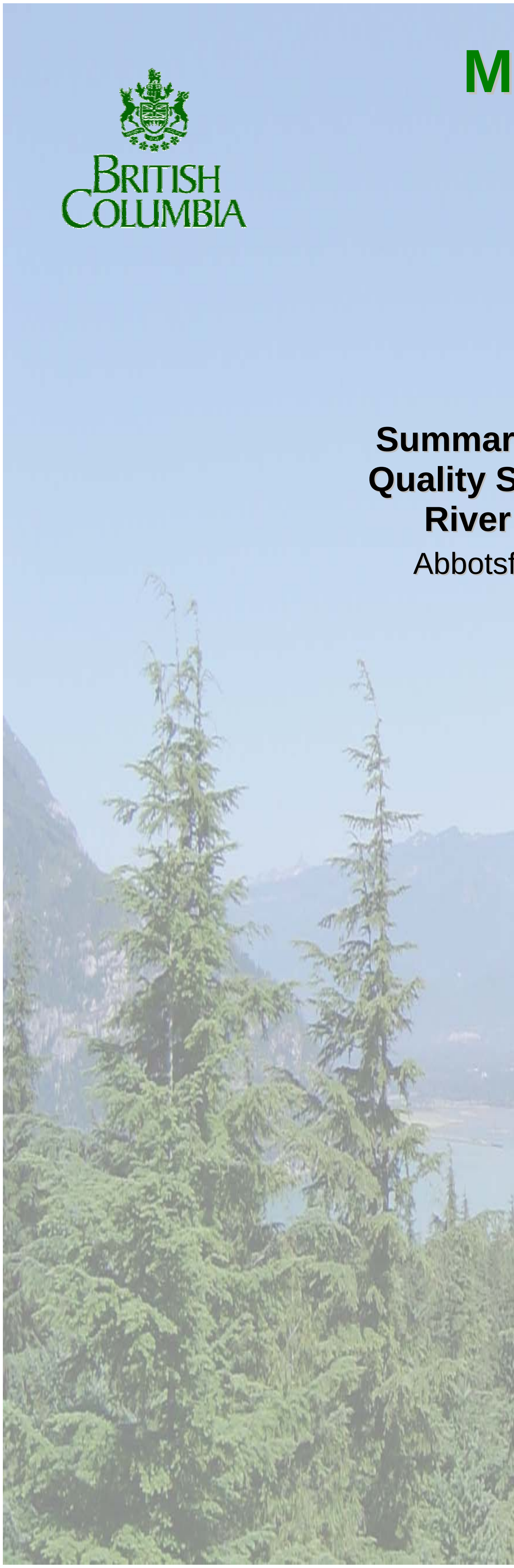

Ministry of Water, Land & Air Protection

LOWER MAINLAND REGION

Summary of Surface Water Quality Sampling on Sumas River and Tributaries

Abbotsford, British Columbia

ENVIRONMENTAL QUALITY

Summary of Surface Water Quality Sampling on Sumas River and Tributaries

Abbotsford, British Columbia

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PREFACE

This report is one in a series of water, groundwater, and air quality reports that are being issued by the Lower Mainland Regional Office in fiscal year 2004/05. It is the intention of the Regional Office to publish water, groundwater and air quality reports on our website (http://wlapwww.gov.bc.ca/sry/p2/eq/index.htm). in order to provide the information to industry and local government, other stakeholders and the public at large. By providing such information in a readily understood format, and on an ongoing basis, it is hoped that local environmental quality conditions can be better understood, and better decisions regarding water, groundwater, and air quality management can be made.

ACKNOWLEDGEMENTS

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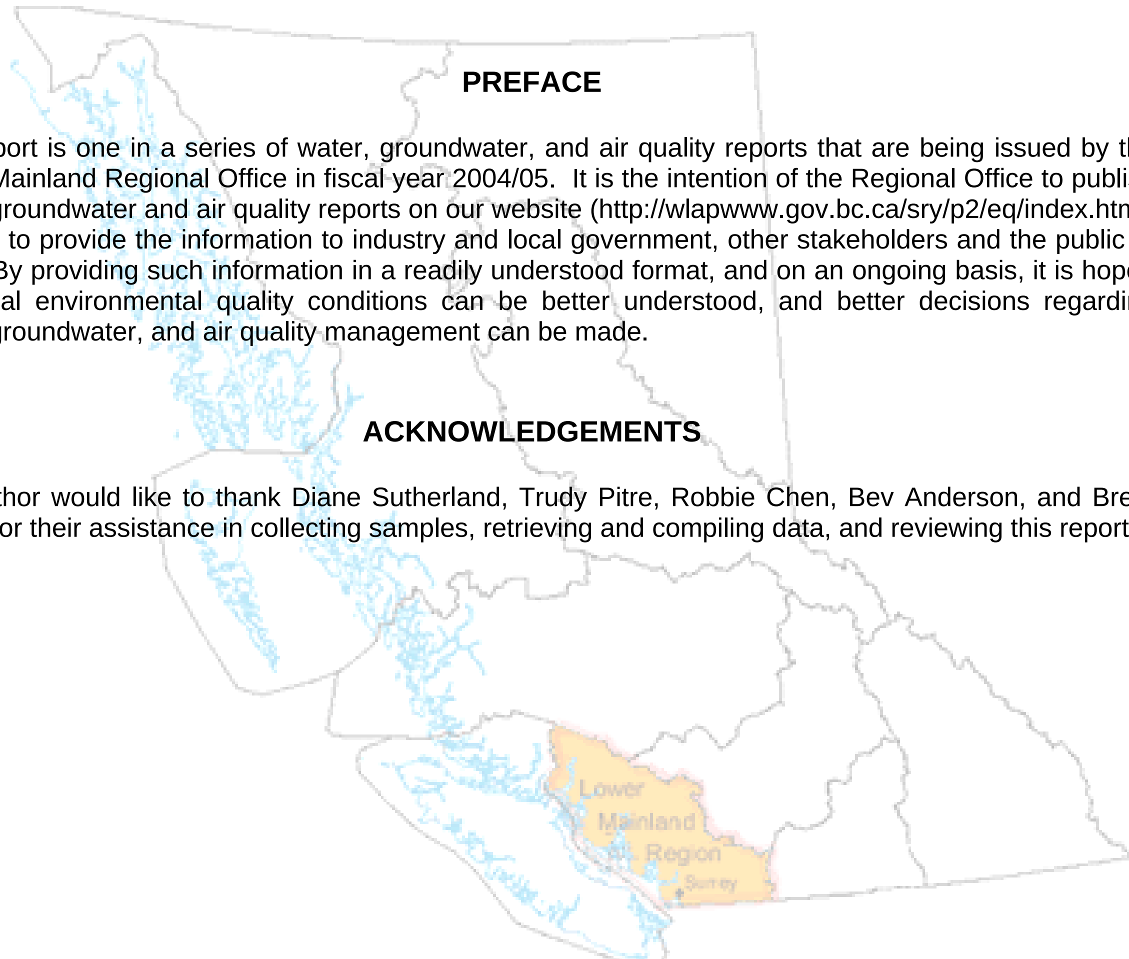

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APPENDICES

1.0 INTRODUCTION

1.1 Non-Point Source Pollution of Surface Waters

The British Columbia *Environmental Management Act* defines pollution as the presence in the environment of substances that substantially alter or impair the environment. Pollution can result from naturally occurring events such as forest fires and floods, or from anthropogenic[1] activities such as land development, industrial/municipal waste discharges, stormwater runoff, agriculture and forest harvesting. Pollution sources are generally classified as being either "point source" or "non-point source". A point source pollutant enters the receiving environment from a specific outlet such as a pipe, while a non-point source pollutant enters the receiving environment from a diffuse source that is not easily identifiable (1).

Non-point source (NPS) water pollution is the release of pollutants to surface/ground water from activities that occur over a large area, and results from water flowing over (and through) the land surface and transporting contaminants (e.g. pathogens, oxygen depleting substances, suspended materials, toxic chemicals) and debris into water bodies. The cumulative effect of multiple non-point sources has potential to diminish fish and wildlife resources, degrade drinking water, impact on agricultural and other industrial water uses, impair aesthetic values, and reduce recreational opportunities. NPS pollution is recognized as a major cause of water pollution in British Columbia and it represents a significant threat to water resources (1).

NPS pollution is difficult to manage using traditional regulatory mechanisms (e.g. discharge permits) because identifying and controlling NPS pollution over large areas is impractical, if not impossible. Therefore, NPS is best managed through source control, planning, and education. In British Columbia, various levels of government, industry, stakeholders, and resource users have addressed NPS water pollution through a variety of strategies such as public education programs, best management practice documents (e.g. Land Development Guidelines for the Protection of Aquatic Habitat), codes of practice documents (e.g. Code of Agricultural Practice for Waste Management) and development of industry specific regulations (e.g. Agricultural Waste Control Regulation). The effectiveness of the above-noted strategies on reducing NPS water pollution is measured by monitoring receiving environments to determine if water quality is improving, declining, or unchanging.

1.2 Water Quality Trend Monitoring

Water quality trend monitoring is used to detect subtle changes over time that may result from an ongoing activity or land-use within the catchment area of the watercourse. Trend monitoring generally involves taking water quality measurements at regular time intervals over a long-term period and analyzing the resultant data set to identify any trends. Trend detection typically requires years of monitoring with the length of time dependant on factors such as the type of water body being monitored, the frequency of data collection, and changes in adjacent land uses (2, 3).

In 2001, the Ministry of Water, Land and Air Protection (WLAP) Environmental Quality Section (Lower Mainland Region) commenced a surface water quality trend monitoring program (Trend Monitoring Program). The objective of the Trend Monitoring Program is to assess impacts of NPS pollution on aquatic environments and to identify trends in water quality (i.e. improving, unchanged, declining) at selected sites within the region. Trend monitoring stations were selected to obtain water quality data at sites representative of particular NPS pollution sources (e.g. urban development, agriculture, forest

[1] anthropogenic - caused or produced by humans

harvesting). The Trend Monitoring Program also provides a measure of the efficacy of strategies implemented to address NPS pollution, and is intended to facilitate better decision making regarding land use practices and the protection of surface water quality.

The regional trend monitoring program is composed of a combination of automated monitoring and grab sampling. Automated monitoring is undertaken by installing a monitoring unit in the stream that can automatically measure a limited number of water quality parameters over very short time periods (e.g. every 15 minutes). As significant water quality changes can occur over very short time periods in developed drainages, largely in response to precipitation events, there is a need for automated monitoring, so that changes to natural water quality responses can be detected. Since automated monitoring is only possible at this time for a limited number of water quality parameters, a sampler physically collects water samples for laboratory analysis twice a month at the regional trend monitoring sites.

To date, trend monitoring sites have been established in Millionaire Creek (Maple Ridge, BC), Saar Creek (Abbotsford, BC), River of Golden Dreams (Whistler, BC) and Crabapple Creek (Whistler, BC). Each regional trend monitoring site will operate for a minimum of three years before assessing the data and re-evaluating the need to continue monitoring. More information on regional trend monitoring can be found at http://wlapwww.gov.bc.ca/sry/p2/eq/wq_trend_monitoring/index.html.

1.3 Trend Monitoring in the Sumas River Watershed

In November 2001, WLAP established a water quality trend monitoring station at Saar Creek in Abbotsford, BC. Saar Creek, a tributary to the Sumas River, is located in an area of the Fraser Valley that has been intensively utilized for agricultural activities since the 1950's. The intent of the Saar Creek trend monitoring station is to identify trends in water quality in a system that is influenced by agricultural NPS pollution.

The *general* objective of this report is to summarize historical water quality information within the lower reaches of the Sumas River watershed to provide context to the above-described Saar Creek Water Quality Trend Monitoring Program. *Specific* objectives of this report are to:

- Summarize findings of previous water quality studies undertaken within the Sumas River watershed;
- summarize results of historic surface water quality sampling undertaken by WLAP in the lower Sumas River watershed;
- discuss *potential* impacts characterized by WLAP sample results on designated water uses by comparing results to federal and provincial water quality guidelines/objectives; and,
- offer recommendations to reduce water quality impacts caused by non-point source pollution.

It is important to note that this report summarizes a relatively small data set collected over a large time period. As such, a detailed assessment of water quality trends and/or impacts is precluded.

This report briefly discusses adjacent land uses, instream habitats, and riparian habitats within the study area as these factors play an important role in water quality. Fish utilization of aquatic habitats is also discussed as utilization can be a reflection of water quality. Also, the ability of aquatic habitats to function as salmonid spawning and rearing habitat is discussed as such values likely influence management decisions within the watershed.

2.0 STUDY AREA

2.1 Sumas River Watershed

The Sumas River watershed encompasses approximately 277 square kilometres within the City of Abbotsford, the City of Chilliwack, and Whatcom County (Washington, USA). The watershed is located within the Coastal Western Hemlock biogeoclimatic zone[2], a zone characterized by mild winters and cool summers with the highest average rainfall of the Province's 14 biogeoclimatic zones (4). The Sumas River headwaters are located in Whatcom County with flows conveyed north-east into Canada where the river traverses a region of the Fraser Valley known as the Sumas Prairie, a low-lying floodplain located between the Vedder and Sumas Mountains (Figure 1.0). Major Sumas tributaries (in Canada) include Marshall Creek, Saar Creek and Kilgaard Creek.

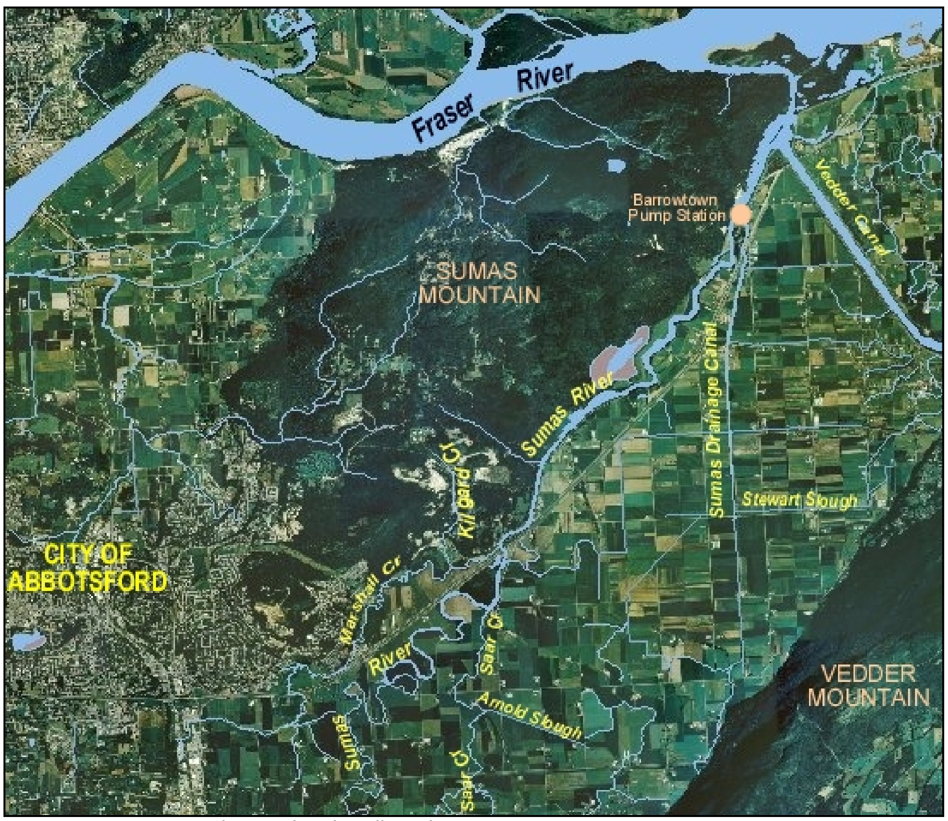

FIGURE 1.0 Sumas River and major tributaries.

[2] The Biogeoclimatic Classification System, developed and used throughout British Columbia, classifies geographic areas into biogeoclimatic units based on regional and local climatic conditions, topography and soils.

