RELATIONSHIPS BETWEEN AGRICULTURAL LAND USE AND SURFACE WATER QUALITY USING A GIS: SUMAS RIVER WATERSHED, ABBOTSFORD, B.C.

by

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ABSTRACT

The Sumas Prairie is one of the most intensively used agricultural floodplains in Canada. Dairy farmers are the traditional occupants of the floodplain, but the past 20 years have seen the development of turf and vegetable farms, and large hog, chicken and turkey operations. Nutrient management and related water contamination have been recognized as major issues over the past decade, but due to the non-point nature of the pollution it has been difficult to analyse the contributing sources and to mitigate the impacts.

The Sumas River watershed was thus investigated as an illustration of how land use activity affects water quality with a focus on non-point source pollution from agriculture. A Geographic Information System (GIS) was used to integrate resource data for the watershed, which included surficial geology, soils, current and historic land use, agricultural intensification and population growth. River sediments and water quality were analysed in seasonal, spatial and historical contexts. GIS overlay techniques were used to summarize land use activities within the drainage areas to sampling points, or "contributing areas". Indices of land use activities were developed within the contributing areas and correlated to the water quality parameters to identify significant relationships. Examples of land use indices included nitrogen loadings over contributing areas and animal stocking densities.

Zinc concentrations in river sediment were elevated from those measured twenty years ago and are attributed to agricultural sources while high chromium and nickel concentrations occur from natural sources. The nutrient concentrations and fecal coliform counts in stream water increased dramatically in the rainy season. Manure, particularly when spread in the wet season due to lack of winter storage, is likely entering the stream via runoff. Dissolved oxygen levels were low in this same period, and on a site specific basis year round. One tributary, Marshall Creek, was found to have elevated nitrate levels in the summer with the suspected source being contaminated groundwater from the neighbouring Abbotsford aquifer.

Animal stocking densities and surplus nitrogen loadings were found to be high, as compared to values found in the literature. Significant relationships were identified between surplus nitrogen applied to farm land, amount of clay soil texture by area, and ammonia-N concentrations in the wet season. Similarly, these two land indices were negatively correlated with dissolved oxygen levels in both the wet and dry seasons. Nitrate-N concentrations were positively correlated to amount of clay and organic soils in the contributing area, but negatively correlated to the amount of sandy texture.

The results indicate agricultural best management practices need to be more aggressively pursued in the watershed, with regard to amount of manure and time of application. Areas with higher nitrogen loadings coincided with areas of water quality degradation. Techniques developed in this research can be used to evaluate the impact of non-point source pollution from agriculture on stream water quality in a quantitative manner and provide watershed managers with a tool to address non-point source pollution. The densification of animals and farms on the floodplain, emergency responses due to frequent flooding, and the impact of contaminated groundwater on the stream, are issues that should be given renewed attention.

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LIST OF ABBREVIATIONS AND SYMBOLS

AES	Atmospheric and Environmental Services
AUE	Animal Unit Equivalent
ALR	Agricultural Land Reserve
CCME	Canadian Council of Ministers of the Environment (formerly CCREM)
CCREM	Canadian Council of Resource and Environment Ministers
DO	Dissolved Oxygen (mg/L)
EA	Enumeration Area
ESP	Environmental Sustainability Parameter (IRC, 1994)
GIS	Geographic Information System
GPS	Geographical Positioning System
ha	hectares ($\approx$ 2.47 acres)
r_s	Spearman rank correlation coefficient
TRIM	Terrain Resource Inventory Management
UBC	University of British Columbia
USDA	United States Department of Agriculture
U.S. EPA	United States Environmental Protection Agency
WMS	Waste Management Survey (by IRC Integrated Resource Consultants)

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1.0 Introduction

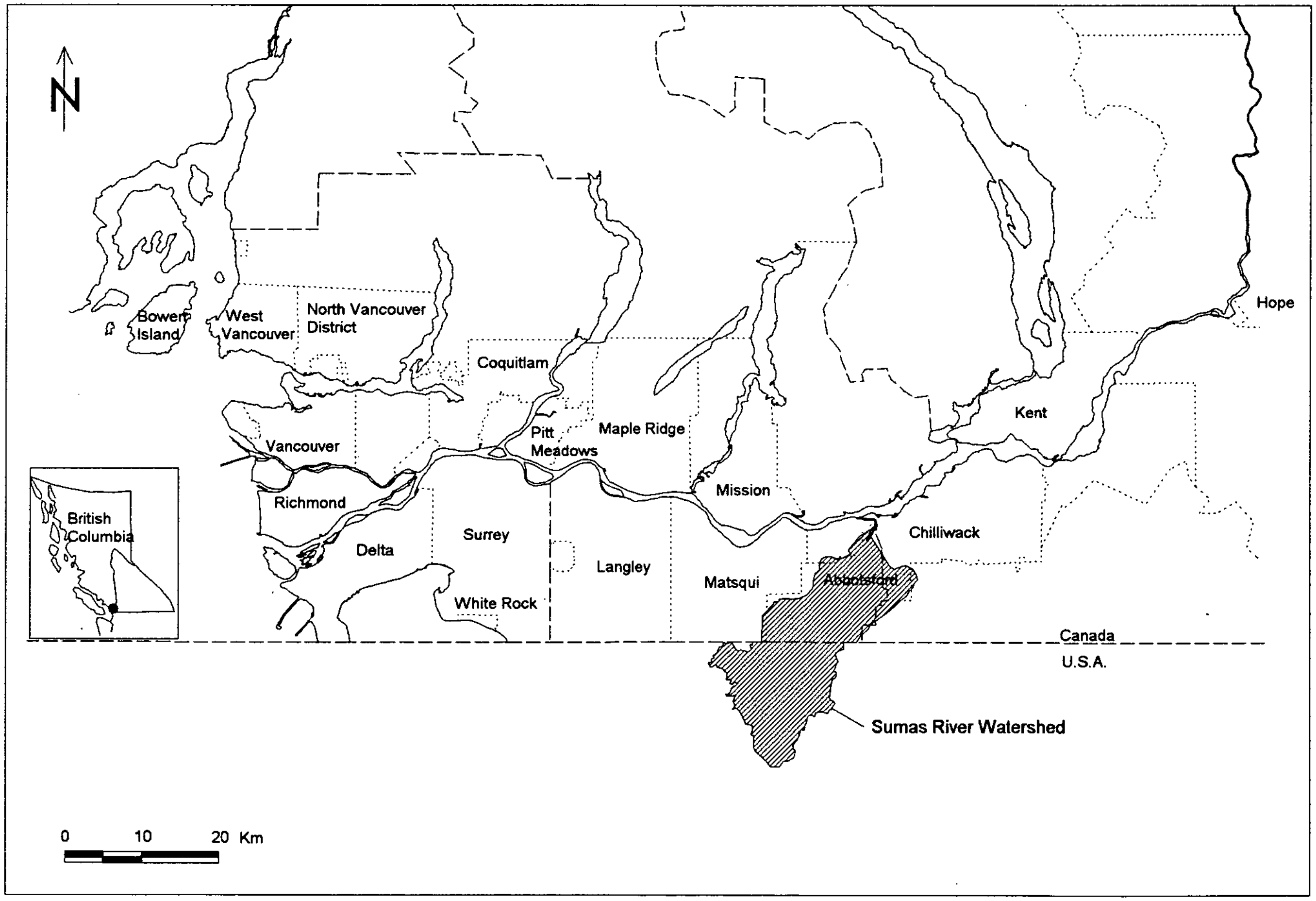
Water pollution from intensive agriculture is now recognized as a problem of global proportion (Owens, 1994) but, due to the non-point nature of the pollution, it has been difficult to analyse the contributing sources and to mitigate the impacts. The aim of this thesis is to explore relationships between land use activity and water quality in the Sumas River watershed in Abbotsford, B.C., with an emphasis on agricultural non-point source pollution.

1.1 Background Issues

The Sumas River originates in Whatcom County, Washington State, and joins the Fraser River east of Abbotsford, British Columbia (Figure 1.1). The watershed comprises a very flat floodplain surrounded by steep mountain slopes. This floodplain, known on the Canadian side as the "Sumas Prairie", is considered one of the most productive agricultural areas in Canada and is part of the B.C. Agricultural Land Reserve (ALR), which protects farmland from urbanization. As a result, high population growth within the City of Abbotsford is steadily urbanizing the mountain slopes of the watershed. This urbanization can impact water quality in terms of urban inputs of non-point source pollution, and water quantity in terms of the hydrological effects of clearing the land and increasing the impervious area.

Flooding of the farmland is a frequent phenomenon, varying from local minor floods to major flooding from the Nooksack River in Washington when it overflows. Flooding has serious ramifications to health, environment, economics and emergency procedures due to the high number of animals in the floodplain, and the presence of an important national

Figure 1.1 Location of the Sumas River Watershed within the Lower Mainland Region



transportation corridor, the TransCanada Highway. Sedimentation within the stream system is also a major issue in the watershed, influenced by flooding and wind erosion in the Prairie. It is of particular concern in the headwaters, where a natural landslide contributes very fine asbestos sediment with high concentrations of trace metals to the stream (Schreier, 1987). The chemical and drainage properties of the asbestos rich sediments provide very poor conditions for vegetative growth.

The agricultural activity in the Sumas River watershed is economically important to the Lower Fraser Basin. The intensive agriculture has developed into a $250 million investment (District of Abbotsford, June 1993), and gross farm revenues in 1991 were greater than $68 million, while expenses were greater than $53.5 million (IRC, 1994). The Prairie produces 17% of all dairy products in British Columbia and is also largely devoted to vegetable production (District of Abbotsford, June 1993). Recent intensification from rapid increases in poultry and swine production has produced livestock densities amongst the highest in Canada. The intensity of agricultural activity in both the Canadian and U.S. portions of the watershed have created water quality problems and degraded fish habitat in various reaches of the Sumas River system (IRC, 1994, Puget Sound Water Quality Authority, 1990). Agricultural activity has also been named responsible for the contamination of groundwater in the Abbotsford aquifer (Liebscher et al., 1992), a portion of which is included in the western area of the watershed study boundary.

The above issues prompted the Sumas Sustainability Study, spearheaded by the District of Abbotsford (now the City of Abbotsford, having amalgamated with Matsqui) and begun in 1993. The Study brought together the City of Abbotsford, the Ministry of

Environment, farmer/producer groups, Whatcom County, and other interest groups and stakeholders to address some of the above issues. Flooding concerns received particular attention. The Westwater Research Centre, UBC, was able to contribute research regarding water quality aspects of sustainability to the Study through the Fraser Basin Ecosystem Study, funded by the Tri-Council Secretariat Eco-Research Program. Thus this thesis plays a dual role. It is one of the watershed case studies investigated in the Fraser Basin Ecosystem Study, which explores general sustainability issues in the Lower Fraser Basin, and it is also part of Westwater's contribution to the Sumas Sustainability Study, which is a locally driven, action-oriented initiative.

1.2 Objectives

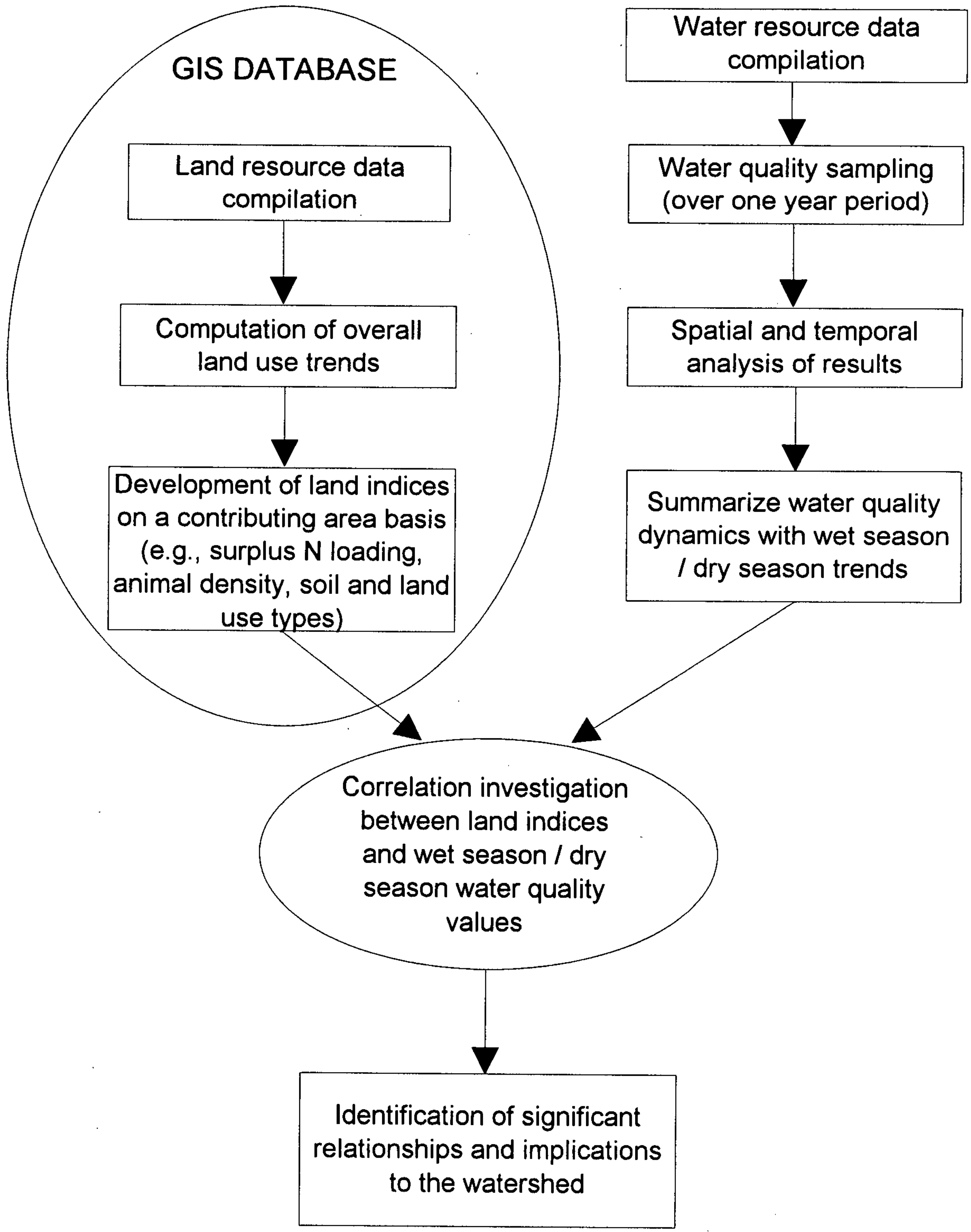
The research documented in this thesis was undertaken with the following objectives:

1) Quantify current land use activities and intensity. Where possible make comparisons to historic land use and identify trends.
2) Document the current status and historic changes in water quality and trace metals in sediments.
3) Compute a terrestrial nitrogen balance.
4) Relate land use to water quality using a Geographic Information System (GIS).

1.3 General Methodology

The general approach used to study non-point source pollution and pursue the objectives of this study can be represented by the flowchart in Figure 1.2. The following

Figure 1.2 Thesis Framework for Studying Non-point Source Pollution



paragraphs describe the components of this flowchart, and collectively describe the study methodology.

1.3.1 GIS Database

A GIS is a computer database and graphics system which can perform spatial analytical functions with geographically referenced data (Burrough, 1986). The GIS *TerraSoft*© is extensively used in this thesis to integrate the land resource data, and analyse and display the spatial pattern of land use activity. Any entity with a position in space can be represented, along with its descriptive attributes, in digital form in a GIS. If resource information is not available digitally (i.e., computer files with positioning coordinates and attribute information related to those coordinates), then hard copy maps or photos can be digitized using computer graphics hardware and the GIS software. The strength of using a GIS in non-point source pollution investigations lies in its spatial analytical capabilities. The main spatial function employed during this research is the "overlay". This allows one to investigate a variety of questions regarding the interactions of the resource data, limited mainly by the availability and quality of the data, and the creativity of the investigator. As simple examples, which farms and how many farms fall within a subdrainage area, or the total area of different surficial soil types within a census enumeration area, can both be determined. In this way, land resource data can be quantified and integrated in various spatial contexts.

1.3.2 Land Resource Data

The provincial government's TRIM (Terrain Resource Inventory Management) maps, at a 1:20 000 scale, were used as a base map for the GIS. Digitally formatted soil survey maps for Canada (Luttmerding, 1980) and the U.S. (USDA, 1992) were input and the coding generalized according to surface and subsurface texture, parent material, and drainage properties. Land use data was digitized into the GIS from aerial photos for different time periods. Farm locations were obtained from a combination of aerial photos, orthophotos, GPS (Geographical Positioning System) data from a waste management survey (IRC, 1994), and windshield surveys. Farm attribute information, such as size, number and type of animals, and types and hectares of crops, was also obtained from the IRC waste management survey. Population and agricultural census data were obtained for the enumeration areas covering the watershed from Statistics Canada, along with a geographical key for the enumeration areas which were digitized into the GIS.

For the U.S. portion of the watershed, the digital base map showing stream and road topology was obtained from the Whatcom County Planning Department. Land use data was also provided by this department, in the form of a database containing land parcel centroid coordinates with associated parcel size and land use code attributes. Information on agricultural activity, including crop acreages in the watershed, dairy farm locations and approximate herd sizes was provided by the Whatcom County Conservation District.

1.3.3 Overall Land Use

The land resource data compiled above was summarized and analyzed for the whole watershed using a combination of database queries, GIS overlays, and the generation of various plots or graphs. Where possible, historical trends were also examined. The treatment of the land resource information is discussed in more detail in Chapter 2.

1.3.4 Land Indices

The land resource data summarized for the whole watershed was then quantified for each area draining to a water sampling station, called "contributing area" in this thesis. Some investigation of resource data by enumeration area was also explored, but this proved to be limited in its application to water quality relationships, as described in Section 5.2. Quantifiable measures, which were labelled "land indices", included hectares of soil texture, parent material, and drainage types within a contributing area, and hectares of land use types within a contributing area. Measures specific to agricultural activity included animal density and surplus nitrogen application to the land. Again, the land indices by contributing area were obtained by GIS overlays with the soils, land use or farm location maps with the contributing area boundaries. The development of land indices is discussed further in Section 5.1.

One index which was given particular attention in the research work was the amount of surplus nitrogen loading to the land. This index value was considered the measure which would most directly impact the nutrient content of the streamwater, and thus have the potential of representing agricultural inputs to the stream. To signify the importance of this index, computing a terrestrial nitrogen balance was included as an objective of this thesis. The nitrogen balance uses a mass balance approach which considers sources and sinks of nitrogen to compute a surplus value applied to the land. This surplus is theoretically available to enter groundwater through leaching or surface water via runoff. The model used to compute the mass balance includes a calculation of: manure production of nitrogen by animals minus management, application and volatilization losses; inorganic fertilizer application minus crop requirements; and atmospheric deposition and denitrification losses. A more detailed description of the mass balance calculations is given in Section 2.5.2.

1.3.5 Water Resource Data

Water resource data was collected to describe the biophysical setting of the water quality investigation. Knowledge of the hydrology, history, and other characteristics of the water resource allow for the interpretation of the water chemistry results in the proper context. The water resource data was not used directly in the GIS analysis or correlation investigation, but rather as a background knowledge base to assist in determining the implications of the results. Information collected includes: flow and precipitation data, reports on hydrology and flooding, fisheries data, reports on groundwater in the Abbotsford aquifer, and waste discharge permits. Chapter 3 describes the sources of information and provides summary highlights.

1.3.6 Water Quality Sampling, Analysis and Trends

Grab samples of river bed sediment were taken at 23 sites in August 1993 and August 1994. Trace metal concentrations for copper, chromium, nickel and zinc in the sediment were determined for the two sampling times. Differences from year to year were computed, and results plotted in the upstream to downstream direction to determine spatial trends. The results were also compared to a baseline dataset recorded in 1974 by Westwater Research Centre, UBC, by statistically testing for significant changes in concentration levels over the 20 year time period.

Water quality sampling was conducted at 16 stations, including one control station, over one annual cycle. Dissolved oxygen, pH, temperature, conductivity, chloride, nitrate-N, ammonia-N, orthophosphate and dissolved organic carbon were all measured. Samples for fecal coliform analysis were collected on three of the eight sampling dates. The results were analysed in seasonal, spatial and historical contexts, the latter by using comparisons with historical water quality data. The spatial analysis was accomplished by a visual comparison of the data for each site as represented by a box plot, and also by plotting the data in an upstream to downstream direction. By separating the sampling dates into "dry" and "wet" season categories, and averaging the results for each site by these seasons, a clear picture of the seasonal dynamics was shown. The averaging of the data into wet/dry seasons served to dampen the "noise" of the water quality data, allowing for clearer and stronger correlations with the land indices. Chapter 4 encompasses the whole of the water quality investigation, including the methods and results of streamwater constituents and sediment trace metal analyses.

1.3.7 Correlation Investigation and Significant Relationships

The measures and analyses of resource data for land and water are finally brought together in a correlation analysis between land indices and water quality values, in order to determine significant relationships. A Spearman rank correlation coefficient matrix was generated to identify the strength of relationships among wet season water quality averages, dry season water quality averages, and the land indices. Strong relationships imply not only that the measured land characteristic or activity has an influence on the water quality, but that the land index, which is often more easily and cheaply measured than the water chemistry, may be a good environmental indicator for water quality. Chapter 5 describes the correlation investigation and significant relationships found. Chapter 6 summarizes the conclusions drawn from Chapter 5 and preceding chapters, and provides recommendations, or implications, to the watershed.

1.4 The Watershed Study Unit

This thesis methodology uses the watershed as a study unit. It assumes that stream water quality is influenced mainly by the properties of the land defined in area by the natural surface drainage boundaries of the stream. It also assumes that water quality at a point is influenced mainly by the subdrainage, or contributing area, to that point. These are reasonable assumptions, as many biological phenomena and human activities are water dependent, and surface water drainage boundaries are comparatively easily delineated.

However, boundaries and properties of influence are not necessarily simply defined. Firstly, while watershed boundaries are defined by topography, data pertaining to the watershed is commonly collected according to political boundaries. This often forces generalizations, assumptions, and inherent inconsistencies in summarizations for contributing areas, but is an unavoidable reality and is rarely ameliorated with the selection of some other basis for a study unit. The Sumas watershed includes jurisdictional areas from two nations (Canada and the U.S.), three municipal districts (Matsqui and Abbotsford- now amalgamated to the City of Abbotsford, and Chilliwack), one county (Whatcom), and one Regional District (Central Fraser Valley). Most of the land area on the Canadian side falls within the City of Abbotsford. Consequently, much of the research focused on the City of Abbotsford portion of the watershed, particularly on the Sumas Prairie floodplain.

Another watershed study limitation is that water quality can very well be impacted by forces which extend beyond the watershed boundary, such as air pollution, and groundwater pollution as discovered in the water quality investigation of Chapter 4. Despite the above recognized limitations, the spatial pattern of measured water quality parameters in the watershed context is useful in interpreting the relationships between land use and water quality (Cook, 1994), especially when investigating non-point source pollution.

1.5 Planning and Community Initiatives

The non-point source pollution investigation should recognize the related goals, programs and initiatives of the Sumas watershed community, although only the Canadian Sumas community is described here due to data availability. The City of Abbotsford must harmonize the background issues described earlier with the objectives listed in their Official Community Plan (District of Abbotsford, 1993). These objectives include: the diversification and promotion of economic activity; "the protection, conservation and maintenance of lands that are environmentally sensitive or subject to hazardous conditions by limiting development in order to reduce high damage costs"; the provision of adequate supply of housing types but the minimization of potential conflicts between housing and other land uses; and, the preservation of agricultural land and the promotion of agricultural industry. Some of these objectives are addressed in the previously mentioned Sumas Sustainability Study.

Another program, which works toward the control of soil erosion, is led by the Sumas Prairie Soil Conservation Group. This group consists of farmers, advisors, and administrators from the public sector, who are responsible for initiatives which not only preserve productive soils, but protect the aquatic environment, as efforts to control soil erosion also tend to control the extent of pollution in agricultural runoff (Owens, 1994). Other groups which work towards addressing environmental issues and commodity group concerns include the Sustainable Poultry Farming Group, the Hog Producers Sustainable Farming Group, the Dairy

Producers' Conservation Group, and the Sumas Prairie Dyking and Drainage Committee (Schmidt, O., pers. comm., 1995).

Soil erosion and the amount of manure applied are recognized problems by farmers of the Sumas Prairie, and irrigation and drainage, including flood mitigation, understandably receive high levels of attention and funding. It appears that water quality in the Sumas River system is not perceived to be a significant problem by the farmers; there has been no concern expressed in the Sumas Sustainability Study meetings regarding the quality of irrigation water for crops nor for animal watering. The issue of water quality in the Sumas River as yet receives low priority. There are many community groups, however, that work or recreate on the river system and may be more concerned with water quality issues. These groups, such as the: no-motors club, the waterski club, the walking society, the rowing club, Ducks Unlimited, the Rod and Gun Club, the historic society, and bird watchers (Wright, F., pers. comm., 1995) may perform a variety of habitat/ecosystem enhancement works, and may help to change the level of priority currently given to water quality issues. It is hoped that the relationships discovered during this research will add to the knowledge and facilitate decisions regarding the abatement of agricultural non-point source pollution, for the Sumas Prairie farmers, other community groups, and government agencies alike.

2.0 Land Characteristics and Use in the Sumas River Watershed

2.1 Physical Setting

The Sumas River watershed comprises a long, flat-lying valley and the steep slopes of the Sumas and Vedder mountains, which sandwich the valley to the northwest and southeast respectively. The valley averages 5 km in width and extends approximately 35 km from the Fraser River in the north to the Nooksack River, Washington, in the south. The two mountains reach elevations of approximately 800 m, while the valley bottom remains close to mean sea level (NHC and Hamilton, 1994; Klohn Leonoff, 1989). The topography of the watershed is depicted in Figure 2.1.

The Sumas valley was an arm of the sea during much of the Quaternary period. The sea filled the valley with 300 m or more of marine deposits which was later topped with less than 5 m of post-glacial lacustrine deposits from Sumas Lake (Armstrong, 1983, *cited in* NHC and Hamilton, 1994). Figure 2.2 shows the predominance of sand and loam in the surficial geology (Luttmerding, 1980; USDA, 1992). Noticeable features in this figure include the sandy lake bottom in the northeast portion of the valley, and the gravel deposits of the Abbotsford aquifer in the west.

2.2 Land Use

A large portion of the Sumas watershed is a floodplain created by the Sumas river itself and affecting neighbouring river systems. Human land use in the Sumas watershed is historically dominated by dairy farming and pastureland use in the floodplain, with some harvesting of forested areas in the surrounding mountainsides. Vegetable production is also a

Figure 2.1 Topography of the Canadian Portion of the Sumas Watershed

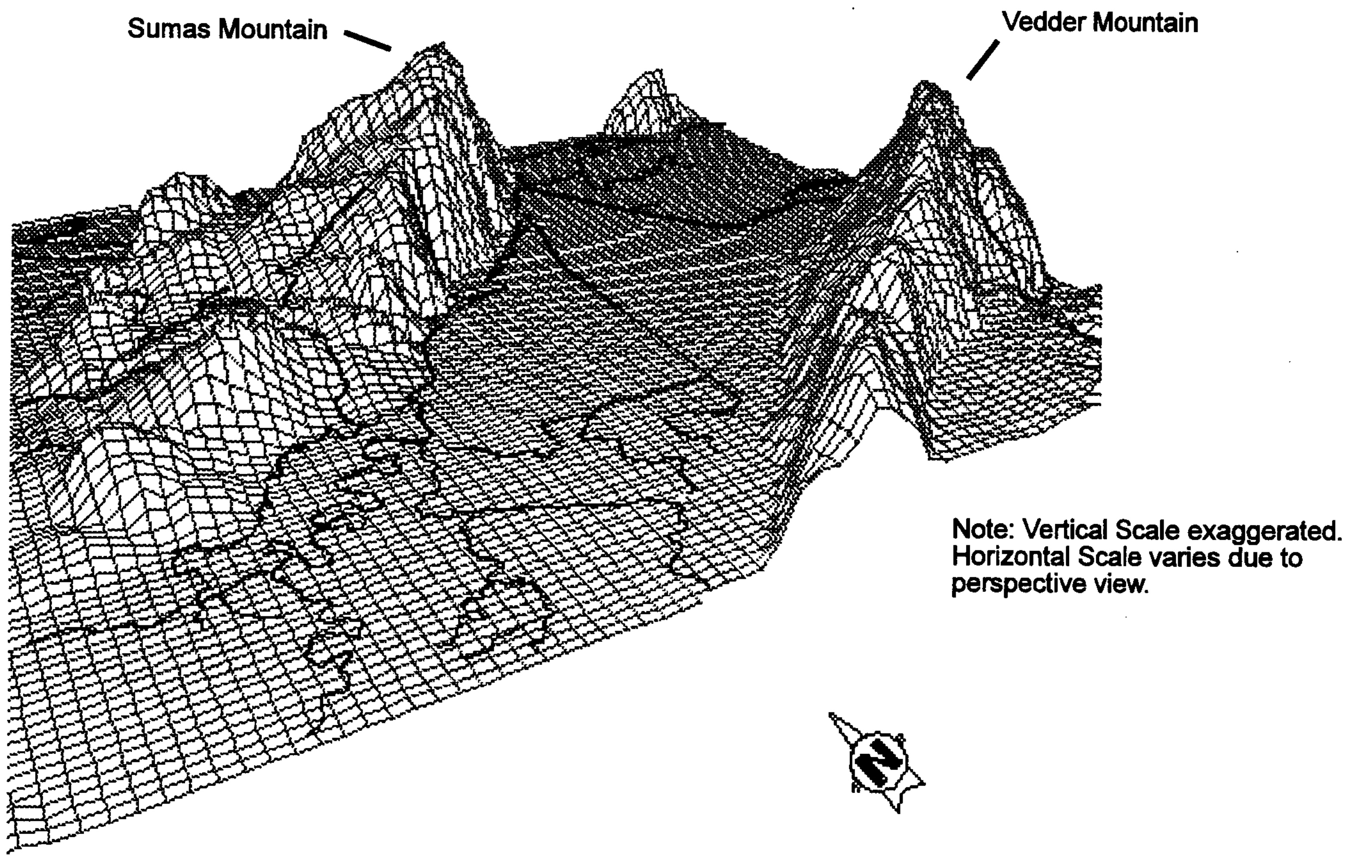
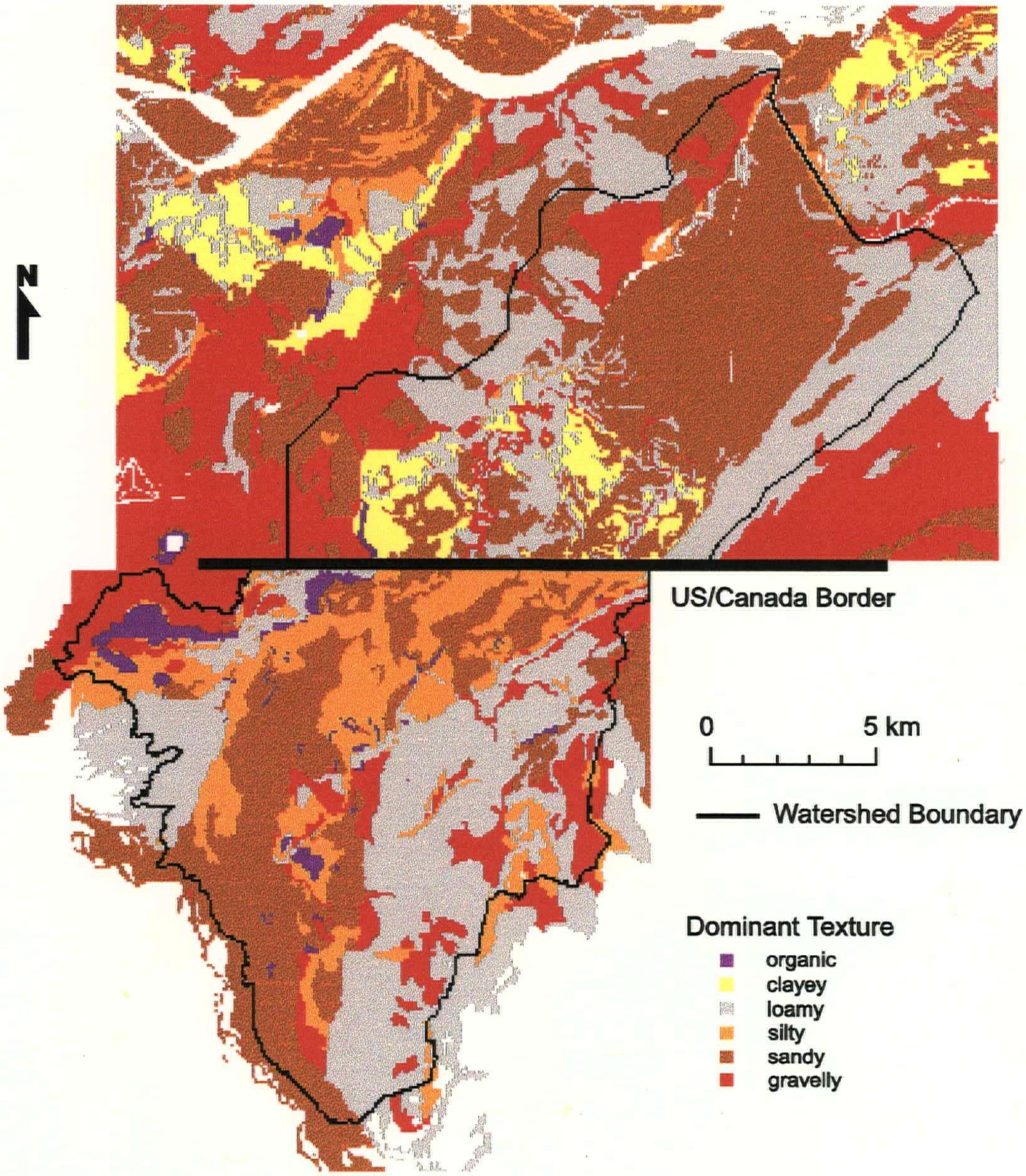


Figure 2.2 Surficial Geology of the Sumas Watershed. Source: Generalized from the 1:25 000 soils map (Luttmerding, 1980) and digital maps provided by Whatcom County Planning Dept. (USDA, 1992).

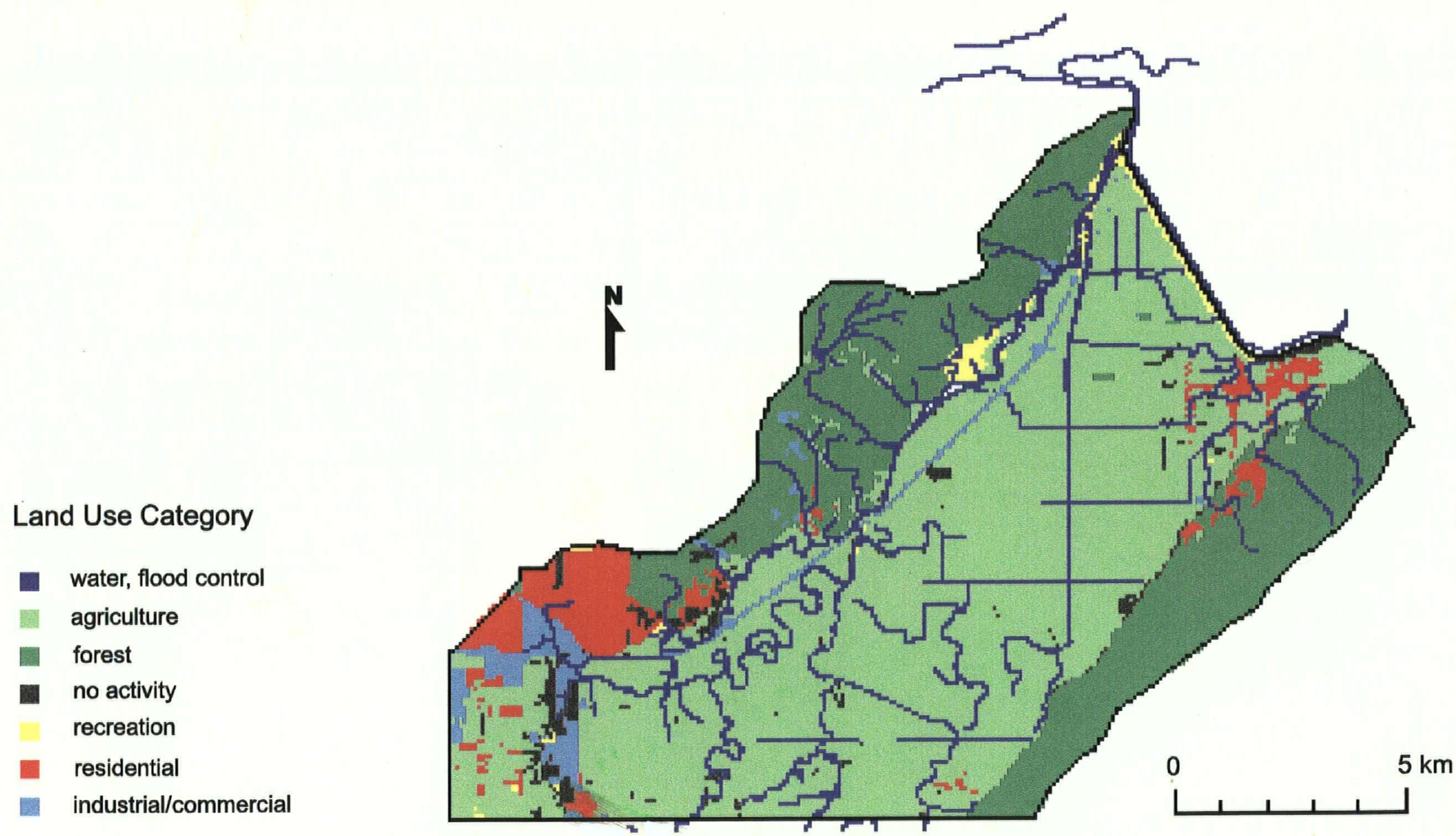


primary activity on the prairie, particularly in the more sandy areas of the floodplain. The last few years have seen a considerable rise in sod, hog and poultry production. The majority of the low lying land falls within the British Columbia Agricultural Land Reserve (ALR), and is therefore is not zoned for urban or industrial use.

