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CONTAMINANT SOURCES

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Many contaminants have been identified in the Fraser River Basin, both in effluents discharging to rivers in the basin and in the receiving environment. These include trace metals (*e.g.* copper and zinc) and organic compounds such as polycyclic aromatic hydrocarbons (PAHs), chlorinated phenolics, dioxins, furans and pesticides. The major sources of these contaminants and estimates of their loading to the basin have been documented by Environment Canada (1995), FREMP (1996) and Schreier *et al.* (1991).

Major sources include point sources such as pulp mill effluents and municipal wastewater treatment plant (WWTP) discharges, variable-flow point sources such as combined sewer outfalls (CSOs), and non-point sources such as urban, industrial and agricultural runoff. Relatively minor sources include five permitted metal mine discharges, atmospheric deposition and runoff from highways, railway right-of-ways and hydro-electric corridors.

There are effluent characterization data for most sources; however, loading data from many of these point and non-point sources, and their relative contribution to overall contaminant stress in the basin, are not available. Although conventional pollutant indicators such as total suspended solids (TSS), "oil and grease" and biochemical oxygen demand (BOD) are monitored in industrial and municipal effluents, efforts to sample a broader spectrum of contaminants have tended to focus on a few selected sites or industries. Concentrations of trace contaminants (*i.e.* metals and persistent organic pollutants) are not well characterized. Thus, overall mass loading of pollutants cannot be calculated accurately. Nor is there a consolidated database of all industrial effluent discharges in the basin.

Recent changes to manufacturing processes in the pulp and paper industry, and to effluent treatment in municipal WWTPs have resulted in significant reductions in the loading of contaminants of concern to the basin. As a result, the relative importance of non-point sources (*e.g.* agricultural and urban runoff, and atmospheric deposition) as contributors to contaminant loading has increased.

DISCHARGE VOLUMES AND CONTAMINANT LOADING IN THE FRASER BASIN

To get an overview of the relative importance of each major point source category, discharge volume data for WWTPs in 1991 (Environmental Protection Branch 1998) and estimates for industrial and pulp mill effluents in the middle to late 1980s (Schreier *et al.* 1991) were used (Table 1). Pulp mills and WWTPs were the major sources of waste water in the pre-Fraser River Action Plan (FRAP) era. The relative importance of these sources likely changed during FRAP in response to population increases in the Vancouver area in particular and the lack of recent industrial expansion in the basin as a whole.

Table 1. *Relative volumes of major discharges in the Fraser River Basin.*

	ANNACIS AND LULU ISLAND MUNICIPAL WWTPs	OTHER MUNICIPAL WWTPs[1]	INDUSTRIAL DISCHARGES[2]	PULP MILLS
Relative Volume	27%	9%	26%	38%

[1] *excluding the Iona Island Municipal WWTP which discharges directly to the Strait of Georgia*
[2] *excluding pulp mills*

The WWTP discharges from the Annacis and Lulu Island plants are separately tabulated to highlight the importance of these two Vancouver area plants which accounted for 75 per cent of the discharge from this category. This percentage is expected to increase over the next 20 years as the population is projected to increase by 50 per cent (GVRD 1997a). Assuming future industrial expansion does not result in large increases of water use, the WWTPs will become the dominant source, in terms of volume, in the near future.

The major pulp mill effluent discharges are located in the upper Fraser and Thompson rivers at Prince George, Quesnel and Kamloops. Two small-volume mill discharges are located at New Westminster and Burnaby in the lower Fraser River. While industrial discharges occur in Prince George and Kamloops, the majority of industrial activity is centred around Greater Vancouver, particularly along the North Arm of the lower Fraser River.

Detailed data on loading for many contaminants are not routinely collected, making loading estimation difficult. More traditional measures of effluent quality, such as BOD or TSS, are regularly obtained as part of permit requirements. Municipal effluent discharges represent a major source of loading for both BOD and TSS. TSS can be an approximate indicator of the loading of chemical contaminants, such as metals and organic compounds which are adsorbed to particles in the effluent.

Another measure of effluent quality, implemented in recent years, is that of effluent toxicity which can be measured using standard bioassays. Effluent toxicity integrates the cumulative effects of many contaminants. It can be used as a surrogate for determining the relative risk to aquatic ecosystems which receive effluent discharges. Much of the recent data on effluent toxicity in the Fraser Basin was collected under the auspices of FRAP funded projects, and the results of these studies are summarized below according to contaminant source.

MUNICIPAL DISCHARGES

Fraser Basin upstream of the Pitt River

Each day, 150,000 m^3 of sewage effluent is discharged to the Fraser River Basin from 87 treatment plants upstream of Langley (Environment Canada 1997d). As part of FRAP, Environment Canada initiated an effluent monitoring program at 15 WWTPs in the basin. These WWTPs were selected from within three basin sub-regions: (1) the upper Fraser including Prince George, Quesnel and Williams Lake; (2) the middle Fraser including Lytton, Lillooet, Cache Creek, Salmon Arm, Merritt, Hope, Enderby and Kamloops; and (3) the lower Fraser including the Kent Institution, Chilliwack, Aldergrove and North West Langley (Figure 1). The majority of these facilities have secondary treatment, the exceptions being Lytton, Lillooet and Hope which have primary treatment. The largest facilities included in the program were located in Prince George, Quesnel, Williams Lake, Kamloops, Chilliwack and Northwest Langley.

The 96-hr LC_{50} acute toxicity bioassay using rainbow trout (*Oncorhynchus mykiss*) was used to assess effluent quality. Each site was tested in the summer, fall, winter and spring. Results for 1992 and 1996 were similar, relative to the number of samples showing non-toxic conditions, although fewer samples passed the toxicity test in 1996 than in 1992. Based on the 1996 testing, 45 per cent of the wastewater effluents discharged to the upper and middle basin passed the bioassay, compared to 51 per cent in 1992.