Sumas Prairie lies within the former footprint of Sumas Lake, a shallow lake that encompassed approximately 10,000 acres (40 km^2). In the 1920's, Sumas Lake was drained and dyked for agricultural and flood control purposes (5). In Canada, drainage within Sumas Prairie is conveyed within low gradient watercourses and drainage canals with pumps and dykes used to alleviate flooding and to divert water for agricultural purposes. Approximately 90 percent of Sumas River's length is dyked between the Canada/USA border and the Barrowtown Pump Station. Flows in the Sumas River are controlled at the Barrowtown Pump Station by gravity draining floodgates which are typically closed during the period of May to September to store water for irrigation (6). From the Barrowtown pump station, Sumas River continues approximately 1.5 kilometres to its confluence with the Vedder Canal. From the Sumas/Vedder confluence, flows continue northeast for approximately 3 kilometres where they drain to the Fraser River at the north-east end of Sumas Mountain. Highest flows in the watershed typically occur November to January with lowest flows typically occurring in July to September (6).

For purposes of this report, the study area consists of the low gradient reaches of the Sumas River and tributaries within the Sumas Prairie, an area generally bound by the Canada/U.S. border to the south, Sumas Mountain to the north, the No 3. Road alignment to the east, and the Sumas Way alignment to the west.

2.2 Agriculture and Potential Water Quality Impacts

The Sumas River and its tributaries have experienced water quality/quantity impacts as a result of urban, commercial, industrial, and agricultural development. While commercial and light industrial development occurs along the western edge of the study area (i.e. west side of Sumas Way) and the study area receives significant drainage from urban development, agriculture is still the dominant land use within the study area. Therefore, the following discussion is limited to potential water quality impacts associated with agricultural activities. Water quality parameters discussed in this report are summarized in Appendix A and it is recommended the reader review Appendix A to better understand impacts discussed below.

Approximately 57 square kilometres of the Sumas Prairie is utilized for agricultural activities such as dairy, hog, poultry and produce. The agricultural land base of the Sumas Prairie has not increased significantly since expansion of agriculture following the draining of Sumas Lake; however, the intensity of operations has increased dramatically with a trend toward densification of livestock operations. For example, an investigation into land use and agriculture in the Sumas River watershed found the agricultural land-base has not increased significantly between 1954 and 1995, but the number of farms has increased 26 percent in the same time period (7).

The impact of agricultural activities on water quality is dependent on a number of factors including precipitation patterns, soil type, topography, intensity of agricultural operations, and farm management practices. Pollution of aquatic habitats via agricultural activities is generally non-point source as pollutants are transferred to aquatic environments via surface runoff, groundwater inputs, or atmospheric deposition (8), but it should be noted that point source discharges to the receiving environment have been discovered on agricultural operations (e.g. milking parlour discharges, manure storage facilities) and have been the subject of legal action (9). Animal waste disposal, application of chemical fertilizers, application of pesticides, excessive water withdrawal (livestock watering and irrigation), and reduction/removal of riparian habitats are examples of activities that have potential to negatively impact on water quality (8).

Previous studies indicate water quality problems in the Sumas River watershed are largely related to improper storage and/or disposal of agricultural waste and use of chemical fertilizers. Runoff from animal waste and chemical fertilizers can impact on aquatic organisms both directly or indirectly. Direct impacts of improper manure storage/disposal include ammonia toxicity, which can be acute under the appropriate temperature and pH conditions. Indirect impacts are primarily related to stimulation of excess growth of aquatic plants due to nutrient enrichment. Excess growth aquatic plants may alter pH (which may promote ammonia or metals toxicity), and it may result in reduced dissolved oxygen levels in the fall when aquatic plants die off and undergo decomposition. Runoff from animal waste also exhibits a high oxygen demand during decomposition and can reduce dissolved oxygen levels. In general, application of animal wastes or chemical fertilizers in amounts that exceed the ability of terrestrial plants (e.g. crops) to assimilate nutrients results in residual nutrients being delivered to aquatic environments via surface runoff or groundwater flow. The intensification of livestock operations on a relatively unchanged land base has resulted in more animal waste being generated (and disposed of) on a land base that is not capable of assimilating the waste. The problem is further compounded by frequent and intense precipitation patterns of the lower mainland. These rain events not only have potential to deliver field-applied nutrients to watercourses, but also have the potential to overwhelm uncovered manure storage facilities which increases the potential for delivery of nutrients to watercourses. Agricultural census data and waste management survey data suggests that over 50 percent of the agricultural land base in the Sumas watershed receives excess nutrients that potentially contribute to water pollution (7).

Pesticides, in general, are synthetic chemicals designed to kill or control unwanted organisms such as weeds, insects, or rodents (8). Pesticides can be transported to the aquatic environment via atmospheric deposition, surface runoff, or erosion (when pesticide residue is sorbed to soil particles). Many pesticides persist and accumulate in the aquatic environment (e.g. sediments, biota) with impacts being acute (e.g. death) or chronic (e.g. impaired reproduction). Impacts associated with improperly applied pesticides are dependent on the properties of the pesticide and the susceptibilities of the organism. Poor management practices such as over-application of pesticides, spraying in close proximity to aquatic environments, or applying pesticides during inappropriate weather conditions (e.g. high winds, precipitation) are common ways pesticides can reach aquatic environments. Fish kills due to pesticide application have been observed in the Sumas River system (9).

Surface water withdrawals (e.g. for irrigation) require a licence under the Provincial *Water Act,* with licenced withdrawals on the Sumas River (primarily for irrigation) totaling approximately 679 cubic decimeters (over 3 million cubic meters). While a *Water Act* licence states the allowable volumes of water for withdrawal, it does not require licencees to monitor the amount of water removed; thus, excessive amounts of water may be withdrawn. In addition to reducing the amount of available aquatic habitat (i.e. reducing the size of the wetted perimeter of a watercourse), excessive water withdrawals may result in higher water temperatures, reduced dissolved oxygen levels, and higher contaminant concentrations (8).

Maximizing use of the land base by cultivating fields to the top-of-bank replaces important riparian habitats[3] with pasture or produce. Important functions provided by well-developed, structured riparian habitats include shading, attenuation of surface flows, and stabilization of soils and stream banks. Shading regulates summer water temperatures while attenuation of flows reduces erosion potential, facilitates infiltration of surface water, and promotes nutrient uptake and/or conversion by plants and terrestrial biota. Stabilization of soils and stream banks reduces delivery of sediment and nutrients (e.g. nitrogen and phosphorous) to watercourses. Riparian habitats also contribute food and nutrients to the aquatic environment, and are a source of coarse woody debris (through tree fall) which adds important structure to the aquatic environment (10).

It is important to note that the Abbotsford Aquifer is a source of drinking water and that some of the above-noted activities have potential to impact on drinking water. A discussion of groundwater impacts is

[3] riparian habitats - areas adjacent to rivers and streams

beyond the scope of this report, but additional information on the Abbotsford aquifer is available at the Abbotsford-Sumas Aquifer International Task Force web page.[4]

2.3 Previous Water Quality Studies

Several water quality studies have been undertaken in the Sumas River watershed and results indicate an association between intensive agricultural activities and degraded surface water quality.

In August 1987, a water quality study was undertaken in 4 Lower Fraser Valley watersheds extensively utilized for agricultural activities. Included in the study was the Sumas River watershed with water quality sampling (primarily dissolved oxygen) undertaken over a 4 month period on the Sumas River, Saar Creek, Arnold Slough, Marshall Creek, and several ditches. The study found dissolved oxygen levels in Sumas River and Stewart Slough were acceptable for aquatic life, but reaches of Saar Creek, Arnold Slough, Marshall Creek, and several roadside ditches experienced dissolved oxygen levels below those recommended for the protection of freshwater aquatic life[5]. Elevated levels of ammonia were also recorded in Arnold Slough and a roadside ditch draining to Saar Creek (6).

In 1991, the Washington State Department of Ecology undertook water quality sampling over a 2-day period to investigate potential impacts of the City of Sumas wastewater treatment plant effluent on the Sumas River. At the time of the study, the treatment plant accepted sewage from approximately 750 residents and discharged to the Sumas River approximately 100 meters upstream of the Canada / United States border. Parameters sampled over the two-day sampling period, included flow, water temperature, pH, dissolved oxygen, turbidity, total suspended solids, nutrients (total ammonia, total nitrogen, total phosphorous, ortho-phosphorous) and fecal coliforms. The study found complete mixing of the effluent and river within 30 metres of the discharge point and measured parameters did not exceed *Water Quality Criteria*. It is noteworthy that elevated levels of fecal coliforms and nitrogen were found upstream of the wastewater treatment plant with non-point sources, likely dairy operations, identified as the most probable source of observed nitrogen and fecal coliform increases. Elevated levels of total phosphorous and ortho-phosphorus were found downstream of the wastewater treatment plant as a result of the treatment plant discharge, but levels did not exceed the *Freshwater Aquatic Life Criterion* (11). In 1996, wastewater from the City of Sumas was diverted to the JAMES (Joint Abbotsford Matsqui Environmental System) wastewater treatment facility in Abbotsford, BC.

In July 1994, an agriculture land use study was prepared for the BC Ministry Environment, Lands and Parks (now WLAP), Environment Canada, and the Department of Fisheries and Oceans. Water quality sampling was undertaken as part of the study with weekly samples collected at 9 sites over a 4 month period (2 months in the fall and 2 months in the winter) at Arnold Slough, Marshall Creek, Saar Creek, Stewart Slough, Sumas River, and Sumas Drainage Canal. Results indicated fecal coliform counts in some reaches of Sumas River and Stewart Slough were unsuitable for irrigating crops which are eaten raw. Metal concentrations were measured twice during the sampling program. Results indicated that total copper exceeded the *Freshwater Aquatic Life Criterion* at all 9 sites on 1 sample date, and at 5 sites during the other sample dates; total iron exceeded the *Freshwater Aquatic Life Criterion* at all sample sites on both dates; and, total nickel exceeded the *Freshwater Aquatic Life Criterion* at 3 sites on 1 sample date. Exceedances of metals guidelines were associated with extended periods of precipitation. Winter dissolved oxygen concentrations were found to be acceptable at all sites; however, fall dissolved oxygen levels dropped below the required minimum at the Arnold Slough, Saar Creek and Marshall Creek

4 http://wlapwww.gov.bc.ca/wat/aquifers/absumas.html

5 Water Quality Criteria are discussed in Section 4.0

sample sites. Sampling results also found elevated levels of nutrients in surface waters. Fish sampling found salmonids and coarse fish species throughout the Sumas River watershed except for the middle reaches of the Sumas River, the Sumas Drainage Canal at the Barrowtown Pump Station and Arnold Slough (12). The study concluded the *Freshwater Aquatic Life Criterion* for total aluminum was exceeded at all sample sites, except for Arnold Slough. It should be noted that a *Freshwater Aquatic Life Criterion* only exists for dissolved aluminum and not total aluminum, accordingly, the above conclusion regarding aluminum exceedances is incorrect.

In 1996, the Ministry of Environment, Lands and Parks prepared a water quality status report for water bodies suspected of having water quality problems. The status report presented results as a value on a water quality index (WQI). The WQI is a number ranging from 0 to 100 divided into one of five categories: excellent (0-3), good (4-17), fair (18-43), borderline (44-59) and poor (60-100). The status report included the Sumas River and Saar Creek. Sumas River water quality was rated "good" (WQI=4), but agricultural non-point source pollution was identified as a potential threat to water quality. Saar Creek water quality was rated "poor" (WQI=66) with agricultural non-point source pollution being identified as a threat to water quality (13). It should be noted that the above data were obtained by grab sampling (i.e. a single sample taken at specific place and time) which can miss short-term events that have potential to impact on surface water quality; accordingly, the above indices may not necessarily be reflective of ambient surface water quality conditions. As discussed in Section 1.2, high frequency automated monitoring (e.g. samples every 15 minutes) is a better tool for characterizing changes in water quality conditions as a result of short-term events.

The Lower Fraser Basin Eco-Research Project (LFBERP) is comprised of research scientists, social scientists, communities, businesses and government representatives, and evaluates the prospects for sustainability in the Lower Fraser region. The LFBERP investigated the relationship between agricultural NPS and water quality in the Sumas River watershed. . Water samples were taken at 16 different sites within the watershed over a 1-year period. The study found increased concentrations of nutrients (e.g. nitrate, ammonia, phosphate) associated with extended periods of precipitation. Runoff from manure laden fields was determined to be the likely source of elevated nutrient levels (14).

In 1997, Fisheries and Oceans Canada released a report summarizing water, sediment and fish tissue contaminant data collected within the lower Fraser River basin. The data set was comprised primarily of sample results from provincial and federal governments sampling undertaken between 1980 and 1995. The summary found exceedances of *Water Quality Criteria* on the Sumas River, Marshall Creek, Saar Creek, Arnold Slough, and Kilgaard Creek. Exceedances included water temperature, dissolved oxygen, nutrients (e.g. nitrate, ammonia, phosphorous), cadmium, chromium, copper and zinc. Reduced water quality (and quantity) was attributed to a variety of land/water uses such as intensive agriculture, industrial discharges, water withdrawal, and urban development (8).

In 1998, Environment Canada released a report of research conducted under the Fraser River Action Plan (7). Research included water quality sampling in the Sumas River watershed to determine if surplus manure application and elevated animal densities were contributing to surface and ground water pollution in the Sumas River watershed. During the study, 16 sites (3 of which were located in the United States) were sampled 7 times per year over a 3 year period. Arnold Slough drains the most intensively utilized agricultural area of the watershed and experienced reduced water quality conditions during the fall with nitrate, ammonia, and dissolved oxygen not meeting *Freshwater Aquatic Life Criterion.* The study also found a positive correlation between surplus nitrogen application and ammonia concentrations, and a negative correlation between surplus nitrogen application and dissolved oxygen. The above correlations indicate an association between excess nutrient application and degraded water quality. It is noteworthy that concentrations of ammonia and nitrate were found within ranges known to impact on amphibian species. Hatching success of amphibians was indeed found to be reduced in the interior habitats of

Sumas Prairie (where intensive agricultural activities occur) compared to control sites at the edge of the Prairie. The report also found elevated levels of metals (i.e. nickel, chromium, copper, zinc) in the sediments of the Sumas River system. The Sumas River headwaters contain a natural asbestos bedrock formation that was exposed as a result of a landslide (15) and it is likely that sediment inputs from the slide are responsible for elevated levels of nickel and chromium found in river sediments. Concentrations of nickel and chromium decreased from the headwaters to the mouth of the Sumas River, thus suggesting the slide is the source. Copper and zinc are used as supplements in some feeds and it is possible that elevated levels of copper and zinc in sediments in the lower reaches of Sumas River are a result of agricultural runoff. Effluent from the City of Sumas wastewater treatment plant also likely contributed to elevated metals found in Sumas River sediments.

As the above studies indicate, an association exists between intensive agricultural activities and degraded surface water quality in the Sumas River watershed. The management of agricultural waste is governed by the Agricultural Waste Control Regulation (AWCR) (B.C.Reg. 131/92) under the *Waste Management Act.* The AWCR states that nutrients (e.g. manure) can only be applied for crop use and agricultural waste must be properly stored during times of the year when it is inappropriate to apply as a soil amendment (i.e. late fall and winter). The intent of the AWCR is to prevent nutrients from entering surface waters and/or drinking water where they have potential to impact on human health and/or the environment. In 2001, the Lower Mainland Regional Office of WLAP carried out a compliance and enforcement audit to assess compliance with the Agricultural Waste Control Regulation (16). Between October 2001 and March 2002, 139 inspections were conducted throughout the central Fraser Valley, including the Sumas Prairie. Inspections resulted in 76 warning letters and 13 *Waste Management Act* orders being issued, as well as 7 legal investigations being initiated. Four (4) of the above-noted warning letters and 1 of the above-noted orders occurred in the study area. The study concluded that additional efforts were needed to minimize agricultural impacts on the environment. It is noteworthy that the study stated the agricultural community was aware of what was needed to comply with the AWCR, but compliance was, in effect, 'voluntary' for a number of reasons such as cost.

Water quality sampling was undertaken on Kilgaard Creek, a Sumas River tributary, between August and November 2001. In addition to summarizing and assessing sample data, the Kilgaard report provides background information relevant to this report and readers are encouraged to review the report. The Kilgaard report can be viewed on the Lower Mainland Region Environmental Quality Section web page at http://wlapwww.gov.bc.ca/sry/p2/eq/index.htm.