Economic and demographic forces shape and define land use surrounding the ALR, as well as modify activity *within* the ALR, resulting in an ever-changing, dynamic watershed. This dynamism was largely evident during the study period, most notably expressed through subdivision activity on the slopes of Sumas mountain, industrial construction on the Sumas highway corridor, and new animal housing units on the Sumas prairie. Various "snapshots" of land use information for different years were compiled from census data and aerial photographs.

Generalized land use categories were used in the interpretation of aerial photos, available for the years 1954, 1963, 1979 and 1988 at a 1:10 000 scale. Land use polygons were digitized from the aerial photos into the GIS using the AP190 Analytical Plotter. Following the land use classification scheme used by the Ministry of Agriculture (Sawicki and Runka, 1986), the following generalized categories were used: 1) Agriculture; 2) Forest, which included areas being harvested; 3) None perceived, which were areas where no obvious activity was discernable and likely included lands kept for speculation;
4) Park/Recreation/Wetlands, which included wildlife parks, 5) Residential, which included the urban areas and agricultural communities with high residential densities, and
6) Commercial/Industrial, which included major transportation corridors, but did not include commercial cultivation of forest resources. The 1988 land use map is shown in Figure 2.3.

Figure 2.3 1988 Land Use in the Canadian Portion of the Sumas Watershed.
Source: 1:10 000 aerial photo interpretation.



Current land use information for Whatcom County was provided by the Whatcom County Planning Department. This consisted of a database of land parcel centroids with *x,y* coordinates, a land use code, and acreage for each land parcel. Table 2.1 presents the total hectares and percentage of the Canadian and U.S. portions of the watershed for each category. The Canada/U.S. border coincidentally divides the watershed into two roughly equal areas, and these areas have a very similar distribution of land use categories.

Table 2.1 Land Use in the Canadian and U.S. Portions of the Sumas Watershed

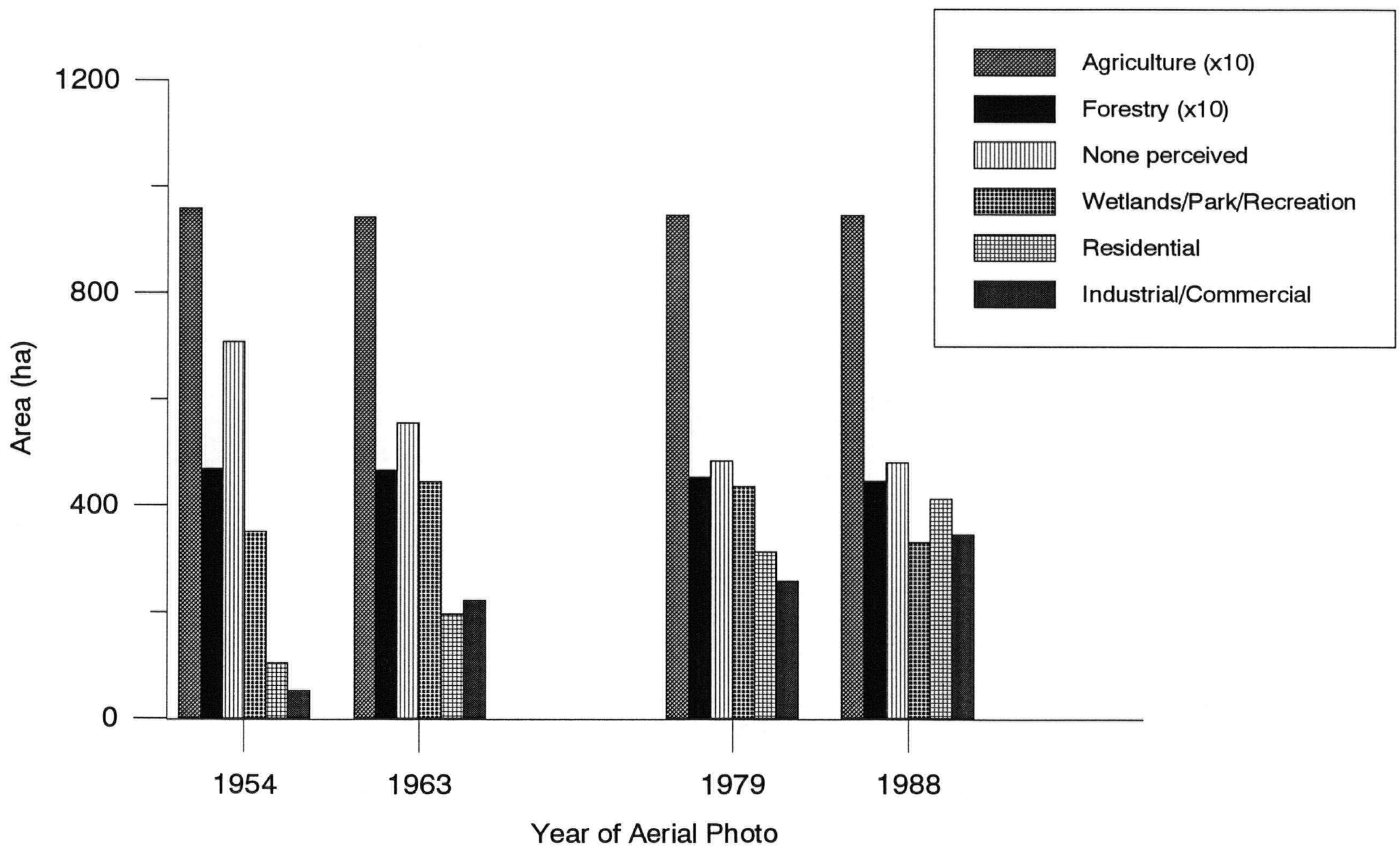
Category	**Area in Canada** (ha)	**% of Canadian Portion**	**Area in U.S.** (ha)	**% of U.S. Portion**
Agriculture	9851	59	9354	56
Forest	4463	27	5289	32
None perceived	494	3	548	3
Wetlands/Park/Recreatio	234	1	153	1
Residential	892	5	1143	7
Industrial/Commercial	550	3	297	2
Not coded	110	1	877	5
Total	16594	100	17661	100

2.3 Trends in Land Use

Land use maps for the Canadian portion of the watershed were also prepared for the years 1954, 1963, and 1979 on the GIS. Figure 2.4 shows the area of each land use category from one year to the next. Note that agriculture and forest areas are reduced by a factor of ten for illustration purposes.

The land areas under agriculture and forest, the two largest land uses in the watershed,

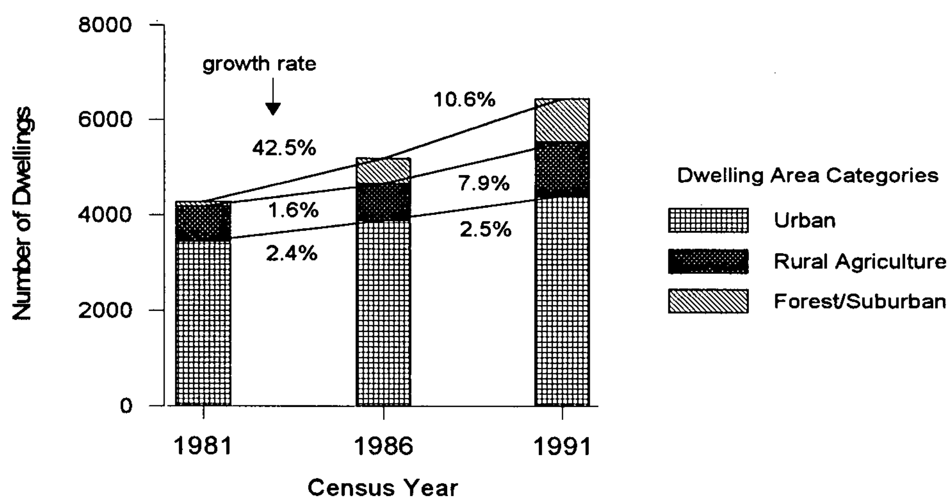
Figure 2.4 Land Use Changes 1954-1988: Canadian Portion of the Sumas Watershed
Source: 1:10 000 Aerial Photo interpretation.



change very little relative to the original areas. Residential and industrial/commercial areas increase by factors of 4 and 6.5 respectively, but still remain a relatively small portion of the whole watershed, as indicated in the 1988 land use map, Figure 2.3.

While illustrating the encroachment of urbanization into forest and agriculture, the preceding examination of land use categories does not indicate how land activity is changing within the categories. Population census data from 1981, 1986, and 1991, is shown below in terms of number of dwellings, to show increasing density of land use in the watershed. The census enumeration areas (EAs) were divided into three groups: urban, rural agriculture, and forest/suburban, which included the EAs which were previously forested but now contain new subdivisions. The highest growth rates are in this latter group, but more surprisingly, the rural agriculture group also exhibits fairly high growth rates. New subdivisions may be included in this group of EAs as well. The rate of growth in dwellings is high across all groups, indicating overall intensification of land use across the Canadian portion of the watershed.

Figure 2.5 Growth in Number of Dwellings from 1981-1991. Source: PCCensus.



2.4 Trends in Agricultural Land Use

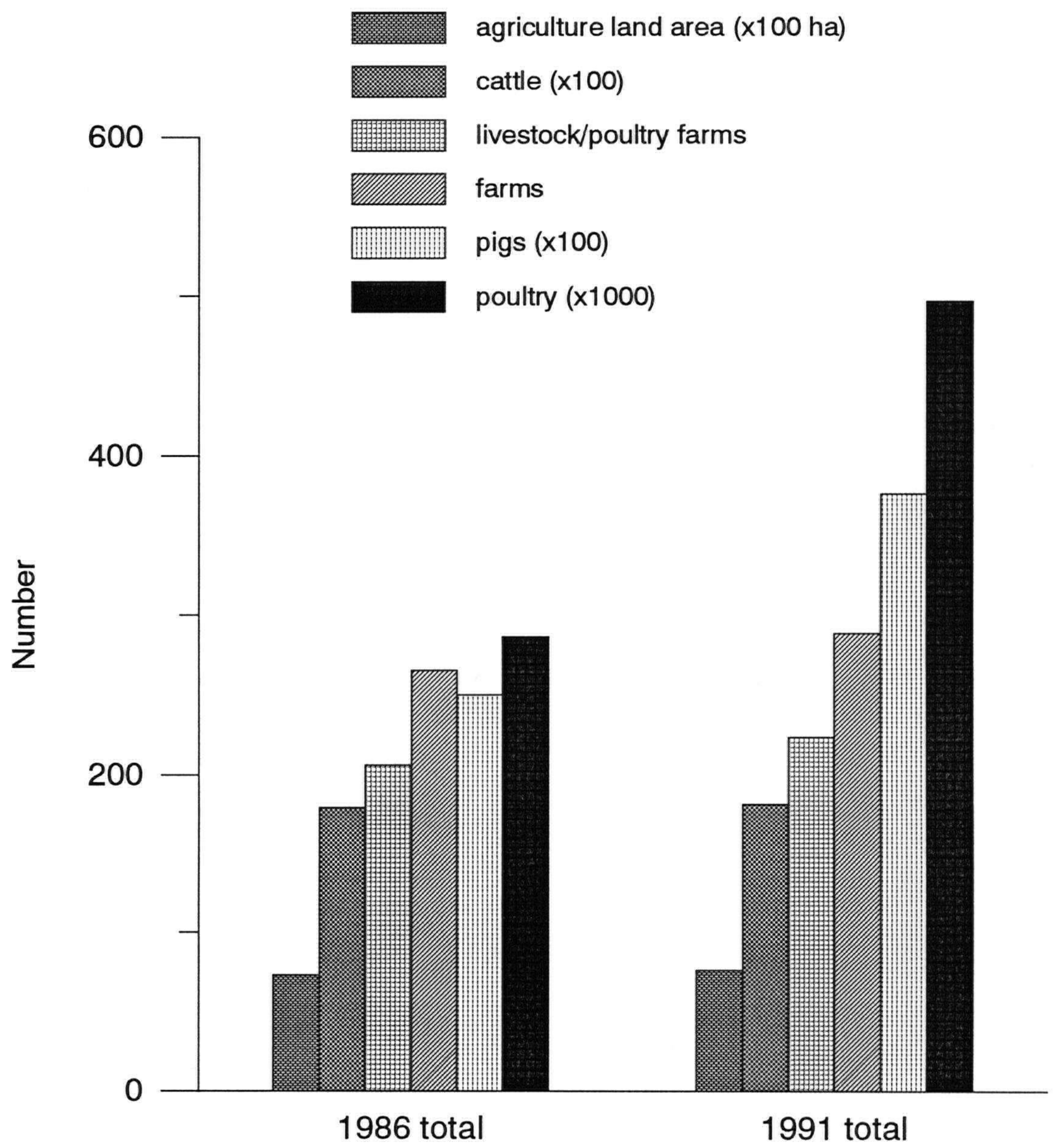
This thesis focusses on agricultural non-point source pollution, hence emphasis was placed on documenting agricultural land use trends. Using the series of aerial photos as a basis, large farms were digitized into the GIS, their approximate locations were identified by a symbol, and the year of the aerial photo in which the farm first appeared was noted. Windshield surveys supplied the locations of farms appearing after 1988. In this manner, the number of new farms added between years, and the rate of increase in farm numbers, were determined. Table 2.2 summarizes the results. Although the rate of increase in number of large farms is low, the steady increase over the years on a constant land base signifies an increased density of agricultural activity.

Table 2.2 Growth in Farm Numbers

Year	Farm Count	% increase/year
1954	224	-
1963	233	0.4
1979	248	0.4
1988	271	1.0
1994	283	0.7

Intensification is more dramatically illustrated by looking at changes between 1986 and 1991 Agriculture Census data, as presented in Figure 2.6. (Note the scale factors for land area, cattle, pig and poultry numbers.) Again, the land base remains constant while number of farms slightly increase between these years. However, while the number of cattle remains

Figure 2.6 Agriculture Census Totals, 1986 and 1991. The Census enumeration areas cover the Canadian portion of the Sumas Watershed only.



relatively constant, the number of pigs increase by about 50% and the number of poultry by about 75%, in just five years.

The windshield surveys conducted during the study period verified that new housing units for hog and poultry were being constructed, suggesting that numbers of these animal types are still on the rise. Although it has been estimated that broiler operations export 30-40% of the manure produced (Brisbin, 1995), the remainder of the manure, together with that from other types of poultry operations, the hog operations, and the dairy farms, is applied to the land. The soils and vegetation of this constant land base have a limited capacity to assimilate the increasing amounts of manure, resulting in a greater risk of contamination of the Sumas water resources.

2.5 Measures of Agricultural Activity

The problem of manure management is neither newly identified nor unique to the Sumas watershed. Many European countries have been struggling for years with the problem of too much manure, not enough land, and contaminated water resources. Technical and regulatory solutions, and the efforts put toward them, vary widely. No panacea has yet been developed which would effectively handle all economic, environmental and population growth issues associated with this non-point source problem. While this thesis confirms the existence of intense agricultural activity in the Sumas watershed, the main objective is to examine *how* the problem is related to water quality in the Sumas River. Measures of agricultural activity, including quantity of excess manure applied to the land, are needed for this examination.

2.5.1 Livestock Densities

One measure of agricultural intensity is livestock density, which is an animals-to-land area ratio. Animals are sometimes converted to animal unit equivalents (AUE), based on the amount of waste they generate or the pollution potential of the waste. The practice of converting animals to animal units, the conversion formula that is used, and the criteria used for regulation of manure application, varies between countries (Anderson et al., 1990). This thesis borrows conversion factors from the Ontario Agricultural Code of Practice (MOAF, 1976) which equates 1 dairy cow (plus calf) to 1 horse, 4 sheep, 125 laying hens, 1000 broiler chickens, etc. based on the amount of nitrogen in their manure. This type of conversion is useful when there are several types of animal operations common to a region, as in the Sumas watershed.

A measure of what is a reasonable density based on nitrogen content of the manure is required as a guideline when evaluating the densities calculated for the Sumas watershed. Denmark regulates the amount of nitrogen per hectare by restricting densities to 2.3 dairy cow units per hectare and 1.7 pig units per hectare (Anderson et al., 1990). Ontario suggests a range depending on soil types and operation size, with more forgiving densities for larger operations and operations on clay or loam. Their values range from 2.5 to 3.7 AUE/ha for small operations on clay/loam and sand respectively, and from 3.1 to 4.7 AUE/ha for large operations (MOAF, 1976). For the purposes of this thesis, 2.5 AUE per hectare is considered the value at which nitrogen application rates may be a valid concern. It is recognized that higher values may be reasonable on some soil types, but a conservative approach must be considered in light of the demonstrated growth in animal numbers occurring in the watershed.

2.5.2 Surplus Nitrogen

The abundance of manure in agricultural areas of the Lower Fraser Valley of British Columbia has not gone unnoticed by government agencies. An agricultural waste management steering committee has been established including representatives from the BC Ministry of Environment, Lands and Parks, the BC Federation of Agriculture, the BC Ministry of Agriculture, Fisheries and Food, Agriculture and Agri-Food Canada, and Westwater Research Centre (UBC). This group has recently guided a study on agricultural nutrient modelling in the Lower Fraser Valley (Brisbin, 1995). The nutrient model for nitrogen calculates the amount of surplus nitrogen being applied to the land using a mass balance approach. Sources of nitrogen, including inorganic fertilizers, atmospheric deposition, and livestock nutrient production, are reduced by crop uptake, volatilization and management losses, and the result is a surplus (or deficit) applied to the soil in kg N/ha/year. The model further estimates denitrification rates in the soil and the final losses of nitrogen to the atmosphere, surface water and groundwater. For a more complete description of the model, see Brisbin (1995); an excerpt of the report with the model methodology is given in Appendix I.

Brisbin's model has been adopted by Wernick (1996) for use in determining nitrogen flows in the Salmon River watershed, Langley, B.C. The methodology of this model can be described by considering a single farm. Firstly, manure production on the farm is calculated by multiplying the nitrogen production rates in kg/year for each type of animal manure by the number of each animal type on the farm. It is assumed that 30% of the broiler manure is exported in this calculation. Losses of nitrogen to the air, land and surface water via volatilization, infiltration and runoff, are estimated using manure management factors for each animal type developed by Brisbin (1995). Similar factors are used to estimate the total mass of manure nitrogen which will be applied to the land. This is added to the net crop requirements, which is the difference between the nitrogen applied as inorganic fertilizer and the estimated uptake of the crops on the farm. The crop uptake is based on nitrogen uptake rates for different crop types used in Brisbin (1995). Finally, an amount of nitrogen is added to account for atmospheric input, and an amount is subtracted to account for some denitrification of the manure nitrogen. The former is assumed to be the sum of an estimated background deposition of 9 kg/ha/year and a 30% return of the volatilized nitrogen calculated in the management losses. The denitrification loss is assumed to be 10% of the net manure applied. The final result of adding and subtracting all the sources and sinks of nitrogen is the mass of surplus nitrogen produced by the farm each year. This is converted to a loading by dividing by the area of the farm, or by the area reported under crops, which gives an even higher loading rate. In this thesis, the surplus nitrogen and the two loading rates were calculated by farm, by contributing areas to sampling stations, and for the watershed overall. A summary of the overall nitrogen balance calculated for the Canadian portion of the Sumas watershed using this model is outlined in Appendix J.

What is deemed "excessive" surplus nitrogen loading is a controversial and complicated issue, as some losses of nitrogen from soils through nutrient cycles is normal and expected. One way this issue is approached in Brisbin (1995) is by computing a rough potential dilution of the nitrogen in water in comparison to the 10 mg/L drinking water criterion for nitrate-N. This would be the concentration if 100 kg N/ha is diluted in 1 metre of water, which could be 1 metre of rainfall (a depth easily reached over one year in the Lower Fraser Valley), or one metre of groundwater recharge. Due to this reasoning, 100 kg surplus N/ha/year is the value used in this thesis to gauge "excessiveness".

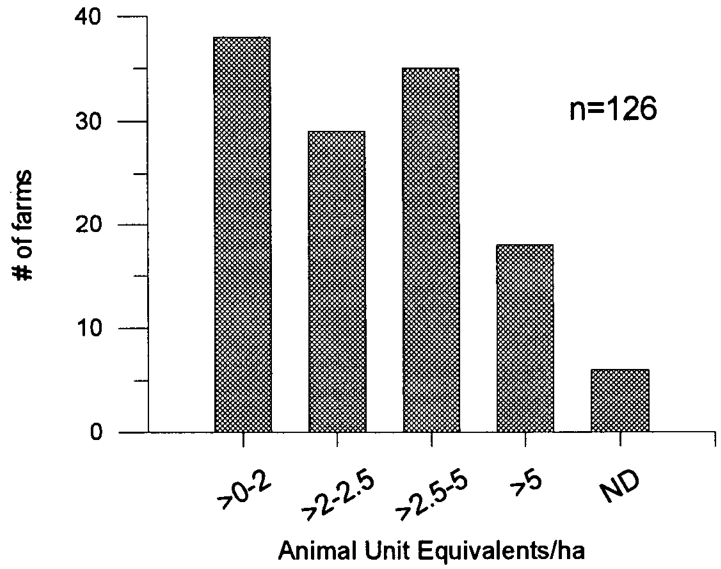
2.5.3 Livestock Densities and Surplus Nitrogen in the Sumas Watershed

Animal numbers for individual farms in the Sumas Prairie were obtained from a Waste Management Survey (WMS) conducted by Integrated Resource Consultants (IRC) in the winter of 1993/1994, under contract to the B.C. Ministry of Environment and Environment Canada. This survey also provided crop information and the geographical location of 132 unique farm locations as determined by a global positioning system (GPS) unit. Farms which did not participate in the WMS (an additional 156 farms) were identified on the aerial photos and field checked to determine the type of operation. These farms were then given average values of size and animal numbers as calculated from the WMS farms by operation type. If the farms surveyed included all the largest farms, then the average values applied to the other farms may be slightly high. However, because the surplus nitrogen loading calculated is roughly the same magnitude as those calculated for the Abbotsford area by Brisbin, and by using the 1991 Census data (see Appenix J), it is believed that the resulting AUE densities and nitrogen balances calculated are reasonable estimates for the watershed. Chapter 5 will also illustrate that smaller areas within the watershed can have much higher densities and surplus loading rates than indicated by the overall figures.

Using the census data, the AUE/farmed ha was calculated to be 3 AUE/farmed ha. Using WMS data for the watershed, plus the WMS averages, the livestock density was calculated to be 2.3 AUE/farmed ha. In the Whatcom County portion of the Sumas watershed, the density was estimated as 1.6 AUE/farmed ha overall. According to the latter two estimates, the densities are not too high, if the value of 2.5 AUE/ha is used as the criterion (see Section 2.5.1). This may well be the case if all the animal manure is equitably spread over all agricultural land within the watershed. However, this is not practically the case. Farmers in general spread on their own land, on land that they rent, and very occasionally on their neighbours' land by special agreement (IRC, 1994 and C. Timblin, pers. comm.). In almost all cases the land is nearby, as it is often impractical and/or uneconomical to transport the manure. Thus some farmed lands in the watershed may receive much less manure than other lands. To illustrate the fact, animal densities were calculated on a farm by farm basis, using the WMS data. Of the WMS farms, 126 were reportedly animal operations. Figure 2.7 shows the number of farms that fall into AUE density ranges from 0 to 5 and above AUE/ha (ND=Not enough Data). About 50% of the farms have densities below, while about 40% have densities above 2.5 AUE/ha. Moreover, at least 40% of the farms below the gauge value of 2.5 are in the 2-2.5 range, which means that many of these farms will approach more critical density levels if animal numbers continue to increase.

In the Whatcom County portion of the watershed, the overall AUE/farmed ha was estimated to be 1.6. Again, the same argument as above applies. Although farm densities could not be calculated with the data available, the Whatcom County Conservation District was able to provide herd sizes and acreages for 14 of the 65 dairy farms (Timblin, C., pers. comm.). The livestock densities calculated for these farms ranged from 2.6 to 7.8 dairy cows per ha, with an average of 5.4 cows per hectare. Animal densities tend to be higher on U.S. farms because they are not restricted by a quota system as are Canadian farms.

Figure 2.7 Frequency of Animal Densities by Farm in the Canadian Portion of the Sumas Watershed. Source: Waste Management Survey (IRC, 1994). ND= no data.

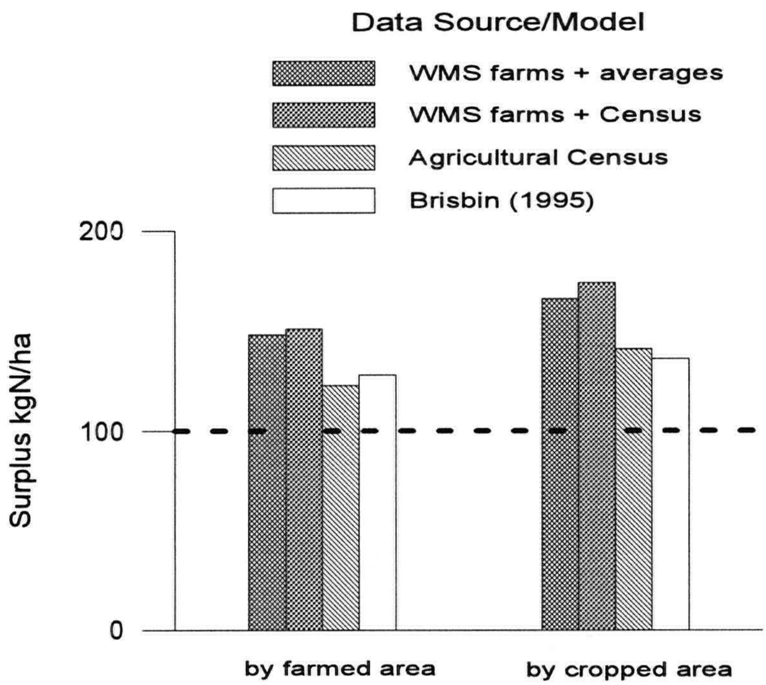


Herd sizes of 600 to 1000 are common, while in the Canadian Sumas watershed, dairy farms of this size are still relatively rare. However, competition with US production, to which the Canadian Sumas dairy farmers are sensitive, is steadily driving up Canadian herd sizes. Up to 700 head are now found in several barns on the Sumas Prairie (Wright, F., pers. comm.).

The nitrogen balance summary in Appendix J shows the surplus nitrogen loading for the Sumas area, in Canada, computed using different data sources. These values are represented by the bar graph in Figure 2.8. The first bar represents the loading computed using the data from the WMS farms and the averages of these farms applied to the missing farms identified in the aerial photographs. For the second bar, WMS averages were not used. Instead, the GIS was queried to determine which WMS farms fell within each agricultural census enumeration area. The total surplus nitrogen produced by the farms within one enumeration area was subtracted from the total surplus nitrogen estimated for that enumeration area. The difference was then distributed evenly over the watershed agricultural area within the enumeration area which was not accounted for by the WMS farms. This procedure was repeated for all the enumeration areas which overlapped with the watershed, and the summation produced a final nitrogen surplus for the watershed which theoretically included the farms missing from the WMS database. The third bar uses only census data from all the enumeration areas which overlap with the watershed, and represents the area covered by the enumeration areas which is much larger than the Canadian portion of the watershed. The final bar represents surplus nitrogen values computed by Brisbin for large and small farms added together. The Abbotsford study area in Brisbin's report includes, but covers a greater area than, the Canadian Sumas watershed. These four different values are shown to illustrate the effort carried out in this thesis work to compute quantities in different ways, using available data sources, as a method of double-checking results. In the complicated and inaccurate task of computing nitrogen budgets, accurate and precise values, although desirable, are not necessary to identify a trend. In this case, all four estimates are in roughly the same range, and all are near or above the 100 kg surplus N/ha gauge value discussed in Section 2.5.2. The overall surplus nitrogen loading calculated for the Whatcom County portion of the watershed is 68 kg/ha. As discussed in the case of AUE densities, this value is likely not indicative of the loadings on more localized areas.

The impacts to the environment and human and animal health from excess nitrogen are well documented in the literature. The impacts to surface water are dependent not only on surplus nitrogen loadings, but on timing of application, amount and intensity of rainfall, soil properties and various management factors, including tillage, crop residue, and cropping systems (Owens, 1994).

Figure 2.8 Surplus Nitrogen Loading Estimates for the Canadian Sumas Watershed/Region.



Projects carried out by the Sumas Soil Conservation Society with various Producer Groups in the Sumas watershed, and the studies guided by the Agricultural Waste Management Steering Committee, attempt to address problems due to runoff and excess nitrogen loadings. The people involved, many of whom work on the land and in the watershed daily, understand the problems well. However, due to the diffuse nature of non-point source pollution, economic pressures, public resistance to regulations, and the difficulty of regulation enforcement, the solutions to the problems remain elusive. By looking at water quality and its relationships with some quantifiable agricultural land use indices, it is hoped that the work presented here will add to the knowledge base and help to target solutions.

3.0 Water Resources in the Sumas River Watershed

3.1 Climate

The weather in the Sumas River watershed is dominated by low pressure systems, particularly in the winter, bringing heavy rains and flooding. Snow and freezing temperatures are occasionally brought by polar air in the winter. Clear skies, warm temperatures and low rainfall predominate in July and August when high pressure systems are more common. During this time, soil moisture deficiencies often develop and irrigation is required to promote high crop yields (ESL and Webb, 1987; Halstead, 1986).

3.1.1 Precipitation

Approximately 75% of precipitation in the Lower Fraser Mainland falls between the months of October to March (Halstead, 1986). This wet period is evident in the hyetographs and cumulative precipitation graphs in Figures 3.1 and 3.2, which show average precipitation data for a 10 year period, and precipitation data for the study period of this thesis (March 1994 to February 1995). Water sampling dates are shown with the latter data. The total precipitation for 1994 was approximately equivalent to the 10 year average of about 1500 mm, yet the summer of 1994 was dryer than the 10 year average. The steep sections on the cumulative precipitation graphs illustrate the wet season period, while the flatter sections show the dry season. Water samples representative of both seasons were collected, and, as is illustrated in the study period hyetograph, samples were collected during a March 1994 and a February 1995 storm.

Figure 3.1 1994 Daily Precipitation and 1984-1994 Average Daily Precipitation Abbotsford Airport, AES gauge.

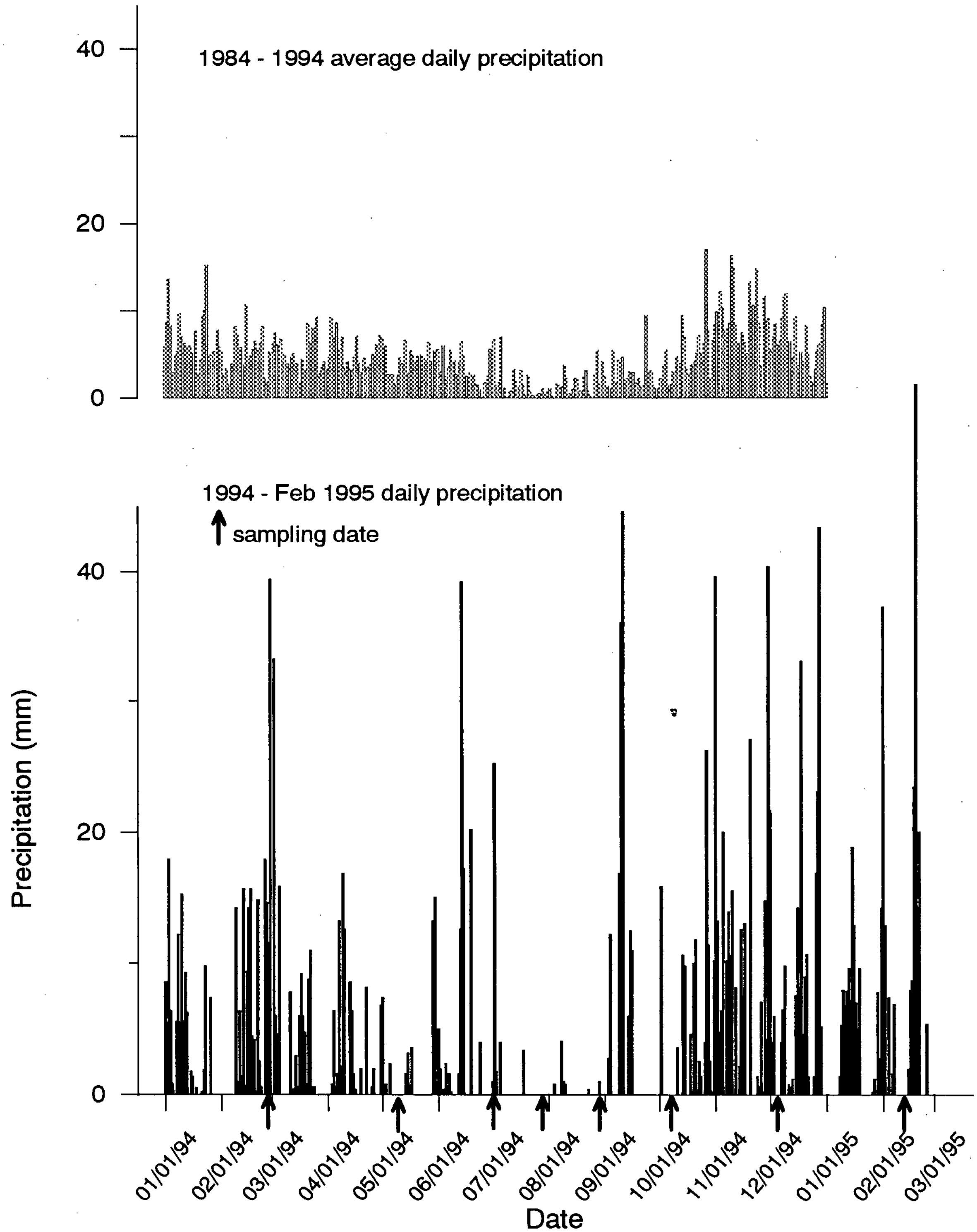
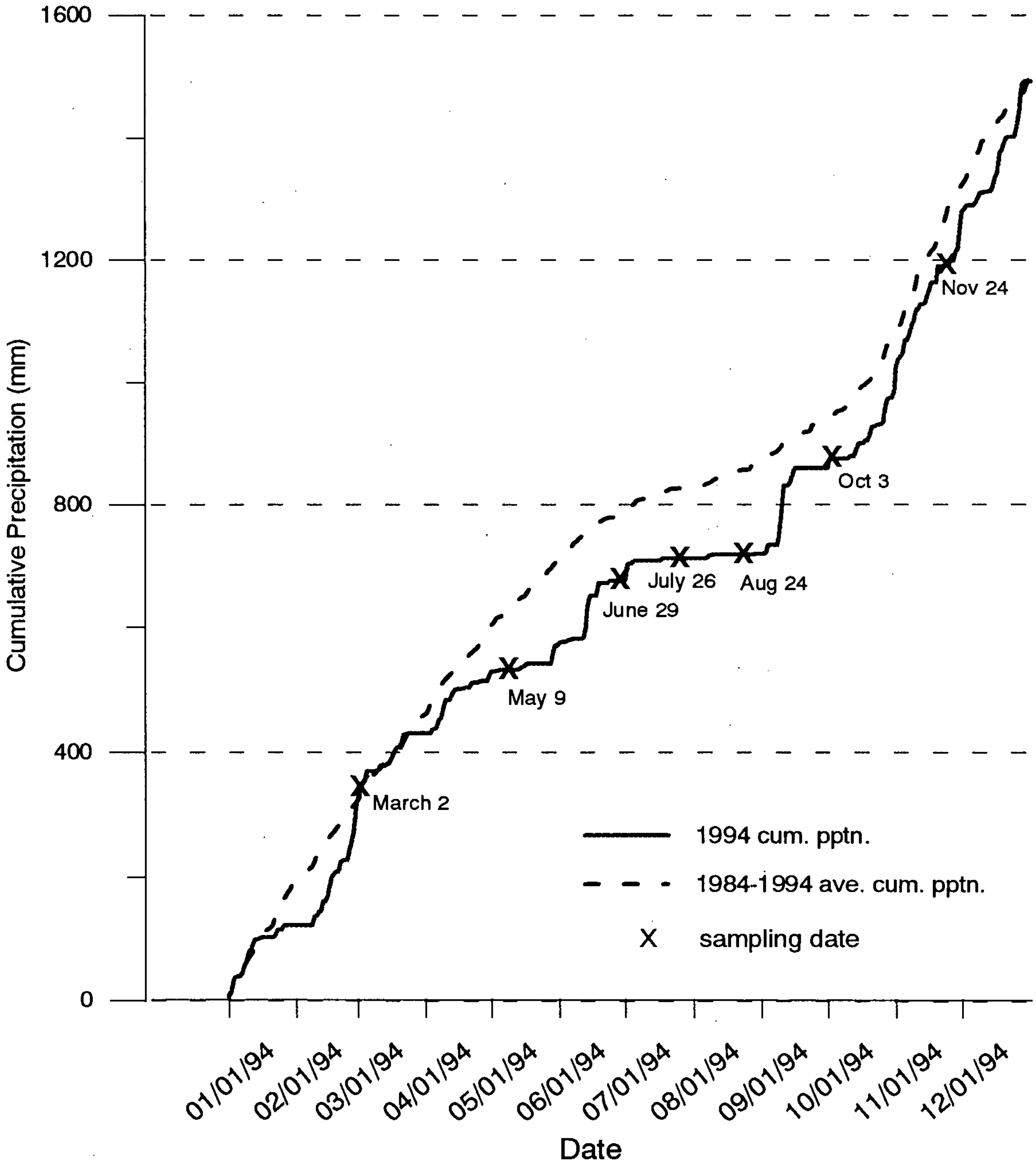


Figure 3.2 1994 Cumulative Precipitation and 1984-1994 Average Cumulative Precipitation. Abbotsford Airport, AES gauge.