In the middle Fraser, the Salmon Arm, Cache Creek, Enderby and Merritt WWTPs all have secondary treatment systems, and effluents were not acutely toxic on three out of four sampling occasions. Similar results were obtained in the lower Fraser at the Kent and Northwest Langley WWTPs which also have secondary treatment systems. The balance of the facilities frequently exhibited acute toxicity with 96-hr LC_{50} rainbow trout bioassay values as low as 41 per cent effluent concentration. These results suggest a trend of declining overall effluent quality. It is known that these facilities are experiencing steadily increasing volumes due to local population increases. As the results are based on a relatively limited sampling program, a more intensive study is required to confirm the apparent trend of increasing toxicity identified above.

At the least, these findings indicate that secondary treatment, although designed to reduce the loading of conventional parameters such as BOD and TSS (and thus contaminants such as trace metals and organic compounds, which are associated with these variables), may not consistently reduce acute effluent toxicity. No companion toxicity-identification evaluation (TIE) studies were conducted on the relative contribution of ammonia, metals or other effluent constituents to the observed toxicity. TIEs can identify causal agents of toxicity (Mount and Anderson-Carnahan 1988), and provide specific data necessary to recommend appropriate pollution abatement measures.

The Kamloops WWTP, which discharges effluent into the Thompson River just prior to its entry into Kamloops Lake, was also sampled for dioxin and furan compounds. None of these compounds were detected in the effluent (Environment Canada 1997d).

Fraser River Estuary

In 1995, the Annacis Island, Lulu Island and Iona Island WWTPs discharged a combined volume of 1.01 million m^3/day into the estuary and Strait of Georgia. Respectively, the Annacis and Lulu Island facilities discharged 421,000 and 57,400 m^3/day of wastewater effluent to the estuary (Environment Canada 1997d). The Iona Island WWTP discharged approximately 537,800 m^3/day directly to deep waters in the Strait of Georgia, and therefore, this discharge has not been included in the totals shown for the Fraser Basin in Table 1.

The wastewater of approximately one million basin residents is treated at the Annacis and Lulu Island WWTPs. On a basin-wide scale, the Annacis and Lulu Island WWTPs accounted for approximately 90 per cent of the TSS discharged from municipal WWTPs into the Fraser Basin as of 1995. By comparison, the

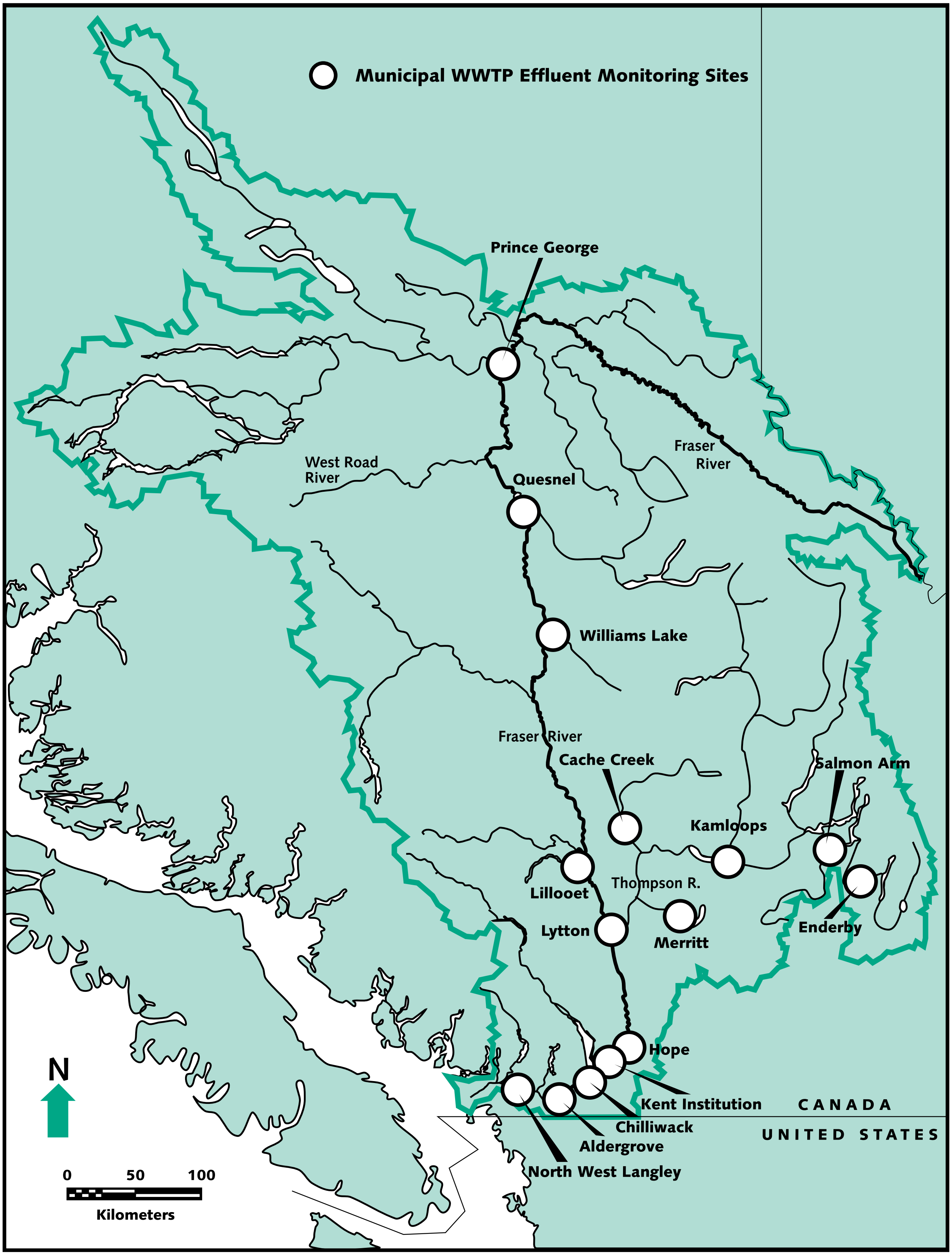

Figure 1. Municipal WWTPs sampled in the Fraser River Basin for FRAP.

next largest WWTP, the Prince George WWTP, contributed only 3.7 per cent of the basin's loading for TSS. Since completion of secondary treatment facilities at the Annacis and Lulu Island plants in 1998, a reduction of 70 per cent in TSS and of 85 per cent in BOD loading from WWTPs has occurred (Environmental Protection Branch 1998).