In Fall 2002, water quality sampling was undertaken to assess attainment of water quality objectives established for several lower Fraser River tributaries (including sample sites on Sumas River and Saar Creek). Where site-specific objectives did not exist, results were compared to applicable water quality guidelines. The study included a water quality index calculation (discussed above) at each site. In Sumas River, samples were collected at the Atkinson Road bridge. Results indicated objectives/guidelines for dissolved oxygen, nitrite and temperature were not met at Sumas River and the water quality index was calculated as ‘fair’ (17). Saar Creek samples were collected at the Lamson Road bridge. Results indicate objectives/guidelines for dissolved oxygen, nitrite and temperature were not met at Saar Creek and the water quality index was calculated as ‘marginal’.

2.4 Fish and Fish Habitats

Watercourses within the study area are characterized by low-gradient channels (see Appendix B photographs) with limited instream and riparian structure as a result of dyking, dredging, water withdrawal, flow regulation, and agricultural development. Salmonid fishes require relatively clean, cool freshwater habitats to fulfill one or more life history functions, thus making them a good indicator of water quality conditions. While watercourses in the study area have been impacted by anthropogenic activities, they do sustain important salmonid migration, spawning, and rearing habitats, a conclusion reflected in the distribution of salmonids throughout the watershed. A 1994 study (12) found salmonids and coarse fish species throughout the Sumas River watershed except for the middle reaches of the Sumas River, the Sumas Drainage Canal at the Barrowtown Pump Station, and Arnold Slough.

Salmonid species documented within Sumas River and tributaries include coho salmon *(Oncorhynchus kisutch)*, chum salmon *(O. keta),* pink salmon *(O. gorbuscha)*, cutthroat trout *(O. clarki clarki)* and rainbow/steelhead trout *(O. mykiss)*. Coarse fish species (i.e. non-salmonids) can tolerate a wider range of environmental conditions (compared to salmonids) and it is reasonable to conclude that habitats supporting salmonid fish species will invariably support coarse fish species. Coarse fish species documented within the Sumas River system include black crappie *(Pomoxis nigromaculatus)*, brown bullhead *(Ictalurus nebulosis)*, threespine stickleback *(Gasterosteus aculeatus)*, redside shiner *(Richardsonius balteatus)*, prickly sculpin *(Cottus asper)* and northern pikeminnow *(Ptychocheilus oregonensis)* (18).

Salmonid spawning habitat potential within the study area is low due to a lack of suitable substrates, gradient, and flow, but salmonid spawning has been reported in Saar Creek and Sumas River with the major coho salmon spawning grounds of the Sumas River being located in Washington State (6). In Canada, suitable salmonid spawning habitats are found in tributary reaches, specifically, the transitional areas between the low gradients reaches of the Sumas Prairie (the study area) and the higher gradient reaches of the Sumas and Vedder Mountains; the combination of substrates, gradient, and flow in these transitional zones provides suitable salmonid spawning habitats. The study area thus sustains important salmonid migratory habitat to upstream spawning areas.

Salmonid production (i.e. rearing habitat values) in the study area is limited by a variety of factors, including a lack of flow diversity (e.g. pool, riffle, run), relatively unproductive substrates (e.g. fines), lack of instream complexing (e.g. woody debris), and a poorly structured (and sometimes nominal) riparian environment. More productive salmonid rearing habitats are found in tributary reaches where higher gradients and well developed instream and riparian environments are found. As with key spawning grounds, these areas are in the transitional zone between the low gradients reaches of the Sumas Prairie (the study area) and the higher gradient reaches of the Sumas and Vedder Mountains.

The Barrowtown Pump Station gates are typically closed during the period of May to September to store water for irrigation and are typically open by mid-September to allow migrating salmon to access upstream spawning habitats (6). It is important to recognize the influence of the Barrowtown Pump Station on fish, fish habitat, and water quality within the Sumas River system as the physical, chemical, and biological characteristics of lotic (i.e. flowing) and lentic (i.e. still water) habitats influence a variety of biotic and abiotic processes such as heat exchange, gas exchange, nutrient cycling, transport of sediment and dissolved substances, and rates of sediment deposition.

3.0 SAMPLING PROGRAM

3.1 Sampled Parameters

Water quality parameters summarized in this report include pH, water temperature, dissolved oxygen, suspended sediments, nitrogen (ammonia, nitrite, nitrate), phosphorous, metals (arsenic, calcium, copper, lead, manganese, nickel, zinc) and fecal coliforms. A description of assessed water quality parameters is provided in Appendix A with sampling data tabled in Appendices C through G. Not all water quality parameters listed in the appended data sets are discussed in this report, but all data were reviewed and notable observations are discussed.

3.2 Sampling Locations and Dates

Sample sites and sampling dates for WLAP sampling are summarized in Table 1.0. A location map with photographs of sample sites is provided in Appendix B. It should be noted that sample parameters varied among sites and sample dates.

TABLE 1.0 SAMPLING LOCATIONS AND DATES

Sample Year	*Site 1* Sumas River at Whatcom Road	*Site 2* Saar Creek at Lamson Road	*Site 3* Marshall Creek at Indian Road	*Site 4* Sumas River at Atkinson Road	*Site 5* Sumas Drainage Canal at No. 3 Road
1972	72 04 24	72 04 24		72 04 24	
	72 08 02	72 08 02		72 08 02	
	72 11 01	72 11 01		72 11 01	
1973	73 02 05	73 02 05		73 02 05	
	73 05 07	73 05 07		73 05 07	
	73 09 24	73 09 24		73 09 24	
	73 11 06	73 11 06		73 11 06	
1974	74 02 05	74 02 05		74 02 05	
	74 05 02	74 05 02		74 05 02	
	74 09 05	74 09 05		74 09 05	
	74 11 06	74 11 06		74 11 06	
1975	75 02 13	75 02 13		75 02 13	
	75 06 26	75 06 26		75 06 26	
	75 09 16	75 09 16		75 09 16	
	75 11 26	75 11 26		75 11 26	
1976	76 02 09	76 02 09		76 02 09	
	76 05 20	76 05 20		76 05 20	
	76 10 14	76 10 14		76 10 14	
	76 11 25	76 11 25		76 11 25	
1977	77 02 10	77 02 10		77 02 10	
	77 05 26	77 05 26		77 05 26	
	77 09 26	77 09 26		77 09 26	
	77 11 30	77 11 30		77 11 30	
1978				78 04 04	
				78 06 22	
				78 09 13	
				78 11 14	
1992		92 07 07		92 07 07	
		92 07 14		92 07 14	
		92 07 23		92 07 23	
		92 07 27		92 07 27	
		92 08 04		92 08 04	
1993		93 07 11		93 07 11	
		93 07 18		93 07 18	
		93 07 25		93 07 25	
		93 07 29		93 07 29	
		93 08 02		93 08 02	

Table 1.0 cont'd…

Sample Year	*Site 1* Sumas River at Whatcom Road	*Site 2* Saar Creek at Lamson Road	*Site 3* Marshall Creek at Indian Road	*Site 4* Sumas River at Atkinson Road	*Site 5* Sumas Drainage Canal at No. 3 Road
2000	00 02 17	00 02 17	00 02 17	00 02 17	00 02 17
	00 02 22	00 02 22	00 02 22	00 02 22	00 02 22
	00 02 29	00 02 29	00 02 29	00 02 29	00 02 29
	00 03 07	00 03 07	00 03 07	00 03 07	00 03 07
	00 03 14	00 03 14	00 03 14	00 03 14	00 03 14
	00 03 21	00 03 21	00 03 21	00 03 21	00 03 21
	00 03 28	00 03 28	00 03 28	00 03 28	00 03 28
	00 04 17	00 04 17	00 04 17	00 04 17	00 04 17
2001		01 10 11			
	01 10 17	01 10 17			01 10 17
		01 10 24			
		01 10 31			
	01 11 07	01 11 07			01 11 07
		01 11 14			
		01 11 22			
		01 11 27			

3.3 Sampling Methodology

3.3.1 Field Methodology

For all samples, bottles were supplied by the analytical laboratory and, with exception for fecal coliforms and metals, sample bottles were rinsed with stream water prior to sample collection. Samples were collected at the margin of the creek by submerging the bottle approximately 10 centimeters below the water surface. Sample bottles were packed in a cooler with ice and transported to the laboratory within 24 hours of sample collection. It should be noted that quality assurance/quality control procedures (e.g. trip blanks, field blanks) were generally not practiced in the 1970's and sample results should be evaluated accordingly.

3.3.2 Laboratory Methodology

Sample analysis followed methods described in the following manuals with modification of methods under Ministry approval.

British Columbia Department of Environment. 1976. Laboratory Manual for the Chemical Analyses of Waters, Wastewaters, Sediments and Biological Tissues, 2nd Edition. Victoria, BC.

British Columbia Ministry of Environment. 1989. Laboratory Manual for the Waters, Wastewaters, Sediments and Biological Materials, Supplement #2, Victoria, BC.

British Columbia Ministry of Environment, Lands and Parks. 1994. British Columbia Environmental Laboratory Manual, Victoria, BC.

4.0 WATER QUALITY CRITERIA

British Columbia *Water Quality Guidelines* and *Water Quality Objectives* (collectively referred to as *Water Quality Criteria* in this report) are both allowable levels of a particular substance for the protection of a designated water use (e.g. drinking water, aquatic life, livestock watering, recreation), but differ in their scope. *Guidelines* are set to protect a designated water use in general, whereas *Objectives* are set to protect a designated water use at a specific location. Site-specific *Objectives* are, in general, the same as *Guidelines*; however, when natural background levels exceed *Guideline* values, the *Objective* values may be less stringent than the *Guidelines*. Conversely, *Objective* values may be more stringent than the *Guidelines* if local resources are unusually valuable or significant. Unless *Water Quality Objectives* have been established for a specific water body, the *Water Quality Guidelines* are the default criteria (19).

Water Quality Objectives are developed on a site-specific basis and only for water bodies that may be affected by human activity (now or in the future). They are set to protect the most sensitive designated water use at a specific location and are developed with consideration for local water quality, water uses, waste discharges, and socio-economic factors. Fecal coliform and dissolved oxygen objectives have been established for the Sumas River and Saar Creek for the protection of *Freshwater Aquatic Life*, *Livestock Watering*, and *Irrigation* water uses (19).

Water Quality Criteria used in this report (19-22) are summarized in Table 2.0 (page 13). Unless noted, all values are from the *British Columbia Approved Water Quality Guidelines*. Results were not compared to water quality guidelines for drinking water use as the Sumas River and tributaries are not used as a drinking water source. However, it should be noted that the Abbotsford Aquifer is contained within a large portion of the Sumas River watershed and degraded surface water quality may be an indicator of potential for degradation of drinking water sources such as the Abbotsford Aquifer.

Fecal coliform *Water Quality Criteria* listed in Table 2.0 use units of "Most Probable Number per 100mL" (MPN/100mL), but some of the fecal coliform data are reported in units of "Colony Forming Units per 100 mL" (CFU/100mL). MPN and CFU both measure the number of colonies per 100mL of sample, but MPN represents a statistical average whereas CFU is an actual colony count. The most appropriate method for analysis (i.e. MPN or CFU) is determined by factors such as sample turbidity and microbial density. As such, a comparison between MPN and CFU cannot be directly made and only fecal coliform samples in units of MPN are compared to water quality criteria in this report.

For fecal coliforms, "recreational-primary contact" is defined as an activity where a person would have direct contact with water over most of the body's surface, to the point of complete submergence, or where there is substantial risk of ingestion or intimate contact with eyes, ears, nose, mouth or groin (e.g. boating, kayaking). The *Recreational-Primary Contact Criterion* is based on the geometric mean of a minimum of 5 samples in 30 days (20).

Water Quality Criteria for the two measures of suspended sediment (i.e. non-filterable residues[6] (NFR) and turbidity), require a knowledge of background conditions and/or the duration of measured concentrations (20). Background NFR or turbidity concentrations are not known at the sample sites and duration of suspended sediments events are not known, thus precluding comparison with updated water quality criteria that recognize both the concentration and duration of the exposure.

[6] non-filterable residues - a measure of the amount of particle matter suspended within the water column, alternatively referred to as total suspended solids (TSS)

TABLE 2.0 WATER QUALITY CRITERIA

Parameter		Water Use Designation			
		Freshwater Aquatic Life	Livestock Watering	Irrigation	Recreation
General	pH	6.0 - 9.0	-	-	5.0-9.0[a]
	Temperature (°C)	max 16.0 (rearing coho salmon)	-	-	max 30.0 (suggested)
	Dissolved Oxygen (mg/L)	• min 11.2 when fish eggs are in "eyed" to hatch stage[c] • min 8.0 when fish eggs, larvae, or alevin present[c] • min 6.0 at all other times[c]			-
	Non-filterable Residue-Induced (mg/L) -	• if background ≤ 25 mg/L = 25 mg/L in 24 hours • if background 25-250 mg/L = background + 25 mg/L • if background ≥ 250 mg/L = background + 10%	-	-	-
	Turbidity-Induced (NTU)	• if background ≤ 8 NTU = 8 NTU in 24 hours • if background 8-80 NTU = background + 8 NTU • if background ≥ 8 NTU = background + 10%	-	-	50 NTU
	Sulphate (mg/L)	max 100	-	-	max 500 mg/L
Metals	Total Arsenic (mg/L)	max 0.005	max 0.025	max 0.1	-
	Total Cadmium (ug/L)	max 0.017[a]	max 80[a]	max 5.1[a]	-
	Dissolved Calcium (mg/L)	max 4 - 8[b]	max 1000[b]	-	-
	Total Copper (ug/L)	max = (0.094 (hardness in mg/L) +2)	max 300	max 200	max 1000
	Total Lead (ug/L)	max = $e^{(1.273 \ln[hardness]-1.460)}$	max 100	max 200	max 50
	Total Manganese (mg/L)	max = (0.01102(hardness in mg/L) +0.54)	-	max 200[b]	-
	Total Nickel (ug/L)	max = 65 (hardness between 60 and 120 mg/L $CaCO_3$)[b]	max 1000[b]	max 200[b]	-
	Total Zinc (ug/L)	max = 33 + 0.75 x (hardness in mg/L - 90)[b]	max 2000[b]	max 2000 (soil pH 6-7)[b]	max 5000[b]
Nutrients	Total Ammonia (mg/L)	pH and temperature dependant (e.g. pH 7-8 and temp 0-20°C max. ammonia ranges between 5.6 and 23.2 mg/L)	-	-	-
	Nitrite (mg/L)	max 0.06	max 10	-	max 1.0
	Nitrate (mg/L)	max 200	max 100	-	max 10
	Total Phosphorous (ug/L)	max 5-15	-	-	max 10
Bacteriology	Fecal Coliforms (MPN/100mL)	• less than or equal to 1000 geometric mean (based on minimum of 5 samples collected during the period of August to September)[c] • max 4000 (April to October)[c]			Primary Contact: less than 200 MPN/100mL geometric mean

[a] Canadian Environmental Quality Guidelines (Canadian Council of the Ministers of Environment)
[b] British Columbia *Working* Water Quality Guidelines
[c] Ambient Water Quality Objectives for the Fraser River Sub-basin from Hope to Kanaka Creek

5.0 SAMPLING RESULTS

This report summarizes a relatively small data set collected over a large time period thus precluding assessment of water quality trends and/or impacts. Assessment of data is limited to comparison with *Water Quality Criteria.*

A summary of criteria exceedances for each of the five sample sites is provided below. For the summary tables below, an exceedance is considered a value in excess of the most stringent water quality criterion. For example, the temperature (maximum) criteria for *Freshwater Aquatic Life* and *Recreational-Primary Contact* are 16 and 30 degrees Celsius, respectively; therefore, an exceedance was considered to be a value above 16 degrees Celsius (the most stringent criterion). For fecal coliforms, the most stringent criterion (*Recreational-Primary Contact*) is 200 MPN/100mL (geometric mean). There were insufficient MPN fecal coliform data (i.e. 5 samples in 30 days) available for calculation of the geometric mean for comparison with the *Recreational-Primary Contact Criterion*. While not an exceedance of *Water Quality Criterion*, fecal coliform concentrations over 200 MPN/100mL have been listed in the exceedance tables. These high values indicate fecal coliforms concentrations approach potentially unsafe levels and it is likely that an increased sampling effort (i.e. an additional 4 samples within 30 days) may result in fecal coliform concentrations exceeding the most stringent criterion (i.e. *Recreational-Primary Contact)*.