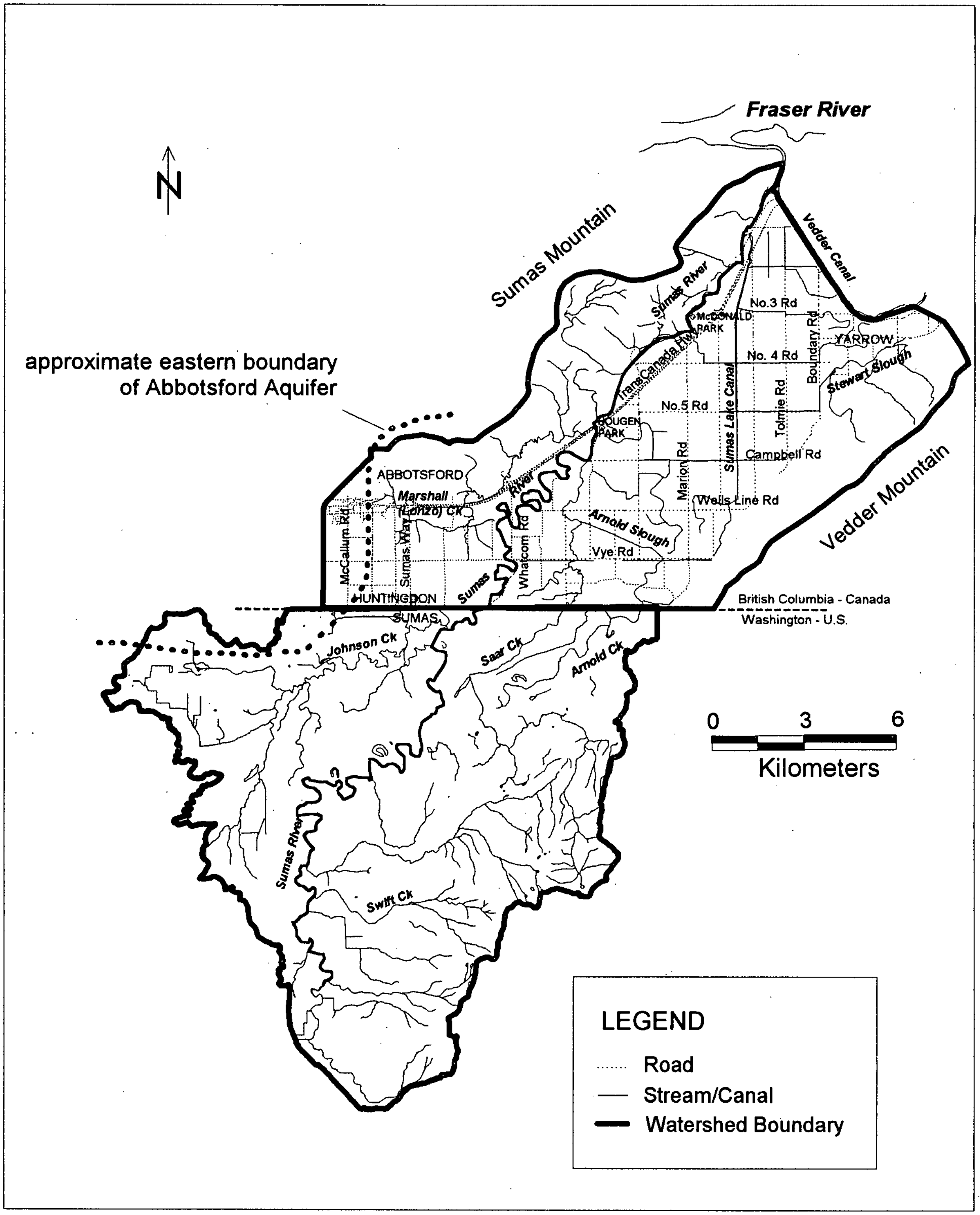
3.2 River and Drainage Network

3.2.1 General

The stream network for the Sumas River watershed is shown in Figure 3.3. The total drainage area of the Sumas River system is approximately 34 255 ha, roughly half of which exists in Canada, and half in Whatcom County, U.S. A large lake of over 8000 ha once occupied the Sumas floodplain, accepting flows from Saar Creek and the Sumas and Vedder Rivers (US Army COE, 1993). The lake was reclaimed in 1925 so that the land could be farmed. The Sumas Lake Reclamation Project included the "construction of the Vedder Canal, the Sumas Pump Station...the diversion of the Sumas River along with four creeks, and the momentous task of the construction of over 40 km of flood protection dykes" (District of Abbotsford, June 1993). The Barrowtown Pump Station, including an earthfill dam and upgraded dyke, replaced the Sumas Pump Station in 1984 to provide improved flood protection, drainage and irrigation.

The old lake bottom is now drained by the Sumas Lake Canal and pumped into the Sumas River downstream of the dam. A network of ditches convey runoff from within the dyked area, including runoff from Vedder Mountain and the town of Yarrow via Stewart Slough, to the Sumas Lake Canal. The ditches are an important source of irrigation water during the dry season, with water licences having been granted to a large number of land owners (Harris, 1990). The irrigation and industrial licences in the Sumas River system can demand a very large part of summer low flows (NHC and Hamilton, 1994). Sedimentation in the ditches and channels is an ongoing problem requiring annual maintenance, including cleaning and deepening, to ensure adequate drainage and irrigation performance. A major

Figure 3.3 The Sumas River System



dredging project for removal of substrate in the lower Sumas River (downstream of the Trans Canada crossing) was undertaken in 1987 to increase the capacity of the channel and minimize winter flooding problems (ESL and Webb, 1987).

Normal flows of the Sumas River and its tributaries drain by gravity to the Fraser River through a floodbox in the dam beside the Barrowtown Pump Station. Flow through the floodbox is controlled by the electro-hydraulic operation of a steel gate (KPA, 1987). Two irrigation inlets from the Sumas River provide water to the Sumas Prairie. Both surface and sub-irrigation methods are used in the Prairie. The reclaimed lake, system of dykes, and other facilities of this complex hydraulic system function similarly to the polders commonly farmed in the Netherlands. Since Dutch settlers had moved into the area before the draining of the lake, this transfer of technology is not surprising.

The Sumas River mainstem is dyked along its south bank to the confluence with Saar Creek (the dyke continues along Saar Creek and then Arnold Slough) to protect the low-lying area to the east from flooding. This downstream portion of the Sumas River mainstem is characterized as slough-like, with approximately a 0.02 percent gradient. High water temperatures are known to occur in the summer months due to the low water velocities. The channel is wide, typically 100 m across with sections reaching 250 m, and the substrate is predominantly silt. From Saar Creek to Vye Road, the channel becomes narrower (40 to 60 m) and meanders through farm land with a more visible current. Small gravel is the predominant bed material, and the water is generally clearer with more abundant tree cover. Although the gradient is still approximately 0.02 percent, the backwater effect from the Barrowtown Dam (see Section 3.2.2) is diminished here resulting in more evident stream flow. Between Vye Road and the U.S. border, the channel gradient increases to 0.06 percent, and the width is generally less than 45 m. The bed material varies from fines in the glide areas to small gravel in the pools and riffles (ESL and Webb, 1987).

The Sumas River mainstem, Saar Creek and Arnold Creek all originate in Whatcom County, U.S. There the Sumas mainstem is meandering with low stream gradients and joined by numerous tributaries and creeks. Of particular significance is Swift Creek which carries very fine sediment from a natural landslide in its headwaters to the Sumas River (Schreier, 1986). Consequently, the mainstem river bed is filled with this sediment below the confluence of Swift Creek (ESL and Webb, 1987). The principal tributary to the Sumas River in Whatcom County is Johnson Creek, which joins the Sumas River near the town of Sumas.

Marshall (or Lonzo) Creek is the main tributary within Canada on the north side of the Sumas River. This creek originates from groundwater springs flowing from a ridge (ESL and Webb, 1987) near the western boundary of the watershed, or approximately the eastern edge of the Abbotsford aquifer. In the summer months, the downstream sections of Marshall Creek are also subject to backwatering from operation of the Barrowtown Pump Station.

3.2.2 Annual Flow Regime

Around mid-May, or at the start of the Fraser freshet, the floodbox gates at the Barrowtown Pump Station are closed and water from the Sumas River is pumped to the downstream side of the dam. This prevents Fraser flood backwater from entering the Sumas River (US Army COE, 1993). The gates remain closed to provide irrigation water for farm land in the Sumas Prairie until September 15, the official start of the salmon spawning period. While the gates are closed, backwatering from the dam results in almost no visible flows in the

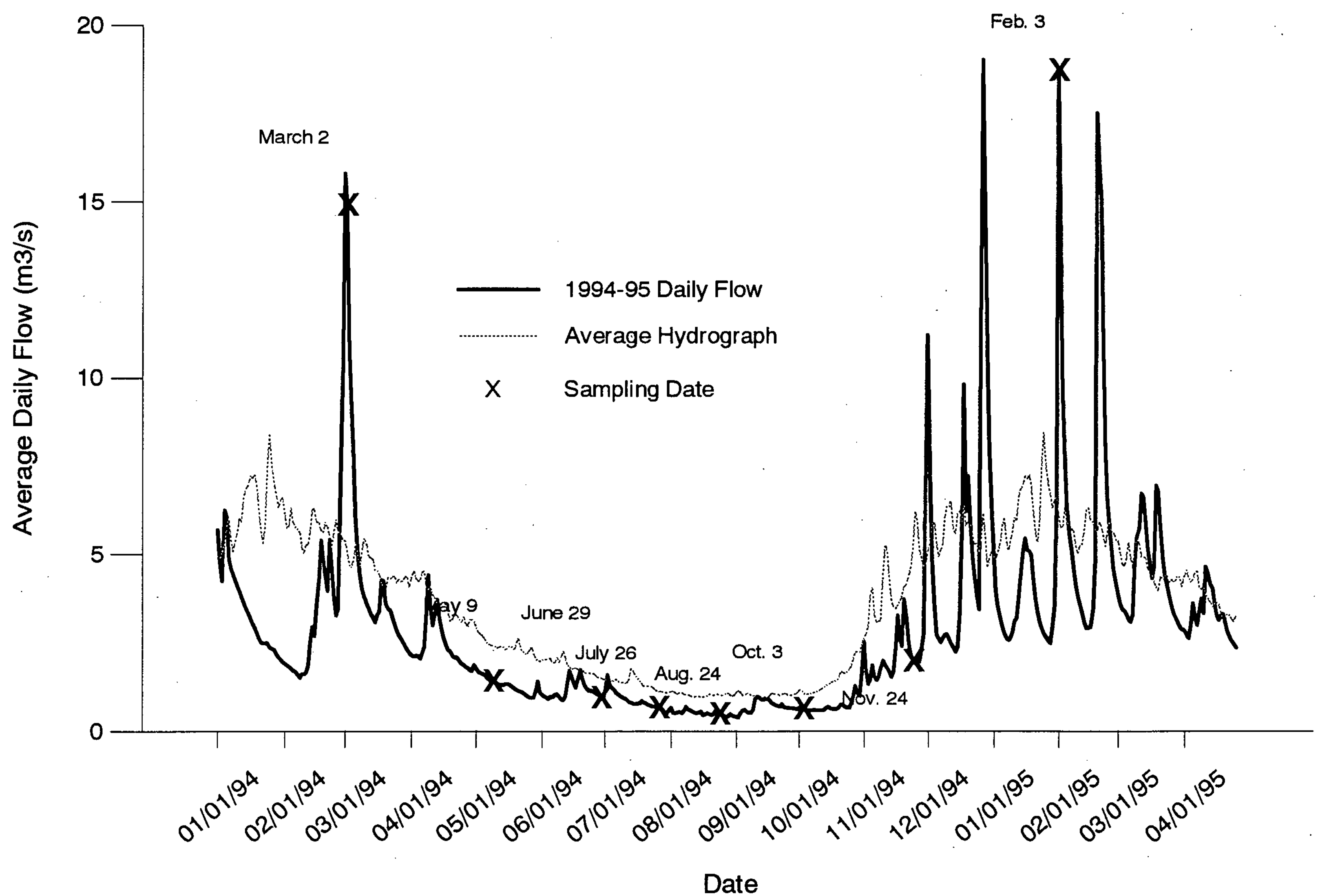
Sumas River from the Barrowtown Pump Station to several kilometres upstream of Hougen Park (ESL and Webb, 1987). Over the winter, the floodbox gates are normally left open and the water level in the Sumas River is generally below an elevation of +3 metres. However, if levels in the Fraser or Vedder Canal rise to an elevation of +3.5 metres within a few hours, then the floodbox gates are closed to prevent flooding of the Sumas River (KPA, 1987).

The only current flow gauge on the Sumas River system is one maintained by the Water Survey of Canada at the Sumas River border crossing near Huntingdon. Figure 3.4 shows the average annual hydrograph determined from average daily flow rates measured from 1952 to 1994 at this gauge. Also shown is the hydrograph for the 1994-95 period of sampling. Again, water sampling was conducted during low flow in the dry season and also during high flow events in the wet season. Flow during the summer of 1994 was generally lower than the 40 year average. The average of daily flows over the 40 year period varied from approximately 1 to 8 m^3/s.

3.2.3 Flooding

Flooding of the Sumas Prairie is a frequent occurrence and has a wide range of consequences. Not only are there major flood damage costs, but also major economic and logistical ramifications due to potential highway closures and emergency evacuations of many thousands of animals. There are also potential human and environmental health consequences due to animal mortalities and pollution from animal waste facilities. Records from 1876 to before the Sumas Lake was drained, indicate that the Sumas Prairie was flooded on four occasions from the Fraser River, and three times from a Nooksack River overflow from the south. The construction of the pump station and dykes have since prevented flooding from

Figure 3.4 Average Annual Hydrograph and 1994/1995 Hydrograph
Sumas River at Huntingdon border crossing. Sampling dates shown with an X.



the Fraser River. However, these facilities were not designed to handle additional floodwaters from Nooksack River overflows. Flood protection from these facilities relies on the assumption that the volume of floodwater from the Sumas drainage is relatively small compared to backflooding from the Vedder and Fraser Rivers (Cook, 1995; US Army COE, 1993).

The Nooksack overflow occurs because the Sumas River shares a portion of its watershed with that of the Nooksack River due to the flat topography between them. As a result, the western portion of the Sumas Prairie, which is not protected by dykes, has been inundated to varying extents by Nooksack overflows on 12 separate occasions since the lake was drained. Four of these floods (two in 1990) have occurred within the last 10 years. The frequency of overflows appears to be increasing, the suspected cause being the aggredation of sediment in the Nooksack channel due to the cessation of gravel mining in this river twenty years ago. Flooding of the West Sumas Prairie is often exacerbated by: 1) backwater in the Sumas River when it is constrained at the floodgates due to high Fraser and Vedder water levels; and/or 2) local storm and snowmelt events which may themselves cause localized flooding in the Prairie. In addition, it has been estimated that a major overflow could cause an avulsion (a permanent change in the direction of river flow) with catastrophic consequences. An International Task Force has been in place since 1991 to investigate the flooding issues of the Sumas Prairie and recommend various solutions. Whatcom County also initiated a Comprehensive Flood Hazard Management Plan, due for completion in 1996, which includes Nooksack overflow mitigation considerations. (Sellars et al., 1991; Cook, 1995; US Army

COE, 1993; District of Abbotsford, June 1993; Klohn Leonoff, 1989, 1991 and 1993; Task Force, 1991 and 1994.)

3.2.4 Groundwater Resources

The Sumas Prairie is unusual in that it is a rural agricultural area serviced with drinking water by the city system. This water comes from the City of Abbotsford's wells located on the Abbotsford aquifer (ERM, 1992), the eastern portion of which lies in the watershed study area (see Figure 3.3). A steep escarpment extending north-south parallel to Sumas Way shows the visible extent of the glaciofluvial sand and gravel deposit, called the Sumas Drift, which comprises the Abbotsford aquifer. The eastern parts of the aquifer are also known to contain glacial till and clay components. Half of this 200 km^2 aquifer lies in Canada, and half in Washington State (Liebscher et al., 1992). Flow in the aquifer is mainly in a southerly direction into the Nooksack River system in Washington. However, groundwater flow from the aquifer is in several directions, including significant discharges to the east into Marshall (Lonzo) Creek, formerly via a series of large springs (BC MOELP and EC, 1994). Halstead (1986) estimated the total discharge to all springs, prior to the development of high yield wells, to be 8.3 M m^3/yr. The annual recharge of the aquifer is estimated to be 26.8 M m^3/yr (BC MOELP and EC, 1994).

This is a very important aquifer, supplying industrial and municipal drinking water to the City of Abbotsford (approximately 4 M m^3/yr); domestic and irrigation water to farms situated on the aquifer (approximately 3 M m^3/yr); and water supply to the Fraser Valley Trout Hatchery (approximately 3.7 M m^3/yr), located below the aquifer escarpment (BC MOELP and EC, 1994). The aquifer is of significance to the Sumas River system in several ways. Firstly, it is an example of agricultural land use practices causing nitrate and pesticide contamination of a water resource. In one region of the aquifer, 60% of the water samples collected had nitrate-N concentrations which exceeded the 10 mg/L acceptable maximum concentration for drinking water. Contamination by nitrate also signals the potential for contamination by other pollutants (Liebscher et al., 1992). Secondly, the Sumas Prairie depends on the Abbotsford aquifer for its drinking water.

Because Marshall Creek is fed by springs from this aquifer, the water quality of the Sumas River system is affected by water quality conditions within the aquifer. Furthermore, there has been a steady decline since 1982 of water levels in nearby observation wells noted by the Fraser Valley Trout Hatchery (BC MOELP and EC, 1994). If in fact the aquifer is being "mined", this may result in a reduction of flow in Marshall Creek, and thus a reduction in dilution potential for contaminants entering the stream. Because ground and surface water interactions are complex, both quantitatively and qualitatively, it is difficult to postulate further on the influence of the Abbotsford aquifer on the Sumas system without the appropriate monitoring and modelling studies.

Other groundwater resources in the Sumas River watershed include groundwater which occurs on Sumas Mountain in sand and gravel formations, or in fractured, fissured or weathered bedrock aquifers. However, wells in these locations are generally shallow with low yields. There are also shallow and relatively low yield wells at the base of Sumas Mountain where significant sand and gravel deposits exist as old beach deposits from the previous lake, or in alluvial fans of major creeks from Sumas Mountain (ERM, 1992). The land in the areas of these other groundwater resources are not intensively farmed. However, the potential of groundwater development beneath the Sumas Prairie has been considered. It is believed that beneath the 240 m or so of silt and clay lie substantial sand and gravel deposits from a pre-glacial and/or glacial Fraser River route. Deep gas wells have found sand and gravel deposits at over 300 m, but the water at this depth was found to be slightly brackish. A deep test/production well would be required to properly determine the potential to produce drinking water (ERM, 1992). If groundwater production were to be pursued in this area, impacts from land activities would likely be minimal and difficult to detect, due to the overlying layer of silt and clay and the extreme depth of the sand and gravel deposits.

3.2.5 Discharge Permits

Water quality investigations for non-point source pollution should not neglect known point sources of potential contamination. The permit database for the Lower Mainland, maintained by the B.C. Ministry of Environment, Lands and Parks, Environmental Protection Branch, was reviewed to determine all permitted discharges into the Sumas River System. Three active effluent permits were identified, and one cancelled permit was also found. These permits, each unique in their terms and conditions, are briefly described below. In Whatcom County, the major point source is the sewage treatment plant for the town of Sumas.

The cancelled permit (permit number PE-8618) belonged to Shell Canada Products Ltd. for discharging "from a petroleum products bulk marketing facility...to Marshall Creek via a drainage ditch". The permit limited effluent flow and stipulated concentration limits of total extractable hydrocarbons. Grab sampling and reporting of results was required. However, according to MOELP staff, this permit was cancelled because of a change in permitting regulations. Under the new regulations, the site was not required to have a permit, although the practices remained the same. Although there was likely good reason for the regulation changes, this example serves as a reminder that the potential for pollution exists from sites not regulated by governments, whether it be from industrial, agricultural, residential or other sites, and of the non-point or point source nature.

Fraser Valley Milk Producers has a permit (permit number PE-4608) to discharge cooling waters from an evaporated milk plant located near the Trans Canada/Sumas Way interchange, to an unnamed tributary of Marshall (Lonzo) Creek. The quantity and temperature are limited to 2300 m^3/day and 23 °C respectively, and a report of monthly measurements of these characteristics is provided to the Ministry every year. No other water quality characteristics are reported.

More parameters were required to be monitored by Coaspac Meat Ltd., which discharged slaughterhouse effluent to a field which contains a ditch tributary to the Marshall (Lonzo) Creek system. Biochemical oxygen demand (BOD), ammonia-nitrogen, pH, and temperature were measured in the ditch once per year upstream and dowstream of the field site. In the five years of data available at the Ministry office, only ammonia levels in the ditch showed the tendency to increase after flowing through the field. These increases, and overall values, were fairly low. The lowest upstream value measured was <0.1 mg/L, while the highest downstream value of ammonia was 3.5 mg/L. These values are within the range measured throughout the Sumas system during this thesis work, and generally within criteria levels, both of which are given in section 4.4.2. The maximum measured discharge of effluent to the field was 0.3 m^3/day and the monthly average was 4.5 m^3/month. While the runoff from this field may have represented a point source of pollution, it was believed that the unalarming values together with the discovery that this plant apparently shut down in April 1994, just one month after this study's sampling was begun, likely meant that the plant's activity did not influence this study to a significant degree.

The major point discharges to the Sumas River system are from the Fraser Valley Trout Hatchery (permit number PE-1726), which discharges to Marshall (Lonzo) Creek, and the town of Sumas wastewater treatment system, located approximately 300 m upstream of the border along the Sumas mainstem. The Trout Hatchery obtains its water from a well tapping the Abbotsford aquifer, and discharges approximately 7000-16000 m^3/day to a lagoon which flows into Marshall (Lonzo) Creek. Samples are taken once every three months of the well water and at the discharge to Marshall (Lonzo) Creek. A wide spectrum of parameters are measured. Generally, the hatchery does not have problems meeting any of the permit level requirements. The interesting exception is the permit level for nitrate-nitrogen, which is 10 mg/L. During the period of investigation for this thesis, the hatchery was in the process of having the permit amended because the water supplied from the well itself exceeded the nitrate levels permitted to be discharged by the hatchery. In this respect, nitrate contamination of the Abbotsford aquifer is decidedly impacting the water quality of Marshall (Lonzo) Creek, since the hatchery pumps water out of the aquifer and drains it to the Creek. The lagoon, however, may provide some treatment of this water.

Water quality problems in the Sumas mainstem may cause one to suspect the town of Sumas wastewater treatment plant, which discharges to the Sumas River approximately 300 m south of the border. However, the facility is monitored daily to ensure that adequate treatment of the sewage is occurring and the levels meet the criteria of the Washington State

Department of Ecology (DOE). Water quality problems recorded in the Sumas River, including low dissolved oxygen levels and high fecal coliform levels, are attributed to non-point pollution from agricultural practices. Before the implementation of Best Management Practices (BMP's) for controlling non-point agricultural pollution in Johnson Creek, the DOE monitored the water quality in this creek in 1980/81 and 1988/89. They found conditions similar or worse than in the Sumas mainstem downstream of the treatment plant (KCM, 1990).

3.3 Fisheries and Wildlife

Inventories of fish habitat and wildlife resources provide useful information regarding the health of an ecosystem. Physical habitat for salmonid fish resources was rated low to moderate for the Sumas reach of the Barrowtown Pump Station to Saar Creek. The quality of habitat improves as one moves further upstream, with the 2-3 km reach just downstream of the international border possessing the highest quality habitat in the Canadian portion of the Sumas River. Saar Creek is considered to have good fish habitat in the U.S. upper reaches, with gravel substrate, a high gradient, and overhanging vegetation. However, during the summer, the Canadian portion of this creek has low levels of dissolved oxygen and high water temperatures, creating very poor rearing habitat for salmonids. Arnold Creek also has poor habitat throughout its stretch for similar reasons, and also due to a silty stream substrate (ESL and Webb, 1987). Marshall Creek has been identified and targeted as having a high potential for enhancement work in the Canadian portion of the system (Klassen et al., 1995). The substrates are predominantly fines mixed with small gravel, there is abundant vegetative cover, and the water generally has low temperatures and turbidity, and adequate levels of dissolved oxygen. The Fraser Valley Trout Hatchery is located in the headwaters of Marshall Creek and has released steelhead and cutthroat trout into the creek since 1978 (ESL and Webb, 1987).

The highest quality fish habitat on the Sumas system overall occurs in the U.S. headwaters, particularly in the many tributary creeks. Problems are encountered, as in Canada, with cattle entering streams, manure storage practices, fish blockages, channelization of creeks, and loss of riparian vegetation. The Washington Department of Fisheries has focused enhancement work on the tributary streams, particularly Johnson Creek, as the Sumas mainstem has been filled by sediment from Swift Creek and is subject to yearly flooding (ESL and Webb, 1987).

The species present in the Sumas River system include coho, chum and pink salmon, steelhead and cutthroat trout, and non-salmonids such as sturgeons, carp, lampreys, whitefish, sculpins and stickleback. The chum and pink salmon spawn in the lower reaches of the Sumas mainstem while the coho spawn mainly in the U.S. headwaters and the steelhead spawn in the upper reaches. Stewart Slough and the upper reaches of Marshall Creek are also popular spawning grounds for coho, chum, steelhead and cutthroat trout. Arnold Slough supports no spawning, and a little rearing outside the summer months. Rearing habitat during the summer months is in general limited to the upper tributaries of the system due to high temperatures and low levels of dissolved oxygen. Migration and spawning activities for the salmon species generally begin in October and may last until January (DFO, 1995). The timing of migration and spawning is particularly important considering the seasonal variation in water quality as discussed in Section 4.4.2. It has also been noted that coho migrations occur as distinct runs which generally occur in conjunction with significant rainfall events (ESL and Webb, 1987).

Agricultural land use occurs along 91% of the stream length of the Sumas River. Many of the constraints to fish production listed in the Department of Fisheries and Oceans' database are therefore related to agriculture. These include siltation from farmlands and erosion from cattle, and the effect on water chemistry from pesticides and nutrients from agricultural runoff. Fish kills due to agricultural runoff have been reported in tributaries to the Sumas Lake Canal (DFO, 1995). Other possible constraints include inadequate fish passage at the Barrowtown Pump Station, dredging of bed sediment, and siltation and pollution in Marshall Creek due to highway construction and industrial development. The industrial and residential development within the Marshall Creek watershed also increases the effective impervious area, which may alter the hydrologic regime (Klassen et al., 1995).

The Sumas River mainstem is described as "heavily angled" (DFO, 1995) and listed fourth in priority for sea-run cutthroat enhancement in a study of the lower mainland and Sechelt Peninsula (De Leeuw, 1981). This study attributed limitations on fish production to lack of quality rearing habitat and inadequate adult escapement. Improvements to the Barrowtown Pump Station by 1984 have decreased the fish mortality through the pumps (District of Abbotsford, June 1993), yet rearing habitat continues to be reported as poor in much of the river system due to slough-like flows and degraded water quality conditions (ESL and Webb, 1987).

Wildlife resources within the Sumas River watershed have experienced dramatic habitat changes over this century. At the turn of the century, millions of ducks and geese enjoyed the Sumas Lake and over 8000 ha of marginal land and sloughs. The drained and farmed Sumas lowlands of today have a reduced capacity to attract and hold waterfowl (ESL and Webb, 1987). Bird species which do frequent the remaining river and marsh areas include eagles and marsh hawks, migrating ducks and geese, and migrating and over-wintering swans. Turkey vultures and grouse nest on Sumas mountain. Sumas mountain also supports wildlife populations of blacktail deer, black bear, coyote, bobcat, racoon, and, unique to British Columbia, the mountain beaver. Cougar have also been sighted in the past (Teskey, 1990) and muskrat and wild mink are abundant along the Sumas ditches and canals (ESL and Webb, 1987).

Urban development on Sumas mountain signifies a permanent loss of habitat to most of the wildlife species. In addition, the use of developed areas by many wildlife species is often incompatible with human use of the area. All types of development, forestry, agriculture or urban, has the potential to degrade the aquatic habitat for both wildlife resources and fisheries. The degradation can be due to: streambank vegetation removal; instream works; alteration of the hydrological regime due to removal of trees and vegetative cover in the watershed; erosion due to increased flood flows as part of the altered hydrological regime; siltation from construction works; urban stormwater pollution; and; contamination from septic systems, animal manure, pesticides and fertilizers (Teskey, 1990). As fish productivity and wildlife use are among the most responsive and strongest indications of the health of an ecosystem, it is essential that distress signals given by these important natural resources are heeded in watershed management decisions.

4.0 Water Quality Investigation

4.1 Water Quality Indicators

The choice of water quality indicators used to characterize a water resource can be based on whether it is used for sustaining aquatic life and fisheries, drinking water, recreation and health, and/or irrigation and livestock watering. To completely characterize the water resource and its implications to all of these functions, with all the possible measures of biota, sediment and the water column, would be costly and impracticable. Therefore, easily measured indicators are often chosen which will reflect the general environmental condition and target suspected anthropogenic stresses on the aquatic resource. The availability of historic data for comparison also influences the choice of indicators. This section describes what indicators were measured, typical sources, and why they are of interest.

4.1.1 Trace Metals in River Sediments

Some metals are required in trace concentrations by living organisms for normal physiological function and the regulation of many biochemical processes (Chapman, 1992). However, most trace metals are of concern when they reach higher concentrations because of their potential to become toxic, to become bioavailable and bioaccumulate within organisms, and because they do not degrade. The toxicity of metals in solution depends upon many factors such as their degree of oxidation and speciation, as well as their total concentrations. Although different trace metals behave very differently in accumulation and transport mechanisms (Moldan and Černý, 1994), the conditions which generally cause a release of metal ions into solution are low pH (acidification) and low redox potential (anoxic or reducing conditions).

Because sediments accumulate and act as a sink for trace metals, they are a common medium to assess metal pollution in aquatic environments (de Groot, 1982). Their assessment is also important to protect aquatic ecosystems, as many benthic and epibenthic organisms may be exposed to chemicals through their contact with bed sediments (CCME, 1995).

The U.S. EPA has identified arsenic, cadmium, copper, chromium, mercury, nickel, lead and zinc as the eight top priority metals of environmental concern (Chapman, 1992). Of the eight metals listed, cadmium, copper, chromium, nickel, lead and zinc were measured in the sediments collected from the Sumas riverbed. These metals may enter the aquatic environment through weathering and erosion of natural geologic components within the river catchment, and by inputs from human activities. The largest anthropogenic sources are sewage, industrial wastewater and mining discharges, and atmospheric deposition resulting from smelting and the burning of fossil fuels. Anthropogenic sources of chromium, lead, nickel and zinc are mainly from industrial activities, such as metal plating or cement manufacturing in the case of chromium. Mining, smelting and combustion of fossil fuels are sources of lead and nickel, and the manufacturing of some foods is also a source of nickel. Zinc, iron, and steel production, wood combustion and waste incineration are all potential sources of zinc. Zinc is also a required nutrient in animal feed (CCREM, 1987).

Accumulation from diffuse sources, such as street runoff (including wear materials from autobodies and tires as well as exhaust products), fertilizers, sludges, pesticides, and animal feed, may also cause significant metal enrichment of soils and sediment. Sutton et al. (1983) found that supplemental $CuSO_4$ in swine diets increased Cu levels in manure spread on the soil. Increased levels of Cu were measured in the top 31cm of the soil. In the Sumas

River watershed, a natural landslide of serpentinitic material is known to contribute sediment containing high levels of chromium and nickel (Schreier, 1987). Cadmium and copper may both potentially be introduced through agricultural activities, and zinc may be selectively added to certain crops and animal rations as a micronutrient. There are no apparent sources of lead, particularly with the decline in the use of leaded gasoline.

It has been stressed that sediment quality must be evaluated in conjunction with natural background concentrations of substances, and that natural levels themselves may have adverse biological effects. A detailed regional assessment of sediment quality, including intensive sampling at a number of uncontaminated sites has been suggested to determine ambient conditions and the contribution of natural processes (CCME, 1995). In a review of natural background levels of metals in rocks and sediments, including the Vancouver, B.C. area and Western U.S. sediments (see Table 4.2 in Section 4.4.1), and a review of the sources of natural variability in sediment analysis, including effects of particle size distribution and organic content, Cook (1994) states that the concentration of trace metals in sediments is limited in its usefulness as an early warning indicator of anthropogenic stress. A very high degree of enrichment is needed to indicate human influence beyond the high natural variability in trace metal concentrations, and suitable background levels are difficult to obtain. In spite of the above, sediments can be evaluated to determine spatial trends, and to prioritize and focus potential future research activities. Results can also be compared with historically collected data to identify long term trends.

4.1.2 Surface Water Indicators

Several parameters were chosen in this study to provide an indication of surface water quality. These included conductivity, pH, temperature, dissolved oxygen, chloride, orthophosphate, ammonia, nitrate, organic carbon and fecal coliforms. Conductivity, or specific conductance, is directly related to the concentration of total dissolved solids and major ions in the water, and thus is used as a surrogate measurement for this concentration. The pH is a master variable that influences all biological and chemical processes within a water body. The pH itself is influenced by industrial effluents and atmospheric deposition, and by photosynthesis and respiration cycles. Temperature affects biological activity in a water body which in turn affects the water chemistry. Temperature and pH affect the toxicity of other subtances, such as ammonia, and high temperatures cause a decrease in dissolved oxygen concentrations. Dissolved oxygen (DO) is easily measured and essential to all forms of aquatic life. The concentration of dissolved oxygen in surface water is a general indication of the degree of pollution by degradable organic matter (Chapman, 1992).

The chloride ion is not toxic to humans but high concentrations can make water unpalatable for drinking or unfit for livestock watering, cause corrosion in metal pipes and kills many types of plants (Stednick, 1991; Chapman, 1992). Major sources of chloride are weathering of igneous rocks and sedimentary salt deposits, atmospheric dispersion of sea salts, volcanic gases and hot springs (Hem, 1985; Chapman, 1992). Higher concentrations in some areas are caused by salt water intrusions, industrial and sewage effluents, salting of roads, and irrigation drainage. Potassium chloride is used intensively in fertilizers and also in the manufacturing of insecticides (CCREM, 1987). The circulation of chloride ions in the hydrological cycle is mainly by physical processes, and thus chloride is often used to calculate water balances or as a tracer to indicate human or animal pollution.