A summary of the annual loading of conventional contaminants from the Annacis and Lulu Island WWTPs in 1996 is given in Table 2. The nutrients and metals are monitored routinely at these WWTPs. A recent study conducted under the GVRD's Liquid Waste Management Plan also measured the levels of organic contaminants (*e.g.* PAHs, phthalate esters, nonylphenol and dichlorobenzene) (GVRD 1999).

The dominance of the Annacis and Lulu Island plants in the Fraser Basin is one of the reasons why they received special attention from federal and provincial agencies for upgrading to secondary treatment. As an example of the decrease in loading that can be expected from increased levels of effluent treatment, preliminary monitoring by the GVRD indicates that reductions in copper, zinc, TSS and BOD loadings of 85, 30, 85 and 87 per cent, respectively, have occurred. While the concentrations of contaminants in the effluents are now substantially reduced, there is a possibility that ammonia concentrations in the effluents could occasionally be high enough to be acutely toxic to fish (P. Wong 1997, pers. comm.).

***Table 2.** Summary of annual loading in 1996 from the Annacis and Lulu Island WWTPs.*

CONSTITUENT MEASURED	ANNACIS ISLAND WWTP (TONNES/YEAR)	LULU ISLAND WWTP (TONNES/YEAR)
N-Kjeldahl	4000	640
N-nitrate+nitrite	<49	<2
N-ammonia	2900	450
Fluoride	10	5
M.B.A.S.[1]	590	100
Sulphate	4900	810
Total Phosphorus	570	93
Oil & Grease	4600	550
Phenol	8	0.9
Cyanide	<4	<0.5
Aluminum	100	20
Arsenic	0.2	<0.03
Boron	24	3.3
Cadmium	<0.09	0.02
Chromium	1	0.33
Cobalt	<4	<0.05
Copper	24	3.6
Iron	798	55.3
Lead	1	0.2
Manganese	29	2
Mercury	<0.09	<0.02
Molybdenum	<6	<0.08
Nickel	2	1.5
Selenium	<0.2	<0.03
Silver	0.5	0.28
Tin	<20	<3
Zinc	10	2

(Source: Greater Vancouver Regional District 1997a)
[1] Methylene-Blue-Active-Substances: this category includes anionic surfactants

COMBINED SEWER OUTFALLS

Combined sewer outfalls (CSOs) collect and convey both domestic sewage and urban stormwater runoff. CSOs are designed to accommodate high wet-weather flow conditions and are prevalent in the Lower Mainland area of the Fraser River Basin. Under dry weather operating conditions, sanitary sewage is conveyed to WWTPs. During wet weather conditions, the influx of large volumes of stormwater can overwhelm the piping system capacity. To reduce public health concerns and risks of flooding, overflow structures have been constructed to discharge excess flows to nearby receiving waters.

An inventory of CSOs within the Fraser Basin (including Burrard Inlet) was completed under FRAP (UMA Engineering 1992). Monthly discharge volumes and frequencies were estimated for each of the CSOs. Twenty of these CSOs, with an estimated annual discharge volume of 6.27 million m^3, discharge directly to the Fraser Basin. The CSOs discharging to the Fraser River make up approximately three per cent of the total volume of sewage effluent discharged to the basin.

Detailed overflow characterization data from four CSO systems in the GVRD showed concentrations of BOD, TSS and nutrients (ammonia and phosphorus) to be four to 14 times below that of typical GVRD raw sewage (GVRD 1996), reflecting the range of dilution from stormwater in these systems.

FREMP (1996) summarized contaminant loading from all major CSO discharges to different areas of the Lower Fraser River (Table 3). Loading estimates from this source made by Hall *et al.* (1998) were of a similar magnitude. CSO discharges occur intermittently during wet weather conditions when stormwater flows cause the sewer pipe capacity to be exceeded. This overflow mechanism results in highly variable daily and seasonal flows of additional amounts of raw sewage to the Fraser River. Operational improvements to CSOs in the New Westminster waterfront area are planned which will reduce discharge volumes by approximately 15 per cent.

Table 3. *Relative loading of ammonia, copper and suspended solids from CSO discharges to the Lower Fraser River.*

SOURCE	SUSPENDED SOLIDS (tonnes/yr)	AMMONIA (kgN/yr)	COPPER (kg/yr)
CSOs in Lower Main Stem of the Fraser River	59	1426	50
CSOs in North Arm of the Fraser River	210	5032	176

(Source: FREMP 1996)

URBAN STORMWATER RUNOFF

Considerable differences may exist in the relative volume of stormwater runoff from sites in the upper basin and in the lower reaches, due to the heavy rainfall experienced in the coastal zone. The relative impact of urban runoff can vary significantly with the degree of dilution that occurs when runoff mixes with the receiving waters. Smaller tributaries are therefore more affected by these runoff events than the main stem of the Fraser River.

The quantification of contaminant loading from urban runoff in the Fraser River Basin was the subject of a FRAP-sponsored study carried out by Stanley Associates Engineering Ltd. (1992). Annual contaminant loading for different portions of the basin was estimated from data on typical contaminant concentration ranges found in North American urban runoff and local urban runoff volumes. These loading estimates are summarized in Table 4.