In summary, there were 29 exceedances of *Water Quality Criteria* for designated water uses such as *Freshwater Aquatic Life*, *Livestock Watering* or *Irrigation.* Exceedances were for temperature (13 samples), dissolved oxygen (11 samples), copper (3 samples), nickel (1 sample), nitrate (1 sample) and zinc (1 sample).

5.1 Site 1 - Sumas River at Whatcom Road Bridge

Water samples were collected from the Sumas River at the Whatcom Road Bridge site 24 times over an 8 year period. Samples were collected once each season (i.e. spring, summer, fall, winter) between 1972 and 1977, winter and spring 2000, and fall 2001. Sampled parameters were not the same each year. Sample results are summarized in Appendix C with water quality criterion exceedances summarized in Table 3.0 below.

Water Quality Criteria for *Freshwater Aquatic Life* were exceeded for temperature (2 of 32 samples), total copper (1 of 20 samples) and total nickel (1 of 18 samples). Calculation of the geometric mean for comparison with the fecal coliform *Recreational-Primary Contact Criterion* was precluded due to some sample results being reported in CFU/100mL and/or insufficient sampling frequency (i.e. a minimum of 5 samples in 30 days). It should be noted that the number of fecal coliform samples (n=8) in excess of 200 MPN/100mL (*Recreational-Primary Contact Criterion)* suggests an increased sampling effort would potentially return results with geometric means in excess of 200 MPN/100mL.

TABLE 3.0 Summary of Water Quality Criterion Exceedances - Sumas River at Whatcom Road Bridge

Date	Parameter			
	Temperature (°C)	Total Copper (μg/L)	Total Nickel (μg/L)	Fecal Coliforms
August 02, 1972	17			
February 05, 1974				240 MPN/100mL
May 02, 1974				1300 MPN/100mL
September 05, 1974	19			
November 06, 1974				790 MPN/100mL
February 13, 1975				1100 MPN/100mL
July 16, 1975				2300 MPN/100mL
November 26, 1975		21[a]	70[b]	3500 MPN/100mL
October 14, 1976				490 MPN/100mL
April 17, 2000				490 MPN/100mL

[a] Sample hardness was 85.8 mg/L $CaCO_3$, therefore, the maximum **Total Copper** concentration for the Protection of Aquatic Life is 10.1 μg/L

[b] Sample hardness was 85.8 mg/L $CaCO_3$, therefore, the maximum **Total Nickel** concentration for the Protection of Aquatic Life is 65 μg/L

5.2 Site 2 - Saar Creek at Lamson Road Bridge

Water samples were collected from Saar Creek at the Lamson Road Bridge site 32 times over a 10 year period. Samples were typically collected once each season (i.e. spring, summer, fall, winter) between 1972 and 1977, summer 1992, summer 1993, winter and spring 2000, and fall 2001. Sampled parameters were not the same each year. Sample results are summarized in Appendix D with water quality criterion exceedances summarized in Table 4.0 below.

Water quality criteria for *Freshwater Aquatic Life* were exceeded for temperature (4 of 42 samples), dissolved oxygen (11 of 43 samples), total copper (1 of 23 samples) and total zinc (1 of 25 samples). The maximum allowable fecal coliform criterion for *Freshwater Aquatic Life*, *Livestock Watering* and *Irrigation* is 4000 MPN/100mL and this value was exceeded on April 17, 2000.

Calculation of the geometric mean for comparison with the fecal coliform *Recreational-Primary Contact Criterion* was precluded due to some sample results being reported in CFU/100mL and/or insufficient sampling frequency (i.e. a minimum of 5 samples in 30 days). It should be noted that the number of fecal coliform samples (n=17) in excess of 200 MPN/100mL (*Recreational-Primary Contact Criterion)* suggests an increased sampling effort may return results with geometric means in excess of 200 MPN/100mL.

TABLE 4.0 Summary of Water Quality Criterion Exceedances - Saar Creek at Lamson Road Bridge

Date	Parameter				
	Temperature (°C)	Dissolved Oxygen (mg/L	Total Copper (μg/L)	Total Zinc (μg/L)	Fecal Coliforms
August 02, 1972		3.3			
July 24, 1973	17				
November 06, 1973					700 MPN/100mL
February 05, 1974					540 MPN/100mL
May 02, 1974					790 MPN/100mL
July 05, 1974	19				1400 MPN/100mL
November 06, 1974					460 MPN/100mL
February 13, 1975					230 MPN/100mL
June 26, 1975					540 MPN/100mL
July 16, 1975		4			700 MPN/100mL
November 26, 1975			22[a]		460 MPN/100mL
February 09, 1976					460 MPN/100mL
May 20, 1976					1300 MPN/100mL
October 14, 1976					240 MPN/100mL
September 26, 1976		5.2			
November 25, 1976				7[b]	>2400 MPN/100mL
May 26, 1977					1600 MPN/100mL
July 26, 1977					540 MPN/100mL
November 30, 1977					1600 MPN/100mL
July 11, 1993		2.9			
July 18, 1993	16.1	3.1			
July 25, 1993		3.4			
July 29, 1993		3.8			
August 02, 1993	17	2.6			
April 17, 2000					4600 MPN/100mL
October 11, 2001		1.67			
October 17, 2001		5.57			
November 22, 2001		5.3			

[a] Sample hardness was 61.5 mg/L $CaCO_3$, therefore, the maximum **Total Copper** concentration for the Protection of Aquatic Life is 7.8 μg/L

[b] Sample hardness was 53.6 mg/L $CaCO_3$, therefore, the maximum **Total Zinc** concentration for the Protection of Aquatic Life is 5.7 μg/L

5.3 Site 3 - Marshall Creek at Indian Road

Water samples were collected from Marshall Creek at Indian Road site 8 times during the winter and spring of 2001. *Water Quality Criteria* were not exceeded, but only 1 of the 8 fecal coliform sample results was reported in units of MPN/100mL. It is noteworthy that 3 of the remaining fecal coliform samples (reported in units of CFU/100mL) exceeded 200.

Sample results are summarized in Appendix E.

5.4 Site 4 - Sumas River at Atkinson Road Bridge

Water samples were collected from Sumas River at Atkinson Road Bridge site 45 times over a 10 year period. Samples were collected once each season (i.e. spring, summer, fall, winter) between 1972 and 1978, summer 1992, summer 1993, winter and spring 2000, and fall 2001. Sample analysis was not the same each year. Sample results are summarized in Appendix F with water quality criterion exceedances summarized in Table 5.0 below.

Water Quality Criteria for *Freshwater Aquatic Life* were exceeded for temperature (7 of 39 samples), total copper (1 of 23 samples) and nitrite (1 of 30 samples).

Calculation of the geometric mean for comparison with the fecal coliform *Recreational-Primary Contact Criterion* was precluded due to some sample results being reported in CFU/100mL and/or insufficient sampling frequency (i.e. a minimum of 5 samples in 30 days). It should be noted that the number of fecal coliform samples (n=11) in excess of 200 MPN/100mL (*Recreational-Primary Contact Criterion)* suggests an increased sampling effort may return results with geometric means in excess of 200 MPN/100mL.

TABLE 5.0 Summary of Water Quality Criterion Exceedances - Sumas River at Atkinson Road Bridge

Date	Parameter			
	Temperature (°C)	Total Copper (µg/L)	Nitrite (mg/L)	Fecal Coliforms
August 02, 1972	17.5			
July 24, 1973				500 MPN/100mL
November 06, 1973				790 MPN/100mL
February 05, 1974				540 MPN/100mL
May 02, 1974				940 MPN/100mL
July 05, 1974	20			490 MPN/100mL
November 06, 1974				490 MPN/100mL
February 13, 1975				1300 MPN/100mL
June 26, 1975				240 MPN/100mL
July 16, 1975				400 MPN/100mL
November 26, 1975		22[a]		2200 MPN/100mL
February 09, 1976				790 MPN/100mL

Table 5.0 cont'd….

Date	Parameter			
	Temperature (°C)	Total Copper (μg/L)	Nitrite (mg/L)	Fecal Coliforms
May 20, 1976				1300 MPN/100mL
November 25, 1976				>2400 MPN/100mL
May 26, 1977				540 MPN/100mL
November 30, 1977				>2400 MPN/100mL
April 04, 1978				540 MPN/100mL
June 22, 1978	21			
September 13, 1978				350 MPN/100mL
November 14, 1978				920 MPN/100mL
July 07, 1992			0.071	
July 18, 1993	19.3			
July 25, 1993	17.6			
July 29, 1993	16.3			
August 02, 1993	20.7			

[a] Sample hardness was 72.7 mg/L $CaCO_3$, therefore, the maximum **Total Copper** concentration for the Protection of Aquatic Life is 8.8 μg/L

5.5 Site 5 - Sumas Drainage Canal at No. 3 Road

Water samples were collected from the Sumas Drainage Canal Creek 10 times in spring 2000 and fall 2001. *Water Quality Criteria* were not exceeded, but only 1 of the 10 fecal coliform sample results was reported in units of MPN/100mL. It is noteworthy that 7 of the remaining fecal coliform samples (reported in units of CFU/100mL) exceeded 200.

Sample results are summarized in Appendix G.

6.0 DISCUSSION

6.1 Limitations of Study

The above results are simply a snap shot of water quality conditions at the time of sampling and results are not necessarily reflective of "mean" water quality conditions; accordingly, assessment of water quality trends and/or impacts is precluded. The following is limited to a discussion of potential impacts to designated water uses based on results summarized above.

6.2 General Water Chemistry

General water chemistry parameters such as water temperature and dissolved oxygen appear to be the two most important parameters with regard to acute impacts on aquatic species in the Sumas River watershed. Water temperatures were elevated, and occasionally exceeded *Water Quality Criteria*, during the summer months. Dissolved oxygen levels were reduced, and occasionally exceeded *Water Quality Objectives*, in the both the summer and fall months.

Problems related to water temperature and dissolved oxygen are not unexpected given flow conditions, riparian environments, and nutrient management challenges within the watershed. The Barrowtown Pump Station gates are closed during the summer months resulting in stagnant water conditions thus limiting opportunity for gas exchange with the atmosphere (i.e. aeration). Also, stagnant flow conditions facilitate heat exchange with the atmosphere thus contributing to elevated water temperatures. Oxygen solubility and water temperature are inversely proportional, thus increased water temperatures further contribute to reduce water quality conditions for aquatic species by reducing levels of dissolved oxygen.

In general, riparian environments within the watershed are poorly structured, discontinuous, and sometimes non-existent. As a result, watercourses in the watershed are afforded little protection from solar radiation and my experience high water temperatures. It should be recognized that establishment of a well-structured, functional riparian environment within the watershed is likely constrained for a number of reasons. First, flows throughout much of the watershed are conveyed within dykes, which must be kept relatively vegetation free for effective maintenance and inspection purposes. Second, the agricultural land base is typically maximized by utilizing land to the top-of-bank. Finally, a well-structured riparian environment may impact on commercial crop production by reducing the amount of light reaching crops.

During the fall months, low dissolved oxygen levels are likely a combination of increased oxygen demand associated with agricultural runoff and improper agricultural waste management practices (i.e. introduction of oxygen consuming wastes), as well as oxygen demand resulting from decomposing aquatic vegetation.

6.3 Bacteriology

Elevated levels of fecal coliforms occur throughout the year suggesting that management of agricultural waste in the watershed is a persistent problem and not just limited to the fall and winter months (when land application is precluded and storage capacity may be limited).

Fecal coliforms are not a concern with regard to impacts on aquatic species, but their presence typically indicates surface waters are receiving nutrient inputs (e.g. nitrogen, phosphorous). Nutrient enrichment can have both direct impacts (i.e. ammonia and/or nitrite-nitrate toxicity) or indirect impacts (e.g. eutrophication) on aquatic species.

From a human health perspective, fecal coliforms are a concern as the lower reaches of the Sumas River are utilized for recreational activities (e.g. canoeing, angling) and paddle boating has been observed on Saar Creek upstream of Lamson Road. As previously mentioned, calculation of the geometric mean for comparison with the fecal coliform *Recreational-Primary Contact Criterion* was precluded due to some sample results being reported in CFU/100mL and/or insufficient sampling frequency (i.e. a minimum of 5 samples in 30 days). However, the data does suggest fecal coliforms are at levels that pose a risk to human health.

6.4 Eutrophication

Eutrophication is the process of nutrient enrichment of a body of water usually resulting from anthropogenic activities (e.g. agricultural runoff, sewage discharges etc.). Based on fecal coliform data, it is reasonable to conclude the Sumas River (and tributaries) experiences significant nutrient inputs. Impacts associated with nutrient enrichment are both direct (i.e. ammonia toxicity) and indirect (e.g. reduced dissolved oxygen levels in the fall when aquatic plants undergo decomposition). Reduced oxygen levels in the fall months are the most likely impact as a result of eutrophication in the Sumas River watershed.

It should be noted that elevated levels of nutrients brings an increase in the potential for ammonia toxicity (ammonia may be a component of nutrient rich runoff). Ammonia toxicity increases as temperature and pH increase. In watercourses with dense aquatic plant growth, pH values increase during the day as plants remove CO_2 from the water column during photosynthesis. As a result, pH values tend being highest in the late afternoon which coincides with the time when water temperatures tend to be highest. The combination of increased pH and water temperature may increase the potential for ammonia to impact on aquatic life. Because watercourses in the study area may experience higher pH values and temperatures during the summer months, and nutrient sources are abundant within the watershed, the potential for ammonia toxicity should be recognized.

While agricultural waste can be a significant source of inorganic nutrients, especially nitrogen and phosphorous, it can also be a significant source of organic nutrients. While such nutrients are not utilized by photosynthetic plants, they can promote growth of heterotrophic aquatic organisms (e.g. aquatic bacteria and fungi) that utilize organic nutrients. Under appropriate conditions, fungal/bacterial growths can proliferate to the point where they form mats on stream bottoms and impact on benthic organisms and their habitats. Such growths have also been found on the gill structures of aquatic organisms, resulting in additional stresses in an environment that is already experiencing reduced water quality conditions. Fungal/bacterial mats are common in water bodies at the point of ongoing agricultural runoff discharges or sewage runoff (9).

6.5 Metals

Metals data were collected at 3 of the 5 sample sites (i.e. Sumas River at Whatcom Road, Sumas River at Atkinson Road and Saar Creek at Lamson Road). Hardness data were absent in the 1990's samples thus precluding calculation of guideline concentrations for copper, lead, manganese, nickel and zinc.

A total of 5 *Water Quality Criteria* exceedances were recorded with 4 of the 5 exceedances occurring on the same day at 3 different sites. On November 26, 1975, *Water Quality Criteria* were exceeded for *Total*

Copper at 3 sites and *Total Nickel* at 1 site. Fecal coliforms were also elevated (i.e. 460, 2200 and 3500 MPN/100mL) at the 3 sites on the same day. Environment Canada climate data for the Abbotsford Airport on November 25 and 26, 1975 indicates the presence of a low pressure system with hourly weather observations described as either rain/fog/cloud/drizzle between November 25th (1400 hrs) and November 26th (1600hrs). Late afternoon on November 26th a high pressure system moved in and weather conditions were described as mainly clear (23). Samples of the above-noted metals and fecal coliform exceedances were collected at 1050, 1105 and 1320 hrs and climate data suggest exceedances may be associated with a precipitation event.

6.6 Emerging Contaminant Concerns

Recent decades have resulted in the recognition of potential impacts to human health and ecological systems resulting from the production, use, and disposal of a wide variety of chemicals used in industry, agriculture, medicine, household products, and personal care products. Research has demonstrated that such “micro-contaminant” compounds are widespread and persistent, but little is known on the fate of these compounds in the environment, largely due to constraints associated with detecting these compounds at concentrations in which they are biologically active. Potential impacts to human health and ecological systems associated with these compounds include impairment of physiological function and reproductive processes, increased cancer risk, contribution to antibiotic resistant bacteria, and chemical toxicity (24).