Phosphorus is an essential nutrient for living organisms, and is often the limiting nutrient which controls primary productivity in freshwater aquatic ecosystems (Waite, 1984). Phosphorus naturally enters aquatic systems through the weathering of phosphorus bearing rocks and the decomposition of organic material. Anthropogenic sources are mainly domestic wastewaters, industrial effluents, and fertilizer runoff. Phosphorus (P) exists in surface waters as both dissolved and particulate species, organic and inorganic. The species measured directly in this study is the dissolved, inorganic orthophosphate (ortho-P) because it is the form of P which is bioavailable. Because ortho-P is readily taken up by plants, its concentrations are usually low in freshwaters. High concentrations indicate the presence of pollution and is responsible for eutrophication (Chapman, 1992; Sharpley et al., 1994).

Unpolluted waters contain small amounts of ammoniacal nitrogen (ammonia-N), and higher concentrations usually indicate organic pollution from domestic sewage, industrial waste, or agricultural runoff. Commercial fertilizers contain highly soluble ammonia and ammonium salts, and transport via the atmosphere or irrigation waters occurs when concentrations exceed the immediate plant requirements (CCREM, 1987). Natural seasonal fluctuations of ammonia concentrations occur with the death and decay of phytoplankton and bacteria. This is very pronounced in nutrient rich waters (Chapman, 1992).

Ammoniacal nitrogen, also described as total ammonia, exists in two forms: as the unionized molecule (NH_3) and as the ammonium ion (NH_4^+). The equilibrium between the two are determined principally by pH and temperature. High pH and high temperatures favours the unionized form, which is appreciably more toxic. There is a pronounced changeover from ammonium to ammonia as the pH rises from 7.0 to 8.0 (Ellis, 1989). Tables have been developed giving undissociated ammonia levels for varying total ammonia concentrations, pH levels, and temperatures for the Fraser River (Drinnan and Clark, 1980), and giving maximum criteria levels for total ammonia based on pH and temperature (BCMOELP, 1994). This study measures total ammonia-N in the Sumas River, and uses the latter reference table to compare with provincial criteria.

The nitrification of ammonia leads to the oxidized nitrite form of nitrogen, and further oxidation produces the nitrate ion. Because the first oxidation is the rate limiting step of the reaction, nitrite is rarely found in appreciable concentrations in surface waters (Ellis, 1989). In anaerobic environments, nitrate may be biochemically reduced to nitrite and eventually to nitrogen gas. This process is called denitrification. The laboratory procedure used in this study measured total nitrite-N plus nitrate-N; however; the concentrations found were assumed to be solely in the nitrate form, and are expressed as such.

Nitrate is a highly mobile ion because it is chemically unreactive in dilute aqueous solutions and its common salts are soluble in water. This makes it a good early warning indicator of contamination, as it is commonly introduced into the environment through anthropogenic sources such as municipal and industrial wastewaters, septic tanks, and feedlot discharges. The leaching of inorganic nitrate fertilizers through soils in suburban and rural areas is also known to contribute nitrate to streamwater, with concentrations generally higher in the spring and early summer months (CCREM, 1987). The use of nitrogen fertilizers and the discharge of wastewaters from intensive indoor rearing of livestock can be the most significant sources of nitrate in regions with intensive agriculture (Chapman, 1992). The actual concentrations depend on a variety of factors, including time of ploughing, soils, fertilizer application rates, proportion and quality of groundwater input versus runoff input in the stream, and biological transformations.

Nitrate is a concern in drinking water, as concentrations exceeding 10 mg L^{-1} are known to cause methaemoglobinaemia (or "blue baby syndrome"or infant cyanosis), a potentially fatal condition. Carcinogenic compounds are also suspected of being formed from nitrates (Ellis, 1989). Excess applications of nitrogen affect the health of soils and waters also. When there is a lack of plant uptake or microbial immobilization, application of excess nitrogen enhances direct leaching and the nitrogen mineralization capacity of the soil, releasing nitrate from soil organic matter as well as fertilizer. In the long term, these factors may contribute to the depletion of soil fertility, increased soil acidity, and acidification and eutrophication of surface waters (Moldan and Černý, 1994).

Organic carbon can act as a surrogate measure for biochemical oxygen demand (BOD), although the degree of pollution measured is less than the latter because of the exclusion of the oxygen consuming reactions of other elements. BOD itself is a measure of the oxygen required by a water sample for aerobic micro-organisms to oxidize organic matter to a stable, inorganic form. The measurement of organic carbon is a reliable, quicker method which provides an approximation to the oxygen demand and degree of pollution (Ellis, 1989).

Fecal coliforms are the microbiological indicators normally measured to indicate the presence of pathogens in water, and therefore they indicate a risk to users for drinking, food preparation, irrigation, and recreation. Waters are contaminated by careless spraying of manures, runoff, and use of water by domestic livestock and wildlife. Any presence of these organisms indicate recent fecal contamination from warm-blooded animals. Fecal streptococci are measured to provide information on the nature of the source, as there are more fecal streptococci in warm-blooded animals other than humans (Stednick, 1991).

4.2 Sampling Methodology

4.2.1 Sediments

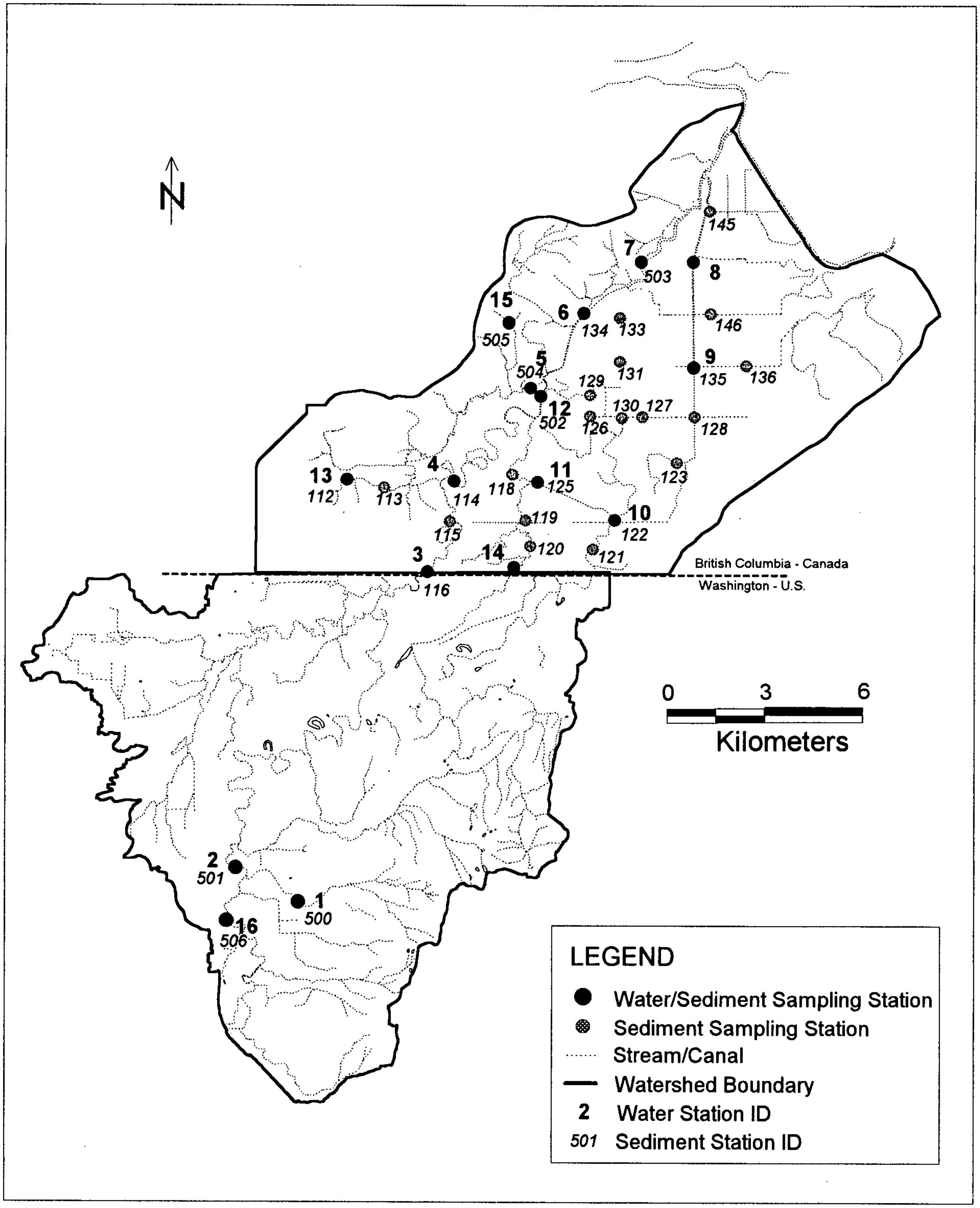
Grab samples of surface stream sediments were taken during low flow conditions on September 3, 1993 and August 15, 1994 at the locations shown in Figure 4.1. In 1993, the locations were based on the locations sampled in 1974 by Hall (unpublished data), in order that historical comparisons could be made. In 1994, several stations were dropped to reduce the laboratory cost and effort while maintaining even coverage of the Canadian portion of the watershed, and some water quality sampling locations were added to obtain continuity between the water and sediment sampling. Altogether, 31 unique sites were sampled; 23 common sites, 29 (including 2 in Whatcom County) in 1993, and 25 (including 3 in Whatcom County) in 1994.

In both years, the streambed sediments were collected using an aluminum pot attached to a 2.5 m wooden pole. At each site, the top several centimetres of sediment were collected. The samples were stored in an ice-filled cooler in plastic bags and then deep frozen in the laboratory until the time of analysis. Replicate samples were collected at 3 of the 25 sites (stations 116, 502, and 503). These replicates provide a means of calculating within site variability of results.

4.2.2 Surface Water

Surface water grab samples were taken monthly or bi-monthly, from March 1994 to

Figure 4.1 Water and Sediment Sampling Stations.
Sediment samples were not taken at stations 8 and 14.



February, 1995 at the locations shown on Figure 4.1. Station 15, located on Kilgard Creek in a forested area on Sumas Mountain, was selected as a control station as little anthropogenic impact was expected in this relatively undeveloped area. On four of the eight sampling days, 3 replicate samples were taken at one station (a different station for each day) in order to obtain a measure of within site sampling and laboratory analysis variability. The samples were stored on ice until analysis the following morning. On three of the sampling days, separate samples were collected in brown glass bottles and sent directly to EVS Environmental Consultants for bacteriological testing.

In situ field measurements, including pH, conductivity, dissolved oxygen and temperature, were taken at the time of water sampling. The pH meter, which also measured temperature, was an Orion model 420A. The conductivity meter was a Yellow Springs Instrument Model 33, and the dissolved oxygen meter a Yellow Springs Instrument Model 57.

4.3 Laboratory Analysis

4.3.1 River Bed Sediment Analysis

The sediment samples were wet-sieved using distilled water to obtain the $<63\ \mu m$ fraction into acid-washed 1 L glass beakers. The separation of the $<63\ \mu m$ fraction includes the clay/silt particles which tend to be the greatest metal accumulators, and is a common practice in sediment studies (Cook, 1994).

The $<63\ \mu m$ fraction was placed in glass beakers and dried at 105°C until all the water had evaporated. The dried samples were then disaggregated using an agate mortar and pestle, and stored in plastic containers. Approximately 2 g of each sample was weighed out into a crucible. Ten percent of the sample set was replicated so that variability of the analysis method could be calculated based on the results of same-sample measurements. Two certified standard reference materials, MESS-1 and BCSS-1 (National Research Council, Chemistry Standards Program) were included in the sample set so that the accuracy of the analysis method could be determined. The samples were then ignited in a furnace at 850 °C for 6 hours and reweighed, to remove and calculate the organic matter content respectively.

The samples were digested using hydrofluoric acid (HF) in a closed vessel (Page et al., 1982). The ratio used was 0.2 g sample to 6 mL HF. Prior to adding the HF (48%), 1 mL of Aqua regia (3 mL HCl to 1 mL HNO_3) was added to the sample and shaken to decompose any carbonates present and disperse the sample. The samples with HF were then placed on a mechanical shaker for approximately 8 hours. Deionized water (10 mL) and 2 g of boric acid (H_3BO_3) were then added to the solution. The samples were brought up to 50 mL in volumetric flasks and given to the laboratory technician in the UBC Soils Department for total metal analysis on the inductively coupled plasma spectrometer (Simultaneous ICP-AES Jarrell Ash).

The analytical method used for the 1974 collection of samples is described in Hall et al., (1976). The main differences are: 1) the samples were dry sieved for the <177 μm fraction, 2) the samples were digested with nitric perchloric acid, 3) heat was used to aid the digestion, and 4) the metal concentrations were detected using flame atomic adsorption (AA) spectrophotometry. Colman and Sanzolone (1992) compared effects of dry sieving versus wet seiving, and found the latter to produce higher metal concentrations. The differences, however, were on average less than 10%, which is small relative to the within site variability of this study given in Table 4.1 of section 4.3.3. Although heat was not used in the digestion step of this study, the digestion is nevertheless considered total since there was no indication of undissolved sample after the mechanical shaking (Page et al., 1982). McCallum (1995) carried out a study to compare flame AA and ICP-AES detection techniques. The ICP produced 55 and 59% lower values for lead and copper respectively, and 19% lower values for nickel. There was no significant difference in zinc results. Because an increase in metal concentrations from 1974 to 1994 is the trend of concern, the lower ICP values serve to ensure that the test is conservative, and will possibly offset the increased concentration effect of wet sieving and smaller particle size analysis.

To further complement the tests carried out by McCallum (1995), the <180 μm fraction of the sediments collected from the replicate sites were sent to Chemex Laboratories Ltd., North Vancouver, with instructions to digest them as closely as possible to the method described in Hall et al. (1976). Changes to the procedure were desired by Chemex Laboratories. Instead of the nitric perchloric acid mixture of 4:1 concentrated HNO_3 and 70% $HClO_4$, and 30 mL final volume, a 10% HCl concentration was used and brought up to a 50 mL final volume. Chemex used an ICP for the metal detection, and their results for the replicate site samples are provided in Appendix A.

4.3.2 Water Constituent Analyses

Nitrate-N, ammonia-N, chloride and orthophosphate were analysed the day after sampling on a Lachat XYZ QuikchemAE autoanalyser in the UBC Soils Department laboratory. If the samples were visibly turbid, they were filtered through 41 Whatman ashless paper before analysis. Methods and standards followed the appropriate QuikChem Method

No. as outlined by the manufacturer (Lachat Instruments, 1990). Dissolved nitrate+nitrite-N was analyzed using Method No. 12-107-04-1-B. In this method, nitrate and nitrite is passed through a copperized cadmium column which reduces all the nitrate to nitrite. This is then diazotized with sulfanilimide and coupled with N-(1-naphthyl)ethylinediamine dihydrochloride. A dye is produced which is read at 520 nm and determines the concentration of nitrate+nitrite-N. Because nitrite is readily oxidized to nitrate in most aquatic environments, the resulting concentrations are assumed to consist of only nitrate-N, or NO_3-N, throughout this thesis.

Method No. 12-115-01-1-A was used to determine dissolved orthophosphate concentrations. This ion is also colorimetrically determined, but at 660 nm following a reaction with ammonium molybdate and antimony potassium tartrate, under acidic conditions, and then a reduction with ascorbic acid (LaChat Instruments, 1990).

Dissolved ammonia concentrations were measured using Method No. 10-107-06-2-D. The samples are digested in sulfuric acid and then the ammonia is converted to the ammonium ion using a mercuric oxide catalyst. A concentrated buffer is added to raise the pH to a known basic level which converts the ion to ammonia. The sample is then heated with salicylate and hypochlorite and colorimetrically determined at 660 nm (LaChat Instruments, 1990).

Method 10-117-07-1-A was used to determine chloride concentrations. Mercuric thiocyanate is reacted with the chloride, displacing the thiocyanate. This reacts with aqueous iron (III) to produce hexacyanoferrate (III). The resultant absorbance of the compound is measured at 480 nm to determine the concentration of dissolved chloride (LaChat Instruments, 1990).

Samples for dissolved organic carbon analysis were filtered through 41 Whatman ashless filter paper and kept frozen until analysis. Dissolved organic carbon was then analyzed using a Shimadzu (TOC-500) Total Organic Carbon Analyzer by the UBC Civil Environmental Engineering laboratory. The concentration of dissolved organic carbon was calculated as the difference between total dissolved carbon and dissolved inorganic carbon, which are measured by the analyzer.

EVS Environmental Consultants performed the microbial analysis using the membrane filtration method, according to procedures described in "Standard Methods for the Examination of Water and Wastewater, 18th ed., 1992, APHA".

4.3.3 Quality Analysis and Quality Control

Variability within a site, or caused by the analytical methodology, was determined by using the coefficient of variance (CV) for the site replications. The results for the site replications are given in Appendix A for sediments and Appendix D for water, and are summarized by average and maximum coefficients of variance in Table 4.1 below. The results of cadmium and lead in sediments are not included in this analysis for reasons described in Section 4.4.1.

In addition, for sediments, measurements of trace metal concentrations in certified standard reference materials provide an accuracy range for analytical results, and measurements of sample replications in the lab provide for analytical variability. See Appendix B for the details of these results. The percentage deviation from the certified values of the standard references ranged from 0% for nickel to 81% for copper. Copper introduced the highest deviation from certified values; the average deviation excluding the copper results

Table 4.1 Variability in Water and Sediment Site Replications

Water (mg L^{-1})	Nitrate-N	Ortho-P	Chloride	Ammonia-N	Organic Carbon
Average coefficient of variance, CV (%)	5	14	5	14	62
Maximum CV (%)	9	25	7	25	126
Sediment (mg kg^{-1})	**Cr**	**Cu**	**Ni**	**Zn**	
Average CV (%)	17	29	19	9	
Maximum CV (%)	19	34	25	13	

was 10%. Copper also showed the highest variability in analytical results. The average percentage difference between sample replicates for copper was 34%, while the averages of all the other metals ranged from 6% for zinc to 10% for chromium. The recovery for copper in the sediment analysis was not satisfactory. Although the exact cause was not investigated, potential sources of error include interference or matrix effects due to the unusual asbestos material present. Because of the low confidence in the copper results, indications of copper trends are not stressed or elaborated upon for the remainder of this thesis.

Accuracy for water analysis was determined by the Soils Department laboratory by measuring samples with known concentrations, or standards, with the autoanalyser for each sampling run. The results obtained from the laboratory are given in Table 4.2 below.

Table 4.2 **Accuracy Measurements for Water Analysis**

Constituent	range of % difference between known and measured (n)	average difference per record (%)	standard deviation
chloride	-15.8 to 13.1 (6)	0.86	9.5
ammonia-N	-89.8 to 11 (9)	-7.57	31.1
nitrate-N	-25.0 to 9.5 (6)	-7.25	11.9
Ortho-P	-10.0 to 36.7 (9)	9.23	15.6

4.4 Spatial and Temporal Trends Shown by Water Quality Indicators

Factors influencing the quality of water at a given sampling station include: proportion of surface runoff and groundwater, reactions within the river system governed by internal processes, mixing of water from tributaries of different quality (more apparent in heterogeneous basins), and inputs of pollutants (Chapman, 1992). These factors manifest themselves by spatial and temporal trends shown in the sampling results. The statistical measures and plots presented in the following sections and respective appendices were calculated using the *SPSS for Windows Release 6.1.2.* software package.

4.4.1 Trace Metals in River Sediments

The range and median of trace metal concentrations measured in the riverbed sediment of the Sumas River and its tributaries is presented in Table 4.3. These are compared with examples of background concentrations of these trace elements found in sediments for other studies, and with preliminary guidelines and criteria for sediment quality compiled by Hall (1992). The trace metal concentrations for cadmium and lead were below the detection limits of 0.2 mg kg^{-1} and 3 mg kg^{-1} respectively, as calculated by McCallum (1995) for the same ICP analyser, and are thus not included in this table. Although McCallum (1995) used a dilution ratio about 1/6 of that used in this study, his detection

Table 4.3 Comparison of Measured Trace Metal Concentrations with Example Background Concentrations and Preliminary Guidelines and Criteria

Element ($mg\ kg^{-1}$)	Cr	Cu	Ni	Zn
1993, *1994* Sumas Sediment Sampling				
Median	120 *119*	41 *38*	149 *171*	154 *133*
Range	45-371 *51-353*	12-117 *8-79*	42-1930 *54-1886*	29-300 *32-276*
Background Concentrations[a]				
world surficial continental rocks[c]	71	32	49	127
River Suspended Sediments:				
Mackenzie River	8.5	42	22	126
Yukon River	115	416		
world average	100	100	90	350
world rivers[c]	120	50	80	240
Streambed Sediments:				
Rhine River	47	51	46	115
Illinois River, median (90th percentile)	56 (74)	23 (35)	26 (35)	100 (241)
Western U.S., range	20-210	0-110		49-510
Vancouver region, mean and range	48 10-1000	26 2-415	7 1-165	48 10-1000
Guidelines and Criteria[b]				
USEPA for Great Lakes Harbours:				
non-polluted	<25	<25	<20	<90
moderately polluted	25-75	25-50	20-25	90-200
heavily polluted	>75	>50	>50	>200
OntarioProvincial Guidelines and British Columbia[d] Criteria:				
lowest effect	26	16	16	120
severe effect	110	110	75	820
Guidelines for dredged material	25	25	25	100
Wisconsin Criteria:	100	100	100	100

a. compiled by Cook (1994) from various sources, unless otherwise noted
b. compiled by Hall (1992) from various sources, unless otherwise noted
c. compiled from various sources in Chapman (1992)
d. BCMOELP (1994)

limits are sufficiently low to assume that even if the detection limits for this study were approximately 6 times greater (i.e., a near linear relationship of matrix effects), the concentrations of cadmium and lead in the Sumas River sediments would still be too low to discern spatial trends and are not sufficiently elevated to cause concern.

The trace metal concentrations, although higher than the preliminary guidelines presented, are not above the natural background range given for Vancouver region sediments. The exception is nickel, whose median falls within natural levels but whose range includes very high concentrations. However, the source is known to be a natural geologic deposit exposed by a landslide (Schreier, 1987). The range in natural levels found and the differences in criteria emphasize the importance of evaluating trace metal enrichment on a site specific basis, with a knowledge of the local geology.

4.4.1.1 Spatial Trends

A table of results for each site is given in Appendix C. When plotted in an upstream-downstream direction as shown in Figure 4.2, the nickel and chromium results show very similar trends. Both metals show low concentrations (station 506) prior to the confluence with Swift Creek (station 501). These upstream values and trends are consistent with studies that researched the stream sediment effects from the landslide in Whatcom County (Schreier, 1987; Schreier et al., 1987; Schreier, 1986). The zinc values are relatively consistent from upstream to downstream, with an anomaly at station 116 for the 1993 sampling; this is assumed to be an outlier due to sampling or analytical error. The copper values show no apparent trend and are less consistent from 1993 to 1994. However, the values are consistently within a natural range of 10 to 50 mg kg^{-1}. Both zinc and copper exhibit peaks

Figure 4.2 Stream Sediment Trace Metal Concentrations

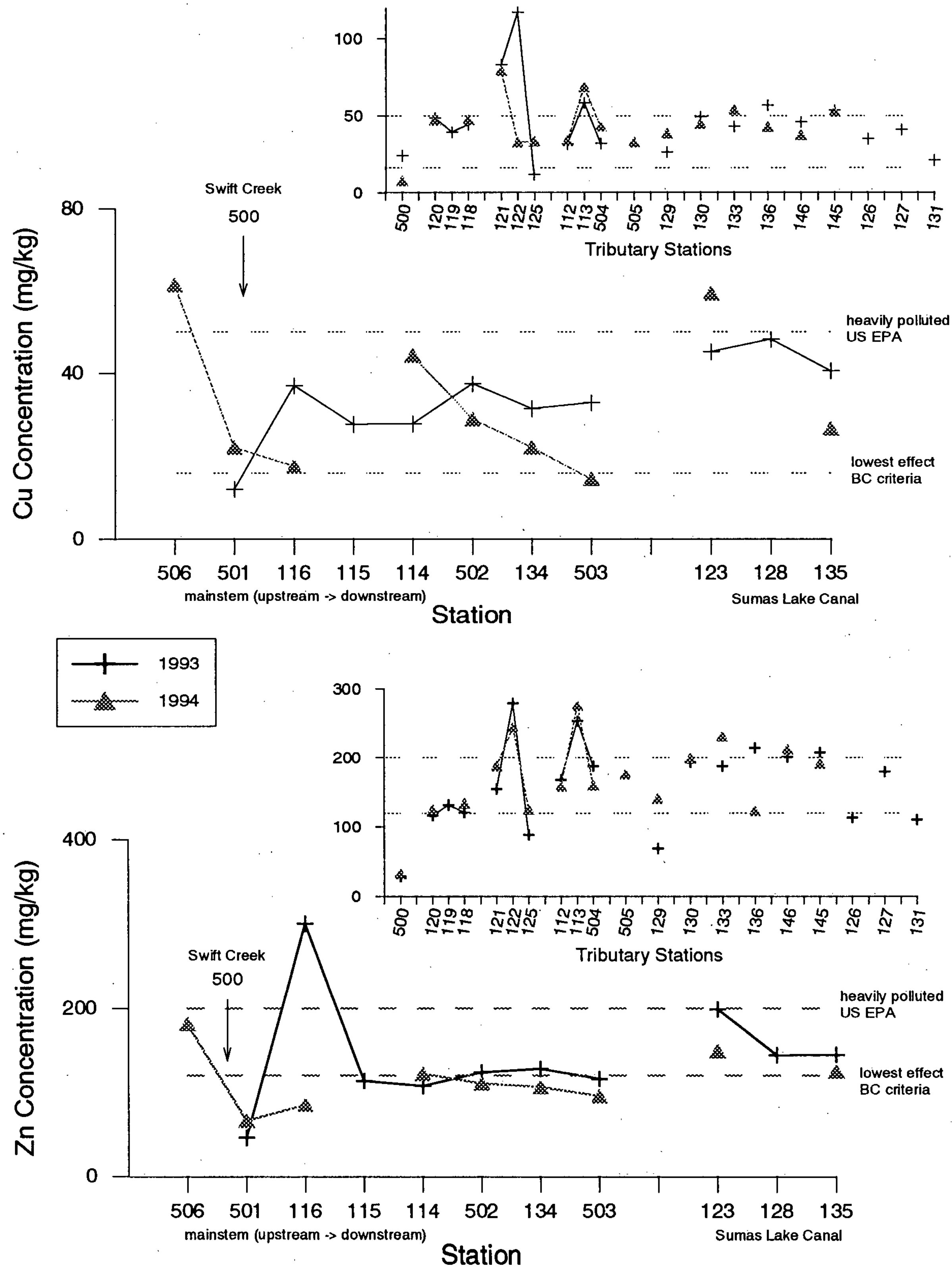
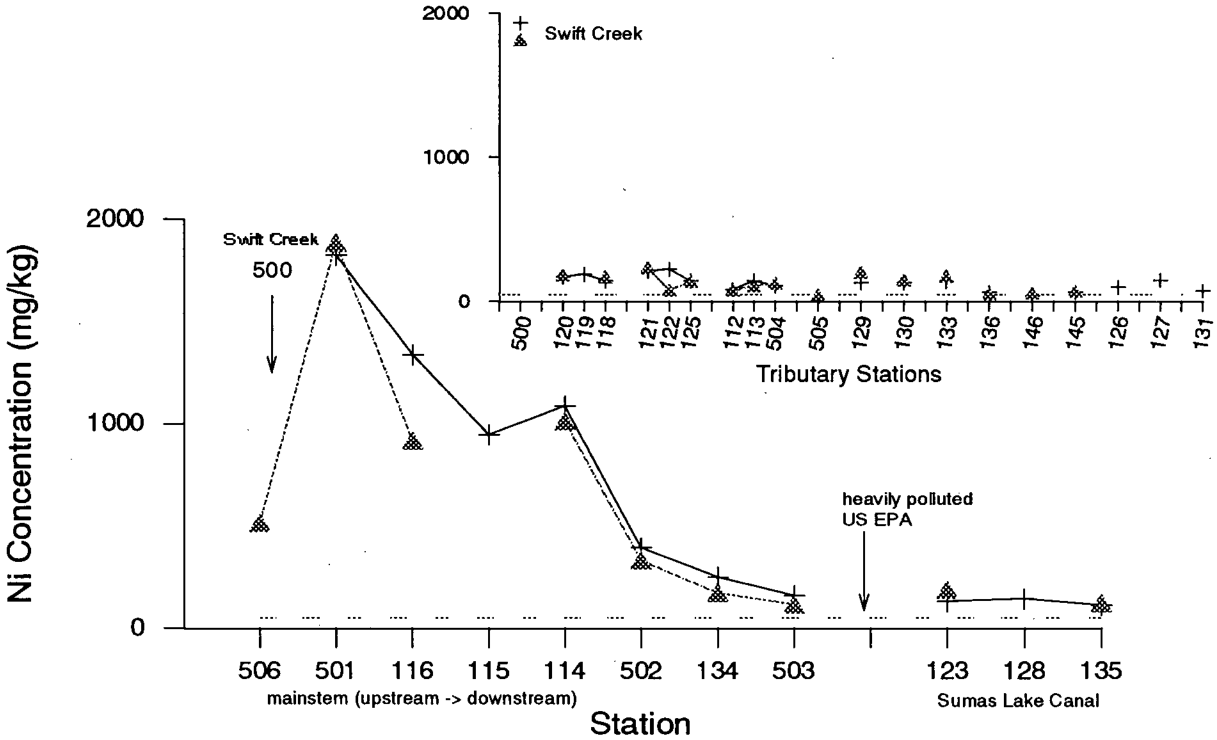
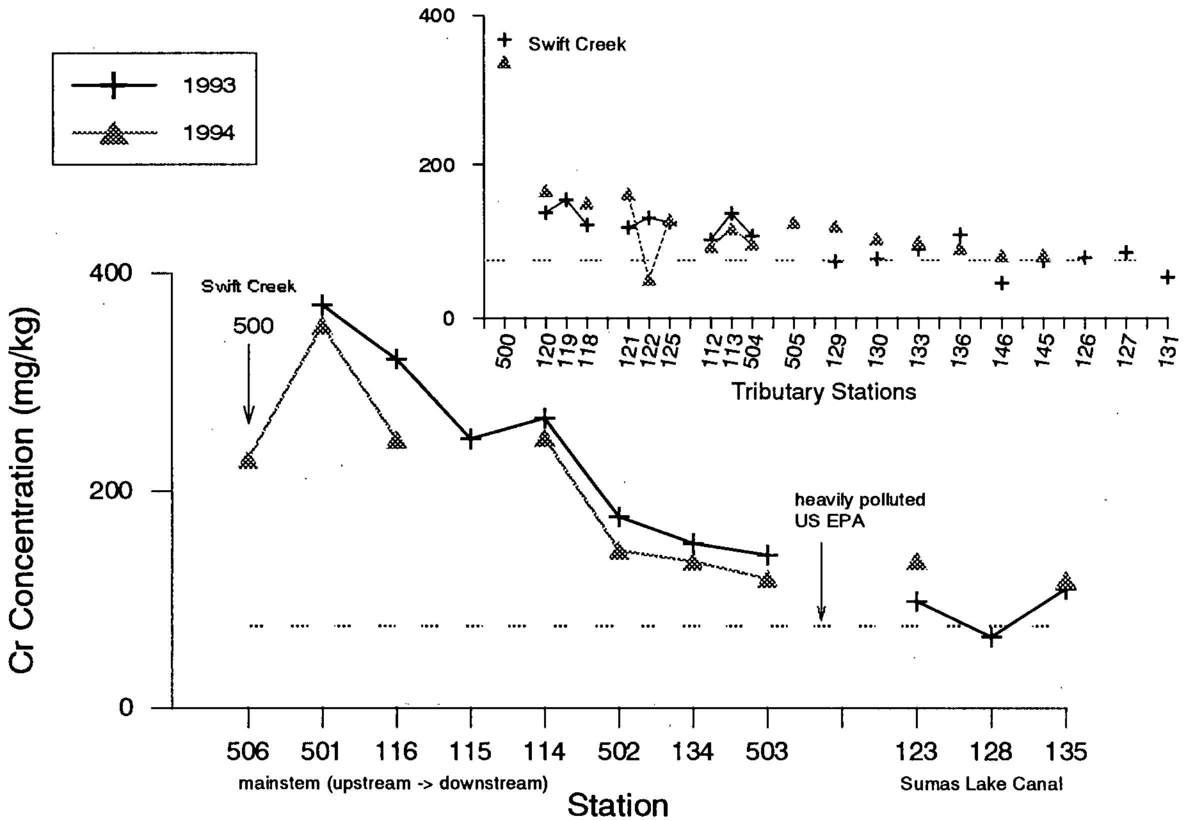


Figure 4.2 (continued) Stream Sediment Trace Metal Concentrations

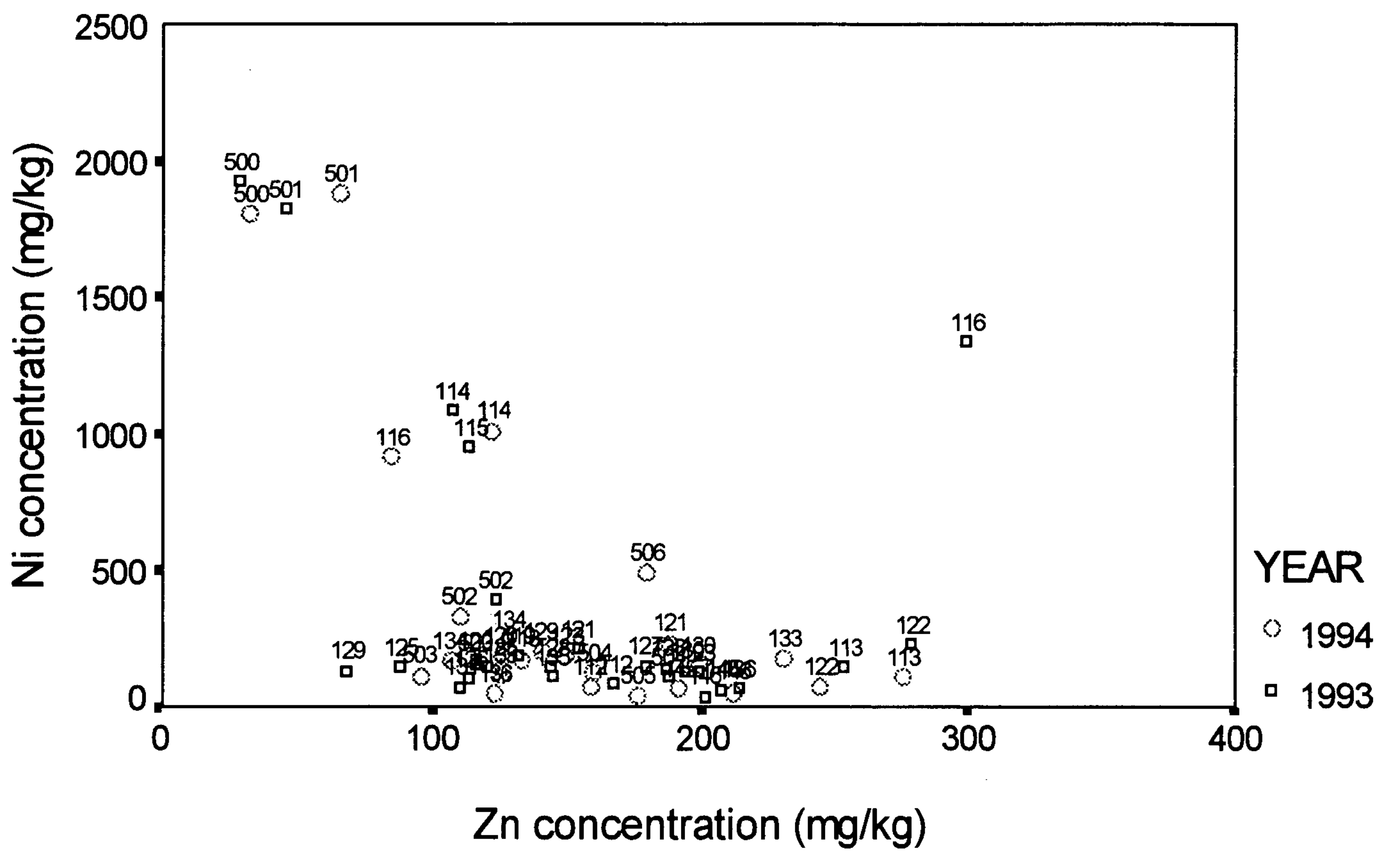




at stations 113 and 122. These do not appear to be in error since the peaks are shown both in 1993 and in 1994. The peaks may be due to road runoff, or from a point source such as a nearby house or farm. More sampling would be required to determine the possible natural or anthropogenic sources.