Contaminants associated with urban runoff at Kamloops were the subject of a special investigation by Environment Canada (1997c). Elevated levels of heavy metals were present in all sediment and water samples collected from 15 storm sewer outlets discharging to the Thompson River. The highest level of heavy metal contamination was found at the Guerin Creek site which drains the highly industrialized area of Kamloops known as Aberdeen.

A FRAP-sponsored study of the Brunette River watershed in the Lower Mainland area of the Fraser Basin (Macdonald *et al.* 1997) was carried out to determine contaminant loading rates in a highly industrialized urban stream. This study found higher export coefficients (loadings expressed in kg N/ha/yr) for nitrate, ammonia and organic nitrogen than mean values reported in three other North American studies. The authors could not give a reason for such high export coefficients relative to the literature values. Elevated coefficients for copper and zinc were associated with runoff from the busiest traffic intersections. Traffic intensity and type (slow moving, high speed, parked) were found to be key factors related to runoff characteristics. Approximately 50 per cent of the cadmium, copper and zinc and up to 75 per cent of the manganese, chromium, lead and nickel were associated with suspended sediments in the street runoff. In a related study, Larkin and Hall (1998) found that 75 to 97 per cent of the flow-weighted concentrations of hydrocarbons in run-off was associated with the particulate fraction.

Table 4. Estimated annual contaminant loading (in tonnes) from urban runoff in the Fraser Basin.

CONTAMINANT	FRASER BASIN	LOWER FRASER	THOMPSON	MIDDLE FRASER	UPPER FRASER
Suspended solids	62782	54584	1689	913	5596
Ammonia	75.3	65.5	2.0	1.1	6.7
Nitrate/nitrite	351.6	305.7	9.5	5.1	31.3
Total nitrogen	878.9	764.2	23.7	12.8	78.3
Total phosphorus	175.8	152.8	4.7	2.6	15.7
Lead	75.3	65.5	2.0	1.1	6.7
Copper	17.6	15.3	0.5	0.3	1.6
Zinc	75.3	65.5	2.0	1.1	6.7
Chromium	5.0	4.4	0.14	0.07	0.45
Cadmium	4.0	3.5	0.1	0.06	0.36
Nickel	12.6	10.9	0.3	0.18	1.1
Arsenic	6.5	5.7	0.2	0.1	0.6
Phenols	6.5	5.7	0.2	0.1	0.6
Total Hydrocarbons	2009	1747	54.1	29.2	179.1
PAHs	0.50	0.44	0.01	0.01	0.004

(Source: Stanley Associates Engineering Ltd. 1992)
Lower Fraser denotes the Fraser River watershed from Hope downstream
Thompson denotes the North and South Thompson and Thompson River watersheds
Middle Fraser denotes the Fraser River watershed upstream of Hope to about the West Road River confluence with the Fraser
Upper Fraser denotes the Fraser River watershed upstream of the West Road River confluence with the Fraser

An accurate estimate of the total contaminant loading from stormwater runoff to the entire Fraser Basin cannot be made because data for the entire basin are not presently available. However, certain relationships between increased urban development and contaminant loading in parts of the basin have been established as a result of FRAP-supported studies. For example, Hall *et al*. (1999) have shown that contaminant loading increases proportionately with increases in vehicle traffic and with increases in the percentage of impervious surface area in the watershed.

PULP AND PAPER EFFLUENTS

Upstream of Hope, pulp mills represent the largest source (by volume) of effluent discharged to the Fraser River. In the late 1980s, elevated levels of dioxins and furans in Fraser Basin sediments, fish and wildlife (Mah *et al.* 1989; Elliott *et al*. 1989) prompted federal and provincial regulators to enact legislation requiring significant reductions in the permitted levels of dioxins and furans in mill effluent. Federal regulations also required mills to conduct effluent and receiving-water monitoring programs.

There are eight pulp and paper mills that discharge into the Fraser River Basin (Northwood Pulp and Timber Ltd., Canadian Forest Products Ltd. and Intercontinental Ltd. at Prince George; Cariboo Pulp and Paper Co. and Quesnel River Pulp Co. at Quesnel; Weyerhaeuser Canada Ltd. at Kamloops; Scott Paper Ltd. and Crown Paper Ltd. in the Lower Mainland) (Figure 2). All are subject to the federal Pulp and Paper Effluent Regulations. These federal regulations prohibit the discharge of acutely toxic effluent, and establish the quantities of BOD and TSS which may be discharged.

The following improvements in pulp mill effluents have been documented since 1990. The figures are for all B.C. mills, but can be considered as representative of those in the Fraser Basin.

- The average toxicity of the effluent improved from 50 per cent fish survival in a 65 per cent concentration of effluent to 100 per cent fish survival in 100 per cent concentration of effluent.
- The number of days toxic effluent was discharged decreased by 99 per cent.
- The quantity of BOD discharged decreased by 88 per cent, and is currently 13 per cent less than the maximum allowable amount.