Veterinary pharmaceuticals (e.g. antibiotics, hormones) contained in animal waste may be released into the environment via surface runoff over animal waste, direct application of animal waste to land, or leaking/overflowing manure storage facilities. There is sufficient evidence to demonstrate these compounds have an impact on the receiving environment and the potential for impacts to terrestrial and aquatic species within the Sumas River watershed should be recognized.

7.0 SUMMARY

Non-point source (NPS) water pollution is the release of pollutants to surface/ground water from activities that occur over a large area, and results from water flowing over (and through) the land surface and transporting contaminants (e.g. pathogens, oxygen depleting substances, suspended materials, toxic chemicals) and debris into water bodies. NPS pollution is recognized as a major cause of water pollution in British Columbia and it represents a significant threat to water resources. Saar Creek, a tributary to the Sumas River, is located in an area of the Fraser Valley that has been intensively utilized for agricultural activities since the 1950’s. In November 2001, the Ministry of Water, Land and Air Protection (Lower Mainland Region) established a water quality trend monitoring station at Saar Creek. The Saar Creek trend monitoring station automatically measures a limited number of water quality parameters every 15 minutes and the data will be used in the assessment of water quality in a system influenced by agricultural NPS pollution.

Approximately 57 square kilometres of the Sumas Prairie is utilized for agricultural activities such as dairy, hog, poultry and produce. The agricultural land base of the Sumas Prairie has not increased significantly since expansion of agriculture following the draining of Sumas Lake; however, the intensity of operations has increased dramatically with a trend toward densification of livestock operations. The intensification of livestock operations has resulted in more animal waste being generated (and disposed of) on a land base that may not be capable of assimilating the waste. Agricultural census data and waste management survey data suggests that over 50 percent of the agricultural land base in the Sumas watershed receives excess nutrients that potentially contribute to water pollution.

General water chemistry parameters such as water temperature and dissolved oxygen appear to be the two most important parameters with regard to impacts on aquatic species in the Sumas River Watershed. Water temperatures were elevated, and occasionally exceeded *Water Quality Guidelines*, during the summer months. Dissolved oxygen levels were reduced, and occasionally exceeded *Water Quality Objectives*, in the both the summer and fall months. During the fall months, low dissolved oxygen levels are likely a combination of increased oxygen demand associated with improper agricultural waste management practices (i.e. introduction of oxygen consuming wastes) as well as oxygen demand resulting from decomposing aquatic vegetation.

Elevated levels of fecal coliforms occur throughout the year suggesting that management of agricultural waste in the watershed is a persistent problem and not just limited to the fall and winter months (when land application is precluded and storage capacity may be limited). Fecal coliforms are not a concern with regard to impacts on aquatic species, but their presence typically indicates surface waters are receiving nutrient inputs (e.g. nitrogen, phosphorous). Nutrient enrichment can have either direct impacts (i.e ammonia and/or nitrite-nitrate toxicity) or indirect impacts (e.g. eutrophication) on aquatic species. Reduced oxygen levels in the fall months are the most likely impact as a result of nutrient enrichement in the Sumas River watershed.

Veterinary pharmaceuticals (e.g. antibiotics, hormones) may be released into the environment via surface runoff, direct application of animal waste to land, or leaking/overflowing manure storage facilities. Pesticides may be released into the aquatic environment directly (i.e. drift) or via surface runoff. There is sufficient evidence to demonstrate these compounds veterinary pharmaceuticals and pesticides have an impact on aquatic environments and, as such, the potential impacts to terrestrial and aquatic species within the Sumas River watershed should be recognized.

It is important to note that water quality sampling results summarized in this report are simply a snap shot of water quality conditions at the time of sampling and results are not necessarily reflective of "mean" water quality conditions; accordingly, assessment of water quality trends and/or impacts is precluded. However, data indicates water quality conditions have potential to impact on designated water uses.

As previously noted, several water quality studies have been undertaken in the Sumas River watershed and results indicate an association between intensive agricultural activities and degraded surface water quality. In 2001, the Lower Mainland Regional Office of WLAP carried out a compliance and enforcement audit to assess compliance with the Agricultural Waste Control Regulation and concluded that additional efforts were needed to minimize agricultural impacts on the environment. The study also concluded the agricultural community was aware of what was needed to comply with the AWCR, but compliance was, in effect, 'voluntary' for a number of reasons such as cost. In 2004, the national Environmental Farm Planning (EFP) Program commenced in British Columbia. The EFP program, developed by Agriculture and Agri-Food Canada with in-kind support from the Province of British Columbia, is being delivered by the British Columbia Agriculture Council with co-operation from Fisheries and Oceans Canada, Environment Canada, BC Ministry of Agriculture, Food and Fisheries, and WLAP. The Environmental Farm Plan process is voluntary and encourages producers to adopt best management practices that enhance agriculture while protecting the environment. EFP participants identify environmental strengths and risk, and prioritize actions to reduce identified risks. Producers that develop an approved EFP are then eligible to apply for cost-shared incentives though the National Farm Stewardship Program to implement their plan.

8.0 RECOMMENDATIONS

1. Continue long-term automated water quality monitoring in the Sumas River watershed to better characterize water quality conditions and facilitate stakeholder co-operation

Advances in automated water quality monitoring technologies allow for basic water quality parameters to be collected at a high frequency (e.g. every 15 minutes) thus facilitating assessment of event-driven impacts on water quality. Dissolved oxygen and temperature appear to be the most important parameters with regard to impacts on Sumas River aquatic habitats, and these parameters can be measured with automated water quality monitors. More importantly, long-term high frequency automated water quality monitoring eliminates sampling bias such as sampling only during rain events, sampling on weekdays only, sampling during the daytime only, and sampling associated with compliance investigations. Collecting an unbiased data set is important in the process of engaging watershed stakeholders.

2. Restore riparian corridors where (if) possible.

A well-structured riparian corridor can reduce water temperatures, decrease instream plant growth (by decreasing light penetration), and filter runoff.

In general, riparian environments within the watershed are poorly structured, discontinuous, and sometimes non-existent. As a result, many of the watercourses are afforded little protection from solar radiation and may experience high water temperatures. It should be recognized that establishment of a well-structured, functional riparian environment within the watershed is likely constrained for a number of reasons. First, flows throughout much of the watershed are conveyed within dykes which must be kept relatively vegetation free for maintenance and inspection purposes. Second, lands are typically utilized to maximize production of crops and/or animals with the land base often exploited to the top-of-bank. Finally, a well-structured riparian environment may also impact on commercial crop production by reducing the amount of light reaching crops. In areas of the watershed where riparian planting is possible, the benefits of a healthy riparian environment should be emphasized and rehabilitation encouraged. In addition to providing watercourse shading, rows of trees and shrubs can reduce winds speeds and thus reduce soil erosion. (Information on erosion control is available at http://www.agf.gov.bc.ca/resmgmt/publist/600series/642200-1.pdf)

3. Conduct comprehensive sampling to better understand association between land use, water quality and fisheries utilization.

A single study designed to educate those most influential at effecting change in the watershed (residents, farmers, industry etc.) is needed and a first step may be an attempt at correlating available aquatic habitat, fish distribution and water quality data. While many studies on land use, water quality, and fish distribution exist for the lower Sumas River watershed, studies have generally been in isolation (or paired) with linkages implied rather than demonstrated. For example, low dissolved oxygen levels have been detected, but distribution of fish associated with low levels has not been demonstrated. A study targeting water temperature, dissolved oxygen, fish distribution, land use, water withdrawal, precipitation, and pump station operation, during summer and fall months could identify cause and effect relationships between land use, water quality, and impacts to the receiving environment. Such a study, however, must be designed, conducted, and written to the target audience that is most likely to create positive change within the watershed.

4. Investigate salmonid access to higher gradient reaches of watershed (i.e. Sumas and Vedder Mountains) where higher quality fisheries habitats exist.

Regionally, salmonids are a valuable fish species from a commercial, recreational, and cultural perspective and they are among the most susceptible of the regional fishes to higher water temperatures and reduced dissolved oxygen levels. Making habitats accessible where such limitations are reduced would be valuable for stakeholders. Where access is limited to higher quality habitats, enhanced access to increase the salmonid productivity/productive capacity of the Sumas River watershed should be investigated. Such investigations should include measures to improve water quality in the lower reaches of the watershed where historic high value fish rearing values have previously been found.

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DISCUSSION OF KEY WATER QUALITY PARAMETERS

Key water quality parameters discussed in this report include dissolved oxygen, fecal coliforms, metals, nitrogen (ammonia, nitrite, nitrate), pH, phosphorous, suspended sediments, and temperature. A discussion of these parameters is provided below; references are listed at the end of the Appendix A.

Temperature

Water temperature is the net result of various energy transfer processes modified by characteristics such as water depth and water velocity. Water temperature is an important regulator of many chemical and physical processes in aquatic environments.

Temperature governs the rates of biological processes in poikilothermic[1] organisms (most aquatic plants and animals are poikilothermic). Temperatures outside the optimal range of aquatic species may affect physiological functions that may stress (or even kill) aquatic organisms, which can have negative impacts on life history functions or impact on aquatic community structure. For example, the distribution of salmonids within a watershed may be limited by high water temperatures and this may be of particular significance if inaccessible reaches sustain habitats critical to important life history functions (e.g. spawning).

Similar to pH, temperature can allow toxic elements to become more bioavailable for uptake by plants and animals. Temperature can influence sorption of organic materials to suspended and benthic sediments, solubility of metals, and the solubility of ammonia.

Dissolved Oxygen

Dissolved oxygen (DO) is a measure of the amount of oxygen in water. Water absorbs oxygen from the atmosphere in turbulent areas of water (e.g. riffles) and from aquatic plants which release oxygen to the water during photosynthesis ($6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + \mathbf{6O_2}$). DO concentrations fluctuate daily and seasonally based on variations in temperature (oxygen solubility and temperature are inversely proportional), photosynthetic activity (adds oxygen), and inputs of oxygen-consuming materials (removes oxygen).

DO is essential to the respiratory metabolism of most aquatic organisms and each has a minimum required concentration of dissolved oxygen. The amount of DO required varies among organisms and is dependant on the species, age, size, metabolism, and activity. However, it is generally the earlier stages of development that are most susceptible to reduced levels of DO. Some organisms will try to avoid low dissolved oxygen conditions while others can adapt to such conditions. Reduced DO levels can result in physiological stresses that may be lethal (i.e. death by asphyxiation) or may impact on one or more life history functions. For example, reduced DO levels may preclude utilization of otherwise suitable habitats, which is of particular importance if inaccessible reaches sustain habitats important for critical life history functions. Upstream migration of adult salmon has been observed to stop at DO concentrations below 5 mg/L; therefore, low dissolved oxygen levels could prevent salmon from reaching upstream spawning habitats which, in turn, could negatively impact on stock survival.

When oxygen-consuming materials (e.g. septic field effluent, sewage, manure, fertilizers) enter watercourses, a large amount of oxygen is utilized during their decomposition and DO levels decrease. Therefore, low levels of dissolved oxygen are often an indicator of elevated levels of pollutants in the aquatic environment.

[1] poikilothermic - organisms whose body temperature is determined by the surrounding environment

pH

pH is a measure of the hydrogen ion (H^+) activity of a solution. It is measured on a scale between 0 and 14 and indicates the alkalinity or acidity of a solution. A solution with a pH value of 7 is considered neutral with solutions becoming more acidic as pH values decrease below 7, and more alkaline as pH increase above 7. Rainwater is slightly acidic (pH 5.6) due to atmospheric carbon dioxide (CO_2) reacting with water (H_2O) to produce hydrogen ions (which decreases the pH of rainwater). In British Columbia, the amount of precipitation and weathering of geology and soils are the primary influences on surface water pH. Streams in coastal areas of British Columbia typically have pH values ranging between 5.5 and 5.6 due to geology and the greater amount of precipitation that they receive.

Many biological processes cannot function in acidic or alkaline waters and aquatic organisms have optimal pH ranges which they can tolerate. pH values outside the optimal range, or rapid fluctuations in pH, affect physiological functions which may stress, or even kill, aquatic organisms. High or low pH levels can also allow toxic elements to become more bioavailable for uptake (e.g. ingestion, absorption) by plants and animals. For example, high pH values tend to increase the solubility of ammonia thus promoting ammonia toxicity, while high or low pH values can convert insoluble metals to soluble forms thus increasing the concentration of toxic metals in the water column.

Watercourses can experience large diurnal fluctuations in pH, particularly when they sustain a large standing crop of aquatic plants with limited exchange of atmospheric gases (i.e. aeration). During the day, pH values tend to be higher when aquatic plants undergo photosynthesis and remove CO_2 from the water column. At night, pH values tend to be lower when aquatic plants undergo respiration and add CO_2 to the water column. As diurnal fluctuations are largely attributed to the photosynthetic activity, such fluctuations are most notable during the spring and summer months and are more prone to occur in exposed, low gradient, stagnant watercourses (e.g. sloughs, ditches) due to limited atmospheric exchange.

Fecal Coliforms

Fecal coliforms are microscopic organisms which are common in the intestines of humans and other warm-blooded animals. Fecal coliforms are an indicator for the potential presence of harmful disease organisms such as *Escherichia coli* (*E. Coli*) which are present in human and animal digestive systems. *E. Coli* are typically the dominant component of fecal coliforms, but another component of fecal coliforms, *Klebsiella* spp., can be significant near sources.

Sources of fecal contamination include human, pet, farm animal and wildlife wastes. Runoff from manure piles or fields fertilized with manure may contaminate surrounding surface water bodies or groundwater and bacterial conditions in surface waters are often strongly correlated with rainfall events.

Recreation in fecal contaminated waters may cause gastrointestinal illnesses from ingestion, and skin, ear or eye infections from immersion. Using fecal contaminated water for livestock watering and irrigation may also pose a threat to livestock and crop consumers. Elevated fecal bacteria can also increase water turbidity and increase the oxygen demand in the water.

Fecal coliforms are not directly toxic to fish, but they typically indicate presence of pollutants that exhibit a high-oxygen demand and can contribute to eutrophication of aquatic environments

Metals

Elevated concentrations of certain metals can be toxic to a variety of aquatic organisms. The types of metals present will depend on local geology and anthropogenic activities, but examples of metals found naturally in aquatic environments include arsenic, boron, chromium, copper, iron, lead, magnesium, mercury, nickel, potassium, sodium and zinc.

In the aquatic environment, metals can occur in two phases, particulate or dissolved. In general, metal solubilities are lowest around neutral pH resulting in particulate phase metals. Solubilities increase under acidic conditions resulting in dissolved phase metals. While particulate metals likely have toxic impacts on aquatic organisms it is the dissolved fraction that is most bioavailable for uptake and therefore the most toxic. The primary mechanism of metals toxicity results from adsorption[2] at the gill surface.

Metals occur naturally and are often present in significant concentrations on soils, but are bound to soil particles in forms that are not readily bioavailable. The transport of soils to watercourses (via erosion) can be a significant source of metals if instream conditions increase the bioavailability of metals (e.g. low pH). Acid mine drainage is of particular concern because it's low pH can increase the bioavailability of metals, and mines occur in areas where geology and soils are rich with minerals and metals. Metals can also be added to waterbodies from point source discharges (e.g. industrial effluents) or non-point sources (e.g. urban runoff). Metals do not degrade in the aquatic environment and they are either transferred or stored in the aquatic environment and become bio-available under the appropriate environmental conditions.

It should be noted that copper is sometime used as a feed additive to increase weight, that elevated levels of copper have been found in manure runoff.

Nitrogen

Nitrogen is present in various forms in the water column. Nitrogen gas (N_2) from the atmosphere dissolves in the water column and undergoes a series of complex reactions (e.g. ammonification, nitrification, denitrification) where it is eventually converted to ammonia (NH_3, NH_4^+), nitrite ion (NO_2^-), and nitrate ion (NO_3^-). These are the most important forms of nitrogen from a water quality perspective as they are readily bioavailable.