The four metals can be divided into two behavioural categories: 1) landslide influenced, comprising nickel and chromium and exhibiting a strong downstream trend, and 2) non-landslide influenced, comprising copper and zinc which have no apparent natural source but exhibit similar spatial patterns nonetheless. This can be seen in scatter plots of Ni vs. Zn or one metal vs. the other (Figure 4.3). In all the scatter plots, similar patterns emerged of the clusters of sites which have high nickel and chromium values with low zinc and copper values, or high zinc and copper with low nickel and chromium values. The highest Ni/Cr, lowest Cu/Zn cluster occurred at Swift Creek and its confluence with the Sumas River. The influence of the landslide is shown further downstream by the next two clusters, comprising stations 114, 115, and 116 for one cluster, and 502 and 506 for the other. It is interesting to note that, not only do these clusters represent sites with the highest Ni and Cr sediment concentrations, but these sites also happen to have among the lowest concentrations of Cu and Zn. This is because the parent serpentinic material from the landslide has lower concentrations of Cu and Zn than other soils in the area (Schreier, 1987). On the opposite side, the cluster which consistently showed high values of Cu and Zn and low values of Ni and Cr was comprised mainly of stations 133, 113, 122 and 121. These sites represent sediments in an irrigation ditch, thus suggesting agricultural inputs, at the west

Figure 4.3 Scatter Plot of Ni vs. Zn Concentrations in Sediments. Similar spatial clusters were found for Cr and Zn.



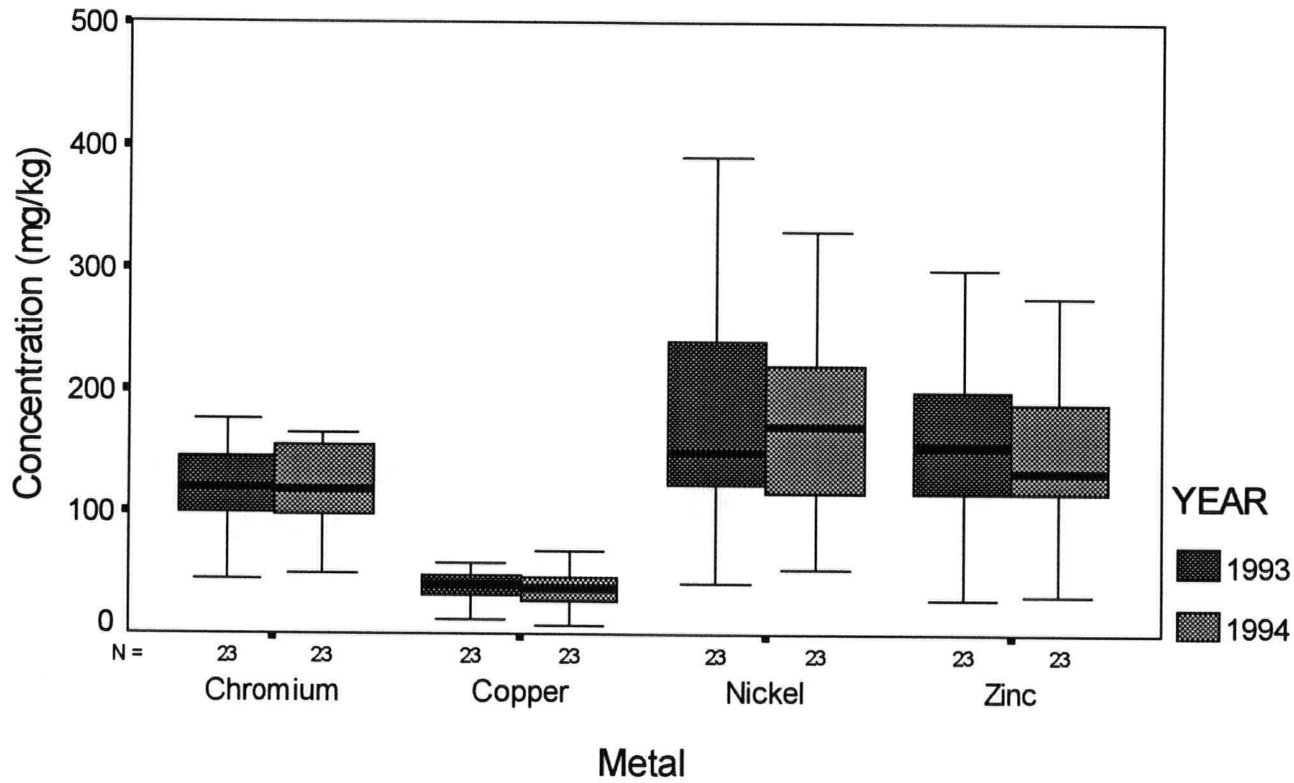
end of No.4 Rd., Marshall Creek at Angus Campbell Rd. mentioned earlier, and upper Arnold Creek, respectively.

4.4.1.2 Temporal Trends

Figure 4.4 is a box plot comparing the results of the 1993 and 1994 sampling for the 23 common sites only. The box plot shows the median, 25th and 75th percentiles, and the largest and smallest observed values that are not outliers or extremes by the extended lines from the box. The apparent similarity of results from 1993 to 1994 are confirmed by the non-parametric Mann-Whitney U test for two independent samples. The two sample sets were found to be not significantly different. This confirms that low flow sediment sampling is very stable, and is a useful basis of comparison for long term trends.

Having determined that the trace metal concentrations of the 1993 and 1994 sediment samples are not significantly different, the two sample sets were combined into one and tested, using the Mann-Whitney U test, against the data set from 1974 (Hall, unpublished data). The concentrations of copper, nickel and zinc were found to be significantly higher in 1993/94 than in 1974 (<0.01). Chromium concentrations were not available from 1974. The comparison of these data sets is questionable due to the differences in analytical methods as described in Section 4.3.1. The results of the digestion of the <180 μm fraction of the replicate samples by Chemex Laboratories (Appendix A) differ greatly from the <63 μm fraction in two of the three replicate sites. This is likely due to the effect of particle size distribution. The results for the site with much finer sediment (station 116 at the border) differed by less than 12% in either direction for all metals. The results for the other two

Figure 4.4 Comparison of 1993 and 1994 Sediment Sampling Results. Box plots show medians, data values within the 25th and 75th percentiles. Outliers and extremes are not shown. There was no significant difference between the two sample sets.



replicate samples, both taken at parks near sandy beaches, tended to be on average 40% lower in metal concentrations for the <180 μm fraction of sediments.

A sensitivity test was performed by testing the 1974 data against the 1993/94 data reduced by 30, 40 and 50%, again using the Mann-Whitney U test for two independent samples. Because there is uncertainty associated with the different digestion methods between the two periods, and other sources of error such as within site variability and instrumental error, it is difficult to ascertain whether the increase in concentrations are real. In general, the nitric perchloric digestion is more rigorous than the HF digestion, which would result in lower concentrations being measured with the HF digestion for the 1994/95 sediments. The larger fraction size measured in 1974 (i.e., <177 μm fraction vs. <63 μm fraction in 1994/95) should bias the results in the other direction, or lower results for the 1974 sediments, since metals tend to associate with the smaller particles in sediments. However, these statements are dependent on many factors including the actual resultant matrix of the solution measured and the organic composition of the sediments. Quantifying the total error would be onerous and difficult as the older digestion techniques are no longer readily available. The sensitivity analysis provides a simple comparison of results assuming different levels of error, and if a significant difference is found when the error is assumed to be large (i.e., 50%) then the change in concentration is believed, in this thesis, to be real. The results of the sensitivity analysis are shown in Table 4.4 below.

Table 4.4 Tests of 1974 and 1993/94 Trace Metal Concentrations in Sediments

1993/94 data reduced by:		30	40	50
Metal:	**Cu**	n.s.	n.s.	§
	Ni	*	n.s.	n.s.
	Zn	*	*	*

n.s. = data sets not significantly different
* = 1993/94 concentrations significantly higher (α<0.01)
§ = 1974 data set significantly higher (α<0.01)

There is no significant difference between the two sample sets for copper, until the 1994 data set is reduced by 50%, which makes the 1974 concentrations significantly higher. Nickel is significantly higher in 1993/94 when the data is reduced by 30%, but further reductions show no significant difference. The significance maintained at a 30% reduction may indicate that the landslide material has continued to travel downstream from the headwaters. Although the enriched nickel sediment appears to have stayed within the main channel, comparison of nickel levels in the Sumas irrigation waterways or tributary streams with nickel levels in other lower Fraser streams (Hall et al., 1976) indicates that the whole Sumas watershed is enriched with nickel. Zinc remains significantly higher in 1993/94 with even a 50% reduction, leading to the postulation that there has been significant enrichment of zinc in the Sumas streambed sediments over the past twenty years. Figure 4.5 shows the change in concentrations, without reductions, between the two time periods.

4.4.2 Surface Water Constituents

Results and field measurements of the water quality sampling are given in Appendix D. These are summarized in Table 4.5 by the median of all sites, and compared with natural background levels and British Columbia water quality criteria. The B.C. criteria are based on

Figure 4.5 Comparison of 1974 and 1993/94 Metal Concentrations in Sediments. Box plots show medians, data values within the 25th and 75th percentiles, and the range of values excluding outliers.

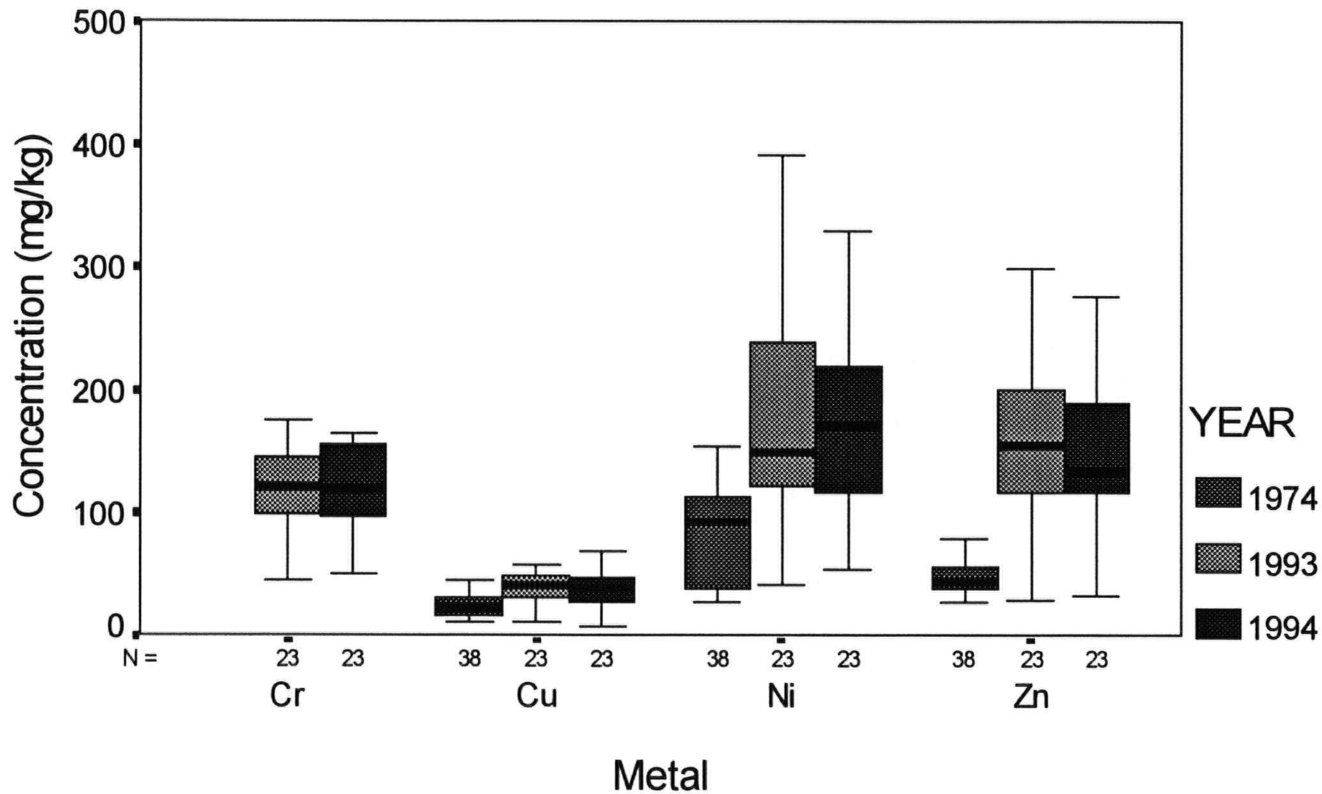


Table 4.5 Comparison of Surface Water Chemistry with Natural and Criteria Levels

Indicator	pH (log scale)	Dissolved Oxygen (mg L^{-1})	Conductivity (µS cm^{-1})	Chloride (mg L^{-1})	Nitrate-N (mg L^{-1})	Ammonia-N, Total (mg L^{-1})	Ortho-P (mg L^{-1})	Dissolved Organic Carbon (mg L^{-1})
Measured (all sites)								
median	7.6	8	212	13.6	1.3	0.245	0.07	18
range	6.5- 9.4	1.5- 13.9	35-400	1.2- 53.5	nd- 7.6§	nd- 4.029§	nd- 2.07§	2- 103
Natural levels in freshwaters[d]	6.0-8.5[b]	nd-18.4 typically>10	10-1000[b]	1-10	0.002-6.6	<0.001-0.49 typically<0.1	0.005-0.02[b]	0.01-26
world river average				7.8[c]	0.2[c]			
Criteria[a]								
Drinking Water	6.5-8.5			250	10			
Aquatic Life (freshwater)	site specific	>3-11 (salmonid)¥ >3-6.5 (non-salmonid)			200 (max) ≤ 40 (ave)	0.752-27.5†(max) 0.102-1.99 †(ave) 10.7‡ (max) 1.54‡ (ave) 1.37-2.2[b]		
Irrigation *	5.0-9.0		700-5000	100-700				
Livestock *	5.0-9.5		1400-4200		100			
Recreation	5.0-9.0	2			10			

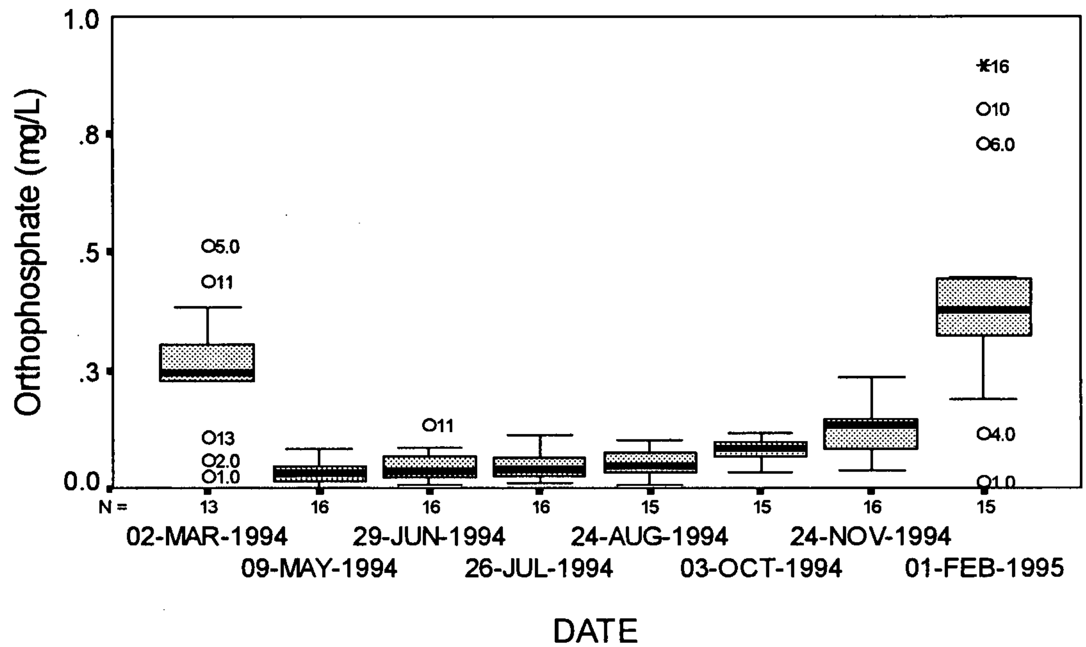
a= BCMOELP (1994), unless otherwise noted
b= Chapman (1992)
c= Moldan and Černý (1994)
d= CCREM (1987), unless otherwise noted

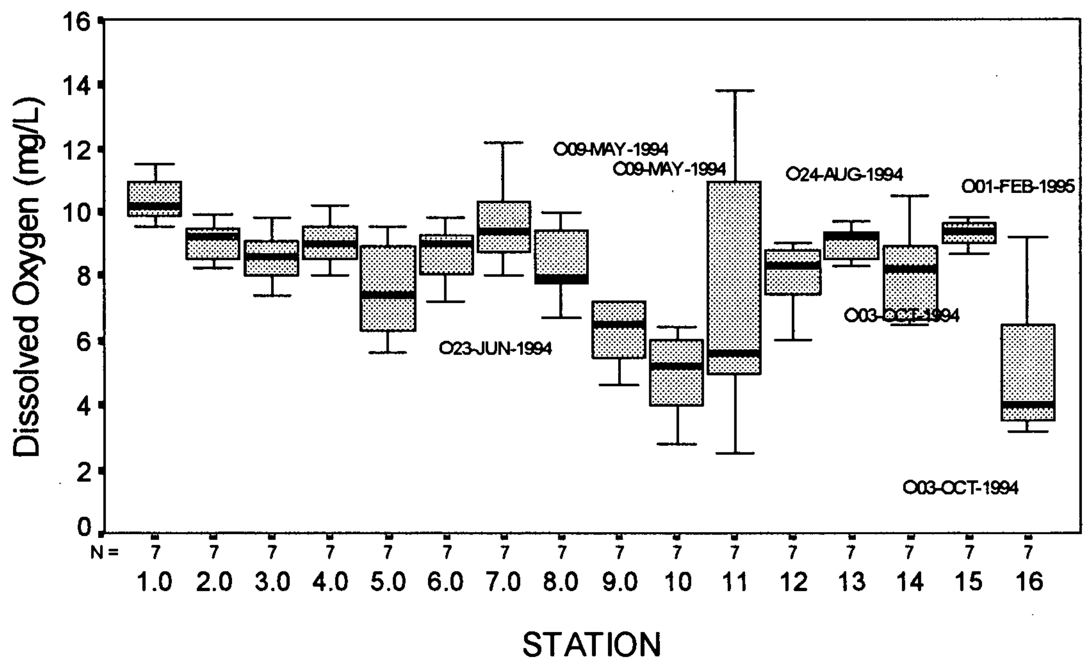
§: nd = not detected; taken as zero for analyses
* : depends on species, crop or soil types
†: based on measured ranges of temperature and pH in Sumas
‡: based on median temperature and pH measured in Sumas
¥: ranges from acute mortality to some production impairment

the Canadian Water Quality Guidelines (CCREM, 1987), and so only the provincial criteria are given since they are largely the same. No criteria levels have been proposed for ortho-P nor for organic carbon. Fecal coliform results will be discussed later on in this section. The medians of the other indicators generally fall below criteria levels, and within natural ranges. However, the use of medians or averages masks the occurrence of more critical levels at specific locations or during different times of the year. This is suggested by the range of values seen, but is more properly addressed by the box plots in Appendix E. These box plots show the range of values of each indicator for each site over the sampling dates, and for each sampling date over all sites. Examples are provided for ortho-P by date and dissolved oxygen by station in Figure 4.6. These figures illustrate well how trends can be observed for parameters both by time of year and by site. The orthophosphate values are greater in high flow winter periods and dissolved oxygen values tend to be consistently lower at stations 9, 10, and 16.

In addition, spatial and seasonal variability may be more clearly shown by the series of figures in Appendix F. In these figures, averages of sampling dates taken during the high flow period of November through March, denoted as "wet season", and averages taken during the low flow period of June to August, denoted as "dry season", are plotted for the Sumas mainstem in an upstream to downstream direction. The average values for the tributaries are shown as inset plots. Careful examination of both of these series of plots allows for a characterization of the seasonal and spatial trends shown by each indicator.

Figure 4.6 Box Plots of Ortho-P by Sampling Date and Dissolved Oxygen by Station. Outliers and extremes are labelled by site or date, and shown by circles and stars respectively. Ortho-P value for October 3, 1994 on Saar Ck. falls outside of axis range.





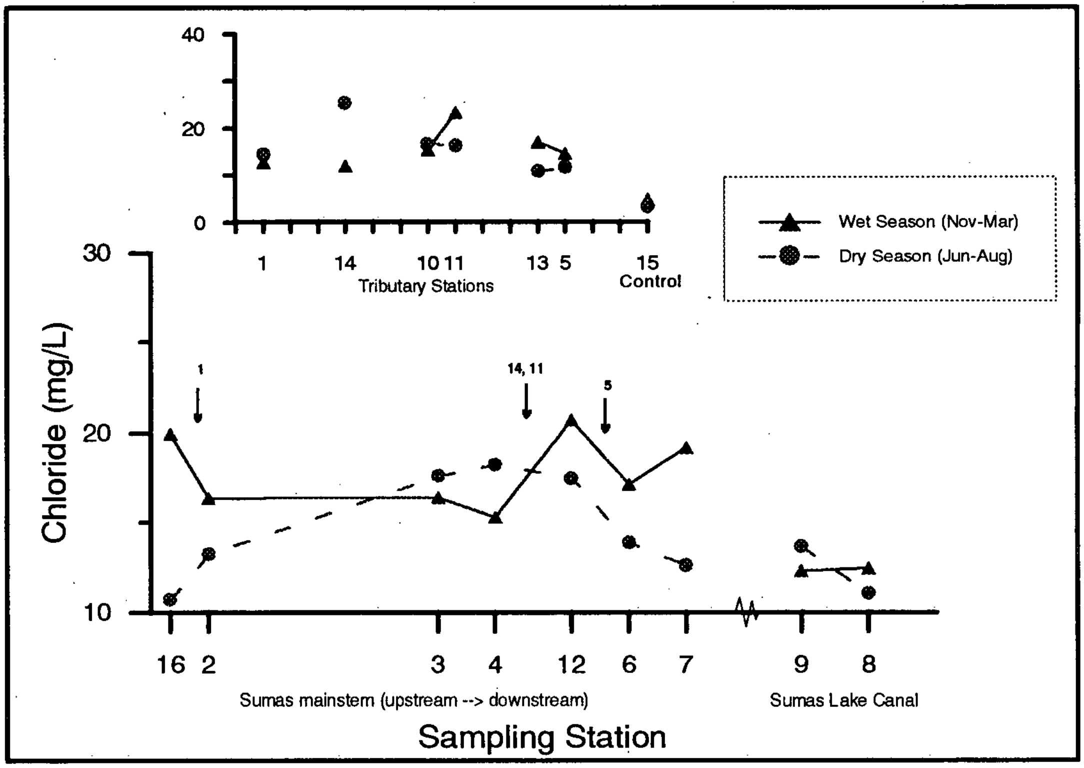
4.4.2.1 Seasonal Trends

The most noticeable trends in both the box plots and the wet season/dry season plots are the consistently higher values of ortho-P, nitrate-N and ammonia-N across all sites in the wet season, as shown in Figure 4.7. During this period, the values of conductivity and pH are consistently lower. The anomalies of these trends are:

- Nitrate-N levels in Marshall Creek (stations 13 and 5). High levels occur in the dry season and lower levels in the wet season. Marshall Creek will be discussed further in the *Spatial Trends* section.
- The higher pH levels in the Sumas headwaters near the Swift Creek confluence. The pH values at the Sumas headwaters are dominated by the asbestos sediments in Swift Creek, known to be alkaline in nature (Schreier, 1987).

Chloride values exhibit no discernable seasonal trend as shown in Figure 4.7, although the largest range and highest median value as seen on the box plot in Appendix E occurs on February 1, 1995, which was the sampling day of highest discharge when many stations were flooded. Fecal coliform and fecal streptococci counts are much greater on this high flow sampling day across all sites. The values are well above the Canadian Guidelines of a maximium of 200 FC/100 mL for recreational use (CCREM, 1987) or the same value designated by the province for irrigation water used on vegetables/fruit which is eaten raw (IRC, 1994). The 200 FC/100 mL criteria level in both cases applies to the geometric mean of at least 5 samples, which cannot be calculated with the limited measurements taken in this study, but the criteria is given for comparison purposes. In the past, the fecal coliform to fecal streptococci ratio was used as an indicator of the nature of the fecal source, with a low

Figure 4.7 Water Quality Plots: Chloride and Ortho-P



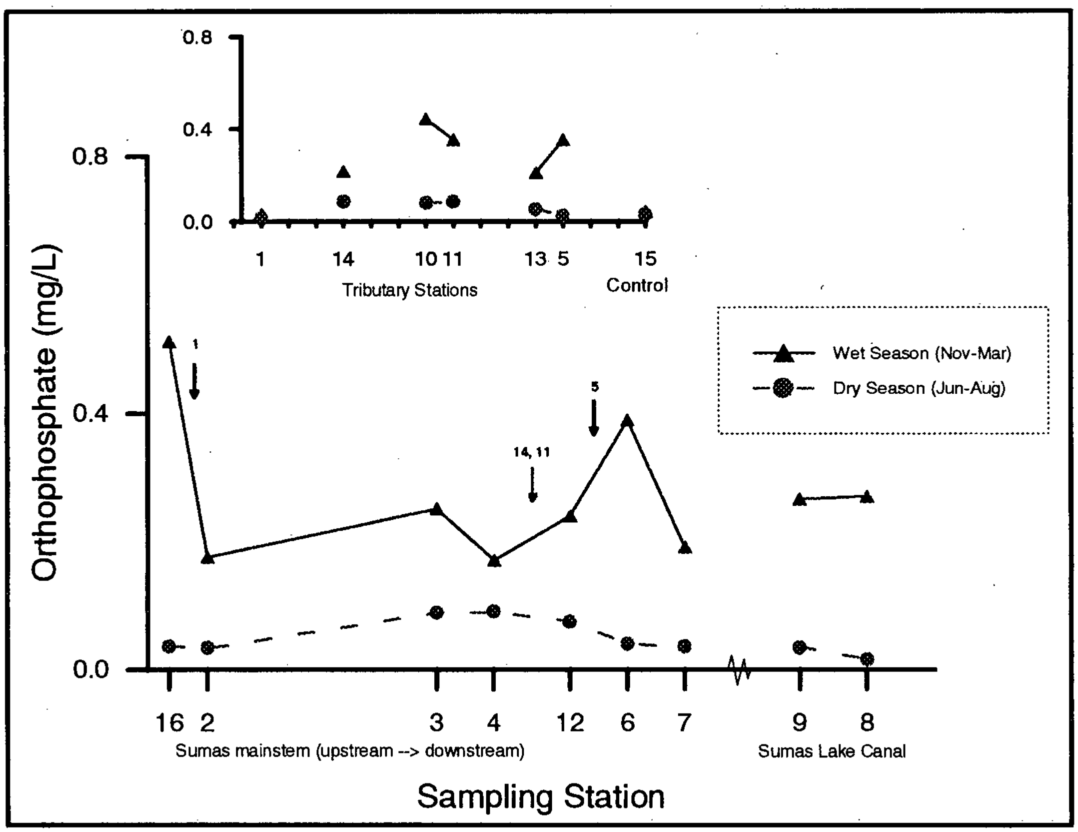
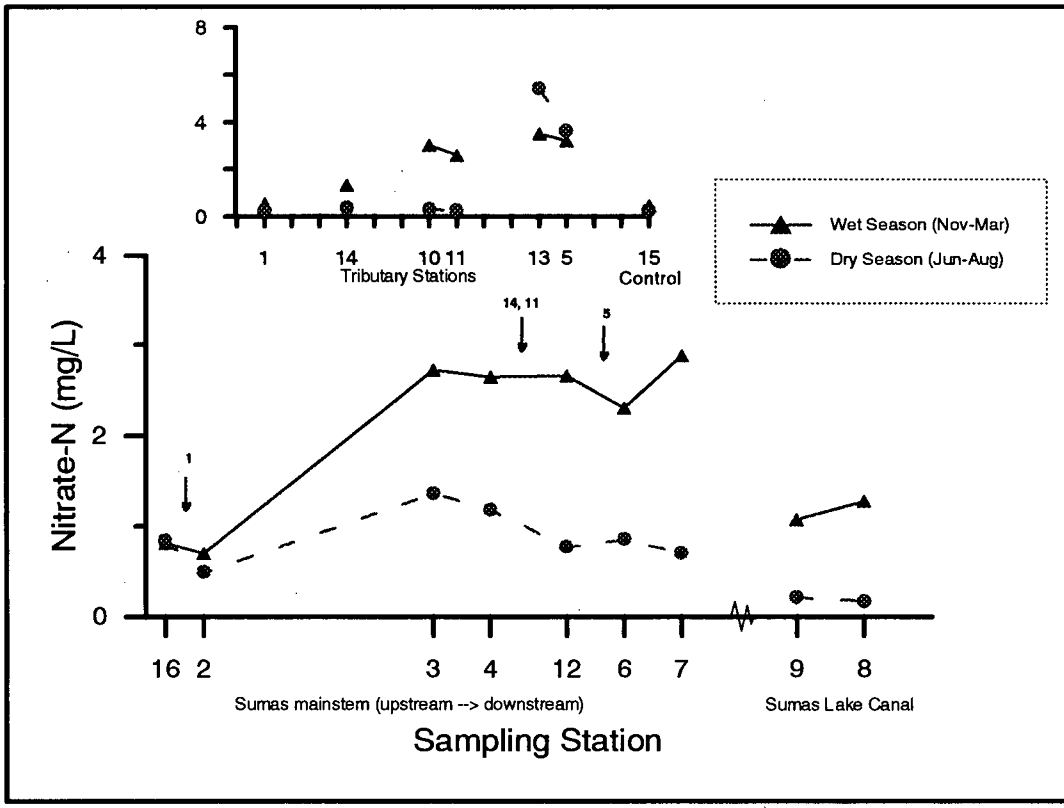
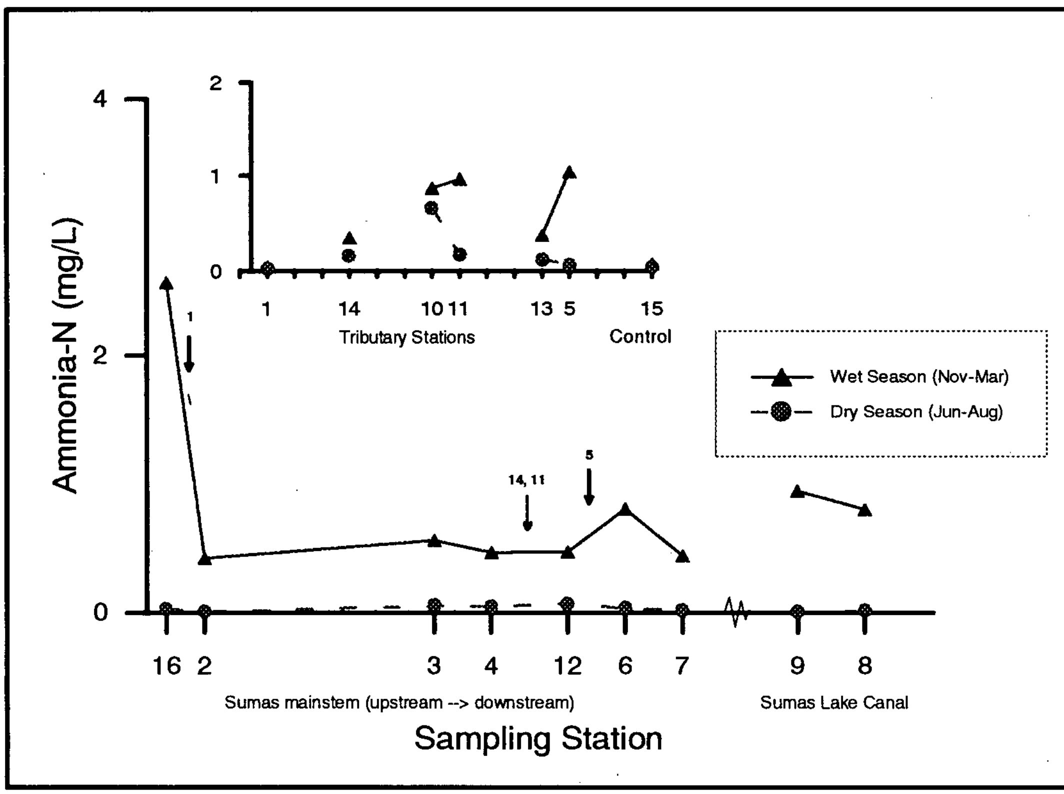


Figure 4.7 (continued) Water Quality Plots: Nitrate-N and Ammonia-N





ratio indicating a non-human animal source. The use of a ratio, however, is now considered "highly questionable, if not inaccurate" (CCREM, 1987) due to many factors, including differential die-off rates between these two groups. The isolation of the enterococcal species, within the fecal streptococcal group, is now considered more useful in the determination of type, source and degree of fecal contamination.

The average concentrations of dissolved oxygen are relatively constant throughout the year. However, very low levels occur at particular sites at certain times of the year, as discussed below. Temperature predictably increases during the summer months, yet it should be noted that temperature values at some sites during these months reach values far above those desired for fisheries purposes (BCMOELP, 1994).

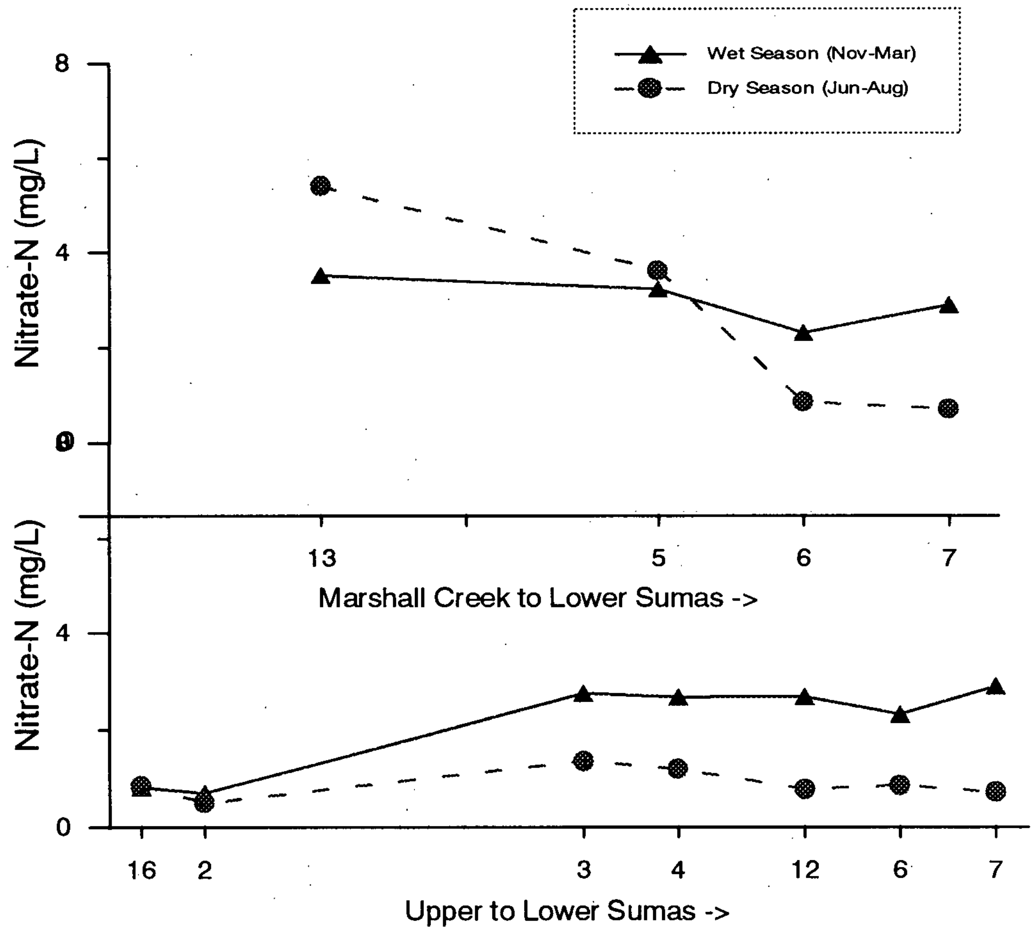
4.4.2.2 Spatial Trends

Chloride, ortho-P, nitrate-N, and conductivity all show a tendency during the dry season to increase in concentration from the headwaters to station 3 (at the US/Canada border) followed by a decrease as one moves further downstream. Without knowing the flows at each station, and modelling the physical and biochemical processes diluting or transforming these constituents, it is difficult to surmise the cause of these trends.