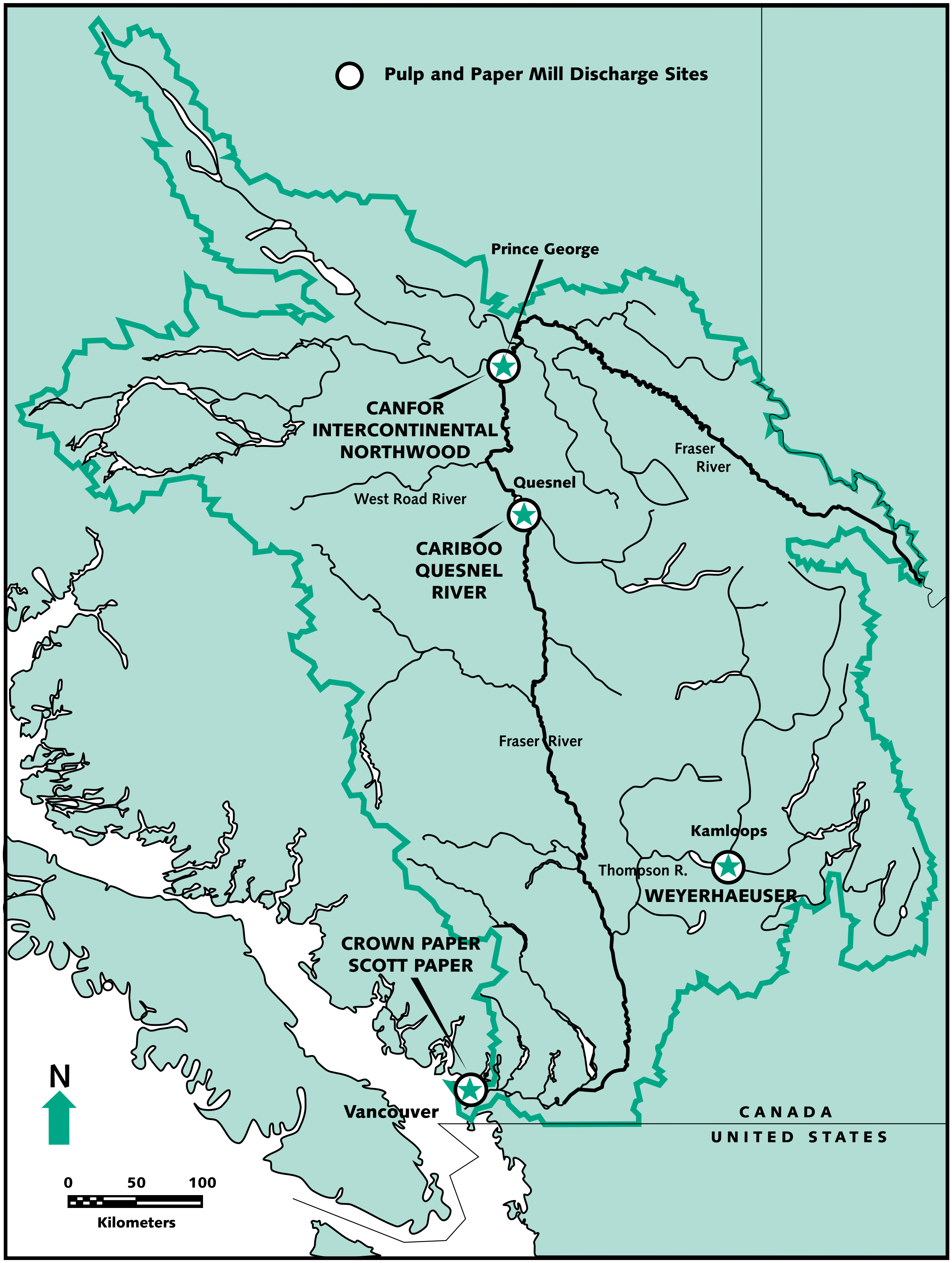

Figure 2. Location of pulp and paper mills in the Fraser River Basin.

- The quantity of TSS discharged decreased by 34 per cent, and is currently 26 per cent less than the maximum allowable amount.
- In 1996, B.C. mills demonstrated a 98.4 per cent compliance rate with the requirements of the Chlorinated Dioxins and Furans Regulations of the federal *Canadian Environmental Protection Act.* This resulted in a decline of over 99 per cent in the discharge of dioxins and furans since the regulations came into effect (see Figure 3; Environment Canada 1997e).

Although regulatory initiatives have focused on dioxins and furans, a range of other chlorinated and non-chlorinated organic compounds such as catechols, guaiacols, vanillins, and resin and fatty acids have been measured in pulp mill effluents (IRC 1994). Low levels of PAH compounds have also been detected in some pulp mill effluents in the Fraser Basin (Derksen 1997).

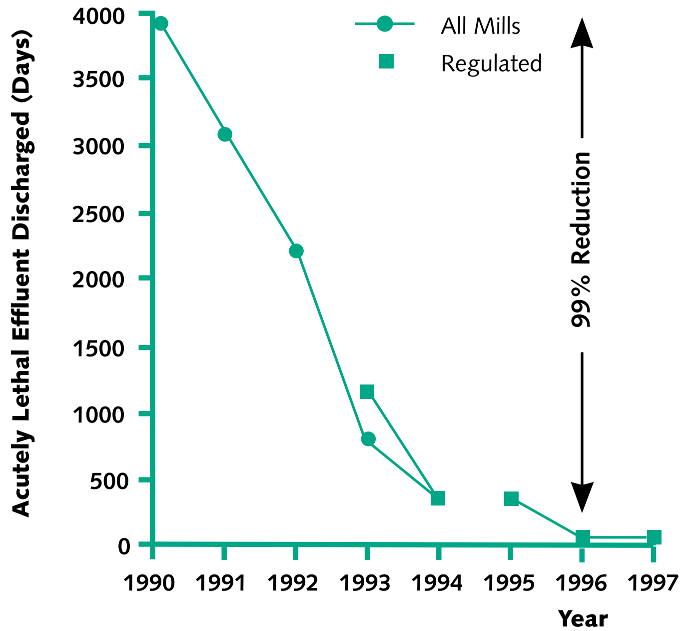

Figure 3. Accumulated number of days (cumulative for all 23 mill discharges in B.C.) that Acutely Lethal Effluent (ALE) was discharged from B.C. pulp and paper mills.
Source: Environment Canada 1997e.

OTHER INDUSTRIES

Lumber products industry

Antisapstains are chemicals used to protect freshly cut softwood lumber from discolouration due to the growth of fungi and moulds. The chemicals can be released to the receiving environment as the result of spills into storm sewers, or by being washed off freshly treated wood during rainstorm events. In British Columbia, the most common antisapstain fungicides are DDAC (didecyl dimethyl ammonium chloride) and IPBC (3-iodo-2-propynyl butyl carbamate). DDAC is one of the most heavily used pesticides in B.C. (Environment Canada 1997a) because of its use in treating large quantities of lumber for export. Currently, the majority of B.C. coastal mills use the commercial formulation NP1, a mixture of DDAC and IPBC. The second most common formulation in use today is F2, containing DDAC and disodium octaborate tetrahydrate as active ingredients.