Ammonia may be present in aquatic environments both naturally, due to the decomposition of organic matter, or from human activities associated with animal waste disposal, use of fertilizers, urban runoff, and atmospheric deposition. Ammonia is the most reduced inorganic form of nitrogen in water and is found in two forms - ionized ammonia (NH_4^+) and un-ionized ammonia (NH_3). The form of ammonia present is determined by temperature and pH, and it is the un-ionized form of ammonia that is most toxic to fish. As pH or temperature increases, the proportion of un-ionized ammonia increases thus promoting ammonia toxicity.

Nitrate (NO_3^-) is the most oxidized and stable form of nitrogen in a water body and is the primary form of nitrogen used by plants. **Nitrite** (NO_2^-) is rapidly oxidized to nitrate and is relatively transient and thus normally only present in minute quantities in surface waters. The main sources of nitrate and nitrite in surface waters are fertilizers, waste from humans, farm animals, domestic pets, wildlife, urban development, and industrial effluents.

Most of the negative effects associated with increased nitrogen concentrations are indirect and result from increased nitrogen concentrations stimulating growth of aquatic plants and algae. Plant growth is necessary to support the aquatic food chain, but excessive growth can impact negatively on aquatic environments. Plant respiration during non-photosynthetic periods and the decay of dead plant material can significantly lower levels of dissolved oxygen and negatively impact on aquatic organisms. It should be noted that increased growth is only

[2] adsorption - the binding of molecules to a surface

possible if the aquatic plants are not limited by light or other nutrients such as phosphorous. Generally, increased plant growth is limited by phosphorous in freshwater systems.

Reproductive success of amphibians has been found to be impaired at ammonia and nitrate concentrations below guidelines designated to protect freshwater aquatic life.

Phosphorous

Phosphorus is an essential plant nutrient and is often the most limiting nutrient to plant growth in freshwater environments. It is readily taken up by aquatic plants and microorganisms and the rapid biological uptake explains why phosphorous concentrations in natural waters are generally very low. Phosphorous is generally immobile and stays bound to terrestrial soils; however, heavy precipitation patterns of the Fraser Valley tend to mobilize phosphorous and transport it to aquatic habitats via surface runoff.

Similar to nitrogen, most of the negative effects associated with increased phosphorous concentrations are indirect and result from increased phosphorous concentrations stimulating growth of aquatic plants and algae. Because phosphorous rarely occurs in significant concentrations in surface waters, even small increases in phosphorus can cause extreme proliferations of plant and algal growth. Inputs of phosphorus are the prime contributing factors to eutrophication in most freshwater systems. In aquatic ecosystems, phosphorous is usually the limiting nutrient. A general rule of thumb is an optimal nitrogen to phosophorus (N:P) ratio ranging from 5:1 to 15:1. A lower ratio suggests that nitrogen is limiting while a higher ratio suggests phosphorous is limiting.

Sources of phosphorous into the aquatic environment include the drainage of fertilized land, urban developments, rock leaching and decomposition of organic matter.

Orthophosphate is a measure of the inorganic oxidized form of soluble phosphorus. It is the form that is most readily available for uptake during photosynthesis, and high concentrations are generally associated with algal blooms.

Suspended Sediments

Sediment generally refers to soil particles that enter the water column via surface runoff or erosion of stream banks. Sediments and sediment transport occurs naturally in rivers and streams with sediments ranging from fine particles (less than 2 millimetres in diameter) to boulders (greater than 256 millimetres in diameter).

High concentrations of suspended sediment in the water column may have many detrimental impacts to aquatic plants and animals. Detrimental effects may occur when the concentration of sediment increases or when the frequency and/or duration of sediment loading increases. Suspended sediments can damage fish gills, destroy spawning grounds, smother incubating eggs, and reduce the ability of fish to feed. Further, high concentrations of suspended sediments restrict the depth to which light can penetrate the water column which may impact on the ability of aquatic plants to carry out photosynthesis. Plant growth is necessary to support the aquatic food chain and most plants cannot grow without photosynthesis. Further, concentrations of suspended sediments are aesthetically displeasing and can result in elevated water temperature due to the heat storage capacity of solids.

Land use is the greatest factor influencing the amount of suspended solids in surface waters. An increase in suspended solids can come from activities such as agriculture, land clearing, forest harvesting and mining. An increase in sediment in watercourses often occurs after rain events as runoff picks up particles and transports them into streams. Changes in stream hydrology that increase water velocities and cause erosion can result in greater sediment inputs into watercourses.

There are direct and indirect methods of quantifying the amount of sediment in the water column. A direct method is to measure non-filterable residue (NFR). NFR is a measure of the amount of particle matter suspended within the water column and is alternatively referred to as total suspended solids (TSS). An indirect method is to measure turbidity. Turbidity is also a measure of particle matter suspended within the water column, but it is quantified by measuring the amount of light backscatter in the water column. NFR is a physical measurement while turbidity is based on the optical properties; accordingly, there is no direct relationship between the two measures. Turbidity is one of a few parameters that have criteria recognizing the importance of the duration of exposure.

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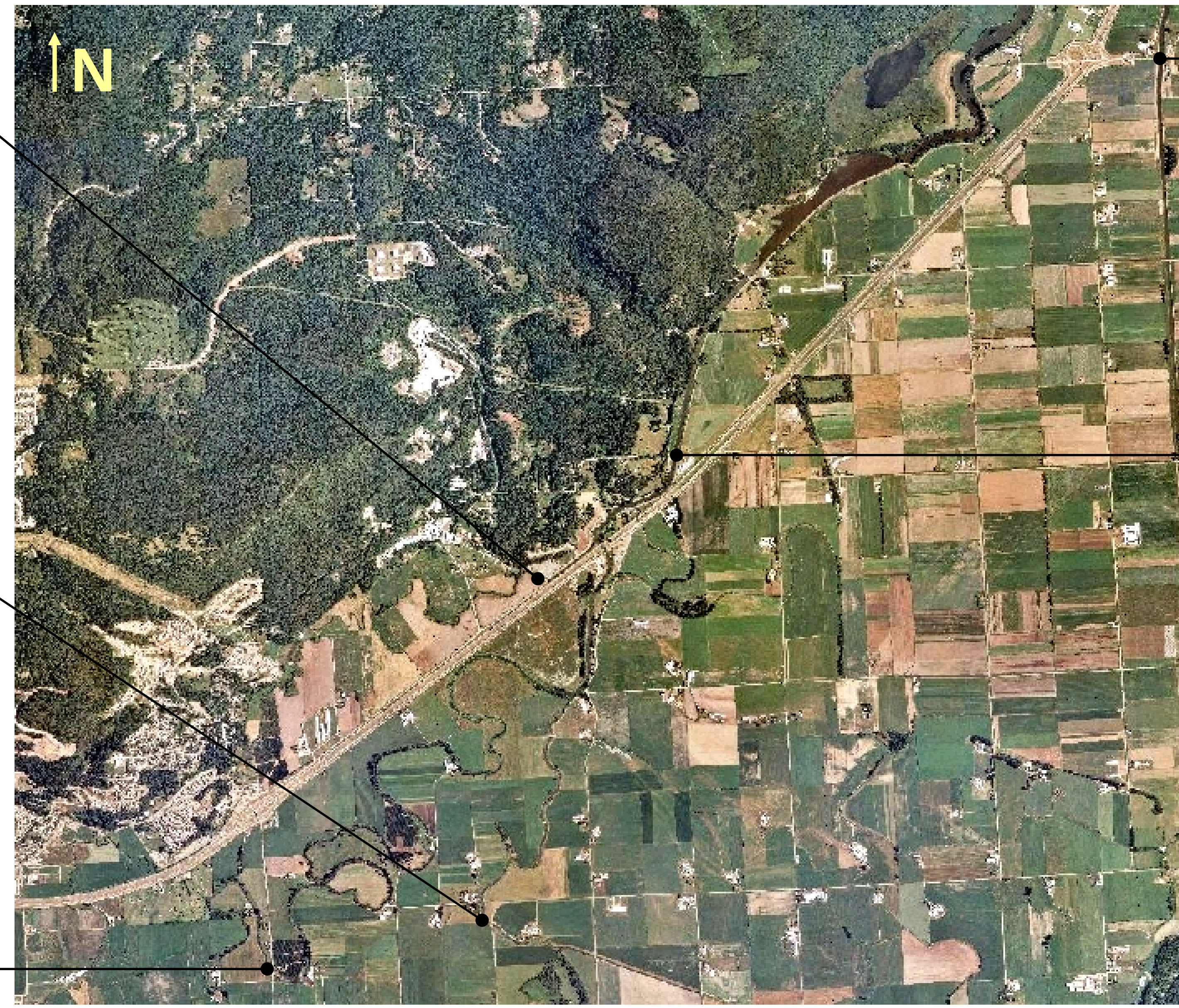
Sample Site 3
Marshall Creek at Indian Road

Sample Site 2
Saar Creek at Lamson Road Bridge

Sample Site 1
Sumas River at Whatcom Road Bridge



Sample Site 5
Sumas Drainage Canal at No. 3 Road

Sample Site 4
Sumas River at Atkinson Road Bridge

General Parameters

Year	Sample Collection Date (YY MM DD)	Sample Collection Time (HH:MM)	pH Field	pH Lab	Water Temp (°C)	Dissolved Oxygen (mg/L)	Specific Conductance (µS/cm)	Specific Conductance (µmho/cm)	Residues (mg/L) Filterable	Residues (mg/L) Total	Residues (mg/L) Non filterable	Turbidity Lab (JTU)	Turbidity Field (NTU)	Turbidity Lab (NTU)	Alkalinity (as $CaCO_3$) (mg/L)	Chloride (mg/L)	Hardness (as $CaCO_3$) (mg/L)	BOD (mg/L)	Color Tr. (Rel. Unit)	Silica (mg/L)	Sulphate (mg/L)
1972	72 04 24	10:30		7.5	5.5	9.9		187	134	136		8.7			78.5	9.3	82		40	15.3	6.2
	72 08 02	10:10		7.9	17	9		253	146	164		7.7			93	15	105		15	20	6.8
	72 11 01	9:50		7.5	9	9.2		245	134	160		5.5			93.7	13	103		15	21	11.6
1973	73 02 05	10:30		7.5	3.5	10.3		235	148			9.1			81.5	12.2	95.2				
	73 05 07	10:15		7.5	11	9.6		260	160			9			91.1	13.1	97.2				
	73 09 24	14:30		7.75	15.5	10.3		195	160	168		3.6			96	13.2	107				
	73 11 06	13:00		8.1	4	11.7		280	164	166					105	13.6	107				
1974	74 02 05	10:55		7.8	5.5	11.6		150		148	35				52.5	6.3	62.4				
	74 05 02	12:10		7.5	10.5	10		210	148	150					85.5	10.2	98.2				
	74 09 05	9:25		7.6	15	8.9		245	160		4				90.6	14.8	98				
	74 11 06	12:05		7.2	9	10.5		240	162		5				90.4	12.7	100	<10			
1975	75 02 13	10:35		7.6	1	13.2		230	152		10				82.3	12.8	93.7				
	75 06 26	9:30		7.7	13	12.3		247	174		6				92.9	15	106				
	75 09 16	11:00		7.6	14.7	6.7		262	176		5				100	15.1	110				
	75 11 26	10:50		7.4	6.5	8.5		201			43				73.9	10.4	85.8				
1976	76 02 09			7.4	6	8		239	156		25				87.2	13.6	99.6				
	76 05 20	13:10		7.7	16	10.6		236	154		13				90	13.1	102				
	76 10 14	11:40		8	11.5	7.9		258	164		8				102	14.5	113				
	76 11 25	11:25		7.8	8.4	8.4		268	182		29				94.6	14.9	103				
1977	77 02 10	11:15		7.9	10	9.7		272	172		9				104	15.5	112				
	77 05 26	9:50		8	12.5	9.3		255	156		8				99.1	13.8	107				
	77 09 26	11:30		8.1	14.5	8.8		266	166		5				106	13.6	113				
	77 11 30	9:15		7.6	8	8.8		223	156		27				75.3	11.5	93.9				
2000	00 02 17		6.79	7.71	5.49	11.6	325								114						
	00 02 22		7.45	7.87	6.96	10.8	318							15	112						
	00 02 29			7.74		10.4	277							27	101						
	00 03 07		7.52	7.8	6.61	12	278							30	104						
	00 03 14		7.45	7.78	8.25	11.6	296							29	109						
	00 03 21		7.36	7.81	8.14	10	290							14	107						
	00 03 28		7.12	7.53	8.62	9.2	296						13.5	17	109						
	00 04 17			7.92	11	9.1	266							42	108						
2001	01 10 17		7.86		10.92	9.25	170														
	01 11 07				8.13	10.26	155														

Metals

Year	Sample Collection Date (YY MM DD)	Sample Collection Time (HH:MM)	Diss. Boron (mg/L)	Diss. Calcium (mg/L)	Total Chromium (mg/L)	Total Copper (mg/L)	Iron (mg/L) Diss.	Iron (mg/L) Total	Total Lead (mg/L)	Magnesium (mg/L) Diss.	Magnesium (mg/L) Total	Total Manganese (mg/L)	Total Nickel (mg/L)	Zinc (mg/L) Diss.	Zinc (mg/L) Total	Dissolved Potassium (mg/L)	Dissolved Sodium (mg/L)	Total Arsenic (mg/L)
1972	72 04 24	11:00	<0.2		<0.005	0.005		0.38	<0.003		11.7	0.08	0.01		<0.005	1.8	<0.005	
	72 08 02	9:40	<0.2		<0.005	0.003		0.34	0.005		13	0.07	<0.01		<0.005	1.4	<0.005	
	72 11 01	10:15	<0.1		<0.005	<0.001		0.86	0.003	13.6	13.6	0.06	<0.01		<0.005	1.8	<0.005	
1973	73 02 05	11:00		13.4				0.6		15								
	73 05 07	10:40		16.5				0.42	0.002	13.6								
	73 09 24	14:05		18.5		0.01		0.25	0.003	14.7				0.13				
	73 11 06	13:30		17.5		0.005		0.17		15.3				0.08				
1974	74 02 05	11:45		9	<0.005	0.003		0.3	<0.001	9.7			0.02					
	74 05 02	12:30		14.6		<0.001		1.7	0.001	15		0.1			0.005			
	74 09 05	12:00		19.8	<0.005	0.001		1	<0.001	11.8		0.07	<0.01		<0.005			
	74 11 06	12:20		19.6	<0.005	<0.001		0.9	<0.001	12.5		0.04	<0.01		<0.005			
1975	75 02 13	10:55		14.3	0.006	0.001		1.3	<0.001	14.1			0.03		0.008			
	75 06 26	9:45		20	<0.005	< 0.001		1	<0.001	13.5			<0.01		<0.005			
	75 09 16	11:30		19.8		0.002		1.1	0.011	14.7		0.07	<0.01		0.009			
	75 11 26	11:05		11.3		0.021		2.5	<0.001	14		0.06	0.07					
1976	76 02 09	10:45		15.5	0.008	0.001		2.4	<0.001	14.8			0.02		<0.005			
	76 05 20	13:20		17	<0.005	<0.001		1.7	0.003	14.4			0.02		<0.005			
	76 10 14	12:05		19.2	<0.005	<0.001		1	<0.001	15.9		0.12	<0.01		<0.005			
	76 11 25	11:55		15.7	<0.005	0.003		2.3	0.003	15.5			0.03		0.007			
1977	77 02 10	11:30		16.7	<0.005	<0.001		1.8	<0.001	17.1		0.12	0.01		<0.005			
	77 05 26	9:55		15.8	<0.005	0.001		0.9	0.001	16.4		0.08	0.01		0.006			
	77 09 26	11:45		18.6	<0.005			0.8	<0.001	16.2		0.06	0.01		<0.005			
	77 11 30	9:30		11.9	0.007	0.003		1.6	<0.001	15.6		0.06	0.04		0.011			

