophenol
2,4,6-trichlorophenol	3,5-dichlorocatechol	2-chlorosyringaldehyde
2,3,6-trichlorophenol	4,5-dichlorocatechol	3,4,5,6-tetrachloroguaiacol
2,3,5-trichlorophenol	2,3,5,6-tetrachlorophenol	3,4,5-trichlorosyringol
2,4,5-trichlorophenol	2,3,4,6-tetrachlorophenol	3,4,5,6-tetrachlorocatechol
2,3,4-trichlorophenol	2,3,4,5-tetrachlorophenol	2,6-dichlorosyringaldehyde
3,4,5-trichlorophenol	5-chlorovanillin	

*Detection limits vary with sample size and matrix heterogeneity (for sediment)

Table 3 Polycyclic Aromatic Hydrocarbons Analysed In Suspended Sediment, Whole Water and Clarified Water*

PAHs	PAHs
Naphthalene	Chrysene
Acenaphthylene	Benzo(a)fluoranthene
Acenaphthene	Benzo(e)pyrene
Fluorene	Benzo(a)pyrene
Phenanthrene	Perylene
Anthracene	Dibenz(a,h)anthracene
Fluoranthene	Indeno(1,2,3-cd)pyrene
Pyrene	Benzo(ghi)perylene
Benz(a)anthracene	

*Detection limits vary with sample size and matrix heterogeneity (for sediment)

Table 4 PCB Congeners Analysed in Suspended Sediment*

Congener	Congener	Congener	Congener	Congener
8/5	44	110	158	193
15	42	107	129	191
19	41/71/64	118	128	170/190
18	40	114	156	189
17	74	105	157	201
24/27	70/76	136	179	197
16/32	66	151	176	198
26	56/60	144/135	178	199
25	95	149	175	196/203
31/28	91	134	187/182	195
33	84/89	131	183	194
22	90/101	146	185	205
45	99	153	174	208
46	83	141	177	207
52	97	130	171	206
49	87	137	172	209
47/48	85	138/163/164	180	

*Detection limits vary with sample size and matrix heterogeneity (for sediment)

Table 5 PCB Aroclors and Coplanars Analysed in Suspended Sediment*

PCB Aroclors	PCB Coplanars
Aroclor 1242	#77 3,3',4,4' TCB
Aroclor 1254	#126 3,3',4,4',5 PCB
Aroclor 1260	#169 3,3'4,4'5,5' HCB

*Detection limits vary with sample size and matrix heterogeneity (for sediment)

Table 6 Pesticides Analysed in Suspended Sediment*

Pesticides	Pesticides	Pesticides
Hexachlorobenzene	trans-Chlordane	Heptachlor Epoxide
alpha HCH	cis-Chlordane	alpha-Endosulphan (I)
beta HCH	p,p'-DDE	Dieldrin
gamma HCH	trans-Nonachlor	Endrin
delta HCH	p,p'-DDD	beta-Endosulphan (I)
Heptachlor	o,p'-DDT	Endosulphan sulphate
Aldrin	p,p'-DDT	Methoxychlor
Oxychlordane	Mirex	

*Detection limits vary with sample size and matrix heterogeneity (for sediment)

Table 7 Fatty and Resin Acids Analysed in Suspended Sediment and Whole Water*

Fatty Acids	Resin Acids
Capric	Pimaric
Lauric	Sandaracopimaric
Myristic	Isopimaric
Palmitic	Palustric
Linolenic	Dehydroabietic
Linoleic/Oleic	Abietic
Stearic	Neoabietic
Arachidic	12/14 Chlorodehydroabietic
Behenic	12,14 Dichlorodehydroabietic
Lignoceric	

*Detection limits vary with sample size and matrix heterogeneity (for sediment)

Table 8 Total Trace Metals Analysed in Whole Water and Method Detection Limits

Parameter	Detection Limit (µg/L)	Parameter	Detection Limit (µg/L)
Aluminum	1.0	Manganese	0.1
Barium	0.1	Molybdenum	0.05
Beryllium	0.05	Nickel	0.2
Cadmium	0.05	Strontium	0.05
Chromium	0.2	Vanadium	0.1
Cobalt	0.05	Zinc	0.2
Copper	0.1	Arsenic	0.01
Iron	0.4	Selenium	0.05
Lithium	0.1	Mercury	0.01
Lead	0.1		

Table 9 Nutrients Analysed in Whole Water, Method Detection Limits and ENVIRODAT Method Codes

Parameter	Detection Limit (mg/L)	ENVIRODAT Method Code
Total Phosphorus	0.002	15406-730-567
Dissolved Phosphorus	0.002	15102-731-567
Ammonia	0.002	07557-615-288
Nitrite	0.002	07206-613-239
Nitrite/Nitrate	0.002	07110-628-239
Total Nitrogen	0.002	07617-635-2554

5.0 QUALITY ASSURANCE/QUALITY CONTROL

5.1 Methods

5.1.1 Field QA/QC Methods

The field quality assurance/quality control (QA/QC) component consisted of field blanks, splits, duplicates and surrogates. Deionized water blanks were taken "Mid-field" (sample containers filled in the field during sampling) and "Post-field" (sample containers filled at the laboratory after sampling). Deionized water blanks were analysed for chlorophenolics, PAHs, resin acids and fatty acids. Suspended sediment field splits were obtained by subsampling each original sediment sample, while whole water field replicates were obtained by taking a second sample immediately following the original sample. Splits and replicates were submitted to the laboratory as blind samples. Field replicates of whole water samples were collected for trace metal and nutrient analysis. Field surrogates were added during solid phase extraction for dioxin and furan and chlorophenolic samples as described under Section 4.2.2.3.1. To check the degree of precision between centrifuges 1 and 2, some suspended sediment analyses from each respective centrifuge were analysed separately.

5.1.2 Laboratory QA/QC Methods

The QA/QC component of the laboratory methods for both organic contaminants and trace metals consisted of surrogate standard recoveries, procedural blanks, laboratory duplicates and reference samples (laboratory spikes and references). Samples were worked up in batches with accompanying QA/QC samples. Refer to Appendix I, Section 20.2., for a detailed description of the laboratory QA/QC methods.

5.2 Results

The reproducibility between field splits of suspended sediment and replicates of whole water samples was generally good for all contaminants as the mean coefficient of variation for each parameter analysed ranged between 6.4-23%. Field deionized water blanks were also acceptable. Laboratory duplicates were in agreement with the original samples ($\pm 20\%$ of the mean value plus the method detection limit) and laboratory blanks, spikes and references were similarly acceptable for the contaminants tested. Due to their ubiquitous nature, some contaminants such as PAHs and fatty acids were found in relatively high concentrations in both field deionized water blanks and laboratory blanks. The term "blank values" is used in the text to indicate the presence of measurable levels of contaminants in blanks. Refer to Appendix II for detailed descriptions of field and laboratory QA/QC results.

6.0 PRESENTATION OF RESULTS AND STATISTICAL RATIONALE

6.1 Presentation of Results

All results presented in the summary tables are the mean of field splits and samples. In the case where laboratory duplicates were present, these were averaged first and the resulting value was then averaged with the sample or field split. In the case when a sample or field split was below the detection limit, one half the detection limit was used to calculate the mean. Field split samples analysed at a laboratory other than AXYS appear in the raw data tables but were not used in calculations of means. Furthermore, NDR values (denoting that a peak was detected but did not meet quantification criteria) were treated as detected values. The mean of the three replicates was taken for both trace metal and nutrient results.

6.2 Statistical Rationale for Total Trace Metal and Nutrient Data Analysis

Two-sample two-tailed t-tests were performed for sample sets of unequal variance in order to test differences between the means of the sample populations. Due to limited sample sizes, it was assumed that samples came from normally distributed populations. The two-tailed t-test was chosen due to the small sample size ($N = 3$), and because the test is not largely affected by skewness in the sample population (Zar, 1984). As most of the samples had unequal variance, the Separate Variance t-test was employed. In the case where all replicates were identical, pseudovariance was generated.

7.0 PHYSICAL PARAMETERS

Refer to Table 10 for summarized results of temperature, conductivity and pH during sampling in the Fraser River Basin. For the Fraser River, temperature varied with time of year sampled, the median pH remained relatively constant (7.59-8.18) and the median specific conductivity varied between 116.7 and 156.0 $\mu\text{S}/\text{cm}$. For the Thompson River System, both the median pH (7.71-7.79) and specific conductivity (81.9-99.7 $\mu\text{S}/\text{cm}$) were lower than those measured in the Fraser River.

7.1 Thompson River System

7.1.1 Results

7.1.1.1 Flow

Refer to Table 11 for flow data for the Thompson River System. At both McLure and Savona, flows during the sampling periods were greatest in October 1992 and lowest in February 1993, whereas November 1993 had intermediate flows. Flow was always higher at the downstream site, Savona, than at the upstream site, McLure.

7.1.1.2 Suspended Sediment Concentrations

Flow and sediment parameters, obtained from field centrifuge data, were used to calculate the suspended sediment concentration at McLure and Savona at time of sampling (Table 12). The suspended sediment concentrations of the Thompson River System were generally highest in November of 1993 and lowest in February 1993. In October 1992 and February 1993, the suspended sediment concentrations were higher at McLure than at Savona (3.1 mg/L and 1.6 mg/L, respectively); however, in November 1993 Savona levels exceeded those of McLure (3.8 mg/L versus 2.4 mg/L).

Table 10 Median Temperature, Conductivity and pH in Fraser River Basin Water (October 1992, November 1993, November 1994)

Fraser River

Sampling Location:	Shelley	Woopdecker		Marguerite			Yale		
Date:	Nov 94	Oct92	Nov 93	Oct92	Nov 93	Nov 94	Oct92	Nov 93	Nov 94
Variable medians									
Temperature (°C) {range}	0.03 {-0.02 - 0.14}	1.76 N/A	1.76 {1.59 - 4.79}	3.93 {3.68 - 4.00}	5.62 {5.49 - 5.65}	2.38 {2.29 - 2.45}	7.88 {7.81 - 7.92}	4.78 {4.76 - 4.82}	5.15 {5.13 - 5.18}
pH {range}	8.01 {7.78 - 8.08}	7.80 N/A	7.80 {7.21 - 8.27}	7.96 {7.46 - 8.00}	7.94 {7.68 - 7.98}	7.63 {7.02 - 8.04}	8.18 {8.00 - 8.21}	7.86 {7.62 - 7.88}	7.59 {6.31 - 7.72}
Specific Conductivity (uS/cm) {range}	154.0 {132.0 - 159.0}	123.8 N/A	123.8 {119.0 - 128.7}	142.5 {141.3 - 143.3}	156.0 {155.0 - 156.0}	150.0 {148.0 - 152.0}	116.7 {116.0 - 117.6}	125.0 {124 - 152}	127.0 {124.0 - 129.0}

N/A denotes not applicable as single reading was taken

Thompson River System

Sampling Location:	McLure		Savona	
Date:	Oct92	Nov 93	Oct92	Nov 93
Variable medians				
Temperature (°C) {range}	7.10 {6.80 - 7.55}	0.10 {0.08 - 0.15}	11.27 {11.2 - 11.35}	5.40 {5.24 - 5.45}
pH {range}	7.79 {7.43 - 7.93}	7.71 {7.54 - 7.74}	7.75 {7.47 - 7.83}	7.55 {7.27 - 7.57}
Specific Conductivity (uS/cm) {range}	81.9 {80.0 - 83.3}	99.7 {99.5 - 100.3}	86.8 {85.1 - 88.4}	97.6 {97.4 - 97.7}

Note: no data were collected in Oct. 1992 at Shelley and in Feb. 93 at all sites

Table 11 Summary of Total Organic Carbon and Particle Size in Suspended Sediment Samples and Flow. Thompson River System (October 1992 , February 1993, November 1993)

Sampling Date	Sample Location	TOC (%)	Particle Size *				Flow (m3/s)
			% Gravel	% Sand	% Silt	% Clay	
October 20, 1992	McLure	3.64	0	16.89	79.94	3.17	179
October 22, 1992	Savona	4.89	0	1.88	84.2	13.92	337**
February 18, 1993	McLure	2.46	0	22.27	74.55	3.18	49.1
February 22, 1993	Savona	18.53	0	8.80	83.70	7.50	134**
November 29, 1993	McLure	1.39	0	10.06	85.49	4.45	90
December 2 , 1993	Savona	1.49	0	0.48	86.37	13.22	204**

*particle size categories are defined as follows:

gravel =2-64 mm

sand =0.062-2 mm

silt =0.004-0.062 mm

clay = <0.004 mm

**Flow estimated from Kamloops Lake water levels

Table 12 Field Centrifuge Data and Calculation of Suspended Sediment Concentration for the Thompson River System

Sampling Time	Site	Total hrs.	Minutes	Litres/ minute	Total Vol. (Litres)	Centrifuge 1 sample wt. (g)	Centrifuge 2 sample wt. (g)	Centrifuge 3 sample wt. (g)	Total Sample wet wt. (g)	% Moisture	Total Sample Dry weight (g)	Total Sample Dry weight (mg)	Susp.Sed. (mg/L)
Oct. 1992	McLure	31.0	1860	4.0	7440	58.0	62.0	-	120.0	80.9	22.9	22920.0	3.1
Oct. 1992	Savona	30.4	1824	4.0	7296	23.4	25.1	-	48.5	86.5	6.5	6547.5	0.9
Feb. 1993	McLure	55.5	3330	6.0	19980	39.4	39.5	-	78.9	59.3	32.1	32112.3	1.6
Feb. 1993	Savona	95.0	5700	6.0	34200	56.5	58.9	-	115.4	67.5	37.5	37505.0	1.1
Nov. 1993	McLure	49.5	2970	4.0	11880	34.1	38.0	35.1	107.2	73.0	28.9	28944.0	2.4
Nov. 1993	Savona	65.3	3915	4.0	15660	60.7	65.4	66.0	192.1	68.9	59.7	59743.1	3.8

7.1.1.3 Total Organic Carbon

On the Thompson River System, the total organic carbon (TOC) fraction was similar between Savona and McLure for October 1992 and November 1993 (Table 11). However a large TOC difference between the two sites was observed in February 1993, when the TOC fraction at Savona measured 18.53 % versus 2.46 % at McLure.

7.1.1.4 Particle Size Distribution

Refer to Table 11 for particle size distribution at sampling sites in the Thompson River System. At both McLure and Savona, silt comprised the greatest fraction of suspended sediments ranging from approximately 75% to 86%. At McLure, sand comprised the next greatest particle size fraction, ranging from approximately 10% to 22% with clay comprising the smallest particle size fraction. Unlike McLure, at Savona clay comprised the second most abundant fraction, ranging between about 7% to 14%. In February 1993, there was an increase in the measured sand fraction at both McLure and Savona. However whereas at McLure this increase was associated with a decrease in the silt fraction, at Savona it was associated with a decrease in the clay fraction.

7.1.2 Discussion

The low flow and suspended sediment concentration observed in February 1993, relative to October 1992 and November 1993, is typical for the North Thompson and Thompson Rivers (Nordin and Holmes, 1992) and is characteristic of river systems whose hydrology is snow-melt dominated (Bothwell, 1992).

However, the TOC of suspended sediment measured at Savona was elevated (18.53%) in February 1993 with respect to both October 1992 and November 1993. As the Kamloops City sewage treatment plant suspends its effluent discharges during the winter period (D. Holmes, BCMELP, personal communication) this increase in TOC likely occurred as a result of a higher proportion of organically rich pulp mill effluent in the water column as well as an increase in Kamloops Lake algal biomass. Bothwell *et al.* (1992) have shown that during the winter, due to inverse thermal stratification in Kamloops Lake, the Thompson River flows over the surface of the lake, thus allowing little or no mixing of effluent rich river water with lake water. Furthermore, according to Dwernychuk (1994), the Thompson River between Savona and Lytton contains approximately 0.8% pulp mill effluent in the winter months as opposed to 0.1% in late spring - early summer. The reduced dilution capacity of Kamloops Lake during the winter may account for some of the increase in the TOC measured at Savona in February 1993.

Algal biomass is a second likely source of the elevated TOC levels measured at Savona.

Historically, algal biomass has been higher at Savona compared to locations upstream of Kamloops Lake and most abundant from January to April (Nordin and Holmes, 1992). This increase in algal biomass is presumably due to reduced nutrient dilution in Kamloops Lake during the limnological winter (St. John *et al.*, 1976).

The higher suspended sediment concentration and sand fraction seen at McLure versus Savona is likely the result of larger and heavier particles settling in Kamloops Lake as the river water enters the lake. Deposition of larger sediment particles such as sand and silt in Kamloops Lake also likely accounts for the higher clay fraction observed at Savona, for all three sampling dates, in comparison to McLure. Furthermore, the observed increase in the sand fraction seen in February 1993 (versus October 1992 and November 1993) at both McLure and Savona is most likely due to sampling location. During the February 1993 sampling period, both the North Thompson River and the Thompson River were completely or partially ice covered which enabled samples to be collected from the mainflow of the river (as opposed to closer to the river bank during fall sampling). The higher water velocity in the mainflow of the river is expected to carry larger particles, such as sand, which would normally settle out of the water column at lower water velocities (RMSS, 1939).

7.2 Fraser River

7.2.1 Results

7.2.1.1 Flow

Table 13 presents a summary of flow at sampling sites on the Fraser River for October 1992, February 1993, November 1993 and November 1994. The highest flows occurred in the months of October 1992 and November 1993, whereas lower flows occurred in February 1993. November 1994 flow measurements from Shelley, Marguerite and Yale were an average of 1.6 times lower than flows measured in November 1993 at the same sites.

7.2.1.2 Suspended Sediment Concentrations

Flow and sediment parameters, obtained from field centrifuge data, were used to calculate the suspended sediment concentration at Fraser River sampling sites at time of sampling (Table 14). Generally, the highest suspended sediment concentrations occurred in October 1992 and November 1993, whereas the lowest occurred in February 1993 and November 1994. An exceptionally high suspended sediment concentration of 226.0 mg/L was measured in October

Table 13 Summary of Total Organic Carbon and Particle Size in Suspended Sediment Samples and Flow, Fraser River (October 1992, February 1993, November 1993, November 1994)

Sampling Date	Sample Location	TOC (%)	Particle Size *				Flow (m3/s)
			% Gravel	% Sand	% Silt	% Clay	
October 14, 1992	Shelley	1.92	0	8.19	73.63	18.18	592
October 15, 1992	Woodpecker	1.95	0	10.34	71.54	18.13	718**
October 16, 1992	Marguerite	2.63	0	0.15	80.27	19.58	918
October 27, 1992	Yale	1.02	0	11.74	74.00	14.24	3380
February 12, 1993	Shelley	1.80	0	7.77	82.45	9.78	159
February 13, 1993	Woodpecker	3.45	0	67.49	30.28	2.24	264**
February 16, 1993	Marguerite	3.34	0	20.16	72.49	7.35	310
March 2, 1993	Yale	2.29	0	10.03	75.42	14.55	593
November 3, 1993	Shelley	0.59	0	7.65	81.22	11.85	541
November 5, 1993	Woodpecker	0.63	0	5.52	80.03	14.46	1080**
November 1, 1993	Marguerite	1.23	0	0.89	81.97	17.14	764
November 9, 1993	Yale	0.71	0	1.75	82.09	16.16	1480
November 9, 1994	Shelley	0.82	0	5.83	79.51	14.64	284
November 11, 1994	Marguerite	2.26	0	5.36	78.71	15.91	563
November 14, 1994	Yale	1.50	0	5.89	79.21	14.89	892

*particle size categories are defined as follows:

gravel = 2-64 mm
sand = 0.062-2 mm
silt = 0.004-0.062 mm
clay = <0.004 mm

** Flow estimated from South Fort George station

Table 14 Field Centrifuge Data and Calculation of Suspended Sediment Concentration for the Fraser River

Sampling Time	Site	Total hrs.	Minutes	Litres/minute	Total Vol. (Litres)	Centrifuge 1 sample wt. (g)	Centrifuge 2 sample wt. (g)	Centrifuge 3 sample wt. (g)	Total Sample wet wt. (g)	%Moisture	Total Sample Dry weight (g)	Total Sample Dry weight (mg)	Susp.Sed. (mg/L)
Oct. 1992	Shelley	7.2	429	4.0	1728	57.9	60.3	-	118.2	72.4	32.6	32623.2	18.9
	Woodpecker	6.5	387	4.0	1560	46.2	58.0	-	104.2	77.5	23.4	23445.0	15.0
	Marguerite	9.5	567	4.0	2280	81.9	74.6	-	156.5	66.5	52.4	52427.5	23.0
	Yale	7.5	450	4.0	1800	390.1	369.0	-	749.1	45.7	406.8	406761.3	226.0
Feb. 1993	Shelley	54.5	3270	6.0	19620	21.9	18.2	-	40.1	58.0	16.8	16842.0	0.9
	Woodpecker	81.5	4890	6.0	29340	211.0	191.7	-	402.7	46.8	214.2	214236.4	7.3
	Marguerite	55.0	3300	6.0	19800	109.7	118.2	-	227.2	59.4	92.2	92243.2	4.7
	Yale	56.4	3384	6.0	20304	54.0	47.8	-	101.8	57.7	43.1	43061.4	2.1
Nov. 1993	Shelley	15.8	945	4.0	3780	116.8	122.0	117.5	356.3	51.8	171.7	171736.6	45.4
	Woodpecker	21.0	1260	4.0	5040	519.2	443.5	445.3	1408.0	40.0	844.8	844800.0	167.6
	Marguerite	19.5	1170	4.0	4680	83.5	80.5	82.5	246.5	78.0	54.2	54230.0	11.6
	Yale	14.3	855	4.0	3420	209.0	150.8	175.5	535.3	54.0	246.2	246238.0	72.0
Nov. 1994	Shelley	30.9	1855	4.0	7421	33.8	39.7	38.1	111.6	69.0	34.6	34596.0	4.7
	Marguerite	33.8	2028	4.0	8112	41.4	44.2	63.7	149.3	75.0	37.3	37325.0	4.6
	Yale	34.5	2070	4.0	8280	34.8	39.5	24.6	98.9	77.0	22.7	22747.0	2.7

1992 at Yale. This value was approximately three times higher than that of November 1993 (72.0 mg/L) at the same site. The lowest suspended sediment concentration was recorded in February 1993 at Shelley (0.9 mg/L). Suspended sediment concentrations measured at Shelley, Marguerite and Yale in November 1994 were approximately 3 to 10 times less than those measured in November 1993 at the same sites.

7.2.1.3 Total Organic Carbon

Refer to Table 13 for TOC concentrations at sampling sites on the Fraser River. Among the four sites, the TOC content of suspended sediments ranged between 0.59-3.45%. Overall, the TOC fraction was greatest in February 1993, followed by October 1992, November 1994 and lastly by November 1993. Generally, Marguerite had the highest TOC fraction with the exception of February 1993 when the TOC fraction at Woodpecker exceeded that at Marguerite.

7.2.1.4 Particle Size Distribution

Refer to Table 13 for the particle size distribution of suspended sediment samples taken from the Fraser River. The silt fraction comprised the greatest percentage of sediment at all sampling sites, generally at 80% of the sample. The next greatest sediment size fraction was comprised of clay particles which usually ranged from 7-19% and, finally, the smallest sediment fraction was composed of sand particles which was frequently less than 10%. Although the particle size distribution was similar between all sites for the four sampling dates, samples taken in February 1993 generally showed a higher sand fraction coupled with lower silt and clay fractions. Results of particle size distribution taken from Woodpecker in February 1993 showed an unusually high sand fraction (67.49%) coupled with unusually low silt and clay fractions (30.28% and 2.24%, respectively).

7.2.2 Discussion

A close association between suspended sediment concentration and flow exists in the Fraser River. The low suspended sediment levels and low flows observed at all sites in February 1993 are typical of winter conditions in the upper and middle Fraser River (Carson, 1988). Atypically low suspended sediment concentrations were measured in November 1994 due to the unusually low flow which occurred in the fall of that year. Flow and suspended sediment comparisons from the Marguerite Water Survey of Canada station (Carson, 1988) illustrate the atypical conditions in the fall of 1994. On November 11, 1994, the flow at Marguerite was only 58% of the 37 year mean flow (1950-1986) recorded at this station, and the suspended sediment concentration was only 12% of the 16 year mean suspended sediment concentration (1971-1986). The high

in the fall of 1994. On November 11, 1994, the flow at Marguerite was only 58% of the 37 year mean flow (1950-1986) recorded at this station, and the suspended sediment concentration was only 12% of the 16 year mean suspended sediment concentration (1971-1986). The high suspended sediment concentration observed at Yale in October 1992 was the result of a rapid increase in flow ($3380 \text{ m}^3/\text{s}$) associated with a recent precipitation event in the upper Fraser River region.

The observed increase in the TOC measured downstream of the pulp mills in February 1993 versus October 1992, November 1993 and November 1994 is most likely related to the higher concentration of organically rich pulp mill and sewage treatment plant effluents in the water column during the winter months. According to Dwernychuk (1994), the Fraser River may contain 1% or greater concentrations of pulp mill effluent from Prince George to Lytton during low flow winter conditions. Conversely, in higher flow conditions, such as in the fall, effluent concentrations comprise only 0.3 - 0.4% of the volume of the Fraser River between Prince George and Hope. Furthermore, an increase in algal biomass, resulting from an increase in light penetration through the water column, as a consequence of a decrease in the suspended sediment concentration, may have also contributed to the observed TOC increase in February 1993. Increases in algal biomass in the Quesnel region (with respect to the Prince George region) have been reported by Dwernychuk (1990). This combination of reduced effluent dilution, low suspended sediment concentration and possible increase in algal biomass may account for the increase in TOC during the February 1993 sampling period.

The silt dominated particle size distribution observed at all sites, during each sampling period, is typical for the flow regimes under which sampling was conducted (Carson, 1988). As with winter samples taken in the Thompson River System, samples taken from the Fraser River during February 1993 were collected from the mainflow of the river (as opposed to closer to the river bank during all other sampling periods). Since Carson (1988) has shown that at low flows silt and clay dominate the particle size distribution, the higher sand fraction observed in sediment samples collected at both Woodpecker and Marguerite in February 1993 (versus October 1992, November 1993 and November 1994) is likely a result of sampling location.

8.0 DIOXINS AND FURANS

8.1 Introduction

Dioxins and furans are highly persistent compounds with a strong affinity for sediments and a high potential for accumulating in biological tissues. Due to their hydrophobic nature, dioxins and furans ($K_{ow} = 6-7$) have a high affinity for both particulate and dissolved organic carbon (Webster *et al.*, 1986; Servos *et al.*, 1989). Sediments which have a high organic carbon content and surface area (frequently silts and clays) have been shown to be a sink for dioxins and furans (Czuczwa and Hites, 1984).

In recent years there has been growing concern over human exposure to dioxins and furans (especially 2,3,7,8-T4CDD and 2,3,7,8-T4CDF), as evidence of both acute and long-term toxicity has been rapidly accumulating. Although 2,3,7,8-T4CDD is not a direct DNA mutagen, it has been shown to cause toxicity to mammals, affect reproduction, cause fetal abnormalities and promote carcinogenesis (CEPA, 1990). Non 2,3,7,8-dioxin and furan congeners appear to be rapidly metabolized and depurated by vertebrates, whereas very limited metabolic transformation of the 2,3,7,8-congeners is observed in most species (Owens *et al.*, 1994). As a consequence of its high toxicity, persistence and bioaccumulative potential, both federal and provincial governments are now in the process of developing guidelines and criteria for 2,3,7,8-T4CDD.

Sources of dioxins and furans to the environment include pulp and paper mills that use chlorine bleaching, commercial chemicals and combustion (CEPA, 1990). Pulp and/or paper mills utilizing the chlorine bleached kraft process have been an industrial source of the lesser chlorinated dioxin and furan congeners (eg. tetra and penta) (Amendola, 1987).

Atmospheric sources of dioxins and furans include forest fires, urban incinerators, boilers, residential stoves, fireplaces and furnaces (Sheffield, 1985). Atmospherically transported dioxins and furans may play a significant role in the total load of these contaminants to the Fraser River Basin. Previous studies have shown atmospheric loading as a source of hepta and octa dioxins/furans to sediments in the Great Lakes (Czuczwa and Hites, 1986).

Prior to 1991, pentachlorophenol contaminated with dioxins and furans was the largest chemical source of dioxins and furans, as this chemical was widely used in Canada to preserve and protect wood (CEPA, 1990). However, as of December 31, 1990, pentachlorophenol has been deregulated as an anti-sapstain wood preservative, and its use has since been restricted to heavy-duty-wood preservation. Recent evidence of dioxin and furan leaching from treated wood utility poles and railway ties has been found by Wan and Van Oostdam (1995). The second largest chemical source of dioxins is the pesticide 2,4-D, which is registered in Canada as a herbicide (Sue Garnet, Agriculture Canada, personal communication). Lastly, PCBs represent the most significant potential source of furans to the Canadian environment (CEPA, 1990). Although the

use and storage of PCBs is now strictly controlled, the potential for releases through accidental spills or fires in equipment containing PCBs still remains.

Previous studies in the Fraser River Basin have shown that furans are detectable in bed sediment material (Mah *et al.*, 1989), and dioxins and furans are detectable in suspended sediments (Sekela *et al.*, 1994; Derksen and Mitchell, in preparation [b]) collected downstream of the six pulp and/or paper mills in the basin.

8.2 Thompson River System

8.2.1 Results

Due to the lengthy nature of dioxin and furan nomenclature, abbreviations have been used. Refer to Table 15 for a list of abbreviations with the corresponding full nomenclature.

8.2.1.1 Suspended Sediments

Refer to Table 16 for a summary of dioxin and furans measured in suspended sediments from the Thompson River System in October 1992, February 1993 and November 1993. At the reference site, McLure, total T4CDD, 2,3,7,8-T4CDD and total P5CDD were below detection limits for all three sampling dates with the exception of total T4CDD which was detected at 2.2 pg/g in November 1993. At Savona, the highest concentrations of total T4CDD and 2,3,7,8-T4CDD (Figure 6) were measured in February 1993. Concentrations of total H6CDD, total H7CDD, and O8CDD at Savona were approximately 2-35 times greater than at McLure, for each sampling date. Furthermore, dioxin concentrations were approximately 2-36 times higher in November 1993 versus October 1992 at Savona. The highest concentration of all dioxins detected on the Thompson River was 490 pg/g of O8CDD measured at Savona in November 1993.

Concentrations of furans in suspended sediments at Savona were considerably higher than those detected at McLure for all three sampling periods. Moreover, furan concentrations were highest at Savona in February 1993 (compared to all other sampling periods) for all furans measured with the exception of O8CDF. Concentrations of 2,3,7,8-T4CDF and total T4CDF measured in February 1993 at Savona were 700 and 433 times greater, respectively, than those measured at McLure in the same month. In February 1993, total T4CDF (260 pg/g) had the highest concentration of all furans measured in suspended sediments in the Fraser River Basin. Refer to Figure 7 for concentrations of 2,3,7,8-T4CDF in suspended sediments from the Thompson River

Table 15**List of Abbreviations for Organic Compounds and
Corresponding Full Nomenclature**

Abbreviation	Full Nomenclature
Dioxins	
M1CDD	Monochlorodibenzo - p - dioxin
D2DCDD	Dichlorodibenzo - p - dioxin
T3CDD	Trichlorodibenzo - p - dioxin
T4CDD	Tetrachlorodibenzo - p - dioxin
P5CDD	Pentachlorodibenzo - p - dioxin
H6CDD	Hexachlorodibenzo - p - dioxin
H7CDD	Heptachlorodibenzo - p - dioxin
O8CDD	Octachlorodibenzo - p - dioxin
Furans	
M1CDF	Monochlorodibenzofuran
D2DCDF	Dichlorodibenzofuran
T3CDF	Trichlorodibenzofuran
T4CDF	Tetrachlorodibenzofuran
P5CDF	Pentachlorodibenzofuran
H6CDF	Hexachlorodibenzofuran
H7CDF	Heptachlorodibenzofuran
O8CDF	Octachlorodibenzofuran

System.

8.2.1.2 Clarified Water (Solid and Liquid Phase Extracted)

Refer to Table 17 for a summary of dioxin and furan concentrations in Thompson River System clarified water samples collected by solid and liquid phase extraction. For solid phase extracted samples from McLure, with the exception of total H7CDD (0.10 pg/L) and O8CDD (0.90 pg/L), all dioxins and furans were below detection limits. At the downstream site, Savona, with the exception of O8CDD (0.10 pg/L), no dioxins were measured above detection limits, and only 2,3,7,8-T4CDF (0.090 pg/L) was measured slightly above the detection limit of 0.030 pg/L.

Table 16 Summary of Dioxins and Furans in Suspended Sediments from the Thompson System (October 1992, February 1993, November 1993)

Sampling Location:	McLure			Savona		
Sampling Date:	Oct 1992	Feb. 1993	Nov. 1993	Oct 1992	Feb. 1993	Nov. 1993
Dioxins(pg/g)						
Total T4CDD	ND(0.4)	ND(0.2)	2.2	ND(0.5)	9.9	8.9
2,3,7,8T4CDD	ND(0.4)	ND(0.2)	ND(0.1)	0.70	5.3	1.5
Total P5CDD	ND(0.5)	ND(0.2)	ND(0.2)	ND(0.5)	6.8	7.1
Total H6CDD	1.3	1.5	3.5	12	52	28
Total H7CDD	24	11	21	38	65	110
O8CDD	36	34	62	100	430	490
Furans (pg/g)						
Total T4CDF	ND(0.2)	0.60	2.6	41	260	64
2,3,7,8-T4CDF	ND(0.2)	0.20	0.30	21	140	35
Total P5CDF	ND(0.3)	ND(0.1)	0.60	2.0	9.5	4.5
Total H6CDF	ND(0.4)	0.50	1.6	4.1	5.5	4.4
Total H7CDF	4.9	3.1	4.6	8.1	9.6	7.9
O8CDF	5.3	3.3	6.5	9.8	7.2	4.9

ND denotes below the indicated detection limit (shown in brackets) when both field splits and samples were below detection limit

Note: all results presented are a mean of field replicates and samples

- one half the detection limit was used when only one of the samples was below the detection limit

- all means rounded to two significant figures

Legend

- ★ Reference Sampling Site
- ★ Downstream Sampling Site
- Thompson River System

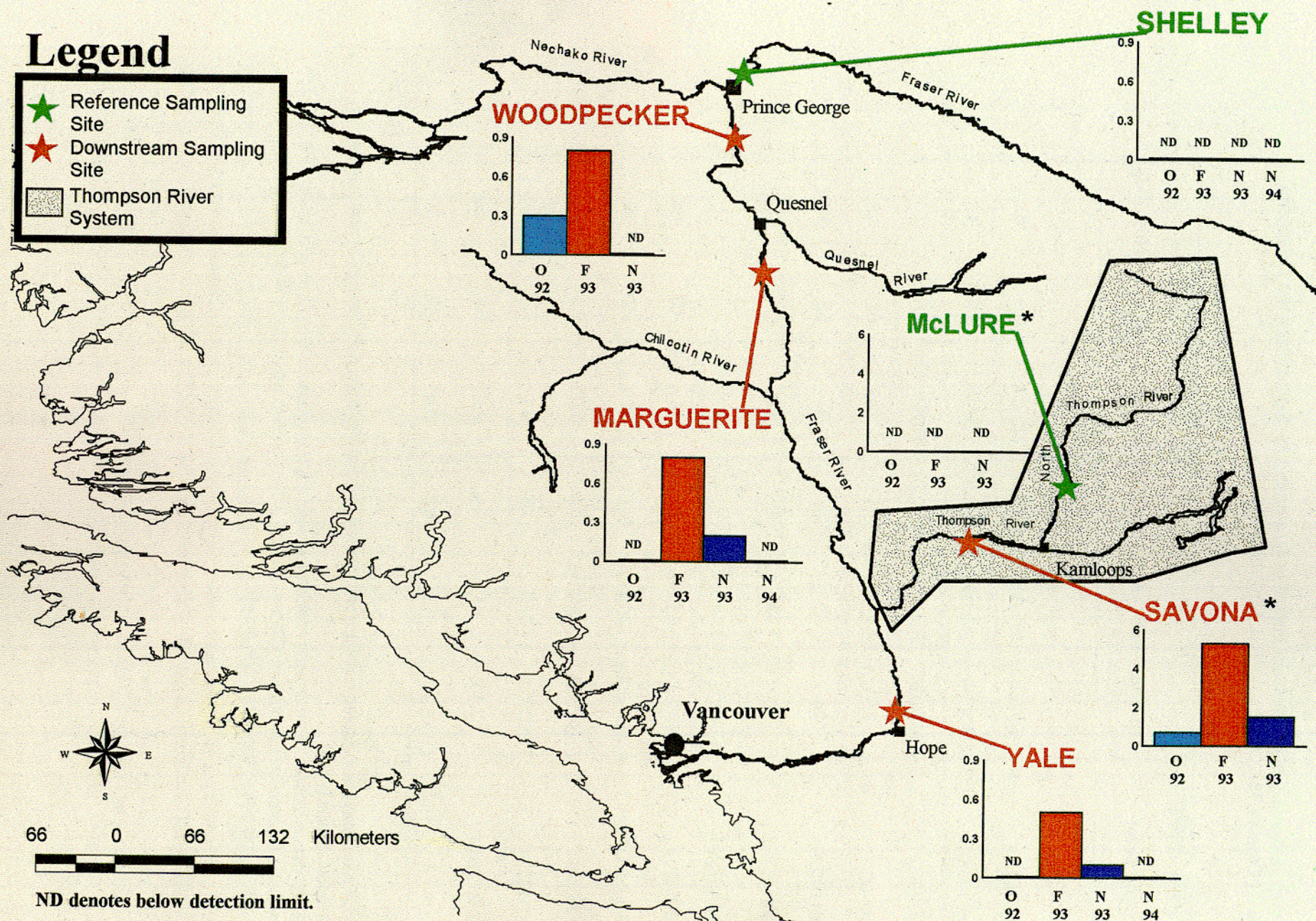


Figure 6 2,3,7,8-T4CDD Concentrations (pg/g) in Suspended Sediment from the Fraser and Thompson River Systems

* Note scale difference for Thompson River System graphs

Legend

- ★ Reference Sampling Site
- ★ Downstream Sampling Site
- Thompson River System

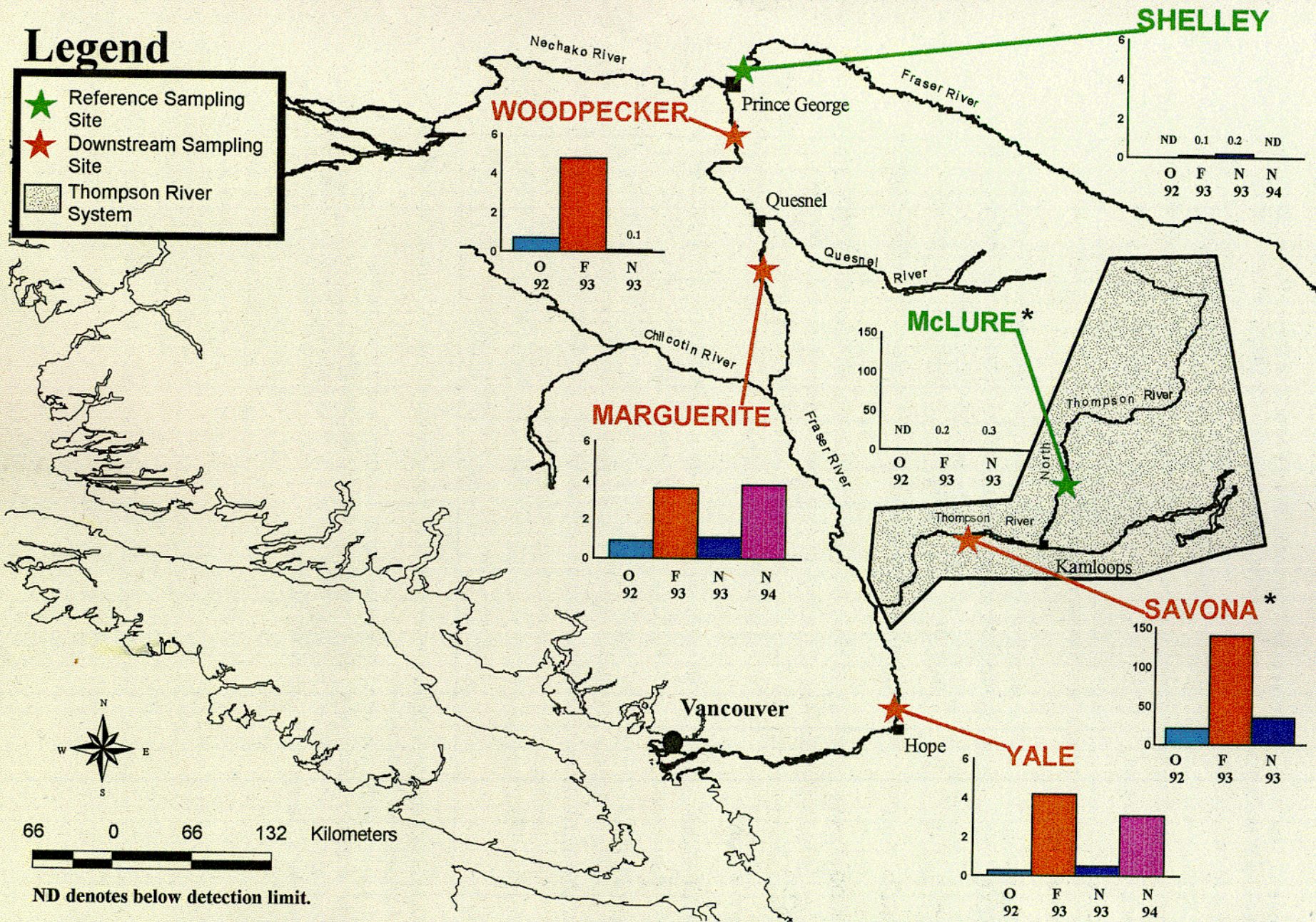


Figure 7 2,3,7,8-T4CDF Concentrations (pg/g) in Suspended Sediment from the Fraser and Thompson River Systems

* Note scale difference for Thompson River System graphs

Table 17 Summary of Dioxins and Furans in Solid Phase and Liquid Phase Extracted Clarified Water from the Thompson River System (February 1993)

Sampling Location:	Solid Phase Extracted		Liquid Phase Extracted	
	McLure	Savona	McLure	Savona
Dioxins (pg/L)				
T4CDD - Total	ND(0.06)	ND(0.06)	ND(0.03)	ND(0.03)
2,3,7,8	ND(0.06)	ND(0.06)	ND(0.03)	ND(0.03)
P5CDD - Total	ND(0.07)	ND(0.07)	ND(0.03)	ND(0.03)
H6CDD - Total	ND(0.06)	ND(0.07)	0.20	ND(0.03)
H7CDD - Total	0.10	ND(0.09)	0.10	0.060
O8CDD	0.90	0.10	2.0	0.20
Furans (pg/L)				
T4CDF - Total	ND(0.03)	ND(0.04)	ND(0.04)	ND(0.03)
2,3,7,8	ND(0.03)	0.090	ND(0.04)	0.10
P5CDF - Total	ND(0.05)	ND(0.06)	ND(0.03)	ND(0.03)
H6CDF - Total	ND(0.04)	ND(0.05)	ND(0.06)	ND(0.04)
H7CDF - Total	ND(0.06)	ND(0.07)	ND(0.03)	ND(0.03)
O8CDF	ND(0.08)	ND(0.01)	ND(0.03)	ND(0.05)

ND denotes below the indicated detection limit (shown in brackets) when both field replicates and samples were below detection

{ } concentration value equal to or below that of laboratory and/or field blanks

Note: all results presented are a mean of field replicates and samples

- one half the detection limit was used when only one of the samples was below the detection limit*
- all means rounded to two significant figures*

For liquid phase extracted samples, no tetra or penta dioxins were detected at either McLure or Savona. Hexa, hepta and octa dioxins ranged between 0.10-2.0 pg/L at McLure, whereas hepta and octa dioxins ranged between 0.060-0.20 pg/L at Savona. No furans were above detection limits at McLure, and only 2,3,7,8-T4CDF (0.10 pg/L) was above detection limits at Savona.

8.2.1.3 Distribution of Dioxins and Furans Between Sediment and Water

To examine the partitioning of organic contaminants between the particulate and aqueous phases, the concentration of contaminant in water (pg/L), as determined by solid phase and/or liquid phase extraction, was compared to the concentration of the contaminant in the suspended solid phase. For this comparison, contaminant concentrations measured in suspended sediments (pg/g) were converted to pg/L using the site specific suspended sediment concentration.

The calculation of phase partitioning was possible only for those contaminants which were measured above detection limits in both clarified water and suspended sediment samples, and therefore results are often based on limited data. Refer to Appendix IV for site specific phase partitioning calculations for dioxins, chlorophenolics and PAHs.

Calculations of sorption partition coefficients ($\log K_{oc}$) were performed on the available phase partitioning data in order to compare them to published $\log K_{oc}$ values. Such a comparison provides information regarding contaminant phase partitioning in the lotic environment under varying physical conditions compared to that observed under constant laboratory conditions. The sorption partition coefficient (K_{oc}) is defined as the ratio of the concentration in suspended sediment to the concentration in water and normalized to the organic carbon content of the sediment (Chiou *et al.*, 1986; Smith *et al.*, 1988). Assuming that the amount of amount of organic carbon in the aqueous phase is negligible, K_{oc} is defined as follows:

$$K_{oc} = \frac{(C_{ss} \times 10^3)}{(C_{aq} \times 1/\rho \times f_{oc})}$$

where:

C_{ss} = concentration of contaminant in suspended sediments in picogram per gram;

C_{aq} = concentration of contaminant in water in picogram per litre;

ρ = density of water in kilograms per litre;

f_{oc} = fraction of organic carbon in sediments;

10^3 = unit conversion of grams per kilograms;

Refer to Table 18 for a summary of dioxin and furan partitioning in suspended sediments, calculated by using both solid phase extracted clarified water data and liquid phase extracted

Table 18 Summary of Dioxin and Furan Phase Partitioning and Log K_{oc} Values Calculated from Data of Solid Phase and Liquid Phase Extracted Clarified Water from the Thompson River System (February 1993). Published Log K_{oc} Values are Presented for Comparison.

		Calculations Made Using Data from Solid Phase Extracted Clarified Water				Calculations Made Using Data from Liquid Phase Extracted Clarified Water			
Compounds	Published Log K_{oc} ⁽¹⁾	% in Suspended Sediments		Calculated Log K_{oc}		% in Suspended Sediments		Calculated Log K_{oc}	
		McLure	Savona	McLure	Savona	McLure	Savona	McLure	Savona
Total H6CDD	5.02 - 7.1	N/A ⁽²⁾	N/A	-	-	1.2	N/A	5.5	-
Total H7CDD	5.47 - 7.8	15	N/A	6.7	-	15	46	6.7	6.8
O8CDD	5.92 - 7.9	5.7	83	6.2	7.4	2.7	30	5.8	7.1
2,3,7,8- T4CDF	5.2 - 7.5	N/A	63	-	6.9	N/A	39	-	6.9

(1) Mackay *et al.*, 1992

(2) N/A denotes not available (due to insufficient data above detection limits)

clarified water data as well as calculated and published log K_{oc} values. Due to the small number of values which were available for log K_{oc} calculations, caution is advised when interpreting the results.

The percent dioxins and furans partitioning to suspended sediments at McLure ranged from 1.2% to 15%, whereas at Savona it ranged from 30% to 83%. Calculated log K_{oc} values for total H6CDD, total H7CDD, O8CDD and 2,3,7,8-T4CDD ranged from 5.5 to 7.4 and were within the range of published log K_{oc} values. Log K_{oc} values calculated from Savona data were higher than log K_{oc} values calculated from McLure data. Moreover, log K_{oc} values calculated by using data from solid phase extracted clarified water were similar to log K_{oc} values calculated by using data from liquid phase extracted clarified water.

8.2.1.4 Loadings of 2,3,7,8-T4CDD and 2,3,7,8-T4CDF

Refer to Table 19 for estimated loadings of 2,3,7,8-T4CDD and 2,3,7,8-T4CDF in suspended sediments collected from the Thompson River System and mill effluent loadings from the Weyerhaeuser pulp mill. Due to the unavailability of clarified water data across all sampling periods, only dioxins and furan levels in suspended sediments were used for loading calculations, and therefore loading values are conservative. Mill effluent loadings were calculated from a single monthly whole effluent sample and the mean monthly effluent discharge.

Measured loadings for 2,3,7,8-T4CDD at Savona indicate that levels of this contaminant increased from 0.018 mg/day in October 1992 to 0.067 mg/day in February 1993 and up to 0.10 mg/day in November 1993. A similar pattern was observed for 2,3,7,8-T4CDF which increased from 0.55 mg/day in October 1992 to 1.8 mg/day in February 1993 and finally to 2.3 mg/day in November 1993. This increase in the estimated loadings at Savona was paralleled with an increase in both 2,3,7,8-T4CDD and 2,3,7,8-T4CDF loadings from the Weyerhaeuser pulp mill. Pulp mill effluent loadings of 2,3,7,8-T4CDD were approximately four to eleven times greater than the measured loadings at Savona, whereas pulp mill effluent loadings of 2,3,7,8-T4CDF were approximately three to eight times greater than measured loadings at the same site.

8.2.2 Discussion

8.2.2.1 Suspended Sediments

For all sampling periods, the levels of dioxins and furans measured downstream of the pulp mill at Savona were clearly higher than those measured upstream at McLure. Furthermore, the

Table 19 Concentrations and Estimated Loadings of 2,3,7,8-T4CDD and 2,3,7,8-T4CDF in Thompson River System Suspended Sediment Samples and Mill Effluent Loadings from the Weyerhaeuser Mill (October 1992, February 1993, November 1993)

Sampling Date	Location	Suspended Sediment (mg/L)	Flow (m ³ /s)	2,3,7,8-T4CDD in susp. sed. (pg/L)	2,3,7,8-T4CDF in susp. sed. (pg/L)	2,3,7,8-T4CDD loading (mg/day)	2,3,7,8-T4CDF loading (mg/day)	2,3,7,8-T4CDD Mill loading (mg/day)	2,3,7,8-T4CDF Mill loading (mg/day)
October 1992	Savona	0.9	337*	0.00063	0.019	0.018	0.55	0.20	2.6
February 1993	Savona	1.1	134*	0.0058	0.15	0.067	1.8	0.30	5.1
November 1993	Savona	3.8	204*	0.0057	0.13	0.10	2.3	0.53	18

* Flow estimated from Kamloops Lake water levels

Note: Due to the unavailability of loading data from the Weyerhaeuser Mill for the month of October 1992, loading values from September 1992 were used

highest concentrations of dioxins and furans were measured in February 1993. This February peak in dioxin and furan concentration is likely the result of winter limnological conditions in Kamloops Lake (Bothwell *et al.*, 1992) which limit mixing of effluent rich river water with lake water.

The higher dioxin concentrations measured at Savona in November 1993 versus October 1992 may be the result of mill operations. Just prior to the November 1993 sampling period, Weyerhaeuser Canada Ltd. completed cleaning and sludge removal procedures of its effluent treatment ponds (Gordon Kerfoot, Weyerhaeuser Canada, Ltd., personal communication). This process may have resuspended and mobilized contaminated material previously stored in the sludge. Effluent characterization data (Environmental Protection Branch, Environment Canada) indicate that concentrations of 2,3,7,8-T4CDD were approximately double, and those of 2,3,7,8-T4CDF were from three to seven times greater in November 1993 compared to both October 1992 and February 1993.

Studies have shown that the site specific dioxin and furan congener profile can be considered a "fingerprint" of various industrial sources of these contaminants (Czuczwa and Hites, 1986). The predominance of the highly chlorinated dioxins and furan congeners in samples from McLure is consistent with the congener profile associated with combustion sources (Czuczwa and Hites, 1984). Conversely, the relatively high levels of tetra-chlorinated dioxins observed at Savona is consistent with the congener profile associated with pulp mill pollution (Amendola, 1987).

8.2.2.2 Clarified Water (Solid and Liquid Phase Extracted)

Dioxins and furans were detected in both solid and liquid phase extracted clarified water at McLure and Savona, in spite of their documented low affinity for the dissolved phase (Fletcher and McKay, 1993). Moreover, although they were detected at both sites, the congener profile for these contaminants differed between the sites. Congeners detected at McLure in both clarified water samples and suspended sediments were limited to the hexa, hepta and octa forms. However, those detected at Savona also included the tetra and penta forms (in addition to the highly chlorinated congeners), suggesting that the pulp mill is a likely source of the lower chlorinated congeners at this site.