Other notable spatial trends are indicator-specific. On the three sampling dates for microbes, fecal coliform counts for stations 3 and 4 on the Sumas mainstem are all slightly higher than the 200 FC/100 mL guideline. Values at station 10 on Arnold Slough and station 13 on Marshall Creek are consistently and considerably higher than the guideline, with values typically around 1000 FC/100 mL. Marshall Creek (stations 13 and 5) has consistently the highest nitrate-N values, on several instances approaching the 10 mg L^{-1} criteria level. And, unlike all other stations, the nitrate-N values are higher during the dry season than in the wet season, as seen in Figure 4.8. It is believed that this behaviour is caused by significant inputs of groundwater from the contaminated Abbotsford aquifer, both from natural springs and the trout hatchery discharge. In the summer these inputs comprise a greater proportion of streamflow, whereas runoff dilutes these inputs in the winter.

Arnold Slough, represented by stations 10 and 11, is also a remarkable tributary. It consistently shows the highest levels of ammonia-N and the lowest pH and dissolved oxygen levels. Fortunately, lower pH pushes the equilibrium of ammoniacal nitrogen towards the less toxic ammonium ion form. However, the pH values are still generally above 7.0, and the temperatures in Arnold Slough can increase substantially in the summer, which would drive the equilibrium in the opposite direction. At pH and temperature values encountered during this sampling survey, the ammonia levels in Arnold Slough are generally below criteria levels, but if higher levels such as that measured at station 10 on July 26, are more chronic than could be detected in this sampling scheme, then the water would be toxic to freshwater aquatic life. This is based on the average 30-day concentration criteria of total ammonia nitrogen (BCMOELP, 1994) for given pH and temperature values. On July 26, 1994 the temperature and pH values at station 10 were 19°C and pH 7.2 respectively, giving an average 30-day concentration criteria of 1.32 mg L^{-1} , while the level measured on this day was 1.64 mg L^{-1} of ammonia-N. Whether the concentrations are maintained around this level over a 30 day period can not be ascertained in this study, but the prospect does not seem infeasible. Similar arguments apply to other stations which exhibited high ammonia-N levels, particularly in the Sumas Lake Canal.

Figure 4.8 Comparison of Nitrate-N Behaviour in Marshall Creek and the Sumas Mainstem. Concentrations are highest and greater in Marshall Creek in the dry season, unlike the remainder of the system which has higher values in the wet season.



Dissolved oxygen levels in Arnold Slough are perhaps a greater concern. The median DO values are around 5 mg L^{-1} with extreme lows of around 2 mg L^{-1} reached in June and November. Continued sampling by Schreier (pers. com.) through 1995, and the sampling conducted by IRC (1994) confirms the low values, particularly in the fall season. Unfortunately, the time of lowest values coincides with the time of migration and spawning of many salmonid species (FREMP, 1990). Provincial objectives for dissolved oxygen levels, although not given for Arnold Slough, are that any discrete sample taken from the Sumas River, Marshall Creek, or Saar Creek, should not be below 11 mg/L during the embryo and larval stages of salmonids, and not below 8 mg/L during other life stages (BCMOELP, 1995). The results in the Sumas River system indicate that various tributaries and reaches have difficulty in meeting this objective.

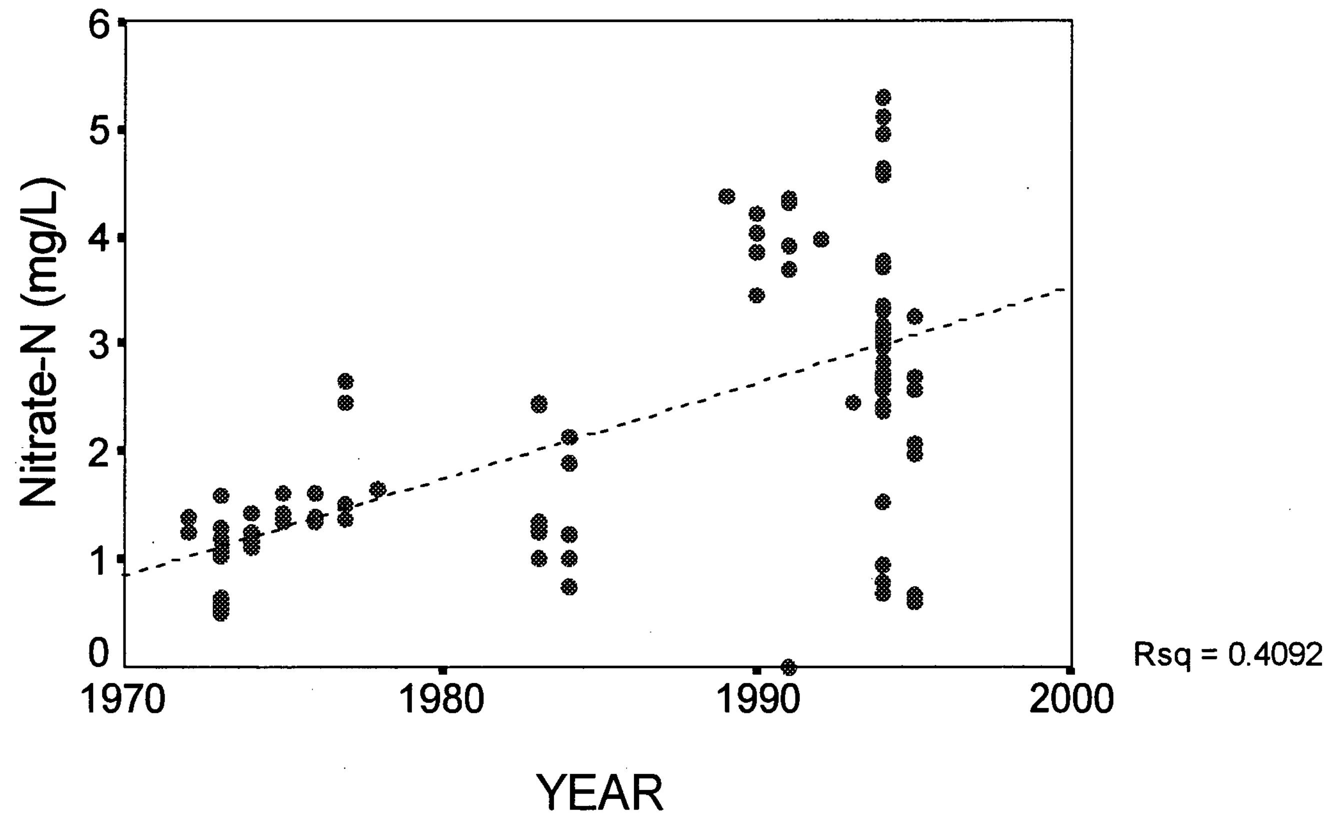
Saar Creek deserves mention due to the results measured at station 14 on October 3, 1994. On this day, unusually high values of ortho-P (2.07 mg L^{-1}) and ammonia-N (4.029 mg L^{-1}) were detected. Both of these indicators were at values well above the values measured at any other station over the whole sampling period. The lowest DO level (1.5 mg L^{-1}) of the sampling period was also measured at Saar Creek on this day. Chloride values were also considerably higher than any other station that day. Fecal coliforms were regrettably not sampled on this day. The elevated levels of so many indicators in concert suggests that sample contamination or analytical error is unlikely. It appears that this anomaly is due to an isolated point source contribution to the stream, possibly from an animal in the stream, as Saar Creek on all other sampling days did not stand out as an area of concern.

Finally, the influence of agriculture on water quality can be illustrated by observing the results at the control station on Sumas mountain (station 15) and on Swift Creek (station 1), both of which have little or no agricultural activity occurring in their catchments. The plots in Appendices E and F show consistently lower values at stations 1 and 15 for ammonia-N, conductivity, nitrate-N, and orthophosphate, and higher levels of dissolved oxygen, than at all the other stations. Station 15 also had lower chloride values than other stations throughout the sampling period.

4.4.2.3 Historical Trends

Historical water quality data from 1970 to the present was compiled from a variety of sources, including the provincial SEAM and older EQUIS databases, the BCMOELP Fisheries and Wildlife files for the Sumas River, the Environment Canada Envirodat database, and previous data published on the Sumas River (Whelan et al., 1986; Schreier, 1986 and 1987; ESL and Webb, 1987; Hall et al., 1974; Benedict et al., 1973). Historical wet season values (November through March) for all the measurements taken on the Sumas mainstem were plotted for each water quality indicator (see Appendix G). Wet season values were examined since that was the period of concern identified by this study's sampling results. Unfortunately, the scarcity of data, large data gaps, and a wide spread of values for almost all the parameters made it difficult to discern any trends. Also, using only the wet season data does not nearly account for the variation in concentration with discharge. Nitrate-N (see Figure 4.9) showed the clearest trend of an increasing spread of data values, particularly since 1990. Despite the poor relationships indicated in Figure 4.9 and the plots of Appendix G, the direction of the trends which one would expect with the gradual deterioration of water

Figure 4.9 Historical Wet Season Values of Nitrate-N in the Sumas Mainstem. The increasing spread of data values over time is thought to be indicative of the increasing types and intensities of activities in the watershed.



quality (increasing chloride and nutrient levels, decreasing dissolved oxygen levels and pH) are shown. These trends may be indicative of the increasing types and intensities of land use activities occurring in the watershed.

4.4.2.4 Variation with Discharge

One weakness in the water quality analysis undertaken in this thesis is the lack of consideration given to discharge and its influence on water quality. During flood periods, water entering a stream has different origins (surface and subsurface runoff, and groundwater) which produces marked variations in water quality (Chapman, 1992). Some of the variation due to discharge was removed with the separation of data into wet and dry season categories. This helped to identify seasonal variation in the 1994-95 sampling period, yet was not sufficient to separate the discharge effects when searching for historical trends. The influence of discharge on concentration is not simply a dilution effect, but is related to sheet erosion and bed remobilization, and the flushing of soil constituents (Chapman, 1992). These in turn are influenced by rainfall intensity and duration, and rainfall patterns prior to the sampling dates. The latter factors influence the quality and quantity of runoff into the stream. Furthermore, when time is included with the relationship between sediment transport and discharge, a hysteris loop is often observed (Chapman, 1992). This means that there may be more than one value of concentration for the same flow magnitude, creating a large spread of values in the scatter diagram. Despite these suspected complications, a simple least squares regression curve was attempted for each indicator using historical flow measured at the border hydrometric station, and the historical water quality data at the nearest stations (3 and 4). The scatterplots with these regressions are presented in Appendix H. The strongest relationship with discharge is shown with ammonia-N and ortho-P concentrations, both of which increase exponentially with increased discharge.

Determining the relationship of water constituent concentrations with discharge is inhibited by the lack of historical data, especially results from high flow sampling. Also, the effect of water quality changes over time are excluded in this search for a relationship, as discharge was excluded from the search for long-term trends presented above. Ideally, all water quality data should have a flow associated with them, measured at the time and place of sampling, so that mass loadings can be used to determine relationships instead of concentrations. This type of flow data was not available for the historical data, nor was flow measured at each station as part of the sampling strategy for this thesis, due to a lack of resources and equipment. This seriously limits the interpretation of the data and the potential for water quality modelling. Nevertheless, certain trends, as described in previous sections in this chapter, can be identified.

5.0 Land Use - Water Quality Relationships

Chapters 2 and 4 presented a picture of the Sumas watershed, including: 1) the types of land use activities and land use trends; 2) spatial, seasonal variability, and historical changes in water quality; and 3) spatial and historical changes in sediment trace metal values. This chapter explores the relationships between land use and water quality characteristics using enumeration areas (EAs) and contributing areas to sampling points as the bases of comparison. Figure 5.1 shows the enumeration area boundaries in relation to the stream network and watershed boundary, and Figure 5.2 shows the delineation of contributing areas to the sampling stations. It is apparent from this latter figure that, due to the human control of drainage in this agroecosystem as described in Chapter 3, the contributing areas appear "unnatural", their boundaries being characterized by straight lines. The absence of topographical relief, together with the action of humans controlling and at times even reversing the natural drainage patterns, made the delineation of contributing areas a considerable challenge in the prairie portion of the watershed. Nevertheless, the overriding drainage pattern to the sampling stations is as shown, and was generally confirmed by Frank Wright, the Superintendent of Dyking, Drainage and Irrigation for the City of Abbotsford.

The relationships explored in this chapter were limited by the availability of the data, and the applicability of the data to be used as indicators on the spatial area basis. Only current land and water characteristics as measured during the study period were statistically tested. Also, analysis of the Canadian portion of the Sumas Watershed, where more detailed information is available, is separated from the analysis of the watershed as a whole, where estimations due to differing information formats and level of detail may compromise the

Figure 5.1 Animal Densities by Enumeration Area. AUE/ha=Animal Unit Equivalents per hectare.

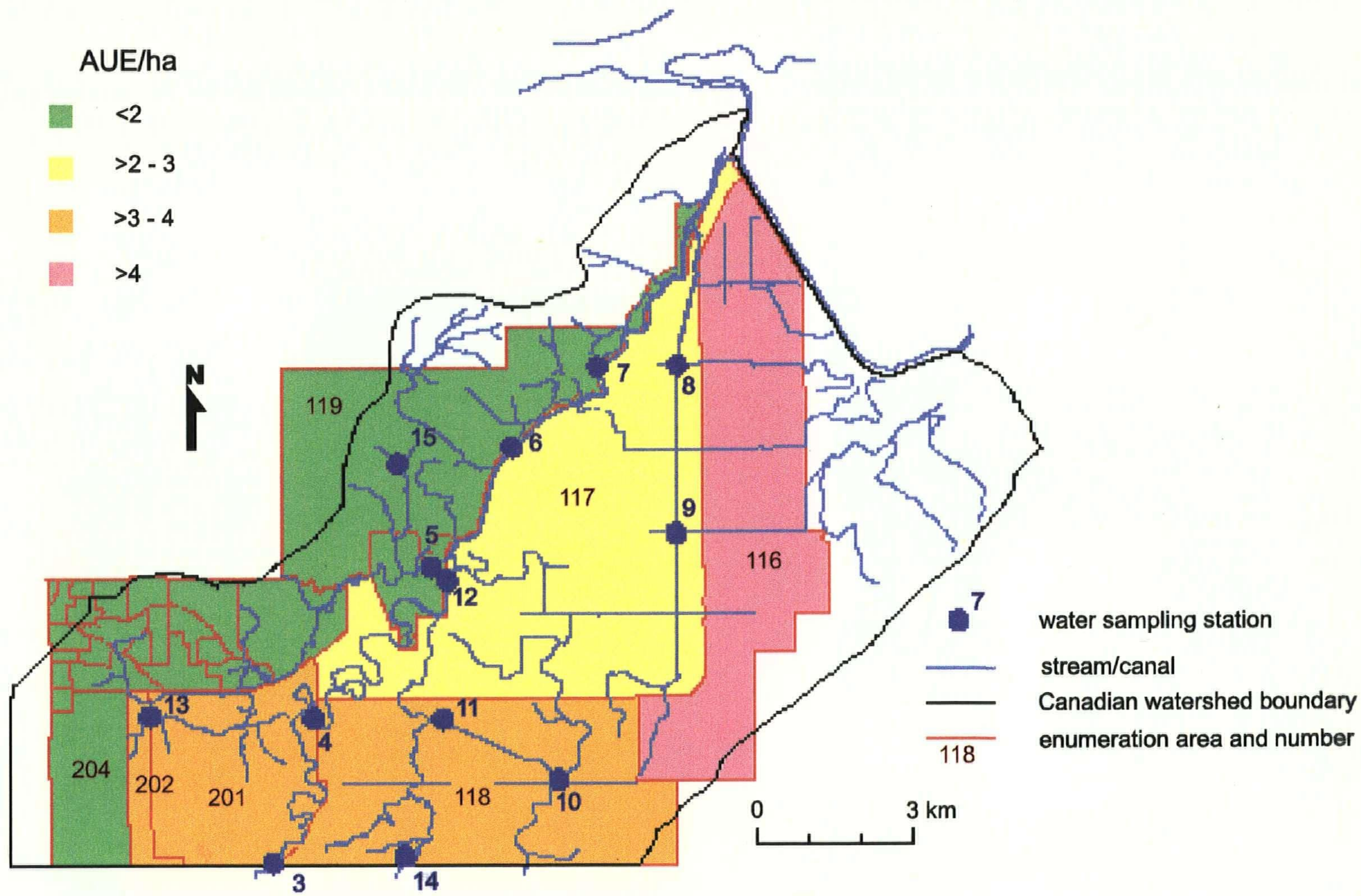
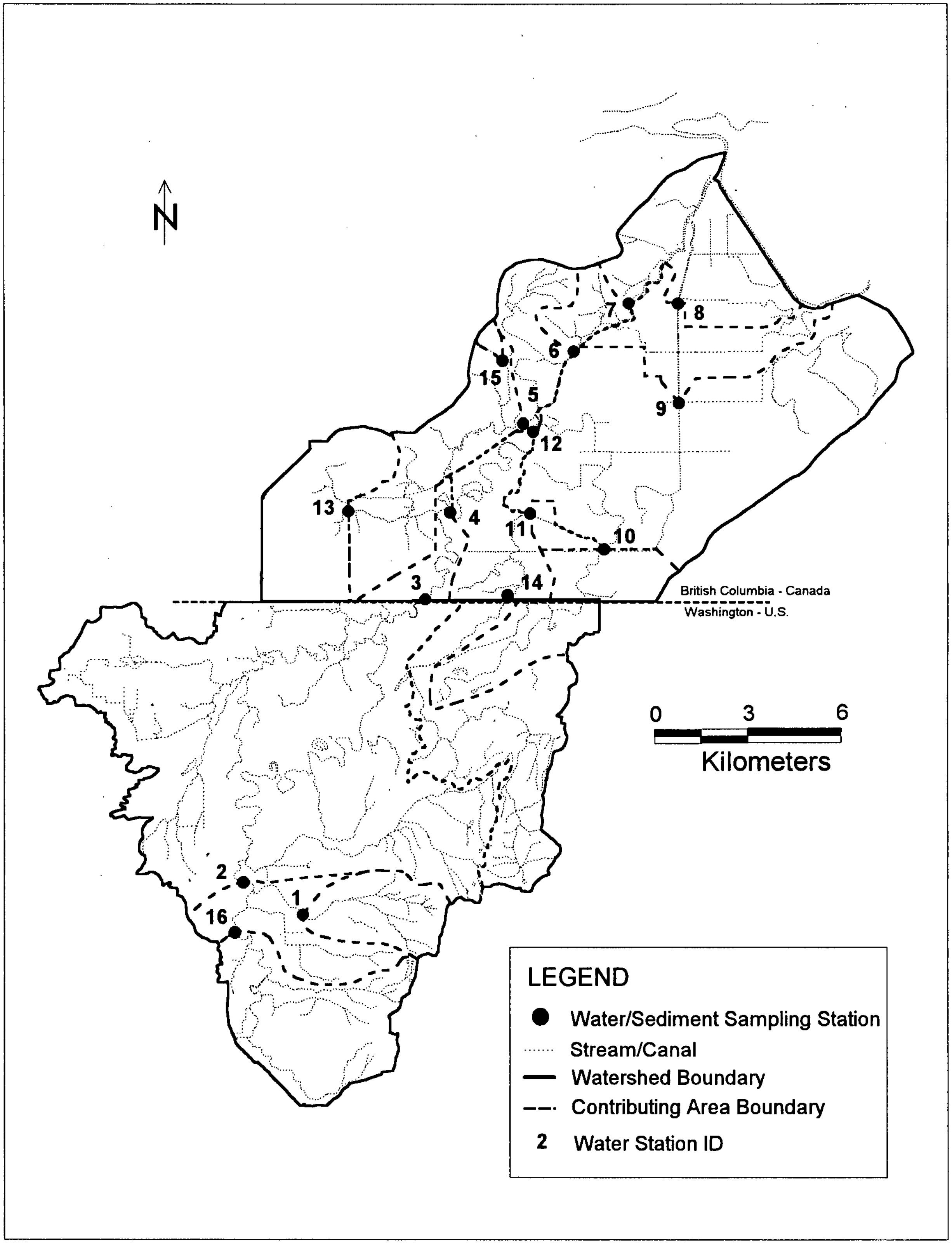


Figure 5.2 Sampling Stations and Contributing Areas in the Sumas Watershed.



results. Because of this separation of information types and availability, some summaries for contributing areas were unavoidably defined or divided by the international border. For the whole watershed analysis the divided areas for contributing area #10 (Arnold Creek) were added together and summarized as one, which resulted in different values for this contributing area than in the Canadian portion analysis.

5.1 Development of Indices

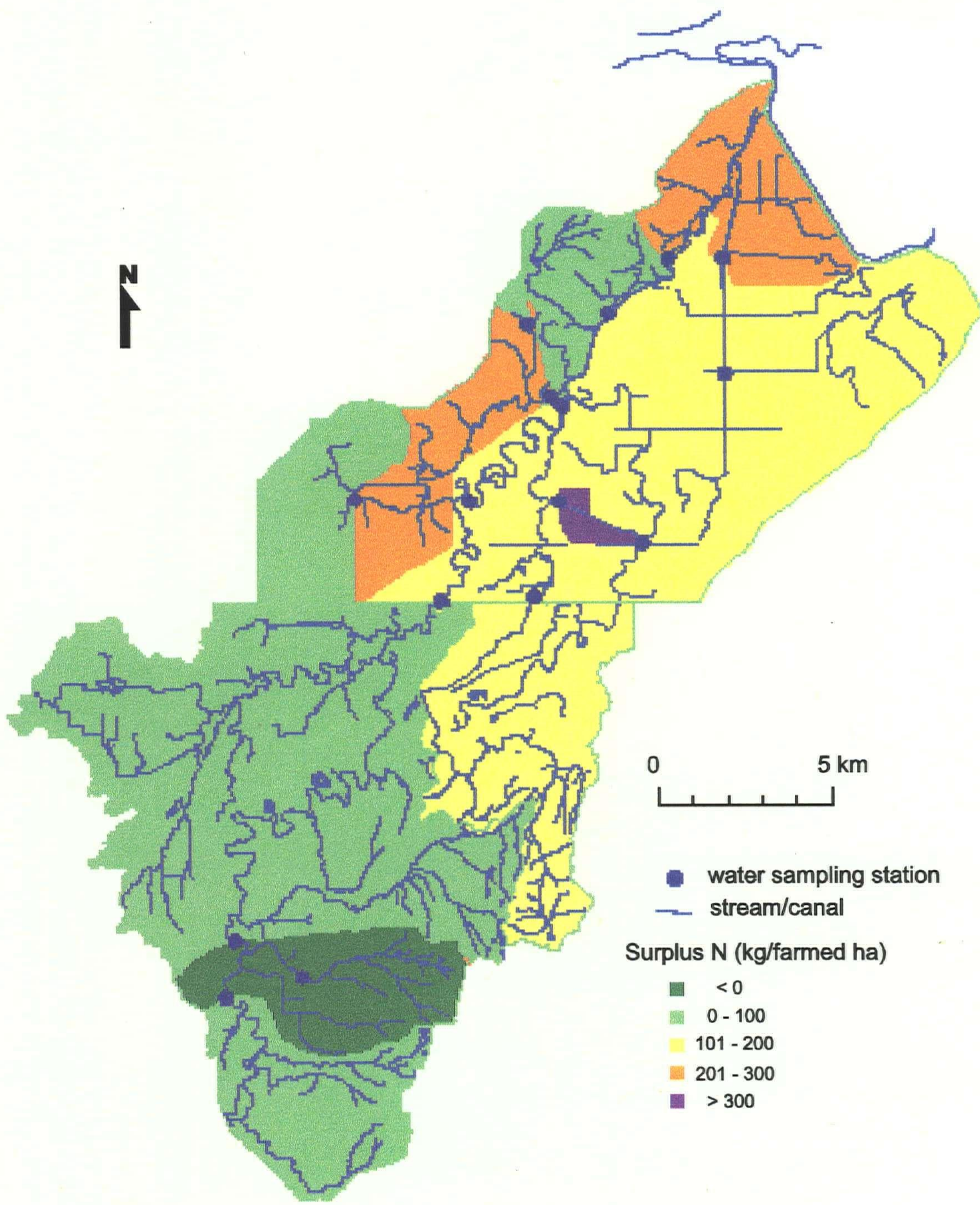
Land indices are simply the characteristics described in Chapter 2, namely the amount of land use types, measures of agricultural intensity such as surplus nitrogen loading and animal densities, and the coverage of the surficial geology, based on properties such as texture class, drainage capability and parent material. The characteristics were quantified and summarized on a spatial basis within the watershed to produce land indices that could be related to water quality values at a sampling point.

Depending on the nature of the data, the calculations were performed using either database queries or GIS spatial analysis functions, or a combination of both. For example, in the case of surplus nitrogen loading by contributing areas, the nitrogen balance results for each farm as mentioned in Section 2.5.2, were input to the farm database, which is linked to the GIS graphics component, i.e., each farm's geographic location is linked to values calculated for that farm. The overlay function of the GIS was used to determine which farms fell into which contributing areas, allowing the total surplus nitrogen loading for each contributing area to be calculated. Similarly, AUEs for each contributing area were summed. Both nitrogen loading and AUEs were divided by total farm and/or crop land area within the contributing area to express these indices as comparable rates or densities.

A major assumption in these calculations is that if a farm building falls within the boundaries of a contributing area, then all values associated with that farm, i.e., land area, crops and animals, also fall within the contributing area. However, because the contributing areas are relatively large in comparison to farm size, the error produced by this assumption should be fairly small. The GIS enables visual presentation of the indices, as shown in Figure 5.3 which illustrates surplus nitrogen loading per farmed hectare by contributing area. For the agricultural contributing areas, the values for surplus nitrogen loading ranged from 57 to 332 kg N/farmed hectare, and 7 out of the 11 contributing areas had surplus nitrogen loadings greater than 100 kg N/farmed hectare. The values for AUE density ranged from 0.4 to 4.5 AUE/farmed hectare and 3 contributing areas had densities near or over the 2.5 AUE/ha average standard. The breakdown of a watershed into smaller contributing areas and the quantification of land use activity by these smaller areas illustrates that while the overall watershed may appear to support the intensity of land use activity, more localized areas can be undergoing much higher stresses and demands, due to the unequal distribution of the activities. As can be seen in Figure 5.3, the highest loading occurs in a contributing area bordering Arnold Slough, where low dissolved oxygen and high ammonia-N values were measured in the stream.

Information on agricultural activity in the U.S. portion of the watershed was obtained from the Whatcom County Conservation District, who provided approximate locations of all (65 in total) dairy farms in the watershed, typical herd sizes (from 150 to 1000 head), and a summary of crop acreage for the Sumas and Saar Creek watersheds. The crop acreages were

Figure 5.3 Surplus Nitrogen Loading by Contributing Area.



apportioned to the contributing areas based on the amount of agricultural land within the contributing area as calculated from the land use information provided by the Whatcom County Planning Department. Locations of other animal operations were not available, although there are reportedly very few (Timblin, C., pers. comm.). Agriculture census data from the USDA for 1992 was obtained, as a check, for the town of Sumas by zip code summary (available on the Internet). Although geographical location is unknown for this data, it confirms the dominance of dairy production in the area listing only 25 small (<50 head) beef , 2 small (<50 head) hog operations, and a few small broiler and layer operations. If these operations do exist within the watershed, they are unaccounted for in the calculations of animal stocking density and surplus nitrogen. The results for nitrogen loading ranged from a deficit of -29 kg N/agricultural ha in the headwaters area to 214 kg N/agricultural ha in the Arnold Creek contributing area. Similarly, the AUE density ranged from 0.2 to 3.7 AUE/agricultural ha.

The GIS overlay function was also used to calculate total and percentage area of land use types and properties of the surficial geology by contributing area. A complete list of the indices used for correlation calculations is given in Appendix K, and the values of the indices for each contributing area are given in Appendix L.

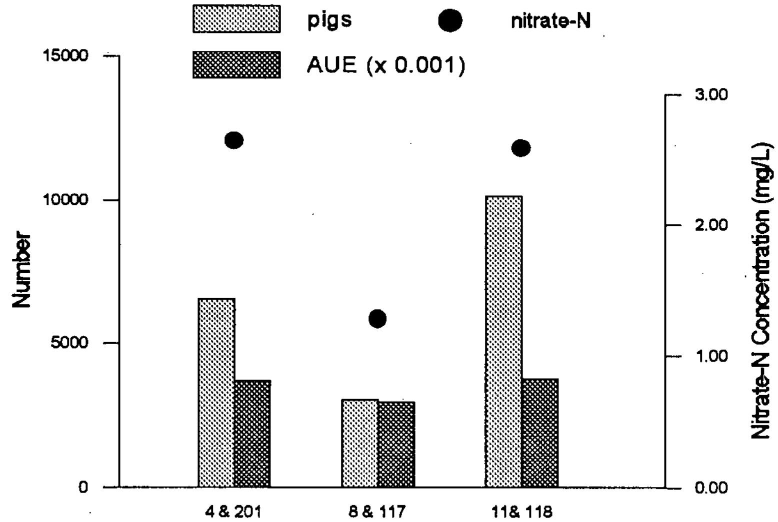
5.2 Relationships Between Indices by Enumeration Area and Water Quality

Enumeration areas are delineated on the basis of political boundaries and population densities; they have no meaningful relationship to the natural course of water (or even human-controlled drainage) to a particular point in a river. Nevertheless, land use information is most readily available in census format, so some initial exploration of this data is a useful first step towards identifying trends. Figure 5.1 shows the major agricultural enumeration areas shaded by livestock density range. As explained in Chapter 2, approximately 2.5 AUEs per ha signifies a density which may be reaching the absorptive capacity of the soil (Anderson et al., 1990). The EAs having densities above this value are shaded in orange and pink in Figure 5.1. Due to the small number of agricultural EAs, and the difficulty of choosing a sampling station representative of the EA's drainage area, statistical analysis of the indices and water quality values is not meaningful. Relationships were thus identified using graphical and visual techniques.

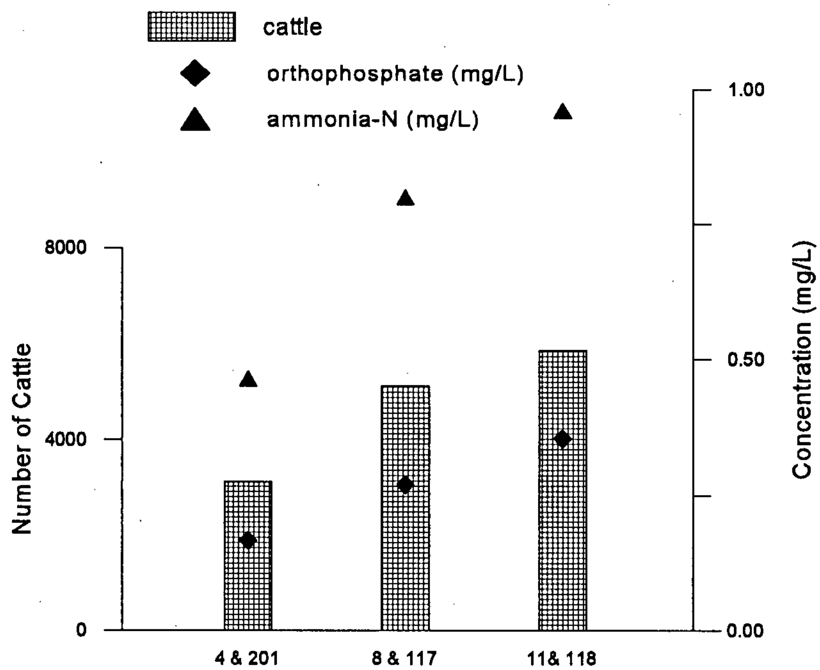
Water quality sampling stations 4, 8, and 11 were chosen to be paired with EAs 201, 117, and 118 respectively (as identified in Figure 5.1) for the comparison of land use and water quality. Figures 5.4 a) and b) illustrate the trends identified. The water quality values in these figures are wet season averages for each sampling site. There is an apparent relationship between cattle numbers and ammonia or orthophosphate in the stream, and between livestock densities or pig numbers, and nitrate levels in the stream. These trends may be a result of different manure handling strategies, or different pathways that nitrate, phosphorus and ammonia enter the aquatic environment.

One further complication of using census data is the combining of data in two separate EAs by Statistics Canada when few farms exist in one of them. This, understandably, is to protect the privacy of individual farms, but renders a less accurate spatial distribution of the data. In particular, the data for the large EA on the north side of the Sumas River, where relatively few farms exist, is combined with that of EA 117. For this reason, the area on the

Figure 5.4 Trends of Water Quality Values and Animal Numbers in Three EAs



a) Sampling Site & Enumeration Area



b) Sampling Site & Enumeration Area

north side of the river was not included in the density calculation, and the area of EA 117 was determined using the GIS rather than the lumped census figure. The combining of data in rural areas also serves to decrease the potential number of cases in a statistical analysis.

Agriculture census data is useful to identify historical and overall land use activity over the watershed, and to corroborate data compiled from other sources, i.e., aerial photographs and the WMS data. With a judicious selection of water sampling stations, tentative relationships to water quality are also shown. However, because of the limitations of using census data for identifying spatial relationships, particularly with the help of statistics, further exploration of relationships based on EA boundaries was abandoned.

5.3 Relationships Between Indices by Contributing Area and Water Quality

5.3.1 Canadian Portion of Watershed

The degree of association between the indices calculated for the contributing areas, and wet and dry season averages for selected water quality parameters, were examined using non-parametric Spearman rank correlation coefficients (r_s). The resultant correlation coefficients which were greater than 0.5 and had significance levels less than 0.05, are presented in Appendix M. A selection of these relationships, which have interesting implications, are highlighted in Table 5.1 below. Appendix M includes tables showing the significant relationships between water quality variables themselves, and between land indices which pertain to land use activity and the indices based on soil properties.

Examination of the correlation matrices lead to the following observations:

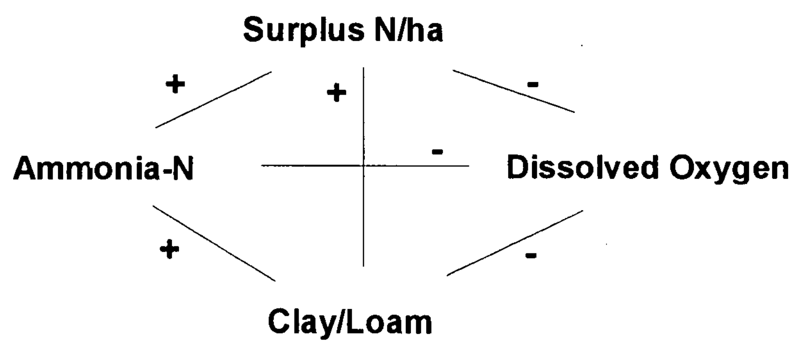
1) Dissolved oxygen levels are negatively correlated, and wet season ammonia levels

Table 5.1 Spearman Rank Correlation Coefficients for Canadian Portion Analysis

Land Index **n=11, p<0.05 in all cases**	Ammonia-N Wet season	Ammonia-N Dry season	Nitrate-N Wet season	Nitrate-N Dry season	Dissolved Oxygen Wet season	Dissolved Oxygen Dry season
Surplus N/farmed ha	0.76				-0.84	-0.63
Surplus N/cropped ha	0.76				-0.84	-0.63
# of pigs	0.67				-0.76	
% area of no perceived activity			0.63	0.61		
Surface Texture						
hectares organic			0.75	0.74		
% organic			0.75	0.74		
hectares loam	0.70				-0.79	-0.62
% loam	0.80				-0.89	-0.71
Subsurface Texture						
hectares clay	0.61				-0.61	-0.61
% clay		0.81			-0.63	-0.63
% loam	0.70					-0.70
% silt			0.65	0.79		
% sand			-0.85	-0.78		
Drainage						
% well					0.71	0.61
hectares poor					-0.67	
% poor					-0.67	
hectares very poor			0.73	0.72		
% very poor			0.82	0.83		
Parent Material						
hectares organic			0.67	0.67		
% organic			0.67	0.67		

are positively correlated, to surplus nitrogen application rates and amount of finer textured soils within a contributing area. This can be represented by the contextual diagram below. Surplus nitrogen application rates are also positively correlated to amount of finer textured soils, which may mean either that one of these land indices' relationship to the water quality is due to the other, or that the two indices compound each other in affecting water quality. The latter is believed to be the case, as stronger relationships are found in the wet season when greater runoff would occur on fine-textured soils.