Nutrients and Bacteriology

Year	Sample Collection		Total Ammonia (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Nitrogen (mg/L)			Phosphorous (mg/L)		Coliform		
	Date (YY MM DD)	Time (HH:MM)				Organic	Kjeldahl	Total	Ortho	Total	Fecal (MPN)	Total (MPN)	Fecal (CFU/100mL)
1972	72 04 24	11:00		0.005	0.91		0.63	1.55		0.119		3500	
	72 08 02	9:40		0.008	1.03		0.27	1.31		0.06		>2400	
	72 11 01	10:15		0.014	1.26		0.42	1.69		0.062		>2400	
1973	73 02 05	11:00	0.02			0.39							
	73 05 07	10:40	0.07			0.34							
	73 09 24	14:05	0.07	0.024	1.01	0.32							
	73 11 06	13:30	0.01	0.009	1.06	0.11			0.03	0.087			
1974	74 02 05	11:45	0.02	0.012	1.26		0.55			0.122	240	540	
	74 05 02	12:30	0.057	0.008	0.94	0.2			0.045	0.096	1300	2400	
	74 09 05	12:00	0.116	0.047	1.05		0.4		0.038	0.095	56	540	
	74 11 06	12:20	0.034	<0.005	1.17		0.25		0.04	0.087	790	5400	
1975	75 02 13	10:55	0.115	0.007	1.35		0.34		0.027	0.078	1100	3500	
	75 06 26	9:45	0.09	0.035	1.21		0.3		0.028	0.095			
	75 09 16	11:30	0.06	0.029	0.94		0.24	1.209	0.024	0.085	2300	2300	
	75 11 26	11:05	0.138	0.018	1.43		0.79	2.238	0.068	0.165	3500	>2400	
1976	76 02 09	10:45	0.102	0.009	1.61		0.43		0.033	0.127			
	76 05 20	13:20	0.052	0.011	1.13	0.034	0.39		0.036	0.093			
	76 10 14	12:05	0.014	0.035	1.1	0.036	0.37		0.015	0.098	490	3500	
	76 11 25	11:55	0.328	0.043	1.62	1.67	2		0.143	0.305		>2400	
1977	77 02 10	11:30	0.144	0.017	1.51	0.32	0.46		0.032	0.099			
	77 05 26	9:55	0.034	0.011	0.89	0.25	0.28		0.024	0.077		920	
	77 09 26	11:45	0.026	0.028	0.95	0.26	0.29		0.04	0.092		1600	
	77 11 30	9:30	0.148	0.039	2.46	0.71	0.86		0.097	0.171		>2400	
2000	00 02 17		0.177	0.015									88
	00 02 22		0.112	0.015									190
	00 02 29		0.104	0.022									2000
	00 03 07		0.069	0.024									72
	00 03 14		0.157	0.023									740
	00 03 21		0.081	0.017									160
	00 03 28		0.057	0.017									5100
	00 04 17		0.032								700		
2001	01 10 17		0.087	0.055									16
	01 11 07		0.055	0.035									93

General Parameters

Year	Sample Collection		pH		Water Temp (°C)	Dissolved Oxygen (mg/L)	Specific Conductance		Residues (mg/L)			Turbidity			Alkalinity (as $CaCO_3$) (mg/L)	Chloride (mg/L)	Hardness (as $CaCO_3$) (mg/L)	BOD (mg/L)	Color Tr. (Rel. Unit)	Silica (mg/L)	Sulphate (mg/L)
	Date (YY MM DD)	Time (HH:MM)	Field	Lab			(µS/cm)	(µmho/cm)	Filterable	Total	Non filterable	Lab (JTU)	Field (NTU)	Lab (NTU)							
1972	72 04 24	11:00		7	8	8.1		143	110	150		22			61.5	4.8	61		45	20.6	7.8
	72 08 02	9:40		7.3	16	3.3		220	150	178		2.7			96	8	98		60	36	6.8
	72 11 01	10:15		7.2	6	7.4		198	140	174		19			80.7	8.2	78		50	27.5	8
1973	73 02 05	11:00		7.4	3	9.3		180	120			13			64	6.2	67.3				
	73 05 07	10:40		7.3	10.5	6.6		195	120			21			72.6	6.6	74.8				
	73 09 24	14:05		7.1	17	7.55		295	166	178					101	12.6	94.8				
	73 11 06	13:30							118	132					71.6	6.4	66.1				
1974	74 02 05	11:45		7.5	5	10.9		120		122	41				38	4.5	45.7				
	74 05 02	12:30		7.1	10.5	7.45		175	132	172					72.9	6.4	78.9				
	74 09 05	12:00		7.05	19	6.25		250	180		13				113	10.1	109				
	74 11 06	12:20		7.2	10	6		205	150		13				85.5	10	84.3	<10			
1975	75 02 13	10:55		7.1	0.9	12.5		109	80		25				38.3	4.5	42.7				
	75 06 26	9:45		7.5	12.7	7		197	140		21				84.3	9	84.2	<10			
	75 09 16	11:30		7.1	15	4		242	178		11				103	10.8	99.2				
	75 11 26	11:05		7		8.9		151		134	16				52.2	6.5	61.5				
1976	76 02 09	10:45		6.9	6	8.1		182	136		12				72.5	7.7	76.9				
	76 05 20	13:20		7	16	6.8		190	138		34				77.3	8	82.2				
	76 10 14	12:05		8.1	12	6.5		213	154		15				91	9.7	93.2				
	76 11 25	11:55		7.5	7.9	9		145	106		44				47.8	6	53.6				
1977	77 02 10	11:30		7.5	10	8.7		193	134		30				76.4	8.2	80.5				
	77 05 26	9:55		7.5	12.5	6.4		165	120		14				69.5	5.9	68.2				
	77 09 26	11:45		7.7	14	5.2		167	116		7				68	7.8	65.9				
	77 11 30	9:30		7.1	7	6.9		164	128		12				49.3	7.7	62.7				
1992	92 07 07	12:00		7.3																	
	92 07 14	11:00		7.5																	
	92 07 23	11:00		7.5																	
	92 07 27	12:05		7.4																	
	92 08 04	11:00		7.5																	
1993	93 07 11	08:00			14.5	2.9															
	93 07 18	08:00			16.1	3.1															
	93 07 25	07:45			15.3	3.4															
	93 07 29	08:50			14	3.8															
	93 08 02	07:50			17	2.6															
2000	00 02 17		7	7.24	5.41	8.6	230								86.4						
	00 02 22	11:15	7.36	7.37	7.07	7.2	233							22	87.1						
	00 02 29	12:25		7.37	7	7.6	237							18	89.2						
	00 03 07	12:07	7.68	7.22	6.01	9.4	206							15	75.2						
	00 03 14	11:18	7.74	7.19	7.49	9.8	163							38	62.7						
	00 03 21	11:32	7.18	7.26	7.93	6.8	206							13	79.2						
	00 03 28	11:38	7.16	7.05	8.29	7	199						6.3	11	75.5						
	00 04 17	13:33		7.35	10.4	7.8	172							20	64.1						
2001	01 10 11				10.81	1.67	135														
	01 10 17		7.18		10.36	5.57	94														
	01 10 24		7.78		8.67	6.75	79														
	01 10 31		7.31		8.99	7.23	88														
	01 11 07		7.6		8.02	7.48	108														
	01 11 14		7.14		9.28	7.7	65														
	01 11 22		6.94		8.88	5.3	105														
	01 11 27		7.29		7.41	6.01	107														

Metals

Year	Sample Collection		Diss. Boron (mg/L)	Diss. Calcium (mg/L)	Total Chromium (mg/L)	Total Copper (mg/L)	Iron (mg/L)		Total Lead (mg/L)	Magnesium (mg/L)		Total Manganese (mg/L)	Total Nickel (mg/L)	Zinc (mg/L)		Dissolved Potassium (mg/L)	Dissolved Sodium (mg/L)	Total Arsenic (mg/L)
	Date (YY MM DD)	Time (HH:MM)					Diss.	Total		Diss.	Total			Diss.	Total			
1972	72 04 24	11:00		9.2	<0.005	0.004	0.68		<0.003		8.5	0.13	<0.01		<0.005		4.2	
	72 08 02	9:40		13.2	<0.005	0.005	0.54		0.004		14.3	0.21	0.01		0.007	2.1		
	72 11 01	10:15		12	<0.005	<0.001	1.68	4.47	<0.003	11.7	11.8	0.17	<0.01		<0.005	2.9	6.9	
1973	73 02 05	11:00		9.8			1.75			10.4								
	73 05 07	10:40		11.5			1.08			11.2								
	73 09 24	14:05		11.1			1.36			16.3			<0.01	0.24				
	73 11 06	13:30		10			1.07	2.69		10			<0.01	0.12				
1974	74 02 05	11:45		7.6			0.6			6.5								
	74 05 02	12:30		10.5		0.003		5.3	0.004	12.8		0.18			0.009			
	74 09 05	12:00		15	<0.005	0.001		3	<0.001	17.5		0.15	<0.01		0.005			
	74 11 06	12:20		12	<0.005	<0.001		3.6	0.001	13.2		0.23	<0.01		0.005			
1975	75 02 13	10:55		6.9	0.01	0.007		2.8	<0.001	6.2			0.05		<0.005			
	75 06 26	9:45		13.1	0.007	0.001		4.8	<0.001	12.5			<0.01		<0.005			<0.005
	75 09 16	11:30		14.5		0.001		3.5	0.005	15.3		0.19	<0.01		0.005			
	75 11 26	11:05		9.3		0.022		2.3	<0.001	9.3		0.07	0.01		0.008			
1976	76 02 09	10:45		11.2	0.009	0.001		3.8	<0.001	11.9		0.2	0.01		<0.005			
	76 05 20	13:20		12	<0.005	0.002		5.3	0.001	12.7		0.22	0.01		<0.005			
	76 10 14	12:05		13.6	<0.005	<0.001		3.1	<0.001	14.4	14.4	0.14	<0.01		<0.005			
	76 11 25	11:55		8.1	<0.005	0.003		2.4	0.003	8.1		0.08	0.02		0.007			
1977	77 02 10	11:30		11.8	<0.005	0.002		4.2	<0.001	12.4		0.17	0.01		0.005			
	77 05 26	9:55		10.5	<0.005	0.003		2.9	<0.001	10.2		0.1	<0.01		0.006			
	77 09 26	11:45		10.9	<0.005	0.003		1.5	<0.001	9.4		0.05	<0.01		<0.005			
	77 11 30	9:30		9.3	<0.005	0.004		1.7	<0.001	9.6		0.05	0.01		<0.005			
1992	92 07 07	12:00	0.026	9.98	0.006	0.004	0.746	2.91	<0.02	8.88	8.93	0.071	0.011		0.006	3.3	4.22	<0.04
	92 07 14	11:00	0.026	13.9	0.004	<0.001	0.915	3.8	<0.02	15.4	15.7	0.161	<0.008	<0.002	0.003	2.6	7.37	<0.04
	92 07 23	11:00	0.038	14.6	0.214	<0.001	0.487	4.25	<0.02	16	16.4	0.165	0.06	<0.002	0.002	2.4	8.4	<0.04
	92 07 27	12:05	0.045	16.5	0.038	0.002	0.759	3.77	<0.02	17.8	18	0.151	0.015		0.004	3.3	10.1	<0.04
	92 08 04	11:00	0.033	15.6	0.004	0.004	0.254	2.24	0.02	17.7	18.2	0.142	0.009	0.004	0.004	3.8	9.07	<0.04

Nutrients and Bacteriology

Year	Sample Collection		Total Ammonia (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Nitrogen (mg/L)			Phosphorous (mg/L)		Coliform		
	Date (YY MM DD)	Time (HH:MM)				Organic	Kjeldahl	Total	Ortho	Total	Fecal (MPN)	Total (MPN)	Fecal (CFU/100mL)
1972	72 04 24	11:00		0.005	0.31		0.07	1.02		0.192			
	72 08 02	9:40		0.018	0.1		0.63	0.75		0.01		>2400	
	72 11 01	10:15		0.013	0.34		0.72	1.07		0.181		>2400	
1973	73 02 05	11:00	0.29			0.39							
	73 05 07	10:40	0.25			0.33						3300	
	73 09 24	14:05	0.9	0.042	0.19	0.51							
	73 11 06	13:30	0.21	0.005	0.34	0.21			0.045	0.114	700	1700	
1974	74 02 05	11:45	0.21	0.011	1	0.64				0.172	540	>2400	
	74 05 02	12:30	0.012	0.01	0.24	0.5			0.035	0.216	790	5400	
	74 09 05	12:00	0.159	0.016	0.08		0.64		0.022	0.12	1400	2100	
	74 11 06	12:20	0.464	<0.005	0.19		0.56		0.024	0.114	460	16000	
1975	75 02 13	10:55	0.157	<0.005	0.7		0.55		0.015	0.105	230	330	
	75 06 26	9:45	0.363	0.02	0.14				0.054	0.18	540	>2400	
	75 09 16	11:30	0.595	0.025	0.18		1.12	1.325	0.021	0.154	700	700	
	75 11 26	11:05	0.231	0.015	1.31		0.95	2.275	0.039	0.147	460	630	
1976	76 02 09	10:45	0.265	0.005	0.45		0.49		0.056	0.146	460	460	
	76 05 20	13:20	0.364	0.007	0.12	0.31	0.67		0.044	0.197	1300	2200	
	76 10 14	12:05	0.259	0.012	0.23	0.48	0.74		0.034	0.158	240		
	76 11 25	11:55	0.264	0.025	1.56	1.01	1.27		0.034	0.218	>2400		
1977	77 02 10	11:30	0.296	0.014	0.72	0.39	0.69		0.038	0.177			
	77 05 26	9:55	0.147	0.01	0.26	0.34	0.49		0.026	0.111	1600		
	77 09 26	11:45	0.075	0.02	0.44	0.24	0.31		0.031	0.071	540		
	77 11 30	9:30	0.232	0.03	2.57	0.7	0.93		0.045	0.125	1600		
1992	92 07 07	12:00	0.207	0.04									2950
	92 07 14	11:00	0.285	0.042									785
	92 07 23	11:00	0.244	0.03									1650
	92 07 27	12:05	0.284	0.039									2100
	92 08 04	11:00	0.149	0.015									127

Nutrients and Bacteriology cont'd…

Year	Sample Collection		Total Ammonia (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Nitrogen (mg/L)			Phosphorous (mg/L)		Coliform		
	Date (YY MM DD)	Time (HH:MM)				Organic	Kjeldahl	Total	Ortho	Total	Fecal (MPN)	Total (MPN)	Fecal (CFU/100mL)
1993	93 07 11	08:00											1500
	93 07 18	08:00											1000
	93 07 25	07:45											190
	93 07 29	08:50											5450
	93 08 02	07:50											1790
2000	00 02 17		0.41		0.013								64
	00 02 22	11:15	0.606		0.017								120
	00 02 29	12:25	1.77		0.035								1300
	00 03 07	12:07	0.411		0.025								150
	00 03 14	11:18	0.49		0.023								2300
	00 03 21	11:32	0.68		0.03								250
	00 03 28	11:38	0.432		0.018								280
	00 04 17	13:33	0.496		.						4600		
2001	01 10 11												
	01 10 17		0.427		0.01								85
	01 10 24		0.492		0.014								1000
	01 10 31		1.9		0.079								9400
	01 11 07		0.317		0.04								41
	01 11 14		0.156		0.034								2700
	01 11 22		0.17		0.072								92
	01 11 27		0.237		0.028								

General Parameters

Year	Sample Collection		pH		Water Temp (°C)	Dissolved Oxygen (mg/L)	Specific Conductance		Residues (mg/L)			Turbidity				Chloride (mg/L)	Hardness (as $CaCO_3$) (mg/L)	BOD (mg/L)	Color Tr. (Rel. Unit)	Silica (mg/L)	Sulphate (mg/L)
	Date	Time	Field	Lab			(µS/cm)	(µmho/cm)	Filterable	Total	Non-filterable	Lab (JTU)	Field (NTU)	Lab (NTU)	Alkalinity (as $CaCO_3$)						
	(YY MM DD)	(HH:MM)																			
2000	00 02 17		6.42	7.61	6.55	6.42	296								83.8						
	00 02 22		7.62	7.46	8.25	7.62	292							22	82.6						
	00 02 29			7.22	8		242							30	68.3						
	00 03 07			7.36	7.8		280							24	81						
	00 03 14		7.6	7.06	8.8	7.6	176							65	49.8						
	00 03 21		7.28	7.35	10.13	7.28	284							15	83.4						
	00 03 28		7.23	7.1	9.68	7.23	274							16	81.2						
	00 04 17			7.52	10.9		297							15	85.7						