Clarified water samples were extracted by both solid phase and liquid phase extraction methods to compare the extraction efficiency of the two techniques. The similar results obtained with both extraction methods indicate that both are equally adequate for dioxin and furan identification in clarified water samples. However, the solid phase extraction method is preferred over the liquid phase extraction method for sampling of clarified river water, as it is more convenient for field application and it is safer for the operator.

A comparison of results obtained from suspended sediment versus clarified water samples indicates that more dioxin and furan congeners were detected in suspended sediments. Since our data indicates that a considerable fraction of dioxins and furans are partitioning in the aqueous phase (Section 8.2.2.3), sample size differences (50 L for clarified water samples versus thousands of litres for suspended sediment) likely account for the observed detection differences.

8.2.2.3 Distribution of Dioxins and Furans Between Sediment and Water

The large variation observed in dioxin and furan phase partitioning is reflective of the varying environmental conditions present between sites. The two environmental factors that govern the distribution of dioxins and furans between suspended sediment and water phases are the concentration of suspended sediment and the fraction of organic carbon in suspended sediment (Bortleson *et al.*, 1994). Although there was very little difference in the suspended sediment concentration of samples from McLure (1.6 mg/L) and Savona (1.1 mg/L), the TOC fraction was much larger at Savona (18.53%) in comparison to that at McLure (2.46%). Accordingly, dioxin and furan congeners measured at Savona had a higher affinity for the suspended solid phase (30-83%) in comparison to those measured at McLure (1.2-15%). Conversely, the relatively low affinity of the dioxin and furan congeners for the sediment fraction in samples from McLure suggests that a considerable fraction of these congeners may be partitioning to dissolved and colloidal organic matter in the water column. Although dioxins and furans have very low water solubilities (0.074-200 ng/L [Shiu *et al.*, 1988]), the solubility of hydrophobic organic compounds is reported to increased by the presence of colloidal matter (Baker *et al.*, 1986) and dissolved organic matter (Carter and Suffet, 1982) which has the effect of lowering the K_{oc} .

8.2.2.4 Loadings of 2,3,7,8-T4CDD and 2,3,7,8-T4CDF

Loading calculations based on data collected from Savona indicate that there was an increase in both 2,3,7,8-T4CDD and 2,3,7,8-T4CDF loadings from October 1992 to November 1993. This observed increase in the receiving environment reflects an increase in pulp mill loadings for this period (Table 19). Some of the difference between the pulp mill loadings and the measured loadings is very likely due to settling of suspended sediments in Kamloops Lake. Moreover, loadings measured in the receiving environment are likely underestimated because only suspended sediment data were used to calculate loadings.

The increase in 2,3,7,8-T4CDD and 2,3,7,8-T4CDF loadings measured both at Savona and at the Weyerhaeuser pulp mill in November 1993 (versus both October 1992 and February 1993) may be a consequence of cleaning of the effluent treatment ponds at the mill, which occurred in the two months prior to the sampling date (Gordon Kerfoot, Weyerhaeuser Pulp and Paper, personal communication).

8.2.2.5 Comparisons of Dioxin and Furan Concentrations to Guidelines and Criteria

Since present federal and provincial government sediment quality guidelines and criteria have been designed for bed sediments, all contaminants measured in suspended sediments were compared to both bed sediment and water quality guidelines or criteria. Note that because the suspended sediment samples are obtained by centrifugation of thousands of litres of river water, these time integrated samples are very concentrated and, as such, are very different in nature from the more "dilute" bed sediments. In order to compare contaminant concentrations in suspended sediments with water quality guidelines or criteria, contaminant concentrations were expressed per unit volume of water (using the site specific suspended sediment concentration).

Suspended sediment concentrations of 2,3,7,8-T4CDD were compared to the Canadian Council of Resource and Environment Ministers (CCME) Draft Sediment Quality Guideline (CCME, in preparation) for the protection of aquatic life. No federal or provincial sediment guidelines or criteria presently exist for 2,3,7,8-T4CDF. Concentrations of dioxins and furans (expressed as pg/L) were compared with the proposed Ontario Ministry of Environment and Energy (OMEE) water quality criteria for the protection of aquatic life. In the Thompson River System, only sediment collected from Savona exceeded these guidelines or criteria (Table 20).

Table 20 2,3,7,8-T4CDD Concentrations in Thompson River Suspended Sediments from Savona Compared to Bed Sediment and Freshwater Guidelines/Criteria for the Protection of Aquatic Life (October 1992, February 1993, November 1993)

Compounds	Concentration in Suspended Sediments (pg/g)		Draft CCME Guideline for Bed Sediment (pg/g)	Concentration in Suspended Sediments (converted to pg/L) ⁽¹⁾		Proposed OMEE Criterion for Fresh Water (pg/L)
	Date	Concentration		Date	Concentration	
2,3,7,8-T4CDD	Oct 92	0.70 0.14 ⁽²⁾	0.25	Oct 92	0.0010	0.02
	Feb 93	5.3 0.29		Feb 93	0.0060	
	Nov 93	1.5 1.0		Nov 93	0.0060	

(1) Conversion from pg/g to pg/L was achieved by using the site specific suspended sediment concentration

(2) Shaded values indicate concentrations adjusted to the site specific organic carbon content

Concentrations of 2,3,7,8-T4CDD exceeded the draft CCME bed sediment quality guideline of 0.25 pg/g at Savona on all three sampling dates. However when suspended sediment concentrations were adjusted to the site specific organic carbon content, the guideline was exceeded only in February and November 1993. When concentrations in suspended sediments

were converted to pg/L and compared to the proposed OMEE water quality criterion of 0.02 pg/L, none of the concentrations exceeded this value. Concentrations of 2,3,7,8-T4CDF in suspended sediments did not exceed the proposed OMEE freshwater criterion of 0.2 pg/L (not shown).

8.2.2.6 Toxicity Equivalents

The overall toxicity of a mixture of dioxins and furans in one sample can be compared with other samples by using toxicity equivalent factors (TEQs). TEQs represent a toxicity-weighted total dioxin and furan concentration based on the sum of all isomers that have chlorine atoms in the 2,3,7,8 positions (CEPA, 1990). TEQ values are determined by using 2,3,7,8-T4CDD as a reference compound since it is the most toxic dioxin or furan. All other isomers are compared to the reference by toxicity equivalent factors (TEFs). TEQs are computed as the sum of individual isomer concentrations after they have been multiplied by their respective TEFs.

TEQ values were calculated according to the NATO method, as described in CEPA (1990). As TEQ guidelines do not exist for suspended sediments, the TEQs calculated from Thompson River System data were compared to the CCME draft TEQ guideline (CCME, in preparation) and the BCMELP bed sediment TEQ objective for the Thompson River (Nordin and Holmes, 1992). Refer to Table 21 for the results of these comparisons.

Table 21 Dioxin and Furan Toxicity Equivalents in Suspended Sediments from the Thompson River System Compared to CCME Draft Bed Sediment TEQ Guideline and the BCMELP Bed Sediment TEQ Objective

Location	Oct 1992 Measured TEQ (pg/g)	Feb 1993 Measured TEQ (pg/g)	Nov 1993 Measured TEQ (pg/g)	CCME Draft Bed Sediment TEQ Guideline (pg/g)	BCMELP Bed Sediment TEQ Objective for the Thompson River (pg/g)
McLure	0.20 0.055*	0.15 0.061	0.39 0.28	0.25	0.7
Savona	3.8 0.78	24 1.3	7.6 5.1	0.25	0.7

*Note: shaded values refer to TEQ values adjusted to the site specific organic carbon content

While at the upstream site, McLure, the draft CCME guideline of 0.25 pg/g was only exceeded in November 1993, at Savona it was exceeded for all three sampling periods (even when adjusted to the site specific organic carbon content). The BCMELP bed sediment TEQ objective of 0.7 pg/g for the Thompson River was also exceeded at Savona on all three occasions.

8.3 Fraser River

8.3.1 Results

8.3.1.1 Suspended Sediments

All four sites sampled on the Fraser River had detectable levels of dioxins and furans. Table 22 summarizes all dioxin and furans measured at the four sites on the Fraser River between October 1992 and November 1994. Note that mono, di and tri dioxins and furans were analysed only in November 1994.

Total D2CDD was detected at Shelley (8.0 pg/g); however, its concentration was lower than that detected at Marguerite (36 pg/g) and Yale (23 pg/g). Marguerite had the highest concentrations of total D2CDD (36 pg/g), total T3CDD (1.5 pg/g) and total T4CDD (5.0 pg/g) of all sites sampled.

The isomer 2,3,7,8-T4CDD was not detected at Shelley; however it was measured at Woodpecker, Marguerite and Yale with the highest concentrations in February (Figure 6). Penta, hexa, hepta and octa-dioxins were higher at all sites downstream of pulp mills with the exception of November 1993, when the levels at Shelley exceeded some of the values measured downstream. Overall, the majority of dioxin congeners, including total T4CDD and 2,3,7,8-T4CDD, were generally highest in concentration in either February 1993 or November 1994, and moreover Marguerite had the highest concentration of dioxins of all Fraser River sites.

While total M1CDF was not detectable at any of the Fraser River sites, maximum levels of total D2CDF (34 pg/g) and total T3CDF (49 pg/g) were measured in November 1994 at Yale and at Marguerite, respectively. Total T4CDF and 2,3,7,8-T4CDF were above detection limits at Shelley in November 1993; however, levels of these contaminants were (with a single exception) higher at all sites downstream of Shelley. Both 2,3,7,8-T4CDF (Figure 7) and total T4CDF were found in the highest concentrations in February 1993 at all sites downstream of pulp mills. Maximum concentrations of both 2,3,7,8-T4CDF (4.8 pg/g) and total T4CDF (9.3 pg/g) were measured in February 1993 at Woodpecker. In November 1993, the reference site, Shelley, had the highest concentration of penta, hexa, hepta and octa-chlorinated furans of all Fraser River sites.

Table 22 Summary of Dioxins and Furans Detected in Suspended Sediments from the Fraser River (October 1992, February 1993, November 1993, November 1994)

Sampling Date:	Shelley				Woodpecker			Marguerite				Yale			
Sample Date:	Oct. 1992	Feb. 1993	Nov. 1993	Nov. 1994	Oct. 1992	Feb. 1993	Nov. 1993	Oct. 1992	Feb. 1993	Nov. 1993	Nov. 1994	Oct. 1992	Feb. 1993	Nov. 1993	Nov. 1994
Dioxins (pg/g)															
Total M1CDD	-	-	-	ND(0.8)	-	-	-	-	-	-	ND(5.0)	-	-	-	ND(1.2)
Total D2CDD	-	-	-	8.0	-	-	-	-	-	-	38	-	-	-	23
Total T3CDD	-	-	-	ND(0.3)	-	-	-	-	-	-	1.5	-	-	-	0.95
Total T4CDD	ND(0.3)	0.80	0.55	0.50	ND(0.2)	1.6	0.80	ND(0.2)	3.7	1.9	5.0	ND(0.2)	1.3	1.2	3.0
2,3,7,8-T4CDD	ND(0.3)	ND(0.1)	ND(0.1)	ND(0.3)	0.30	0.80	ND(0.1)	ND(0.2)	0.80	0.20	ND(3.0)	ND(0.2)	0.5	0.10	ND(0.8)
Total P5CDD	ND(0.4)	ND(0.2)	0.98	ND(0.3)	ND(0.2)	ND(0.1)	ND(0.2)	ND(0.4)	0.80	1.7	1.35	ND(0.2)	0.3	0.40	ND(0.7)
Total H6CDD	ND(0.8)	3.3	13	2.7	2.5	13	2.9	7.0	23	10	22	1.4	9.5	5.8	14
Total H7CDD	7.8	15	50	17	ND(0.8)	30	10	23	38	26	90	15	31	16	44
O8CDD	28	72	180	81	47	130	44	85	170	110	470	80	130	65	230
Furans (pg/g)															
Total M1CDF	-	-	-	ND(5.5)	-	-	-	-	-	-	ND(2.1)	-	-	-	ND(17)
Total D2CDF	-	-	-	ND(1.2)	-	-	-	-	-	-	26	-	-	-	34
Total T3CDF	-	-	-	ND(0.4)	-	-	-	-	-	-	48	-	-	-	36
Total T4CDF	ND(0.2)	ND(0.1)	0.93	ND(0.3)	1.0	9.3	0.40	1.9	7.3	3.1	5.8	0.17	8.3	1.3	6.3
2,3,7,8-T4CDF	ND(0.2)	{0.10}	0.18	ND(0.3)	0.70	4.8	0.10	0.90	3.8	1.1	3.8	0.27	4.2	0.50	3.1
Total P5CDF	ND(0.4)	ND(0.2)	5.9	ND(0.3)	ND(0.2)	0.30	ND(0.2)	ND(0.2)	0.30	1.1	2.5	0.13	0.2	0.60	0.90
Total H6CDF	ND(0.4)	1.2	29	1.9	ND(0.3)	1.2	1.8	2.3	0.80	3.5	2.7	0.66	2.2	1.6	1.9
Total H7CDF	2.2	7.1	45	2.3	ND(0.4)	4.8	5.3	6.2	2.3	7.8	6.1	2.2	6.9	4.9	5.1
O8CDF	2.2	3.4	12	ND(3.0)	2.4	5.8	2.6	8.0	2.3	3.8	3.8	3.0	8.0	2.6	6.1

ND denotes below the indicated detection limit (shown in brackets) when both field splits and samples were below detection

Note: all results presented are a mean of field splits and samples - one half the detection limit was used when only one of the samples was below the detection limit

- all means rounded to two significant figures

() concentration value equal to or below that of laboratory and/or field blank

8.3.1.2 Clarified Water (Solid and Liquid Phase Extracted)

Refer to Table 23 for a summary of dioxin and furan concentrations in solid phase extracted clarified water samples collected in February 1993 and November 1994. Note that no data are available for the reference site, Shelley, for February 1993 and that Woodpecker was not sampled in November 1994. No tetra, penta or hexa-chlorinated dioxins were measured above detection limits at Woodpecker, Marguerite or Yale. Total H7CDD was detected only at Marguerite in November 1993 (0.20 pg/L). Octa-chlorinated dioxin was detected at all sites downstream of Shelley, and its concentration ranged from 0.20-0.30 pg/L. No furans were measured above detection limits.

Refer to Table 24 for a summary of dioxin and furan concentrations measured in liquid phase extracted water samples from the Fraser River. Note that clarified water was liquid phase extracted only in February 1993 and that there is no data for the reference site, Shelley. All three downstream sites, Woodpecker, Marguerite and Yale had detectable levels of total H6CDD (0.080 pg/L - 0.18 pg/L). Both Marguerite and Yale had detectable levels of total H7CDD in the range of 0.080 pg/L to 0.20 pg/L. Woodpecker and Marguerite had detectable levels of O8CDD ranging from 0.37 pg/L to 0.51 pg/L. All other dioxins were below detection limits. All three downstream sites had detectable levels of total T4CDF (0.040 pg/L - 0.060 pg/L), whereas 2,3,7,8-T4CDF was detected only at Woodpecker (0.080 pg/L) and Marguerite (0.51 pg/L).

8.3.1.3 Distribution of Dioxins and Furans Between Sediment and Water

Phase partitioning of dioxins and furans in the Fraser River was calculated by comparing concentrations of these contaminants in both solid phase extracted clarified water and liquid phase extracted clarified water with concentrations in suspended sediments. Refer to Table 25 for a summary of phase partitioning data from February 1993 for all Fraser River sampling sites. Due to the small number of values which were available for log K_{oc} calculations, caution is advised when interpreting the results.

Based on results from solid phase extracted clarified water, partitioning of O8CDD to suspended sediments ranged between 48-82%. Results from liquid phase extracted clarified water indicate that partitioning of total H6CDD, total H7CDD, O8CDD and total T4CDF to suspended sediments ranged between 10-71%. The calculated log K_{oc} values ranged between 7.0-7.3 for O8CDD measured by solid phase extraction and 4.3-7.3 for the congeners measured by liquid phase extraction. Calculated log K_{oc} values were generally within the range of published log K_{oc} values.

Table 23 Summary of Dioxin and Furans Detected in Solid Phase Extracted Clarified Water from the Fraser River (February 1993 and November 1994)

Sampling Location:	Shelley	Woodpecker	Marguerite		Yale	
Sampling Date:	Nov. 1994	Feb. 1993	Feb. 1993	Nov. 1994	Feb. 1993	Nov. 1994
Dioxins (pg/L)						
T4CDD - Total	ND(0.03)	ND(0.04)	ND(0.05)	ND(0.03)	ND(0.1)	ND(0.03)
2,3,7,8	ND(0.03)	ND(0.04)	ND(0.05)	ND(0.03)	ND(0.1)	ND(0.03)
P5CDD - Total	ND(0.04)	ND(0.05)	ND(0.06)	ND(0.04)	ND(0.2)	ND(0.04)
H6CDD - Total	ND(0.06)	ND(0.05)	ND(0.06)	ND(0.06)	ND(0.1)	ND(0.06)
H7CDD - Total	ND(0.08)	ND(0.07)	ND(0.07)	ND(0.08)	ND(0.2)	ND(0.08)
O8CDD	ND(0.14)	0.20	0.20	ND(0.1)	0.30	ND(0.1)
Furans (pg/L)						
T4CDF - Total	ND(0.03)	ND(0.03)	ND(0.03)	ND(0.03)	ND(0.1)	ND(0.03)
2,3,7,8	ND(0.03)	ND(0.03)	ND(0.03)	ND(0.03)	ND(0.1)	ND(0.03)
P5CDF - Total	ND(0.04)	ND(0.03)	ND(0.05)	ND(0.04)	ND(0.1)	ND(0.04)
H6CDF - Total	ND(0.06)	ND(0.04)	ND(0.05)	ND(0.06)	ND(0.1)	ND(0.06)
H7CDF - Total	ND(0.08)	ND(0.06)	ND(0.07)	ND(0.08)	ND(0.1)	ND(0.08)
O8CDF	ND(0.1)	ND(0.07)	ND(0.07)	ND(0.1)	ND(0.3)	ND(0.1)

ND denotes below the indicated detection limit (shown in brackets)

Table 24 Summary of Dioxins and Furans Detected in Liquid Phase Extracted Clarified Water from the Fraser River (February 1993)

Sampling Location:	Woodpecker	Marguerite	Yale
Sampling Date:	Feb. 1993	Feb. 1993	Feb. 1993
Dioxins(pg/L)			
T4CDD - Total	ND (0.04)	ND (0.03)	ND (0.03)
2,3,7,8	ND (0.04)	ND (0.03)	ND (0.03)
P5CDD - Total	ND (0.03)	ND (0.03)	ND (0.03)
H6CDD - Total	0.13	0.080	0.18
H7CDD - Total	ND (0.05)	0.20	0.080
O8CDD	0.37	0.51	ND (0.11)
Furans (pg/L)			
T4CDF - Total	0.060	0.050	0.040
2,3,7,8	0.080	ND (0.04)	0.010
P5CDF - Total	ND (0.08)	ND (0.08)	ND (0.04)
H6CDF - Total	ND (0.05)	ND (0.04)	ND (0.05)
H7CDF - Total	ND (0.04)	ND (0.05)	ND (0.04)
O8CDF	ND (0.06)	ND (0.05)	0.13

- ND denotes below the indicated detection limit (shown in brackets) when both field replicates and samples were below detection
- all results presented are a mean of field replicates and samples
- one half the detection limit was used when only one of the samples was below the detection limit
- all means rounded to two significant figures

Table 25 Summary of Dioxin and Furan Phase Partitioning and Log K_{oc} Values Calculated From Data of Solid Phase and Liquid Phase Extracted Clarified Water from Woodpecker, Marguerite and Yale - Fraser River (February 1993). Published log K_{oc} Values are Presented for Comparison.

		Calculations made using Solid Phase Extracted Clarified Water Data		Calculations made using Liquid Phase Extracted Clarified Water Data	
Compounds	Published Log K_{oc} Values ⁽¹⁾	% in Suspended Sediments ⁽²⁾	Calculated Log K_{oc} Values	% in Suspended Sediments ⁽²⁾	Calculated Log K_{oc} Values
Total H6CDD	5.02 - 7.1	N/A ⁽³⁾	-	10 - 57	4.3 - 6.9
Total H7CDD	5.47 - 7.8	N/A	-	45 - 47	6.8 - 7.2
O8CDD	5.92 - 7.9	48 - 82	7.0 - 7.3	61 - 71	4.9 - 7.0
Total T4CDF	5.2 - 7.5	N/A	-	30 - 53	4.5 - 7.0
2,3,7,8- T4CDF	5.2 - 7.5	N/A	-	47	7.3
O8CDF	6 - 7.4	N/A	-	11	6.4

(1) Mackay *et al.*, 1992

(2) Values expressed as a range across all sampling sites

(3) N/A denotes not available (due to insufficient data above detection limits)

8.3.1.4 Loadings of 2,3,7,8-T4CDD and 2,3,7,8-T4CDF

Table 26 presents the estimated loadings of 2,3,7,8-T4CDD and 2,3,7,8-T4CDF in Fraser River suspended sediments and the corresponding loadings from the pulp and paper mills upstream of each sampling site. In October 1992, a single loading of 2,3,7,8-T4CDD (0.28 mg/day) was estimated for Woodpecker, as levels of this contaminant were below detection limits at all other sites. This measured loading represents 40% of the 0.70 mg/day combined mill effluent loading from upstream mills located in Prince George. The measured loading of 2,3,7,8-T4CDF was lower than the combined mill loadings at both Woodpecker and Marguerite, but at Yale the calculated loading of 18 mg/day was 2.5 times greater than the combined mill effluent loading from the five kraft pulp and/or paper mills upstream of this site. Refer to Figure 8 for a

Table 26 Concentrations and Loadings of 2,3,7,8-T4CDD and 2,3,7,8-T4CDF in Fraser River Suspended Sediment Samples and Combined Mill Effluent Loadings from the Prince George, Northwood, Cariboo and Weyerhaeuser Pulp Mills (October 1992, February 1993, November 1993, November 1994)

Sampling Date	Location	Suspended Sediment (mg/L)	Flow (m ³ /s)	2,3,7,8-T4CDD in susp. sed. (pg/L)	2,3,7,8-T4CDF in susp. sed. (pg/L)	2,3,7,8-T4CDD loading (mg/day)	2,3,7,8-T4CDF loading (mg/day)	2,3,7,8-T4CDD *Combined Mill loading (mg/day)	2,3,7,8-T4CDF *Combined mill loading (mg/day)
October 1992	Woodpecker	15.0	718**	0.0045	0.011	0.28	0.65	0.70	3.7
	Marguerite	23.0	918	ND	0.021	NA	1.6	0.90	4.6
	Yale	226.0	3380	ND	0.072	NA	18	1.1	7.2
February 1993	Woodpecker	7.3	264**	0.0058	0.035	0.13	0.80	NA	3.0
	Marguerite	4.7	310	0.0038	0.017	0.10	0.45	0.20	4.0
	Yale	2.1	593	0.0011	0.0088	0.054	0.45	0.50	9.1
November 1993	Woodpecker	167.6	1080**	ND	0.017	NA	1.6	NA	2.0
	Marguerite	11.6	764	0.0023	0.013	0.15	0.84	0.19	2.6
	Yale	72.0	1480	0.0072	0.036	0.92	4.6	0.72	20
November 1994	Marguerite	4.6	563	ND	0.017	NA	0.85	NA	3.3
	Yale	2.7	892	ND	0.0082	NA	0.63	NA	7.6

ND denotes below detection limit (refer to Table 22 for detection limits in suspended sediments)

NA denotes not applicable due to values below detection limit

* Combined mill loadings are cumulative of the pulp and paper mills upstream of the sampling site; only mill loadings above detection limits have been included

** Flow estimated from South Fort George station

Note: Combined mill loadings are general estimates due to unavailability of some mill loadings

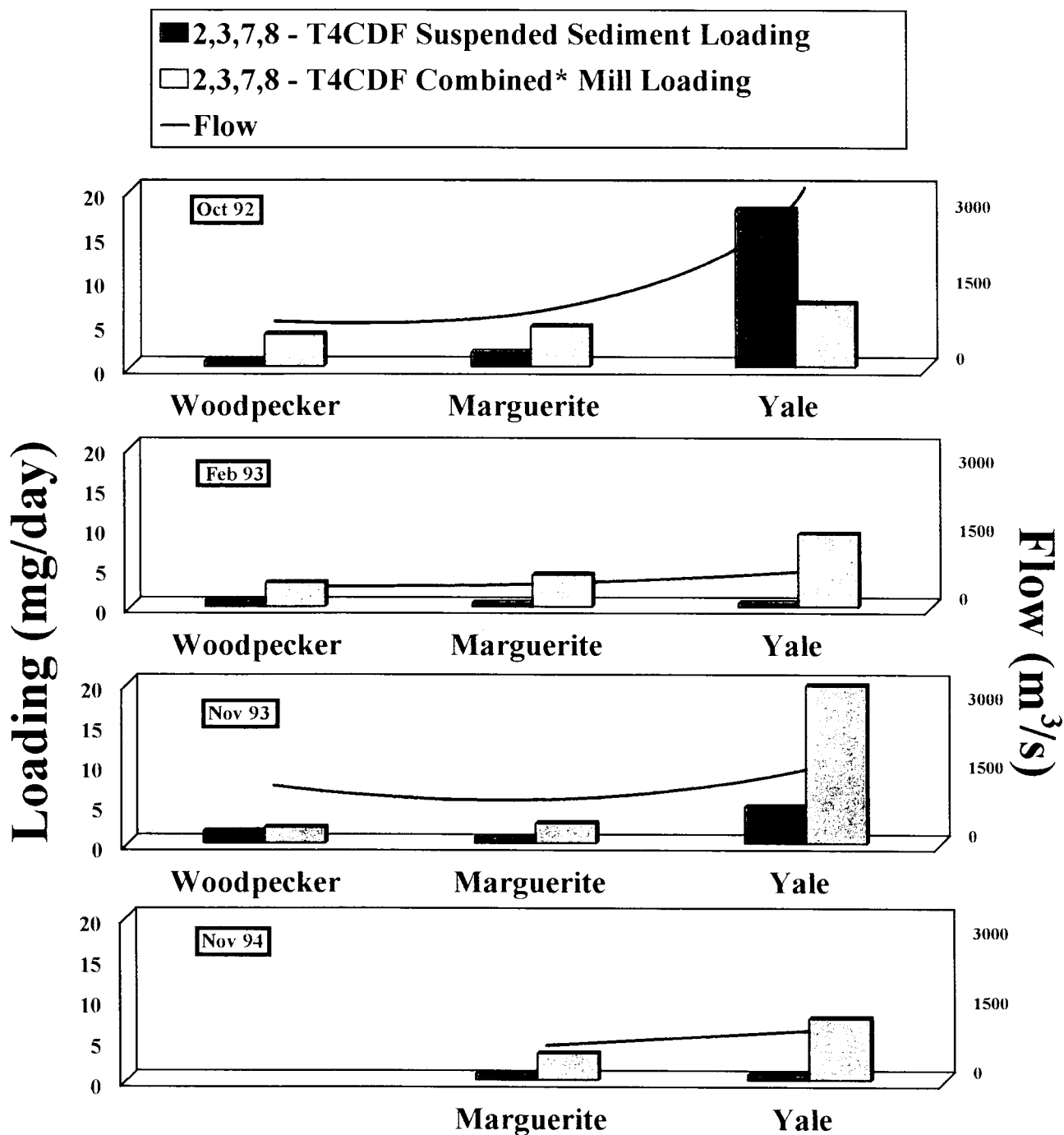


Figure 8 Estimated Loadings of 2,3,7,8 -T4CDF in Fraser River Suspended Sediment and Combined* Mill Effluent

* Combined mill loadings are a cumulative of all pulp mills upstream of the sampling site.

comparison of measured loadings of 2,3,7,8-T4CDF in Fraser River suspended sediments and combined loadings from upstream pulp mills.

Although none of the Prince George mills detected 2,3,7,8-T4CDD in their effluents in February 1993, calculations based on our suspended sediment data indicate that the highest loadings of this contaminant were measured at Woodpecker (0.13 mg/day). Similarly, the estimated loading of 2,3,7,8-T4CDF (0.80 mg/day) was also highest at Woodpecker. This loading represents 27% of the combined mill effluent loading of 2,3,7,8-T4CDF from all Prince George pulp mills for the month of February 1993. None of the loadings measured at the other Fraser River sites exceeded combined loadings from upstream pulp mills during the sampling period.

In November 1993, 2,3,7,8-T4CDD was measured at both Marguerite and Yale at 0.15 mg/day and 0.92 mg/day, respectively. The measured loading of 2,3,7,8-T4CDD at Yale exceeded combined loadings from upstream pulp mills by 28%. The highest 2,3,7,8-T4CDF loading was similarly measured at Yale (4.6 mg/day). However, this loading represents approximately 23% of the combined mill effluent loading from pulp mills upstream of this site. The measured 2,3,7,8-T4CDF loading at Woodpecker (1.6 mg/L) represents 80% of the combined pulp mill effluent loading from the Prince George mills. None of the 2,3,7,8-T4CDF measured loadings exceeded combined loadings from upstream pulp mills.

In November 1994, 2,3,7,8-T4CDD was not detected in either pulp mill effluent or at any of the sites sampled. Loadings of 2,3,7,8-T4CDF were higher at Marguerite (0.85 mg/day) than at Yale (0.64 mg/day). Neither of these loadings exceeded the loadings from upstream pulp mills.

Over all sampling periods, measured loadings of 2,3,7,8-T4CDF were approximately 2 to 18 times greater than measured loadings of 2,3,7,8-T4CDD.

8.3.2 Discussion

8.3.2.1 *Suspended Sediments*

For all sampling periods, most dioxin and furan concentrations measured downstream of the pulp mills at the Woodpecker, Marguerite and Yale sampling sites were higher than those measured at the upstream reference site, Shelley. The higher concentrations of di, tri and tetra-chlorinated dioxins and furans measured in November 1994 at all sites downstream of pulp and paper mills, relative to Shelley, confirms the association of these contaminants with pulp mill effluents.

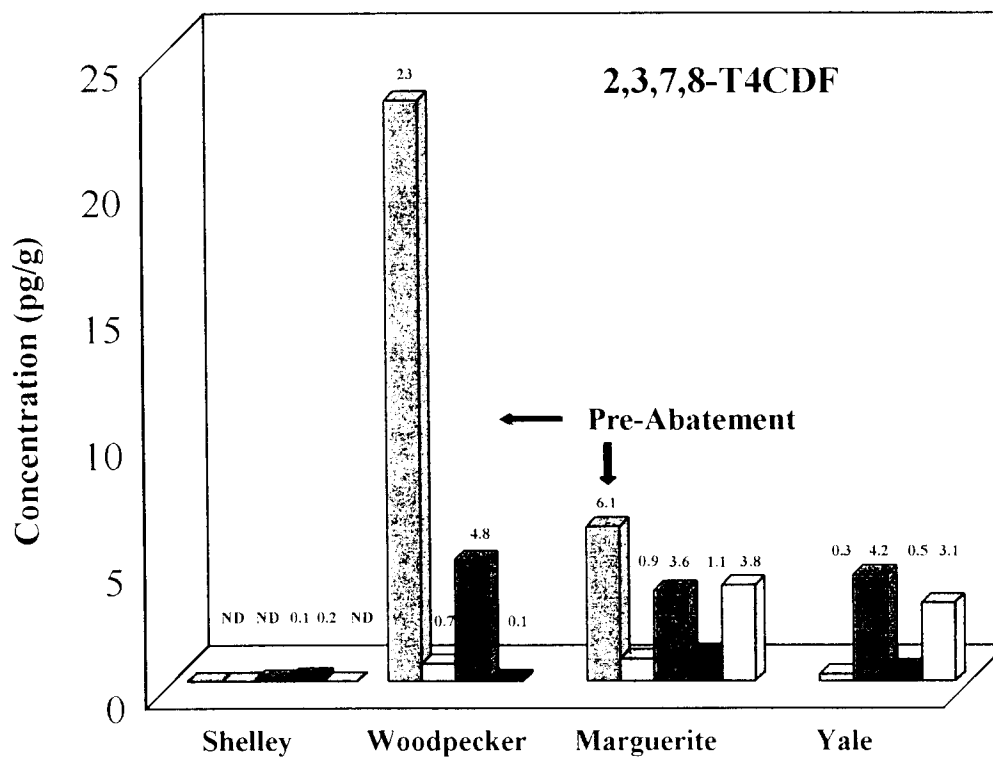
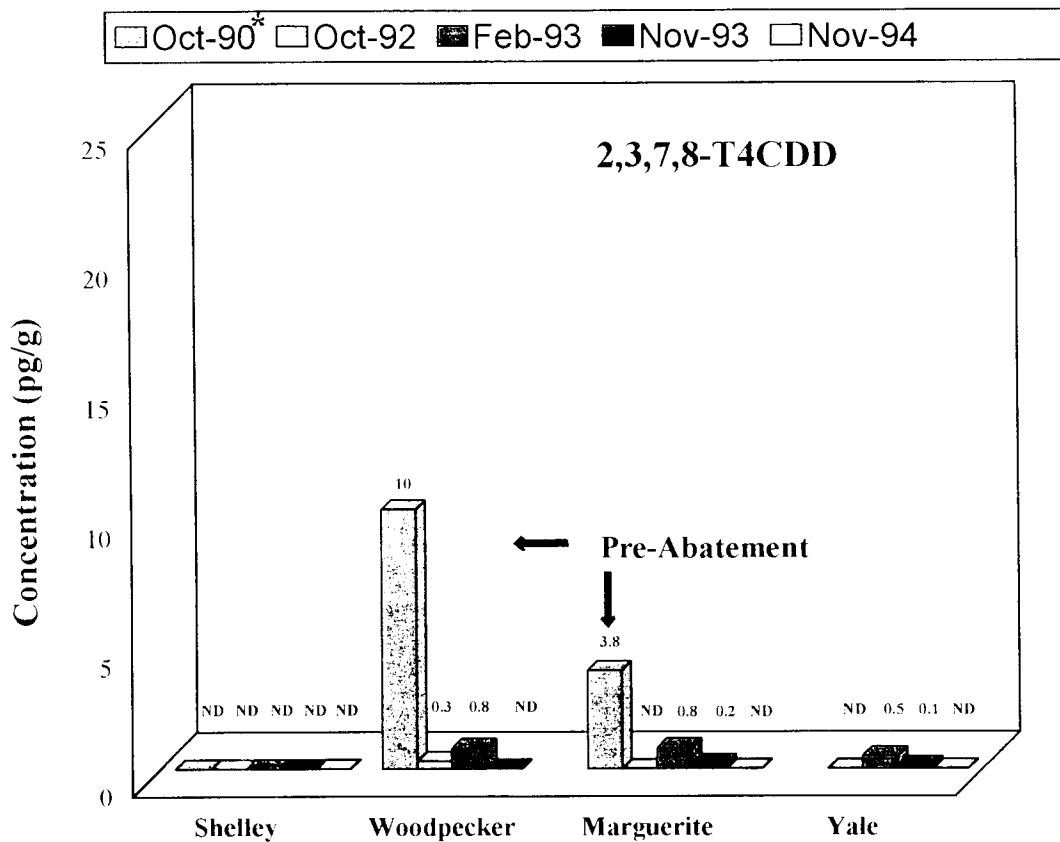
Although the association between tetra-chlorinated dioxins and furans and pulp mill effluents (Amendola, 1987) has been documented for some time, recent studies by Pastershank and Muir (1995) have identified di and tri-chlorinated dioxins and furans as useful markers of hydrophobic

organics of bleached kraft mill origin in abiotic samples. Furthermore, the relatively high concentration of penta, hexa, hepta and octa-furans detected at Shelley in November 1993 is likely from combustion origins, since the higher chlorinated dioxins and furan congeners in the receiving environment have been shown to be associated with this source (Czuczwa and Hites, 1986).

The highest concentrations of dioxins and furans were generally found downstream of the pulp mills in February 1993 and November 1994. This increase in dioxin and furan concentration observed for these two sampling periods is likely the result of both an increased effluent concentration in the water column and a decrease in the suspended sediment concentration. During the winter low flow period, (typically November through March), effluent concentrations in the Fraser River can reach an average of 1% v/v of river water (Dwernychuk, 1994), and suspended sediment concentrations can decrease to below 5 mg/L (at Marguerite) (Carson, 1988). As a result, in the winter low flow period, the Fraser River would be expected to contain the highest concentration of pulp mill contaminated suspended sediments relative to other times of the year. This increase in contaminant concentration under low flow conditions was observed at all downstream locations, including Yale.

For all sampling periods, Marguerite had the highest concentration of dioxins measured. This is likely the result of its close proximity (downstream) to the five upper Fraser River pulp mills. However, furan concentrations were slightly higher at Yale than at Marguerite in February 1993. This may be a consequence of an increased loading of furans from the Thompson River which enters the Fraser River downstream of Marguerite. Although Yale is approximately 265 rkm downstream of Weyerhaeuser (the nearest pulp mill), Dwernychuk (1994) has reported that effluent concentrations can reach 0.7% v/v of river water in this reach of the river during the winter low flow period.

A comparison of dioxin and furan concentrations measured in Fraser River suspended sediments by Derksen and Mitchell (in preparation[b]) in October 1990, prior to implementation of pulp mill abatement measures, to levels measured in October 1992, February 1993, November 1993 and November 1994 (post abatement) are presented in Figure 9. Both 2,3,7,8-T4CDD and 2,3,7,8-T4CDF concentrations decreased dramatically following process changes which replaced molecular chlorine, used in the bleaching process, with 70-100% chlorine dioxide substitution. Concentrations of 2,3,7,8-T4CDD measured at Woodpecker and Marguerite in 1992, 1993 and 1994 were 79-97% lower than October 1990 concentrations, whereas concentrations of 2,3,7,8-T4CDF were 38-99% lower than October 1990 concentrations. The largest relative decrease in both dioxin and furan concentrations was seen at Woodpecker.



* October 1990 data provided by George Derksen, Environment Canada

Figure 9 2,3,7,8-T4CDD and 2,3,7,8-T4CDF in Fraser River Suspended Sediment

8.3.2.2 Clarified Water (Solid and Liquid Phase Extracted)

The relatively low number of detectable concentrations of dioxins and furans in clarified water compared to suspended sediment samples is related primarily to sample size differences (Section 8.2.2.2). As with data collected from the Thompson River System, the most prevalent congeners detected in clarified water were hepta and octa-dioxins. These congeners, which are associated with combustion sources, are highly hydrophobic ($\log K_{ow} = 7.5-8.7$ [Shiu *et al.*, 1988]), and consequently their presence in clarified water is likely associated with their complexation with dissolved and colloidal organic carbon (Webster *et al.*, 1986).

8.3.2.3 Distribution of Dioxins and Furans Between Sediment and Water

As with data collected from the Thompson River System, $\log K_{oc}$ values calculated from data obtained from solid phase extracted clarified water, were similar to $\log K_{oc}$ values calculated from data obtained from liquid phase extracted clarified water. Since dioxins and furans have low water solubilities, binding to dissolved and colloidal organic matter in the water column very likely accounts for the relatively high presence of some of these contaminants in the water phase. Due to the low variability in both the suspended sediment concentration (0.9-7.3 mg/L) and TOC (1.80-3.45%) among sampling sites in February 1993, the effect of these parameters on dioxin and furan phase partitioning could not be ascertained.

8.3.2.4 Loadings of 2,3,7,8-T4CDD and 2,3,7,8-T4CDF

Based on loadings calculated from suspended sediment data, the measured loadings of 2,3,7,8-T4CDD at all downstream sampling stations on the Fraser River were generally less than the total loadings from the upstream pulp mills. This was expected due to deposition of some of the larger sized sediment particles contaminated with dioxins and furans. However, the measured loadings exceeded the combined loadings from upstream pulp mills on two occasions (February 1993 at Woodpecker and November 1993 at Yale). On both of these dates, both pulp mills upstream of Woodpecker did not detect 2,3,7,8-T4CDD in their effluent; however their detection limits were approximately 100 times larger than those reported in our data. This large difference in detection limits therefore likely accounts for the higher loadings of 2,3,7,8-T4CDD measured in the receiving environment on both occasions.

Loadings of 2,3,7,8-T4CDF were less than the combined loadings from the upstream pulp mills for all but one of the sampling sites and sampling periods (Yale, October 1992). Since all five kraft pulp mills upstream of Yale reported levels of this contaminant above detection limits for that month, the relatively high loading measured at Yale in October 1992 (18 mg/day) is likely the

result of resuspension of contaminated bed sediments. A recent study on Fraser River suspended sediments (Sekela *et al.*, 1994) found that contaminants associated with suspended sediments, including furans, may increase in concentration with increasing flow, and this increase is likely the result of resuspension of contaminated bed material. Therefore the dramatic increase in flow (3380 m³/s) may have contributed to resuspension of previously deposited contaminated sediments, hence accounting for the elevated 2,3,7,8-T4CDF loading measured at Yale in October 1992.

8.3.2.5 Comparisons of Dioxin and Furan Concentrations to Guidelines and Criteria

As with data collected from the Thompson River System, suspended sediment concentrations of 2,3,7,8-T4CDD were compared to the Canadian Council of Resource and Environment Ministers (CCME) Draft Sediment Quality Guideline for the protection of aquatic life (CCME, in preparation). No federal or provincial sediment guidelines or criteria presently exist for 2,3,7,8-T4CDF. Concentrations of dioxins and furans (expressed as pg/L) were compared with the proposed Ontario Ministry of Environment and Energy (OMEE) water quality criteria for the protection of aquatic life (OMEE, 1994).

Refer to Table 27 for 2,3,7,8-T4CDD concentrations which exceeded bed sediment quality guidelines or criteria in Fraser River suspended sediments. The draft CCME bed sediment guideline for 2,3,7,8-T4CDD was exceeded most commonly in February 1993 during base flow conditions. During this month, concentrations 2,3,7,8-T4CDD exceeded this guideline at all three downstream sites, Woodpecker, Marguerite and Yale. However, once these concentrations were adjusted to the site specific organic carbon content, none of the resulting values exceeded the draft CCME guideline. Moreover, upon conversion of 2,3,7,8-T4CDD concentrations to pg/L, none of the concentrations exceeded the proposed OMEE fresh water criterion of 0.02 pg/L. Lastly, concentrations of 2,3,7,8-T4CDF in suspended sediments (converted to pg/L) did not exceed the proposed OMEE freshwater criterion of 0.2 pg/L (not shown).

8.3.2.6 Toxicity Equivalents

Refer to Table 28 for TEQ values for dioxins and furans measured in suspended sediments from the Fraser River and the CCME draft bed sediment TEQ guidelines for the protection of aquatic life (CCME, in preparation).

Table 27 2,3,7,8-T4CDD Concentrations in Fraser River Suspended Sediments Exceeding Bed Sediment and/or Freshwater Quality Guidelines or Criteria for the Protection of Aquatic Life

Compound	Concentrations in Suspended Sediments (pg/g)				Draft CCME Guideline for Bed Sediment (pg/g)	Concentrations in Suspended Sediments (expressed as pg/L ⁽¹⁾)			Proposed OMEE Criterion for Fresh Water (pg/L)
		Date	Concentration				Date	Concentration	
2,3,7,8-T4CDD	Woodpecker	Oct 92	0.30	0.15 ⁽²⁾	0.25	Woodpecker	Oct 92	0.0050	0.02
		Feb 93	0.80	0.23			Feb 93	0.0060	
	Marguerite	Feb 93	0.80	0.24		Marguerite	Feb 93	0.0040	
	Yale	Feb 93	0.50	0.22		Yale	Feb 93	0.0010	

(1) Conversion from pg/g to pg/L was achieved by using the site specific suspended sediment concentration

(2) Shaded values indicate concentrations adjusted to the site specific organic carbon content

Table 28 Dioxin and Furan Toxicity Equivalents in Suspended Sediments from the Fraser River Compared to the CCME Draft Bed Sediment Quality TEQ Guideline for the Protection of Aquatic Life

Location	October 1992 Measured TEQ (pg/g)	February 1993 Measured TEQ (pg/g)	November 1993 Measured TEQ (pg/g)	November 1994 Measured TEQ (pg/g)	CCME Draft Sediment Quality TEQ Guideline (pg/g)
Shelley	0.070 0.036*	0.28 0.16	1.2 2.0	0.70 0.85	0.25
Woodpecker	0.55 0.28	2.1 0.61	0.15 0.24	-	0.25
Marguerite	0.49 0.19	2.3 0.69	0.92 0.75	4.9 2.2	0.25
Yale	0.21 0.21	1.8 0.79	0.40 0.56	2.0 1.3	0.25

*Note: shaded values refer to TEQ values adjusted to the site specific organic carbon content

Based on TEQ values adjusted to the site specific organic carbon content, the draft CCME bed sediment quality TEQ guideline of 0.25 pg/g was exceeded at Woodpecker in October 1992, at all three downstream sites in February 1993, at all sites (with the exception of Woodpecker) in November 1993 and at all sites sampled in November 1994. The highest TEQ (2.2 pg/g), measured at Marguerite in November 1994, is approximately nine times greater than the draft TEQ guideline for bed sediment.

Note that the TEQs measured in the Thompson River at Savona were considerably greater than those measured at the Fraser River sites (Table 21). Moreover, for sites below pulp mills on both the Thompson and Fraser Rivers, the highest TEQ values were obtained from data collected in the periods of lowest flow, February 1993 at Savona and both February 1993 and November 1994 at the Fraser River sites. This association between high TEQs and low flow indicates that the greatest potential for stress to the aquatic environment may be during the late fall low flow or winter base flow periods.

9.0 CHLOROPHENOLICS

9.1 Introduction

There are three main classes of chlorinated phenolic compounds, phenols, guaiacols and catechols. The environmental behaviour of these individual compounds is related to their physical and chemical properties. Volatility and water solubility decrease with increasing molecular weight, and sorption appears to play a significant role in the removal of some chlorinated phenols from the water column (CCREM, 1987). Chlorophenolic K_{ow} values vary between 0.88 to 5.0, and highly chlorinated chlorophenolics such as pentachlorophenol ($K_{ow} = 5.0$) tend to be more hydrophobic (Solomon *et al.*, 1993). In general, as the degree of chlorine substitution increases, the octanol/water partition coefficient (K_{ow}) of individual compounds also increases, indicating a greater affinity for the organic content of sediments (CCREM, 1987). The sorption partition coefficient (K_{oc}) also increases with increasing hydrophobicity of a compound but represents a more accurate measure of the potential of a compound to partition into the sediment versus the water phase, because it takes into account the organic carbon fraction of the sorbing medium (Chiou *et al.*, 1986).

The concern over the presence of chlorophenolics in the aquatic environment stems from their immunotoxic, fetotoxic and embryotoxic properties. Toxicity to aquatic life and the generation of an unpleasant taste in fish and shellfish living in contaminated wastewater has been documented even in relatively low concentrations. However, in mammals chlorophenolics are not bioaccumulated to a high degree in fat due to their rapid excretion as glucuronide conjugates (Water Quality Branch, 1993a).

Chlorophenolics are found world-wide in water, soil, sediment and biota (Konasewich *et al.*, 1978). Their widespread presence has been attributed to their historically extensive use in treated wood products as well as from leachate from waste dumps and accidental spills (Water Quality Branch, 1993a). Until its restriction on December 31, 1990, about one half of the 750 tonnes of pentachlorophenol which entered British Columbia annually (WHO, 1989) was used as anti-sapstain treatment on cut lumber. However, present legislation has banned pentachlorophenol use as a general anti-sapstain agent and has restricted its use to heavy duty wood preservation. In British Columbia, chlorophenols in mixtures of creosote are presently used in railway ties, tresles and utility and telecommunication poles (Wan and Van Oostdam, 1995). Other sources of chlorophenolics to the environment include: sewage treatment plant effluents (Pierce, 1978), chlorinated pesticides and kraft pulp and paper mill effluent (Water Quality Branch, 1993a).

Pulp and paper mills are an important source of chlorophenolics to the aquatic environment. Chlorophenols, chloroguaiacols and chlorocatechols are all produced in paper making during chlorine bleaching operations and have been observed in bleach plant wastewater and in water, sediment and biota from aquatic systems receiving pulp mill discharge. In particular, chlorinated

guaiacols can be used as tracers to identify the presence of pulp mill effluent in the aquatic environment (Carey and Hart, 1988). Previous studies in the Fraser River Basin have shown that chlorophenolics are measurable in bottom sediments (Voss and Yunker, 1983; Dwernychuk, 1990; Dwernychuk *et al.*, 1991) and suspended sediments (Sekela *et al.*, 1994; Duncan, in preparation) collected from sites downstream of pulp and paper mills.

9.2 Thompson River System

9.2.1 Results

9.2.1.1 Suspended Sediments

Refer to Table 29 for a summary of all chlorophenolics detected at McLure and Savona. Although suspended sediment samples collected from McLure had detectable levels of a number of chlorophenolics, with the exception of 3,4-dichlorophenol, all chlorophenolics were higher in concentration at Savona than at McLure. Samples collected from Savona had measurable levels of over 20 individual chlorophenolics. The majority of the chlorophenolics measured at Savona were higher in concentration in February 1993 than on the other two sampling dates. Figure 10 presents the concentration of 6-chlorovanillin at the McLure and Savona sampling sites. Whereas 6-chlorovanillin was below detection limits for all three sampling dates at McLure, at the downstream site of Savona it measured 57 ng/g, 1100 ng/g and 210 ng/g in October 1992, February 1993 and November 1993, respectively. Moreover, this contaminant had the highest concentration of all chlorophenolics measured in the Fraser River Basin. Other relatively high levels of chlorophenolics detected at Savona included 4-chloroguaiacol (42 ng/g), 4,5-dichloroguaiacol (61 ng/g), 3,5-dichlorocatechol (27 ng/g), 3,4,5-trichloroguaiacol (55 ng/g) and 5,6-dichlorovanillin (36 ng/g), all measured in February 1993, and 3,4,5,6-tetrachloroguaiacol (23 ng/g) measured in October 1992.