Figure 5.5 Ammonia, Dissolved Oxygen, Surplus N, and Soils: System of Relationships in Canada

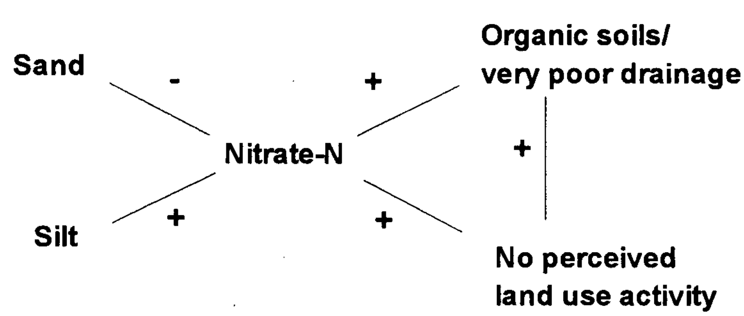


2) There is a positive relationship between nitrate values and the amount of organic soils, or soils with very poor drainage, in a contributing area. Both of these variables are also positively correlated with the area of land with "no perceived activity", a land use tending to occur in the more industrial areas, and bordering the Abbotsford Aquifer. It is believed therefore that these relationships are strongly influenced by the contribution of contaminated water from the Abbotsford Aquifer. However, it is possible that the organic soils are

providing a source of nitrogen which is mineralized and then nitrified to nitrate.

Nitrate values are also positively correlated to the percentage of silt in a contributing area, and negatively correlated to the percentage of sand in the area. These two soil variables are not correlated to the "no perceived activity" land use type. From these observations, it can be postulated that nitrates are higher from areas with poor drainage and/or organic material, and lower nitrate values occur in the stream water when the area has sandy texture. Nitrates in the sandy areas may be infiltrating into the subsurface and undergoing denitrification. This may be possible in sandy soils, which are normally considered well aerated, if the surface and subsurface irrigation produce an anaerobic environment, and applied manure acts as a carbon source to the denitrifying bacteria. Alternatively, the nitrates may be entering the stream outside the contributing area due to the various influences on groundwater flows from extensive pumping and drainage. The diagram below summarizes the system of relationships found for nitrate levels.

Figure 5.6 Nitrates, Soils and Land Use: System of Relationships in Canada



Strong relationships with other water quality variables and the land indices were not identified. Because phosphorus tends to be associated with sediment, sampling for total phosphorus over many storm events, with frequent sampling intervals (and thus a modified statistical analysis) may yield relationships with land use. Unfortunately, this is a very labour, equipment and time intensive process to carry out. Other relationships which one might expect to surface may not be presented because of a failure to meet the chosen relationship criteria. This does not mean that they did not nearly meet the criteria. In the statistical analysis of contributing areas in the Canadian portion of the Sumas watershed, no relationships or patterns emerged which conflicted with common sense or contradicted each other.

5.3.2 Whole Watershed

Using the soils, land use, and agricultural data collected for Whatcom County, and the water quality results from stations 2 and 16 in Whatcom County and stations 3 and 14 near the border, the non-parametric correlation computation was repeated in a "whole watershed" context. The Spearman rank correlation coefficients for the whole watershed analysis are given in Table 5.2. In general, the relationships found were similar to those of the Canadian portion analysis, but the values of the coefficients were lower. This is likely the result of two major factors. Firstly, the sampling sites in Whatcom County had a poor spatial distribution since the focus was on conditions in the headwaters and monitoring the water quality crossing the border. Secondly, no field verification was conducted in the United States for agricultural activity, and as the census data suggests, some animal operations were missed.

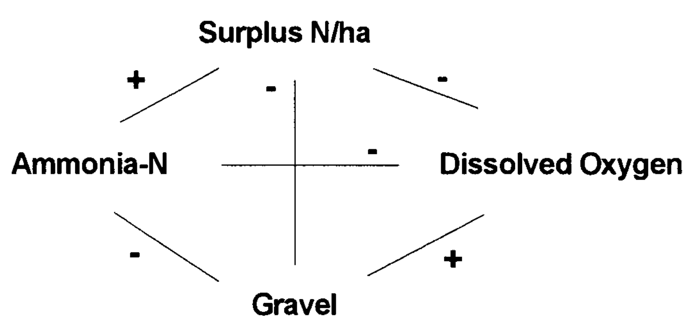
Conductivity, specifically in the wet season, is correlated to indices of agricultural

Table 5.2 Spearman Rank Correlation Coefficients for Whole Watershed Analysis

Land Index **n=15, $p<0.05$ in all cases**	Ammonia-N Wet season	Ammonia-N Dry season	Nitrate-N Wet season	Nitrate-N Dry season	Dissolved Oxygen Wet season	Dissolved Oxygen Dry season	Conductivity Wet season	Conductivity Dry season
Surplus N/farmed ha	0.54				-0.61	-0.52	0.54	
Surplus N		0.55					0.65	
AUE density		0.60						0.54
AUE total							0.64	
Texture								
hectares clay			0.53				0.69	0.56
% clay		0.56	0.53				0.61	0.73
hectares sand								
% sand			-0.69	-0.61				
% gravel	-0.56				0.58			
Drainage								
hectares imperfect							0.65	0.60
% imperfect							0.54	0.72
hectares very poor			0.56	0.54				
% very poor			0.69	0.62				
Parent Material								
hectares organic				0.57				
% organic				0.58				

intensity in the whole watershed analysis. This further confirms the wet season phenomena of contaminated runoff, as more fertilizer and manure entering the stream would increase the salt concentration. Interestingly, the amount of clay in the contributing area as a relevant index disappears, and in its place the amount of gravel appears instead, showing the opposite relationships to ammonia-N, dissolved oxygen and surplus nitrogen as did the amount of clay. Thus Figure 5.5 is transformed to Figure 5.7. Again, the relationships appear in the wet season, suggesting that less contaminated runoff occurs in the coarser textured contributing areas during this time. It should be noted that changes in relationships with soils from the Canadian analysis to the whole watershed analysis are likely due to the different soil classification system used by the United States. Although the same basis for categorization of the soil properties was attempted using the soil descriptions, some inconsistencies were inevitable.

Figure 5.7 Ammonia, Dissolved Oxygen, Surplus N, and Soils: System of Relationships in the Whole Watershed



With respect to nitrates, the relationship with "no perceived land use" disappears, while the relationships with organics, sand and finer texture material remain. This is represented in the figure below.

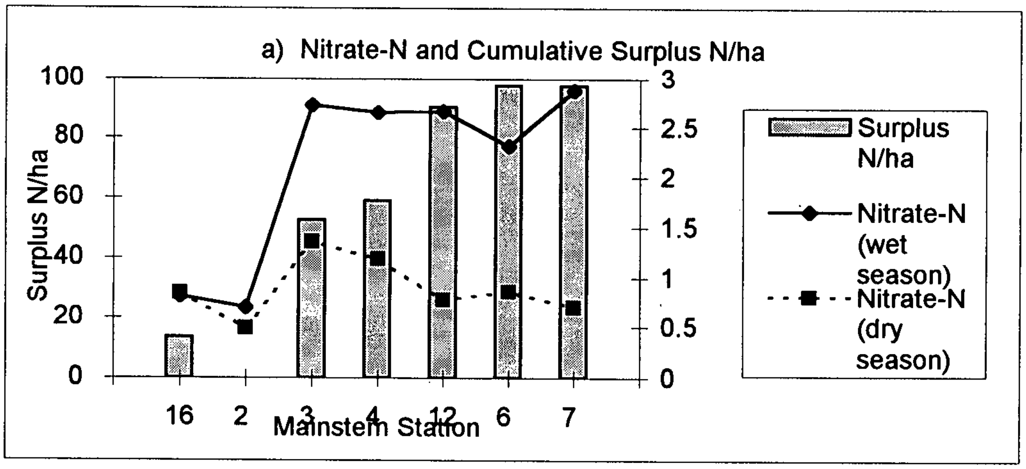
Figure 5.8 Nitrates and Soils: System of Relationships in the Whole Watershed

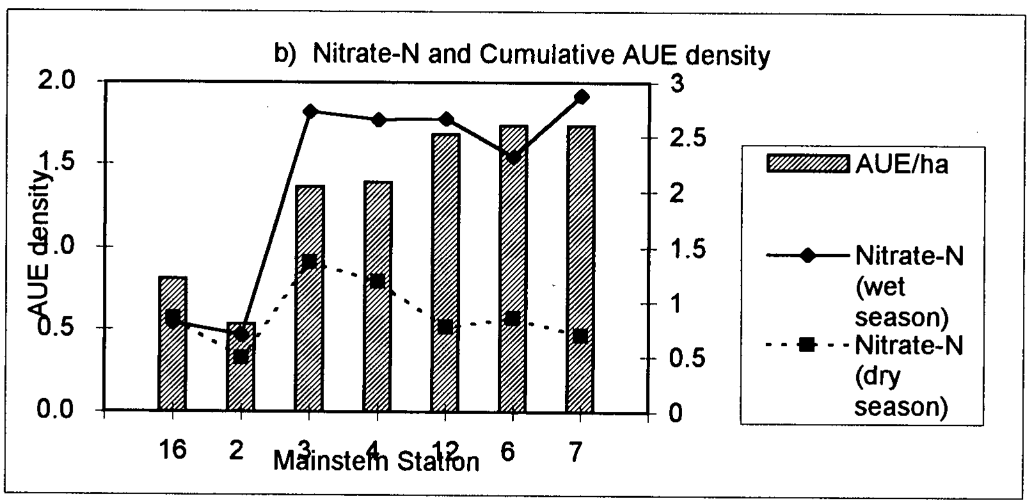
The conceptual diagrams for both the Canadian and the whole watershed analysis demonstrate an important issue in the study of non-point source pollution. This is that the influence of land use activity on non-point source pollution cannot be separated from the inherent features of the land, i.e., soils. Although the statistical analysis assumes indices are independent, in reality humans concentrate certain activities over certain soil types; this is necessary for agricultural productivity. In the Sumas Prairie, vegetable production is concentrated on the sandier soils of the old lake bed, resulting in the animal operations tending to develop on the less desirable, finer soils. Although finer textured soils have greater adsorption capacities, the poorer drainage of these soils appears to contribute to more surface runoff. Unfortunately, the combination of animal waste on these finer soils exacerbates the problem of agricultural pollution to the stream during the wet season.

In both the Canadian and the whole watershed analysis, nitrate levels in the stream do not appear to be related to the indices of agricultural intensity. In the water quality investigation, nitrate was the only constituent measured that clearly increased in concentration from upstream to downstream (see Figure 4.8). This corresponds with the cumulative increase in the indice values if the contributing areas are added together from upstream to downstream, as illustrated in Figure 5.9.

While the method of independently testing contributing areas, regardless of land activity upstream, identifies relationships of land use with ammonia and dissolved oxygen, the method appears to be inappropriate for relationships with nitrate. There may be a sufficient lag time as ammonia-N is nitrified to nitrate-N in the stream, so that nitrate values are less influenced by nearby land use, and more influenced by the cumulative effects of intense activity in the watershed as a whole. Examination of the system dynamics using water quality modelling techniques would be useful in testing this hypothesis.

Figure 5.9 Cumulative Indices and Nitrate-N Values.
Upstream to Downstream on the Sumas Mainstem.
AUE = Animal Unit Equivalents.





6.0 Summary and Recommendations

Problems related to agricultural waste management in the Sumas River watershed consist of an inadequate land base for manure disposal, low dissolved oxygen and high ammonia levels, and the potential for fish kill conditions. Despite the introduction of Environmental Guidelines for various producer groups (BCMOAFF, 1992 and 1993) and the 1992 Code of Agricultural Practice for Waste Management, IRC (1994) found that farms are operating on average at only 60% of the recommended environmental sustainability level, which was determined from an environmental sustainability parameter (ESP) based on the Guidelines and the Code (Palmer and Rising, 1996). The standard of practices were found to vary widely from farm to farm, as represented by the ESP, with manure storage being identified as one of the most critical factors for environmental sustainability.

This thesis aimed to explore relationships between land use activity and water quality in the Sumas River watershed with an emphasis on agricultural non-point source pollution. Links between agricultural intensity, soil characteristics, and water quality were identified. In the process of investigating these links, spatial and temporal trends in land use and water and sediment quality were documented, and a potential watershed management tool was developed through the use of a GIS. Throughout the thesis work, trends and links were considered in context of the biophysical factors which characterize the Sumas River watershed, including flooding recurrences, controlled hydraulics, fisheries resources, and the contamination from a natural landslide. Social and economic factors were not considered, and these have potentially serious and broad implications to water quality and quantity management. This thesis therefore contributes a small but significant piece of the Sumas Sustainability Study, the start of an evolving watershed management puzzle.

6.1 Land Use Summary

Compilation and analysis, with the help of a GIS, of aerial photos, census data, Waste Management Survey (IRC, 1994) data, and this study's field work data, has revealed the following land use trends: 1) Residential and industrial/commercial encroachment is occurring onto other land use types, such as forested or lands under speculation; 2) The agricultural land base remains constant, but agricultural intensification is apparent since farm and dwelling numbers continue to grow. The 1954 aerial photos of the Canadian portion of the Sumas watershed revealed 224 farms; 283 farms were identified in the 1994 aerial photos. Within the Canadian agricultural land base, cattle numbers remained constant between 1986 and 1991, while pig and poultry numbers increased by 50 and 75% respectively. The combination of increasing animal densities and flooding problems results in an increasing risk of economic and environmental damage, in terms of evacuation procedures, animal mortalities, and the spread of wastes and pathogenic organisms.

The overall animal density for the Canadian portion of the watershed was 2.3 animal unit equivalents (AUE)/farmed ha. On a contributing area basis, the density ranged from 0.4 to 4.5 AUE/farmed ha for the Canadian side and 0.2 to 3.7 AUE/farmed ha on the U.S. side. When calculated on a farm basis, 44% of the farms that participated in the Waste Management Survey had densities above the 2.5 AUE/ha average standard. Annual surplus nitrogen loadings were found to range from 123 to 151 kg N/farmed ha for the overall watershed, compared to the benchmark figure of 100 kg N/ha, and from a deficit of -29 to a surplus of 332 kg N/farmed ha on a contributing area basis.

6.2 Water Quality Summary

Sampling of stream sediment for trace metals revealed a general enrichment since the 1970's of zinc levels throughout the watershed, with many areas having concentrations above the lowest effect level given by British Columbia and Ontario criteria. At local sites, including one on Arnold Creek and another on Marshall Creek, the sediment zinc concentrations were well above the U.S. EPA designated "heavily polluted" level for the Great Lakes Harbours. Potential anthropogenic sources of zinc include automobile traffic, and fertilizer and animal feed supplements.

The nickel and chromium contamination of sediments due to the landslide in the headwaters was apparent in the results. A dramatic decrease in these metal concentrations with distance downstream of the landslide was measured, but the levels remained well above natural levels even at the lowest station. Overall nickel and chromium levels increased since the 1970's, likely due to the gradual movement of landslide sediment downstream over time. Further distribution of this contaminated sediment within the watershed will likely occur with each successive flood.

Nutrient and fecal coliform levels in the water column were much higher in the wet season than in the dry season, and highest on the sampling day of greatest discharge. This is likely from runoff carrying manure which is spread in the wet season due to lack of winter storage. Winter flood waters could potentially carry very high loads of agricultural contaminants. Nitrate-N levels exhibited an increase in the downstream direction; ammonia may be nitrifying to nitrate as it is carried in the often slow-moving stream. The highest nitrate-N levels were recorded in Marshall Creek. This creek differed from the rest of the system in that nitrate-N levels were highest in the dry season. Groundwater input, which is proportionately greater in the dry season, is the suspected source.

Arnold Slough was identified as having the poorest water quality within the system. High ammonia and temperature levels, and low dissolved oxygen levels create a hazardous environment for fish, particularly in the fall season which coincides with the migration of spawning salmon. Fecal coliform levels were found to be highest in Arnold Slough, Marshall Creek and Saar Creek. Although a 5 sample/30 day geometric mean could not be calculated, the individual coliform counts were often above the 200 FC/100 mL limit recommended for water recreation and irrigation of vegetables/fruit eaten raw (CCREM, 1987 and BCMOELP, 1994).

Finally, collection of historic data since 1970 from other sources allowed a tentative illustration of the trends toward an increasing spread of data values during the wet season for nitrate-N, ortho-P, ammonia-N and chloride. This data also illustrated the relationship of increased levels of ammonia-N and ortho-P with increased discharge.

6.3 Summary of Relationships Between Water Quality and Land Use

The correlation of land use indicators with surface water quality on a contributing area basis resulted in several significant relationships. Ammonia-N correlated positively with surplus nitrogen loading and with the amount of clay as a surficial texture in the contributing area. Dissolved oxygen levels had a negative correlation with these same two indicators. These relationships were strongest using the wet season water quality data. It therefore appears that the more surplus nitrogen applied to the land, the lower will be the dissolved oxygen levels, and the higher the ammonia-N levels, in the stream. These negative impacts are compounded in the wet season and if the surplus nitrogen is applied to very fine surface textures, both factors equating to increased runoff conditions.

Nitrate-N levels did not correlate with any of the agricultural activity indicators. It did, however, correlate positively with the amount of organic soils and clay surficial texture, and negatively with the amount of sandy texture in the contributing area. Mineralization of organic nitrogen in soils may be another source of nitrates to the stream. Nitrates in the field may be infiltrating into sandy areas and undergoing denitrification and/or appearing in the system further downstream of the sampling point, which would offer another explanation for the increasing nitrate levels in the downstream direction.

An interesting point emerging from these relationships is the implication to certain traditional agricultural waste management philosophies applicable to most other agricultural watersheds. Agricultural applications are usually considered more of a risk on coarse textured soils due to groundwater quality concerns. However, groundwater quality beneath the Sumas Prairie is a relative non-issue, since farms are serviced with municipal water. It is therefore on the fine textured soils, which serve to protect the groundwater, where agricultural applications pose the greatest threat to the water resource of concern, the surface water.

6.4 Recommendations

The above summaries lead to several possible recommendations, addressed to individuals or agencies able to pursue research within the watershed, or to decision-makers and managers which influence the activities within the watershed.

1. *Investigation of high zinc levels.* This study did not pursue the identification of the potential sources of high zinc concentrations in the sediment. Possible anthropogenic sources should be researched. Further sediment and soil sampling is required to help determine both the source and whether the trend of increasing levels continues.

2. *Investigation of groundwater inputs to Marshall Creek.* Groundwater contribution from the contaminated Abbotsford aquifer is indicated in this study. However, what and how much of the potential contaminants from the aquifer is not known. An investigation of the groundwater hydrology in this vicinity and the discharge of the trout hatchery, and their effects on water quality and quantity in the stream, should be conducted to determine if this phenomena/practice should be of concern.

3. *Agricultural waste management.* The use of best management practices should continue to be encouraged to reduce agricultural pollution, including nutrient inputs and fecal coliform counts. Over the long term, the best management practices for the Sumas River watershed would ideally include measures to decrease the potential for the spread of contaminants during floods, considering the frequency of their occurrence. This may involve the modification of manure and animal storage facilities.

Better manure management during the fall rainy season needs to be more aggressively encouraged. This critical period results from the unfortunate combination of a) farmers needing to empty their manure storage facilities in preparation for the winter, b) an increase in volume and intensity of rainfall, c) oxygen-consuming die-off of summer algal blooms (themselves a result of nutrient enrichment), and d) the migration of spawning salmon. The Arnold Slough subwatershed should be particularly targeted for the implementation of best management practices.

4. *Continued monitoring and consideration of land use trends, agricultural intensification, and flooding impacts.* Increasing industrial and residential areas will generate water contaminants of their own, and will gradually change the nature of water quantity and quality as it is currently documented in the watershed. The increasing animal densities, farm and dwelling numbers should be monitored to see if these trends continue. Land management decisions regarding intensification should be made in light of the capacity of the land to accept the wastes generated or alternatives available to deal with the wastes, and in light of the flooding risk to the Prairie. Increasing animal densities have major implications to flood emergency response plans, mitigation, and environmental health.

5. *Incorporation of site specifics into land management policies.* The relationships identified between land use and water quality illustrate the importance of the influence of soil types. Blanket policies which do not take into consideration these details in the context of other watershed characteristics may prove to be overly restrictive, ineffective and inefficient.

6. *Development of water quality/watershed management model.* To aid further research investigations and facilitate land management decisions, a water quality/watershed management model needs to be developed. This would include water sampling in conjunction

with flow measurement to develop and calibrate a water quality model. The GIS database built in this study could be further developed to provide input to the water quality model and explore management scenarios.

The ESP developed by IRC (1994) could be used as a more comprehensive management indicator to relate to water quality than the animal densities and surplus nitrogen loading used in this study. The quantification of the ESP on a contributing area basis and its correlation with water quality values may lend more understanding to land use - water quality relationships. Future sampling schemes should have a greater sampling density on the U.S. side than employed in this study, and also should increase the sampling density in identified problem subwatersheds (e.g., Arnold Creek watershed).

7. *Consideration of social and economic factors.* It is impossible to make good water management decisions in isolation from social and economic influences. Although they are not addressed in this study, the watershed management model will naturally need to incorporate these complicating factors. For example, community goals and desires, urbanization and industrialization pressures, behaviour of commodity markets, free trade impacts and agricultural competition, and prices of animal feed and other agricultural inputs, all influence the dynamics of land use and the resulting water quality in the watershed.

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Appendix A: Within Site Replication Results and Comparison of Chemex and 1993/94 Digestion Methods

1994	HF	Chemex	deviation	HF	Chemex	deviation	HF	Chemex	deviation	HF	Chemex	deviation
Sample	**Cr ppm**		from HF	**Cu ppm**		from HF	**Ni ppm**		from HF	**Zn ppm**		from HF
	(mg/kg)		(%)	(mg/kg)		(%)	(mg/kg)		(%)	(mg/kg)		(%)
2116	318			25			1226			88		
2116B	235	238	1	19	23	23	922	928	1	76	72	-6
2116C	225	236	5	10	19	81	832	896	8	81	72	-11
2116D	211	209	-1	16	22	37	685	753	10	93	82	-12
ave.	248	228		18	21		916	859		84	75	
std.dev.	48	16		6	2		229	93		7	6	
coeff. of var. (%	19	7		34	10		25	11		9	8	
2502	182			42			429			131		
2502B	142	76	-46	31	18	-41	323	180	-44	107	68	-37
2502C	133	81	-39	22	18	-20	288	179	-38	102	68	-33
2502D	121	75	-38	21	17	-18	281	175	-38	99	67	-33
ave.	145	77		29	18		330	178		110	68	
std.dev.	27	3		10	1		68	3		15	1	
coeff. of var. (%	18	4		33	3		21	1		13	1	
2503	167			33			171			118		
2503B	131	38	-71	13	15	13	121	60	-50	93	54	-42
2503C	97	41	-58	6	14	125	94	59	-37	85	54	-36
2503D	98	40	-59	11	15	42	102	60	-41	90	54	-40
2503D-R	100			9			97			90		
ave.	119	40		15	15		117	60		95	54	
std.dev.	16	1		3	1		12	1		4	0	
coeff. of var. (%	14	2		20	5		10	1		4	0	

Note: HF denotes hydrofluoric acid digestion of <63 um fraction
Chemex denotes 10% HCl digestion of <180 um fraction by Chemex Laboratories

Appendix B: Accuracy and Precision Calculations

Standard Reference		Cr ppm (mg/kg)	Cu ppm (mg/kg)	Ni ppm (mg/kg)	Zn ppm (mg/kg)
MESS-1	measured:	51.19	3.95	25.29	158.63
	certified:	71 +/- 11	25.1 +/- 3.8	29.5 +/- 2.7	191 +/- 17
%error outside range:		15	81	7	9
BCSS-1	measured:	90.18	4.09	54.53	92.99
	certified:	123 +/- 14	18.5 +/- 2.7	55.3 +/- 3.6	119 +/- 12
%error outside range:		17	74	0	13
	Chemex:	52	14	49	106
REPLICATES					
1114		276.96	30.75	1086.63	106.50
1114-R		257.58	24.88	1085.94	107.72
%diff		7	19	0	1
1122		131.94	111.11	228.32	274.46
1122-R		127.74	123.59	230.13	284.01
%diff		3	11	1	3
1503		178.92	54.83	206.55	135.40
1503-R		101.45	10.97	112.28	95.64
%diff		43	80	46	29
2501		348.26	16.22	1862.43	63.38
2501-R		357.03	27.92	1910.15	67.85
%diff		3	72	3	7
2503D		97.86	10.54	102.49	90.17
2503D-R		100.30	9.17	97.32	89.58
%diff		2	13	5	1
2506		222.43	49.41	492.85	179.15
2506-R		235.51	73.21	532.76	182.45
%diff		6	48	8	2
788C		18.27	6.35	14.96	51.66
788C-R		18.94	4.83	13.36	48.49
%diff		4	24	11	6
792B		38.71	-6.74	21.92	75.25
792B-R		32.71	-6.83	20.65	73.70
%diff		15	1	6	2
AVE %diff		10.4	33.6	9.8	6.5
std. dev		13.9	29.6	14.9	9.5
AVE %diff	(excluding	5.8	27.0	4.7	3.2
std. dev	sample 1503)	4.6	24.7	3.9	2.5

Appendix C: Sediment Sampling Results, September 1993 and August 1994

Note: Cd and Pb results were below detection limits

1993					1994				
Station	Cr ppm (mg/kg)	Cu ppm (mg/kg)	Ni ppm (mg/kg)	Zn ppm (mg/kg)	Station	Cr ppm (mg/kg)	Cu ppm (mg/kg)	Ni ppm (mg/kg)	Zn ppm (mg/kg)
1112	101.50	31.68	86.08	167.48	2112	92.78	33.75	78.68	158.18
1113	162.16	79.08	163.49	338.55	2113	115.35	68.63	114.46	275.82
1114	276.96	30.75	1086.63	106.50	2114	249.32	44.21	1011.41	121.94
1114-R	257.58	24.88	1085.94	107.72					
1115	248.16	27.68	946.40	113.27					
1116	321.40	36.92	1334.87	299.69	2116	318.37	24.97	1225.99	87.63
					2116B	235.32	18.73	921.76	76.47
					2116C	225.03	10.49	831.54	80.60
					2116D	211.32	16.01	684.84	92.93
1118	120.38	44.20	148.83	120.31	2118	149.42	47.20	176.00	133.25
1119	153.84	39.31	190.19	131.72					
1120	136.82	48.60	173.53	115.79	2120	165.33	46.86	188.51	124.92
1121	117.33	83.31	215.85	154.05	2121	160.93	79.38	236.11	187.65
1122	131.94	111.11	228.32	274.46	2122	50.56	32.53	81.29	244.16
1122-R	127.74	123.59	230.13	284.01					
1123	97.46	45.21	130.99	198.58	2123	134.96	59.25	187.30	149.22
1125	123.93	11.75	147.34	87.85	2125	126.98	33.36	144.57	125.20
1126	78.73	34.99	104.65	113.34					
1127	84.76	40.92	150.30	178.91					
1128	65.03	48.25	143.80	144.03					
1129	72.82	26.53	133.84	68.18	2129	118.47	38.48	204.99	140.52
1130	76.28	49.16	132.88	193.66	2130	102.45	44.63	153.36	198.60
1131	52.44	20.99	75.11	110.10					
1133	89.00	42.86	142.50	187.13	2133	98.84	53.78	180.47	230.69
1134	150.62	31.40	249.61	127.94	2134	134.21	22.01	170.97	105.98
1135	108.81	40.64	112.01	144.64	2135	117.35	26.54	120.81	124.89
1136	107.71	56.87	68.62	214.08	2136	90.17	42.45	53.92	123.06
1145	74.37	53.65	66.93	207.46	2145	81.87	52.56	69.51	191.06
1146	44.97	45.81	42.18	200.86	2146	80.28	37.41	58.82	211.56
1500	367.70	24.01	1929.59	28.78	2500	338.32	7.73	1809.03	32.29
1501	370.86	12.10	1827.30	45.32	2501	348.26	16.22	1862.43	63.38
					2501-R	357.03	27.92	1910.15	67.85
1502	175.52	37.53	391.52	123.47	2502	182.49	41.55	429.01	131.05
					2502B	141.55	30.66	322.96	107.17
					2502C	133.42	22.39	288.44	101.66
					2502D	120.72	20.70	281.18	99.41
1503	178.92	54.83	206.55	135.40	2503	167.03	33.46	171.20	118.14
1503-R	101.45	10.97	112.28	95.64	2503B	130.92	13.32	121.07	93.43
					2503C	96.55	6.21	93.74	84.57
					2503D	97.86	10.54	102.49	90.17
					2503D-R	100.30	9.17	97.32	89.58
1504	106.21	32.10	110.30	187.60	2504	95.85	42.78	129.36	159.70
					2505	123.56	32.61	47.87	175.99
					2506	222.43	49.41	492.85	179.15
					2506-R	235.51	73.21	532.76	182.45

Appendix D: Water Sampling Results

	pH											
	March 2	May 9	June 23	June 29	July 26	Aug 24	Oct 3	Nov 24	Feb 1, 95			
	03-02	05-09	06-23	06-29	07-26	08-24	10-03	11-24	02-01			
Station										Median	Max	Min
1	8.5	8.5	8.5	8.1	9.4	8.3	8.4	9.1	9.2	8.5	9.4	8.1
2	7.7	7.6	8.0	8.0	7.8	7.6	8.0	7.9	8.2	8.0	8.2	7.6
3	7.3	7.5	8.2	7.8	7.9	7.8	7.2	7.8	7.9	7.8	8.2	7.2
4	7.3	7.9	8.0	8.1	8.2	7.9	7.8	7.8	7.6	7.8	8.2	7.3
5	6.7	7.2	-	8.0	7.5	7.3	7.3	7.5	6.9	7.3	8.0	6.7
6	6.8	7.4	7.4	8.0	8.1	8.0	7.6	7.8	7.1	7.7	8.1	6.8
7	7.0	8.3	7.6	8.1	9.1	8.0	7.8	7.7	7.1	7.9	9.1	7.0
8	6.9	8.5	6.9	8.0	7.8	7.4	7.5	7.4	7.0	7.5	8.5	6.9
9	6.8	7.7	-	7.7	7.5	7.4	7.4	7.2	6.9	7.4	7.7	6.8
10	6.9	6.6	7.3	7.5	7.2	7.3	7.2	8.4	6.8	7.3	8.4	6.6
11	6.9	6.5	7.4	7.4	7.9	8.6	7.4	7.3	6.9	7.4	8.6	6.5
12	7.2	7.6	7.1	8.0	8.4	8.2	7.8	7.6	7.1	7.7	8.4	7.1
13	6.8	7.5	7.2	7.8	7.8	7.5	7.7	7.4	6.6	7.5	7.8	6.6
14	-	7.1	7.6	7.5	7.3	7.3	6.8	7.5	7.1	7.3	7.6	6.8
15	-	6.9	7.9	7.7	7.9	7.5	7.7	9.1	7.2	7.7	9.1	6.9
16	-	6.9	7.1	7.3	7.1	7.2	6.9	7.0	7.0	7.0	7.3	6.9
Median	6.9	7.5	7.5	7.9	7.9	7.5	7.6	7.7	7.1	7.6		
Max	8.5	8.5	8.5	8.1	9.4	8.6	8.4	9.1	9.2		9.4	
Min	6.7	6.5	6.9	7.3	7.1	7.2	6.8	7.0	6.6			6.5

	Conductivity (micromhos/cm)											
	March 2	May 9	June 23	June 2	July 26	Aug 24	Oct 3	Nov 24	Feb 1, 95			
	03-02	05-09	06-23	06-29	07-26	08-24	10-03	11-24	02-01			
Station										Median	Max	Min
1	130	400	160	185	290	250	170	125	90	170	400	90
2	166	240	245	240	290	230	165	180	107	230	290	107
3	180	260	250	260	320	250	170	185	111	250	320	111
4	182	265	250	270	350	270	170	190	122	250	350	122
5	183	245	245	240	280	235	140	215	91	235	280	91
6	140	265	225	275	300	265	175	162	95	225	300	95
7	140	260	230	265	270	215	170	175	132	215	270	132
8	155	205	220	210	260	200	150	190	92	200	260	92
9	198	175	180	210	295	260	160	200	86	198	295	86
10	192	260	250	295	315	280	180	232	91	250	320	91
11	203	290	245	270	335	270	-	205	35	258	335	35
12	160	290	245	270	325	300	-	175	130	258	325	130
13	126	200	212	235	240	230	-	210	120	211	240	120
14	-	130	108	142	205	295	-	65	37	130	295	37
15	-	100	242	135	130	110	100	110	75	110	242	75
16	-	240	200	192	200	230	120	152	98	200	240	98
Median	166	253	236	240	290	250	168	183	94	212		
Max	203	400	250	295	350	300	180	232	132		400	
Min	126	100	108	135	130	110	100	65	35			35

Appendix D: Water Sampling Results

	Dissolved Oxygen (mg/L)											
	March 2	May 9	June 2	June 29	July 26	Aug 24	Oct 3	Nov 24	Feb 1, 95			
	03-02	05-09	06-23	06-29	07-26	08-24	10-03	11-24	02-01			
Station										Median	Max	Min
1	-	10.0	10.2	9.5	9.7	11.5	10.5	13.9	11.4	10.4	13.9	9.5
2	-	8.2	8.4	9.2	9.2	9.7	9.9	9.7	8.6	9.2	9.9	8.2
3	-	9.1	7.4	8.0	8.0	9.0	9.8	10.3	8.6	8.8	10.3	7.4
4	-	9.6	8.0	8.9	8.1	9.4	10.2	10.2	9.0	9.2	10.2	8.0
5	-	8.6	6.0	9.2	5.6	6.6	9.5	6.9	7.4	7.2	9.5	5.6
6	-	9.5	5.8	9.0	7.2	8.9	9.8	11.9	9.0	9.0	11.9	5.8
7	-	12.2	8.2	10.4	8.0	9.3	10.2	11.9	9.4	9.8	12.2	8.0
8	-	12.0	7.8	10.0	8.8	7.9	7.8	6.6	6.7	7.9	12.0	6.6
9	-	11.4	5.8	8.4	5.1	4.6	6.5	6.0	7.2	6.3	11.4	4.6
10	-	6.4	2.8	4.1	4.0	5.2	6.0	2.7	6.0	4.7	6.4	2.7
11	-	4.5	2.5	5.4	5.6	13.8	12.4	2.1	9.5	5.5	13.8	2.1
12	-	9.0	6.0	8.3	6.9	11.2	8.0	10.4	8.6	8.5	11.2	6.0
13	-	9.7	9.2	9.3	9.4	8.7	6.8	10.2	8.3	9.3	10.2	6.8
14	-	9.5	8.3	8.2	6.5	6.8	1.5	10.9	10.5	8.3	10.9	1.5
15	-	9.4	9.8	9.2	8.7	8.8	9.5	12.0	10.8	9.5	12.0	8.7
16	-	5.5	3.2	3.8	3.3	4.0	9.2	4.5	7.5	4.3	9.2	3.2
Median		9.5	7.6	9.0	7.6	8.9	9.5	10.2	8.6	8.0		
Max		12.2	10.2	10.4	9.7	13.8	12.4	13.9	11.4		13.9	
Min		4.5	2.5	3.8	3.3	4.0	1.5	2.1	6.0			1.5

	Temperature (deg C)											
	March 2	May 9	June 23	June 2	July 26	Aug 24	Oct 3	Nov 24	Feb 1, 95			
	03-02	05-09	06-23	06-29	07-26	08-24	10-03	11-24	02-01			
Station										Median	Max	Min
1	-	16.0	14.0	16.0	17.0	12.7	6.4	3.3	8.1	14.0	17.0	3.3
2	-	13.0	13.0	13.5	13.5	12.3	9.5	4.9	8.5	12.3	13.5	4.9
3	-	16.0	17.0	17.0	17.0	15.0	11.0	4.9	8.7	16.0	17.2	4.9
4	-	17.0	17.5	18.0	20.0	17.3	12.0	4.6	8.8	17.3	20.0	4.6
5	-	18.0	20.0	18.5	20.0	16.1	13.0	7.3	9.3	18.0	20.0	7.3
6	-	19.5	19.5	20.0	24.0	22.0	15.0	5.4	8.6	19.5	24.0	5.4
7	-	21.0	20.0	20.5	25.0	23.0	13.0	4.7	8.6	20.5	25.0	4.7
8	-	21.0	20.5	20.0	25.0	22.3	14.4	6.7	8.8	20.3	25.0	6.7
9	-	20.0	19.0	19.0	24.0	20.9	13.4	6.4	8.7	19.0	24.0	6.4
10	-	18.0	16.5	17.0	19.0	18.3	11.5	6.8	8.8	17.0	20.4	6.8
11	-	20.0	20.0	20.0	26.0	22.2	13.5	6.1	8.0	20.0	26.0	6.1
12	-	21.0	20.0	20.0	25.0	22.1	13.2	5.4	8.6	20.0	25.0	5.4
13	-	12.0	12.5	14.5	14.0	14.6	12.2	8.5	8.9	12.5	14.6	8.5
14	-	17.0	14.5	16.0	19.0	16.8	12.5	4.4	7.8	15.3	19.0	4.4
15	-	14.0	13.0	15.0	15.5	13.6	11.0	3.7	7.6	13.6	15.5	3.7
16	-	12.0	13.0	-	17.5	11.8	7.2	5.0	8.6	11.9	17.5	5.0
Median		17.5	17.3	18.0	19.5	17.1	12.4	5.2	8.6	16.7		
Max		21.0	20.5	20.5	26.0	23.0	15.0	8.5	9.3		26.0	
Min		12.0	12.5	13.5	13.5	11.8	6.4	3.3	7.6			3.3