Prior to 1987, there were approximately 100 facilities in British Columbia (70 in the Fraser River Basin) that discharged an estimated 260 million m^3/yr of acutely toxic stormwater. As shown in Figure 4, this volume had been reduced to approximately 1.6 million m^3/yr by 1996; a 99 per cent improvement (Environment Canada 1997a). In contrast, the amount of antisapstain chemicals used increased from about 350,000 kg/yr in 1987 to 846,000kg/yr in 1996. This increase was due to the replacement of chlorophenate with less toxic chemicals such as DDAC and IPBC which require heavier applications to achieve the same efficacy. Based on the 1996 inspection program carried out by Environment Canada, 87 per cent of the recommended best management practices had been implemented at the sites examined (Environment Canada 1997a). Best management practices include such operational changes as improved chemical handling, more effective application technology, and covered storage for the treated lumber. The actual loading of DDAC and IPBC to the river cannot be calculated accurately due to the lack of regular rainfall-event monitoring at most mills.

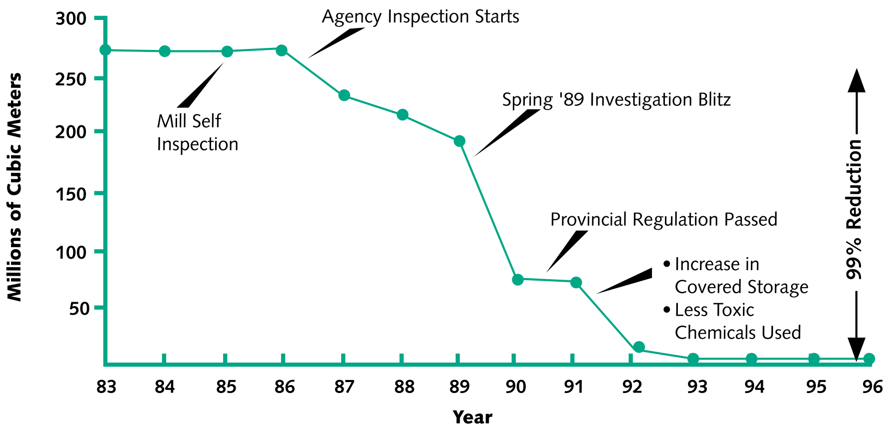

Figure 4. *Quantity of toxic effluent discharged annually from antisapstain facilities in British Columbia.*
Source: Environment Canada 1997a.

Heavy duty wood preservation industry

The heavy duty wood preservation industry is responsible for the manufacture of preserved wood products such as treated lumber, railway ties, pilings and utility poles (*e.g.* telephone poles). The wood is preserved with chemicals such as creosote, pentachlorophenol (PCP), chromated copper arsenate (CCA) and ammoniacal copper arsenate (ACA). Creosote and PCP are oil-based preservatives used in the manufacture of railroad ties, marine pilings and utility poles. ACA and CCA are water-based preservatives used in the manufacture of lumber, timbers and utility poles.

It is estimated that, prior to the initiation of FRAP, the annual effluent discharge from the heavy duty wood preservation industry along the Fraser River was 600,000 m^3. Contaminant loading from these effluent discharges is estimated to have been reduced by more than 90 per cent due to the FRAP enforcement initiative targeted at this industry sector (Environment Canada 1997b).

Permitted discharges from these facilities are typically limited to steam condensate from water used to make steam for site operations. Under normal conditions, any water discharged to the Fraser River is first run through an activated carbon/sand or similar filter system. Typical contaminant permit criteria specified by BC Ministry of Environment, Lands and Parks include maximum allowable concentrations for oil and grease, phenolics as phenol, pentachlorophenol, tetrachlorophenol, trichlorophenols, arsenic and copper. Unfortunately, PAH compounds, which are components of creosote, are not routinely measured.

Stormwater is generally collected and reused on-site in the water-based preservative operations. Thus, it is not considered a source of contaminant loading to the Fraser River Basin.

Inspections by Environment Canada have found that historical seepage of creosote into the soil at former industrial operations along the lower Fraser River has resulted in significant underground reservoirs of contaminants. These deposits may be future long term sources of contamination to the river (Environment Canada 1997b). Actions are presently underway to initiate remedial programs at these affected sites.

AGRICULTURAL OPERATIONS

Agricultural practices create non-point sources of contaminants. These contaminants, including nutrients, bacteria and pesticides, can impair the water quality of both ground and surface waters. Agricultural activities are a major source of contaminants to streams in the Lower Fraser Valley, the Thompson/Shuswap, Vanderhoof and Cariboo regions of the Fraser River Basin.

Agricultural intensification in the Lower Fraser Valley has reached levels where pollution of streams and groundwater is widespread (FREMP 1996; Schreier *et al.* 1999). While accurate estimates are not available for nitrogen and phosphorus loading to tributaries in the central and eastern sectors of the Lower Fraser

Valley, these loadings, combined with the 1,400 tonnes of nitrogen and 300 tonnes of phosphorus (FREMP 1996) estimated for the western end of the valley, likely result in a total loading to the lower Fraser River of the same order as those contributed by GVRD WWTPs.

Detailed estimates of nutrient losses to streams throughout the basin require data on fertilizer application rates, number of animal units/area (see Schreier *et al.* 1999), soil characteristics and local hydrogeology. All of these data are not available for estimating basin-wide loading of nutrients. Similarly, data are not available on the rates of pesticide applications and the amounts entering waterways in the basin. Consequently, pollution control has focused on the development and implementation of "best management practices" by the agricultural community (Environmental Protection Branch 1998) and monitoring conditions in affected waters.