9.2.1.2 Whole Water

Refer to Table 30 for a summary of chlorophenolics measured in whole water samples from the Thompson River System. The majority of chlorophenolics measured at both McLure and Savona were below detection limits. At McLure, concentrations exceeding blank values were detected for six chlorophenolics in October 1992 and February 1993, with 4-chloroguaiacol (20 ng/L) having the highest detected concentration. At Savona, seven chlorophenolics in October 1992 and four in February 1993 were above detection limits and blank values. Of these, 5-chloroguaiacol had the highest concentration (39 ng/L) in October 1992. This chlorophenolic was also the only one

Table 29 Summary of Chlorophenolics Detected in Suspended Sediments from the Thompson River System (October 1992, February 1993, November 1993)

Sampling Location:	McLure			Savona		
Sampling Date:	Oct. 1992	Feb. 1993	Nov. 1993	Oct. 1992	Feb. 1993	Nov. 1993
Chlorophenols (ng/g)						
4-chlorophenol	ND(0.5)	ND(1.4)	ND(1.3)	ND(0.6)	3.2	ND(0.7)
2,6-dichlorophenol	1.8	ND(2.1)	ND(0.3)	ND(0.6)	7.9	0.60
2,4/2,5-DCP	0.60	ND(1.5)	ND(1.2)	ND(0.5)	ND(1.2)	ND(1.2)
3,5-dichlorophenol	ND(0.3)	ND(1.9)	ND(0.3)	ND(0.6)	ND(1.7)	0.20
2,3-dichlorophenol	ND(0.3)	ND(1.8)	ND(0.3)	ND(0.6)	ND(1.6)	ND(0.2)
3,4-dichlorophenol	ND(0.2)	ND(1.3)	9.1	ND(0.4)	ND(1.1)	0.60
6-chloroguaiacol	ND(0.1)	ND(1.3)	ND(0.6)	ND(0.3)	ND(1.8)	ND(0.6)
4-chloroguaiacol	ND(0.1)	ND(1.6)	ND(0.7)	2.8	42	ND(0.7)
5-chloroguaiacol	ND(0.1)	ND(1.5)	2.5	ND(0.3)	ND(2.2)	11
2,4,6-trichlorophenol	ND(0.1)	ND(2.1)	ND(0.7)	ND(0.1)	3.4	ND(0.9)
2,3,6-trichlorophenol	ND(0.3)	ND(1.6)	ND(0.4)	ND(0.4)	ND(1.3)	ND(0.2)
2,3,5-trichlorophenol	ND(0.3)	ND(1.7)	ND(0.4)	ND(0.4)	ND(1.3)	ND(0.2)
2,4,5-trichlorophenol	ND(0.3)	ND(1.4)	ND(0.3)	ND(0.3)	ND(0.9)	ND(0.2)
2,3,4-trichlorophenol	ND(0.3)	ND(1.4)	ND(0.3)	ND(0.3)	ND(1.0)	ND(0.2)
3,4,5-trichlorophenol	ND(0.3)	ND(1.5)	ND(0.3)	ND(0.6)	ND(1.1)	ND(0.2)
3-chlorocatechol	ND(0.7)	ND(3.2)	ND(0.6)	ND(0.8)	ND(1.2)	0.60
4-chlorocatechol	ND(0.6)	ND(5.0)	ND(0.9)	2.1	ND(1.9)	ND(0.6)
3,4-dichloroguaiacol	ND(0.4)	--	ND(0.2)	ND(0.6)	--	ND(0.1)
4,6-dichloroguaiacol	ND(0.4)	--	ND(0.2)	0.70	--	ND(0.2)
3,4/4,6-dichloroguaiacol	--	ND(2.2)	--	--	3.7	--
4,5-dichloroguaiacol	ND(0.2)	ND(2.0)	ND(0.2)	7.8	61	2.0
3-chlorosyringol	ND(0.1)	ND(1.2)	ND(0.2)	ND(0.2)	ND(10)	ND(0.1)
3,4-dichlorocatechol	ND(1.5)	ND(9.0)	ND(1.1)	ND(2.0)	ND(10)	ND(0.9)
3,6-dichlorocatechol	ND(1.9)	ND(11)	ND(1.2)	ND(2.5)	ND(4.3)	ND(1.0)
3,5-dichlorocatechol	1.7	ND(8.7)	4.8	2.6	27	5.9
4,5-dichlorocatechol	ND(1.9)	ND(11)	ND(1.4)	ND(2.8)	ND(4.7)	8.1
2,3,5,6-tetrachlorophenol	ND(0.5)	ND(5.1)	ND(0.6)	ND(1.0)	ND(2.4)	ND(0.5)
2,3,4,6-tetrachlorophenol	ND(0.5)	ND(5.5)	ND(0.6)	ND(1.0)	ND(2.6)	ND(0.5)
2,3,4,5-tetrachlorophenol	ND(0.3)	ND(3.4)	ND(0.4)	ND(0.8)	ND(1.7)	ND(0.3)
5-chlorovanillin	ND(2.0)	ND(26)	ND(5.2)	ND(3.5)	ND(16)	ND(3.2)
6-chlorovanillin	ND(2.3)	ND(28)	ND(5.7)	57	1100	210
3,5-dichlorosyringol	ND(0.6)	ND(8.0)	ND(0.8)	ND(1.0)	ND(3.5)	ND(0.6)
3,4,6-trichloroguaiacol	--	ND(4.1)	ND(0.5)	--	ND(3.5)	ND(0.8)
3,4,5-trichloroguaiacol	ND(0.4)	ND(4.0)	ND(0.6)	8.3	55	3.5
4,5,6-trichloroguaiacol	ND(0.2)	ND(2.8)	ND(0.4)	1.0	ND(2.3)	ND(0.7)
3,4,6-trichlorocatechol	--	ND(7.7)	ND(0.3)	--	3.7	0.60
3,4,5-trichlorocatechol	ND(1.0)	ND(7.1)	ND(0.2)	10	ND(2.8)	2.9
5,6-dichlorovanillin	ND(0.6)	ND(6.8)	ND(0.8)	1.2	36	ND(0.5)
pentachlorophenol	ND(0.8)	ND(9.8)	ND(0.6)	ND(1.3)	ND(3.8)	ND(0.6)
2-chlorosyringaldehyde	--	ND(5.4)	ND(0.3)	--	ND(3.2)	ND(0.4)
3,4,5,6-tetrachloroguaiacol	ND(0.6)	ND(5.5)	ND(0.4)	23	20	1.6
3,4,5-trichlorosyringol	ND(0.4)	ND(5.3)	ND(0.5)	ND(1.0)	ND(3.0)	ND(0.6)
3,4,5,6-tetrachlorocatechol	ND(4.9)	NQ	ND(4.9)	2.4	NQ	17
2,6-dichlorosyringaldehyde	--	NQ	ND(9.0)	--	NQ	ND(7.2)

ND denotes below the indicated detection limit (shown in brackets) when both field splits and samples were below detection

NQ denotes not quantifiable

Note: all results presented are a mean of field splits and samples

-one half the detection limit was used when only one of the samples was below the detection limit

- all means rounded to two significant figures

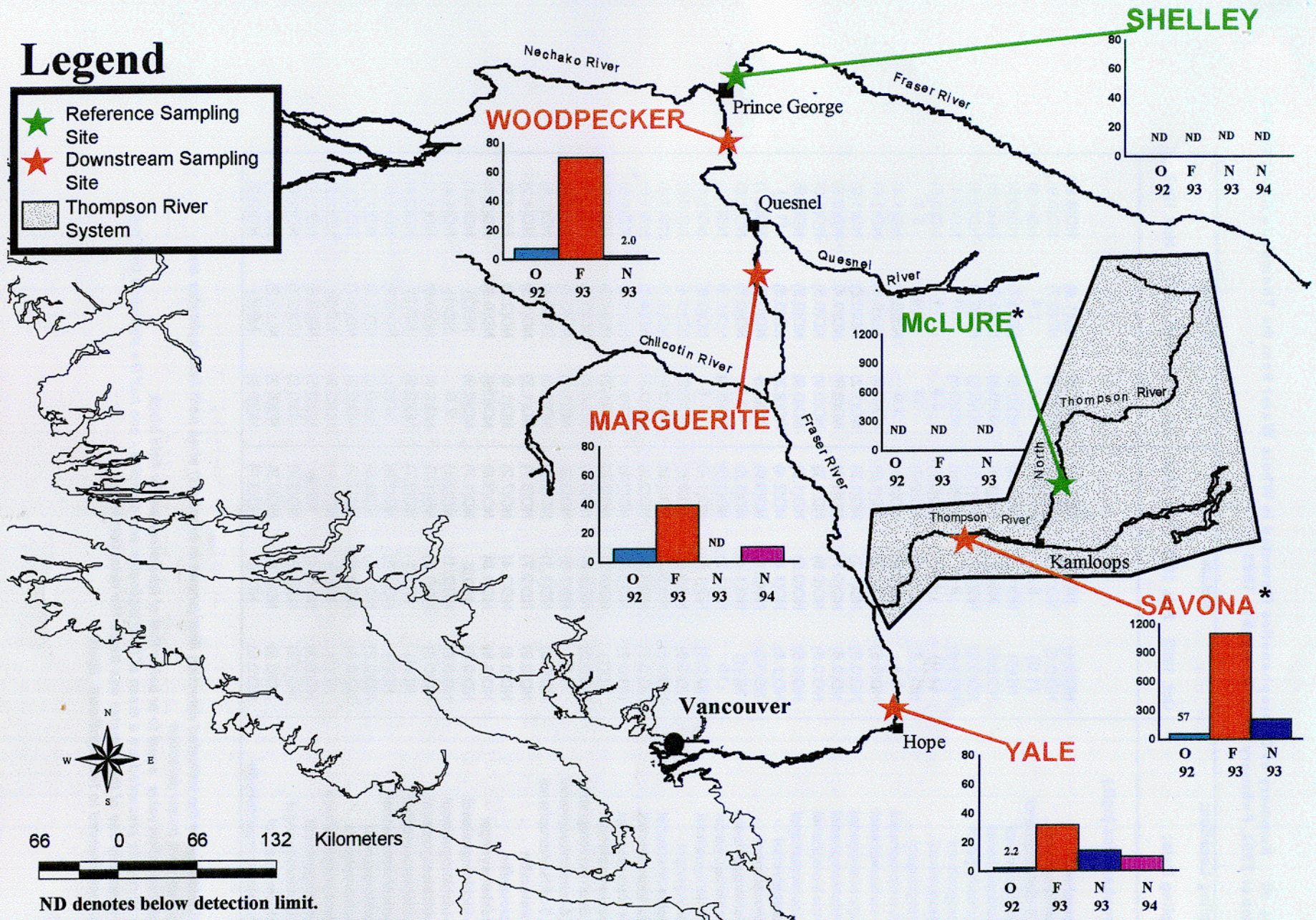


Figure 10 6-Chlorovanillin Concentrations (ng/g) in Suspended Sediment from the Fraser and Thompson River Systems

* Note scale difference for Thompson River System graphs

Table 30 Summary of Chlorophenolics Detected in Whole Water from the Thompson River System (October 1992, February 1993, November 1993)

Sampling Location:	McLure			Savona		
Sampling Date:	Oct. 1992	Feb. 1993	Nov. 1993	Oct. 1992	Feb. 1993	Nov. 1993
Chlorophenolics (ng/L)						
4-chlorophenol	ND(0.4)	ND(3)	ND(1.2)	ND(0.8)	ND(1.6)	ND(0.8)
2,6-dichlorophenol	ND(0.6)	ND(1.7)	ND(1.6)	ND(0.9)	ND(0.7)	ND(0.9)
2,4/2,5-dichlorophenol	{1.5}	5.9	ND(1.7)	2.1	3.4	ND(1.3)
3,5-dichlorophenol	ND(6)	ND(1.2)	ND(1.5)	ND(0.8)	ND(0.7)	ND(0.8)
2,3-dichlorophenol	ND(0.6)	ND(1)	ND(1.4)	ND(0.8)	ND(0.6)	ND(0.8)
3,4-dichlorophenol	ND(0.6)	ND(0.7)	ND(1.1)	ND(0.6)	ND(0.4)	ND(0.6)
6-chloroguaiacol	ND(0.6)	2.5	ND(0.5)	ND(0.6)	1.0	ND(0.4)
4-chloroguaiacol	{2.0}	20	ND(0.7)	3.8	11	ND(0.5)
5-chloroguaiacol	ND(0.6)	ND(1.6)	ND(0.7)	39	6.6	5.6
2,4,6-trichlorophenol	1.2	ND(0.4)	ND(1.5)	3.0	ND(0.6)	ND(1.4)
2,3,6-trichlorophenol	ND(0.6)	ND(1.2)	ND(1.3)	ND(0.9)	ND(0.6)	ND(1.0)
2,3,5-trichlorophenol	ND(0.9)	ND(1.2)	ND(1.3)	ND(1.2)	ND(0.6)	ND(1.0)
2,4,5-trichlorophenol	ND(0.8)	ND(0.7)	ND(1.1)	ND(0.8)	ND(0.4)	ND(0.9)
2,3,4-trichlorophenol	ND(0.6)	ND(0.9)	ND(1.2)	ND(0.9)	ND(0.5)	ND(1.0)
3,4,5-trichlorophenol	ND(0.6)	ND(0.9)	ND(1.2)	ND(0.9)	ND(0.5)	ND(0.9)
3-chlorocatechol	ND(1.8)	ND(1.4)	ND(2.4)	ND(2.3)	ND(0.6)	{1.9}
4-chlorocatechol	ND(10)	ND(2.1)	ND(3.9)	ND(13)	ND(0.9)	ND(2.7)
3,4-dichloroguaiacol	ND(1)	ND(1.4)	ND(1.6)	1.2	ND(0.7)	ND(1.2)
4,6-dichloroguaiacol	15	ND(1.2)	ND(1.5)	ND(0.9)	ND(1.3)	ND(1.1)
4,5-dichloroguaiacol	ND(0.9)	ND(1.3)	ND(1.4)	1.5	ND(0.8)	ND(1.1)
3-chlorosyringol	ND(0.6)	ND(0.6)	ND(0.6)	ND(0.8)	ND(0.4)	ND(0.6)
3,4-dichlorocatechol	ND(0.5)	ND(3.2)	ND(1.9)	ND(0.6)	ND(3.7)	ND(1.3)
3,6-dichlorocatechol	ND(0.5)	ND(4.2)	ND(2.3)	ND(0.8)	ND(4.8)	ND(1.6)
3,5-dichlorocatechol	ND(0.2)	ND(3.3)	ND(2.1)	ND(0.4)	ND(3.9)	ND(1.5)
4,5-dichlorocatechol	ND(1)	ND(4.2)	ND(2.8)	ND(1.2)	ND(4.9)	ND(1.9)
2,3,5,6-tetrachlorophenol	ND(0.9)	ND(1.6)	ND(3.2)	ND(0.8)	ND(0.6)	ND(2.4)
2,3,4,6-tetrachlorophenol	1.5	ND(1.9)	ND(3.3)	ND(1.2)	ND(0.7)	ND(2.6)
2,3,4,5-tetrachlorophenol	ND(0.8)	ND(1.1)	ND(2.2)	ND(0.6)	ND(0.4)	ND(1.6)
5-chlorovanillin	ND(0.9)	ND(2.7)	ND(6.7)	ND(1.3)	ND(1.3)	ND(4.2)
6-chlorovanillin	ND(0.8)	ND(3.4)	ND(7.2)	ND(1.6)	ND(2.2)	ND(4.9)
3,5-dichlorosyringol	ND(0.8)	ND(1.9)	ND(3.6)	ND(0.8)	ND(0.9)	ND(3.1)
3,4,6-trichloroguaiacol	ND(0.6)	ND(3)	ND(1.7)	ND(0.9)	ND(2)	ND(1.1)
3,4,5-trichloroguaiacol	ND(0.8)	ND(2.1)	ND(2.1)	2.0	ND(1)	ND(1.4)
4,5,6-trichloroguaiacol	ND(0.6)	ND(1.3)	ND(1.7)	ND(0.9)	ND(0.6)	ND(1.1)
3,4,6-trichlorocatechol	ND(1)	ND(2)	ND(2.7)	ND(0.9)	ND(2)	ND(2.4)
3,4,5-trichlorocatechol	ND(1)	ND(1.6)	ND(2.3)	ND(2)	ND(0.9)	ND(1.9)
5,6-dichlorovanillin	ND(0.6)	ND(3.5)	ND(2.6)	ND(0.8)	ND(1.2)	ND(1.7)
pentachlorophenol	ND(0.6)	ND(1.2)	ND(2.2)	ND(0.9)	ND(0.7)	ND(2.1)
2-chlorosyringaldehyde	ND(1)	ND(5)	ND(1.9)	ND(0.9)	ND(5)	ND(1.2)
tetrachloroguaiacol	ND(0.3)	ND(1.4)	ND(2)	ND(0.6)	ND(0.6)	ND(1.1)
3,4,5-trichlorosyringol	ND(0.6)	ND(2.3)	ND(2.4)	ND(0.6)	ND(0.7)	ND(1.6)
tetrachlorocatechol	ND(0.9)	ND(2.6)	ND(2.9)	ND(5.2)	ND(3.2)	ND(1.7)
2,6-dichlorosyringaldehyde	ND(0.8)	ND(5)	ND(3.3)	ND(5.8)	ND(5)	ND(2.2)

ND denotes below the indicated detection limit (shown in brackets) when both field replicates and samples were below detection

{ } concentration value equal to or below that of laboratory and/or field blank

Note: all results presented are a mean of field replicates and samples - one half the detection limit was used when only one of the samples was below the detection limit

- all means rounded to two significant figures

above blank values and detection limits in November 1993 and, furthermore, it was the only chlorophenolic measured at Savona whose concentration was considerably above that measured at McLure. Refer to Figure 11 for 5-chloroguaiacol concentrations at sampling sites on the Thompson River System.

9.2.1.3 Distribution of Chlorophenolics Between Sediment and Water

Calculations of chlorophenolic phase partitioning were performed by subtracting the chlorophenolic concentration in suspended sediments (converted to pg/L) from that of whole water. Note that due to the limited number of chlorophenolics measured above detection limits, phase partitioning calculations were possible for only a small number of congeners, all detected at Savona. Consequently, caution is advised when interpreting the results. Log K_{oc} values were calculated from the field data, however no published log K_{oc} values exist for comparison. Refer to Table 31 for a summary of phase partitioning data for chlorophenolics measured at Savona.

Table 31 Summary of Chlorophenolic Phase Partitioning and Calculated Log K_{oc} Values - Savona, Thompson River System (October 1992, February 1993, November 1993)

Compounds	% Partitioning to Suspended Sediments ⁽¹⁾	Calculated Log K_{oc}
4-chloroguaiacol	0.070 - 0.42	4.2 - 4.3
5-chloroguaiacol	0.72	5.2
3-chlorocatechol	0.12	4.3
4,5-dichlorocatechol	0.47	5.0
3,4,5-trichlorocatechol	0.37	4.9

(1) Values expressed as a range across all sampling periods

The percent partitioning to suspended sediments ranged from 0.070% for 4-chloroguaiacol to 0.72% for 5-chloroguaiacol, whereas the calculated log K_{oc} values ranged from 4.2 for 4-chloroguaiacol to 5.2 for 5-chloroguaiacol.

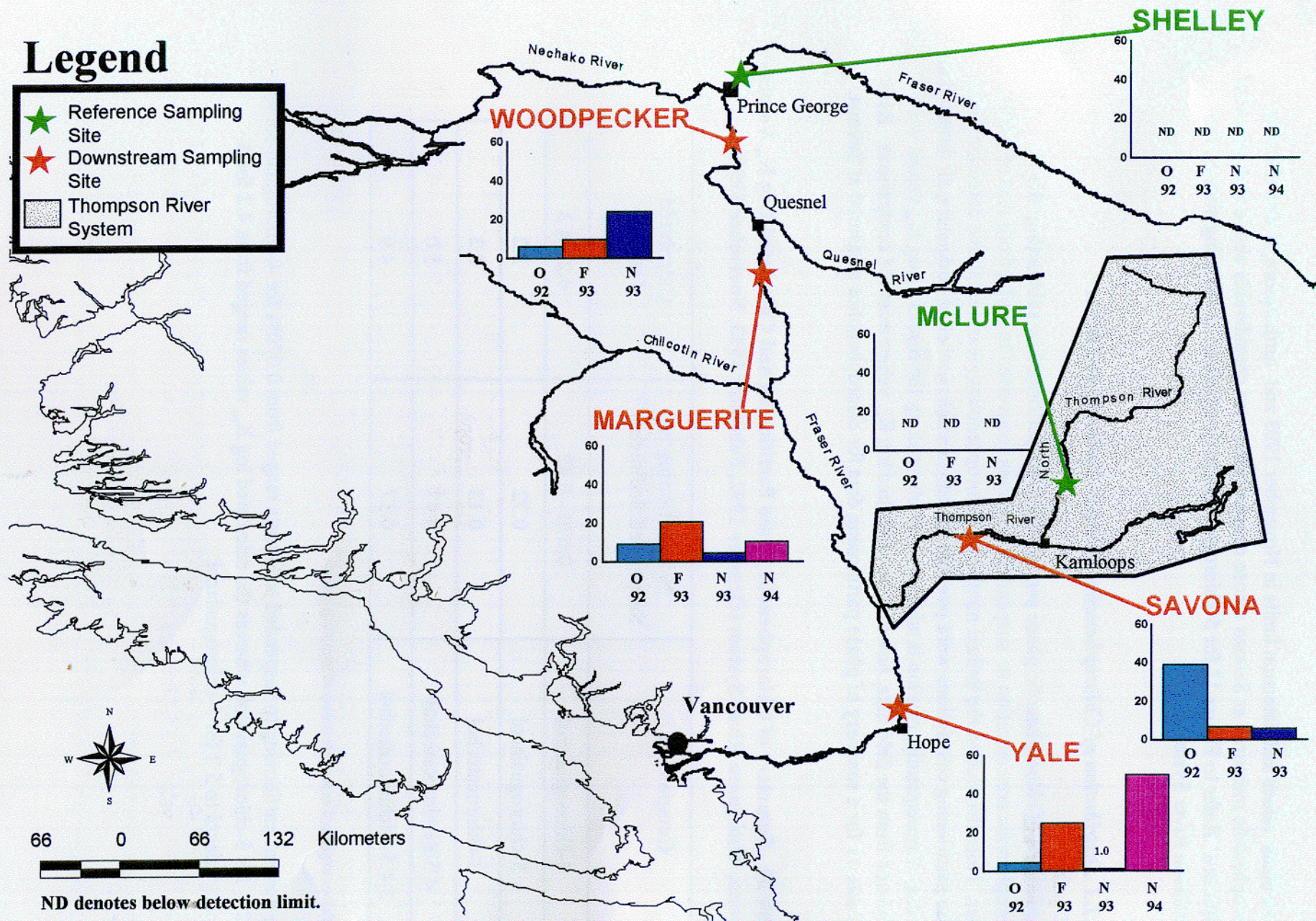


Figure 11 5-Chloroguaiacol Concentrations (ng/L) in Whole Water from the Fraser and Thompson River Systems

9.2.2 Discussion

9.2.2.1 *Suspended Sediments*

For all sampling periods, the large majority of chlorophenolics measured downstream of the pulp mill at Savona were clearly higher in concentration than those measured upstream at McLure. Furthermore, the observed peak in chlorophenolic concentration measured at Savona in February 1993 (relative to the two fall sampling dates) is likely the result of reduced mixing of Thompson River water with Kamloops Lake water during the limnological winter (Bothwell *et al.*, 1992).

The higher concentrations of chlorophenolics, in particular 6-chlorovanillin (57-1100 ng/g), measured at Savona relative to McLure may be related to pulp mill effluent discharges. This chlorophenolic is known to constitute approximately 90% of the total chlorophenolics in softwood bleaching mill effluents, such as Weyerhaeuser, which employ 100% chlorine dioxide substitution (Liebergott *et al.*, 1991). Chloroguaiacol, identified as a tracer of pulp mill effluent (Carey and Hart, 1988), was higher in concentration at Savona than at McLure. Levels of 4,5-dichloroguaiacol at Savona ranged from 2-61 ng/g, while not detectable at McLure (detection limit 0.20-2.0 ng/g).

Lastly, the low concentrations of chlorophenolics detected in suspended sediments collected at McLure were likely from utility poles and railway ties (Wan and Van Oostdam, 1995) and possibly combustion sources (Paasivirta and Sarkka, 1985).

9.2.2.2 *Whole Water*

Of the 43 chlorophenolics analysed in whole water from McLure and Savona, only 10 were found above detection limits, and concentrations of these chlorophenolics were, for the most part, similar between the two sites. Given that our data indicate that chlorophenolic partitioning to the aqueous phase occurred in excess of 99% (Section 9.2.1.3), the detection difference between the two media is most likely a direct consequence of sample size differences (1 L for whole water versus thousands of litres of water for suspended sediments).

9.2.2.3 *Distribution of Chlorophenolics Between Sediment and Water*

The calculated log K_{oc} values for chlorophenolics measured at Savona ranged from 4.2 to 5.2. Since a log K_{oc} value of 3.84 indicates a high potential for partitioning to sediment (Water Quality Branch, 1993a), all of the chlorophenolics detected would be expected to have a high affinity for suspended sediments. However, the phase partitioning data indicate that partitioning to suspended sediments was surprisingly low (0.070-0.72%). This apparent weak affinity for the suspended

solid phase may be related to the low amount of suspended sediment (0.9-3.8 mg/L) present at this site. Studies have shown that in water bodies containing relatively high suspended sediment concentrations (~100 mg/L), the extent of partitioning of hydrophobic contaminants to suspended sediments is approximately 40% greater than in those with lower suspended sediment loads (~10 mg/L) (Olsen *et al.*, 1982). This observed behaviour is most likely due to the increased availability of sediment binding sites at higher suspended sediment concentrations. Furthermore, the association of some of the more hydrophobic chlorophenolics with dissolved and colloidal organic material in the water column may also increase the apparent solubility of these compounds.

9.2.2.4 Comparisons of Chlorophenolic Concentrations to Guidelines and Criteria

Since no water quality criteria currently exist for chloroguaiacols, chlorocatechols, chlorosyringols, chloroaldehydes and chlorovanillins, comparisons of data to existing criteria was limited to the chlorophenol group. Chlorophenol concentrations in both suspended sediments (expressed as pg/L) and whole water from the Thompson River System were compared to B.C. Ministry of Environment, Lands and Parks' interim aquatic life toxicity criteria (BCMELP, 1994a). All of the chlorophenols measured in both suspended sediments and whole water were well below BCMELP criteria.

2.3 Fraser River

9.3.1 Results

9.3.1.1 Suspended Sediments

Refer to Table 32 for a summary of chlorophenolics detected in suspended sediment samples from the Fraser River. The reference site, Shelley, had detectable levels of a number of chlorophenolics with 3,5-dichlorocatechol (4.1 ng/g) having the highest concentration. However, concentrations of these chlorophenolics were lower than those measured downstream of the pulp mills. At the downstream sites, chlorophenolic concentrations were generally highest at Woodpecker and Marguerite and lowest at Yale. The majority of chlorophenolics peaked in concentration in February 1993 at all downstream sites. Figure 12 presents the concentration of 4,5-dichlorocatechol measured in suspended sediments at sampling sites in the Fraser River Basin. Levels of this contaminant measured at Woodpecker and Marguerite in February 1993 were 670 ng/g and 520 ng/g, respectively, whereas at Yale it was detected at 29 ng/g. (Note that relatively low concentrations of this congener were measured Savona.) Other chlorophenolics found in relatively high concentrations included 3,4,5-trichlorocatechol (290 ng/g) and 3,4,5,6-tetrachlorocatechol (270 ng/g), both measured at Woodpecker in February 1993.

Table 32 Summary of Chlorophenolics Detected in Suspended Sediments from the Fraser River (October 1992, February 1993, November 1993, November 1994)

Sampling Location:	Shelley				Woodpecker			Marguente				Yale			
Sampling Date:	Oct. 1992	Feb. 1993	Nov. 1993	Nov. 1994	Oct. 1992	Feb. 1993	Nov. 1993	Oct. 1992	Feb. 1993	Nov. 1993	Nov. 1994	Oct. 1992	Feb. 1993	Nov. 1993	Nov. 1994
Chlorophenolics (ng/g)															
4-chlorophenol	ND(0.4)	ND(0.1)	ND(0.7)	ND(0.26)	0.40	ND(1.6)	ND(0.3)	ND(0.3)	ND(2.0)	ND(1.6)	ND(0.23)	ND(0.5)	ND(1.6)	ND(0.4)	ND(0.09)
2,6-dichlorophenol	ND(0.1)	ND(0.3)	ND(0.1)	ND(0.21)	1.3	ND(1.9)	ND(0.2)	1.3	ND(1.9)	ND(2.1)	0.38	ND(0.5)	ND(2.1)	ND(0.3)	0.38
2,4/2,5-dichlorophenol	ND(0.1)	ND(0.2)	0.30	1.1	ND(0.1)	4.5	ND(0.5)	ND(0.1)	ND(1.4)	4.8	1.0	ND(0.3)	4.8	ND(0.7)	0.47
3,5-dichlorophenol	ND(0.1)	ND(0.2)	ND(0.1)	ND(0.31)	ND(0.1)	ND(1.7)	ND(0.04)	ND(0.1)	ND(1.7)	ND(1.8)	ND(0.4)	ND(0.3)	ND(1.8)	ND(0.1)	ND(0.15)
2,3-dichlorophenol	ND(0.1)	ND(0.2)	ND(0.1)	ND(0.29)	ND(0.3)	ND(1.6)	ND(0.04)	ND(0.1)	ND(1.6)	ND(1.8)	ND(0.37)	ND(0.2)	ND(1.8)	ND(0.1)	ND(0.14)
3,4-dichlorophenol	ND(0.1)	ND(0.1)	ND(0.1)	ND(0.27)	ND(0.3)	ND(1.2)	ND(0.02)	0.30	ND(1.2)	ND(1.2)	ND(0.38)	ND(0.2)	ND(1.2)	ND(0.05)	ND(0.11)
6-chloroguaiacol	ND(0.2)	ND(0.1)	ND(0.2)	ND(0.16)	ND(0.1)	ND(0.7)	ND(0.05)	ND(0.2)	ND(1.1)	ND(1.1)	ND(0.2)	ND(0.2)	ND(1.1)	ND(0.2)	ND(0.08)
4-chloroguaiacol	ND(0.2)	ND(0.1)	ND(0.2)	ND(0.14)	ND(0.5)	3.1	ND(0.1)	ND(0.2)	1.7	ND(1.3)	ND(0.16)	ND(0.2)	ND(1.3)	ND(0.2)	ND(0.07)
5-chloroguaiacol	ND(0.2)	ND(0.1)	ND(0.9)	ND(0.2)	ND(0.1)	1.8	ND(0.8)	ND(0.2)	2.5	3.0	ND(0.24)	ND(0.2)	ND(1.3)	8.9	ND(0.73)
2,4,6-trichlorophenol	ND(0.1)	ND(0.2)	ND(0.4)	ND(0.23)	ND(0.1)	1.1	ND(0.3)	ND(0.2)	ND(1.5)	ND(1.8)	1.0	ND(0.1)	3.0	ND(0.3)	ND(0.25)
2,3,6-trichlorophenol	ND(0.1)	ND(0.1)	ND(0.1)	ND(0.33)	ND(0.1)	ND(1.4)	ND(0.03)	ND(0.1)	ND(1.1)	ND(1.2)	ND(0.41)	ND(0.2)	ND(1.2)	ND(0.04)	ND(0.16)
2,3,5-trichlorophenol	ND(0.1)	ND(0.1)	ND(0.1)	ND(0.33)	ND(0.1)	ND(1.1)	ND(0.03)	ND(0.1)	ND(1.2)	ND(1.2)	ND(0.41)	ND(0.2)	ND(1.2)	ND(0.04)	ND(0.16)
2,4,5-trichlorophenol	ND(0.1)	ND(0.1)	0.10	ND(0.15)	ND(0.1)	ND(1.2)	ND(0.03)	ND(0.1)	ND(0.9)	ND(1.0)	ND(0.25)	ND(0.1)	ND(1.0)	ND(0.03)	ND(0.1)
2,3,4-trichlorophenol	ND(0.1)	ND(0.3)	ND(0.1)	ND(0.24)	ND(0.1)	ND(0.9)	ND(0.03)	ND(0.1)	ND(0.9)	ND(1.0)	ND(0.31)	ND(0.1)	ND(1.0)	ND(0.04)	ND(0.12)
3,4,5-trichlorophenol	ND(0.1)	ND(0.1)	0.40	ND(0.23)	ND(0.1)	ND(0.9)	ND(0.03)	ND(0.1)	ND(1.0)	ND(1.1)	ND(0.3)	ND(0.2)	ND(1.1)	ND(0.03)	ND(0.11)
3-chlorocatechol	ND(0.2)	ND(0.3)	ND(0.3)	ND(0.48)	0.40	ND(1.0)	ND(0.3)	0.30	ND(2.2)	2.6	ND(0.62)	ND(0.3)	2.6	ND(0.3)	ND(0.24)
4-chlorocatechol	ND(0.2)	ND(0.4)	ND(0.3)	ND(0.33)	3.4	7.9	ND(0.2)	1.7	ND(3.3)	ND(2.5)	1.7	0.20	ND(2.5)	ND(0.2)	1.0
3,4-dichloroguaiacol	ND(0.2)	ND(0.3)	ND(0.1)	ND(0.2)	ND(0.2)	—	ND(0.04)	ND(0.2)	—	—	0.17	ND(0.2)	—	ND(0.05)	ND(0.09)
4,6-dichloroguaiacol	ND(0.2)	ND(0.2)	ND(0.1)	ND(0.25)	0.20	—	ND(0.04)	ND(0.2)	—	—	0.70	ND(0.2)	—	ND(0.05)	0.54
3,4/4,6-dichloroguaiacol	—	—	—	—	—	4.6	—	—	4.4	1.4	—	—	1.4	—	—
4,5-tetrachloroguaiacol	ND(0.1)	ND(0.2)	ND(0.1)	ND(0.14)	3.7	89	0.30	1.7	43	15	8.3	1.1	15	1.2	4.8
3-chlorosyringol	ND(0.1)	ND(0.09)	ND(0.5)	ND(0.24)	ND(0.1)	ND(1.0)	ND(0.1)	ND(0.1)	ND(0.9)	ND(0.8)	ND(0.32)	ND(0.1)	ND(0.8)	ND(0.04)	ND(0.13)
3,4-dichlorocatechol	ND(0.5)	ND(1.7)	ND(0.6)	1.3	0.60	ND(4.3)	ND(0.2)	0.60	ND(12)	ND(7.3)	5.7	ND(0.6)	ND(7.3)	ND(0.3)	ND(3.7)
3,6-dichlorocatechol	ND(0.6)	ND(2.0)	ND(0.8)	ND(1.7)	13	44	ND(0.3)	13	40	ND(8.3)	ND(1.4)	0.90	ND(8.3)	0.50	ND(0.59)
3,5-dichlorocatechol	ND(0.5)	4.1	1.4	ND(2.4)	5.8	21	1.5	5.4	48	ND(7.0)	8.0	0.80	ND(7.0)	2.4	3.2
4,5-dichlorocatechol	ND(0.8)	ND(2.1)	ND(0.6)	ND(1.3)	62	670	6.3	64	520	29	40	8.4	29	10	13
2,3,5,6-tetrachlorophenol	ND(0.3)	ND(0.2)	ND(0.2)	ND(0.47)	ND(0.2)	ND(2.4)	ND(0.2)	ND(0.3)	ND(2.3)	ND(2.7)	ND(0.6)	ND(0.3)	ND(2.7)	ND(0.1)	ND(0.26)
2,3,4,6-tetrachlorophenol	ND(0.3)	ND(0.3)	ND(0.5)	ND(0.28)	ND(0.2)	ND(2.6)	ND(0.2)	ND(0.3)	ND(2.5)	ND(2.9)	ND(0.34)	ND(0.3)	ND(2.9)	ND(0.1)	ND(0.15)
2,3,4,5-tetrachlorophenol	ND(0.2)	ND(0.2)	ND(0.1)	ND(0.27)	ND(0.2)	ND(1.8)	ND(0.1)	ND(0.2)	ND(1.5)	ND(1.8)	ND(0.42)	ND(1.2)	ND(1.8)	ND(0.1)	ND(0.17)
5-chlorovanillin	ND(1.0)	ND(2.5)	ND(1.8)	ND(4.4)	ND(0.6)	ND(10)	ND(0.7)	ND(0.8)	ND(9.4)	ND(15)	ND(1.4)	ND(1.2)	ND(15)	ND(0.9)	ND(0.32)
6-chlorovanillin	ND(1.0)	ND(2.9)	ND(1.9)	ND(4.6)	7.3	70	2.0	9.1	39	ND(4.1)	10	2.2	32	14	10
3,5-dichlorosyringol	ND(0.4)	ND(0.4)	ND(0.4)	ND(0.52)	ND(0.3)	ND(4.0)	ND(0.2)	ND(0.4)	ND(3.9)	ND(2.1)	ND(0.66)	0.20	ND(4.1)	ND(0.2)	ND(0.33)
3,4,6-trichloroguaiacol	—	ND(0.1)	ND(0.1)	ND(0.21)	—	ND(1.8)	ND(0.1)	—	ND(1.5)	ND(0.4)	ND(0.22)	ND(0.3)	ND(2.1)	—	ND(0.1)
3,4,5-trichloroguaiacol	ND(0.2)	ND(0.1)	ND(0.1)	ND(0.25)	1.3	30	0.40	1.6	26	8.1	5.2	0.40	8.1	1.5	2.1
4,5,6-trichloroguaiacol	ND(0.2)	ND(0.09)	ND(0.1)	ND(0.16)	0.20	4.5	ND(0.05)	0.20	4.0	2.1	1.4	ND(0.2)	2.1	ND(0.3)	0.30
3,4,6-trichlorocatechol	—	ND(0.7)	ND(0.1)	ND(1.3)	—	6.9	ND(0.1)	—	2.5	ND(2.7)	2.5	—	ND(2.7)	0.70	1.2
3,4,5-trichlorocatechol	ND(0.3)	ND(0.2)	ND(0.1)	ND(1.3)	38	290	1.7	47	85	24	42	4.8	24	3.6	20
5,6-dichlorovanillin	ND(0.3)	ND(0.2)	ND(0.1)	ND(0.61)	ND(0.4)	1.5	ND(0.1)	0.50	ND(2.6)	ND(2.7)	0.53	ND(0.2)	ND(2.7)	ND(0.1)	0.79
pentachlorophenol	ND(0.4)	ND(0.4)	1.3	ND(0.44)	ND(0.3)	2.1	0.10	1.0	ND(2.7)	ND(3.5)	ND(0.46)	ND(0.2)	ND(3.5)	ND(0.4)	ND(0.2)
2-chlorosyringaldehyde	—	ND(0.2)	ND(0.1)	3.1	—	ND(2.8)	ND(0.1)	—	ND(2.2)	ND(2.3)	ND(0.36)	ND(0.3)	ND(2.3)	ND(0.1)	ND(0.17)
3,4,5,6-tetrachloroguaiacol	ND(0.4)	ND(0.2)	ND(0.1)	ND(0.4)	ND(0.3)	3.6	0.10	ND(0.4)	2.9	ND(2.1)	0.36	ND(0.3)	ND(2.1)	0.20	0.45
3,4,5-trichlorosyringol	ND(0.3)	ND(0.2)	ND(0.1)	ND(0.46)	ND(0.4)	ND(2.5)	ND(0.1)	ND(0.5)	ND(2.0)	ND(2.4)	ND(0.4)	ND(0.3)	ND(2.4)	ND(0.1)	ND(0.16)
3,4,5,6-tetrachlorocatechol	ND(0.6)	ND(1.1)	ND(1.2)	ND(1.2)	20	270	1.0	21	88	37	7.6	2.7	37	2.2	5.5
2,6-dichlorosyringaldehyde	—	ND(2.8)	1.8	ND(1.5)	—	ND(120)	ND(0.6)	—	ND(43)	ND(59)	ND(1.6)	—	ND(59)	ND(3.7)	ND(0.72)

ND denotes below the indicated detection limit (shown in brackets) when both field splits and samples were below detection

NQ denotes not quantifiable

{ } concentration value equal to or below that of laboratory blank

Note: all results presented are a mean of field splits and samples - one half the detection limit was used when only one of the samples was below the detection limit

- all means rounded to two significant figures

Legend

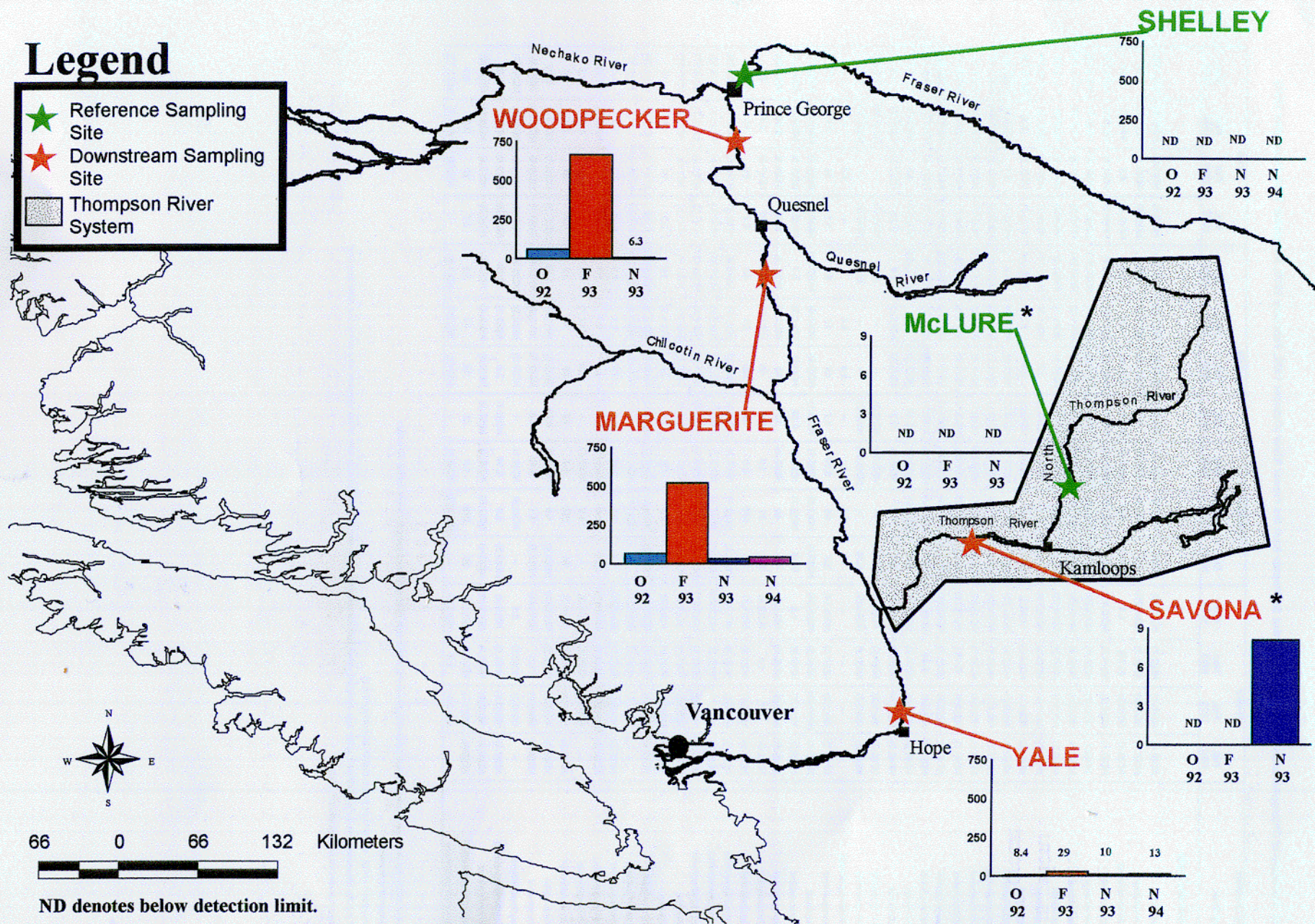


Figure 12 4,5-Dichlorocatechol Concentrations (ng/g) in Suspended Sediment from the Fraser and Thompson River Systems

* Note scale difference for Thompson River System graphs

9.3.1.2 Whole Water

Refer to Table 33 for a summary of chlorophenolics detected in whole water samples from the Fraser River. Ten chlorophenolics were detected at Shelley; however, with the exception of pentachlorophenol and 2,6-dichlorosyringaldehyde, both measured at 18 ng/L, all other chlorophenolics were detected in concentrations < 5.0 ng/L. The majority of chlorophenolics measured on the Fraser River were detected at Woodpecker, Marguerite and Yale, and the highest concentrations of these were generally measured in February 1993. As with suspended sediments, 4,5-dichlorocatechol was detected in the highest concentration relative to other chlorophenolics, with a maximum value of 130 ng/L measured at Woodpecker in February 1993. Although concentrations of 3,4,5-trichloroguaiacol were not as high as those of 4,5-dichlorocatechol, levels of this contaminant peaked in February 1993 at all three sampling locations downstream of Prince George (Figure 13). Note that 3,4,5-trichlorocatechol was not as prominent in samples collected from Savona on the Thompson River System.

9.3.1.3 Clarified Water Samples (Solid Phase Extracted)

Chlorophenolics were measured in solid phase extracted clarified water samples from the Fraser River in November 1994 (Table 34). With the exception of 3,5-dichlorophenol, chlorophenolic concentrations were clearly higher at Marguerite and Yale than at Shelley and, moreover, concentrations were generally highest at Marguerite. At Marguerite and Yale, both 5-chloroguaiacol (10-11 ng/L) and 6-chlorovanillin (10-14 ng/L) were found in higher concentrations in comparison to other chlorophenolics.

9.3.1.4 Distribution of Chlorophenolics Between Sediment and Water

Note that due to the low number of chlorophenolics measured above detection limits, phase partitioning calculations were possible for only a small number of congeners. Consequently, caution is advised when interpreting the results. Log K_{oc} values were calculated from the field data; however, due to the absence of published log K_{oc} values, no comparisons could be made. Refer to Table 35 for a summary of chlorophenolic phase partitioning in suspended sediments and calculated log K_{oc} values for the Fraser River.

Table 33 Summary of Chlorophenolics Detected in Whole Water from the Fraser River (October 1992, February 1993, November 1993, November 1994)

Sampling Location:	Shelley				Woodpecker			Marguerite				Yale			
Sampling Date:	Oct. 1992	Feb. 1993	Nov. 1993	Nov. 1994	Oct. 1992	Feb. 1993	Nov. 1993	Oct. 1992	Feb. 1993	Nov. 1993	Nov. 1994	Oct. 1992	Feb. 1993	Nov. 1993	Nov. 1994
Chlorophenolics (ng/L)															
4-chlorophenol	ND(0.4)	ND(0.6)	ND(1.0)	ND(0.78)	ND(0.8)	ND(0.3)	ND(1.1)	ND(0.8)	ND(0.4)	ND(1.5)	ND(0.99)	ND(2.4)	ND(2.1)	ND(1)	ND(2.2)
2,6-dichlorophenol	ND(0.7)	ND(0.6)	ND(0.7)	ND(0.30)	ND(1.0)	ND(0.2)	ND(1.0)	1.7	ND(0.3)	ND(1.2)	0.45	2.3	ND(1.5)	ND(0.8)	ND(0.47)
2,4/2,5-dichlorophenol	{1.5}	ND(0.5)	ND(1.1)	{2.0}	1.8	5.7	ND(2.0)	2.8	5.3	ND(2.1)	6.0	2.5	4.8	ND(1.8)	2.1
3,5-dichlorophenol	ND(0.4)	ND(0.6)	ND(0.4)	ND(0.50)	ND(0.6)	0.20	ND(0.5)	0.70	0.35	ND(0.4)	ND(1.6)	ND(1.6)	2.8	ND(0.5)	ND(0.78)
2,3-dichlorophenol	ND(0.2)	ND(0.9)	ND(0.4)	ND(0.44)	ND(0.6)	ND(0.2)	ND(0.5)	ND(0.4)	ND(0.9)	ND(0.4)	ND(1.4)	ND(1.4)	ND(1.3)	ND(0.5)	ND(0.84)
3,4-dichlorophenol	ND(0.3)	ND(0.4)	ND(0.3)	ND(0.33)	ND(0.6)	ND(0.1)	ND(0.3)	ND(0.3)	0.40	ND(0.3)	ND(1.0)	ND(1.2)	ND(0.9)	ND(0.3)	ND(0.51)
6-chloroguaiacol	ND(0.2)	ND(0.7)	ND(0.2)	ND(0.17)	ND(0.4)	0.30	ND(0.2)	ND(0.4)	0.70	ND(0.2)	ND(0.28)	ND(1)	1.8	ND(0.2)	ND(0.29)
4-chloroguaiacol	ND(0.1)	ND(0.9)	ND(0.2)	ND(0.14)	5.0	{0.4}	ND(0.3)	5.0	{7.4}	ND(0.2)	0.62	4.4	48	ND(0.3)	0.85
5-chloroguaiacol	ND(0.3)	ND(0.8)	ND(0.2)	ND(0.22)	6.0	8.6	24	9.0	20.5	4.3	10	4.3	25	1.0	50
2,4,6-trichlorophenol	1.8	ND(0.4)	ND(0.3)	ND(0.14)	2.7	2.4	1.2	2.7	1.0	4.8	8.0	3.0	2.3	1.1	ND(0.32)
2,3,5-trichlorophenol	ND(0.3)	ND(0.5)	ND(0.3)	ND(0.21)	ND(0.8)	ND(0.1)	ND(0.3)	ND(0.6)	0.20	ND(0.2)	ND(0.44)	ND(1.3)	ND(1.1)	ND(0.3)	ND(0.46)
2,3,5-trichlorophenol	ND(0.3)	ND(0.9)	ND(0.3)	ND(0.20)	ND(0.8)	ND(0.3)	ND(0.3)	ND(0.6)	0.10	ND(0.2)	ND(0.44)	ND(1.3)	ND(1.2)	ND(0.3)	ND(0.45)
2,4,5-trichlorophenol	ND(0.4)	ND(0.4)	ND(0.3)	ND(0.14)	ND(0.4)	ND(0.1)	ND(0.3)	ND(0.8)	ND(0.1)	ND(0.2)	ND(0.26)	ND(1.2)	ND(0.7)	ND(0.3)	ND(0.27)
2,3,4-trichlorophenol	ND(0.3)	ND(0.4)	ND(0.2)	ND(0.20)	ND(0.3)	ND(0.1)	ND(0.3)	ND(0.6)	ND(0.2)	ND(0.2)	ND(0.38)	1.5	ND(0.8)	ND(0.3)	ND(0.40)
3,4,5-trichlorophenol	ND(0.3)	ND(0.4)	ND(0.3)	ND(0.18)	ND(0.6)	ND(0.1)	ND(0.3)	ND(0.6)	ND(0.2)	ND(0.2)	ND(0.83)	ND(1)	ND(0.9)	ND(0.3)	ND(0.38)
3-chlorocatechol	ND(0.9)	ND(1.3)	ND(0.2)	ND(7.0)	ND(4.5)	ND(0.2)	ND(2.5)	ND(1.5)	ND(0.3)	ND(3)	23	ND(8)	27	ND(3.0)	9.2
4-chlorocatechol	ND(6.0)	ND(1.0)	ND(2.5)	ND(1.0)	ND(30)	ND(0.3)	ND(1.1)	ND(10)	0.30	ND(1.1)	ND(1.4)	ND(50)	ND(1.7)	ND(1.2)	ND(1.30)
3,4-dichloroguaiacol	ND(0.3)	ND(0.5)	ND(1.4)	ND(0.36)	ND(0.6)	ND(0.1)	ND(0.4)	ND(0.9)	ND(0.2)	ND(0.4)	2.3	1.8	2.4	ND(0.4)	ND(0.79)
4,6-dichloroguaiacol	ND(1.0)	ND(0.6)	ND(0.4)	ND(0.25)	3.0	12	0.8	3.5	11	2.4	ND(0.59)	{1.8}	6.1	1.8	ND(0.55)
4,5-dichloroguaiacol	ND(0.6)	ND(0.5)	ND(0.4)	ND(0.27)	2.7	5.4	2.8	3.0	11	2.4	5.7	1.0	8.0	1.7	5.1
3-chlorosyringol	ND(0.4)	ND(0.2)	ND(0.2)	ND(0.33)	ND(0.6)	ND(0.1)	ND(0.2)	ND(0.6)	ND(0.1)	ND(0.2)	ND(0.54)	ND(2)	ND(0.7)	ND(0.2)	ND(0.55)
3,4-dichlorocatechol	ND(1.0)	ND(9.7)	ND(0.4)	ND(0.65)	ND(1.0)	ND(28)	ND(0.4)	ND(1.0)	ND(12)	ND(0.7)	ND(0.77)	ND(1.4)	ND(9.7)	ND(0.4)	ND(0.69)
3,5-dichlorocatechol	ND(2.0)	ND(11)	ND(0.4)	ND(0.60)	ND(2.0)	ND(33)	ND(0.5)	1.5	ND(14)	ND(0.8)	ND(1.3)	ND(1.7)	6.7	ND(0.5)	ND(0.64)
3,5-dichlorocatechol	ND(0.4)	ND(5.7)	ND(0.4)	ND(1.0)	ND(0.4)	ND(25)	ND(0.4)	ND(0.5)	ND(0.06)	ND(0.7)	ND(1.0)	0.80	ND(9.8)	ND(0.4)	ND(1.10)
4,5-dichlorocatechol	ND(2.0)	ND(12)	ND(0.9)	ND(0.58)	18	130	3.4	19	ND(14)	5.2	2.3	4.8	10	10	ND(0.62)
2,3,5,6-tetrachlorophenol	ND(0.6)	ND(0.8)	ND(0.8)	ND(0.55)	ND(0.6)	ND(0.3)	ND(0.9)	ND(0.6)	ND(0.4)	ND(0.8)	ND(0.9)	ND(1.2)	ND(1.5)	ND(1.0)	ND(0.72)
2,3,4,6-tetrachlorophenol	ND(1.0)	ND(1.0)	ND(0.9)	ND(0.32)	{0.6}	1.5	ND(1.0)	{0.80}	1.8	ND(0.9)	ND(0.5)	0.70	2.1	ND(1.1)	ND(0.42)
2,3,4,5-tetrachlorophenol	ND(0.4)	ND(0.6)	ND(0.6)	ND(0.44)	ND(0.4)	ND(0.2)	ND(0.6)	ND(0.8)	ND(0.2)	ND(0.6)	ND(0.72)	ND(0.8)	ND(1)	ND(0.6)	ND(0.59)
5-chlorovanillin	ND(1.0)	ND(1.5)	ND(1.4)	ND(0.56)	ND(1.2)	ND(0.4)	ND(1.5)	ND(0.9)	ND(0.5)	ND(1.5)	ND(1.1)	ND(3)	ND(4.1)	ND(1.3)	ND(0.72)
6-chlorovanillin	2.4	ND(1.6)	ND(1.1)	ND(0.69)	3.2	11	1.5	2.8	15	4.6	5.0	ND(3.2)	3.4	ND(2.0)	2.2
3,5-dichlorosyringol	ND(1.0)	ND(1.3)	ND(0.5)	ND(1.0)	ND(0.9)	ND(0.4)	ND(0.6)	ND(1.0)	ND(0.6)	ND(0.6)	ND(1.1)	ND(2.1)	ND(2.2)	ND(0.6)	ND(0.89)
3,4,6-trichloroguaiacol	ND(0.6)	ND(2.0)	ND(0.3)	ND(0.32)	ND(0.3)	2.7	ND(0.3)	ND(0.9)	1.3	ND(0.4)	0.39	ND(1.5)	ND(1)	ND(0.3)	ND(0.31)
3,4,5-trichloroguaiacol	3.6	ND(1.1)	ND(0.3)	ND(0.45)	8.0	45	1.1	8.0	35	3.8	2.8	5.2	19	2.5	0.87
4,5,6-trichloroguaiacol	0.30	ND(0.8)	ND(0.2)	ND(0.28)	0.80	11	0.80	2.0	8.2	1.2	1.3	ND(1.1)	2.8	0.8	0.40
3,4,6-trichlorocatechol	ND(1.0)	ND(2.0)	ND(0.6)	ND(0.49)	ND(0.1)	ND(1.0)	ND(0.7)	ND(0.1)	ND(1.0)	ND(0.8)	ND(0.82)	ND(1.4)	ND(1)	ND(0.6)	ND(0.47)
3,4,5-trichlorocatechol	ND(1.5)	ND(1.3)	ND(0.5)	ND(0.50)	28	2.8	1.4	32	4.2	1.8	1.2	13	11	1.8	ND(0.51)
5,6-dichlorovanillin	1.4	ND(1.3)	ND(0.8)	ND(0.49)	ND(0.4)	ND(0.2)	ND(0.7)	ND(0.6)	3.0	ND(0.8)	ND(0.74)	ND(0.8)	ND(3.4)	ND(0.8)	ND(0.91)
pentachlorophenol	ND(0.7)	ND(1.5)	18	ND(0.50)	0.80	1.5	2.3	1.2	1.2	ND(0.9)	0.85	1.7	ND(1.8)	1.5	ND(0.49)
2-chlorosyringaldehyde	ND(0.6)	ND(5.0)	ND(0.4)	ND(0.37)	ND(0.6)	ND(5.0)	ND(0.5)	ND(1.0)	ND(5)	ND(0.4)	ND(0.54)	ND(1.5)	ND(5)	ND(0.4)	ND(0.46)
tetrachloroguaiacol	1.8	ND(1.0)	ND(0.4)	ND(0.38)	1.2	7.8	ND(0.8)	1.5	5.5	0.80	ND(0.92)	1.8	1.7	1.0	ND(0.74)
3,4,5-trichlorosyringol	2.4	ND(1.2)	ND(1.3)	ND(1.0)	ND(0.5)	ND(0.3)	ND(1.2)	ND(0.6)	ND(11.4)	ND(1.4)	ND(1.0)	ND(0.9)	ND(1.9)	ND(1.9)	ND(0.7)
tetrachlorocatechol	ND(5.0)	ND(16)	ND(0.4)	ND(0.22)	2.4	ND(10)	ND(0.8)	3.0	5.8	ND(0.9)	0.25	8.0	ND(5.1)	ND(5.1)	ND(0.28)
2,6-dichlorosyringaldehyde	18	ND(5.0)	ND(0.6)	ND(0.68)	ND(1.8)	ND(5.0)	ND(0.7)	ND(1.8)	ND(5)	ND(0.8)	ND(1.20)	ND(15)	ND(5)	ND(5)	ND(0.78)