Nutrients and Bacteriology

Year	Sample Collection		Total Ammonia (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Nitrogen (mg/L)			Phosphorous (mg/L)		Coliform		
	Date	Time				Organic	Kjeldahl	Total	Ortho	Total	Fecal (MPN)	Total (MPN)	Fecal (CFU/100mL)
	(YY MM DD)	(HH:MM)											
2000	00 02 17		0.875		0.034								10
	00 02 22		0.409		0.043								120
	00 02 29		0.512		0.047								400
	00 03 07		0.404		0.035								110
	00 03 14		0.366		0.035								1400
	00 03 21		0.401		0.042								120
	00 03 28		0.813		0.043								1200
	00 04 17		0.397								790		

General Parameters

Year	Sample Collection		pH		Water Temp (°C)	Dissolved Oxygen (mg/L)	Specific Conductance		Residues (mg/L)			Turbidity			Alkalinity (as $CaCO_3$) (mg/L)	Chloride (mg/L)	Hardness (as $CaCO_3$) (mg/L)	BOD (mg/L)	Color Tr. (Rel. Unit)	Silica (mg/L)	Sulphate (mg/L)
	Date (YY MM DD)	Time (HH:MM)	Field	Lab			(µS/cm)	(µmho/cm)	Filterable	Total	Non filterable	Lab (JTU)	Field (NTU)	Lab (NTU)							
1972	72 04 24	11:30		7	8	9.1		171	122	140		22			72	6.3	73		40	18.4	11.5
	72 08 02	09:20		7.6	17.5	8		220	138	162		10			81	11.3	92		<5	21	6.8
	72 11 01	11:15		7.6	6	10.3		228	154	170		16			83.8	10.5	92		20	23	11.6
1973	73 02 05	11:30		7.5	3.5	10.3		210	158			13			72	9.9	82.8				
	73 05 07	11:40		7.5	12	8.8		235	156			12			81	10.9	87.3				
	73 09 24	13:40		7.55	15	9.3		240	158	222		29			89.1	11.1	97.6				
	73 11 06	14:40		8.1	3.5	11.9		240	152	168					84.7	11.4	95.1				
1974	74 02 05	13:00		6.9	5.5	11.2		120		140	39				43.5	5.2	52.3				
	74 05 02	13:30		7.25	11	9.2		195	138	150						9	85.2				
	74 09 05	13:00		7.15	20	7.45		213	142		16				79	10.3	86.8				
	74 11 06	13:30		6.9	9	10.7		210	154		14				81.3	10.7	93	<10			
1975	75 02 13	12:05		7.3	0.2	12.8		184	126		15				59	11.4	69.6				
	75 06 26	12:30		7.7	14.5	10.4		230	162		15				87.6	12.6	99.1				
	75 09 16	12:20		7.5	15.5	6.4		238	158		9				92.4	11.8	101				
	75 11 26	13:20		7.4	6.2	9.2		176		160	39				61	8.4	72.7				
1976	76 02 09	11:30		7.3	6	7.9		221	150		12				80.7	11.7	90.5				
	76 05 20	14:50		7.3	14	7.9		215	150		20				82	10.9	92.6				
	76 10 14	13:00		8.1	12	9.6		237	158		14				93.3	13.3	102				
	76 11 25	13:15		7.8	8.6	9.2		218	148		43				77.7	10.8	87				
1977	77 02 10	12:55		7.7	10.5	11.9		228	154		22				86.2	12	92				
	77 05 26	10:55		7.9	14	8.7		229	146		20				89.6	10.9	94				
	77 09 26	13:15		8.1	16	8.4		242	158		9				92.9	12.6	98.5				
	77 11 30	10:00		7.3	8	8.1		218	152		24				64.4	10.8	84				
1978	78 04 04	14:45		7.8	12	8.4		209	150		30				82.5	10.2	91.9				
	78 06 22	14:00		8	21	8.4		234		164	15				90.2	12.9	96.7				
	78 09 13	12:20		7.8	15.5	7.4		228		174	19				87.1	10.2	97.4				
	78 11 14	16:15		7.8	6	8.1		250		168	9				90.2	13	97.5				
1992	92 07 07	16:15																			
	92 07 14	13:50		7.5																	
	92 07 23	13:00		8																	
	92 07 27	14:25		7.7																	
	92 08 04	13:35		8																	
1993	93 07 11	12:30		8.2	13.8	7.3															
	93 07 18	13:40			19.3	9.6															
	93 07 25	12:05			17.6	8.1															
	93 07 29	12:15			16.3	6															
	93 08 02	12:05			20.7	9															
2000	00 02 17		7.03	7.52	5.3	11.3	295								102						
	00 02 22	13:55	7.66	7.61	7.16	10.4	296							12	101						
	00 02 29	14:50		7.46	7.5	10	265							21	89						
	00 03 07	14:40		7.65	6.9	11.5	258							22	93.2						
	00 03 14	13:36	7.59	7.38	8.67	10	224							34	78.4						
	00 03 21	13:55	7.33	7.51	8.84	9	265							11	94.3						
	00 03 28	14:15	7.37	7.32	9.21	8.4	269						18.5	10	94.7						

Metals

Year	Sample Collection		Diss. Boron (mg/L)	Diss. Calcium (mg/L)	Total Chromium (mg/L)	Total Copper (mg/L)	Iron (mg/L)		Total Lead (mg/L)	Magnesium (mg/L)		Total Manganese (mg/L)	Total Nickel (mg/L)	Zinc (mg/L)		Dissolved Potassium (mg/L)	Dissolved Sodium (mg/L)	Total Arsenic (mg/L)
	Date (YY MM DD)	Time (HH:MM)					Diss.	Total		Diss.	Total			Diss.	Total			
1972	72 04 24	11:30	<0.2	14.4	<0.005	0.005	0.48		<0.003		8	0.16	<0.01		<0.005	1.7	4.8	
	72 08 02	09:20	<0.2	18.8	<0.005	<0.001	0.38		0.004		10.4	0.07	<0.01		0.007	1.4		
	72 11 01	11:15	<0.1	18	<0.005	<0.001	0.43	1.56	<0.003	11.3	11.3	0.08	<0.01		<0.005	1.9	9.3	
1973	73 02 05	11:30		12.9			0.4			12.3								
	73 05 07	11:40		15.5				2.3	0.001	11.8								
	73 09 24	13:40		18.5				1.5		12.5				0.2				
	73 11 06	14:40		17				1.7	0.003	12.8								
1974	74 02 05	13:00		8.4			0.4			7.6				0.017				
	74 05 02	13:30		13.5		<0.001		2.3	0.003	12.5		0.12			0.008			
	74 09 05	13:00		19.6	<0.005	0.003		1.5	0.002	9.2		0.11	<0.01		<0.005			
	74 11 06	13:30		19.6	<0.005	0.002		1.7	<0.001	10.7		0.04	<0.01		<0.005			

Metals cont'd…

Year	Sample Collection Date (YY MM DD)	Time (HH:MM)	Diss. Boron (mg/L)	Diss. Calcium (mg/L)	Total Chromium (mg/L)	Total Copper (mg/L)	Iron (mg/L) Diss.	Iron (mg/L) Total	Total Lead (mg/L)	Magnesium (mg/L) Diss.	Magnesium (mg/L) Total	Total Manganese (mg/L)	Total Nickel (mg/L)	Zinc (mg/L) Diss.	Zinc (mg/L) Total	Dissolved Potassium (mg/L)	Dissolved Sodium (mg/L)	Total Arsenic (mg/L)
1975	75 02 13	12:05		13.2	0.007	0.002		1.5	<0.001	8.9			0.02		<0.005			
	75 06 26	12:30		19.1	< 0.005	<0.001		2	<0.001	12.5			0.01		<0.005			<0.005
	75 09 16	12:20		19.5		0.002		1.7	0.002	12.7		0.1	<0.01		<0.005			
	75 11 26	13:20		11		0.022		2.9		11		0.08	0.05		0.012			
1976	76 02 09	11:30		14.5	0.005	0.001		2.2	<0.001	13.2		0.15	0.01		<0.005			
	76 05 20	14:50		16.3	<0.005	<0.001		2.6	0.001	12.6		0.15	0.01		<0.005			
	76 10 14	13:00		18.3	<0.005	<0.001		1.6	<0.001	13.8	13.9	0.08	<0.01		<0.005			
	76 11 25	13:15		14.9	<0.005	0.005		3.3	**0.007**	12.1		0.14			0.012			
1977	77 02 10	12:55		15.4	<0.005	0.004		3	**0.003**	13		0.15	0.01		0.009			
	77 05 26	10:55		16.2	<0.005	0.004		2.2	<0.001	13		0.09	0.01		0.011			
	77 09 26	13:15		18.2	<0.005	0.001		1.2	<0.001	12.9		0.05	<0.01		<0.005			
	77 11 30	10:00		13.2	<0.005	0.005		1.8	<0.001	12.4		0.07	0.02		<0.005			
1978	78 04 04	14:45		14.7				2.4	<0.001	13.4		0.11						
	78 06 22	14:00		19.1				1.7	<0.001	11.9		0.09						
	78 09 13	12:20		15.6				1.4	<0.001	14.2		0.06						
	78 11 14	16:15		13.5				1.7	<0.001	15.5		0.13						
1992	92 07 07	16:15	0.025	17.4	0.005	0.004	0.385	1.33	<0.02	16.1	16.2	0.077	0.021	0.007	0.007	5.5	6.74	<0.04
	92 07 14	13:50	0.023	19.1	0.004	<0.001	0.229	1.66	<0.02	16.4	16.7	0.092	0.008	<0.002	0.006	2.1	8.3	<0.04
	92 07 23	13:00	0.031	22.7	<0.002	0.002	0.127	0.943	<0.02	13.9	14.6	0.058	<0.008	<0.002	0.003	2.4	9.56	<0.04
	92 07 27	14:25	0.029	24.9	0.024	<0.001	0.138	0.648	<0.02	17.1	17.4	0.025	0.023	<0.002	<0.002	2.1	9.47	<0.04
	92 08 04	13:35	0.023	25.3	<0.002	0.002	0.066	0.392	<0.02	14.2	14.3	0.027	<0.008	<0.002	0.003	1.8	9.9	<0.04

Nutrients and Bacteriology

Year	Sample Collection Date (YY MM DD)	Time (HH:MM)	Total Ammonia (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Nitrogen (mg/L) Organic	Nitrogen (mg/L) Kjeldahl	Nitrogen (mg/L) Total	Phosphorous (mg/L) Ortho	Phosphorous (mg/L) Total	Coliform Fecal (MPN)	Coliform Total (MPN)	Coliform Fecal (CFU/100mL)
1973	72 04 24	11:30		0.005	0.41		0.92	1.34		0.078		54200	
	72 08 02	9:20		0.027	1.35		0.3	1.68		0.01		>2400	
	72 11 01	11:15		0.016	1.39		0.68	2.09		0.142		>2400	
1973	73 02 05	11:30	0.12			0.39						5400	
	73 05 07	11:40	0.2			0.37						>24000	
	73 09 24	13:40	0.15	0.032	1.19	0.43					500	1700	
	73 11 06	14:40	0.15	0.012	1.04	0.3			0.032	0.11	790	2200	
1974	74 02 05	13:00	0.12	0.011	1.12	0.57				0.14	540	>2400	
	74 05 02	13:30	0.119	0.01	0.83	0.38			0.044	0.12	940	5400	
	74 09 05	13:00	0.085	0.041	1.71		0.39		0.028	0.107	490	2400	
	74 11 06	13:30	0.114	<0.005	1.43		0.47		0.028	0.102	490	3500	
1975	75 02 13	12:05	0.144	0.008	1.36		0.41		0.027	0.073	1300	2200	
	75 06 26	12:30	0.101	0.021	1.26		0.29		0.027	0.102	240	540	
	75 09 16	12:20	0.083	0.022	1.09		0.36	1.472	0.034	0.101	400	700	
	75 11 26	13:20	0.17	0.018	1.37		0.9	2.288	0.044	0.165	1700	2200	
1976	76 02 09	11:30	0.172	0.01	1.35		0.56		0.034	0.109	790	790	
	76 05 20	14:50	0.143	0.016	1.07	0.55	0.69		0.031	0.126	1300	1300	
	76 10 14	13:00	0.113	0.039	1.31	0.25	0.36		0.022	0.094	170		
	76 11 25	13:15	0.259	0.032	1.4	0.83	1.09		0.056	0.207	>2400		
1977	77 02 10	12:55	0.22	0.021	1.38	0.38	0.6		0.039	0.141			
	77 05 26	10:55	0.083	0.016	1.01	0.35	0.43		0.039	0.102	540		
	77 09 26	13:15	0.083	0.035	1.16	0.37	0.45		0.038	0.102	79		
	77 11 30	10:00	0.203	0.034	2.65	0.79	0.99		0.082	0.185	>2400		
1978	78 04 04	14:45	0.127	0.017	1.29	0.6	0.73		0.058	0.147	540		
	78 06 22	14:00	0.08	0.037	1.25	0.46	0.54		0.03	0.041	79		
	78 09 13	12:20	0.053	0.041	1.09	0.56	0.61		0.034		350		
	78 11 14	16:15	0.309	0.019	1.66	0.39	0.7		0.031	0.042	920		
1992	92 07 07	16:15	0.303	0.071						0.12			1070
	92 07 14	13:50	0.126	0.034						0.05			435
	92 07 23	13:00	0.104	0.039						0.04			61
	92 07 27	14:25	0.025	0.02						0.04			49
	92 08 04	13:35	0.04	0.013						0.04			
1993	93 07 11												
	93 07 18	13:40											94
	93 07 25	12:05											120
	93 07 29	12:15											130
	93 08 02	12:05											279

General Parameters

Year	Sample Collection		pH		Water Temp (°C)	Dissolved Oxygen (mg/L)	Specific Conductance		Residues (mg/L)			Turbidity			Alkalinity (as $CaCO_3$) (mg/L)	Chloride (mg/L)	Hardness (as $CaCO_3$) (mg/L)	BOD (mg/L)	Color Tr. (Rel. Unit)	Silica (mg/L)	Sulphate (mg/L)
	Date (YY MM DD)	Time (HH:MM)	Field	Lab			(µmho/cm)	(µS/cm)	Filterable	Total	Non filterable	Lab (JTU)	Field (NTU)	Lab (NTU)							
2000	00 02 17		7.1	7.65	4.42	10.7		225							88.2						
	00 02 22		7.41	7.59	6.99	9.8		223					21.8	21	86.9						
	00 02 29				7.2	9.4		244						22	96						
	00 03 07		7.89	7.49	5.68	10.6		239						18	95.8						
	00 03 14		7.58		7.69	10.8		197						61	76						
	00 03 21		7.18	7.45	8.63	7		238						18	94.5						
	00 03 28		7.25	7.11	8.46	7.4		227					17.7	22	89.6						
	00 04 17			7.55	12.2	8.7		226						20	92.1						
2001	01 10 17		7.5		11.01	6.35															
	01 11 07		7.6		9.01	6.9															

Nutrients and Bacteriology

Year	Sample Collection		Total Ammonia (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Nitrogen (mg/L)			Phosphate (mg/L)		Coliform		
	Date (YY MM DD)	Time (HH:MM)				Organic	Kjeldahl	Total	Ortho	Total	Fecal (MPN)	Total (MPN)	Fecal (CFU/100mL)
2000	00 02 17		1.26	0.017									<2
	00 02 22		1.08	0.021									350
	00 02 29		1.63	0.028							2400		
	00 03 07		1.33	0.022									300
	00 03 14		1.43	0.024									2300
	00 03 21		1.14	0.024									140
	00 03 28		1.11	0.017									590
	00 04 17		1.07										215
2001	01 10 17		0.92		0.035								364
	01 11 07		1		0.047								200