ATMOSPHERIC SOURCES

Atmospheric contaminant sources that have been assessed recently in British Columbia include vehicular emissions, agricultural emissions and long-range transport. Studies have focused on the Lower Fraser Valley, which has the highest population density and the most intense agricultural activity in the province.

Contaminants associated with vehicular emissions include metals and organic chemicals (McLaren *et al.* 1996; Pott 1996; Barrie and Vet 1984). These contaminants have been measured in the ambient air of the Greater Vancouver area, as well as in snow samples from the mountains along the northern slopes of the Lower Fraser Valley. Snow from one-metre-depth cores collected in 1995 from the mountains in the Lower Fraser Valley showed few patterns in contaminant concentrations relative to distance from the Greater Vancouver urban centre (Belzer *et al.* 1998c). The exception was zinc, and possibly copper and manganese, which had maximum values at sites closest to the urban centre. These three metals are often associated with transportation sources.

Agricultural activities have intensified in the Lower Fraser Valley (Schreier *et al.* 1999) and, as a consequence, have resulted in increases in the atmospheric concentration of some of the chemicals found in fertilizers and pesticide formulations. For example, ammonia volatilizing from manure is likely the major natural source of nitrogen compounds to the atmosphere. Ammonia has been linked to the formation of atmospheric particulates which are believed to create episodes of poor air quality in eastern portions of the Fraser Valley (Pryor *et al.* 1997).

Table 5 presents a summary of nitrogen compounds and sulphate measured over a year in dry deposition and for seven months in wet deposition at Abbotsford, an agricultural community in the Lower Fraser Valley (see Figure 5). Based on these data, the mean total nitrogen deposition is about 11.5 kg nitrogen/ha/yr (Belzer *et al.* 1998a). This represents a significant component of the 50 to 100 kg nitrogen/ha/yr which has been suggested as an acceptable level of nitrogen loading to valley agricultural soils (Summary Report Steering Committee 1997). However, the largest source of nitrogen loading to these soils is from manure application. For example, some areas in the Lower Fraser Valley are estimated to receive over 300 kg nitrogen/ha/yr, largely from manure (Summary Report Steering Committee 1997).

Pesticides and herbicides that have been applied over agricultural crops were observed in the air and precipitation at Agassiz and Abbotsford (Table 6) (Belzer *et al.* 1998b). Some of the pesticides (*e.g.* aldrin, dieldrin, chlordane) measured within this airshed are no longer applied in the local area, suggesting that their presence may be due to long-range transport or emission from local soils (Finizio *et al.* 1998). Long-range transport of contaminants is also identified as the major source of pesticides, and possibly PCBs, to the aquatic environment of large lakes in the basin (MacDonald *et al.* 1999).

Table 5. *Mean nitrogen and sulphate deposition at Abbotsford. Measurements are based on weekly samples taken as follows: dry deposition sampled from January 1996 to February 1997; wet deposition sampled from July 1996 to February 1997. (Yearly estimates are based on the number of days for either dry [199 days] or wet [165 days] deposition; some sample periods had both wet and dry deposition contribution).*

MEAN (DEPOSITION AS mg N OR SO_4)	NH_3	NO_3	NO_2	SO_4
Daily dry deposition ($mg/m^2/day$)	1.41	0.041	0.011	0.212
Daily wet deposition ($mg/m^2/day$)	4.04	1.12	0.050	4.40
Yearly dry deposition ($mg/m^2/year$)	281	8.21	2.12	42.2
Yearly wet deposition ($mg/m^2/year$)	666	184	8.25	726
Yearly Total deposition ($mg/m^2/year$)	947	192	10.4	768

(Source: Belzer et al. *1998a)*

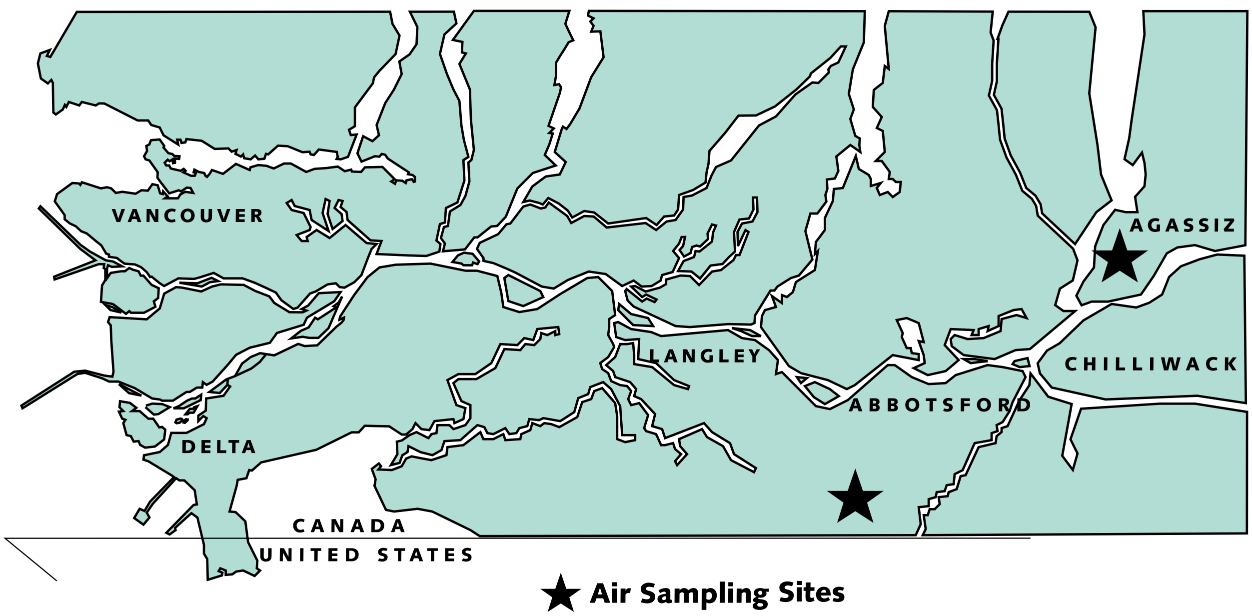

Figure 5. *Lower Fraser Valley air quality sites sampled for contaminants associated with agricultural activities.*

SUMMARY OF MAJOR SOURCES OF CONTAMINANTS TO THE FRASER BASIN AND LIKELY FUTURE TRENDS

Based on the information presented above, the major sources of chemical contaminants to the Fraser River Basin have been listed in Table 7, together with the most likely future trends for each source.