ND denotes below the indicated detection limit (shown in brackets) when both field replicates and samples were below detection

{ } Concentration value equal to or below that of laboratory and/or field blank

Note: all results presented are a mean of field replicates and samples - one half the detection limit was used when only one of the samples was below the detection limit

- all means rounded to two significant figures

Legend

- ★ Reference Sampling Site
- ★ Downstream Sampling Site
- Thompson River System

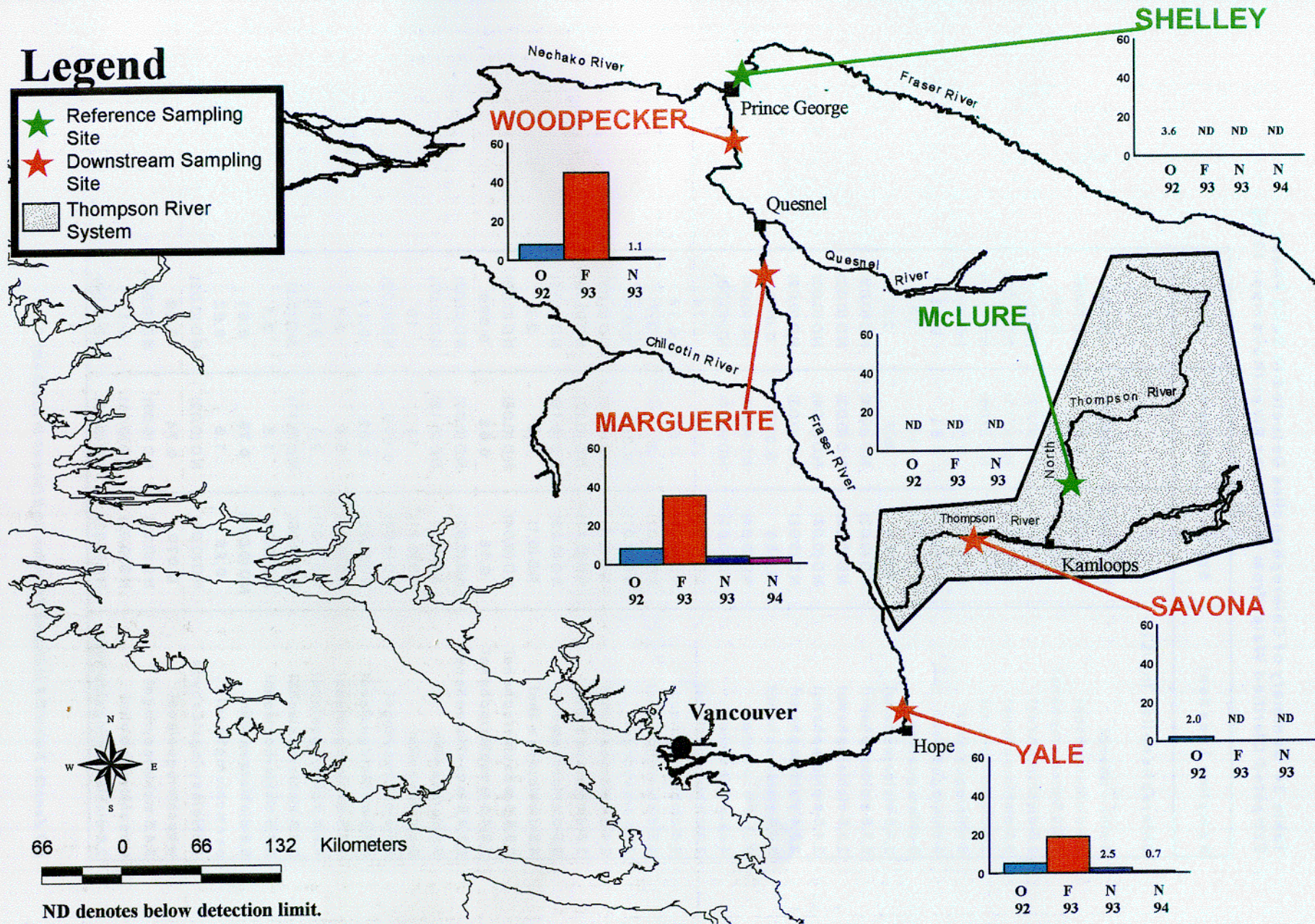


Figure 13 3,4,5-Trichloroguaiacol Concentrations (ng/L) in Whole Water from the Fraser and Thompson River Systems

**Table 34 Summary of Chlorophenolics Detected in Solid Phase
Extracted Clarified Water from the Fraser River (November 1994)**

Sampling Location:	Shelley	Marguerite	Yale
Chlorophenolics (ng/L)			
4-chlorophenol	ND (0.09)	ND (0.1)	0.15
2,6-dichlorophenol	ND (0.08)	0.20	ND (0.06)
2,4/2,5-dichlorophenol	0.26	2.9	0.83
3,5-dichlorophenol	0.90	ND (0.13)	ND (0.11)
2,3-dichlorophenol	ND (0.11)	ND (0.11)	ND (0.09)
3,4-dichlorophenol	ND (0.03)	ND (0.08)	ND (0.07)
6-chloroguaiacol	ND (0.02)	0.16	ND (0.02)
4-chloroguaiacol	ND (0.03)	0.54	0.58
5-chloroguaiacol	ND (0.04)	11	10
2,4,6-trichlorophenol	0.070	6.7	2.5
2,3,6-trichlorophenol	ND (0.03)	ND (0.04)	ND (0.03)
2,3,5-trichlorophenol	ND (0.03)	ND (0.03)	ND (0.02)
2,4,5-trichlorophenol	ND (0.03)	ND (0.04)	ND (0.02)
2,3,4-trichlorophenol	ND (0.02)	ND (0.03)	ND (0.02)
3,4,5-trichlorophenol	0.050	0.060	0.060
3-chlorocatechol	ND (0.04)	ND (0.09)	ND (0.04)
4-chlorocatechol	ND (0.02)	ND (0.06)	ND (0.03)
3,4-dichloroguaiacol	ND (0.02)	1.6	0.74
4,6-dichloroguaiacol	ND (0.01)	0.65	0.14
4,5-dichloroguaiacol	ND (0.01)	8.1	3.7
3-chlorosyringol	ND (0.01)	0.050	0.030
3,4-dichlorocatechol	ND (0.1)	ND (0.18)	ND (0.08)
3,6-dichlorocatechol	ND (0.11)	ND (0.27)	ND (0.12)
3,5-dichlorocatechol	ND (0.18)	ND (0.16)	ND (0.11)
4,5-dichlorocatechol	ND (0.1)	1.7	2.6
2,3,5,6-tetrachlorophenol	ND (0.04)	ND (0.06)	ND (0.03)
2,3,4,6-tetrachlorophenol	0.15	0.53	0.060
2,3,4,5-tetrachlorophenol	ND (0.02)	ND (0.02)	ND (0.02)
5-chlorovanillin	ND (0.1)	ND (0.12)	ND (0.07)
6-chlorovanillin	ND (0.11)	14	10
3,5-dichlorosyringol	ND (0.04)	0.070	ND (0.09)
3,4,6-trichloroguaiacol	ND (0.02)	0.62	0.17
3,4,5-trichloroguaiacol	ND (0.02)	5.6	3.1
4,5,6-trichloroguaiacol	ND (0.01)	2.1	0.63
3,4,6-trichlorocatechol	ND (0.05)	ND (0.11)	ND (0.1)
3,4,5-trichlorocatechol	ND (0.04)	1.5	3.1
5,6-dichlorovanillin	ND (0.004)	0.75	0.61
pentachlorophenol	0.29	1.5	0.22
2-chlorosyringaldehyde	ND (0.01)	ND (0.02)	ND (0.02)
tetrachloroguaiacol	0.070	0.74	0.29
3,4,5-trichlorosyringol	ND (0.02)	ND (0.03)	ND (0.02)
tetrachlorocatechol	ND (0.02)	ND (0.21)	0.17
2,6-dichlorosyringaldehyde	ND (0.02)	ND (0.03)	ND (0.04)

ND denotes below the indicated detection limit (shown in brackets)

Table 55 Summary of Chlorophenolic Phase I partitioning - Shoney, Woodpecker, Marguerite, Pale - Fraser River (October 1992, February 1993, November 1993, November 1994)

Compounds	% in Suspended Sediments ⁽¹⁾				Calculated Log K _{oc}			
	Oct. 1992	Feb. 1993	Nov. 1993	Nov. 1994	Oct. 1992	Feb. 1993	Nov. 1993	Nov. 1994
2,6-dichlorophenol	1.8	N/A	N/A	0.39	4.5	-	-	4.5
2,4/2,5-dichlorophenol	N/A	0.22 - 0.58	N/A	0.060 - 0.26	-	4.4 - 4.7	-	3.9 - 4.8
4-chloroguaiacol	N/A	0.11 - 5.7	N/A	N/A	-	3.8 - 5.4	-	-
5-chloroguaiacol	N/A	0.060 - 0.14	0.81 - 64	N/A	-	3.6 - 3.7	4.8 - 6.1	-
2,4,6-trichlorophenol	N/A	0.27 - 0.33	N/A	0.060	-	4.1 - 4.8	-	3.8
3-chlorocatechol	N/A	0.021	N/A	N/A	-	3.6	-	-
4,6-dichloroguaiacol	0.10	N/A	N/A	N/A	3.5	-	-	-
4,5-dichloroguaiacol	1.3 - 25	0.39 - 9.2	1.8 - 7.3	0.25 - 0.67	4.3 - 5.2	4.9 - 5.6	4.2 - 5.7	4.8
3,6-dichlorocatechol	20	N/A	N/A	N/A	5.6	-	-	-
3,5-dichlorocatechol	20	N/A	N/A	N/A	5.0	-	-	-
4,5-dichlorocatechol	5.8 - 40	0.61 - 3.7	6.5 - 31	8.5	5.1 - 5.5	5.1 - 5.2	5.2 - 5.7	5.9
6-chlorovanillin	3.4 - 7.5	1.3 - 4.7	22	0.95 - 1.2	5.1	4.9 - 5.6	5.4	5.0 - 5.5
3,4,5-trichloroguaiacol	0.24 - 1.7	0.092 - 0.48	2.5 - 6.1	0.85 - 0.86	3.9	4.3	4.8 - 5.3	4.9 - 5.3
4,5,6-trichloroguaiacol	0.23 - 0.33	0.16 - 0.30	2.0	0.21 - 0.49	3.5 - 4.1	4.1 - 4.5	5.2	4.7
3,4,5-trichlorocatechol	2.0 - 8.3	0.48 - 73	14 - 20	19	4.6 - 4.9	5.0 - 7.0	5.4 - 6.2	6.3
pentachlorophenol	1.9	1.0	0.33 - 0.73	N/A	4.5	4.6	3.8 - 4.1	-
tetrachloroguaiacol	N/A	0.25	1.4	N/A	-	4.2	4.5	-
tetrachlorocatechol	6.8 - 16	7.4	N/A	17	4.5 - 5.7	5.7	-	6.2

(1) Values expressed as a range across all sampling sites

(2) N/A denotes not available (due to insufficient data above detection limits)

Chlorophenolic phase partitioning calculations indicate that the percent partitioning in suspended sediments versus the water phase was variable, as percent values ranged from 0.020% for 3-chlorocatechol to 73% for 3,4,5-trichlorocatechol. The log K_{oc} values calculated from the data ranged from 3.5 to 7.0. Variation in percent partitioning to suspended sediments and calculated log K_{oc} values occurred both between individual compounds as well as with the same compound measured at different sites or at different times of the year.

9.3.2 Discussion

9.3.2.1 Suspended Sediments

For all sampling periods, concentrations of chlorophenolics measured downstream of pulp mills at Woodpecker, Marguerite and Yale were clearly higher than those measured upstream at Shelley. Furthermore, for almost all of the chlorophenolics analysed, the highest concentrations were generally measured in February 1993. This increase in chlorophenolic concentration is likely the result of higher effluent concentrations in the water column and a lower suspended sediment load during the winter low flow period.

The higher concentrations of chlorophenolics measured at both Woodpecker and Marguerite, relative to Yale (Table 32), provide evidence that these areas of the river are exposed to higher concentrations of pulp mill effluent (Dwernychuk, 1994) by virtue of their relative proximities downstream of pulp and paper mills located at Prince George and Quesnel. The lower concentrations observed at Yale indicate that a considerable amount of sediment dilution occurs between Marguerite and this site.

The chlorophenolics found in the highest concentrations in Fraser River suspended sediments were those identified as tracers of pulp mill effluent (catechols, guaiacols and vanillins), indicating that pulp mill effluent is the most probable source of these contaminants.

9.3.2.2 Whole Water

As was the case for suspended sediments, with the exception of pentachlorophenol and 2,6-dichlorosyringaldehyde, concentrations of chlorophenolics in whole water measured downstream of the pulp mills, at Woodpecker, Marguerite and Yale, were clearly higher than those measured upstream at Shelley. Furthermore, as was found in the suspended sediments, the majority of chlorophenolics detected in whole water were chlorinated catechols, guaiacols and vanillins. Although pulp mills are the most likely source of chlorophenolics, heavy-duty-wood preservation plants, located on the banks of the Fraser River, may also be a contributing factor. One such

plant, located in Prince George, has been shown to be a source of pentachlorophenol contamination to both soil and groundwater and is consequently presently undergoing remediation (Del Reiheimer, BCMELP, personal communication). Although detected at relatively low levels, the presence of chlorophenolics in whole water from Shelley indicates that there may be a possible source of these contaminants upstream of Prince George. Studies by the B.C. Ministry of Environment, Lands and Parks have shown the abandoned Northwood sawmill site at Shelley, located upstream of our sampling site, to be a source of pentachlorophenol to groundwater (Dave Sutherland, BCMELP, personal communication). Other upstream sources may include: domestic sewage (Pierce, 1978), treated lumber for railway ties and bridges (Envirochem, 1992) and aerial deposition from combustion sources (Paasivirta and Sarkka, 1985).

Lastly, the higher concentrations of chlorophenolics measured in February 1993 (relative to all other sampling dates) is indicative of the importance of flow reduction in increasing the concentration of these contaminants in the receiving environment.

9.3.2.3 Clarified Water (Solid Phase Extracted)

As was the case for chlorophenolics measured in both suspended sediments and whole water, concentrations measured in clarified water were higher at Marguerite and Yale, downstream of pulp and paper mills, than at the reference site, Shelley. Moreover, concentrations at Marguerite were higher than at Yale, reflecting the effect of dilution by the Thompson River and other tributaries. Concentrations of chlorophenolics in clarified water were comparable to those measured in whole water sampled in November 1994, indicating that sorption to sediments at a sediment concentration of 2.7-4.7 ng/g may not be extensive for these contaminants. Due to differences in detection limits, a larger number of chlorophenolics were detected in solid phase extracted clarified water than in whole water. This detection limit difference was a direct result of sample size differences: 50 L for solid phase extracted water samples versus 1 L for whole water samples.

It should be noted that, to the best of our knowledge, this is the first time that solid phase extraction with an XAD column was employed in a field study for the purpose of chlorophenolic identification in river water. Both laboratory and field surrogate spikes indicate a high degree of accuracy, with recoveries ranging between 70-130% for the former and 87-95.7% for the latter.

9.3.2.4 Distribution of Chlorophenolics Between Sediment and Water

The large variability observed in chlorophenolic phase partitioning across different sampling periods is likely related to the highly variable suspended sediment concentrations. Unlike the Thompson River System where suspended sediment concentrations were similar between sites, but the TOC fraction was highly variable, samples from the Fraser River had highly variable suspended sediment concentrations (0.9-226 mg/L) but similar TOC fractions (0.59-3.45%). Field studies described in Olsen *et al.* (1982) have shown that a greater proportion of organic contaminants are found in the particulate phase at higher suspended sediment concentrations. Based on our data, it appears that the majority of chlorophenolics which partitioned >20% to the suspended solid phase did so at a suspended sediment concentration greater than 50 mg/L (Yale in October 1992 and Woodpecker in November 1993). However, there is insufficient data for statistical analysis of the association between these two parameters.

9.3.2.5 Comparisons of Chlorophenolic Concentrations to Guidelines and Criteria

Since no water quality criteria currently exist for chloroguaiacols, chlorocatechols, chlorosyringols, chloroaldehydes and chlorovanillins, comparisons of data to existing criteria was limited to the chlorophenol group. Chlorophenol concentrations in both suspended sediments (expressed as pg/L) and whole water from the Fraser River were compared to B.C. Ministry of Environment, Lands and Parks' interim aquatic life toxicity criteria (BCMELP, 1994a). All of the chlorophenols measured in both suspended sediments and whole water were well below BCMELP criteria.

10.0 POLYCYCLIC AROMATIC HYDROCARBONS

10.1 Introduction

PAHs are generally classified into two groups, low molecular weight PAHs (PAHs containing three or less benzene rings) and high molecular weight PAHs (PAHs with four or more benzene rings) (CCREM, 1987). PAHs are hydrophobic in nature ($\log K_{ow} = 3.37 - 7.66$) and their aqueous solubilities are low ($0.3 - 3,420 \mu\text{g/L}$) with the exception of naphthalene ($12,500 - 34,000 \mu\text{g/L}$) (Neff, 1979). Their sorption coefficients ($\log K_{oc}$) vary between 2.38 to 7.53. Consequently, most PAHs adsorb strongly to the organic carbon fraction of sediments (CCREM, 1987) which can act as a final environmental sink for these contaminants (Payne *et al.*, 1988).

Low molecular weight PAHs are acutely toxic to aquatic organisms, whereas several high molecular weight PAHs have been associated with carcinogenesis (Water Quality Branch, 1993b). Of special concern are benzo[*a*]pyrene, benzo[*b*]fluoranthene, benzo[*j*]fluoranthene, benzo[*k*]fluoranthene and indeno[1,2,3-*cd*]pyrene which have all been classified as 'probably carcinogenic to humans' by the Environmental Health Directorate (CEPA, 1994).

Polycyclic aromatic hydrocarbons are introduced into the Canadian environment from both natural and anthropogenic sources. Natural sources of PAHs to the Fraser River Basin include forest fires, biosynthesis by plants and bacteria and diagenesis (combustion of organic material over a significant span of time at low temperatures) (Water Quality Branch, 1993b). Anthropogenic sources include creosote treated products, spills of petroleum products (CEPA, 1994), urban runoff from upstream communities (Boom and Marsalek, 1988), industrial combustion sources, slash burning and automobile exhaust (Water Quality Branch, 1993b). Derksen and Mitchell (in preparation [a]) found that, with the exception of naphthalene and phenanthrene, PAHs were generally not detectable in the organically rich solids centrifuged from Fraser and Thompson River pulp mill effluents. However, PAHs were detected in centrifuged suspended solids of sewage treatment plant effluent from Prince George and in the liquid phase of sewage treatment plant effluent from Greater Vancouver (Derksen, unpublished data).

10.2 Thompson River System

10.2.1 Results

10.2.1.1 Suspended Sediments

Refer to Table 36 for a summary of PAHs measured at McLure and Savona and to Figure 14

Table 36 Summary of Polycyclic Aromatic Hydrocarbons Detected in Suspended Sediments from the Thompson River System (October 1992, February 1993, November 1993)

Sampling Location:	McLure			Savona		
Sampling Date:	Oct. 1992	Feb. 1993	Nov. 1993	Oct. 1992	Feb. 1993	Nov. 1993
PAHs (ng/g)						
Naphthalene	9.0	6.1	21	16	180	17
Acenaphthylene	0.90	1.4	3.3	2.8	83	2.9
Acenaphthene	ND(2.0)	1.8	1.2	ND(6.0)	6.6	1.6
Fluorene	2.0	3.3	2.9	5.0	30	2.6
Phenanthrene	13	9.6	21	33	280	18
Anthracene	2.0	{1.0}	4.5	8.5	30	3.5
Fluoranthene	14	10	19	35	340	20
Pyrene	10	7.7	14	29	500	17
Benz(a)anthracene	4.0	4.4	5.4	14	63	5.5
Chrysene	10	8.1	15	26	140	12
Benzo(a)fluoranthene	16	12	23	32	120	14
Benzo(e)pyrene	9.0	5.0	7.7	20	100	6.4
Benzo(a)pyrene	6.0	3.4	4.4	11	83	1.8
Perylene	59	48	110	36	92	130
Dibenz(ah)anthracene	ND(2.0)	{2.1}	ND(2.0)	3.2	6.0	ND(5.8)
Indeno(1,2,3-cd)pyrene	9.0	5.2	12	19	33	3.6
Benzo(ghi)perylene	6.0	4.6	9.7	5.5	200	7.5
Total PAHs	172	134	275	299	2287	266

ND denotes below the indicated detection limit (shown in brackets) when both field splits and samples were below detection

{ } concentration value equal to or below that of laboratory and/or field blank

Note: all results presented are a mean of field splits and samples - one half the detection limit was used when only one of the samples was below the detection limit

- all means rounded to two significant figures

for total PAHs measured in Thompson River System suspended sediments. On all three sampling dates, the total PAH concentration was higher at Savona (up to 17 times higher in February 1993) than at McLure.

Legend

- ★ Reference Sampling Site
- ★ Downstream Sampling Site
- Thompson River System

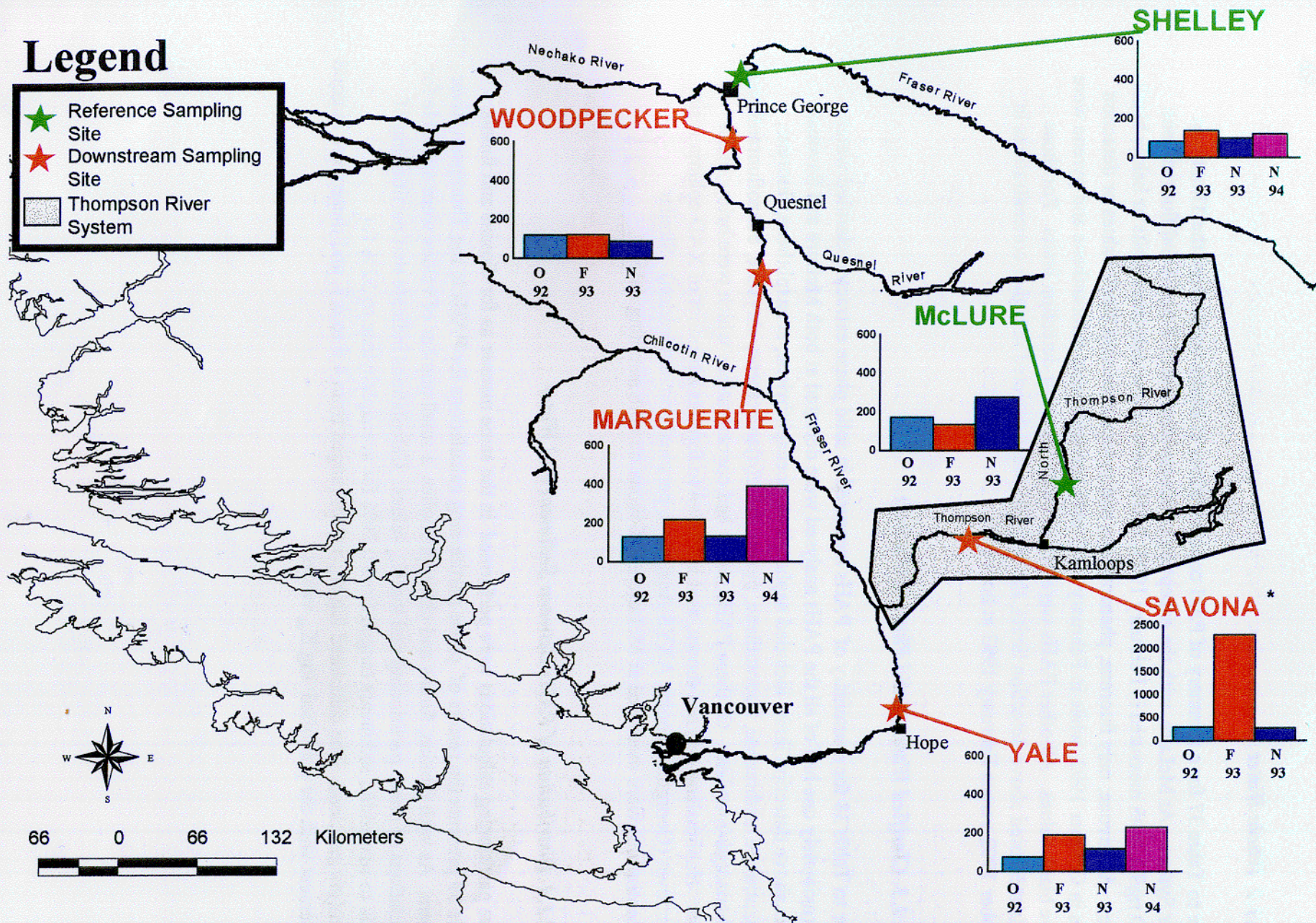


Figure 14 Total PAH Concentrations (ng/g) in Suspended Sediment from the Fraser and Thompson River Systems

* Note scale difference for Savona graph

10.2.1.2 Whole Water

Refer to Table 37 for a summary of PAH concentrations in whole water from the Thompson River System. At McLure, with the exception of acenaphthylene (1.8 ng/L) and fluoranthene (0.90 ng/L), both measured in February 1993, PAHs were below detection limits or below blank values. At Savona, only fluorene, phenanthrene and pyrene exceeded blank values or detection limits in October 1992, while in February 1993 only acenaphthene, fluoranthene and pyrene were above blank values. All other PAHs were below blank values or detection limits. For those PAHs measured above detection limits, the majority were detected in higher concentrations in October 1992 versus February 1993 at both sites.

10.2.1.3 Clarified Water (Solid Phase Extracted)

Refer to Table 38 for a summary of PAHs measured in solid phase extracted clarified water. Approximately one half of all the PAHs analysed were detected at both McLure and Savona. PAHs above detection limits included naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(*a*)anthracene, chrysene, benzo(*ghi*)perylene. Of these PAHs, many had concentrations which were below blank values. Naphthalene was not shown, as it is known to form as a product of XAD column resin breakdown (Georgina Brooks, AXYS Analytical, personal communication). Similar concentrations were measured at McLure and Savona on both sampling dates.

10.2.1.4 Distribution of PAHs Between Sediment and Water

Phase partitioning calculations were performed in the same manner as for dioxins and furans. Table 39 presents the results of phase partitioning calculations for PAHs in the Thompson River System. As with dioxins, furans and chlorophenolics, a small number of values were available for calculations of phase partitioning and log K_{oc} values. Calculations indicate that partitioning of PAHs to suspended sediments ranged from 0.20% for acenaphthylene to 52% for benzo[*ghi*]perylene. The calculated log K_{oc} values ranged from 4.5 to 6.7, and these were in good agreement with the published log K_{oc} values.

Table 37 Summary of Polycyclic Aromatic Hydrocarbons Detected in Whole Water from the Thompson River System (October 1992, February 1993)

Sampling Location:	McLure		Savona	
Sampling Date:	Oct. 1992	Feb. 1993	Oct. 1992	Feb. 1993
PAHs (ng/L)				
Naphthalene	{6.4}	{14}	ND(10)	{3.1}
Acenaphthylene	{1.6}	1.8	{4.7}	{0.40}
Acenaphthene	ND(3.8)	{1.1}	ND(4.3)	0.60
Fluorene	ND(3.5)	{0.8}	5.2	ND(0.5)
Phenanthrene	{13}	{2.8}	18	{1.7}
Anthracene	ND(3.6)	{0.30}	ND(5.8)	ND(0.2)
Fluoranthene	{4.3}	0.90	{6.0}	0.70
Pyrene	{6.4}	{0.50}	9.6	1.1
Benz(a)anthracene	ND(4.6)	{0.40}	ND(4.2)	ND(0.4)
Chrysene	{2.8}	{0.50}	{4.6}	{0.50}
Benzofluoranthenes	ND(2.0)	ND(0.6)	ND(2.3)	ND(0.6)
Benzo(e)pyrene	ND(2.6)	ND(0.6)	ND(3.0)	ND(0.7)
Benzo(a)pyrene	ND(4.4)	ND(0.6)	ND(5.1)	ND(0.7)
Perylene	ND(3.3)	ND(0.6)	ND(3.8)	ND(0.6)
Dibenz(ah)anthracene	ND(8.4)	ND(0.8)	ND(10)	ND(1.0)
Indeno(1,2,3-cd)pyrene	ND(11)	ND(0.9)	ND(14)	ND(0.6)
Benzo(ghi)perylene	ND(7.1)	ND(0.6)	ND(8.3)	{0.50}

ND denotes below the indicated detection limit (shown in brackets) when both field replicates and samples were below detection

{ } concentration value equal to or below that of laboratory and/or field blank

Note: all results presented are a mean of field replicates and samples - one half the detection limit was used when only one of the samples was below the detection limit
- all means rounded to two significant figures

Table 38 Summary of Polycyclic Aromatic Hydrocarbons Detected in Solid Phase Extracted Clarified Water from the Thompson River System (October 1992, February 1993)

Sampling Location:	McLure		Savona	
Sampling Date:	Oct. 1992	Feb. 1993	Oct. 1992	Feb. 1993
PAHs (ng/L)				
Acenaphthylene	0.76	1.1	{0.17}	0.20
Acenaphthene	0.44	0.40	0.40	{0.10}
Fluorene	1.1	0.70	0.54	{0.20}
Phenanthrene	1.9	{1.6}	1.28	{0.60}
Anthracene	0.24	0.20	0.15	ND(0.1)
Fluoranthene	0.62	0.50	0.60	0.80
Pyrene	{0.44}	0.40	{0.36}	0.80
Benz(a)anthracene	{0.08}	ND(0.1)	{0.040}	ND(0.1)
Chrysene	0.10	{0.10}	0.12	0.20
Benzofluoranthenes	0.080	ND(0.1)	ND(0.04)	ND(0.1)
Benzo(e)pyrene	ND(0.04)	ND(0.1)	ND(0.02)	ND(0.1)
Benzo(a)pyrene	ND(0.04)	ND(0.1)	ND(0.02)	ND(0.1)
Perylene	ND(0.03)	ND(0.1)	ND(0.01)	ND(0.1)
Dibenz(ah)anthracene	ND(0.02)	ND(0.1)	ND(0.02)	ND(0.4)
Indeno(1,2,3-cd)pyrene	ND(0.01)	ND(0.2)	ND(0.01)	ND(0.3)
Benzo(ghi)perylene	ND(0.01)	ND(0.1)	ND(0.01)	0.20

ND denotes below the indicated detection limit (shown in brackets)

{ } concentration value equal to or below that of laboratory and/or field blank

Table 39 Polycyclic Aromatic Hydrocarbon Phase Partitioning and Calculated and Published Log K_{oc} Values - Thompson River System (October 1992, February 1993)

Compounds	% Partitioning in Suspended Sediments				Calculated Log K _{oc}				Published Log K _{oc} ⁽¹⁾
	McLure		Savona		McLure		Savona		
	Oct. 92	Feb. 93	Oct. 92	Feb. 93	Oct. 92	Feb. 93	Oct. 92	Feb. 93	
Acenaphthylene	0.37	0.20	1.5	31	4.5	4.7	5.5	6.4	3.4 - 3.83
Acenaphthene	N/A ⁽²⁾	0.71	N/A	4.0	-	5.3	-	5.6	3.59 - 5.38
Fluorene	0.55	0.75	0.83	13	4.7	5.3	5.3	5.9	3.76 - 5.47
Phenanthrene	2.1	0.95	2.2	32	5.3	5.4	5.7	6.4	3.97 - 6.12
Anthracene	2.5	0.79	4.9	N/A	5.4	5.3	6.1	-	2.96 - 5.76
Fluoranthene	6.6	3.1	5.0	30	5.8	5.9	6.1	6.4	4.0 - 6.38
Pyrene	6.6	3.0	6.7	39	5.8	5.9	6.2	6.5	3.11 - 6.51
Benz[<i>a</i>]anthracene	13	N/A	24	N/A	6.1	-	6.9	-	4.0 - 7.3
Chrysene	24	11	16	41	6.4	6.5	6.7	6.6	3.66 - 6.9
Benzo[fluoranthenes	38	N/A	N/A	N/A	6.7	-	-	-	4.0 - 7.0
Benzo[<i>ghi</i>]perylene	N/A	N/A	N/A	52	-	-	-	6.7	6.2 - 6.26

(1) Mackay *et al.*, 1992

(2) N/A denotes not available (due to insufficient data above detection limits)

10.2.2 Discussion

10.2.2.1 *Suspended Sediments*

The presence of PAHs in suspended sediments at the reference site, McLure, is indicative of the ubiquitous nature of these compounds in the environment. The higher PAH concentrations measured at Savona relative to McLure, for both October 1992 and February 1993, indicate that municipal and industrial effluents may be an important source of PAHs to the Thompson River upstream of this site.

The notably elevated PAH concentrations measured at Savona in February 1993 may be related to the higher TOC content of suspended sediment at this site (18.53%) versus that at McLure (2.46%). Sorption to sediments, especially those with a high organic carbon content (Karickhoff *et al.*, 1979), has been shown to be the primary removal mechanism for high molecular weight PAHs (Knap and Williams, 1982). Perylene, a PAH derived from terrestrial plant sources (Bouloubassi and Saliot, 1993), was the most abundant PAH found at McLure, as it comprised between 34–40% of the total PAH concentration. Whereas a high perylene predominance (up to 90% of total PAHs) has been associated with diagenetic sources, a low relative abundance of this PAH has been associated with anthropogenic sources. Perylene comprised a much smaller fraction of the total PAH concentration at Savona in both October 1992 and February 1993 (4.0–12%), where other PAHs, particularly those with a molecular mass > 178, were much more prominent.

The fact that at McLure the highest PAH concentrations coincided with the periods of highest flow during the study period (October 1992 and November 1993) indicates that increased surface runoff of automobile and combustion-related PAHs (Water Quality Branch, 1993b) may be an important source of these contaminants at this site. The inverse relationship between flow and total PAH concentration in suspended sediments from Savona suggests that municipal and industrial sources likely provide a much larger PAH load than surface runoff and combustion-related sources at this site. The low flow winter period is associated with reduced dilution of Thompson River water as it passes across Kamloops Lake, a factor also contributing to the high PAH levels observed at Savona in February 1993.

10.2.2.2 *Whole and Clarified (Solid Phase Extracted) Water*

With a few exceptions, all PAHs measured in whole water and clarified water in the Thompson River System were near or below detection limits or blank values. However PAH concentrations measured in whole water were higher in October 1992 versus February 1993 at both McLure and Savona, although neither the suspended sediment or clarified water data showed a corresponding

increase. Since similar PAH concentrations were detected in the laboratory blank run with the October 1992 samples, laboratory error may be responsible for this apparent contradiction.

As PAHs are highly hydrophobic, the presence of detectable levels of PAHs in clarified water is likely due to their association with dissolved and colloidal organically rich material in the water column. The predominance of lower molecular mass PAHs (four or less rings) in clarified water samples is reflective of their higher aqueous solubilities relative to that of PAHs with five or more rings.

10.2.2.3 Distribution of PAHs Between Sediment and Water

The PAH partitioning pattern was clearly related to the TOC fraction of suspended sediment, since the partitioning profile in February 1993 was strikingly different at Savona (TOC = 18.53%) compared to McLure (TOC = 2.46%). Whereas at McLure PAH partitioning to the suspended solid phase ranged between 0.20-11%, at Savona it ranged between 4.0-52%. The lower TOC fraction measured at Savona in October 1992 (4.89%) clearly influenced the partitioning profile during this sampling period, as a much smaller PAH fraction was found in the suspended sediments (0.83-24%).

A second factor influencing PAH partitioning to the suspended sediment fraction was molecular mass. All samples showed a pattern of increasing affinity for the suspended solid phase as molecular mass increased. This was particularly apparent in the February 1993 sample from Savona in which 52% of benzo(*ghi*)perylene was found in the suspended sediment phase. Similar findings were reported by Yunker *et al.* (1993) who found that the lower molecular-mass (up to 178), more water soluble PAHs, predominate in the dissolved phase of Mackenzie River water, whereas the larger molecular mass PAHs (>178) predominate in the particulate phase.

10.2.2.4 Comparisons of PAH Concentrations to Guidelines and Criteria

PAHs measured in suspended sediments from the Thompson River System were compared with the BCMELP recommended interim bed sediment criteria for the protection of aquatic life (Water Quality Branch, 1993b), and concentrations in suspended sediments (expressed as pg/L) were compared with the BCMELP recommended interim freshwater water quality criteria for the protection of aquatic life (Water Quality Branch, 1993b).

Only naphthalene and benzo[*a*]pyrene, measured in suspended sediments, exceeded the BCMELP interim bed sediment quality criteria (Table 40). Based on concentrations adjusted to the site

Table 40 Naphthalene and Benzo[a]pyrene Concentrations in Thompson River System Suspended Sediments Compared to BCMELP Interim Bed Sediment Quality and Freshwater Quality Criteria for the Protection of Aquatic Life (October 1992, February 1993, November 1993)

Compound	Concentration in Suspended Sediments (ng/g)				BCMELP Bed Sediment Quality Criteria ⁽¹⁾ (ng/g)	Concentrations in Suspended Sediments (expressed as ng/L) ⁽²⁾			BCMELP Fresh Water Criteria (ng/L)
	Date		Concentration			Date	Concentration		
Naphthalene	McLure	Nov 93	21	15 ⁽³⁾	10	McLure	Nov 93	0.050	1000
	Savona	Oct 92	16	3.3		Savona	Oct 92	0.014	
		Feb 93	180	9.7			Feb 93	0.20	
		Nov 93	17	11			Nov 93	0.065	
Benzo[a]pyrene	Savona	Feb 93	83	4.5	60	Savona	Feb 93	0.091	10

(1) Based on sediment containing 1% organic carbon

(2) Conversion from ng/g to ng/L achieved by using the site specific suspended sediment concentration

(3) Shaded values indicate concentrations adjusted to the site specific organic carbon content

specific organic carbon content, naphthalene exceeded the BCMELP bed sediment criterion of 10 ng/g at both McLure and Savona in November 1993. Benzo[*a*]pyrene levels measured at Savona in February 1993 did not exceed the BCMELP criterion when adjusted to the site specific organic carbon content (18.53%). None of the PAHs exceeded the BCMELP interim freshwater criteria when expressed as ng/L. It should be noted that no sediment or water criteria exist for benzo[*ghi*]perylene which was detected at a relatively high concentration (200 ng/L) in February 1993.

PAH concentrations in whole and clarified water were also compared to BCMELP interim fresh water criteria for the protection of aquatic life (Water Quality Branch, 1993b). None of the PAHs measured in whole and clarified water samples from McLure and Savona exceeded the criteria.

10.3 Fraser River

10.3.1 Results

10.3.1.1 Suspended Sediments

Refer to Table 41 for a summary of PAHs detected in suspended sediments from sample sites on the Fraser River. Although total PAHs were similar between Shelley and Woodpecker, they were 32-322% higher at Marguerite than at Shelley for all dates sampled. In comparison to Shelley, total PAHs at Yale were higher in both February 1993 and November 1994, but similar to those detected at Shelley in October 1992 and November 1993. For all sampling sites, total PAHs were highest in concentration in both February 1993 and November 1994. Perylene was detected in the highest concentration (14-58 ng/g) of all PAHs measured at the Fraser River sites. Refer to Figure 14 for total PAHs measured in suspended sediments from the Fraser River.

10.3.1.2 Whole Water

Refer to Table 42 for a summary of PAHs measured in whole water from the Fraser River in October 1992 and February 1993. PAH concentrations in the whole water samples were generally found to be similar to blank values. The only PAH which had concentration levels consistently above blank values was pyrene. In October 1992, this contaminant was found in similar concentrations at all four sampling sites (8.3- 9.3 ng/L), including Shelley. In February 1993 pyrene was also found in similar concentrations at all four sites (1.0 -1.2 ng/L). However, pyrene concentrations were approximately nine times larger in October 1992 than in February

Table 41 Summary of Polycyclic Aromatic Hydrocarbons Detected in Suspended Sediments from the Fraser River (October 1992, February 1993, November 1993, November 1994)

Sampling Location:	Shelley				Woodpecker			Marguerite				Yale			
Sampling Date:	Oct. 1992	Feb. 1993	Nov. 1993	Nov. 1994	Oct. 1992	Feb. 1993	Nov. 1993	Oct. 1992	Feb. 1993	Nov. 1993	Nov. 1994	Oct. 1992	Feb. 1993	Nov. 1993	Nov. 1994
PAHs (ng/g)															
Naphthalene	6.0	6.6	6.3	5.9	10	11	4.5	6.0	15	9.1	16	6.3	16	7.5	14
Acenaphthylene	ND(0.5)	1.8	0.70	ND(0.31)	ND(1.0)	2.8	{0.40}	ND(0.6)	6.0	1.2	3.8	0.30	2.9	1.0	2.0
Acenaphthene	ND(0.2)	3.1	0.50	ND(1.2)	ND(3.0)	{1.6}	0.40	ND(1.0)	2.1	0.80	2.3	ND(1.0)	2.8	0.60	3.3
Fluorene	1.0	5.4	1.3	2.6	2.0	5.4	1.0	3.0	5.3	2.6	8.0	2.0	11	1.9	6.0
Phenanthrene	8.0	12	11	12	15	18	8.9	15	22	19	55	9.8	26	12	35
Anthracene	ND(0.7)	1.3	1.5	1.0	1.0	2.4	1.5	4.0	33	3.9	17	1.0	7.1	2.2	7.9
Fluoranthene	4.0	8.0	6.7	7.4	8.0	9.7	5.0	11	20	11	47	5.5	23	7.1	26
Pyrene	4.0	5.9	5.5	6.0	8.0	12	3.9	9.0	24	9.7	50	4.8	21	6.3	26
Benz(a)anthracene	1.0	4.2	2.1	3.4	3.0	7.0	ND(0.3)	4.0	6.0	3.1	15	1.5	7.9	2.9	7.3
Chrysene	4.0	6.0	7.6	8.0	3.0	10	4.5	12	8.8	10	30	4.5	15	8.0	17
Benzo(a)fluoranthene	6.0	6.5	7.9	11	9.0	7.4	6.1	10	9.4	12	29	4.5	14	10	16
Benzo(e)pyrene	5.0	2.6	5.1	5.2	7.0	2.4	{2.6}	7.0	6.7	7.3	21	3.8	8.4	5.6	12
Benzo(a)pyrene	ND(0.6)	2.0	1.3	1.9	2.0	3.6	ND(1.0)	2.0	3.4	ND(1.5)	17	1.0	3.8	ND(1.3)	8.3
Perylene	39	58	37	48	43	18	39	36	36	37	45	24	14	40	27
Dibenz(ah)anthracene	ND(1.0)	7.3	ND(4.7)	0.89	ND(1.0)	{2.8}	{6.0}	1.0	6.5	ND(4.5)	1.8	ND(0.6)	{3.0}	ND(9.7)	1.1
Indeno(1,2,3-cd)pyrene	2.0	3.3	2.2	3.4	3.0	4.4	ND(3.9)	3.0	4.5	ND(3.3)	13	2.0	5.4	ND(2.6)	6.8
Benzo(ghi)perylene	2.0	4.3	2.9	4.4	3.0	4.1	2.5	4.0	8.6	3.8	22	2.8	8.9	4.7	14
Total PAHs	84	138	102	122	120	120	89	128	217	135	393	75	190	117	230

ND denotes below the indicated detection limit (shown in brackets) when both field splits and samples were below detection

{ } concentration value equal to or below that of laboratory blank

Note: all results presented are a mean of field splits and samples

- one half the detection limit was used when only one of the samples was below the detection limit

- all means rounded to two significant figures

**Table 42 Summary of Polycyclic Aromatic Hydrocarbons Detected in Whole Water Samples from the Fraser River
(October 1992, February 1993)**

Sampling Location:	Shelley		Woodpecker		Marguerite		Yale	
Sampling Date:	Oct. 1992	Feb. 1993	Oct. 1992	Feb. 1993	Oct. 1992	Feb. 1993	Oct. 1992	Feb. 1993
PAHs (ng/L)								
Naphthalene	{11}	{4.2}	{5.2}	{3.7}	{5.8}	{4.4}	{5.4}	{6.2}
Acenaphthylene	{3.3}	0.5	{2.8}	0.5	ND(1.7)	0.6	ND(1.6)	0.9
Acenaphthene	{3.6}	1	ND(3.4)	1	ND(3.8)	1.3	ND(3.5)	ND(4.4)
Fluorene	ND(6.4)	{1.2}	{3.2}	ND(1.1)	{2.2}	{1.5}	ND(2.4)	{3.6}
Phenanthrene	{18}	{3.2}	{14}	1.7	{15}	{2}	{12}	{3.5}
Anthracene	ND(5.5)	1.1	3	{0.4}	ND(5.8)	{0.2}	ND(5.9)	1.3
Fluoranthene	{5.7}	1.3	{5.4}	0.6	{5.3}	{0.4}	{5.1}	1.3
Pyrene	9.3	1	8.3	1	8.8	1	9.2	1.2
Benz(a)anthracene	ND(3.0)	1.3	ND(3.6)	0.9	ND(4.6)	{0.3}	ND(1.9)	0.9
Chrysene	4.8	1.6	{3.5}	0.9	{4.1}	{0.7}	{4.4}	1.1
Benzofluoranthenes	ND(1.5)	1.6	ND(1.7)	ND(0.5)	ND(2.0)	{0.4}	ND(1.5)	1.1
Benzo(e)pyrene	ND(2.0)	1.7	ND(2.2)	ND(0.5)	ND(2.6)	{0.4}	ND(2.0)	0.7
Benzo(a)pyrene	ND(3.3)	1.9	ND(3.8)	{0.7}	ND(4.3)	{0.7}	ND(3.4)	0.9
Perylene	ND(2.5)	2	ND(2.8)	{0.6}	ND(3.2)	{0.6}	ND(2.5)	{0.6}
Dibenz(ah)anthracene	ND(5.4)	1.5	ND(5.1)	NDR(1)	ND(9.6)	{0.6}	ND(9.0)	1.7
Indeno(1,2,3-cd)pyrene	ND(8.2)	1.6	ND(7.8)	{0.8}	ND(10)	{0.5}	ND(12.0)	1.0
Benzo(ghi)perylene	ND(4.6)	1.9	ND(4.4)	0.8	ND(7.8)	{0.5}	ND(7.2)	1.2

ND denotes below the indicated detection limit (shown in brackets) when both field replicates and samples were below detection
{ } concentration value equal to or below that of laboratory and/or field blank

Note: all results presented are a mean of field replicates and samples - one half the detection limit was used only when only one of the samples was below the detection limit

1993 at each site sampled.

10.3.1.3 Clarified Water (Solid Phase Extracted)

Refer to Table 43 for a summary of PAH concentrations in solid phase extracted clarified water samples collected from Fraser River. Note that naphthalene is known to form as a breakdown product of XAD column resin (Georgina Brooks, AXYS Analytical, personal communication) and was therefore not included in the table. For the majority of PAHs analysed in samples from Shelley and Woodpecker, concentrations were similar to the blank values or were below detection limits. Trace levels (≤ 2.4 ng/L) of the smaller molecular mass PAHs were detected at Marguerite and Yale. No data were collected for November 1993.

10.3.1.4 Distribution of PAHs Between Sediment and Water

Phase partitioning of measured PAHs was determined in the same manner as for dioxins and furans. Table 44 presents the summarized results of phase partitioning calculations for PAHs at all Fraser River sampling sites. Refer to Appendix IV for site specific calculations.

Partitioning of PAHs to suspended sediments ranged between 0.24% for acenaphthene to 91% for chrysene. Variation in phase partitioning occurred between individual PAH congeners as well as between sample sites and sampling times. The percent partitioning to the suspended solid phase was greater for PAHs measured in October 1992 versus February 1993 for the majority of congeners. Calculated $\log K_{oc}$ values ranged from 4.7 to 6.9 and were generally within the range of published $\log K_{oc}$ values.

10.3.2 Discussion

10.3.2.1 Suspended Sediments

The increase in PAH concentrations observed at Marguerite, relative to the other Fraser River sites (Figure 14), may be attributed to surface runoff due to this site's proximity to a major highway. Furthermore, the location of this site downstream of both Prince George and Quesnel may subject it to additional PAH loadings from industrial and municipal effluents. Evidence of PAHs associated with municipal effluents has been found by Derksen (unpublished data) who has found PAHs in both the solid and aqueous phases of municipal effluents from Greater Vancouver and Prince George.

Table 43 Summary of Polycyclic Aromatic Hydrocarbons Detected in Solid Phase Extracted Clarified Water from the Fraser River (October 1992, February 1993)

Sampling Location:	Shelley		Woodpecker		Marguerite		Yale	
Sampling Date:	Oct. 1992	Feb. 1993	Oct. 1992	Feb. 1993	Oct. 1992	Feb. 1993	Oct. 1992	Feb. 1993
PAHs (ng/L)								
Acenaphthylene	{0.10}	ND(0.01)	0.28	0.20	0.50	0.30	0.28	0.30
Acenaphthene	{0.080}	{0.10}	{0.14}	{0.10}	0.54	{0.10}	0.58	2.4
Fluorene	{0.26}	{0.10}	0.50	{0.20}	2.0	{0.20}	1.1	1.7
Phenanthrene	{0.50}	{0.40}	{1.1}	{0.50}	2.4	{0.50}	1.7	{1.6}
Anthracene	{0.050}	0.10	1.2	ND(0.1)	0.36	0.30	0.18	0.20
Fluoranthene	{0.19}	{0.10}	{0.26}	{0.10}	0.68	{0.10}	0.56	0.50
Pyrene	{0.22}	{0.10}	{0.30}	{0.20}	{0.56}	{0.30}	{0.48}	0.40
Benzo(a)anthracene	{0.060}	ND(0.1)	{0.060}	ND(0.1)	{0.080}	ND(0.1)	{0.050}	0.10
Chrysene	{0.060}	{0.10}	{0.070}	ND(0.1)	0.12	ND(0.1)	0.10	{0.10}
Benzo(b)fluoranthene	ND(0.044)	ND(0.2)	0.060	ND(0.1)	ND(0.05)	ND(0.1)	ND(0.03)	ND(0.1)
Benzo(e)pyrene	ND(0.026)	ND(0.1)	ND(0.022)	ND(0.1)	ND(0.03)	ND(0.1)	ND(0.02)	ND(0.1)
Benzo(a)pyrene	ND(0.018)	ND(0.2)	ND(0.018)	ND(0.1)	ND(0.02)	ND(0.1)	ND(0.03)	ND(0.1)
Perylene	ND(0.014)	ND(0.2)	ND(0.012)	ND(0.1)	ND(0.01)	ND(0.1)	ND(0.02)	ND(0.1)
Dibenz(ah)anthracene	ND(0.032)	0.70	ND(0.022)	ND(0.1)	ND(0.02)	ND(0.1)	ND(0.02)	0.50
Indeno(1,2,3-cd)pyrene	ND(0.014)	0.20	ND(0.014)	ND(0.2)	ND(0.01)	ND(0.1)	ND(0.02)	0.20
Benzo(ghi)perylene	ND(0.02)	0.20	ND(0.016)	ND(0.1)	ND(0.01)	ND(0.1)	ND(0.02)	0.20

ND denotes below the indicated detection limit (shown in brackets) when both field replicates and samples were below detection
{ } concentration value equal to or below that of laboratory and/or field blank

Table 44 Summary of Polycyclic Aromatic Hydrocarbon Phase Partitioning and Calculated and Published Log K_{oc} Values - Shelley, Woodpecker, Marguerite, Yale - Fraser River (October 1992, February 1993)

Compounds	% Partitioning in Suspended Sediments ⁽¹⁾		Calculated Log K_{oc}		Published Log K_{oc} ⁽²⁾
	October 1992	February 1993	October 1992	February 1993	
Acenaphthylene	20	2.0 - 9.3	5.0	5.6 - 5.8	3.4 - 3.83
Acenaphthene	N/A ⁽³⁾	0.24 - 10	-	4.7 - 6.2	3.59 - 5.38
Fluorene	3.4 - 30	1.3 - 16	4.8 - 5.3	5.5 - 6.5	3.76 - 5.47
Phenanthrene	13 - 57	2.6 - 21	5.4 - 5.9	5.9 - 6.2	3.97 - 6.12
Anthracene	1.3 - 56	1.2 - 34	4.7 - 5.7	5.9 - 6.5	2.96 - 5.76
Fluoranthene	27 - 69	6.7 - 48	5.8 - 6.2	6.3 - 6.8	4.0 - 6.38
Pyrene	26 - 69	5.0 - 30	5.8 - 6.1	6.2 - 6.5	3.11 - 6.51
Benz(a)anthracene	24 - 87	14	5.9 - 6.5	6.5	4.0 - 7.3
Chrysene	39 - 91	5.1 - 24	6.3 - 6.6	6.5 - 6.8	3.66 - 6.9
Benzofluoranthenes	69	N/A	6.9	-	4.0 - 7.0
Dibenz(ah)anthracene	N/A	0.93 - 1.2	-	5.4 - 5.8	5.2 - 6.52
Indeno(1,2,3-cd)pyrene	N/A	1.5 - 5.4	-	6.0 - 6.1	-
Benzo(ghi)perylene	N/A	1.9 - 8.6	-	6.1 - 6.3	6.2 - 6.26

(1) Values expressed as a range across all sampling sites

(2) Mackay *et al.*, 1992

(3) N/A denotes not available due to insufficient data above detection limits

The higher total PAH concentrations measured at Marguerite and Yale at low flows (February 1993 and November 1994) in comparison to those measured at higher flows (October 1992 and November 1993) suggests that municipal and industrial effluents may be an important source of PAHs to the Fraser River, as these effluents are less diluted during low flow. However, non point sources of PAHs are also likely to be very important to the PAH load of the river. This is demonstrated by the relatively high levels of total PAHs found at the reference site, Shelley. Such non point sources may be both natural and anthropogenic in nature and likely include: atmospheric deposition from combustion sources (Water Quality Branch, 1993b), surface run-off (Boom and Marsalek, 1988) and natural oil seeps (Allan, 1990). It is unlikely, however, that atmospheric sources and surface runoff are a significant source of PAHs during the winter low flow period due to reduced surface run-off in sub-zero temperatures and ice capping of the Fraser River.

10.3.2.2 Whole and Clarified (Solid Phase Extracted) Water

As was the case in the Thompson River System, virtually all PAHs measured in whole water from the Fraser River System were near or below detection limits. Although PAHs were detected in higher concentrations in October 1992 versus February 1993, this was likely the result of laboratory error (Section 10.2.2.2). No spatial or temporal patterns were observed for PAHs in clarified water, as concentrations were near or below detection limits at all sites sampled. Nevertheless, their presence in clarified water indicates that they are measurable in the dissolved and/or colloidal phases where they are likely associated with organically rich material.

10.3.2.3 Distribution of PAHs Between Sediment and Water

Phase partitioning of measured PAHs appeared to be influenced by both sampling time and individual congener solubility. Higher suspended sediment concentrations during fall sampling in October 1992 (18.9-226.0 mg/L) may have increased partitioning to the suspended solid phase in comparison to February 1993 when suspended sediment concentrations were substantially lower (0.9-7.3 mg/L). This is consistent with results of other studies which have reported greater scavenging of PAHs by particulates at higher suspended sediment loads (Yunker *et al.*, 1993; Bouloubassi and Saliot, 1993). Secondly, the extent of PAH partitioning to the suspended solid phase appeared to increase with increasing molecular weight for the majority of PAH congeners. Similar studies have found that the dissolved phase composition of PAHs depends primarily on PAH solubility (Yunker *et al.*, 1991a; Yunker *et al.*, 1991b).

10.3.2.4 Comparisons of PAH Concentrations to Guidelines and Criteria

PAHs measured in suspended sediments from the Fraser River were compared with BCMELP recommended interim bed sediment criteria for the protection of aquatic life (Water Quality Branch, 1993b), and concentrations in suspended sediments (expressed as pg/L) were compared with BCMELP recommended interim freshwater water quality criteria for the protection of aquatic life (Water Quality Branch, 1993b).

The only PAH measured on the Fraser River which exceeded BCMELP interim bed sediment quality criteria was naphthalene. Refer to Table 45 for a comparison of naphthalene concentrations (exceeding the provincial criterion) in Fraser River suspended sediments with bed sediment and water quality criteria.

Table 45 Naphthalene Concentrations in Fraser River Suspended Sediments Compared to BCMELP Interim Sediment Quality and Freshwater Quality Criteria for the Protection of Aquatic Life

Sampling Site	Concentration in Suspended Sediments (ng/g)		BCMELP Criterion for Bed Sediments (ng/g) ^(1,2)	Concentrations in Suspended Sediments (expressed as ng/L) ⁽³⁾		BCMELP Interim Fresh Water Criterion (ng/L) ⁽¹⁾
	Date	Concentration		Date	(ng/L)	
Woodpecker	Feb 93	11 32 ⁽⁴⁾	10	Feb 93	0.080	1000
Marguerite	Feb 93	15 45	10	Feb 93	0.071	1000
	Nov 94	16 71		Nov 94	0.073	
Yale	Feb 93	16 70	10	Feb 93	0.034	1000
	Nov 94	14 93		Nov 94	0.030	

(1) Maximum values reported

(2) Based on sediment containing 1% organic carbon

(3) Conversion from ng/g to ng/L was achieved by using the site specific suspended sediment concentration

(4) Shaded values indicate concentrations adjusted to the site specific organic carbon content

The 10 ng/g criterion for naphthalene was exceeded at Woodpecker in February 1993, at Marguerite in February 1993 and November 1994, and at Yale in February 1993 and November 1994. However when measured concentrations were adjusted to the site specific organic carbon content, none of these values exceeded the criterion. Moreover, when expressed as ng/L, naphthalene did not exceed the BCMELP interim fresh water criterion of 1000 ng/L. None of

the PAHs measured in whole and clarified water samples from the Fraser River exceeded the BCMELP interim freshwater criteria for the protection of aquatic life.

11.0 POLYCHLORINATED BIPHENYLS

11.1 Introduction

Polychlorinated biphenyls have been widely used in industrial applications because they are thermally stable, resistant to both acid and base hydrolysis, generally inert, soluble in organic solvents, possessive of excellent dielectric properties, resistant to oxidation and reduction and nonflammable. They are also good lubricants and have high film strength (Gustafson, 1970; Safe *et al.*, 1982). In 1980, the use of PCBs was prohibited as a constituent of any product, machinery or equipment manufactured in Canada (Environment Canada, 1980). In Canada, PCBs remain only in old closed electrical equipment, such as transformers.

PCB congeners can be divided into two main classes: ortho-substituted coplanars and non ortho-substituted coplanars. As studies have determined that non-ortho-substituted PCB coplanars are more immunotoxic than the ortho-substituted forms (Silkworth and Grabstein, 1982), these congeners have become the focus of criteria development. Owing to their resistance to oxidation and hydrolysis (Hutzinger *et al.*, 1974), low vapour pressure and reduced levels of biodegradation, PCBs are environmentally persistent compounds which bioaccumulate and bioconcentrate in biological systems (Hansen, 1976).

Individual PCBs vary widely in their physical and chemical properties according to the degree and position of chlorination (USEPA, 1979). Most PCBs are slightly soluble in water (2.7-15,000 µg/L [USEPA, 1979]), and their solubility decreases with increasing chlorine content. Evidence suggests that solutions of PCBs in water are actually stable emulsions of PCB aggregations (Schoor, 1975). As a consequence of their hydrophobic nature ($K_{ow} = 3.6-8.26$ [Miller *et al.*, 1985]), PCBs have a high affinity for suspended solids, especially those of high organic carbon content (Hamelink *et al.*, 1971).

PCBs have been found in final effluents of kraft pulp and paper mills (Merriman, 1988; Derksen, unpublished data) and sewage treatment plant effluent (Derksen, unpublished data). PCBs have also been found in suspended sediments in five northern Ontario rivers with concentrations ranging between 0.23-1.57 ng/L (McCrea *et al.*, 1984). More recently, PCBs were found in bed sediments collected in 1994 from the Fraser River Basin (Sekela, unpublished data), and in 1995 total PCB levels up to 100 ng/g were measured in a residential catch area in Vancouver, British Columbia (K. Hall, Westwater Research Institute, personal communication).

11.2 Results

Polychlorinated biphenyls (PCBs) were measured in suspended sediments from the Fraser River in February 1993 and November 1994. No PCBs were measured in the Thompson River System.

11.2.1 PCB Aroclors

Refer to Table 46 for a summary of PCB aroclors in suspended sediments collected from the Fraser River in February 1993 and November 1994. Note that there was no data available for Shelley in February 1993.

Table 46 Summary of PCB Aroclors Detected in Suspended Sediments from the Fraser River (February 1993, November 1994)

Compounds (ng/g)	February 1993		November 1994		
	Woodpecker	Yale	Shelley	Marguerite	Yale
Aroclor 1242	4.6	0.70	ND(0.48)	ND(0.82)	ND(0.75)
Aroclor 1254	ND(1.5)	ND(2.0)	ND(1.2)	ND(1.6)	ND(2.0)
Aroclor 1260	ND(1.3)	ND(2.2)	ND(0.31)	ND(1.4)	ND(1.1)

ND = Not detected (detection limits in brackets)

Aroclor 1242 was the only aroclor measured above detection limits in Fraser River suspended sediments. This contaminant mixture was detected only in February 1993 at Woodpecker and at Yale.

11.2.2 PCB Congeners

Refer to Table 47 for a summary of PCB congeners measured above detection limits in Fraser River suspended sediments in February 1993 and November 1994. Refer to Section 4.3.1 for a complete list of all PCB congeners measured.

In February 1993, three PCB congener pairs (31/28, 70/76 and 90/101) were detected at Woodpecker, with the highest concentration measured for congeners 31/28 at 0.90 ng/g. The only PCB congener pair detected at Yale was 31/28 at 0.20 ng/g. In November 1994, nine congeners were measured at Shelley, however their concentrations were only slightly above detection limits (0.010-0.060 ng/g). At Marguerite, four congeners were detected with a maximum concentration of 0.11 ng/g for congener 193, whereas at Yale five congeners were

Table 47 PCB Congeners Detected in Suspended Sediments from the Fraser River (February 1993, November 1994)

Congeners (ng/g)	February 1993		November 1994		
	Woodpecker	Yale	Shelley	Marguerite	Yale
31/28	0.90	0.20	ND(0.03)	0.080	ND(0.11)
22	ND(0.5)	ND(0.1)	ND(0.03)	0.070	ND(0.11)
52	ND(0.06)	ND(0.06)	0.040	0.040	ND(0.07)
49	ND(0.06)	ND(0.06)	0.010	ND(0.04)	ND(0.07)
44	ND(0.07)	ND(0.08)	0.010	ND(0.04)	ND(0.08)
70/76	0.070	ND(0.07)	0.030	ND(0.04)	ND(0.08)
66	ND(0.05)	ND(0.05)	0.010	ND(0.03)	ND(0.05)
90/101	0.040	ND(0.2)	ND(0.04)	ND(0.07)	ND(0.09)
149	ND(0.07)	ND(0.09)	ND(0.01)	ND(0.06)	0.16
153	ND(0.04)	ND(0.05)	0.010	ND(0.06)	0.10
138/163/164	ND(0.05)	ND(0.07)	0.030	ND(0.07)	0.21
180	ND(0.06)	ND(0.1)	0.040	ND(0.08)	0.16
193	ND(0.07)	ND(0.1)	0.060	0.11	0.16

ND = Not detected (detection limits in brackets)

detected with a maximum concentration of 0.21 ng/g for congeners 138/163/164.

11.2.3 PCB Coplanars

Refer to Table 48 for a summary of PCB coplanar concentrations in suspended sediments collected from the Fraser River in February 1993 and November 1994. Note that there is no data from Shelley for February 1993.

In February 1993, all three PCB coplanars measured (# 77, # 126, and # 169) were each detected at a concentration of 11 pg/g at Woodpecker. No PCB coplanars were detected in suspended sediments from Yale in February 1993 or from Shelley, Marguerite or Yale in

November 1994.

Table 48 Summary of PCB Coplanars Detected in Suspended Sediments from the Fraser River (February 1993, November 1994)

Compounds (pg/g)	February 1993		November 1994		
	Woodpecker	Yale	Shelley	Marguerite	Yale
# 77 3,3',4,4' TCB	11	ND(3.2)	ND(0.7)	ND(3.4)	ND(2.4)
# 126 3,3',4,4',5 PCB	11	ND(5.0)	ND(0.3)	ND(0.8)	ND(0.7)
#169 3,3',4,4',5,5' HCB	11	ND(3.4)	ND(0.5)	ND(1.7)	ND(1.4)

ND = Not detected (detection limits in brackets)

11.3 Discussion

Although low levels of aroclor 1242, coplanars #77, #126, and #169 and various congeners were detected at the four Fraser River sites, these were often near detection limits. Furthermore, PCB concentrations measured downstream of pulp and paper mills generally did not differ from those at the reference site, Shelley. One possible source of PCBs detected in suspended sediments is sewage treatment plant effluent. In a recent study conducted by Derksen (unpublished data), many of the same PCBs were found in biosolids recovered from the Prince George sewage treatment plant final effluent. Other potential sources of the PCBs measured in Fraser River suspended sediment may include landfill leachate (Hammond, 1972), transformer stations and long range aerial deposition (CCREM, 1987).

11.3.1 Comparisons of PCB Concentrations to Guidelines and Criteria

Total PCBs in suspended sediments did not exceed the BCMELP bed sediment criterion of 20 ng/g (BCMELP, 1994a). Similarly, none of the non ortho-substituted PCB coplanars or total PCBs (converted to ng/L) exceeded BCMELP freshwater criteria (BCMELP, 1994a). Lastly, total PCBs (converted to ng/L) did not exceed the CCREM water quality guideline of 1.0 ng/L (CCREM, 1987).

12.0 PESTICIDES

12.1 Introduction

Pesticides vary widely in their physical and chemical properties according to the chemical family to which they belong. Organochlorine pesticides are, environmentally, the most important group of synthetic organic pesticides because of their great stability, hydrophobicity and toxicity (McNeely *et al.*, 1979). Hexachlorocyclohexane, containing a mixture of eight isomers, is an organochlorine pesticide which, historically, has been widely used in Canada (CCREM, 1987). Although the γ - isomer (lindane) has the highest insecticidal activity, the α -isomer is the most prevalent in surface waters of western Canada (Inland Waters Directorate, 1986). Alpha-hexachlorocyclohexane was detected close to the CCME maximum in river water in northern Quebec (Hudson and Ungava Bay drainage) (Lockhart *et al.*, 1992). Hexachlorobenzene, an organochlorine fungicide, has been found in particulate material from the Mackenzie River, Northwest Territories (Lockhart *et al.*, 1992), in water samples from the Waterton River, Alberta, and in precipitation samples collected from Yoho National Park, British Columbia (Donald *et al.*, 1993).

Various types of pesticides, including insecticides, herbicides and fungicides are presently employed in agriculture in the Fraser River Basin. Pesticides can enter the aquatic environment in a number of ways: surface runoff, percolation and subsurface runoff from treated lands, careless application, sewage discharge and industrial effluents (McNeely *et al.*, 1979). Moreover, pesticides are subject to atmospheric transport and redeposition (Lockhart *et al.*, 1992).

12.2 Results

Pesticides were measured in suspended sediments from the Fraser River in November 1994. Only hexachlorobenzene and α -hexachlorocyclohexane were found above detection limits in suspended sediment samples. Refer to Table 49 for the concentrations of these pesticides in Fraser River suspended sediments and to Section 4.3.1 for a complete list of all pesticides analysed.

Concentrations of hexachlorobenzene and α - hexachlorocyclohexane were from three to four times higher at Marguerite and Yale than at Shelley.

Table 49 Summary of Pesticide Concentrations in Suspended Sediments from the Fraser River (November 1994)

Compounds (ng/g)	Shelley	Marguerite	Yale
Hexachlorobenzene	0.080	0.30	0.21
α -Hexachlorocyclohexane	0.040	0.13	0.17

12.3 Discussion

Only two pesticides, the fungicide hexachlorobenzene and the insecticide α -hexachlorocyclohexane were detected in Fraser River suspended sediments. Although lindane (the γ -isomer of hexachlorocyclohexane) is still registered for use in Canada, hexachlorobenzene has been discontinued from use since 1976 (Sue Garnet, Agriculture Canada, personal communication). The presence of low levels of both of these pesticides at all Fraser River sites is indicative of their wide distribution and high persistence. Since pesticide use has historically not been heavily employed in the Fraser River region upstream of Prince George (Schreier, 1991), the presence of these pesticides at the reference site, Shelley, suggests that aerial deposition (Lockhart *et al.*, 1992) may be an important mechanism for their distribution in the Fraser River Basin.

12.3.1 Comparisons of Pesticide Concentrations to Guidelines and Criteria

Concentrations of hexachlorobenzene and hexachlorocyclohexane in suspended sediments were well below BCMELP (1994a) and OMEE (Persaud *et al.*, 1991) bed sediment quality criteria and guidelines for the protection of aquatic life. Concentrations of these pesticides (expressed as ng/L) were similarly below both CCREM (1987) and USEPA (1990) water quality guidelines for the protection of aquatic life.

13.0 FATTY ACIDS

13.1 Introduction

Fatty acids are composed of both hydrophilic and hydrophobic groups. They are poorly soluble in aqueous solutions and are known to associate with suspended solids in water (TECW, 1987). Because of their dual hydrophilic and hydrophobic nature, fatty acids tend to concentrate at the interfaces of aqueous mixtures (CCREM, 1987).

Natural sources of fatty acids have been identified as breakdown products of vegetation and wood fibre in lakes and rivers (Fox, 1977). Fatty acids of anthropogenic origin have been reported in untreated whole mill effluent in total concentrations ranging from 20 µg/L (sublethal) to 22,000 µg/L (above acutely lethal levels) (McLeay and Associates, 1987). However there is evidence that well-operated secondary wastewater treatment plants readily degrade fatty acids.

Degradation of over 99% of fatty acids present in raw kraft mill effluent has been reported by Beak (1987) at an Ontario mill with an aerated lagoon. Although not as toxic as resin acids, sodium salts of unsaturated fatty acids have been shown to contribute up to 20% of the toxicity of the whitewater from kraft pulping (Leach and Thakore, 1973).

13.2 Thompson River System

13.2.1 Results

13.2.1.1 Whole Water

Refer to Table 50 for a summary of fatty acid concentrations measured in whole water samples collected from the Thompson River System. The majority of fatty acids analysed were detected at the reference site, McLure. Total fatty acids were 85% higher in February 1993 versus October 1992 at this site. Due to high detection limits, all fatty acids measured were below detection in November 1993. At Savona, total fatty acid concentrations were 3.4 times greater in February 1993 than October 1992. In October 1992, total fatty acid concentrations at Savona (1486 ng/L) were similar to those measured at McLure (1594 ng/L), whereas in February 1993 total fatty acids were 71% higher at Savona than at McLure.

**Table 50 Summary of Fatty Acids Detected in Whole Water from the Thompson River System
(October 1992, February 1993, November 1993)**

Sampling Location:	McLure			Savona		
Sampling Date:	Oct. 1992	Feb. 1993	Nov. 1993	Oct. 1992	Feb. 1993	Nov. 1993
Fatty Acids (ng/L)						
Capric	ND(150)	ND(310)	ND(160)	ND(150)	ND(310)	ND(160)
Lauric	{220}	220	ND(230)	{250}	360	ND(210)
Myristic	200	460	ND(340)	200	680	ND(240)
Palmitic	240	1000	ND(2200)	230	1500	ND(1200)
Linolenic	ND(120)	140	ND(200)	ND(120)	510	ND(180)
Linoleic/Oleic	ND(1000)	180	ND(100)	ND(1000)	210	ND(250)
Stearic	100	{720}	ND(1300)	71	{1300}	ND(730)
Arachidic	ND(12)	ND(24)	ND(16)	ND(12)	34	ND(20)
Behenic	ND(5)	13	ND(37)	84	28	ND(22)
Lignoceric	190	55	ND(44)	ND(20)	270	ND(42)
Total Fatty Acids	1594	2955	2314	1486	5047	1527

ND denotes below the indicated detection limit (shown in brackets) when both field replicates and samples were below detection

{ } concentration value equal to or below that of laboratory and/or field blank

Data have been blank corrected

Note: all results presented are a mean of field replicates and samples - one half the detection limit was used when only one of the samples was below the detection limit

- all means rounded to two significant figures

13.2.2 Discussion

13.2.2.1 Whole Water

The presence of relatively high levels of fatty acids at the reference site, McLure, reflects the natural occurrence of these compounds in river water. Furthermore, the increase in total fatty acid concentration in February 1993 versus October 1992 at both McLure and Savona indicates that a natural fluctuation in fatty acid levels may occur between fall and winter. In the case of

Savona, the higher total fatty acid concentration measured in the winter versus the fall may be related to an increase in algal biomass. Winter limnological conditions at Kamloops Lake, which are conducive to an increase in nutrient concentration downstream of the lake at Savona (St. John *et al.*, 1976), have been shown to be associated with an increase in periphytic diatom growth (Nordin and Holmes, 1992). Diatomic algae have been demonstrated to contain high levels of C₁₄, C₁₆, and C₂₀ fatty acids relative to other fatty acids (Werner, 1977). These fatty acids (myristic, palmitic and arachidic) comprised 44% of total fatty acids in suspended sediments from Savona collected in February 1993, whereas in October 1992 they comprised only 29% of the total. A similar change in the fatty acid ratio between fall and winter was observed at McLure. Whereas C₁₄, C₁₆, and C₂₀ fatty acids comprised 49% of total fatty acids in February 1993, they comprised only 29% of the total in October 1992. No comparisons could be made with November 1993 data due to high detection limits.

Conversely, it is possible that the 340% increase in total fatty acid concentration measured at Savona in February 1993, relative to October 1992, may be pulp mill related. Reduced mixing in Kamloops Lake during winter limnological conditions (Bothwell *et al.*, 1992) may account for the higher fatty acid levels observed at this time of the year compared to the fall, when pulp mill effluent is more extensively diluted. However, since there are numerous natural fatty acid sources and since these compounds have not been investigated in effluent from the Weyerhaeuser mill, it is difficult to accurately evaluate the source of fatty acids found in the receiving environment downstream of the pulp mill.

13.2.2.2 Comparisons of Fatty Acid Concentrations to Guidelines and Criteria

No guidelines or criteria presently exist for fatty acids concentrations. However, total fatty acid concentrations (based on linolenic and linoleic/oleic acids) measured in whole water from the Thompson River were approximately 29 to 93 times lower than the sublethal concentration (20 µg/L) and approximately 29,000 to 93,000 times lower than the lethal concentration (22,000 µg/L) for rainbow trout as reported by McLeay and Associates (1987).

13.3 Fraser River

13.3.1 Results

13.3.1.1 Suspended Sediments

Fatty acids were measured in suspended sediments at Shelley, Marguerite and Yale in November 1994. Refer to Table 51 for a summary of these results. All fatty acids measured were clearly higher in concentration at both Marguerite and Yale relative to Shelley. Accordingly, the total

Table 51 Summary of Fatty Acids Detected in Suspended Sediments from the Fraser River (November 1994)

Sampling Location	Shelley	Marguerite	Yale
Fatty Acid (ng/g)			
Capric	570	4,900	2,900
Lauric	1,300	5,000	3,900
Myristic	17,000	33,000	44,000
Palmitic	37,000	140,000	100,000
Linolenic	3,900	8,500	11,000
Linoleic	3,500	11,000	5,100
Oleic	9,600	46,000	27,000
Stearic	4,400	33,000	23,000
Arachidic	740	2,600	1,400
Behenic	530	3,200	1,000
Lignoceric	70	460	110
Total Fatty Acids	78,610	288,660	219,410

Note: all results presented are a mean of field splits and samples - one half the detection limit was used when only one of the samples was below the detection limit
All means rounded to two significant figures

fatty acid concentration measured at Marguerite and Yale were 3.7 times and 2.8 times greater, respectively, than that measured at Shelley. Palmitic acid was the most abundant fatty acid measured in suspended sediment from the Fraser River, comprising approximately 50% of the total fatty acid concentration.

13.3.1.2 Whole Water

Refer to Table 52 for a summary of fatty acids measured in whole water samples from the Fraser River for October 1992, February 1993 and November 1993. All fatty acids, with the exception of linoleic/oleic acids, were detected at most sampling sites including Shelley. However, with

Table 52 Summary of Fatty Acids Detected in Whole Water from the Fraser River (October 1992, February 1993, November 1993)

Sampling Location:	Shelley			Woodpecker			Marguerite			Yale		
Sampling Date:	Oct. 1992	Feb. 1993	Nov. 1993	Oct. 1992	Feb. 1993	Nov. 1993	Oct. 1992	Feb. 1993	Nov. 1993	Oct. 1992	Feb. 1993	Nov. 1993
Fatty Acids (ng/L)												
Capric	ND(150)	ND(85)	ND(160)	ND(150)	ND(44)	ND(160)	ND(150)	ND(44)	ND(160)	ND(150)	150	ND(160)
Lauric	{190}	ND(47)	100	{90}	ND(24)	150	{110}	ND(24)	ND(90)	{210}	ND(90)	ND(90)
Myristic	190	ND(51)	ND(130)	130	ND(26)	ND(130)	170	ND(26)	ND(130)	340	{160}	ND(130)
Palmitic	310	ND(73)	480	240	ND(38)	ND(320)	280	ND(73)	ND(320)	420	{410}	ND(320)
Linolenic	ND(120)	ND(67)	ND(110)	ND(120)	18	ND(110)	ND(120)	ND(34)	ND(110)	ND(120)	ND(130)	ND(110)
Linoleic/Oleic	ND(1000)	ND(58)	ND(110)	ND(1000)	ND(30)	ND(100)	ND(1000)	ND(30)	ND(100)	ND(1000)	ND(110)	ND(100)
Stearic	180	ND(32)	470	91	ND(16)	ND(270)	85	ND(32)	ND(270)	110	{1300}	ND(270)
Arachidic	ND(12)	ND(6.7)	ND(12)	33	22	26	38	10	37	41	21	14
Behenic	64	{2.6}	39	460	470	260	490	230	370	370	240	130
Lignoceric	160	7.4	70	760	1200	290	880	610	360	870	710	170

ND denotes below the indicated detection limit (shown in brackets) when both field replicates and samples were below detection

{ } concentration value equal to or below that of laboratory and/or field blank

Data have been blank corrected

Note: all results presented are a mean of field replicates and samples - one half the detection limit was used when only one of the samples was below the detection limit

- all means rounded to two significant figures

the exception of arachidic (10-41 ng/L), behenic (2.6-490 ng/L) and lignoceric (7.4-1200 ng/L) acids, the behaviour of the majority of the fatty acids was difficult to interpret due to high detection limits. Nevertheless, arachidic, behenic and lignoceric acids accounted for the majority of the total fatty acid concentration downstream of Shelley. These three fatty acids were higher in concentration at all three downstream sites relative to Shelley for all three dates sampled. Refer to Figure 15 for the concentration of lignoceric acid in Fraser River Basin whole water samples for October 1992, February 1993 and November 1993. Note that this fatty acid was detected in considerably lower concentrations in the Thompson River in comparison to the Fraser River.

13.3.2 Discussion

13.3.2.1 *Suspended Sediments*

Although all fatty acids measured were present at the reference site, the total fatty acid concentration at Yale and Marguerite was three to four times greater, respectively, than at Shelley. In spite of the fact that all Fraser River pulp mills employ secondary treatment, the data suggest that pulp mill effluent inputs from Prince George, Quesnel and Kamloops may be contributing to elevating the levels of these compounds in suspended sediments downstream of the mills. Several fatty acids detected in suspended sediments from the three sites have been shown to be major components ($>100 \mu\text{g/L}$) of kraft pulp mill effluent (Fox, 1977). These include myristic, palmitic, stearic, arachidic, behenic, lignoceric, oleic and linoleic acids. It is interesting to note that although total fatty acids were higher at both Marguerite and Yale than at Shelley, individual fatty acids did not differ in their relative proportions of the total fatty acid concentration at each of the three sites (Figure 16).

13.3.2.2 *Whole Water*

Although all fatty acids measured in suspended sediments showed an increase in concentration downstream of pulp mills relative to upstream, due to higher detection limits in whole water samples, only three fatty acids showed this pattern in whole water samples. Arachidic (C_{20}), behenic (C_{22}) and lignoceric (C_{24}) acids were the only fatty acids which were clearly higher in concentration at Woodpecker, Marguerite and Yale, relative to Shelley. All three fatty acids have been found to be major components of kraft pulp mill effluent (Fox, 1977). The behaviour of the remainder of the fatty acids was difficult to interpret due to high detection limits. We would therefore recommend that a much larger sample size be taken in order to obtain lower detection limits.

Legend

- ★ Reference Sampling Site
- ★ Downstream Sampling Site
- Thompson River System

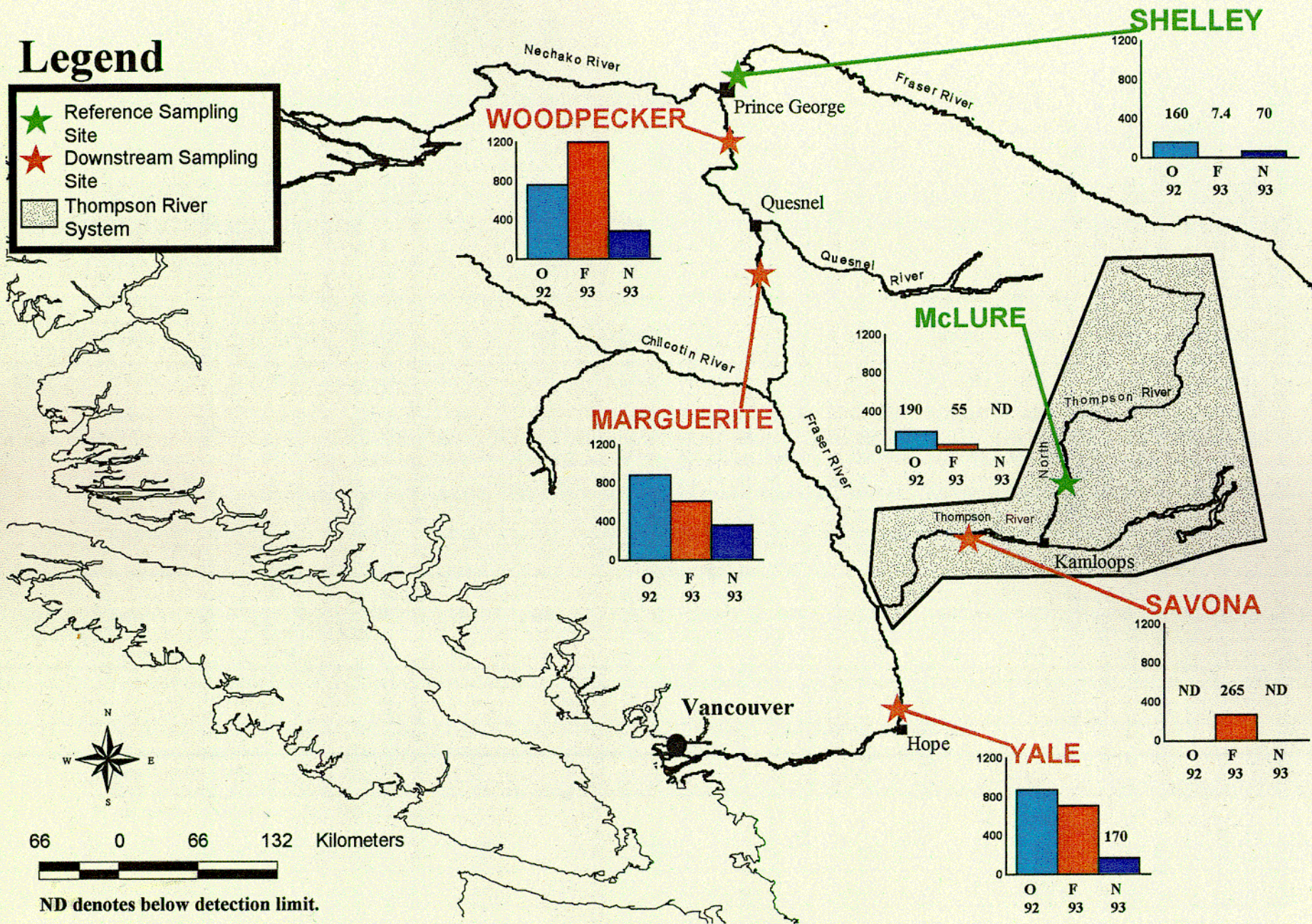


Figure 15 Lignoceric Acid Concentrations (ng/L) in Whole Water from the Fraser and Thompson River Systems

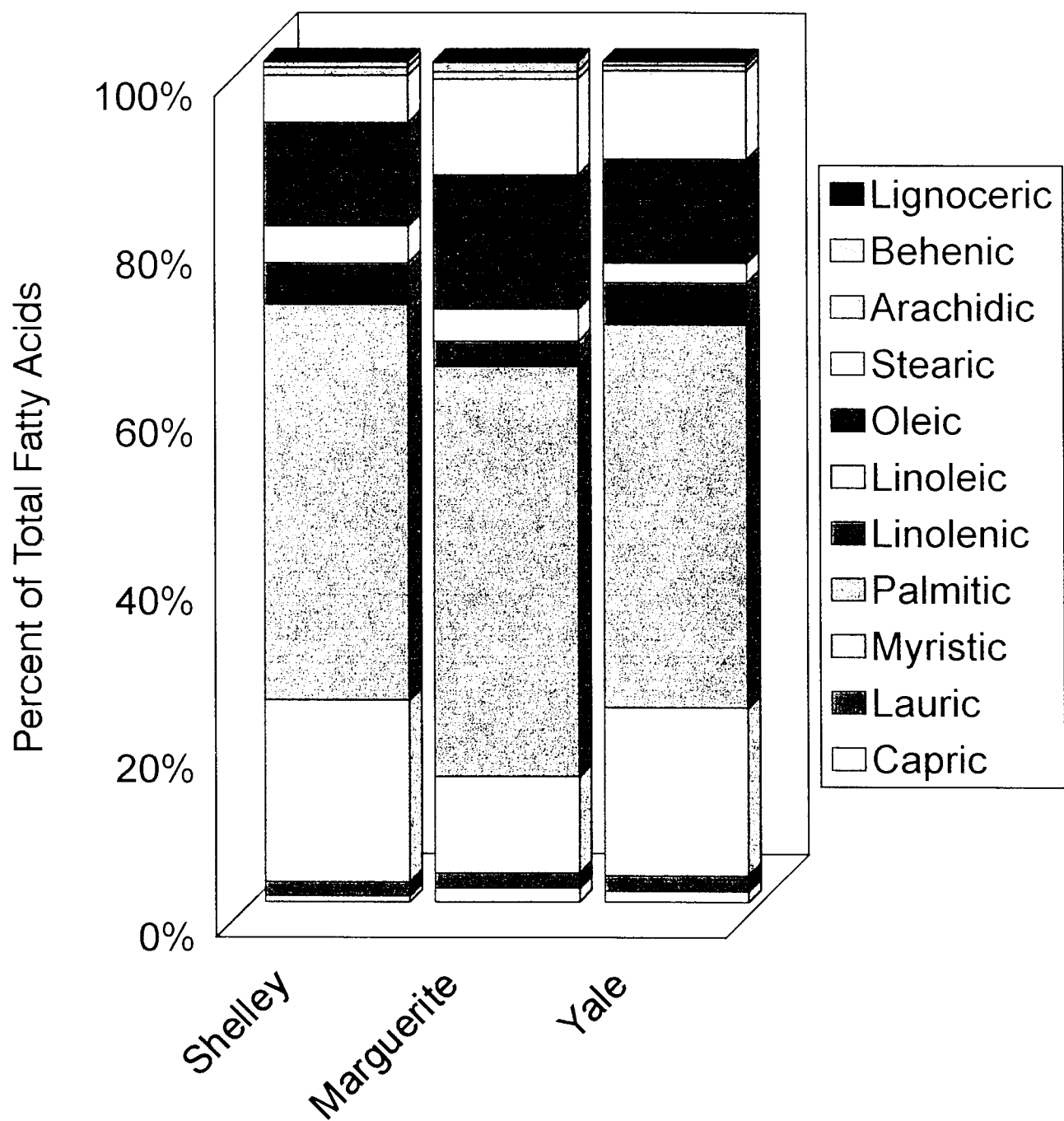


Figure 16 Fatty Acid Profile of
Fraser River Suspended Sediment
(November 1994)

13.3.2.3 Comparisons of Fatty Acid Concentrations to Guidelines and Criteria

No guidelines or criteria presently exist for fatty acids concentrations. Total fatty acid concentrations (based on linolenic and linoleic/oleic acids) from the Fraser River were approximately 36 to 360 times less than sublethal concentrations (20 µg/L) and 39,000 to 700,000 times less than the lethal concentration (22,000 µg/L) for rainbow trout as reported by McLeay and Associates (1987).

14.0 RESIN ACIDS

14.1 Introduction

Resin acids are unsaturated, tricyclic monocarboxylic acids. They are normally insoluble in water but are soluble in various organic solvents and in dilute sodium hydroxide through the formation of sodium salts (Windholtz *et al.*, 1983). Resin acids are present in oleoresin, a composition of hydrophobic material from conifers (Swan, 1973), and in tall oil, a resin containing by-product of the kraft pulping process (Rogers and Harris, 1970). While resin acids represent only a few per cent of the weight of the wood (Enos *et al.*, 1970), the quantities which can be released into the environment through pulp mill effluents may reach toxic levels (Davis and Hoos, 1975). Even when diluted by receiving waters, concentrations of these compounds may still be sufficient enough to exert chronic effects on the aquatic community (Brownlee *et al.*, 1977). With the exception of dehydroabietic acid, resin acids are all bioaccumulated and their toxicity increases with decreasing pH (Dwernychuk, 1994).

Numerous resin acids have been identified in mechanical pulping effluents, unbleached white water, woodroom wastes, bleached kraft whole mill effluents, sulphite effluents and paper mill effluents (Hemmigway and Greaves, 1973; Leach and Thakore, 1976). Resin acid concentrations entering a receiving water will depend upon the wood furnish in the mill, the age of chips used, the mill process and the extent of biological treatment prior to effluent discharge (Swanson, 1992). Although biological treatment of pulp mill effluent has been shown to reduce resin acid levels by up to 96% (Beak, 1987), resin acids have been detected in the final effluent of pulp and/or paper mills located on the Fraser River (IRC, 1994). In the receiving environment, Dwernychuk (1990) found resin acid levels exceeding the recommended surface water guidelines in Fraser River water samples collected from the Prince George region; samples from the Quesnel region, however, were within the recommended guidelines.

14.2 Thompson River System

14.2.1 Results

14.2.1.1 Whole Water

Refer to Table 53 for a summary of resin acids measured in whole water from the Thompson River System. High detection limits for samples collected in October 1992 and November 1993 restricted comparisons to samples taken from McLure and Savona in February 1993. Although pimaric (12 ng/L), sandaracopimaric (2.0 ng/L), isopimaric (20 ng/L), dehydroabietic (46 ng/L) and abietic (12 ng/L) acids were detected at Savona in concentrations slightly higher than at

**Table 53 Summary of Resin Acids Detected in Whole Water from the Thompson River System
(October 1992, February 1993, November 1993)**

Sampling Location:	McLure			Savona		
Sampling Date:	Oct. 1992	Feb. 1993	Nov. 1993	Oct. 1992	Feb. 1993	Nov. 1993
Resin Acids (ng/L)						
Pimaric	ND(17)	ND(1.1)	ND(3.2)	ND(23)	12	ND(4.8)
Sandaracopimaric	ND(16)	ND(1.0)	ND(3.2)	ND(210)	20	ND(4.8)
Isopimaric	ND(20)	5.3	ND(4.1)	ND(16)	20	ND(5.7)
Palustic	ND(25)	ND(4.5)	ND(6.3)	ND(20)	ND(8.4)	ND(8.4)
Dehydroisopimaric	ND(37)	ND(2.4)	ND(5.7)	ND(24)	ND(4.8)	ND(7.9)
Dehydroabietic	{46}	{15}	ND(150)	ND(18)	{46}	ND(150)
Abietic	ND(60)	ND(4.7)	ND(17)	ND(54)	12	ND(27)
Neoabietic	ND(18)	ND(1.1)	ND(3.8)	ND(15)	ND(2.4)	ND(4.7)
12/14 Chlorodehydroabietic	ND(6.7)	ND(0.8)	ND(2.2)	ND(6.8)	ND(2.4)	ND(3.1)
12,14 Dichlorodehydroabietic	ND(12)	ND(1.0)	ND(2.5)	ND(9.4)	ND(4.1)	ND(3.3)

ND denotes below the indicated detection limit (shown in brackets) when both field replicates and samples were below detection

{ } concentration value equal to or below that of laboratory and/or field blank

Note: all results presented are a mean of field replicates and samples - one half the detection limit was used when only one of the samples was below the detection limit

- all means rounded to two significant figures

McLure, there appears to be very little difference in resin acid concentrations between the two sites.

14.2.2 Discussion

14.2.2.1 Whole Water

Since concentrations of resin acids measured at Savona were similar to those measured at McLure, it is unlikely that industrial sources are major contributors to resin acids in the Thompson River between Kamloops and Savona.

14.2.2.2 Comparison of Resin Acid Concentrations to Guidelines and Criteria

Resin acid concentrations in whole water samples from the Thompson River System were compared to BCMELP working criteria for resin acids for the protection of aquatic life (BCMELP, 1994a). Both dehydroabietic acid and total resin acids were well below the BCMELP working criteria for resin acids in water. No resin acid guidelines or criteria presently exist for resin acids in freshwater sediments.

14.3 Fraser River

14.3.1 Results

14.3.1.1 Suspended Sediments

Resin acids were measured in suspended sediments at Shelley, Marguerite and Yale in November 1994. Refer to Table 54 for a summary of these results. Resin acid concentrations in suspended sediment samples from Marguerite and Yale were clearly higher than those measured at Shelley. Relative to Shelley, total resin acids were approximately 124 times greater at Marguerite and approximately 64 times greater at Yale. Moreover, the total resin acid concentration measured at Marguerite was almost double of that measured at Yale. Two resin acids, dehydroabietic and abietic acids, comprised between 61-72% of total resin acids measured at all three sites.

Table 54 Summary of Resin Acids Detected in Suspended Sediments from the Fraser River (November 1994)

Sampling Location Resin Acid (ng/g)	Shelley	Marguerite	Yale
Pimaric	24	18,000	9,300
Sandaracopimaric	40	2,400	1,500
Isopimaric	140	15,000	7,700
Palustric	17	61	40
Dehydroisopimaric	ND(2.1)	1,700	770
Dehydroabietic	420	31,000	15,000
Abietic	170	32,000	17,000
Neoabietic	2.5	76	33
12/14 Chlorodehydroabietic	ND(1.7)	900	550
12,14 Dichlorodehydroabietic	ND(1.4)	340	190
Total Resin Acids	816	101,477	52,083

Note: all results presented are a mean of field splits and samples - one half the detection limit was used when only one of the samples was below the detection limit

ND = Not detected (detection limit in brackets)

For values below detection limits, one half the specified detection limit was used in summing total resin acids

All means rounded to two significant figures

14.3.1.2 Whole Water

Refer to Table 55 for a summary of resin acid concentrations measured in Fraser River whole water in October 1992, February 1993 and November 1993. With the exception of palustric (19 ng/L) and dehydroabietic acids (4.0-510 ng/L), resin acids were found in concentrations below detection limits or blank values at the reference site, Shelley. Resin acid levels were generally observed to be higher at all downstream sites for all three sampling dates. Moreover, resin acids were generally higher in concentration in October 1992 and February 1993 relative to November 1993. Refer to Figure 17 for the concentration of abietic acid in whole water from the Fraser

Table 55 Summary of Resin Acids Detected in Whole Water from the Fraser River. (October 1992, February 1993, November 1993)

Sampling Location:	Shelley			Woodpecker			Marguerite			Yale		
Sampling Date:	Oct. 1992	Feb. 1993	Nov. 1993	Oct. 1992	Feb. 1993	Nov. 1993	Oct. 1992	Feb. 1993	Nov. 1993	Oct. 1992	Feb. 1993	Nov. 1993
Resin Acids (ng/L)												
Pimaric	ND(7.6)	ND(2.4)	ND(1.1)	150	260	26	170	160	39	92	24	15
Sandaracopimaric	ND(7.1)	ND(2.1)	ND(0.6)	24	31	3.5	21	17	5.0	ND(35)	4.4	2.3
Isopimaric	ND(11)	ND(4.0)	{12}	170	200	50	180	130	72	90	30	34
Palustric	ND(15)	19	ND(7.0)	ND(41)	55	15	ND(32)	27	{13}	ND(47)	ND(3)	ND(7.0)
Dehydroisopimaric	ND(23)	ND(3.7)	ND(1.6)	ND(20)	6.7	ND(1.3)	ND(20)	5.7	ND(2.5)	ND(34)	3.5	ND(1.5)
Dehydroabietic	510	4.0	ND(160)	390	310	{160}	470	ND(230)	180	290	{53}	ND(160)
Abietic	ND(32)	ND(16)	ND(3.5)	120	390	71	190	240	90	69	38	39
Neoabietic	ND(4.1)	ND(2.6)	ND(0.5)	ND(4.6)	21	2.5	ND(4.9)	4.0	1.2	ND(24)	ND(0.8)	0.80
12/14 Chlorodehydroabietic	ND(5.2)	ND(1.7)	ND(0.6)	31	46	2.7	27	20	1.6	ND(12)	10	1.8
12,14 Dichlorodehydroabietic	ND(6.4)	ND(1.7)	ND(1.3)	ND(4.7)	8.0	ND(0.5)	ND(7.5)	4.4	ND(0.4)	ND(16)	3.0	ND(0.3)

ND denotes below the indicated detection limit (shown in brackets) when both field replicates and samples were below detection

{ } concentration value equal to or below that of laboratory and/or field blank

- all results presented are a mean of field replicates and samples - one half the detection limit was used when only one of the samples was below the detection limit

- all means rounded to two significant figures

Legend

- ★ Reference Sampling Site
- ★ Downstream Sampling Site
- Thompson River System

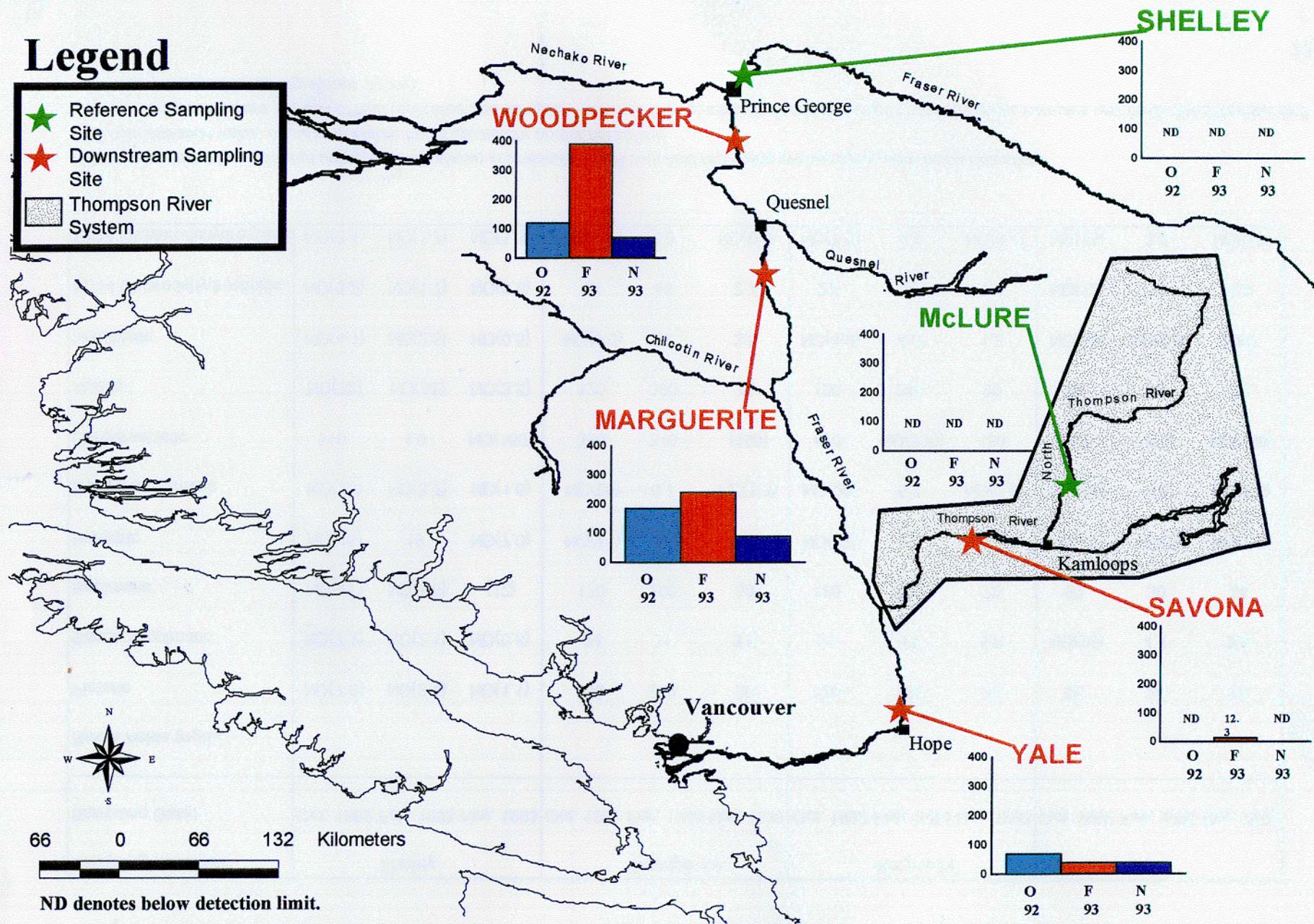


Figure 17 Abietic Acid Concentrations (ng/L) in Whole Water from the Fraser and Thompson River Systems

River Basin. Whereas abietic acid was only slightly above the detection limit at Savona (12 ng/L), considerably higher concentrations were measured at Woodpecker (390 ng/L) and Marguerite (240 ng/L) in February 1993. Similarly, the large majority of resin acids were notably higher in the Fraser River in comparison to the Thompson River System.