CONCLUSIONS

- Due to increased regulation, enforcement and compliance of point-source effluent discharges, non-point sources such as runoff from intensive agriculture and heavily urbanized areas are increasingly responsible for chemical contamination in the basin.

Table 6. Mean concentrations (ng/m³) of agricultural chemicals in ambient air samples collected weekly from January 1996 to December 1996.

PESTICIDE GROUP	CHEMICAL	AGASSIZ	ABBOTSFORD
Organochlorine Pesticides	Aldrin	ND	0.246
	Captan	1.448	1.823
	cis-Chlordane (a)	0.226	0.188
	trans-Chlordane (g)	0.260	0.102
	Dacthal	0.363	0.478
	4,4'-DDE	0.139	ND
	Dicofol	0.337	ND
	Dieldrin	1.010	0.062
	Endosulfan I	0.708	0.620
	Endosulfan II	0.253	0.184
	Heptachlor	0.148	1.024
	Heptachlor Epoxide	0.288	0.131
	Hexachlorobenzene	0.474	0.190
	Lindane (g-BHC)	0.338	0.213
	cis-Nonachlor	0.184	ND
	trans-Nonachlor	0.217	0.077
	Oxychlordane	0.278	0.244
Herbicides	2,4-D	6.646	2.301
	Dicamba	1.708	ND
	Dinoseb	ND	4.770
	Silvex (2,4,5-TP)	2.065	1.242
	Atrazine	5.529	2.622
Organophosphate Pesticides	Chlorpyrifos	0.612	0.666
	Diazinon	0.484	4.664
	Dichlorvos	2.990	1.172
	Dimethoate	0.340	ND
	Fonofos	0.957	0.128
	Malathion	1.963	3.688
	Mevinphos	ND	5.556
	Parathion Methyl	0.157	0.418
	Terbufos	0.512	1.246

(Source: Belzer et al. *1998b)*
N.D. denotes not detected

- Municipal wastewater discharges will continue to be a major source of contaminants to the basin due to projected population growth and the continued acute toxicity of many municipal effluents receiving secondary treatment. However, discharges from CSOs should decrease.
- Discharges of dioxins and furans from pulp mills have declined by 99 per cent and effluents now consistently pass acute toxicity tests.
- A large decrease in the release of antisapstain chemicals has occurred since the early 1990s. Increases are not likely as lumber production in the lower Fraser area has declined.
- Heavy duty wood-preservative chemical loading has declined by over 90 per cent since the early 1990s.
- Atmospheric deposition of locally generated airborne contaminants is likely to escalate with population growth. There is evidence of deposition of airborne contaminants brought by long-range transport; however, loading from this source has not been quantified.

RECOMMENDED FUTURE STUDIES AND ACTIONS

- Develop strategies for monitoring non-point source contaminant input to sensitive aquatic ecosystem components of the basin (*e.g.* tributaries affected by increasing urbanization and areas of intensive agricultural operation).
- Expand the routine use of bioassays (including sublethal tests) on contaminant sources as a measure of their cumulative toxic loading. Toxicity identification evaluation (TIE) studies should be used to identify specific causal toxic agents and guide mitigation efforts.

Table 7. Summary of likely future trends for major sources of contaminant loadings.

LOADING SOURCE	LIKELY FUTURE TREND	COMMENT
Municipal Discharges	↑	- volumes expected to increase with increases in basin population - loading dependent on level of treatment and its effectiveness.
Combined Sewer Outfalls	↓	- loading to decrease with implementation of Liquid Waste Management Plans.
Pulp and Paper Effluents	→←	- if controls are required for other compounds besides those currently regulated, total contaminant loading will decrease.
Urban Stormwater Runoff	↑	- expected to increase in proportion to increasing population and urbanization.
Agricultural Runoff	↑	- reversal of present increasing trend dependent upon successful implementation of best management practices in areas of intensive agricultural operations. - more detailed tracking of fertilizer, pesticide and other agro-chemical use are required to evaluate losses to surface and ground waters
Lumber Products Industry	→←	- future loadings of antisapstains dependent on lumber exports and any changes in effluent guidelines.
Heavy Duty Wood Preservation Industry	↓	- decrease in loading dependent on high degree of regulatory control on discharges, and good industry compliance record.
Atmospheric Sources	↑	- regional emissions are expected to increase with population - long-range transport of contaminants has not been quantified.

↑ *= indicates increased loading and a high degree of ecological concern*
↓ *= indicates decreased loading and a low degree of ecological concern*
→← *= indicates a degree of uncertainty with respect to future trend in contaminant loading and in ecological concern; may be dependent upon successful completion of best management practice or other pollution abatement program or compliance with future regulations*

- Implement routine monitoring of the effectiveness of pollution abatement and prevention measures with pre- and post-treatment assessments including collection of data for both contaminant loading and aquatic ecosystem responses.
- Expand the characterization of pulp mill effluents to include more organic compounds of concern, as well as dioxins and furans.
- Evaluate impacts of existing levels of airborne contamination and monitor changes in deposition of airborne contaminants from local and global sources.
- Develop an easily accessible watershed database for contaminant loading data from different industry and government programs.
- Develop an information system to track the total amounts of agrochemicals used in sub-watersheds.

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