14.3.2 Discussion

14.3.2.1 *Suspended Sediments*

Resin acid concentrations in suspended sediments collected in November 1994 were clearly higher at Marguerite and Yale relative to Shelley. As with fatty acids measured in suspended sediments, resin acid concentrations in samples from Marguerite were the highest of all Fraser River sites. Furthermore, dehydroabietic and abietic acids, which were found to comprise >60% of total resin acids, were detected at Marguerite in concentrations of 74 and 188 times higher than the reference site, Shelley (Figure 18). Similar findings were reported in a study conducted by Brownlee *et al.* (1977) in which dehydroabietic acid measured in surficial sediments from Lake Superior was found at concentrations up to 67 times greater downstream of a kraft pulp and paper mill relative to upstream sites. Both abietic acid and isopimaric acid (an isomer of pimaric acid) were identified in kraft pulp mill effluents discharged into Lake Superior (Brownlee and Strachan, 1977; Fox, 1977). Lastly, the fact that the two chlorinated resin acids (12/14 chlorodehydroabietic and 12,14 dichlorodehydroabietic) were only detected at sites downstream of pulp mills (Woodpecker and Yale) is indicative of their association with industrial sources.

14.3.2.2 *Whole Water*

With the exception of dehydroabietic acid, resin acid concentrations were higher downstream of the Fraser River pulp mills than at Shelley. Similar findings have been reported by Dwernychuk (1990) who found that resin acids measured in whole water were elevated downstream of the Prince George and Quesnel pulp mills. Although the highest concentrations at Woodpecker were generally measured during the winter low flow period (February 1993), this was not observed at either Marguerite or Yale. Moreover, during the winter low flow period, resin acid concentrations decreased from Woodpecker to Yale. This would indicate that the Prince George pulp mills may be contributing the largest portion of resin acids to the upper Fraser River.

The greater prominence of resin acids in the Fraser River receiving environment relative to that of the Thompson River may be reflective of differences in pulp mill resin acid outputs or alternatively it may be indicative of differences in natural resin acid sources between the two riverine systems.

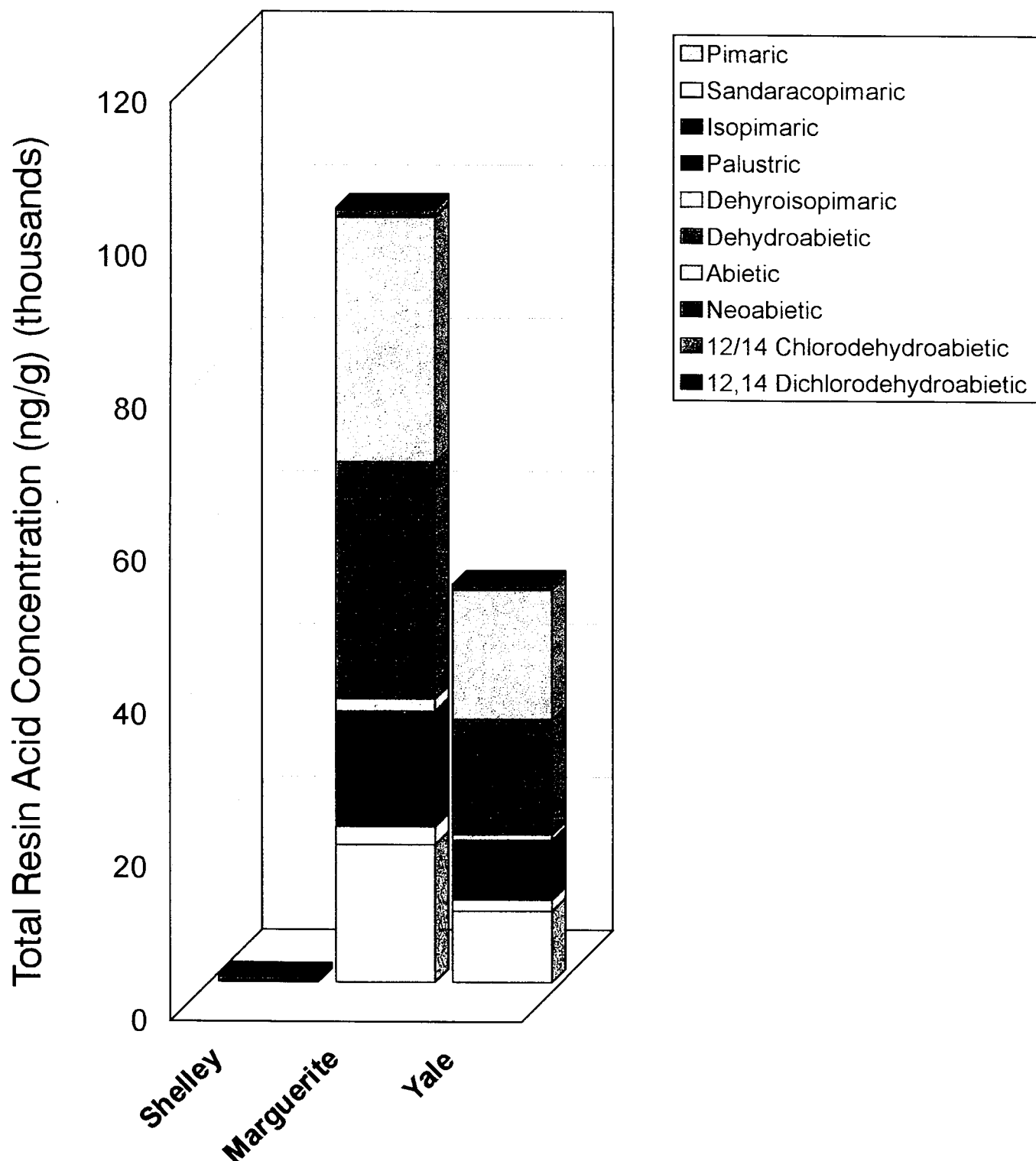


Figure 18 Total Resin Acids in Fraser River Suspended Sediment (November 1994)

As with fatty acids, analytical detection of resin acids was superior in suspended sediment samples in comparison to that of whole water samples. Research shows that resin acids are nearly insoluble in water (Winholtz *et al.*, 1983) and are therefore expected to travel with particles or organic matter (Taylor and Yeager, 1987). As such, suspended sediments may be the preferred medium for the detection of resin acids in the water column.

14.3.2.3 Comparison of Resin Acid Concentrations to Guidelines and Criteria

Resin acid concentrations in whole water samples from the Fraser River were compared to BCMELP working criteria for resin acids for the protection of aquatic life (BCMELP, 1994a). Both dehydroabietic acid and total resin acids were well below the BCMELP working criteria for resin acids in fresh water. No resin acid guidelines or criteria presently exist for resin acids in freshwater sediments.

15.0 TOTAL TRACE METALS

15.1 Introduction

Trace metal concentrations in river water are an important indicator of water quality due to their potential toxicity to aquatic life. Some trace metals such as iron are required elements of freshwater biota, while others such as mercury, arsenic and lead can be toxic to freshwater organisms. Metal toxicity has been shown to be affected by a number of variables, including temperature, oxygen levels, pH (Foulkes 1990), water hardness and the presence or absence of other metal ions (Enserink *et al.*, 1991). Heavy metals such as lead, mercury and cadmium have been shown to readily accumulate in the food chain with resultant harmful effects in the uppermost trophic levels (Watras and Bloom, 1982).

Most metals found in surface waters are derived from natural weathering of metal-bearing soils and rocks, whereas anthropogenic sources include metal plating plants, sewage treatment plants and atmospheric deposition (Shaw and El-Shaarawi, 1995). Mining may also contribute trace metals to receiving waters in the Fraser River Basin. As of 1991, there were six active metal mines in the basin extracting copper, molybdenum, silver and gold (Schreier *et al.*, 1991). Although most mines have self-contained water treatment systems, acid mine drainage from tailings and waste rock from abandoned mines still remains a concern. For example, the Giant Mascot Nickel mine near Hope, although no longer in operation for more than 20 years, was still still releasing acid mine drainage, likely rich in nickel and copper, as recently as 1991 (Schreier *et al.*, 1991). There is also concern over mercury contamination from the abandoned Pinchi Lake mine in the Stuart River area, where mercury-rich tailings were deposited in Pinchi Lake during the 1930s and 1940s. Moreover, the disturbance and release of mercury sediments in historic placer mining could potentially have an impact in some selected locations where old claims are reworked. There are currently several large placer mining sites and over 200 smaller ones in operation in the Cariboo and upper Bridge areas of the Fraser River Basin (Schreier *et al.*, 1991).

15.2 Thompson River System

15.2.1 Results

All trace metal and nutrient data are presented in summarized form. Refer to Appendix V for complete data results and to Appendix III for a detailed description of the statistical analyses performed on the data.

Refer to Table 56 for a summary of total trace metal concentrations in whole water samples from the Thompson River System. Table 57 presents a summary of significant t-test results ($P < 0.05$) for spatial comparisons of total trace metals. In October 1992, the aluminum, cobalt, iron, lithium,

Table 56 Summary of Total Trace Metal Concentrations in Whole Water from the Thompson River System (October 1992 , February 1993)

Sampling Location:	McLure		Savona	
Sampling Date:	Oct. 92	Feb. 93	Oct. 92	Feb. 93
Metals (ug/L)				
Aluminium	140	29	67	19
Barium	7.8	8.7	9.3	9.4
Beryllium	<0.050	<0.050	<0.050	<0.050
Cadmium	0.057	<0.050	<0.050	<0.050
Chromium	<0.20	{0.24}	<0.20	<0.20
Cobalt	0.16	0.13	0.073	0.12
Copper	{0.82}	{0.24}	{0.82}	0.21
Iron	280	110	100	51
Lithium	0.82	<0.10	0.56	<0.10
Lead	<0.10	1.5	<0.10	1.2
Manganese	5.5	6.4	3.1	5.6
Molybdenum	0.51	1.1	0.54	0.92
Nickel	0.64	0.60	{0.21}	0.58
Strontium	81	90	79	84
Vanadium	0.37	0.31	0.29	0.29
Zinc	{0.26}	1.8	0.88	2.1
Arsenic	0.068	0.10	0.13	0.14
Selenium	<0.050	<0.050	<0.050	<0.050
Mercury	0.011	{0.010}	<0.010	<0.010

{ } denotes concentration values equal to or below that of the laboratory and/or field blanks

all results presented are a mean of field replicates - when samples were below detection limits, these were used in calculation of the means
- all means rounded to two significant figures

Table 57 Summary of Significant t-test Results for Spatial Comparisons of Total Trace Metals in Whole Water from the Thompson River System

Date	Sites Compared	Parameter	t*	d.f.	p
October 1992	McLure vs. Savona	Aluminum	9.713	2.6	0.004
		Barium	-6.784	2.7	0.009
		Cobalt	6.859	3.4	0.004
		Iron	25.182	2.4	0.001
		Lithium	12.775	2.7	0.000
		Manganese	22.112	3.3	0.000
		Molybdenum	-1.315	3.9	0.035
		Nickel	5.021	2.1	0.035
		Vanadium	7.778	2.6	0.008
		Arsenic	-10.298	3.9	0.001
February 1993	McLure vs. Savona	Aluminum	3.721	2.9	0.035
		Arsenic	-4.243	2.6	0.033

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value indicates that the parameter is significantly higher at the second site indicated.

manganese, nickel and vanadium were significantly higher at Savona than at McLure. In February 1993, arsenic concentrations were significantly higher at Savona versus McLure, whereas aluminum was significantly higher at McLure than at Savona.

Refer to Table 58 for a summary of significant t-test results ($P < 0.05$) for temporal comparisons of total trace metals measured in whole water. Aluminum, copper, and iron were significantly higher in October 1992 versus February 1993 at both McLure and Savona, whereas the rest of the metals in Table 58 were significantly higher in February 1993 than in October 1992 at both sites sampled.

15.2.2 Discussion

The significantly higher ($P < 0.05$) concentrations of aluminum, cobalt, iron, lithium, manganese,

Table 58 Summary of Significant t-test Results for Temporal Comparisons of Total Trace Metals in Whole Water from the Thompson River System

Site	Dates Compared	Parameter	t*	d.f.	p
McLure	October 1992 vs February 1993	Aluminum	15.146	2.5	0.002
		Copper	5.149	3.4	0.011
		Iron	7.695	2.4	0.009
		Lead	-81.228	2.0	0.000
		Arsenic	-6.625	3.8	0.003
Savona	October 1992 vs February 1993	Aluminum	16.403	2.8	0.001
		Copper	3.761	3.9	0.033
		Iron	15.309	3.0	0.000
		Lithium	-7379.695	3.7	0.000
		Lead	-21.520	2.0	0.002
		Manganese	-12.460	3.0	0.001
		Molybdenum	-21.541	4.0	0.000
		Nickel	-11.000	2.4	0.004
		Zinc	-5.735	2.6	0.016

* A positive t value signifies that the parameter is significantly higher on the first date indicated, whereas a negative value signifies that the parameter is significantly higher on the second date indicated.

nickel and vanadium observed in October 1992 at McLure versus Savona are likely due to the higher suspended sediment concentration at the former site (3.1 mg/L) compared to the latter site (0.9 mg/L). Since these trace metals occur naturally in sediments (CCREM, 1987), a higher trace metal concentration would be expected in whole water samples from sites with higher suspended sediment concentrations. The similarity between most trace metal concentrations at McLure and Savona in February 1993 is likely the result of comparable suspended sediment concentrations (1.6 mg/L and 1.1 mg/L, respectively) at these sites. Moreover, the significantly higher ($P < 0.05$) concentrations of aluminum, copper and iron observed at McLure and Savona in October 1992 compared to February 1993 is also likely related the higher suspended sediment concentrations measured at both sites in the former versus the latter months.

15.2.2.1 Comparisons of Total Trace Metal Concentrations to Guidelines and Criteria

Total trace metal concentrations from the Thompson River System were compared with BCMELP freshwater criteria for the protection of aquatic life (BCMELP, 1994a) and CCREM guidelines for freshwater aquatic life (CCREM, 1987). Refer to Table 59 for comparisons of trace metal concentrations in whole water samples collected from the Thompson River System with the available water quality criteria and guidelines. (Refer to Table 56 for time specific trace metal concentrations.)

With the exception of total lead and aluminum, no other trace metals exceeded BCMELP criteria or CCREM guidelines. Aluminum exceeded the CCREM guideline of 100 µg/L at McLure in October 1992 (Table 56). Lead exceeded the CCREM guideline of 1 µg/L at both McLure and Savona in February 1993 but not in October 1992. However, lead did not exceed the BCMELP criteria of 34-82 µg/L at either site. No guidelines or criteria presently exist for lithium, strontium and vanadium.

15.3 Fraser River

15.3.1 Results

Refer to Table 60 for a summary of total trace metal concentrations in Fraser River whole water for October 1992 and February 1993. Only the February 1993 sample is available for the Woodpecker site. Refer to Table 61 for a summary of significant t-test results ($P < 0.05$) for spatial comparisons of total trace metals in whole water. In October 1992, molybdenum, strontium and nickel were the only trace metals found in significantly higher concentrations at Marguerite compared to Shelley. Concentrations at Yale were generally several orders of magnitude higher than at the other sites. Thirteen trace metals were detected at Yale in concentrations which were significantly higher compared to Shelley. Yale also had significantly higher trace metal concentrations when compared to Marguerite for 13 of the 19 metals measured.

In February 1993, aluminum, manganese, molybdenum, vanadium and arsenic were significantly higher at Woodpecker with respect to Shelley. The same trace metals (with the exception of manganese) were significantly higher at Yale compared to Shelley.

Table 59 Total Trace Metal Concentrations in Whole Water from the Thompson River System Compared to BCMELP Freshwater Quality Criteria and CCREM Freshwater Quality Guidelines for the Protection of Aquatic Life (October 1992, February 1993)

Total Trace Metals	Concentration in Whole Water (µg/L)		BCMELP Fresh Water Criteria (µg/L) ^{(1),(2)}	CCREM Fresh Water Guidelines (µg/L) ⁽¹⁾
	McLure	Savona		
Aluminum	29 - 140	14 - 69	N/A ⁽³⁾	100
Barium	7.8 - 8.7	9.3 - 9.4	5000	N/A
Beryllium	<0.050	<0.050	5.3	N/A
Cadmium	<0.050 - 0.057	<0.050	0.2	0.2
Chromium	<0.20 - 0.24	<0.20	2 - 20 ⁽⁴⁾	2 - 20 ⁽⁴⁾
Cobalt	0.16 - 0.13	0.073 - 0.12	50	N/A
Copper	0.24 - 0.82	0.21 - 0.82	2.0 - 7.4	2
Iron	100 - 280	51 - 100	300	300
Lead	<0.10 - 1.5	<0.10 - 1.2	34-82 ⁽⁵⁾	1
Manganese	5.5 - 6.4	3.1 - 5.6	100 - 1000	N/A
Molybdenum	0.51 - 1.1	0.54 - 0.92	2000	N/A
Nickel	0.60 - 0.64	0.22 - 0.58	25	25
Zinc	0.26 - 1.8	0.88 - 2.1	30 ⁽⁶⁾	30 ⁽⁷⁾
Arsenic	0.068 - 0.10	0.13 - 0.14	50	50
Selenium	<0.050	<0.050	1	1
Mercury	0.010 - 0.011	<0.010	0.1	0.1

(1) Based on a water hardness of 0-60 mg/L CaCO₃ (unless otherwise specified)

(2) Maximum values reported (unless otherwise specified)

(3) Not applicable to whole water samples

(4) Maximum of 2 µg/L for phytoplankton and zooplankton; maximum of 20 µg/L for fish

(5) Hardness 50-100 mg/L CaCO₃

(6) Tentative criterion

(7) Tentative guideline

**Table 60 Summary of Total Trace Metal Concentrations in Whole Water from the Fraser River
(October 1992, February 1993)**

Sampling Location:	Shelley		Woodpecker	Marguerite		Yale	
Date:	Oct. 92	Feb. 93	Feb. 93	Oct. 92	Feb. 93	Oct. 92	Feb. 93
Metals (ug/L)							
Aluminium	790	32	65	510	85	2100	110
Barium	20	22	21	19	18	45	20
Beryllium	<0.050	<0.050	<0.050	<0.050	<0.050	0.078	<0.050
Cadmium	<0.050	0.065	0.054	<0.050	<0.050	0.077	<0.050
Chromium	<0.20	0.40	0.32	<0.20	0.31	3.9	0.36
Cobalt	0.62	0.29	0.22	0.40	0.21	2.3	0.21
Copper	{1.6}	{0.39}	{0.49}	{2.2}	{0.63}	4.9	{0.81}
Iron	1200	200	200	1000	210	1800	190
Lithium	1.1	2	1.3	0.87	1.2	1.3	0.20
Lead	0.59	<0.10	0.10	0.48	0.14	1.9	1.8
Manganese	29	7.4	18	23	14	120	6.6
Molybdenum	0.14	0.50	1.1	0.39	0.86	0.57	1.3
Nickel	1.6	1.0	0.98	1.1	0.81	8.2	0.95
Strontium	110	160	110	120	100	110	120
Vanadium	0.92	0.18	0.45	0.82	0.61	3.3	0.75
Zinc	{2.5}	1.9	2.7	{2.4}	3.0	{11}	3.0
Arsenic	0.33	0.18	0.31	0.35	0.34	1.0	0.55
Selenium	<0.050	<0.050	<0.050	<0.050	<0.050	0.061	<0.050
Mercury	0.010	{0.010}	0.010	0.011	{0.010}	0.011	{0.010}

{ } denotes concentration values equal to or below that of the laboratory and/or field blanks

- all results presented are a mean of field replicates - when samples were below detection limits, these were used in calculation of the means

- all means rounded to two significant figures

Table 61 Summary of Significant t-test Results for Spatial Comparisons of Total Trace Metals in Whole Water from the Fraser River

Date	Sites Compared	Parameter	t*	d.f.	p
October 1992	Shelley vs. Yale	Aluminum	-15.371	3.7	0.000
		Barium	-15.639	2.8	0.001
		Chromium	-12.333	2.0	0.007
		Cobalt	-17.720	2.8	0.001
		Copper	-9.260	3.7	0.001
		Iron	-5.195	2.0	0.035
		Lead	-30.984	3.6	0.000
		Manganese	-28.259	2.0	0.001
		Molybdenum	-15.203	2.6	0.001
		Nickel	-22.883	2.1	0.001
		Vanadium	-7.754	2.9	0.003
		Zinc	-13.069	2.1	0.005
		Arsenic	-17.922	2.4	0.001
	Shelley vs. Marguerite	Aluminum	-4.763	3.1	0.016
		Cobalt	-5.300	2.4	0.023
		Iron	-9.480	2.0	0.011
		Lithium	-4.115	2.9	0.029
		Manganese	-10.553	3.7	0.001
		Molybdenum	9.493	2.6	0.004
		Nickel	5.900	3.9	0.004
		Strontium	5.189	2.0	0.035
	Marguerite vs Yale	Aluminum	-21.564	2.7	0.000
		Barium	-17.013	2.4	0.002
		Chromium	-12.332	2.0	0.007
		Cobalt	-21.684	2.1	0.002
		Copper	-5.561	3.6	0.007
		Iron	-7.153	2.2	0.015
		Lead	-33.373	3.7	0.000
		Manganese	-29.890	2.1	0.001
		Molybdenum	-4.941	4.0	0.008
		Nickel	-24.335	2.2	0.001
		Strontium	9930.371	2.1	0.000
Vanadium		-8.326	2.6	0.006	
Zinc		-12.906	2.3	0.004	
Arsenic		-17.629	2.3	0.002	
February 1993	Shelley vs. Marguerite	Lithium	5.051	2.0	0.036
		Arsenic	-42.485	2.9	0.000
	Shelley vs. Woodpecker	Aluminum	-12.020	2.6	0.002
		Lithium	9.944	2.2	0.007
		Manganese	-18.176	2.0	0.003
		Molybdenum	-5.794	2.2	0.024
		Strontium	3108.000	3.9	0.000
		Vanadium	-8.835	2.0	0.012
		Arsenic	-21.911	2.3	0.001
	Shelley vs. Yale	Aluminum	-9.453	2.1	0.010
		Lithium	6.708	2.9	0.007
		Molybdenum	-41.676	2.1	0.000
		Strontium	13.005	2.0	0.006
		Vanadium	-85.000	3.2	0.000
		Arsenic	-12.854	2.0	0.006
	Woodpecker vs. Marguerite	Arsenic	-4.000	3.2	0.025
	Woodpecker vs. Yale	Aluminum	-4.970	2.4	0.025
		Lithium	-5.814	2.9	0.011
		Manganese	48.592	2.0	0.000
		Vanadium	-9.820	2.1	0.008
Arsenic		-8.152	2.2	0.012	

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated.

T-tests comparing trace metal concentrations between October 1992 and February 1993 (Table 62) indicate that 42% of metals analysed were significantly higher ($P < 0.05$) in the fall versus the winter sampling period at Shelley, 21% of metals were significantly higher in October 1992 versus February 1993 at Marguerite, and 63% were significantly higher in the former versus the latter months at Yale.

15.3.2 Discussion

The significantly higher concentrations ($P < 0.05$) of trace metals measured at Yale in October 1992 in comparison to both Shelley and Marguerite is clearly related to the suspended sediment concentration which was between 10 to 12 times greater at Yale than at the other two sites. Similar levels of these metals were measured in October 1992 at the Federal-Provincial Water Quality Monitoring Network Station located approximately 28 rkm downstream of Yale at Hope (Monitoring and Systems Branch, Environment Canada). It is unlikely that anthropogenic sources of trace metals are significant to the Fraser River, since under conditions of similar suspended sediment concentrations, such as those at Shelley and Marguerite in October 1992, trace metal concentrations were generally higher at the reference site in comparison to those at Marguerite.

Similarly, the significant increase ($P < 0.05$) in trace metal concentrations at Shelley, Marguerite and Yale in October 1992 with respect to February 1993 is also likely related to the higher suspended sediment concentration during the higher flow fall period versus the low flow winter period. The Federal-Provincial Water Quality Monitoring Network Stations located on the Fraser River at Hansard (approximately 144 rkm upstream of Shelley) and Marguerite also measured a decrease in trace metal concentration in February 1993 compared to October 1992 (Monitoring and Systems Branch, Environment Canada).

The importance of high suspended sediment concentrations in trace metal transport in the lotic environment has been studied by Gibbs (1977) and Trefry (1977) who found that in rivers with high suspended sediment loads, more than 90% of total Fe, Mn, Co, Cu, Zn, Cr and Ni are transported in the particulate phase. Furthermore, Shaw and El-Shaarawi (1995) have shown that there is a close relationship between total iron and non-filterable residue from the Fraser River at Marguerite. Results of Pearson correlations indicate that there is a strong linear relationship between total trace metal concentrations and the suspended sediment concentration for 14 of the 19 trace metals analysed in our study (Table 63). Note that lead was not strongly correlated with the suspended sediment concentration.

Table 62 Summary of Significant t-test Results for Temporal Comparisons of Total Trace Metals in Whole Water from the Fraser River

Site	Dates Compared	Parameter	t*	d.f.	p
Shelley	October 1992 vs. February 1993	Aluminum	15.029	2.0	0.004
		Cobalt	3.894	3.0	0.030
		Iron	173.205	2.0	0.000
		Lithium	-14.078	2.3	0.003
		Lead	20.516	2.0	0.002
		Manganese	31.620	3.2	0.000
		Molybdenum	-16.997	3.0	0.000
		Strontium	-29.001	2.0	0.001
		Vanadium	5.694	2.0	0.029
		Zinc	3.130	3.9	0.037
		Arsenic	13.000	2.1	0.005
Marguerite	October 1992 vs. February 1993	Aluminum	12.156	3.8	0.000
		Cobalt	6.626	2.8	0.009
		Iron	16.140	3.5	0.000
		Lead	8.586	3.8	0.001
Yale	October 1992 vs. February 1993	Aluminum	29.234	2.1	0.001
		Barium	14.709	3.3	0.000
		Chromium	10.564	2.9	0.002
		Cobalt	23.719	2.1	0.001
		Copper	12.510	3.1	0.001
		Iron	13.949	2.0	0.005
		Lead	15.319	2.4	0.002
		Manganese	34.915	2.0	0.001
		Molybdenum	-27.601	2.0	0.001
		Nickel	23.163	2.8	0.000
		Vanadium	9.222	2.0	0.012
		Zinc	9.868	3.8	0.001
		Arsenic	137.000	3.8	0.001

A positive t value signifies that the parameter is significantly higher on the first date indicated, whereas a negative value signifies that the parameter is significantly higher on the second date indicated.

Table 63 Pearson Correlation Values for Total Trace Metal and Suspended Sediment Concentrations (Fraser River Basin - October 1992, February 1993)

Metal	r	p-value
Aluminum	0.954	0.000
Barium	0.870	0.000
Beryllium	0.993	0.000
Cadmium	0.819	0.002
Chromium	0.982	0.000
Cobalt	0.973	0.000
Cobalt	0.973	0.000
Copper	0.939	0.000
Iron	0.823	0.002
Manganese	0.989	0.000
Nickel	0.995	0.000
Zinc	0.959	0.000
Arsenic	0.871	0.000
Selenium	0.993	0.000

Note: the number of observations for each r value = 11

15.3.2.1 Comparisons of Total Trace Metal Concentrations to Guidelines and Criteria

Total trace metal concentrations from the Fraser River were compared with BCMELP freshwater criteria for the protection of aquatic life (BCMELP, 1994a) and CCREM guidelines for freshwater aquatic life (CCREM, 1987).

Refer to Table 64 for comparisons of trace metal concentrations measured in Fraser River whole water to water quality guidelines and criteria. (Refer to Table 60 for site specific concentrations.) Four trace metals exceeded the BCMELP and CCREM freshwater criteria or guidelines.

Table 64 Total Trace Metal Concentrations in Whole Water from the Fraser River Compared to BCMELP Freshwater Quality Criteria and CCREM Freshwater Quality Guidelines for the Protection of Aquatic Life (October 1992, February 1993)

Total Trace Metals	Concentration in Whole Water (µg/L)	BCMELP Fresh Water Criteria (µg/L)^{(1),(2)}	CCREM Fresh Water Guidelines (µg/L)⁽¹⁾
Aluminum	32 - 2100	N/A ⁽³⁾	100
Barium	18 - 45	5000	N/A
Beryllium	<0.050 - 0.078	5.3	N/A
Cadmium	<0.050 - 0.077	0.8 ⁽⁴⁾	0.8
Chromium	<0.20 - 3.9	2 - 20 ⁽⁵⁾	2 - 20 ⁽⁵⁾
Cobalt	0.21 - 2.3	50	N/A
Copper	0.39 - 4.9	7.64 - 13.2	2
Iron	190 - 1800	300	300
Lead	<0.10 - 1.9	34-82 ⁽⁴⁾	2
Manganese	6.6 - 120	100 - 1000	N/A
Molybdenum	0.14 - 1.3	2000	N/A
Nickel	0.81 - 8.2	65	65
Zinc	1.9 - 11	30 ⁽⁶⁾	30 ⁽⁷⁾
Arsenic	0.18 - 1.0	50	50
Selenium	<0.050 - 0.061	1	1
Mercury	0.010 - 0.011	0.1	0.1

(1) Based on a water hardness of 60-120 mg/L CaCO₃ (unless otherwise specified)

(2) Maximum values reported (unless otherwise specified)

(3) Not applicable to whole water samples

(4) Hardness 50-100 mg/L CaCO₃

(5) Maximum of 2 µg/L for phytoplankton and zooplankton; maximum of 20 µg/L for fish

(6) Tentative criterion

(7) Tentative guideline

Aluminum exceeded the CCREM guideline of 100 µg/L at Shelley, Marguerite and Yale in October 1992 and at Yale in February 1993. Chromium exceeded the CCREM guideline and BCMELP criterion of 2 µg/L (for phytoplankton and zooplankton) at Yale in October 1992 only. Copper exceeded the CCREM guideline of 2 µg/L only at Marguerite and Yale, both in October 1992. Lastly iron exceeded the CCREM guideline and BCMELP criterion of 300 µg/L at Shelley, Marguerite and Yale in October 1992. It should be noted that all trace metals which exceeded federal guidelines and/or provincial criteria did so in October 1992 when suspended sediment concentrations in the water column were high (18.9 - 226 mg/L). In addition, federal and provincial water quality monitoring data collected from the Fraser River between 1985-1991 indicates that our data fall well within the range of median values for total aluminum, copper, iron and zinc concentrations (Shaw and El-Shaarawi, 1995), indicating that although concentrations of these trace metals exceeded guidelines, they are normal values for the Fraser River.

16.0 PHOSPHORUS

16.1 Introduction

Phosphorus in the aquatic environment exists in association with particulate matter or in dissolved form. Principal dissolved inorganic phosphorus forms found in water with pH values ranging between 5 and 9 are H_2PO_4^- , HPO_4^{2-} , orthophosphate (PO_4^{3-}), polyphosphates and phosphorus combined with adsorptive colloids (Wetzel, 1975). Phosphate has a high affinity to clays as a consequence of the specific chemical interaction of PO_4^{3-} with Al^{3+} on the edges of the clay plates (Stumm and Leckie, 1971). Soluble phosphate concentrations in unpolluted rivers are usually less than 0.01 mg/L (Goldman and Horne, 1983).

Natural phosphorus sources to the aquatic environment of the Fraser River Basin include leaching and weathering of rock, soil erosion (Wetzel, 1975) and decomposition of organic matter (IJC, 1980). Anthropogenic phosphorus sources include domestic effluents, industrial effluents and agricultural runoff (CCREM, 1987). Pulp and paper mills employing aerobic stabilization basins for the purpose of reducing the biochemical oxygen demand of effluent may be adding a considerable load of phosphorus to receiving waters (Bothwell, 1992). Atmospheric deposition also contributes phosphorus to the aquatic environment (Wetzel, 1975).

16.2 Thompson River System

16.2.1 Results

Table 65 presents the results of whole water, clarified water and filtered whole water from the Thompson River System. Total phosphorus in whole water was similar at McLure and Savona for both October 1992 and February 1993, respectively. Both sites had significantly higher ($P < 0.05$) total phosphorus concentrations in February 1993 versus October 1992 (Table 66).

Dissolved phosphorus in clarified water was below detection limits at McLure, whereas at Savona concentrations of 0.0030 mg/L and 0.0020 mg/L (just above the detection limit) were measured in October 1992 and February 1993, respectively. No detectable levels of dissolved phosphorus were found in filtered water samples from either McLure or Savona.

Table 65 Summary of Phosphorus Concentrations in Water from the Thompson River System (October 1992, February 1993)

Sample Type	Parameter (mg/L)	McLure		Savona	
		Oct. 1992	Feb. 1993	Oct. 1992	Feb. 1993
Whole Water	Total Phosphorus	0.0020	0.0050	0.0020	0.0060
Clarified Water	Dissolved Phosphorus	<0.0020	<0.0020	0.0030	0.0020
Filtered Water	Dissolved Phosphorus	<0.0020	<0.0020	<0.0020	<0.0020

Note: All results presented are a mean of field replicates - when samples were below detection limits, these were used in calculation of the means

- all means rounded to two significant figures

Table 66 Summary of Significant t-test Results for Temporal Comparisons of Total Phosphorus in Whole Water from the Thompson River System

Site	Dates Compared	t*	d.f.	p
McLure	October 1992 vs. February 1993	-6.867	2.5	0.011
Savona	October 1992 vs. February 1993	-6.859	2.0	0.020

* A positive t value signifies that the parameter is significantly higher on the first date indicated, whereas a negative value signifies that the parameter is significantly higher on the second date indicated.

16.2.2 Discussion

Phosphorus concentrations measured in whole and clarified water from the Thompson River System (0.0020-0.0060 mg/L) were near or below the detection limit. Total phosphorus was similar to mean levels reported by Provincial Water Monitoring Stations located at McLure and Savona from 1971 to 1982 (Nordin and Holmes, 1992). The significantly higher total phosphorus concentration ($P < 0.05$) measured at Savona in February 1993 versus October 1992 is likely related to winter limnological conditions precluding efficient mixing of Thompson River water with Kamloops Lake water.

Although the total phosphorus concentration at Savona was higher in the winter base flow period (February 1993) than in October 1992, it is unlikely to be related to the historical eutrophication problem downstream of Kamloops Lake, since the majority of the total phosphorus is normally

found in the form of apatite which is biologically unavailable. Although algal biomass is thought to have declined since eutrophic conditions were first identified in the mid 1970s, concern over eutrophication of the Thompson River still persists. Research by Bothwell *et al.* (1992) has shown that the concentration of dissolved phosphorus required to saturate the specific growth rate of attached diatom communities is very low (~ 0.001 mg/L). Since dissolved phosphorus in filtered water samples was below the detection limit (0.0020 mg/L), we cannot determine from our data whether dissolved phosphorus levels exceeded this value. However water monitoring data collected between 1987 - 1992 from the Thompson River at Spence's Bridge indicates that the monthly median total dissolved phosphate concentration at this site varied between 0.003 mg/L and 0.004 mg/L which would exceed the concentration required to saturate the specific growth rate of periphytic diatoms.

A comparison of clarified and filtered water from Savona indicates that clarified water had higher phosphorus concentrations (up to 0.001 mg/L greater) than whole water filtered through a 0.45 μ m filter, thereby indicating that centrifugally clarified water very likely contains small amounts of phosphorus rich particulate material. Consequently, unfiltered clarified river water does not appear to be an appropriate medium for the detection of dissolved phosphorus. However, clarifying river water via centrifugation can be a useful preliminary step prior to filtration for water samples with high suspended sediment concentrations.

16.2.2.1 Comparisons of Phosphorus Concentrations to Guidelines and Criteria

As federal guidelines and BCMELP criteria have not been developed for total phosphorus in flowing water, total phosphorus concentrations from the Thompson River System were compared with the OMEE (1994) guideline of 0.03 mg/L for the protection of aquatic life in rivers. Total phosphorus concentrations from McLure and Savona did not exceed the OMEE guideline for total phosphorus in either October 1992 or February 1993.

16.3 Fraser River

16.3.1 Results

Refer to Table 67 for results of phosphorus concentrations in whole and clarified water samples collected from the Fraser River in February 1993. Refer to Table 68 for a summary of significant t-test results ($P < 0.05$) for spatial comparisons of total and dissolved phosphorus concentrations. Total phosphorus levels in whole water from Marguerite (0.036 mg/L) were significantly higher than at Shelley (0.028 mg/L), Woodpecker (0.031 mg/L) or Yale (0.017 mg/L). Dissolved phosphorus in clarified water was significantly higher at both Shelley (0.024 mg/L) and Marguerite (0.025 mg/L) relative to Woodpecker (0.015 mg/L).

Table 67 Summary of Phosphorus Concentrations in Water from the Fraser River (February 1993)

Sample Type	Parameter (mg/L)	Shelley	Woodpecker	Marguerite	Yale
Whole Water	Total Phosphorus	0.028	0.031	0.036	0.017
Clarified Water	Dissolved Phosphorus	0.024	0.015	0.025	N/A*

*Sample unavailable

All results are a mean of field replicates - when samples were below detection limits, these were used in calculation of the means

All means rounded to two significant figures

Table 68 Summary of Significant t-test Results for Spatial Comparisons of Total and Dissolved Phosphorus in Whole and Clarified Water from the Fraser River

Date	Sites Compared	Parameter	t*	d.f.	p
February 1993	Shelley vs. Marguerite	Total Phosphorus	-5.336	2.2	0.026
	Shelley vs. Yale	Total Phosphorus	4.184	3.6	0.011
	Woodpecker vs. Marguerite	Total Phosphorus	-9.192	4.0	0.001
	Woodpecker vs. Yale	Total Phosphorus	7.425	2.1	0.015
	Marguerite vs. Yale	Total Phosphorus	9.723	2.1	0.008
	Shelley vs. Woodpecker	Dissolved Phosphorus	25.522	2.3	0.001
	Woodpecker vs. Marguerite	Dissolved Phosphorus	-9.171	2.4	0.006

* A positive t value signifies that the parameter is significantly higher on the first date indicated, whereas a negative value signifies that the parameter is significantly higher on the second date indicated.

16.3.2 Discussion

The significant increase ($P < 0.05$) in total phosphorus concentration at Marguerite relative to Shelley in February 1993 indicates that this site may be most affected by municipal and industrial effluents from Prince George and Quesnel. Recent analysis of data collected by the Provincial Water Quality Monitoring Stations on the Fraser River between 1987-1992 indicates that there is an increasing trend in total phosphorus concentration from Red Pass (at the headwaters of the Fraser River) to Hope (Shaw and El-Shaarawi, 1995). Although dissolved phosphorus was not

found to be significantly higher at any of the downstream sites relative to the reference site, Shelley, data collected by the Provincial Water Quality Monitoring Station at Marguerite between 1987-1992 indicates that dissolved phosphorus followed a linear increasing trend with time at this site (Shaw and El-Shaarawi, 1995). This trend is likely related to anthropogenic sources which include municipal sewage from Prince George and Quesnel (both subject only to secondary treatment), pulp mill effluents (which have nutrients added for secondary treatment processes) and agricultural runoff.

Although the majority of total phosphorus is normally found in the particulate fraction, which is biologically unavailable, our data indicates that between 48-96% of total phosphorus was found in the aqueous phase as dissolved phosphorus (Table 67). It should be noted, however, that these calculations were based on the assumption that all phosphorus measured in clarified water was found in the dissolved form, and consequently the dissolved phosphorus fraction may be overestimated. Furthermore, dissolved phosphorus would be expected to comprise a considerably lower fraction of the total phosphorus concentration during peak flow conditions (May - June) when suspended sediment concentrations reach maximum values for the year. Federal and provincial water monitoring data from Marguerite indicates that during freshet, the total phosphorus concentration often exceeds 0.5 mg/L, whereas the dissolved phosphorus does not normally exceed 0.02 mg/L (Shaw and El-Shaarawi, 1995).

A comparison of total and dissolved phosphorus concentrations measured at Savona on the Thompson River with those measured on the Fraser River indicates that total phosphorus was 3-18 times higher and dissolved phosphorus (in clarified water) was 5-12 times higher compared to levels in the Thompson River System. This difference is primarily due to geological differences between the two systems (C. Gray, Environment Canada, personal communication). It is interesting to note that in spite of the relatively high levels of dissolved phosphorus (monthly median 0.003-0.013 mg/L) measured by the Provincial Monitoring Station at Marguerite between 1987-1994 (Shaw and El-Shaarawi, 1995), eutrophication has not been identified as a problem in the Fraser River. This is likely attributed to the naturally high suspended sediment concentration of the Fraser River which may prevent adequate light penetration required for abundant algal growth.

16.3.2.1 Comparisons of Phosphorus Concentrations to Guidelines and Criteria

Total phosphorus concentrations from the Fraser River were compared with the OMEE (1994) guideline of 0.03 mg/L for the protection of aquatic life in rivers (Table 69). Total phosphorus in whole water samples from the Fraser River exceeded the OMEE guideline at both Woodpecker and Marguerite in February 1993.

Table 69 Total Phosphorus Concentrations in Whole Water from the Fraser River Compared to the OMEE Guideline for the Protection of Aquatic Life in Rivers (February 1993)

Parameter	Shelley	Woodpecker	Marguerite	Yale	OMEE Guideline*
Total Phosphorus (mg/L)	0.028	0.031	0.036	0.017	0.030

* Based on the Theoretical Toxicological Approach

17.0 NITROGEN

17.1 Introduction

Nitrogen is always present in aquatic ecosystems and most abundantly as a gas. Relatively small quantities exist in the combined forms of ammonia (NH_4), nitrate (NO_3^-), nitrite (NO_2^-), urea ($\text{CO}[\text{NH}_2]_2$) and dissolved organic compounds. Nitrate is the most common form of combined inorganic nitrogen in lakes and streams and is intimately connected with the land use practices of the surrounding watershed (Goldman and Horne, 1983). Natural nitrate sources to the Fraser River Basin include weathering of igneous rocks, vegetable and animal debris, animal excrement (McNeely *et al.*, 1979) and fires and floods (Goldman and Horne, 1983).

Anthropogenic sources include municipal wastewaters (USEPA, 1976), pulp and paper mill effluents (Bothwell, 1992), feedlot discharges, leachate from waste disposal dumps (Ontario Ministry of the Environment, 1981), explosives use in mining and construction (Pommen, 1983), logging (Goldman and Horne, 1983) and agricultural fertilizers (CCREM, 1987). Because nitrate ions move easily in the aqueous phase, their concentration in the lotic environment increases proportionately with flow (Likens *et al.*, 1977).

Nitrite is produced biochemically by incomplete nitrification of ammonia and by denitrification of nitrate. It is usually present only under conditions of limited oxygen supply (Wetzel, 1975). Nitrite toxicity has been shown to be associated with oxidation of methaemoglobin leading to cyanosis and tissue hypoxia (Hellawell, 1988). Anthropogenic nitrite sources to the aquatic environment include industrial and municipal effluents (McNeely, *et al.*, 1979) and explosives use (Pommen, 1983).

Ammonia is produced naturally by the biological degradation of nitrogenous matter (McKee and Wolf, 1963) including biological litter, animal waste and forest fires (Geadah, 1985). At a pH of 7.5 and a temperature of 0-10°C, more than 99% of ammonia is present as positively charged ammonium ions (Trussel, 1972). Whereas ammonia is very soluble in water (McNeely *et al.*, 1979), ammonium ions have an affinity for clay minerals and can enter the aquatic environment through soil erosion. Ammonia has been shown to be toxic to fish, and its toxicity varies with pH and temperature (Hellawell, 1988). Anthropogenic sources of ammonia to the Fraser River Basin include pulp and paper mill effluents (Bothwell, 1992), commercial fertilizers (McNeely *et al.*, 1979), municipal wastewaters and explosives use (Pommen, 1983).

17.2 Thompson River System

17.2.1 Results

Table 70 presents a summary of nitrogen in whole water, clarified water and filtered water from the Thompson River System.

Table 70 Summary of Nitrogen Concentrations in Water from the Thompson River System (October 1992, February 1993)

Sample Type	Location:	McLure		Savona	
	Sampling Date:	Oct 92	Feb. 93	Oct 92	Feb. 93
Whole Water	Nitrogen (mg/L)				
	Ammonia	0.0030	N/A	0.0030	N/A
	Nitrate/Nitrite	0.10	N/A	0.085	N/A
	Total Nitrogen	0.17	0.31	0.16	0.32
Clarified Water	Ammonia	0.0020	0.014	<0.0020	0.0030
	Nitrite	N/A	<0.0020	N/A	N/A
	Nitrate/Nitrite	0.10	0.076	0.086	0.14
	Total Nitrogen	0.15	N/A	0.15	N/A
Filtered Water	Ammonia	0.0030	N/A	0.0020	N/A
	Nitrate/Nitrite	0.10	N/A	0.085	N/A
	Total Nitrogen	0.17	N/A	0.16	N/A

N/A = Not Analysed

Note: All results presented are a mean of field replicates - when samples were below detection limits, these were used in calculation of the means

- all means rounded to two significant figures

Refer to Table 71 for a summary of significant t-test results ($P < 0.05$) for spatial comparisons of nitrate/nitrite in whole, clarified and filtered water.

Table 71 Summary of Significant t-test Results for Spatial Comparisons of Nitrate/Nitrite in Whole, Clarified and Filtered Water from the Thompson River System

Date	Sites Compared	Sample Type	t*	d.f.	p
October 1992	McLure vs. Savona	Whole Water	18.381	2.2	0.002
		Clarified Water	67.535	3.2	0.000
		Filtered Water	36.062	4.0	0.000
February 1993	McLure vs. Savona	Clarified Water	-107.112	2.2	0.000

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated.

In October 1992 whole water samples, only nitrite/nitrate concentrations were significantly higher at McLure (0.10 mg/L) versus Savona (0.085 mg/L). Ammonia and total nitrogen concentrations were relatively similar between the two sites. Total nitrogen levels were also similar between the two sites in February 1993.

In October 1992 clarified water samples, nitrite/nitrate concentrations were significantly higher at McLure (0.10 mg/L) versus Savona (0.086 mg/L), whereas ammonia and total nitrogen were similar between the two sites. Conversely, in February 1993 nitrate/nitrite was significantly higher at Savona (0.14 mg/L) than at McLure (0.076 mg/L).

Filtered water samples collected in October 1992 also indicate that nitrate/nitrite was significantly higher at McLure (0.10 mg/L) versus Savona (0.085 mg/L), whereas ammonia and total nitrogen were not significantly different between the two sites. Filtered water was not analysed in February 1993 water samples.

Refer to Table 72 for a summary of significant results ($P < 0.05$) for temporal comparisons of total nitrogen and nitrate/nitrite in whole and clarified water from McLure and Savona. Temporal comparisons between October 1992 and February 1993 indicate that at McLure total nitrogen was significantly higher in whole water samples in February 1993, whereas nitrate/nitrite was significantly higher in clarified water samples in October 1992. At Savona, both total nitrogen in whole water samples and nitrate/nitrite in clarified water samples were significantly higher in February 1993.

Table 72 Summary of Significant t-test Results for Temporal Comparisons of Total Nitrogen and Nitrate/Nitrite in Whole and Clarified Water (Thompson River System)

Site	Dates Compared	Parameter	Sample Type	t*	d.f.	p
McLure	October 1992 vs February 1993	Total Nitrogen	Whole Water	-8.741	2.6	0.005
		Nitrate/Nitrite	Clarified Water	44.745	2.1	0.000
Savona	October 1992 vs February 1993	Total Nitrogen	Whole Water	-15.495	2.4	0.002
		Nitrate/Nitrite	Clarified Water	-426.014	4.0	0.000

* A positive t value signifies that the parameter is significantly higher on the first date indicated, whereas a negative value signifies that the parameter is significantly higher on the second date indicated.

Concentrations of ammonia, nitrite/nitrate and total nitrogen were generally similar between whole water, clarified water and filtered water samples collected from the Thompson River System.

17.2.2 Discussion

Significantly higher ($P < 0.05$) concentrations of nitrate/nitrite were measured in whole water, clarified water and filtered whole water from McLure in October 1992 in comparison to Savona. The lower nitrate/nitrite levels measured at Savona in October 1992 are reflective of the naturally low levels of these nutrients present in Kamloops Lake in the fall (C. Gray, Environment Canada, personal communication). Furthermore, nutrient dilution also is likely to occur as Thompson River water thoroughly mixes with Kamloops Lake water during fall limnological conditions prior to reaching Savona. However, as nutrient dilution is greatly reduced during winter limnological conditions (St John *et al.*, 1976), higher nutrient levels may occur at this time downstream of Kamloops Lake. Accordingly, at Savona both total nitrogen in whole water and nitrate/nitrite in clarified water were significantly higher ($P < 0.05$) in February 1993 relative to October 1992. Although slight seasonal differences in nitrogen levels were observed, nitrogen levels at McLure and Savona were relatively similar. This similarity suggests that nitrogen inputs from the Weyerhaeuser mill (Bothwell, 1992) and City of Kamloops sewage treatment plant do not seem to alter the water chemistry of this element in the Thompson River at Savona.

The similarity between nitrogen levels in whole, clarified and filtered river water indicates that almost all the nitrogen in the water column was found in the dissolved phase. This similarity is primarily due to the fact that water soluble nitrate/nitrite accounted for the majority of the total nitrogen fraction.

17.2.2.1 Comparison of Nitrogen Concentrations to Guidelines and Criteria

Nitrogen concentrations measured in the Thompson River System were compared to guidelines and criteria for the protection of aquatic life. Ammonia concentrations in whole water were compared with the BCMELP criterion of 12.7-14.4 mg/L (based on a pH of 7.5 and a temperature of 0-10°C) (BCMELP, 1994a) and with the CCREM (1987) guideline of 2.2 mg/L. Nitrate/nitrite was compared to the BCMELP criterion of 200 mg/L (Water Quality Branch, 1991). Total nitrogen concentrations were compared to the Alberta Environment (1977) criterion of 1.0 mg/L. Neither ammonia, nitrate/nitrite nor total nitrogen concentrations in the Thompson River System exceeded BCMELP criteria, the CCREM guideline or the Alberta Environment criterion for the protection of aquatic life.

17.3 Fraser River

17.3.1 Results

The summarized results of nitrogen in whole and clarified water samples collected in February 1993 are presented in Table 73. Refer to Table 74 for a summary of significant t-test results ($P < 0.05$) for spatial comparisons of nitrogen species.

Table 73 Summary of Nitrogen Concentrations in Water from the Fraser River (February 1993)

Sample Type	Parameter (mg/L)	Shelley	Woodpecker	Marguerite	Yale
Whole Water	Total Nitrogen	0.22	0.40	0.41	0.22
Clarified Water	Ammonia	<0.0020	0.044	0.057	0.017
	Nitrite	<0.0020	0.0020	0.0040	N/A
	Nitrate/Nitrite	0.14	0.10	0.17	0.0040

N/A = Not analysed

All results presented are a mean of field replicates - when samples were below detection limits, these were used in calculations of the means

All means rounded to two significant figures

Table 74 Summary of Significant t-test Results for Spatial Comparisons of Total Nitrogen, Ammonia, Nitrite and Nitrate/Nitrite in Whole and Clarified Water from the Fraser River

Sites Compared	Sample Type	Parameter	t*	d.f.	p
Shelley vs. Marguerite	Whole Water	Total Nitrogen	-15.234	2.3	0.002
	Clarified Water	Ammonia	-24.955	2.0	0.002
		Nitrite	-18.187	3.2	0.000
		Nitrate/Nitrite	-5.726	2.1	0.027
Shelley vs. Woodpecker	Whole Water	Total Nitrogen	-27.500	3.2	0.000
	Clarified Water	Ammonia	-41.830	2.0	0.001
		Nitrate/Nitrite	46.000	2.9	0.000
Shelley vs. Yale	Clarified Water	Ammonia	-14.875	2.0	0.004
		Nitrate/Nitrite	74.464	2.6	0.000
Woodpecker vs. Marguerite	Clarified Water	Ammonia	-5.270	2.8	0.016
		Nitrite	-15.500	3.9	0.000
		Nitrate/Nitrite	-11.739	2.0	0.007
Woodpecker vs. Yale	Whole Water	Total Nitrogen	13.250	2.9	0.001
	Clarified Water	Ammonia	19.092	4.0	0.000
		Nitrate/Nitrite	58.246	2.2	0.000
Marguerite vs. Yale	Whole Water	Total Nitrogen	10.786	4.0	0.000
	Clarified Water	Ammonia	16.502	2.8	0.001
		Nitrate/Nitrite	27.748	2.3	0.001

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated.

With the exception of nitrate/nitrite, all other nitrogen forms measured were significantly higher at all sites downstream of Prince George than at the reference site, Shelley. Total nitrogen in whole water samples ranged between 0.22 mg/L at Shelley to 0.41 mg/L at Marguerite. There was a significant increase in total nitrogen in whole water at both Marguerite

(0.41 mg/L) and Woodpecker (0.40 mg/L) relative to Shelley (0.22 mg/L). Ammonia (0.057 mg/L), nitrite (0.0040 mg/L) and nitrate/nitrite (0.17 mg/L) in clarified water were all higher in concentration at Marguerite, with respect to the other sites, including Shelley.

17.3.2 Discussion

The significant increase ($P < 0.05$) in total nitrogen, ammonia and nitrate/nitrite in whole and clarified water samples at Marguerite, in comparison to Shelley, in February 1993 may be due to additional nitrogen loadings from agricultural runoff and municipal and pulp mill effluents from Prince George and Quesnel. Recently analysed data of total dissolved nitrogen measured at the Federal-Provincial Water Monitoring Stations between 1985-1991 indicates that there is a clear increase in total dissolved nitrogen from Red Pass (near the headwaters of the Fraser River) to Marguerite (Shaw and El-Shaarawi, 1995). Dilution of the Fraser River by the Thompson River and other tributaries likely accounts for the lower total nitrogen, ammonia and nitrate/nitrite levels observed at Yale relative to both Woodpecker and Marguerite.

17.3.2.1 Comparison of Nitrogen Concentrations to Guidelines and Criteria

Nitrogen concentrations measured in Fraser River water were compared to guidelines and criteria for the protection of aquatic life. Ammonia concentrations in whole water were compared with the BCMELP criterion of 12.7-14.4 mg/L (based on a pH of 7.5 and a temperature of 0-10°C) (BCMELP, 1994a) and with the CCREM (1987) guideline of 2.2 mg/L. Nitrate/nitrite was compared to the BCMELP criterion of 200 mg/L (Water Quality Branch, 1991). Total nitrogen concentrations were compared to the Alberta Environment (1977) criterion of 1.0 mg/L. Neither ammonia, nitrate/nitrite nor total nitrogen concentrations in the Fraser River exceeded BCMELP criteria, the CCREM guideline or the Alberta Environment criterion for the protection of aquatic life.

18.0 CONCLUSIONS

1. Dioxins, furans, chlorophenolics, polycyclic aromatic hydrocarbons, resin acids and fatty acids measured in suspended sediments, and some chlorophenolics, fatty acids and resin acids, measured in whole water, were generally found in higher concentrations downstream of pulp and paper mills than at reference sites upstream of the mills on both the Thompson and Fraser River Systems.
2. Dioxins, furans, chlorophenolics, polycyclic aromatic hydrocarbons, fatty acids and resin acids, measured in suspended sediments, were generally found in higher concentrations during winter base flow periods compared to fall low flow periods.
3. Estimated loadings of 2,3,7,8-T4CDD and 2,3,7,8-T4CDF, measured in suspended sediments, were compared with loadings discharged by the pulp mills into the receiving environment. Loadings in suspended sediments were, with two exceptions, lower than effluent loadings. Resuspension of previously deposited contaminated bed sediment (during episodic high flow events) may have been responsible for the higher dioxin and furan loadings measured in the receiving waters relative to those of the mills.
4. Concentrations of 2,3,7,8-T4CDD and 2,3,7,8-T4CDF in suspended sediments have decreased from levels measured in 1990 prior to implementation of pulp mill abatement measures.
5. Phase partitioning of dioxins, furans, chlorophenolics and PAHs between sediment and water was highly variable and appeared to be influenced by the site specific environmental conditions.
6. None of the organic contaminants measured exceeded federal guidelines or provincial water quality criteria for the protection of aquatic life. However, guidelines or criteria currently do not exist for many organic contaminants which were measured at elevated levels downstream of pulp and paper mills.
7. Some total trace metals (aluminum, lead, chromium, copper and iron) and total phosphorus, measured in whole water, were found to exceed existing federal guidelines and/or provincial water quality criteria for the protection of aquatic life. However, when compared to available water monitoring data, these parameters were within normal values for both the Thompson and Fraser River Systems. In the case of the Fraser River, the majority of the metals exceeded guidelines or criteria during high flow periods when suspended sediment concentrations were relatively high.

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APPENDIX I

20.0 LABORATORY ANALYTICAL AND QUALITY ASSURANCE/QUALITY CONTROL METHODS

20.1 Analytical Methods

20.1.1 Organic Contaminants

The analytical analysis for organic contaminants was performed by AXYS Analytical Services Ltd. in Sydney, British Columbia.

20.1.1.1 Dioxin and Furan Analysis

Sediment samples were ground with powdered anhydrous sodium sulphate and allowed to stand until free-flowing. They were then spiked with an aliquot of surrogate standard solution containing nine ^{13}C -labelled dioxin and furan congeners and extracted by soxhlet for 20 hours. A separate subsample of sediment was taken for moisture determination (oven dried at 105°C) and this result as used to convert sample wet weight to a dry weight. Results were reported on a dry weight basis.

XAD resin columns were first spiked with an aliquot of surrogate standard solution. The columns were extracted by elution first with methanol and then with dichloromethane. The extract was backwashed with base and then acid and processed through four cleanup columns (silica, alumina, carbon, alumina).

The dichloromethane extracts from the Goulden extractors (liquid phase extractors) were cleaned up using the same column chromatography as described above for the XAD extracts.

Prior to GC/MS analysis, the extract was evaporated to dryness, and an aliquot of recovery standard (^{13}C -labelled 1,2,3,4-tetrachlorodioxin and ^{13}C -labelled 1,2,3,7,8,9-H6CDD) was added. Final analysis was performed via high resolution gas chromatography with high resolution mass spectrometric detection (HRGC/HRMS).

20.1.1.2 PAH Analysis

Sediment, water and XAD resin columns analysed for PAHs were first spiked with an aliquot of surrogate standard solution containing nine perdeuterated PAHs.

Each sediment sample was ground with sodium sulphate, packed in a glass chromatographic column and eluted with methanol and dichloromethane. The eluate was backwashed with dilute base and extracted water. Water samples were extracted with dichloromethane in a separatory funnel. The extraction of the XAD resin columns was identical as that for dioxins/furans.

Sediment, water and XAD column extracts were then solvent exchanged with iso-octane and cleaned up by column chromatography on silica gel. An aliquot of recovery standard containing three deuterated PAHs was added to each extract in preparation for analysis by high resolution gas chromatography with low resolution mass spectrometric detection (HRGC/LRMS).

20.1.1.3 Chlorophenolic Analysis

Sediment samples were first spiked with an aliquot of surrogate standard solution containing twelve ^{13}C -labelled chlorinated phenolics and one deuterated chlorophenol. Water samples were extracted with dichloromethane. Sediment samples were extracted with a solution of potassium hydroxide in methanol:water. The sample extracts were converted to acetate derivatives of chlorophenolics by reaction with acetic anhydride. The derivatives were then back extracted with solvent, dried over sodium sulphate and cleaned up by column chromatography on silica gel. An aliquot of recovery standard (deuterated fluoranthene) was added to each extract prior to analysis by high resolution gas chromatography with low resolution (quadrupole) mass spectrometric detection (HRGC/LRMS).

20.1.1.4 Polychlorinated Biphenyl and Pesticide Analysis

All samples were spiked with a solution containing ^{13}C -labelled surrogates (hexachlorobenzene, γ -HCH, mirex, p,p'-DDE, p,p'-DDT, PCB 101, PCB 180 and PCB 209) for analysis of pesticides and PCB congeners by GC/MS, and d4-endosulphan I for the analysis of F3 pesticides by GC/ECD (gas chromatography / electron capture detection). The samples were also spiked with an aliquot of ^{13}C -labelled analogues of PCB 77, PCB 126 and PCB 169 for the analysis of non-ortho-substituted (coplanar) PCBs by GC/MS. Sediment samples were solvent extracted on a shaker table prior to fractionation and cleanup into two fractions (F1+F2 and F3) on a Florisil column. The first fraction (F1 +F2) was split gravimetrically and one half analysed by GC/MS for PCBs as individual congeners and non-polar to moderately polar chlorinated pesticides. The other half of the F1+ F2 fraction underwent additional column cleanup and an additional GC/MS run for the analysis of coplanar PCBs. The F3 fraction was analysed for the most polar chlorinated pesticides by HRGC/ECD.

20.1.1.5 Resin and Fatty Acid Analysis

All samples were spiked with an aliquot of internal standard solution containing surrogate standards for both resin and fatty acid analysis. Each sample was acidified, solvent extracted with diethylether and hexane and dried over sodium sulphate. The extract was then solvent evaporated under a stream of nitrogen and then reacted with diazomethane to derivitize the resin and fatty

acids to their methyl esters. Next, the methylated extract was cleaned up on a basic silica gel chromatographic column (Biosil A column). An aliquot of recovery standard was added to each extract prior to analysis by HRGC/LRMS.

20.1.2 Trace Metal Analysis

A portion of the trace metal samples collected in October 1992 were analysed by the National Laboratory for Environmental Testing (NLET) in Burlington, Ontario, whereas the remainder of samples collected in October 1992 and those collected in February 1993 were analysed by Elemental Research Inc. in North Vancouver, British Columbia. NLET employed inductively coupled argon plasma emission spectrometry (ICAP) while Elemental Research Inc. employed inductively coupled plasma - mass spectrometry (ICP/MS) for all metals except total Hg which was analysed by atomic absorption methods. The following is a summary of the methods for trace metals analysis in water samples as performed by Elemental Research Inc. Laboratory in North Vancouver, British Columbia.

20.1.2.1 Methodology for the Determination of Metals in Water

- 1) All glass and plastic ware was pre cleaned per procedure required.
- 2) Homogenized samples were spiked with an internal standard of yttrium plus an internal standard of indium.
- 3) The majority of elements were determined following sample digestion in 12% reverse aqua regia in a sealed 60 ml teflon vessel at 100°C. Elements lithium and vanadium were determined following a nitric acid/hydrogen peroxide digestion.
- 4) Ultra sonic nebulization was not used, since it was not necessary in ICP/MS due to its intrinsically high sensitivity.
- 5) Hydride generation ICP/MS was used for the determination of arsenic and selenium, and Cold Vapour Atomic Absorption Spectroscopy was used for the determination of mercury.

20.1.3 Nutrient Analysis

Nutrient analysis of whole water samples was performed at the Environment Canada Conservation and Protection Laboratories, West Vancouver, British Columbia (now located in North Vancouver, British Columbia). All nutrient analyses were performed using colorimetric methods.

20.1.3.1 Total and Dissolved Phosphate Analysis

Phosphorus present in the sample was converted to soluble ortho-phosphate by digesting the sample with persulphate in an acidic medium. The resulting ortho-phosphate was then reacted with ammonium molybdate and antimony tartrate in an acidic medium to form an antimony-phosphomolybdate complex which was reduced to an intensely blue coloured complex by ascorbic acid. The absorbance of this complex was measured at 880 nm. Dissolved phosphate was analysed by first filtering the sample through a 0.45 μm filter before following the same procedure as described above.

20.1.3.2 Total Nitrogen Analysis

The total nitrogen present in the sample was oxidized to nitrate by digesting the sample with potassium persulphate in an alkaline medium. The resulting nitrate was reduced to nitrite by passing it through a column containing granulated copper-cadmium. The nitrite was then reacted with sulfanilamide under acidic conditions to form a diazo compound. This compound was then complexed with N-1-naphthylethylenediamine dihydrochloride to form a reddish-purple azo dye, the absorbance of which was measured at 550 nm.

20.1.3.3 Nitrite/Nitrate Analysis

The filtered sample was passed through a column containing granulated copper-cadmium which reduces nitrate to nitrite. Quantitative reduction was ensured by maintaining a stable H-ion concentration through addition of ammonium chloride (NH_4Cl). The nitrite that was originally present in the sample plus the reduced nitrate was then reacted with sulfanilamide under acidic conditions to form a diazo compound. This compound was then complexed with N-1-naphthylethylenediamine dihydrochloride to form a reddish-purple azo dye, the absorbance of which was measured at 550 nm.

20.1.3.4 Nitrite Analysis

Nitrite in the sample was reacted with sulfanilamide under acidic conditions to form a diazo compound. This compound was then complexed with N-1-naphthylethylenediamine dihydrochloride to form a reddish-purple azo dye, and the absorbance of this complex was measured at 550 nm.

20.1.3.5 Ammonia Analysis

Phenol, sodium nitroprusside and an oxidizing solution composed of sodium hypochlorite in a basic citrate solution were sequentially added to the sample. Under basic conditions, ammonia reacts with phenol and is oxidized by sodium hypochlorite to form an organic complex, indophenol blue. The blue colour formed was intensified with sodium nitroprusside, and the absorbance of the resulting complex was measured at 630 nm. (Sodium citrate complexes calcium and magnesium ions and prevents precipitation of their respective hydroxides). A heating coil was used to accelerate the colour development.

20.2 Laboratory Quality Assurance/Quality Control Methods

20.2.1 Organic Contaminants

The sample results were reviewed and evaluated in relation to the QA/QC samples worked up at the same time.

20.2.1.1 Procedural Blanks

One procedural blank was analysed with each batch sample. Sediment blanks were analysed for dioxins, furans, chlorophenolics, PAHs, PCBs, pesticides, fatty acids and resin acids. Water blanks were analysed for chlorophenolics, PAHs, fatty acids and resin acids. XAD column blanks were analysed for dioxins/furans, chlorophenolics and PAHs.

20.2.1.2 Laboratory Duplicates

One laboratory duplicate was analysed with each batch sample. Duplicates must agree within acceptable limits, generally $\pm 20\%$ of mean value plus Method Detection Limit (MDL). Results for laboratory duplicates are reported with the sample results in Appendix II.

20.2.1.3 Surrogate Standard Recoveries

These consist of internal standards (usually chemically labelled analogs of the target compounds) which are added to samples prior to analysis and are expressed as percent recoveries. Quality assurance protocols require that surrogate standard recoveries must be within an acceptable range for data to be reported. These acceptable ranges vary with contaminant type. In cases where this criterion was not achieved, samples were repeated. All reported concentrations were corrected for recovery of the surrogate standards.

20.2.1.4 Reference Samples

Reference samples were used as a method performance test. Each batch of samples analysed included a spiked matrix sample or a certified reference sample. Spiked sediment samples were analysed with field sediment samples for dioxins, furans, chlorophenolics, PCBs, pesticides, fatty acids and resin acids. A marine sediment certified reference material, HS-6 (National Research Council of Canada), was used to provide an indication of the accuracy of the PAH sediment data. Spiked water samples were used as reference samples with whole water samples analysed for chlorophenolics, PAHs, resin acids and fatty acids. A spiked XAD resin column extract was analysed along with solid phase extracted samples for PCDDs/PCDFs, chlorophenolics and PAHs.

20.2.1.5 Detection Limits

Detection limits were calculated on a sample-specific basis and were reported with each sample result. The detection limit was calculated as the concentration corresponding to the area reject. The area reject, determined from the mass chromatogram of each compound, is the area of a peak with height three times the maximum height of the noise. Only peaks with responses greater than three times the background noise level were quantified.

Fatty acid results were reported with statistically-derived Limits of Detection (LOD) since procedural blank levels usually had detectable concentrations. LODs were calculated by multiplying by three the standard deviation of the analyte concentration in twelve fatty acid blanks. Behenic and lignoceric acids, however, were reported with sample specific detection limits, since these two fatty acids were not detected in the procedural blanks.

20.2.2 Trace Metals

The QA/QC component of trace metal analysis consisted of requisite blanks, spiked samples and duplicates. The following QA/QC protocol was employed in trace metal analysis of whole water samples analysed by Elemental Research Inc..

- a) In the analysis of 34 samples, and required replicates, 4 method blanks were run.
- b) Six of every 34 samples were run in duplicate.
- c) A minimum of 2 different water standards were run at the start of the analysis and at the end or midpoint.
- d) An instrument check standard was run at the start and end of the analytical run. The two standards were prepared with concentrations approximately at the mid point for all the elements determined.
- e) A detection limit standard was run at the start and end of the analysis run. Element concentrations were twice the stated laboratory detection limits.

APPENDIX II

21.0 SAMPLE QUALITY ASSURANCE/QUALITY CONTROL RESULTS

To assess the degree of precision between samples and field splits, the coefficient of variation (CV) was calculated for each type of analysis according to the method described by Sokal and Rohlf (1969). When values were not detectable for either sample or field split, the CV was not calculated for the pair in order to avoid uncertainty due to unquantifiable error. Refer to Appendix III for all QA/QC results.

21.1 Sediment Samples

21.1.1 Particle Size and Total Organic Carbon

QA/QC results for particle size in suspended sediment field split samples were in agreement with the original samples (mean CV = 6.83%). Similarly, the total organic carbon (TOC) field split and samples had an acceptable coefficient of variance (mean CV = 8.43%).

21.1.2 Dioxins and Furans

Results of dioxin and furan field splits showed a high degree of agreement (mean CV = 14.03%). Field replicates indicated an acceptable degree of precision between centrifuges 1 and 2. Laboratory duplicates were generally acceptable and satisfied the requirement of +/- (20% of the mean value + MDL). Laboratory sediment blanks were below detection limits except for total M1CDF, M2CDF, M4CDF, O8CDD and O8CDF which showed low background levels. Dioxin sediment blanks SBLK 838 and SBLK 997 and DC-S-BLK 37 had low recoveries (17-19%) of the O8CDD surrogate but were worked up with samples that had acceptable surrogate recoveries, and so the batch was therefore deemed acceptable. Laboratory sediment spikes were within the acceptable range of 30-100%, indicating an acceptable level of accuracy.

21.1.3 Chlorophenolics

Field splits were in agreement with the original samples (mean CV = 18.20%) indicating a high level of reproducibility. Field replicates indicated an acceptable degree of precision between centrifuges 1 and 2. Moreover, where surrogate standards were used, recoveries were generally within the acceptable range of 20-120%. Lab duplicates were generally acceptable, and satisfied the requirement of +/- (20% of the mean value + MDL). In addition, sediment blanks had either non-detectable or very low levels of the target analytes, and the sediment spike recoveries were within the accepted range of 40-130%.

21.1.4 Polycyclic Aromatic Hydrocarbons

Field splits were in good agreement with original samples (mean CV = 7.43%), indicating a high level of reproducibility. Surrogate standard recoveries were within the accepted range of 20-120%. Field replicates indicated an acceptable degree of precision between centrifuges 1 and 2. Laboratory duplicates were generally acceptable and satisfied the requirement of $\pm(20\%$ of the mean value + MDL). Furthermore, laboratory sediment blanks were not detectable or had low background levels of the target analytes. Laboratory reference samples were deemed acceptable since most analytes were within 20% of the certified value range.

21.1.5 Polychlorinated Biphenyls

The surrogate recovery standards for PCB coplanars were within the acceptable range of 30-120% and were therefore deemed acceptable. Sediment blanks for PCB aroclors, congeners and coplanars were essentially free of any detectable contamination. Sediment spike recoveries for PCB aroclors, congeners and coplanars were within the accepted range of 40-130%. The coefficient of variance could not be calculated due to insufficient data.

21.1.6 Pesticides, Fatty Acids and Resin Acids

Surrogate standard recoveries were within the acceptable range of 20-120%. The lab duplicates satisfied the requirement of $\pm(20\%$ of the mean value + MDL). Sediment blanks had non-detectable levels of the target analytes, and sediment spike recoveries were within the accepted range of 40-130%. Insufficient data did not permit the calculation for coefficient of variance.

21.2 Whole Water Samples

21.2.1 Chlorophenolics

Field replicates were in good agreement with original samples (mean CV = 15.32%). Surrogate standard recoveries were within the accepted range of 20-120%. Laboratory duplicates also showed good replication to within $\pm(20\%$ of mean value + MDL). Laboratory water blanks were essentially free of detectable contamination. Water spikes generally showed acceptable recovery values within the acceptable range of 40-130%. However due to their reactive nature, some chloroguaiacols, chlorocatechols, chlorosyringols, chlorosyringaldehydes and chlorovanillins did not meet this criterion. A number of chlorophenolics were detected in deionized water field blanks, however most were < 10 ng/L with the exception of 4-chloroguaiacol (22 ng/L), 3-chlorocatechol (22 ng/L) and pentachlorophenol (12 ng/L).

21.2.2 Polycyclic Aromatic Hydrocarbons

Field replicates were in good agreement with original sample values (mean CV = 23.31%), indicating high reproducibility. Surrogate standard recoveries were generally within the acceptable range of 20-120%. Laboratory duplicates were generally acceptable and satisfied the requirement of $\pm(20\%$ of the mean value + MDL). Laboratory water blanks showed background values for many of the PAHs analysed, and these values were similar to those found in the whole water samples. Moreover, laboratory water spikes showed acceptable recovery levels within the specified range of 70-130%. Field deionized water blanks also showed background values for many of the PAHs analysed, and these values were also similar to those found in the whole water samples.

21.2.3 Fatty Acids

Field replicates were in close agreement (mean CV = 13.50%) with the exception of YAL-2CH and FRS-6CH which showed greater variability. Surrogate standard recoveries were within the accepted range of 40-120%. Laboratory duplicates were acceptable as they agreed to within $\pm(20\%$ of mean value + MDL). Laboratory water blanks showed background levels for all fatty acids analysed. Since fatty acid blanks are normally above sample detection limits, the background contribution to the observed response can be significant. For this reason, fatty acid samples have been blank corrected for the amount detected in each batch blank. The levels of fatty acids detected in the blanks in most cases did not exceed 1000 ng/L. Laboratory water spikes showed an acceptable level of recovery (within 70-130%). Field blanks showed detections for a number of fatty acids, but these are considered to be normal background levels (Georgina Brooks, AXYS, personal communication).

21.2.4 Resin Acids

Field replicates were in good agreement with original samples (mean CV = 11.16%), indicating a high level of reproducibility. Laboratory duplicates showed good replication, to within $\pm(20\%$ of mean value + MDL). Surrogate standard recoveries were within the accepted range of 40-120%. Laboratory water blanks had mostly non-detectable levels of the target resin acids with the exception of WBLK 94, WBLK 96, WBLK 97, WBLK 98 and WBLK 99 which contained comparatively high levels of dehydroabietic acid. For this reason, data run in the same batches with the above laboratory water blanks were blank corrected for this product. All laboratory spiked samples had acceptable levels of recovery in the range of 30-130%. Field deionized water blanks were mostly below detection limits with the exception of a few low level detections.

21.2.5 Trace Metals

Laboratory blanks showed non-detectable or very low levels of the target analytes. Field deionized water blanks generally showed either low background levels or non-detectable levels of the target analytes with the exception of the mid field blanks filled in October 1992 at Marguerite which showed relatively higher concentrations of copper and lead compared to the other field blanks.

21.2.6 Nutrients

Both regular and filtered deionized water field blanks contained non-detectable or very low levels of the target analytes.

21.3 Solid Phase Extracted Clarified Water Samples

21.3.1 Dioxins and Furans

Surrogate standard recoveries were within the accepted range of 30-130%. XAD column blanks showed not detectable or low background levels of dioxin and furans. XAD column spikes satisfied the criterion of 70-130% recovery. The field blank had relatively high levels of H6CDD due to contamination from the field surrogate, rendering this sample unfit for interpretation.

21.3.2 Chlorophenolics

Surrogate standard recoveries were generally within the accepted range of 30-130%. XAD column blanks were free of any detectable contamination. XAD column spikes generally satisfied the criterion of 70-130% recovery.

21.3.4 Polycyclic Aromatic Hydrocarbons

Laboratory XAD column blanks and proofs showed not detectable or low background PAH levels. Laboratory spikes had acceptable recovery values within the specified range of 70-130%. XAD column field blanks had levels similar to those of the clarified water column samples for a number of lower molecular weight PAHs.

21.4 Liquid Phase Extracted Clarified Water Samples

21.4.1 Dioxins and Furans

Surrogate standard recoveries for dioxins and furans were generally within the acceptable range of 30-130%. Concentrations in laboratory water blanks were below detection levels with the exception of O8CDD which showed low background levels. Laboratory spikes were within the acceptable range of 30-130%. An acceptable level of reproducibility between centrifuge 1 and centrifuge 2 was indicated by close agreement between samples SHL-11E and SHL 21-E. Lastly, due to contamination of the field blank by the use of a contaminated surrogate, this sample was rendered unfit for interpretation.

APPENDIX III

22.0 STATISTICAL ANALYSES RESULTS

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Table 1 Descriptive Statistics for Total Trace Metals in Whole Water at Shelley (October 1992) - Elemental Research Lab

Metal	Min	Max	Mean	S.D.
Aluminium	730.000	885.000	785.000	86.747
Barium	19.000	21.000	19.667	1.155
Beryllium	0.050	0.050	0.050	0.000
Cadmium	0.050	0.500	0.050	0.000
Chromium	0.200	0.200	0.200	0.000
Cobalt	0.560	0.695	0.622	0.068
Copper	1.300	2.000	1.600	0.361
Iron	1200.000	1200.000	1200.000	0.000
Lithium	1.020	1.200	1.140	0.104
Lead	0.560	0.640	0.593	0.042
Manganese	28.000	29.000	28.667	0.577
Molybdenum	0.120	0.150	0.140	0.017
Nickel	1.500	1.650	1.550	0.087
Strontium	110.000	115.000	111.667	2.887
Vanadium	0.670	1.100	0.923	0.225
Zinc	2.300	2.700	2.467	0.208
Arsenic	0.310	0.350	0.330	0.020
Selenium	0.050	0.050	0.050	0.000
Mercury	0.010	0.010	0.010	0.000

Table 2 Descriptive Statistics for Total Trace Metals in Whole Water at Marguerite (October 1992) - Elemental Research Lab

Metal	Min	Max	Mean	S.D.
Aluminium	460.000	550.000	513.333	47.256
Barium	18.000	19.500	18.833	0.764
Beryllium	0.050	0.050	0.050	0.000
Cadmium	0.005	0.050	0.050	0.000
Chromium	0.200	0.200	0.200	0.000
Cobalt	0.380	0.420	0.403	0.021
Copper	1.550	2.900	2.150	0.687
Iron	910.000	1000.000	953.330	45.092
Lithium	0.810	0.900	0.867	0.049
Lead	0.440	0.525	0.478	0.430
Manganese	22.000	23.500	22.833	0.764
Molybdenum	0.350	0.435	0.392	0.043
Nickel	1.000	1.200	1.083	0.104
Strontium	120.000	120.000	120.000	0.000
Vanadium	0.610	0.960	0.823	0.187
Zinc	2.100	2.700	2.433	0.360
Arsenic	0.330	0.365	0.348	0.018
Selenium	0.050	0.050	0.050	0.000
Mercury	0.100	0.012	0.011	0.000

Table 3 Descriptive Statistics for Total Trace Metals in Whole Water at Yaie (October 1992) - Elemental Research Lab

Metal	Min	Max	Mean	S.D.
Aluminium	2000.000	2200.000	2066.667	115.470
Barium	42.000	47.000	44.667	2.517
Beryllium	0.064	0.092	0.078	0.014
Cadmium	0.050	0.093	0.077	0.023
Chromium	3.600	4.500	3.900	0.520
Cobalt	2.200	2.500	2.333	0.153
Copper	4.300	5.200	4.867	0.493
Iron	1600.000	2000.000	1800.000	200.000
Lithium	1.100	1.500	1.267	0.208
Lead	1.800	1.900	1.867	0.058
Manganese	120.000	130.000	123.330	5.774
Molybdenum	0.530	0.620	0.570	0.046
Nickel	7.600	8.500	8.167	0.493
Strontium	110.000	110.000	110.000	0.000
Vanadium	2.900	3.800	3.267	0.473
Zinc	10.000	12.000	11.330	1.155
Arsenic	0.980	1.100	1.027	0.064
Selenium	0.053	0.073	0.061	0.011
Mercury	0.010	0.012	0.011	0.001

Table 4 Descriptive Statistics of Total Trace Metals in Whole Water at McLure (October 1992) - Elemental Research Lab

Metal	Min	Max	Mean	S.D.
Aluminium	130.000	150.000	136.667	11.547
Barium	7.700	8.000	7.833	0.153
Beryllium	0.050	0.050	0.050	0.000
Cadmium	0.050	0.072	0.057	0.013
Chromium	0.200	0.200	0.200	0.000
Cobalt	0.150	0.170	0.157	0.012
Copper	0.680	1.000	0.817	0.165
Iron	270.000	29.000	276.667	11.547
Lithium	0.800	0.830	0.817	0.015
Lead	0.100	0.100	0.100	0.000
Manganese	5.400	5.600	5.500	0.100
Molybdenum	0.490	0.540	0.510	0.026
Nickel	0.550	0.810	0.640	0.147
Strontium	81.000	82.000	81.330	0.577
Vanadium	0.350	0.380	0.367	0.015
Zinc	0.200	0.310	0.263	0.057
Arsenic	0.060	0.074	0.068	0.007
Selenium	0.050	0.050	0.050	0.000
Mercury	0.010	0.013	0.011	0.002

Table 5 Descriptive Statistics of Total Trace Metals in Whole Water at Savona (October 1992) - Elemental Research Lab

Metal	Min	Max	Mean	S.D.
Aluminium	62.000	71.000	67.000	4.583
Barium	9.000	9.700	9.330	0.351
Beryllium	0.050	0.050	0.050	0.000
Cadmium	0.050	0.050	0.050	0.000
Chromium	0.200	0.200	0.200	0.000
Cobalt	0.057	0.092	0.073	0.018
Copper	0.660	1.075	0.822	0.222
Iron	98.000	105.000	101.000	3.606
Lithium	0.510	0.575	0.535	0.035
Lead	0.100	0.100	0.100	0.000
Manganese	2.900	3.200	3.083	0.161
Molybdenum	0.510	0.550	0.537	0.023
Nickel	0.200	0.230	0.210	0.017
Strontium	76.000	81.000	78.667	2.517
Vanadium	0.290	0.300	0.293	0.006
Zinc	0.200	1.000	0.467	0.267
Arsenic	0.125	0.140	0.135	0.005
Selenium	0.050	0.050	0.050	0.000
Mercury	0.010	0.011	0.010	0.000

Table 6 Descriptive Statistics of Total Trace Metals in Whole Water at Shelley (February 1993) - Elemental Research Lab

Metal	Min	Max	Mean	S.D.
Aluminium	30.500	34.000	32.167	1.756
Barium	21.000	22.000	21.330	0.577
Beryllium	0.050	0.050	0.050	0.000
Cadmium	0.050	0.085	0.065	0.018
Chromium	0.200	0.680	0.398	0.251
Cobalt	0.200	0.440	0.290	0.131
Copper	0.285	0.480	0.388	0.098
Iron	190.000	210.000	200.000	10.000
Lead	0.100	0.100	0.100	0.000
Lithium	2.000	2.050	2.017	0.029
Manganese	6.250	8.200	7.383	1.013
Molybdenum	0.470	0.535	0.502	0.033
Nickel	0.675	1.200	0.958	0.265
Strontium	160.000	160.000	160.000	0.000
Vanadium	0.180	0.190	0.183	0.006
Zinc	2.050	2.000	1.883	0.247
Arsenic	0.175	0.180	0.178	0.003
Selenium	0.050	0.050	0.050	0.000
Mercury	0.010	0.010	0.010	0.000

Table 7 Descriptive Statistics of Total Trace Metals in Whole Water at Woodpecker (February 1993) - Elemental Research Lab

Metal	Min	Max	Mean	S.D.
Aluminium	62.000	70.000	65.000	4.359
Barium	20.000	22.000	21.000	1.000
Beryllium	0.050	0.050	0.050	0.000
Cadmium	0.050	0.061	0.054	0.006
Chromium	0.200	0.560	0.320	0.208
Cobalt	0.200	0.260	0.223	0.032
Copper	0.400	0.570	0.487	0.085
Iron	190.000	200.000	196.667	5.774
Lead	0.100	0.100	0.100	0.000
Lithium	1.200	1.400	1.333	0.115
Manganese	18.000	18.000	18.000	0.000
Molybdenum	0.880	1.200	1.060	0.164
Nickel	0.860	1.200	0.977	0.193
Strontium	110.000	110.000	110.000	0.000
Vanadium	0.390	0.480	0.450	0.052
Zinc	2.300	3.300	2.700	0.529
Arsenic	0.300	0.320	0.310	0.010
Selenium	0.050	0.050	0.050	0.000
Mercury	0.010	0.010	0.010	0.000

Table 8 Descriptive Statistics of Total Trace Metals in Whole Water at Marguerite (February 1993) - Elemental Research Lab

Metal	Min	Max	Mean	S.D.
Aluminium	60.000	130.000	85.833	38.433
Barium	14.000	24.000	18.333	5.132
Beryllium	0.050	0.050	0.050	0.000
Cadmium	0.050	0.050	0.050	0.000
Chromium	0.200	0.390	0.310	0.098
Cobalt	0.170	0.260	0.213	0.045
Copper	0.120	1.200	0.633	0.542
Iron	150.000	280.000	208.333	66.018
Lead	0.100	0.200	0.140	0.053
Lithium	0.950	1.500	1.183	0.284
Manganese	10.000	18.000	13.833	4.010
Molybdenum	0.590	1.200	0.862	0.310
Nickel	0.400	1.300	0.807	0.456
Strontium	79.000	130.000	102.333	25.775
Vanadium	0.490	0.830	0.613	0.188
Zinc	1.900	3.950	3.017	1.037
Arsenic	0.330	0.340	0.337	0.006
Selenium	0.050	0.050	0.050	0.000
Mercury	0.010	0.010	0.010	0.000

Table 9 Descriptive Statistics for Total Trace Metals in Whole Water at Yale (February 1993) - Elemental Research Lab

Metal	Min	Max	Mean	S.D.
Aluminium	95.000	120.000	105.000	13.229
Barium	18.000	21.000	19.667	1.528
Beryllium	0.050	0.050	0.050	0.000
Cadmium	0.050	0.050	0.050	0.000
Chromium	0.200	0.660	0.363	0.257
Cobalt	0.190	0.240	0.213	0.025
Copper	0.570	1.100	0.813	0.268
Iron	180.000	200.000	186.667	11.547
Lead	0.100	0.410	0.203	0.179
Lithium	1.700	1.800	1.767	0.058
Manganese	6.300	7.100	6.667	0.404
Molybdenum	1.300	1.300	1.300	0.000
Nickel	0.820	1.200	0.947	0.219
Strontium	110.000	120.000	116.667	5.774
Vanadium	0.740	0.760	0.750	0.010
Zinc	2.300	4.000	2.967	0.907
Arsenic	0.500	0.600	0.550	0.050
Selenium	0.050	0.050	0.050	0.000
Mercury	0.010	0.010	0.010	0.000

Table 10 Descriptive Statistics for Total Trace Metals in Whole Water at McLure (February 1993) - Elemental Research Lab

Metal	Min	Max	Mean	S.D.
Aluminium	26.000	34.000	29.333	4.163
Barium	6.650	11.000	8.650	2.196
Beryllium	0.050	0.050	0.050	0.000
Cadmium	0.050	0.050	0.050	0.000
Chromium	0.220	0.260	0.240	0.020
Cobalt	0.089	0.160	0.126	0.036
Copper	0.120	0.320	0.237	0.104
Iron	83.000	150.000	109.000	35.930
Lead	0.100	0.100	0.100	0.000
Lithium	1.250	2.000	1.617	0.375
Manganese	5.050	7.800	6.383	1.377
Molybdenum	0.800	1.300	1.067	0.252
Nickel	0.490	0.790	0.640	0.150
Strontium	76.500	97.000	89.500	11.303
Vanadium	0.270	0.380	0.313	0.059
Zinc	1.200	2.850	1.750	0.953
Arsenic	0.100	0.110	0.103	0.006
Selenium	0.050	0.050	0.050	0.010
Mercury	0.010	0.010	0.010	0.000

Table 11 Descriptive Statistics for Total Trace Metals in Whole Water at Savona (February 1993) - Elemental Research Lab

Metal	Min	Max	Mean	S.D.
Aluminium	17.000	21.000	19.333	2.082
Barium	8.900	9.800	9.400	0.458
Beryllium	0.050	0.050	0.050	0.000
Cadmium	0.050	0.050	0.050	0.000
Chromium	0.200	0.200	0.200	0.000
Cobalt	0.110	0.120	0.117	0.006
Copper	0.110	0.310	0.210	0.141
Iron	48.000	56.000	51.000	4.359
Lead	0.100	0.100	0.100	0.000
Lithium	1.200	1.200	1.200	0.000
Manganese	5.300	5.900	5.567	0.306
Molybdenum	0.900	0.940	0.923	0.021
Nickel	0.540	0.640	0.577	0.055
Strontium	79.000	92.000	83.667	7.234
Vanadium	0.280	0.300	0.290	0.010
Zinc	2.000	2.300	2.100	0.173
Arsenic	0.130	0.160	0.143	0.015
Selenium	0.050	0.050	0.050	0.000
Mercury	0.010	0.010	0.010	0.000

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Table 1 Results of Spatial Comparisons for Total Trace Metals Using the Separate Variance t-test - October 1992 - Shelley vs Marguerite

Metal	t*	d.f.	p - value
Aluminium	-4.763	3.100	0.016
Barium	-1.043	3.500	0.364
Beryllium	NA	NA	NA
Cadmium	NA	NA	NA
Chromium	NA	NA	NA
Cobalt	-5.30	2.400	0.023
Copper	-1.227	3.000	0.307
Iron	-9.480	2.000	0.011
Lithium	-4.115	2.900	0.029
Lead	-3.324	4.000	0.290
Manganese	-10.553	3.700	0.001
Molybdenum	9.493	2.600	0.004
Nickel	5.900	3.900	0.004
Strontium	5.189	2.000	0.035
Vanadium	-0.592	3.900	0.587
Zinc	-0.156	3.500	0.885
Arsenic	1.193	3.900	0.300
Selenium	NA	NA	NA
Mercury	-1.427	2.1	0.285

NA = t-test not applicable as all samples below detection limit

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated

Table 2 Results of Spatial Comparisons for Total Trace Metals Using the Separate Variance t-test - October 1992 - Shelley vs Yale

Metal	t*	d.f.	p - value
Aluminium	-15.371	3.7	0.000
Barium	-15.639	2.8	0.001
Beryllium	-3.399	2.0	0.077
Cadmium	-1.973	2.0	0.187
Chromium	-12.333	2.0	0.007
Cobalt	-17.720	2.8	0.001
Copper	-9.26	3.7	0.001
Iron	-5.195	2.0	0.035
Lithium	-0.943	2.9	0.417
Lead	-30.984	3.6	0.000
Manganese	-28.259	2.0	0.001
Molybdenum	-15.203	2.6	0.001
Nickel	-22.883	2.1	0.001
Strontium	1.005	2.0	0.419
Vanadium	-7.754	2.9	0.003
Zinc	-13.069	2.1	0.005
Arsenic	-17.922	2.4	0.001
Selenium	-1.681	2.0	0.235
Mercury	-0.744	2.1	0.532

NA = t-test not applicable as all samples below detection limit

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated

Table 3 Results of Spatial Comparisons for Total Trace Metals Using the Separate Variance t-test - October 1992 - Marguerite vs Yale

Metal	t*	d.f.	p - value
Aluminium	-21.564	2.7	0.000
Barium	-17.013	2.4	0.002
Beryllium	-3.403	2.0	0.077
Cadmium	-1.966	2.0	0.188
Chromium	-12.332	2.0	0.007
Cobalt	-21.684	2.1	0.002
Copper	-5.561	3.6	0.007
Iron	-7.153	2.2	0.015
Lithium	-3.239	2.2	0.073
Lead	-33.373	3.7	0.000
Manganese	-29.890	2.1	0.001
Molybdenum	-4.941	4.0	0.008
Nickel	-24.335	2.2	0.001
Strontium	9930.371	2.1	0.000
Vanadium	-8.326	2.6	0.006
Zinc	-12.906	2.3	0.004
Arsenic	-17.629	2.3	0.002
Selenium	-1.691	2.000	0.233
Mercury	0.378	3.900	0.725

NA = t-test not applicable as all samples below detection limit

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated

Table 4 Results of Spatial Comparisons for Total Trace Metals Using the Separate Variance t-test - February 1993 - Shelley vs Woodpecker

Metal	t*	d.f.	p - value
Aluminium	-12.02	2.6	0.002
Barium	0.500	3.2	0.649
Beryllium	NA	NA	NA
Cadmium	1.062	2.5	0.380
Chromium	0.417	3.9	0.699
Cobalt	0.857	2.2	0.473
Copper	-1.312	3.9	0.261
Iron	0.500	3.2	0.649
Lithium	9.944	2.2	0.007
Lead	-0.316	3.4	0.770
Manganese	-18.176	2.0	0.003
Molybdenum	-5.794	2.2	0.024
Nickel	-0.097	3.7	0.928
Strontium	3108.000	3.9	0.000
Vanadium	-8.835	2.0	0.012
Zinc	-2.423	2.8	0.099
Arsenic	-21.911	2.3	0.001
Selenium	NA	NA	NA
Mercury	NA	NA	NA

NA = t-test not applicable as all samples below detection limit

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated

Table 5 Results of Spatial Comparisons for Total Trace Metals Using the Separate Variance t-test - February 1993 - Shelley vs Marguerite

Metal	t*	d.f.	p - value
Aluminium	-2.416	2.0	0.136
Barium	1.06	2.1	0.418
Beryllium	NA	NA	NA
Cadmium	1.471	2.0	0.279
Chromium	0.568	2.6	0.615
Cobalt	0.960	2.5	0.421
Copper	-0.770	2.1	0.517
Iron	-0.216	2.1	0.848
Lithium	5.051	2.0	0.036
Lead	1.306	2.0	0.322
Manganese	-2.701	2.3	0.100
Molybdenum	-1.998	2.0	0.181
Nickel	0.498	3.2	0.651
Strontium	3.876	2.0	0.061
Vanadium	-3.955	2.0	0.058
Zinc	-1.841	2.2	0.194
Arsenic	-42.485	2.9	0.000
Selenium	NA	NA	NA
Mercury	NA	NA	NA

NA = t-test not applicable as all samples below detection limit

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated

Table 6 Results of Spatial Comparisons for Total Trace Metals Using the Separate Variance t-test - February 1993 - Shelley vs Yale

Metal	t*	d.f.	p - value
Aluminium	-9.453	2.1	0.010
Barium	1.768	2.6	0.191
Beryllium	NA	NA	NA
Cadmium	1.464	2.0	0.281
Chromium	0.169	4.0	0.874
Cobalt	0.997	2.1	0.417
Copper	-2.583	2.5	0.097
Iron	1.512	3.9	0.207
Lithium	6.708	2.9	0.007
Lead	-0.999	2.0	0.423
Manganese	1.138	2.6	0.348
Molybdenum	-41.676	2.1	0.000
Nickel	0.059	3.9	0.956
Strontium	13.005	2.0	0.006
Vanadium	-85	3.2	0.000
Zinc	-1.996	2.3	0.168
Arsenic	-12.854	2.0	0.006
Selenium	NA	NA	NA
Mercury	NA	NA	NA

NA = t-test not applicable as all samples below detection limit

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated

Table 7 Results of Spatial Comparisons for Total Trace Metals Using the Separate Variance t-test - February 1993 - Woodpecker vs Marguerite

Metal	t*	d.f.	p - value
Aluminium	-0.933	2.1	0.447
Barium	0.883	2.2	0.464
Beryllium	NA	NA	NA
Cadmium	0.977	2.0	0.432
Chromium	0.075	2.9	0.945
Cobalt	0.313	3.6	0.772
Copper	-0.463	2.1	0.687
Iron	-0.305	2.0	0.789
Lithium	0.847	2.6	0.467
Lead	-1.305	2.0	0.322
Manganese	1.805	2.0	2.130
Molybdenum	0.979	3.0	0.399
Nickel	0.594	2.7	0.599
Strontium	0.517	2.0	0.657
Vanadium	-1.449	2.3	0.269
Zinc	-0.471	3.0	0.670
Arsenic	-4.000	3.2	0.025
Selenium	NA	NA	NA
Mercury	NA	NA	NA

NA = t-test not applicable as all samples below detection limit

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated

Table 8 Results of Spatial Comparisons for Total Trace Metals Using the Separate Variance t-test - February 1993 - Woodpecker vs Yale

Metal	t*	d.f.	p - value
Aluminium	-4.970	2.4	0.025
Barium	1.265	3.4	0.285
Beryllium	NA	NA	NA
Cadmium	0.958	2.0	0.439
Chromium	-0.227	3.8	0.832
Cobalt	4.240	3.8	0.694
Copper	-2.015	2.4	0.160
Iron	1.342	2.9	0.274
Lithium	-5.814	2.9	0.011
Lead	-0.999	2.0	0.423
Manganese	48.592	2.0	0.000
Molybdenum	-2.502	2.0	0.129
Nickel	0.178	3.9	0.868
Strontium	-1.994	2.0	0.184
Vanadium	-9.820	2.1	0.008
Zinc	-0.440	3.2	0.688
Arsenic	-8.152	2.2	0.012
Selenium	NA	NA	NA
Mercury	NA	NA	NA

NA = t-test not applicable as all samples below detection limit

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated

Table 9 Results of Spatial Comparisons for Total Trace Metals Using the Separate Variance t-test - October 1992 - McLure vs Savona

Metal	t*	d.f.	p - value
Aluminium	9.713	2.600	0.004
Barium	-6.784	2.700	0.009
Beryllium	NA	NA	NA
Cadmium	9.770	2.000	0.432
Chromium	NA	NA	NA
Cobalt	6.859	3.400	0.004
Copper	-0.031	3.700	0.977
Iron	25.182	2.400	0.001
Lithium	12.775	2.700	0.000
Lead	NA	NA	NA
Manganese	22.112	3.300	0.000
Molybdenum	-1.315	3.900	0.035
Nickel	5.021	2.100	0.035
Strontium	1.789	2.200	0.203
Vanadium	7.778	2.600	0.008
Zinc	-0.757	2.100	0.526
Arsenic	-10.298	3.900	0.001
Selenium	NA	NA	NA
Mercury	0.632	2.400	0.581

NA = t-test not applicable as all samples below detection limit

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated

Table 10 Results of Spatial Comparisons for Total Trace Metals Using the Separate Variance t-test - February 1993 - McLure vs Savona

Metal	t*	d.f.	p - value
Aluminium	3.721	2.9	0.035
Barium	-0.579	2.2	0.594
Beryllium	NA	NA	NA
Cadmium	NA	NA	NA
Chromium	3.438	2.0	0.075
Cobalt	0.464	2.1	0.686
Copper	0.229	1.7	0.843
Iron	2.776	2.1	0.106
Lithium	1.922	2.0	0.194
Lead	NA	NA	NA
Manganese	1.003	2.2	0.413
Molybdenum	0.983	2.0	0.428
Nickel	0.606	2.5	0.550
Strontium	0.753	3.4	0.500
Vanadium	0.680	2.1	0.563
Zinc	-0.626	2.1	0.592
Arsenic	-4.243	2.6	0.033
Selenium	NA	NA	NA
Mercury	NA	NA	NA

NA = t-test not applicable as all samples below detection limit

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated

List of Tables for Total Trace Metal Temporal Comparisons

Table 1	Results of Temporal Comparisons for Total Trace Metals Using the Separate Variance t-test - Shelley - October 1992 vs February 1993	III[5a]
Table 2	Results of Temporal Comparisons for Total Trace Metals Using the Separate Variance t-test - Marguerite - October 1992 vs February 1993	III[5b]
Table 3	Results of Temporal Comparisons for Total Trace Metals Using the Separate Variance t-test - Yale - October 1992 vs February 1993	III[5c]
Table 4	Results of Temporal Comparisons for Total Trace Metals Using the Separate Variance t-test - McLure - October 1992 vs February 1993	III[5d]
Table 5	Results of Temporal Comparisons for Total Trace Metals Using the Separate Variance t-test - Savona - October 1992 vs February 1993	III[5e]

Table 1 Results of Temporal Comparisons for Total Trace Metals Using the Separate Variance t-test - Shelley - October 1992 vs February 1993

Metal	t*	d.f.	p - value
Aluminium	15.029	2.0	0.004
Barium	-2.236	2.9	0.113
Beryllium	NA	NA	NA
Cadmium	-1.474	2.0	0.278
Chromium	-1.370	2.0	0.304
Cobalt	3.894	3.0	0.030
Copper	5.617	2.3	0.022
Iron	173.205	2.0	0.000
Lithium	-14.078	2.3	0.003
Lead	20.516	2.0	0.002
Manganese	31.620	3.2	0.000
Molybdenum	-16.997	3.0	0.000
Nickel	3.676	2.4	0.049
Strontium	-29.001	2.0	0.001
Vanadium	5.694	2.0	0.029
Zinc	3.130	3.9	0.037
Arsenic	13.000	2.1	0.005
Selenium	NA	NA	NA
Mercury	NA	NA	NA

NA = t-test not applicable as all samples below detection limit

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated

Table 2 Results of Temporal Comparisons for Total Trace Metals Using the Separate Variance t-test - Marguerite - October 1992 vs February 1993

Metal	t*	d.f.	p - value
Aluminium	12.156	3.8	0.000
Barium	0.167	2.1	0.882
Beryllium	NA	NA	NA
Cadmium	NA	NA	NA
Chromium	-1.930	2.0	0.193
Cobalt	6.626	2.8	0.009
Copper	3.001	3.8	0.043
Iron	16.140	3.5	0.000
Lithium	-1.901	2.1	0.190
Lead	8.586	3.8	0.001
Manganese	3.818	2.1	0.056
Molybdenum	-2.598	2.1	0.117
Nickel	1.024	2.2	0.405
Strontium	1.870	2.0	0.357
Vanadium	1.037	4.0	0.242
Zinc	-0.943	2.3	0.436
Arsenic	1.093	2.4	0.371
Selenium	NA	NA	NA
Mercury	1.484	2.1	0.271

NA = t-test not applicable as all samples below detection limit

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated

Table 3 Results of Temporal Comparisons for Total Trace Metals Using the Separate Variance t-test - Yale - October 1992 vs February 1993

Metal	t*	d.f.	p - value
Aluminium	29.234	2.1	0.001
Barium	14.709	3.3	0.000
Beryllium	3.447	2.1	0.068
Cadmium	1.880	2.0	0.200
Chromium	10.564	2.9	0.002
Cobalt	23.719	2.1	0.001
Copper	12.510	3.1	0.001
Iron	13.949	2.0	0.005
Lithium	-4.009	2.3	0.045
Lead	15.319	2.4	0.002
Manganese	34.915	2.0	0.001
Molybdenum	-27.601	2.0	0.001
Nickel	23.163	2.8	0.000
Strontium	-1.999	2.0	0.184
Vanadium	9.222	2.0	0.012
Zinc	9.868	3.8	0.001
Arsenic	10.137	3.8	0.001
Selenium	1.691	2.0	0.233
Mercury	NA	NA	NA

NA = t-test not applicable as all samples below detection limit

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated

Table 4 Results of Temporal Comparisons for Total Trace Metals Using the Separate Variance t-test - McLure - October 1992 vs February 1993

Metal	t*	d.f.	p - value
Aluminium	15.146	2.5	0.002
Barium	-0.843	2.0	0.586
Beryllium	NA	NA	NA
Cadmium	0.986	2.0	0.428
Chromium	-3.444	2.0	0.075
Cobalt	1.402	2.4	0.276
Copper	5.149	3.4	0.011
Iron	7.695	2.4	0.009
Lithium	-3.689	2.0	0.066
Lead	81.228	2.0	0.000
Manganese	-1.108	2.0	0.382
Molybdenum	-3.810	2.0	0.060
Nickel	NA	NA	NA
Strontium	-1.250	2.0	0.337
Vanadium	1.526	2.3	0.252
Zinc	-2.698	2.0	0.113
Arsenic	-6.625	3.8	0.003
Selenium	NA	NA	NA
Mercury	0.795	2.1	0.508

NA = t-test not applicable as all samples below detection limit

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated

Table 5 Results of Temporal Comparisons for Total Trace Metals Using the Separate Variance t-test - Savona - October 1992 vs February 1993

Metal	t*	d.f.	p - value
Aluminium	16.403	2.8	0.001
Barium	-0.200	3.7	0.852
Beryllium	NA	NA	NA
Cadmium	NA	NA	NA
Chromium	NA	NA	NA
Cobalt	-4.064	2.4	0.040
Copper	3.761	3.9	0.033
Iron	15.309	3.0	0.000
Lithium	-7379.695	3.7	0.000
Lead	21.520	2.0	0.002
Manganese	-12.460	3.0	0.001
Molybdenum	-21.541	4.0	0.000
Nickel	-11.000	2.4	0.004
Strontium	-1.131	2.5	0.356
Vanadium	0.500	3.2	0.649
Zinc	-5.735	2.6	0.016
Arsenic	-0.822	3.2	0.468
Selenium	NA	NA	NA
Mercury	-1.989	2.0	0.185

NA = t-test not applicable as all samples below detection limit

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated

**Table 1 Total Trace Metals vs Suspended Sediment Concentration
Pearson Correlation Results - Fraser River Basin
October 1992 and February 1993**

Metal	r	p-value
Aluminium	0.954	0.000
Barium	0.870	0.000
Beryllium	0.993	0.000
Cadmium	0.819	0.002
Chromium	0.982	0.000
Cobalt	0.973	0.000
Copper	0.939	0.000
Iron	0.823	0.002
Lithium	0.260	0.440
Lead	0.514	0.106
Manganese	0.989	0.000
Molybdenum	-0.201	0.554
Nickel	0.995	0.000
Strontium	0.090	0.793
Vanadium	-0.026	0.939
Zinc	0.959	0.000
Arsenic	0.871	0.000
Selenium	0.993	0.000
Mercury	0.556	0.076

Number of Observations for each r value = 11

List of Tables for Nutrient Descriptive Statistics

Table 1	Descriptive Statistics for Nitrogen in Whole Water from the Thompson River System (October 1992)	III[7a]
Table 2	Descriptive Statistic for Nitrogen in Whole Water from the Fraser River Basin (February 1993)	III[7b]
Table 3	Descriptive Statistics for Phosphorus in Whole Water from the Thompson River System (October 1992)	III[7c]
Table 4	Descriptive Statistics for Phosphorus in Whole Water from the Fraser River Basin (February 1993)	III[7d]

Table 1 Descriptive Statistics for Nitrogen in Whole Water from the Thompson River System (October 1992)

Type	Site	Nitrogen	Min.	Max.	Mean	S.D.
Whole Water	McLure	Ammonia	0.002	0.003	0.003	0.001
		Nitrate/Nitrite	0.100	0.103	0.102	0.002
		Total Nitrogen	0.160	0.180	0.170	0.010
	Savona	Ammonia	0.002	0.004	0.003	0.001
		Nitrate/Nitrite	0.085	0.085	0.085	0.000
		Total Nitrogen	0.150	0.160	0.157	0.006
Clarified Water	McLure	Ammonia	0.002	0.002	0.002	0.000
		Nitrate/Nitrite	0.102	0.102	0.102	0.000
		Total Nitrogen	0.150	0.150	0.150	0.000
	Savona	Ammonia	0.002	0.002	0.002	0.000
		Nitrate/Nitrite	0.086	0.086	0.086	0.000
		Total Nitrogen	0.140	0.160	0.153	0.012
Filtered Water	McLure	Ammonia	0.003	0.003	0.003	0.000
		Nitrate/Nitrite	0.102	0.103	0.102	0.001
		Total Nitrogen	0.160	0.170	0.167	0.006
	Savona	Ammonia	0.002	0.003	0.002	0.001
		Nitrate/Nitrite	0.085	0.086	0.085	0.001
		Total Nitrogen	0.150	0.160	0.157	0.006

Table 2 Descriptive Statistics of Nitrogen in Whole Water from the Fraser River Basin (February 1993)

Type	Site	Nitrogen Form	Min.	Max.	Mean	S.D.
Whole Water	McLure	Total Nitrogen	0.280	0.330	0.307	0.025
	Savona		0.310	0.340	0.320	0.017
	Shelley		0.210	0.220	0.217	0.006
	Woodpecker		0.390	0.410	0.400	0.010
	Marguerite		0.390	0.430	0.407	0.021
	Yale		0.200	0.240	0.223	0.021
Clarified Water	McLure	Ammonia	0.009	0.022	0.014	0.007
		Nitrite	0.002	0.002	0.002	0.000
		Nitrate/Nitrite	0.075	0.077	0.076	0.001
	Savona	Ammonia	0.020	0.004	0.003	0.001
		Nitrite	NA	NA	NA	NA
		Nitrate/Nitrite	0.139	0.139	0.139	0.000
	Shelley	Ammonia	0.002	0.002	0.002	0.000
		Nitrite	0.002	0.002	0.002	0.000
		Nitrate/Nitrite	0.136	0.138	0.137	0.001
	Woodpecker	Ammonia	0.042	0.045	0.044	0.002
		Nitrite	0.002	0.002	0.002	0.000
		Nitrate/Nitrite	0.120	0.103	0.103	0.001
	Marguerite	Ammonia	0.054	0.061	0.057	0.004
		Nitrite	0.004	0.004	0.004	0.000
		Nitrate/Nitrite	0.163	0.182	0.171	0.010
	Yale	Ammonia	0.016	0.019	0.017	0.002
		Nitrite	NA	NA	NA	NA
		Nitrate/Nitrite	0.002	0.007	0.004	0.003

NA = Not Available

Table 3 Descriptive Statistics of Phosphorus in Whole Water from the Thompson River System (October 1992)

Type	Site	Phosphorus	Min.	Max.	Mean	S.D.
Whole Water	McLure	Total Phosphorus	0.002	0.002	0.002	0.000
	Savona		0.002	0.002	0.002	0.000
Clarified Water	McLure	Dissolved Phosphorus	0.002	0.002	0.002	0.000
	Savona		0.002	0.003	0.003	0.001
Filtered Water	McLure	Dissolved Phosphorus	0.002	0.002	0.002	0.000
	Savona		0.002	0.002	0.002	0.000
Filtered (Yellow) Water	McLure	Dissolved Phosphorus	0.002	0.002	0.002	0.000
	Savona		0.002	0.002	0.002	0.000

* Note that two different filtering methods were used

Table 4 Descriptive Statistics of Phosphorus in Whole Water from the Fraser River Basin (February 1993)

Type	Site	Phosphorus	Min.	Max.	Mean	S.D.
Whole Water	McLure	Total Phosphorus	0.004	0.005	0.005	0.001
	Savona		0.005	0.007	0.006	0.001
	Shelley		0.027	0.031	0.028	0.002
	Woodpecker		0.031	0.032	0.031	0.001
	Marguerite		0.035	0.036	0.036	0.001
	Yale		0.015	0.021	0.017	0.003
Clarified Water	McLure	Dissolved Phosphorus	0.002	0.002	0.002	0.000
	Savona		0.002	0.003	0.002	0.001
	Shelley		0.024	0.024	0.024	0.000
	Woodpecker		0.015	0.016	0.015	0.001
	Marguerite		0.023	0.026	0.025	0.002
	Yale		NA	NA	NA	NA

NA = Not Available

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**Table 1 Results of Temporal Comparisons for Phosphorus Using the Separate Variance t-test
October 1992 vs February 1993**

Type	Site	Phosphorus	t*	d.f	p - value
Whole Water	McLure Savona	Total Phosphorus	-6.867	2.5	0.011
			-6.859	2.0	0.020
Clarified Water	McLure Savona	Dissolved Phosphorus	NA	NA	NA
			0.707	4.0	0.519

NA = Not Analysed

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated

Table 2 Results of Spatial Comparisons for Phosphorus Using the Separate Variance t-test (February 1993)

Type	Sites	Phosphorus	t*	d.f.	p - value
Whole Water	McLure vs Savona	Total Phosphorus	-2.000	3.2	0.134
	Shelley vs Marguerite		-5.336	2.2	0.026
	Shelley vs Woodpecker		-2.183	2.2	0.147
	Shelley vs Yale		4.184	3.6	0.011
	Woodpecker vs Marguerite		-9.192	4.0	0.001
	Woodpecker vs Yale		7.425	2.1	0.015
	Marguerite vs Yale		9.723	2.1	0.008
Clarified Water	McLure vs Savona	Dissolved Phosphorus	-1.006	2.2	0.412
	Shelley vs Marguerite		-0.863	2.0	0.478
	Shelley vs Woodpecker		25.522	2.3	0.001
	Shelley vs Yale		NA	NA	NA
	Woodpecker vs Marguerite		-9.171	2.4	0.006
	Woodpecker vs Yale		NA	NA	NA

NA = Not Analysed

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated

**Table 3 Results of Temporal Comparisons for Nitrogen Using the Separate Variance t-test
October 1992 vs February 1993**

Type	Sites	Nitrogen	t*	d.f.	p-value
Whole Water	McLure	Total Nitrogen	-8.741	2.6	0.005
	Savona		-15.495	2.4	0.002
Clarified Water	McLure	Ammonia	-2.745	2.0	0.111
		Nitrate/Nitrite	44.745	2.1	0.000
	Savona	Ammonia	-1.551	2.0	0.259
		Nitrate/Nitrite	-426.014	4.0	0.000

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated

Table 4 Results of the Spatial Comparisons for Nitrogen Using the Separate Variance t-test - October 1992

Date	Type	Sites	Nitrogen	t*	d.f.	p-value
October 1992	Whole Water	McLure vs Savona	Ammonia	0.000	2.9	1.000
			Nitrate/Nitrite	18.381	2.2	0.002
			Total Nitrogen	2.000	3.2	0.134
	Clarified Water	McLure vs Savona	Ammonia	0.000	3.7	1.000
			Nitrate/Nitrite	67.535	3.2	0.000
			Total Nitrogen	-0.498	2.0	0.667
	Filtered Water	McLure vs Savona	Ammonia	2.875	2.5	0.080
			Nitrate/Nitrite	36.062	4.0	0.000
			Total Nitrogen	2.121	4.0	0.101

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated

Table 5 Results of Spatial Comparisons for Nitrogen Using the Separate Variance t-test - February 1993

Type	Sites	Nitrogen	t*	d.f.	p-value
Whole Water	McLure vs Savona	Total Nitrogen	-0.756	3.5	0.497
	Shelley vs. Woodpecker	Total Nitrogen	-27.500	3.2	0.000
	Shelley vs. Marguerite	Total Nitrogen	-15.234	2.3	0.002
	Shelley vs. Yale	Total Nitrogen	-0.535	2.3	0.640
	Woodpecker vs. Marguerite	Total Nitrogen	-0.500	2.9	0.653
	Woodpecker vs. Yale	Total Nitrogen	13.250	2.9	0.001
	Marguerite vs Yale	Total Nitrogen	10.786	4.0	0.000
Clarified Water	McLure vs Savona	Ammonia	2.530	2.1	0.123
		Nitrite	NA	NA	NA
		Nitrate/Nitrite	-107.112	2.2	0.000
	Shelley vs. Woodpecker	Ammonia	-41.830	2.0	0.001
		Nitrite	-0.316	3.4	0.770
		Nitrate/Nitrite	46.000	2.9	0.000
	Shelley vs. Marguerite	Ammonia	-24.955	2.0	0.002
		Nitrite	-18.187	3.2	0.000
		Nitrate/Nitrite	-5.726	2.1	0.027
	Shelley vs. Yale	Ammonia	-14.875	2.0	0.004
		Nitrite	NA	NA	NA
		Nitrate/Nitrite	74.464	2.6	0.000
	Woodpecker vs. Marguerite	Ammonia	-5.270	2.8	0.016
		Nitrite	-15.500	3.9	0.000
		Nitrate/Nitrite	-11.739	2.0	0.007
	Woodpecker vs. Yale	Ammonia	19.092	4.0	0.000
		Nitrite	NA	NA	NA
		Nitrate/Nitrite	58.246	2.2	0.000
	Marguerite vs Yale	Ammonia	16.502	2.8	0.001
		Nitrite	NA	NA	NA
		Nitrate/Nitrite	27.748	2.3	0.001

NA = Not Analysed

* A positive t value signifies that the parameter is significantly higher at the first site indicated, whereas a negative value signifies that the parameter is significantly higher at the second site indicated

APPENDIX IV

23.0 PHASE PARTITIONING CALCULATIONS

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Table 1 Summary of Dioxin and Furan Partitioning to Suspended Sediments, Published and Calculated Log Koc Values - Thompson River System - Solid Phase Extraction (February 1993)

	Published Range of Log Koc Values (1)	McLure		Savona	
		% In S.S. (2)	Log Koc	% In S.S. (2)	Log Koc
Dioxins					
T4CDD - Total	2.11 - 7.59	N/A	N/A	N/A	N/A
2,3,7,8	4.76-7.59	N/A	N/A	N/A	N/A
P5CDD - Total	4.85- 6.38	N/A	N/A	N/A	N/A
H6CDD - Total	5.02 - 7.1	N/A	N/A	N/A	N/A
H7CDD - Total	5.47 - 7.8	14.97	6.65	N/A	N/A
O8CDD	5.92 - 7.9	5.70	6.19	82.55	7.37
Furans					
T4CDF - Total	5.2 - 7.5	N/A	N/A	N/A	N/A
2,3,7,8	5.2 - 7.5	N/A	N/A	63.11	6.92
P5CDF - Total	5.59 - 7.4	N/A	N/A	N/A	N/A
H6CDF - Total	7.4	N/A	N/A	N/A	N/A
H7CDF - Total	5 - 7.9	N/A	N/A	N/A	N/A
O8CDF	6 - 7.4	N/A	N/A	N/A	N/A

N/A denotes not applicable as dioxins/furans were not detected in both the suspended sediment and the solid phase extracted clarified water samples

(1) Mackay et al., 1992.

(2) % in S.S. =
$$\frac{(\text{concentration in suspended sediment})(\text{suspended sediment concentration})(1/1000)}{(\text{concentration in susp. sed.})(\text{susp. sed. conc.})(1/1000) + \text{concentration in solid phase extract}}$$

x 100

Table 2 Summary of Dioxin and Furan Partitioning to Suspended Sediments, Published and Calculated Log Koc Values - Thompson River System - Liquid Phase Extraction (February 1993)

	Published Range of Log Koc Values (1)	McLure % in S.S. (2)	Log Koc	Savona % in S.S. (2)	Log Koc
Dioxins					
T4CDD - Total	2.11 - 7.59	N/A	N/A	N/A	N/A
2,3,7,8	4.76-7.59	N/A	N/A	N/A	N/A
P5CDD - Total	4.85- 6.38	N/A	N/A	N/A	N/A
H6CDD - Total	5.02 - 7.1	1.19	5.48	N/A	N/A
H7CDD - Total	5.47 - 7.8	14.97	6.65	45.63	6.77
O8CDD	5.92 - 7.9	2.65	5.84	29.72	7.06
Furans					
T4CDF - Total	5.2 - 7.5	N/A	N/A	N/A	N/A
2,3,7,8	5.2 - 7.5	N/A	N/A	39.37	6.87
P5CDF - Total	5.59 - 7.4	N/A	N/A	N/A	N/A
H6CDF - Total	7.4	N/A	N/A	N/A	N/A
H7CDF - Total	5 - 7.9	N/A	N/A	N/A	N/A
O8CDF	6 - 7.4	N/A	N/A	N/A	N/A

N/A denotes not applicable as dioxins/furans were not detected in both the suspended sediment and the liquid phase extracted clarified water samples

(1) Mackay et al, 1992.

(2) % in S.S. =
$$\frac{(\text{concentration in suspended sediment})(\text{suspended sediment concentration})(1/1000)}{(\text{concentration in susp. sed.})(\text{susp. sed. conc.})(1/1000) + \text{concentration in liquid phase extract}}$$

x 100%

Table 3 Summary of Dioxin and Furan Partitioning to Suspended Sediments, Published and Calculated Log Koc Values - Fraser River - Solid Phase Extraction (February 1993)

	Published Range of Log Koc Values (1)	Woodpecker		Marguerite		Yale	
		Feb. 1993		Feb. 1993		Feb. 1993	
		% in S.S. (2)	Log Koc	% in S.S. (2)	Log Koc	% in S.S. (2)	Log Koc
Dioxins							
Total T4CDD	2.11 - 7.59	N/A	N/A	N/A	N/A	N/A	N/A
2,3,7,8 T4CDD	4.76-7.59	N/A	N/A	N/A	N/A	N/A	N/A
Total P5CDD	4.85- 6.38	N/A	N/A	N/A	N/A	N/A	N/A
Total H6CDD	5.02 - 7.1	N/A	N/A	N/A	N/A	N/A	N/A
Total H7CDD	5.47 - 7.8	N/A	N/A	N/A	N/A	N/A	N/A
O8CDD	5.92 - 7.9	82.02	7.02	79.98	7.27	47.64	7.28
Furans							
Total T4CDF	5.2 - 7.5	N/A	N/A	N/A	N/A	N/A	N/A
2,3,7,8-T4CDF	5.2 - 7.5	N/A	N/A	N/A	N/A	N/A	N/A
Total P5CDF	5.59 - 7.4	N/A	N/A	N/A	N/A	N/A	N/A
Total H6CDF	7.4	N/A	N/A	N/A	N/A	N/A	N/A
Total H7CDF	5 - 7.9	N/A	N/A	N/A	N/A	N/A	N/A
O8CDF	6 - 7.4	N/A	N/A	N/A	N/A	N/A	N/A

N/A denotes not applicable as dioxins/furans were not detected in both the suspended sediment and the solid phase extracted clarified water samples

(1) Mackay et al , 1992.

*(2) % in S.S. =
$$\frac{(\text{concentration in suspended sediment})(\text{suspended sediment concentration})(1/1000)}{(\text{concentration in susp. sed.})(\text{susp. sed. conc.})(1/1000) + \text{concentration in solid phase extract}}$$*

x 100%

Table 4 Summary of Dioxin and Furan Partitioning to Suspended Sediments, Published and Calculated Log Koc Values - Fraser River - Liquid Phase Extraction (February 1993)

	Published Range of Log Koc Values (1)	Woodpecker		Marguerite		Yale	
		% In S.S. (2)	Log Koc	% In S.S. (2)	Log Koc	% In S.S. (2)	Log Koc
Dioxins							
Total T4CDD	2.11 - 7.59	N/A	N/A	N/A	N/A	N/A	N/A
2,3,7,8 T4CDD	4.76-7.59	N/A	N/A	N/A	N/A	N/A	N/A
Total P5CDD	4.85- 6.38	N/A	N/A	N/A	N/A	N/A	N/A
Total H6CDD	5.02 - 7.1	42.20	4.33	57.47	6.93	9.98	6.36
Total H7CDD	5.47 - 7.8	N/A	N/A	47.17	6.75	44.87	7.23
O8CDD	5.92 - 7.9	71.15	4.85	61.04	7.00	N/A	N/A
Furans							
Total T4CDF	5.2 - 7.5	53.08	4.52	40.70	6.64	30.35	6.96
2,3,7,8-T4CDF	5.2 - 7.5	N/A	N/A	N/A	N/A	46.87	7.26
Total P5CDF	5.59 - 7.4	N/A	N/A	N/A	N/A	N/A	N/A
Total H6CDF	7.4	N/A	N/A	N/A	N/A	N/A	N/A
Total H7CDF	5 - 7.9	N/A	N/A	N/A	N/A	N/A	N/A
O8CDF	6 - 7.4	N/A	N/A	N/A	N/A	11.44	6.43

N/A denotes not applicable as dioxins/furans were not detected in both the suspended sediment and the liquid phase extracted clarified water samples

(1) Mackay et al, 1992.

(2) % in S.S. = $\frac{(\text{concentration in suspended sediment})/(\text{suspended sediment concentration})/(1/1000)}{(\text{concentration in susp. sed.})/(\text{susp. sed. conc.})/(1/1000) + \text{concentration in liquid phase extract}}$ x 100%

**Table 6 Summary of Chlorophenolic Partitioning to Suspended Sediments and Calculated Log K_{oc} Values
Thompson River System - (October 1992, February 1993, November 1993)**

	McLure		McLure		McLure		Savona		Savona		Savona	
	% in S.S. (1)		% in S.S. (1)		% in S.S. (1) Log K _{oc}		% in S.S. (1) Log K _{oc}		% in S.S. (1) Log K _{oc}		% in S.S. (1) Log K _{oc}	
Sampling Date:	Oct 92		Feb. 93		Nov. 93		Oct 92		Feb 93		Nov. 93	
Chlorophenols												
4-chlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,6-dichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,4/2,5-DCP	0.12	4.041	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,5-dichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3-dichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4-dichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6-chloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4-chloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	0.068	4.178	0.420	4.316	N/A	N/A
5-chloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.719	5.107
2,4,6-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3,6-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3,5-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,4,5-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3,4-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4,5-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3-chlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.120	4.327
4-chlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4-dichloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4,6-dichloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4,5-dichloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	0.468	5.029	N/A	N/A	N/A	N/A
3-chlorosyringol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4-dichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,6-dichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,5-dichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4,5-dichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3,5,6-tetrachlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3,4,6-tetrachlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3,4,5-tetrachlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5-chlorovanillin	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6-chlorovanillin	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,5-dichlorosyringol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4,6-trichloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4,5-trichloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	0.3735	4.930	N/A	N/A	N/A	N/A
4,5,6-trichloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4,6-trichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4,5-trichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5,6-dichlorovanillin	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
pentachlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2-chlorosyringaldehyde	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
tetrachloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4,5-trichlorosyringol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
tetrachlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,6-dichlorosyringaldehyde	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

N/A denotes not applicable as chlorophenols were not detected in both suspended sediment and whole water samples

$$(1) \quad \% \text{ in S.S.} = \frac{(\text{concentration in suspended sediment}) / (\text{suspended sediment concentration}) / (1/1000)}{\text{concentration in whole water}} \times 100\%$$

Table 6 Summary of Chlorophenolic Partitioning to Suspended Sediments and Calculated Log Koc Values - Fraser River (October 1992)

	Shelley		Woodpecker		Marguerite		Yale	
	% in S.S. (1)	Log Koc	% in S.S. (1)	Log Koc	% in S.S. (1)	Log Koc	% in S.S. (1)	Log Koc
Chlorophenols								
4-chlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,6-dichlorophenol	N/A	N/A	N/A	N/A	1.76	4.471	N/A	N/A
2,4/2,5-DCP	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,5-dichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3-dichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4-dichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6-chloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4-chloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5-chloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,4,6-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3,6-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3,5-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,4,5-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3,4-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4,5-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3-chlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4-chlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4-dichloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4,6-dichloroguaiacol	N/A	N/A	0.10	3.534	N/A	N/A	N/A	N/A
4,5-dichloroguaiacol	N/A	N/A	2.06	4.856	1.30	4.336	24.90	5.157
3-chlorosyringol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4-dichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,6-dichlorocatechol	N/A	N/A	N/A	N/A	19.93	5.614	N/A	N/A
3,5-dichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	20.00	5.038
4,5-dichlorocatechol	N/A	N/A	5.81	5.324	7.75	5.142	39.55	5.453
2,3,5,6-tetrachlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3,4,6-tetrachlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3,4,5-tetrachlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5-chlorovanillin	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6-chlorovanillin	N/A	N/A	3.42	5.083	7.48	5.126	N/A	N/A
3,5-dichlorosyringol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4,6-trichloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4,5-trichloroguaiacol	N/A	N/A	0.24	3.922	0.46	3.883	1.74	3.885
4,5,6-trichloroguaiacol	N/A	N/A	0.33	4.058	0.23	3.581	N/A	N/A
3,4,6-trichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4,5-trichlorocatechol	N/A	N/A	2.04	4.852	3.43	4.789	8.34	4.596
5,6-dichlorovanillin	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
pentachlorophenol	N/A	N/A	N/A	N/A	1.92	4.509	N/A	N/A
2-chlorosyringaldehyde	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
tetrachloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4,5-trichlorosyringol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
tetrachlorocatechol	N/A	N/A	12.50	5.689	18.10	5.501	6.78	4.499
2,6-dichlorosyringaldehyde	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

N/A denotes not applicable as chlorophenols were not detected in both suspended sediment and whole water samples

$$(1) \quad \% \text{ in S.S.} = \frac{(\text{concentration in suspended sediment})(\text{suspended sediment concentration})(1/1000)}{\text{concentration in whole water}} \times 100\%$$

Table 7 Summary of Chlorophenolic Partitioning to Suspended Sediments and Calculated Log Koc Values - Fraser River (February 1993)

	Shelley		Woodpecker		Marguerite		Yale	
	% in SS (1)	Log Koc	% in SS (1)	Log Koc	% in SS (1)	Log Koc	% in SS (1)	Log Koc
Chlorophenols								
4-chlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,6-dichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,4/2,5-DCP	N/A	N/A	0.58	4.362	N/A	N/A	0.219	4.66
3,5-dichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3-dichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4-dichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6-chloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4-chloroguaiacol	N/A	N/A	5.66	5.377	0.11	3.838	N/A	N/A
5-chloroguaiacol	N/A	N/A	0.14	3.736	0.06	3.563	N/A	N/A
2,4,6-trichlorophenol	N/A	N/A	0.33	4.125	N/A	N/A	0.274	4.76
2,3,6-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3,5-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,4,5-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3,4-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4,5-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3-chlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	0.021	3.63
4-chlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4-dichloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4,6-dichloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4,5-dichloroguaiacol	N/A	N/A	9.23	5.606	1.92	5.097	0.394	4.91
3-chlorosyringol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4-dichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,6-dichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,5-dichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4,5-dichlorocatechol	N/A	N/A	3.74	5.189	N/A	N/A	0.609	5.10
2,3,5,6-tetrachlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3,4,6-tetrachlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3,4,5-tetrachlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5-chlorovanillin	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6-chlorovanillin	N/A	N/A	4.65	5.286	1.26	4.911	1.976	5.61
3,5-dichlorosyringol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4,6-trichloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4,5-trichloroguaiacol	N/A	N/A	0.48	4.282	0.35	4.349	0.092	4.28
4,5,6-trichloroguaiacol	N/A	N/A	0.30	4.075	0.23	4.165	0.158	4.52
3,4,6-trichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4,5-trichlorocatechol	N/A	N/A	73.43	7.040	9.51	5.826	0.480	5.00
5,6-dichlorovanillin	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
pentachlorophenol	N/A	N/A	1.02	4.613	N/A	N/A	N/A	N/A
2-chlorosyringaldehyde	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
tetrachloroguaiacol	N/A	N/A	N/A	N/A	0.25	4.199	N/A	N/A
3,4,5-trichlorosyringol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
tetrachlorocatechol	N/A	N/A	N/A	N/A	7.39	5.706	N/A	N/A
2,6-dichlorosyringaldehyde	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

N/A denotes not applicable as chlorophenols were not detected in both suspended sediment and whole water samples

$$(1) \quad \% \text{ in S.S.} = \frac{(\text{concentration in suspended sediment})(\text{suspended sediment concentration})(1/1000)}{\text{concentration in whole water}} \times 100\%$$

Table 8 Summary of Chlorophenolic Partitioning to Suspended Sediments and Calculated Log Koc Values - Fraser River (November 1993)

	Shelley		Woodpecker		Marguerite		Yale	
	% in SS (1)	Log Koc	% in SS (1)	Log Koc	% in SS (1)	Log Koc	% in SS (1)	Log Koc
Chlorophenols								
4-chlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,6-dichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,4/2,5-DCP	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,5-dichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3-dichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4-dichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6-chloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4-chloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5-chloroguaiacol	N/A	N/A	N/A	N/A	0.81	4.757	64.080	6.10
2,4,6-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3,6-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3,5-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,4,5-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3,4-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4,5-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3-chlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4-chlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4-dichloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4,6-dichloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4,5-dichloroguaiacol	N/A	N/A	1.80	4.238	7.25	5.739	5.082	5.00
3-chlorosyringol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4-dichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,6-dichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,5-dichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4,5-dichlorocatechol	N/A	N/A	31.06	5.630	6.47	5.685	7.200	5.15
2,3,5,6-tetrachlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3,4,6-tetrachlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,3,4,5-tetrachlorophenol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5-chlorovanillin	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6-chlorovanillin	N/A	N/A	22.35	5.435	N/A	N/A	N/A	N/A
3,5-dichlorosyringol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4,6-trichloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4,5-trichloroguaiacol	N/A	N/A	6.09	4.789	2.47	5.250	4.320	4.93
4,5,6-trichloroguaiacol	N/A	N/A	N/A	N/A	2.03	5.162	N/A	N/A
3,4,6-trichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3,4,5-trichlorocatechol	N/A	N/A	20.35	5.384	17.40	6.169	14.400	5.45
5,6-dichlorovanillin	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
pentachlorophenol	0.33	4.089	0.73	3.842	N/A	N/A	N/A	N/A
2-chlorosyringaldehyde	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
tetrachloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A	1.440	4.45
3,4,5-trichlorosyringol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
tetrachlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2,6-dichlorosyringaldehyde	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

N/A denotes not applicable as chlorophenols were not detected in both suspended sediment and whole water samples

$$(1) \quad \% \text{ in S.S.} = \frac{(\text{concentration in suspended sediment})(\text{suspended sediment concentration})(1/1000)}{\text{concentration in whole water}} \times 100\%$$

Table 9 Summary of Chlorophenolic Partitioning to Suspended Sediments, and Calculated Log Koc Values - Fraser River (November 1994)

	Shelley		Marguerite		Yale	
	% in Susp. Sed. (1)	Log Koc	% in Susp. Sed. (1)	Log Koc	% in Susp. Sed. (1)	Log Koc
Chlorophenols						
4-chlorophenol	N/A	N/A	N/A	N/A	N/A	N/A
2,6-dichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A
2,4/2,5-DCP	0.26	4.83	0.08	3.87	0.06	4.17
3,5-dichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A
2,3-dichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A
3,4-dichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A
6-chloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A
4-chloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A
5-chloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A
2,4,6-trichlorophenol	N/A	N/A	0.06	3.75	N/A	N/A
2,3,6-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A
2,3,5-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A
2,4,5-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A
2,3,4-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A
3,4,5-trichlorophenol	N/A	N/A	N/A	N/A	N/A	N/A
3-chlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A
4-chlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A
3,4-dichloroguaiacol	N/A	N/A	0.03	3.51	N/A	N/A
4,6-dichloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A
4,5-dichloroguaiacol	N/A	N/A	0.67	4.81	0.25	4.80
3-chlorosyringol	N/A	N/A	N/A	N/A	N/A	N/A
3,4-dichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A
3,6-dichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A
3,5-dichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A
4,5-dichlorocatechol	N/A	N/A	8.58	5.92	N/A	N/A
2,3,5,6-tetrachlorophenol	N/A	N/A	N/A	N/A	N/A	N/A
2,3,4,6-tetrachlorophenol	N/A	N/A	N/A	N/A	N/A	N/A
2,3,4,5-tetrachlorophenol	N/A	N/A	N/A	N/A	N/A	N/A
5-chlorovanillin	N/A	N/A	N/A	N/A	N/A	N/A
6-chlorovanillin	N/A	N/A	0.95	4.96	1.24	5.49
3,5-dichlorosyringol	N/A	N/A	N/A	N/A	N/A	N/A
3,4,6-trichloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A
3,4,5-trichloroguaiacol	N/A	N/A	0.85	4.91	0.86	5.33
4,5,6-trichloroguaiacol	N/A	N/A	0.49	4.67	0.21	4.71
3,4,6-trichlorocatechol	N/A	N/A	N/A	N/A	N/A	N/A
3,4,5-trichlorocatechol	N/A	N/A	18.92	6.26	N/A	N/A
5,6-dichlorovanillin	N/A	N/A	N/A	N/A	N/A	N/A
pentachlorophenol	N/A	N/A	N/A	N/A	N/A	N/A
2-chlorosyringaldehyde	N/A	N/A	N/A	N/A	N/A	N/A
tetrachloroguaiacol	N/A	N/A	N/A	N/A	N/A	N/A
3,4,5-trichlorosyringol	N/A	N/A	N/A	N/A	N/A	N/A
tetrachlorocatechol	N/A	N/A	16.52	6.20	N/A	N/A
2,6-dichlorosyringaldehyde	N/A	N/A	N/A	N/A	N/A	N/A

N/A denotes not applicable as chlorophenols were not detected in both suspended sediment and whole water samples

$$(1) \quad \% \text{ in S.S.} = \frac{(\text{concentration in suspended sediment})(\text{suspended sediment concentration})(1/1000)}{\text{concentration in whole water}}$$

x 100%

Table 10 Summary of Polycyclic Aromatic Hydrocarbon Partitioning to Suspended Sediment, Published and Calculated Log Koc Values - Thompson River System (October 1992, February 1993)

	Published Range of Log Koc (1)	McLure				Savona			
		Oct 92		Feb 93		Oct 92		Feb 93	
		% in SS (2)	Log Koc	% in SS (2)	Log Koc	%in SS (2)	Log Koc	% in SS (2)	Log Koc
PAHs									
Naphthalene	2.38 - 5.0	0.15	4.12	0.03	3.85	0.13	4.47	0.45	4.35
Acenaphthylene	3.4 - 3.83	0.37	4.51	0.20	4.71	1.46	5.53	31.34	6.35
Acenaphthene	3.59 - 5.38	N/A	N/A	0.71	5.26	N/A	N/A	3.97	5.55
Fluorene	3.76 - 5.47	0.55	4.69	0.75	5.28	0.83	5.28	13.00	5.90
Phenanthrene	3.97 - 6.12	2.06	5.27	0.95	5.40	2.23	5.71	31.81	6.40
Anthracene	2.96 - 5.76	2.52	5.35	0.79	5.30	4.85	6.06	N/A	N/A
Fluoranthene	4.0 - 6.38	6.54	5.79	3.10	5.91	4.99	6.08	29.82	6.36
Pyrene	3.11 - 6.51	6.58	5.80	2.99	5.89	6.65	6.21	38.46	6.53
Benz(a)anthracene	4.0 - 7.3	13.42	6.14	N/A	N/A	23.95	6.85	N/A	N/A
Chrysene	3.66 - 6.9	23.66	6.44	11.47	6.52	16.32	6.65	41.18	6.58
Benzofluoranthenes	4.0 - 7.0	38.27	6.74	N/A	N/A	N/A	N/A	N/A	N/A
Benzo(e)pyrene	4.0 - 7.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Benzo(a)pyrene	4.0 - 8.3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Perylene	3.75 - 5.74	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Dibenz(ah)anthracene	5.2 - 6.52	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Indeno(1,2,3-cd)pyrene	-	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Benzo(ghi)perylene	6.2 - 6.26	N/A	N/A	N/A	N/A	N/A	N/A	52.38	6.74

N/A denotes not applicable as PAH's were not detected in both suspended sediment and solid phase extracted samples

(1) MacKay et al, 1992.

(2) % in S.S. =
$$\frac{(\text{concentration in suspended sediment})(\text{suspended sediment concentration})(1/1000)}{(\text{concentration in susp. sed.})(\text{susp. sed. conc.})(1/1000) + \text{concentration in solid phase extract}} \times 100\%$$

Table 11 Summary of Polycyclic Aromatic Hydrocarbon Partitioning to Suspended Sediments, Calculated and Published Log Koc Values - Fraser River (October 1992, February 1993)

	Published Range of Log Koc (1)	Shelley				Woodpecker				Marguerite				Yale			
		Oct. 1992		Feb. 1993		Oct 1992		Feb. 1993		Oct 1992		Feb. 1993		Oct 1992		Feb. 1993	
		% in S.S. (2)	Log Koc	% in S.S. (2)	Log Koc	% in S.S. (2)	Log Koc	% in S.S. (2)	Log Koc	% in S.S. (2)	Log Koc	% in S.S. (2)	Log Koc	% in Susp. Sed. (2)	Log Koc	% in Susp. Sed. (2)	Log Koc
PAHs																	
Naphthalene	2.38 - 5.0	1.02	4.45	0.02	4.18	1.20	4.62	0.16	3.80	0.72	4.08	0.17	4.03	8.78	4.62	0.08	4.07
Acenaphthylene	3.4 - 3.83	N/A	N/A	N/A	N/A	N/A	N/A	9.27	5.61	N/A	N/A	8.59	5.78	19.49	5.02	1.99	5.63
Acenaphthene	3.59 - 5.38	N/A	N/A	2.71	6.24	N/A	N/A	10.46	5.87	N/A	N/A	8.98	5.80	N/A	N/A	0.24	4.71
Fluorene	3.76 - 5.47	6.78	5.30	4.63	6.48	5.66	5.31	16.46	5.89	3.37	4.76	11.08	5.90	30.29	5.28	1.34	5.45
Phenanthrene	3.97 - 6.12	23.22	5.92	2.63	6.22	17.24	5.85	20.81	6.02	12.57	5.38	17.14	6.12	56.87	5.76	3.30	5.85
Anthracene	2.96 - 5.76	N/A	N/A	1.18	5.86	1.29	4.85	N/A	N/A	20.35	5.63	34.06	6.52	56.00	5.74	8.94	6.19
Fluoranthene	4.0 - 6.38	28.46	6.04	6.72	6.65	31.58	6.20	41.46	6.45	27.12	5.79	48.46	6.78	68.94	5.98	8.81	6.30
Pyrene	3.11 - 6.51	25.58	5.98	5.04	6.52	28.57	6.14	30.46	6.24	26.99	5.79	27.33	6.38	69.00	5.99	9.93	6.36
Benz(a)anthracene	4.0 - 7.3	23.95	5.94	N/A	N/A	33.33	6.41	N/A	N/A	53.49	6.28	N/A	N/A	87.00	6.47	14.23	6.54
Chrysene	3.66 - 6.9	55.75	6.54	5.12	6.52	39.13	6.34	N/A	N/A	69.70	6.58	N/A	N/A	91.05	6.84	23.95	6.82
Benzo(a)anthracene	4.0 - 7.0	N/A	N/A	N/A	N/A	69.23	6.89	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Benzo(e)pyrene	4.0 - 7.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Benzo(a)pyrene	4.0 - 8.3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Perylene	3.75 - 5.74	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Dibenz(a,h)anthracene	5.2 - 6.52	N/A	N/A	0.93	5.76	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.24	5.42
Indeno(1,2,3-cd)pyrene	-	N/A	N/A	1.46	5.96	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5.37	6.07
Benzo(ghi)perylene	6.2 - 6.26	N/A	N/A	1.90	6.08	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	8.55	6.29

N/A denotes not applicable as PAH's were not detected in both suspended sediment and solid phase extracted samples

(1) Mackay et al, 1992.

(2) % in S.S. = $\frac{(\text{concentration in suspended sediment})/(\text{suspended sediment concentration})(1/1000)}{(\text{concentration in susp. sed.})(\text{susp. sed. conc.})(1/1000) + \text{concentration in solid phase extract}} \times 100\%$

APPENDIX V

**COMPLETE DATA RESULTS FOR SAMPLES, FIELD QA/QC AND LABORATORY
QA/QC**

Data tables have been provided in digital form (Lotus 123, version 4) in the enclosed disk. Refer to the following table of contents for lists of tables for individual parameters and corresponding file names.

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List of Tables for Suspended Sediment Parameters and Flow

	File Name	Worksheet #
Total Organic Carbon, Particle Size, Flow and Suspended Sediment Concentrations from the Thompson River System	physical	1
Total Organic Carbon, Particle Size, Flow and Suspended Sediment Concentrations from the Fraser River	physical	2

List of Tables for Dioxin and Furan Analyses

	File Name	Worksheet #
Sample Cross Reference Table for Dioxins and Furans in Suspended Sediments from the Fraser River Basin	diox-fur	1
Dioxins and Furans in Suspended Sediments at McLure	diox-fur	2
Dioxins and Furans in Suspended Sediments at Savona	diox-fur	3
Dioxins and Furans in Suspended Sediments at Shelley	diox-fur	4
Dioxins and Furans in Suspended Sediments at Woodpecker	diox-fur	5
Dioxins and Furans in Suspended Sediments at Marguerite	diox-fur	6
Dioxins and Furans in Suspended Sediments at Yale	diox-fur	7
Dioxins and Furans in Laboratory Sediment Blanks	diox-fur	8
Dioxins and Furans in Laboratory Sediment Spikes and References	diox-fur	9
Sample Cross Reference Table for Dioxins and Furans in Solid Phase Extracted Clarified Water from the Fraser River Basin	diox-fur	10
Dioxins and Furans in Solid Phase Extracted Clarified Water from the Thompson River System	diox-fur	11
Dioxins and Furans in Solid Phase Extracted Clarified Water from the Fraser River	diox-fur	12
Dioxins and Furans in Solid Phase Extracted Deionized Water Field Blanks	diox-fur	13
Dioxins and Furans in Solid Phase Extracted Laboratory Blanks and Proofs	diox-fur	14
Dioxins and Furans in Solid Phase Extracted Laboratory Spikes	diox-fur	15
Sample Cross Reference Table for Dioxins and Furans in Liquid Phase Extracted Clarified Water from the Fraser River Basin	diox-fur	16
Dioxins and Furans in Liquid Phase Extracted Clarified Water from McLure	diox-fur	17
Dioxins and Furans in Liquid Phase Extracted Clarified Water from Savona	diox-fur	18
Dioxins and Furans in Liquid Phase Extracted Clarified Water from Shelley	diox-fur	19
Dioxins and Furans in Liquid Phase Extracted Clarified Water from Woodpecker	diox-fur	20
Dioxins and Furans in Liquid Phase Extracted Clarified Water from Marguerite	diox-fur	21

	File Name	Worksheet #
Dioxins and Furans in Liquid Phase Extracted Clarified Water from Yale	diox-fur	22
Dioxins and Furans in Liquid Phase Extracted Deionized Water Field Blanks	diox-fur	23
Dioxins and Furans in Liquid Phase Extracted Laboratory Blanks and Spikes	diox-fur	24

List of Tables for Chlorophenolic Analyses

	File Name	Worksheet #
Sample Cross Reference Table for Chlorophenolics in Suspended Sediments from the Fraser River Basin	chloroph	1
Chlorophenolics in Suspended Sediments at McLure	chloroph	2
Chlorophenolics in Suspended Sediments at Savona	chloroph	3
Chlorophenolics in Suspended Sediments at Shelley	chloroph	4
Chlorophenolics in Suspended Sediments at Woodpecker	chloroph	5
Chlorophenolics in Suspended Sediments at Marguerite	chloroph	6
Chlorophenolics in Suspended Sediments at Yale	chloroph	7
Chlorophenolics in Laboratory Sediment Blanks	chloroph	8
Chlorophenolics in Laboratory Sediment Spikes	chloroph	9
 Sample Cross Reference Table for Chlorophenolics in Whole Water from the Fraser River Basin	 chloroph	 10
Chlorophenolics in Whole Water at McLure	chloroph	11
Chlorophenolics in Whole Water at Savona	chloroph	12
Chlorophenolics in Whole Water at Shelley	chloroph	13
Chlorophenolics in Whole Water at Woodpecker	chloroph	14
Chlorophenolics in Whole Water at Marguerite	chloroph	15
Chlorophenolics in Whole Water at Yale	chloroph	16
Chlorophenolics in Deionized Water Field Blanks	chloroph	17
Chlorophenolics in Laboratory Water Blanks	chloroph	18
Chlorophenolics in Laboratory Water Spikes	chloroph	19
 Sample Cross Reference Table for Chlorophenolics in Solid Phase Extracted Clarified Water from the Fraser River Basin	 chloroph	 20
Chlorophenolics in Solid Phase Extracted Clarified Water from the Fraser River	chloroph	21
Chlorophenolics in Solid Phase Extracted Laboratory Blanks and Spikes	chloroph	22

List of Tables for PAH Analyses

	File Name	Worksheet #
Sample Cross Reference Table for PAHs in Suspended Sediments from the Fraser River Basin	pah	1
PAHs in Suspended Sediments at McLure	pah	2
PAHs in Suspended Sediments at Savona	pah	3
PAHs in Suspended Sediments at Shelley	pah	4
PAHs in Suspended Sediments at Woodpecker	pah	5
PAHs in Suspended Sediments at Marguerite	pah	6
PAHs in Suspended Sediments at Yale	pah	7
PAHs in Laboratory Sediment Blanks	pah	8
PAHs in Laboratory Sediment References	pah	9
 Sample Cross Reference Table for PAHs in Whole Water from the Fraser River Basin	 pah	 10
PAHs in Whole Water at McLure	pah	11
PAHs in Whole Water at Savona	pah	12
PAHs in Whole Water at Shelley	pah	13
PAHs in Whole Water at Woodpecker	pah	14
PAHs in Whole Water at Marguerite	pah	15
PAHs in Whole Water at Yale	pah	16
PAHs in Deionized Water Field Blanks	pah	17
PAHs in Laboratory Water Blanks and Spikes	pah	18
 Sample Cross Reference Table for PAHs in Solid Phase Extracted Clarified Water from the Fraser River Basin	 pah	 19
PAHs in Solid Phase Extracted Clarified Water at McLure	pah	20
PAHs in Solid Phase Extracted Clarified Water at Savona	pah	21

	File Name	Worksheet #
PAHs in Solid Phase Extracted Clarified Water at Shelley	pah	22
PAHs in Solid Phase Extracted Clarified Water at Woodpecker	pah	23
PAHs in Solid Phase Extracted Clarified Water at Marguerite	pah	24
PAHs in Solid Phase Extracted Clarified Water at Yale	pah	25
PAHs in Solid Phase Extracted Deionized Water Field Blanks	pah	26
PAHs in Solid Phase Extracted Laboratory Blanks, Spikes and Proofs	pah	27

List of Tables for PCB Analyses

	File Name	Worksheet #
Sample Cross Reference Table for PCBs in Suspended Sediments from the Fraser River	pcb	1
PCB Aroclors in Suspended Sediments from the Fraser River	pcb	2
PCB Congeners in Suspended Sediments from the Fraser River	pcb	3
PCB Coplanars in Suspended Sediments from Fraser River	pcb	4
PCB Aroclors in Laboratory Sediment Blanks and Spikes	pcb	5
PCB Congeners in Laboratory Sediment Blanks	pcb	6
PCB Congeners in Laboratory Sediment Spikes	pcb	7
PCB Coplanars in Laboratory Sediment Blanks and Spikes	pcb	8

List of Tables for Pesticide Analyses

	File Name	Worksheet #
Sample Cross Reference Table for Pesticides in Suspended Sediments from the Fraser River	pesticide	1
Pesticides in Suspended Sediment Samples from the Fraser River	pesticide	2
Pesticides in Laboratory Sediment Blanks and Spikes	pesticide	3

List of Tables for Fatty and Resin Acid Analyses

	File Name	Worksheet #
Sample Cross Reference Table for Fatty Acids in Whole Water from the Fraser River Basin	f-r-acid	1
Fatty Acids in Whole Water at McLure	f-r-acid	2
Fatty Acids in Whole Water at Savona	f-r-acid	3
Fatty Acids in Whole Water at Shelley	f-r-acid	4
Fatty Acids in Whole Water at Woodpecker	f-r-acid	5
Fatty Acids in Whole Water at Marguerite	f-r-acid	6
Fatty Acids in Whole Water at Yale	f-r-acid	7
Fatty Acids in Deionized Water Field Blanks	f-r-acid	8
Fatty Acids in Laboratory Water Blanks	f-r-acid	9
Fatty Acids in Laboratory Water Spikes	f-r-acid	10
 Sample Cross Reference Table for Resin Acids in Whole Water from the Fraser River Basin	 f-r-acid	 11
Resin Acids in Whole Water at McLure	f-r-acid	12
Resin Acids in Whole Water at Savona	f-r-acid	13
Resin Acids in Whole Water at Shelley	f-r-acid	14
Resin Acids in Whole Water at Woodpecker	f-r-acid	15
Resin Acids in Whole Water at Marguerite	f-r-acid	16
Resin Acids in Whole Water at Yale	f-r-acid	17
Resin Acids in Deionized Water Field Blanks	f-r-acid	18
Resin Acids in Laboratory Water Blanks	f-r-acid	19
Resin Acids in Laboratory Water Spikes	f-r-acid	20

	File Name	Worksheet #
Sample Cross Reference Table for Fatty and Resin Acids in Suspended Sediments from the Fraser River	f-r-acid	21
Fatty Acids in Suspended Sediment from the Fraser River	f-r-acid	22
Fatty Acids in Laboratory Sediment Blanks and Spikes	f-r-acid	23
Resin Acids in Suspended Sediments from the Fraser River	f-r-acid	24
Resin Acids in Sediment Blanks and Spikes	f-r-acid	25

List of Tables for Trace Metal Analyses

	File Name	Worksheet #
Trace Metals in Whole Water Samples from the Thompson River System (October 1992) - Elemental Research Lab	metals	1
Trace Metals in Whole Water Samples from the Thompson River System (February 1993) - Elemental Research Lab	metals	2
Trace Metals in Whole Water Samples from the Fraser River (October 1992) - Elemental Research Lab	metals	3
Trace Metals in Whole Water Samples from the Fraser River (February 1993) - Elemental Research Lab	metals	4
Trace Metals in Deionized Water Field Blanks (October 1992) - Elemental Research Lab	metals	5
Trace Metals in Deionized Water Field Blanks (February 1993) - Elemental Research Lab	metals	6
Trace Metals in Whole Water Samples from the Thompson and Fraser Rivers (October 1992) - Burlington Lab (provided for inter-laboratory comparison only)	metals	7

List of Tables for Nutrient Analyses

	File Name	Worksheet #
Total Phosphorus in Whole Water from the Thompson River System	nutrient	1
Dissolved Phosphorus in Clarified Water from the Thompson River System	nutrient	2
Dissolved Phosphorus in Filtered Water from the Thompson River System	nutrient	3
Total Phosphorus in Whole Water from the Fraser River	nutrient	4
Total Phosphorus in Clarified Water from the Fraser River	nutrient	5
Total and Dissolved Phosphorus in Deionized Water Field Blanks	nutrient	6
Nitrogen in Whole Water from the Thompson River System	nutrient	7
Nitrogen in Clarified Water from the Thompson River System	nutrient	8
Nitrogen in Filtered Water from the Thompson River System	nutrient	9
Nitrogen in Whole Water from the Fraser River	nutrient	10
Nitrogen in Clarified Water from the Fraser River	nutrient	11
Nitrogen in Filtered Water from the Fraser River	nutrient	12
Nitrogen in Deionized and Filtered Deionized Water Field Blanks	nutrient	13