Appendix D: Water Sampling Results

	Orthophosphate (mg/L)										
	March 2	May 9	June 29	July 26	Aug 24	Oct 3	Nov 24	Feb 1, 95			
	03-02	05-09	06-29	07-26	08-24	10-03	11-24	02-01			
Station									Median	Max	Min
1	0.030	0.013	0.016	0.012	0.528	0.039	0.040	0.017	0.024	0.528	0.012
2	0.062	0.030	0.027	0.038	0.033	0.057	0.100	0.360	0.048	0.360	0.027
3	0.236	0.056	0.068	0.098	0.098	0.088	0.142	0.372	0.098	0.372	0.056
4	0.244	0.042	0.080	0.090	0.097	0.087	0.143	0.120	0.094	0.244	0.042
5	0.514	0.046	0.031	0.015	0.018	0.037	0.135	0.412	0.042	0.514	0.015
6	0.302	0.049	0.053	0.022	0.044	0.088	0.135	0.732	0.071	0.732	0.022
7	0.227	0.021	0.030	0.030	0.045	0.102	0.152	0.191	0.074	0.227	0.021
8	0.237	0.000	0.010	0.028	0.011	0.088	0.183	0.389	0.058	0.389	0.000
9	0.266	0.003	0.023	0.030	0.050	0.098	0.236	0.293	0.074	0.293	0.003
10	0.383	0.084	0.068	0.066	0.104	0.120	0.140	0.807	0.112	0.807	0.066
11	0.441	0.046	0.139	0.062	0.048	0.099	0.169	0.447	0.119	0.447	0.046
12	0.246	0.063	0.090	0.064	0.069	0.084	0.118	0.354	0.087	0.354	0.063
13	0.113	0.028	0.044	0.049	0.060	0.054	0.069	0.442	0.057	0.442	0.028
14	-	0.039	0.052	0.114	0.087	2.074	0.051	0.376	0.087	2.074	0.039
15	-	0.011	0.025	0.029	0.026	-1	0.044	-1	0.025	0.044	0.000
16	-	0.027	0.032	0.042	0.035	0.099	0.125	0.900	0.042	0.900	0.027
Median	0.244	0.035	0.038	0.040	0.049	0.088	0.135	0.374	0.069		
Max	0.514	0.084	0.139	0.114	0.528	2.074	0.236	0.900		2.074	
Min	0.030	0.000	0.010	0.012	0.011	0.000	0.040	0.000			0.000

	Chloride (mg/L)										
	March 2	May 9	June 2	July 26	Aug 24	Oct 3	Nov 24	Feb 1, 95			
	03-02	05-09	06-29	07-26	08-24	10-03	11-24	02-01			
Station									Median	Max	Min
1	7.674	11.452	10.643	16.214	16.894	21.542	15.421	15.146	15.284	21.542	7.674
2	8.852	14.120	14.104	14.207	11.383	13.002	14.694	25.535	14.112	25.535	8.852
3	9.319	18.699	17.910	19.700	15.157	14.836	14.961	24.921	16.534	24.921	9.319
4	9.559	18.626	19.196	20.373	15.053	14.451	16.375	19.998	17.501	20.373	9.559
5	13.518	17.682	12.664	11.988	10.865	9.816	16.765	13.923	13.091	17.682	9.816
6	8.250	17.249	15.887	13.660	12.098	13.775	14.236	28.896	14.006	28.896	8.250
7	8.294	16.958	16.762	11.737	9.244	13.765	13.949	35.382	13.857	35.382	8.294
8	8.912	9.882	9.234	14.040	9.919	11.449	11.748	16.732	10.684	16.732	8.912
9	11.022	6.867	10.966	16.739	13.197	11.376	13.169	12.749	12.063	16.739	6.867
10	11.780	17.106	18.355	19.174	12.703	13.188	16.707	18.117	16.907	19.174	11.780
11	12.555	17.276	17.556	20.205	11.114	13.105	14.374	16.159	15.267	20.205	11.114
12	7.797	17.756	17.389	19.612	15.480	13.663	13.704	40.729	16.435	40.729	7.797
13	12.705	11.096	12.094	10.380	10.167	11.262	10.936	27.751	11.179	27.751	10.167
14	-	9.064	8.152	53.461	14.914	30.542	3.833	20.497	14.914	53.461	3.833
15	-	3.317	1.238	3.964	4.915	7.290	3.425	6.479	3.964	7.290	1.238
16	-	12.032	11.555	10.589	9.972	11.486	11.825	28.150	11.555	28.150	9.972
Median	9.319	15.539	13.384	15.211	11.741	13.147	14.093	20.248	13.584		
Max	13.518	18.699	19.196	53.461	16.894	30.542	16.765	40.729		53.461	
Min	7.674	3.317	1.238	3.964	4.915	7.290	3.425	6.479			1.238

Appendix D: Water Sampling Results

	Ammonia-N (mg/L)										
	March 2	May 9	June 2	July 26	Aug 24	Oct 3	Nov 24	Feb 1, 95			
	03-02	05-09	06-29	07-26	08-24	10-03	11-24	02-01			
Station									Median	Max	Min
1	0.051	0.029	0.036	-1	0.003	0.027	0.035	0.006	0.028	0.051	0.000
2	0.209	0.003	0.009	-1	0.010	0.006	0.031	1.022	0.010	1.022	0.000
3	0.588	0.022	0.049	0.018	0.055	0.025	0.102	0.996	0.052	0.996	0.018
4	0.656	0.021	0.057	-1	0.037	0.020	0.091	0.641	0.047	0.656	0.000
5	2.379	0.043	0.025	-1	0.098	0.013	0.039	0.703	0.041	2.379	0.000
6	1.213	0.128	0.029	-1	0.037	0.125	0.196	1.009	0.127	1.213	0.000
7	0.650	0.020	0.024	0.019	0.017	0.148	0.207	0.456	0.086	0.650	0.017
8	0.927	0.000	-1	0.015	0.010	0.703	0.572	0.904	0.294	0.927	0.000
9	1.118	0.000	0.009	-1	-1	0.760	1.032	0.673	0.341	1.118	0.000
10	0.566	0.634	0.600	1.641	0.729	1.545	0.862	1.178	0.796	1.641	0.566
11	0.843	0.752	0.341	-1	0.010	0.702	1.049	0.994	0.727	1.049	0.000
12	0.509	0.153	0.103	0.048	0.036	0.243	0.234	0.664	0.194	0.664	0.036
13	0.385	0.026	0.082	-1	0.164	-1	0.104	0.652	0.093	0.652	0.000
14	-	0.268	0.086	0.105	0.285	4.029	0.054	0.655	0.268	4.029	0.054
15	-	0.037	0.042	-1	0.023	0.085	0.006	0.149	0.037	0.149	0.000
16	-	0.040	0.038	-1	0.018	0.206	-1	2.570	0.038	2.570	0.000
Median	0.650	0.033	0.040	0.000	0.030	0.148	0.103	0.688	0.199		
Max	2.379	0.752	0.600	1.641	0.729	4.029	1.049	2.570		4.029	
Min	0.051	0.000	0.000	0.000	0.000	0.000	0.000	0.006			0.000

	Nitrate-N (mg/L)										
	March 2	May 9	June 29	July 26	Aug 24	Oct 3	Nov 24	Feb 1, 95			
	03-02	05-09	06-29	07-26	08-24	10-03	11-24	02-01			
Station									Median	Max	Min
1	0.599	0.121	0.231	0.198	-1	0.392	0.631	0.378	0.305	0.631	0.000
2	0.789	0.324	0.48	0.578	0.411	0.510	0.690	0.619	0.544	0.789	0.324
3	3.105	2.048	1.629	1.422	1.037	1.597	2.985	2.084	1.839	3.105	1.037
4	2.834	1.869	1.456	1.253	0.851	1.324	3.044	2.073	1.662	3.044	0.851
5	3.132	4.364	3.463	3.867	3.520	2.638	4.366	2.117	3.492	4.366	2.117
6	2.384	1.715	1.469	0.394	0.703	1.369	2.569	1.982	1.592	2.569	0.394
7	2.581	1.526	1.236	0.165	-1	1.198	3.360	2.700	1.381	3.360	0.000
8	1.425	0.374	0.189	0.224	0.111	0.449	1.233	1.166	0.412	1.425	0.111
9	1.288	0.438	0.296	0.227	0.117	0.391	0.682	1.248	0.414	1.288	0.117
10	4.102	0.324	0.209	0.344	0.311	0.285	2.775	2.169	0.334	4.102	0.209
11	4.586	0.236	0.406	0.224	0.097	0.256	1.817	1.358	0.331	4.586	0.097
12	2.736	1.105	1.148	0.746	0.427	0.936	2.678	2.572	1.126	2.736	0.427
13	1.882	7.606	5.159	7.090	3.972	4.642	6.170	2.472	4.901	7.606	1.882
14	-	0.683	0.377	-1	-1	-1	1.666	1.017	0.377	1.666	0.000
15	-	0.073	0.203	0.352	0.137	0.278	0.136	0.803	0.203	0.803	0.073
16	-	0.714	0.872	0.951	0.720	0.743	0.948	0.675	0.743	0.951	0.675
Median	2.581	0.699	0.676	0.373	0.361	0.627	2.193	1.670	1.228		
Max	4.586	7.606	5.159	7.090	3.972	4.642	6.170	2.700		7.606	
Min	0.599	0.073	0.189	0.000	0.000	0.000	0.136	0.378			0.000

Appendix D: Water Sampling Results

	Dissolved Carbon (mg/L)																				
		May 9			June 29			July 26			Aug 24			Nov 24			Feb 1, 95				
		05-09			06-29			07-26			08-24			11-24			02-01		Dissolved OC		
Station	Total	IC	OC	Total	IC	OC	Total	IC	OC	Total	IC	OC	Total	IC	OC	Total	IC	OC	Median	Max	Min
1	40.8	11.1	29.7	37.3	20.0	17.3	48.0	22.0	26.0	47.0	28.0	19.0	44.8	13.3	31.5	9.8	6.6	3.2	22.5	31.5	3.2
2	53.8	16.2	37.6	45.1	29.7	15.4	41.0	22.0	19.0	13.0	4.0	9.0	29.3	20.9	8.4	50.0	4.7	45.3	17.2	45.3	8.4
3	32.6	13.6	19.0	31.4	17.0	14.4	43.0	20.0	23.0	27.0	25.0	2.0	58.5	4.0	54.5	44.5	10.9	33.6	21.0	54.5	2.0
4	61.2	16.8	44.4	27.4	14.2	13.2	46.0	22.0	24.0	27.0	24.0	3.0	34.7	20.7	14.0	21.6	12.1	9.5	13.6	44.4	3.0
5	36.5	7.9	28.6	26.2	13.4	12.8	34.0	16.0	18.0	15.0	13.0	2.0	24.6	14.3	10.3	20.5	6.3	14.2	13.5	28.6	2.0
6	37.3	8.9	28.4	119.3	19.6	99.7	38.0	18.0	20.0	29.0	24.0	5.0	29.3	17.9	11.4	22.1	8.0	14.1	17.1	99.7	5.0
7	46.5	11.4	35.1	38.7	18.3	20.4	43.0	17.0	26.0	24.0	17.0	7.0	-	-	-	24.0	12.4	11.6	20.4	35.1	7.0
8	50.1	8.2	41.9	-	-	-	54.0	22.0	32.0	20.0	16.0	4.0	28.9	20.1	8.8	22.3	8.2	14.1	14.1	41.9	4.0
9	23.1	8.6	14.5	24.7	14.5	10.2	58.0	24.0	34.0	29.0	22.0	7.0	33.0	21.3	11.7	18.8	6.7	12.1	11.9	34.0	7.0
10	48.7	11.7	37.0	46.4	19.7	26.7	78.0	35.0	43.0	35.0	26.0	9.0	32.5	18.2	14.3	26.4	8.1	18.3	22.5	43.0	9.0
11	30.4	12.0	18.4	41.4	24.3	17.1	50.0	24.0	26.0	26.0	21.0	5.0	34.5	20.3	14.2	17.5	4.4	13.1	15.7	26.0	5.0
12	53.7	12.9	40.8	85.9	22.0	63.9	62.0	25.0	37.0	26.0	12.0	14.0	-	-	-	25.0	11.2	13.8	37.0	63.9	13.8
13	42.7	9.1	33.6	19.7	11.2	8.5	36.0	12.0	24.0	19.0	14.0	5.0	19.8	13.4	6.4	21.8	9.8	12.0	10.3	33.6	5.0
14	33.8	5.8	28.0	26.5	12.3	14.2	41.0	13.0	28.0	41.0	37.0	4.0	14.0	6.3	7.7	15.6	3.9	11.7	13.0	28.0	4.0
15	45.0	7.1	37.9	113.8	11.1	102.7	35.0	12.0	23.0	17.0	12.0	5.0	28.6	15.0	13.6	34.9	9.3	25.6	24.3	102.7	5.0
16	53.5	13.4	40.1	28.1	14.3	13.8	34.0	17.0	17.0	33.0	25.0	8.0	26.6	17.9	8.7	39.5	11.3	28.2	15.4	40.1	8.0
Median	43.9	11.3	34.4	37.3	17.0	15.4	43.0	21.0	25.0	26.5	21.5	5.0	29.3	17.9	11.6	22.2	8.2	14.0	18.1		
Max	61.2	16.8	44.4	119.3	29.7	102.7	78.0	35.0	43.0	47.0	37.0	19.0	58.5	21.3	54.5	50.0	12.4	45.3		102.7	
Min	23.1	5.8	14.5	19.7	11.1	8.5	34.0	12.0	17.0	13.0	4.0	2.0	14.0	4.0	6.4	9.8	3.9	3.2			2.0

Appendix D: Water Sampling Results

Fecal Coliform and Fecal Streptococci Levels in the Sumas River

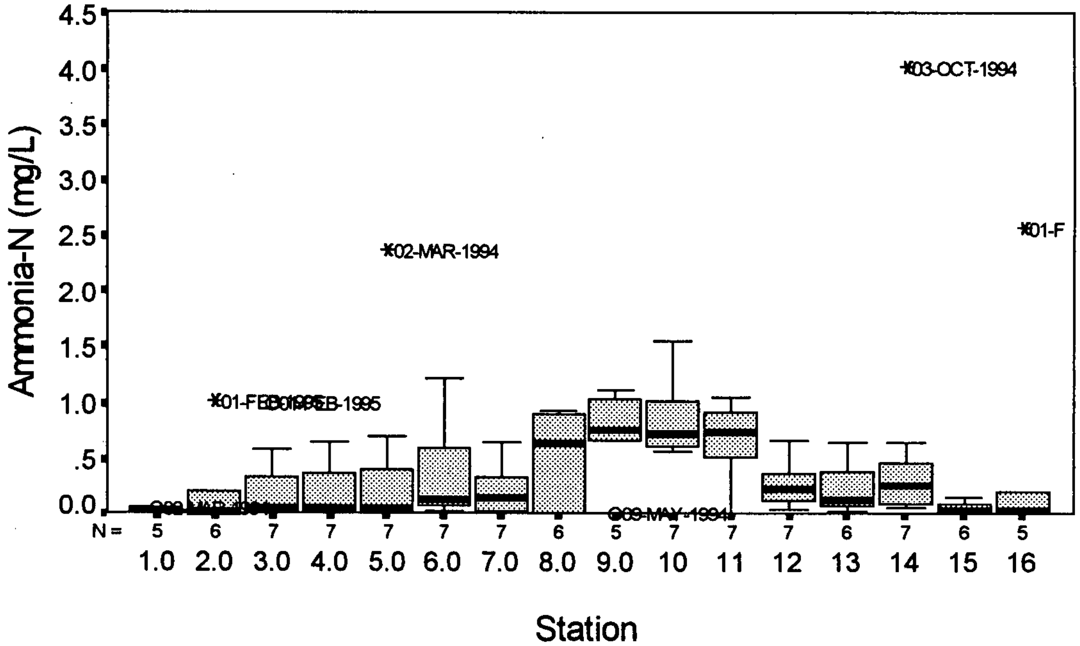
(CFU/100 mL)

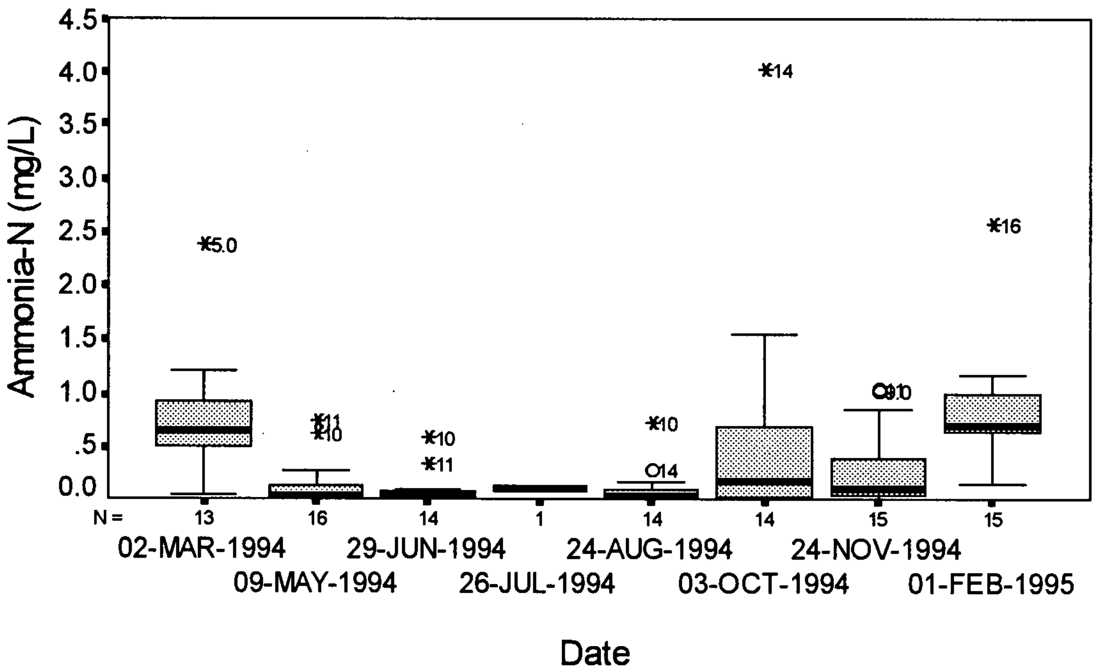
July 26, 1994		August 24, 1994		February 1, 1995	
F.coliforms	streptococci	F.coliforms	streptococci	F.coliforms	streptococci
120	250	620	790	<20	<20
42	32	65	14	1100	800
330	330	360	39	700	1100
350	80	249	16	800	500
150	30	1040	25	<10	9400
86	80	140	<10	4700	4300
450	<10	10	10	1300	800
100	<100	50	<10	2900	3400
20	<10	100	<10	<10	4300
690	700	1530	90	800	2600
100	<100	180	80	500	900
230	90	170	40	1600	1300
680	380	1230	1440	1200	1100
430	610	610	500	170	800
130000	300	1320	90	6	2
41	91	40	30	300	800

Appendix D (continued): Site Replications for Water Samples

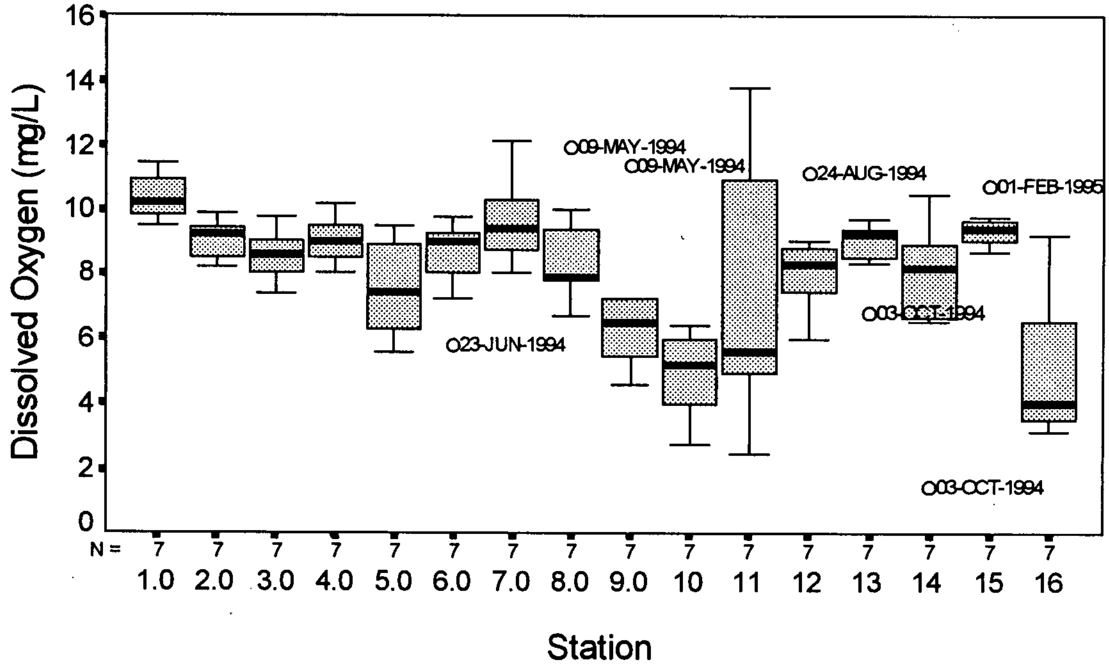
Date	Station	Ortho-P	Chloride	Ammonia-N	Nitrate-N	TDC	DIC	DOC
June 29	6	0.053	15.887	0.029	1.469	119.3	19.6	99.7
		0.065	15.888	0.034	1.539	33.4	22.2	11.2
		0.058	15.781	0.047	1.496	29.8	19.1	10.7
average		0.059	15.852	0.037	1.501	60.8	20.3	40.5
std.dev.		0.006	0.061	0.009	0.035	50.7	1.7	51.2
CV (%)		10	0	25	2	83	8	126
Aug 24	13	0.060	10.167	0.164	3.972	19.0	14.0	5.0
		0.055	9.325	0.166	3.953	20.0	14.0	6.0
		0.055	9.214	0.107	3.667	22.0	19.0	3.0
		0.082	8.799	0.145	3.622			
average		0.063	9.376	0.146	3.804	20.3	15.7	4.7
std.dev.		0.013	0.574	0.027	0.185	1.5	2.9	1.5
CV (%)		20	6	19	5	8	18	33
Nov 24	13	0.069	10.936	0.104	6.170	19.8	13.4	6.4
		0.051	12.312	0.106	7.247	25.2	17.1	8.1
		0.084	10.910	0.105	5.941	26.9	0.0	26.9
		0.094	10.845	0.095	6.081	24.3	14.8	9.5
average		0.075	11.251	0.103	6.360	24.1	11.3	12.7
std.dev.		0.019	0.709	0.005	0.599	3.0	7.7	9.5
CV (%)		25	6	5	9	13	68	75
Feb 1, 95	11	0.447	14.859	0.994	1.358	17.5	4.4	13.1
		0.444	16.713	0.987	1.407	15.8	3.2	12.6
		0.447	16.905	1.102	1.378	19.4	3.5	15.9
		0.462		0.951	1.404	19.7	3.4	16.3
average		0.450	16.159	1.009	1.387	18.1	3.6	14.5
std.dev.		0.008	1.130	0.065	0.023	1.8	0.5	1.9
CV (%)		2	7	6	2	10	15	13
Average CV (%)		14	5	14	5	28	27	62
Maximum CV (%)		25	7	25	9	83	68	126

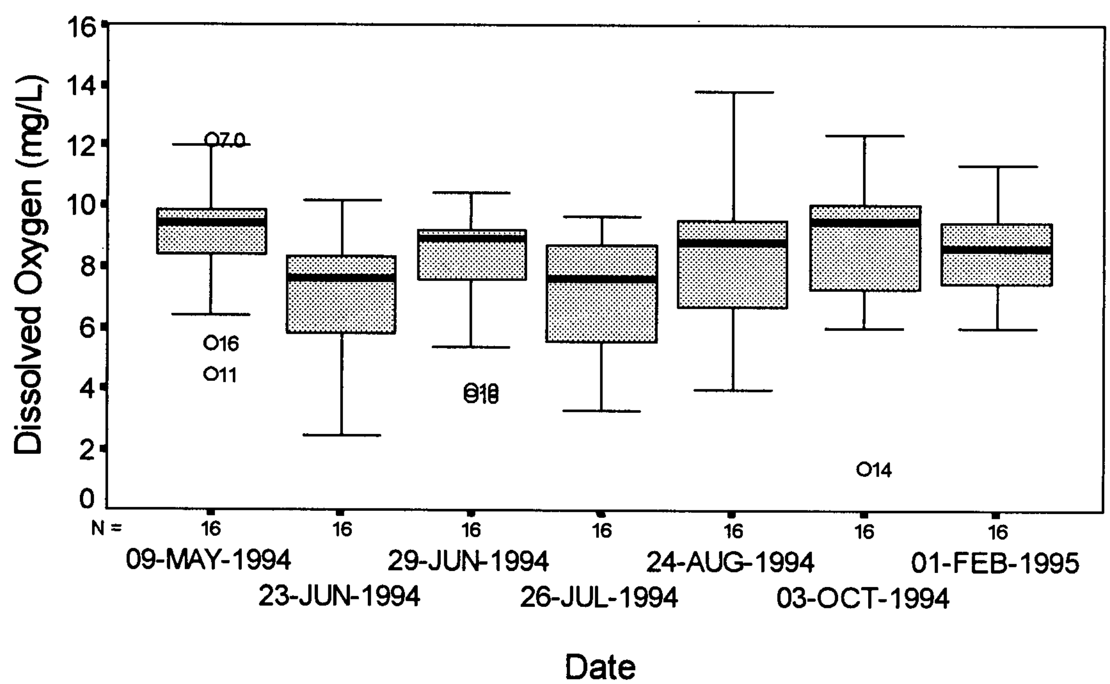
Appendix E: Box Plots of Water Quality Results by Station and by Sampling Date
Ammonia-N



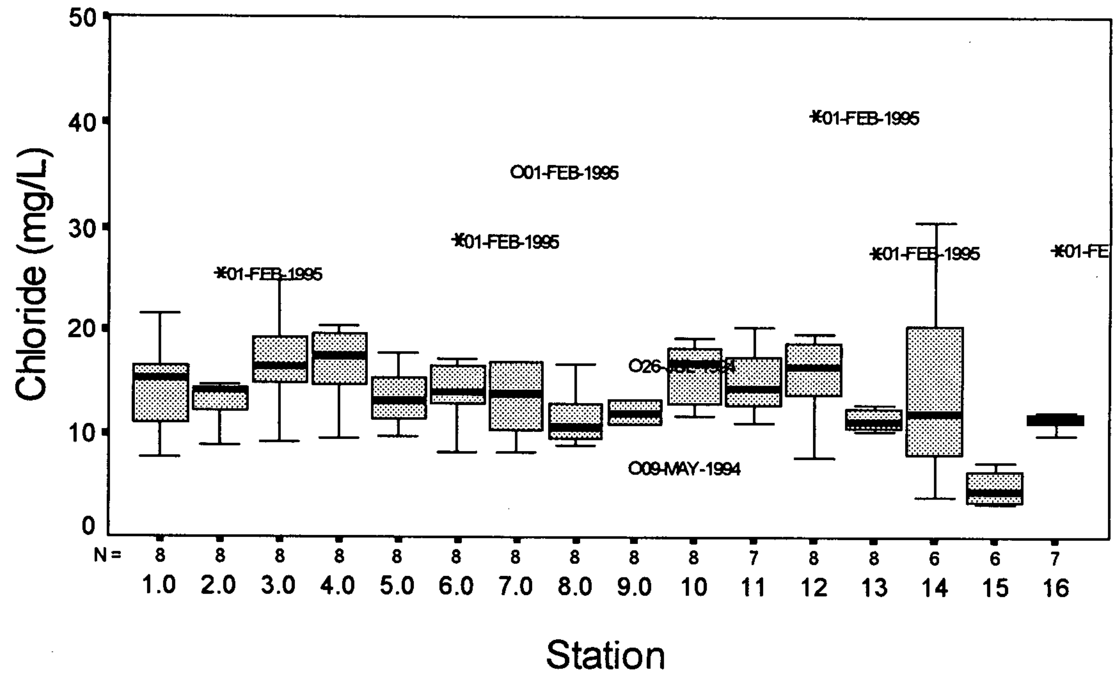


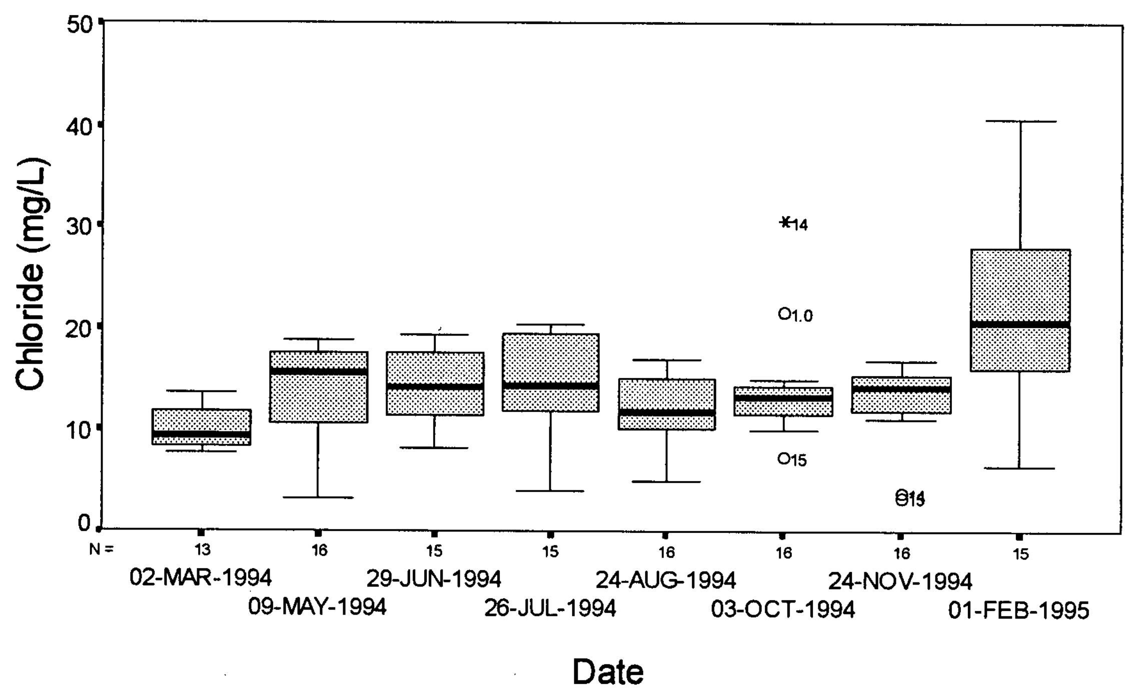
Appendix E: Box Plots of Water Quality Results by Station and by Sampling Date
Dissolved Oxygen



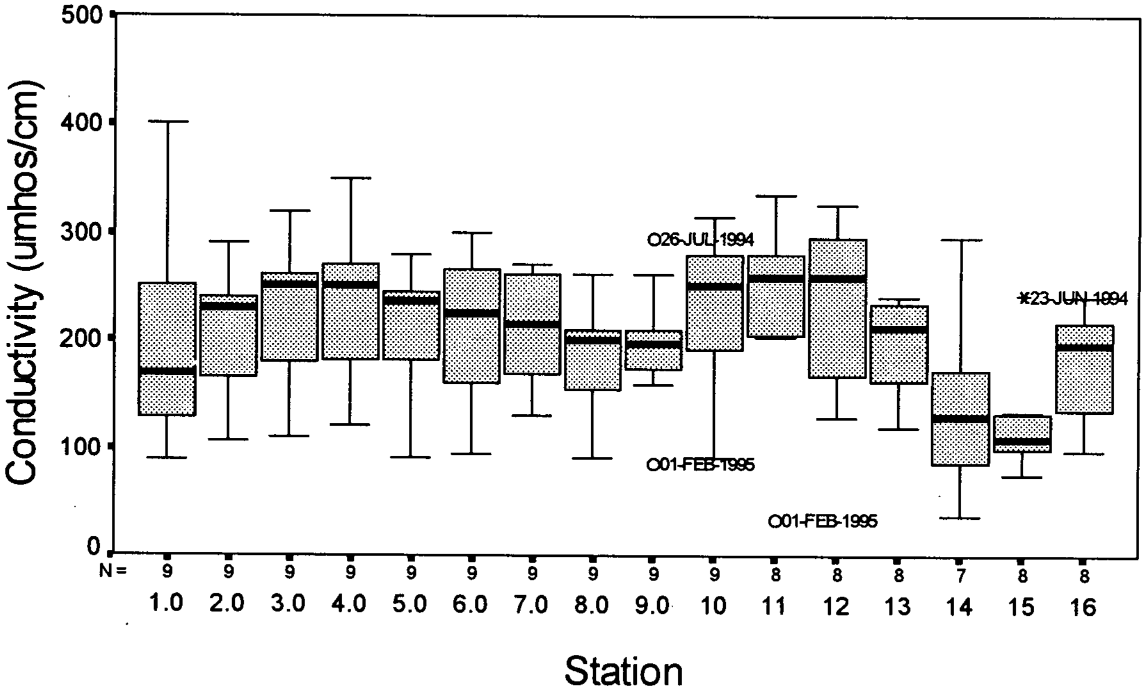


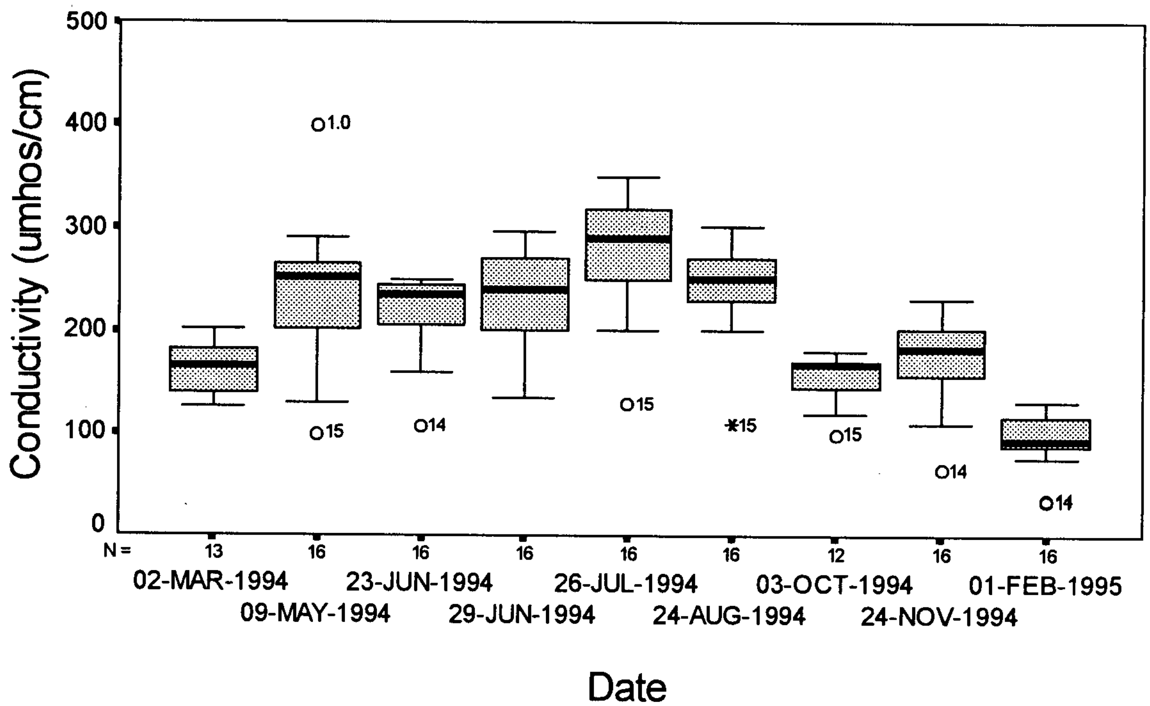
Appendix E: Box Plots of Water Quality Results by Station and by Sampling Date
Chloride



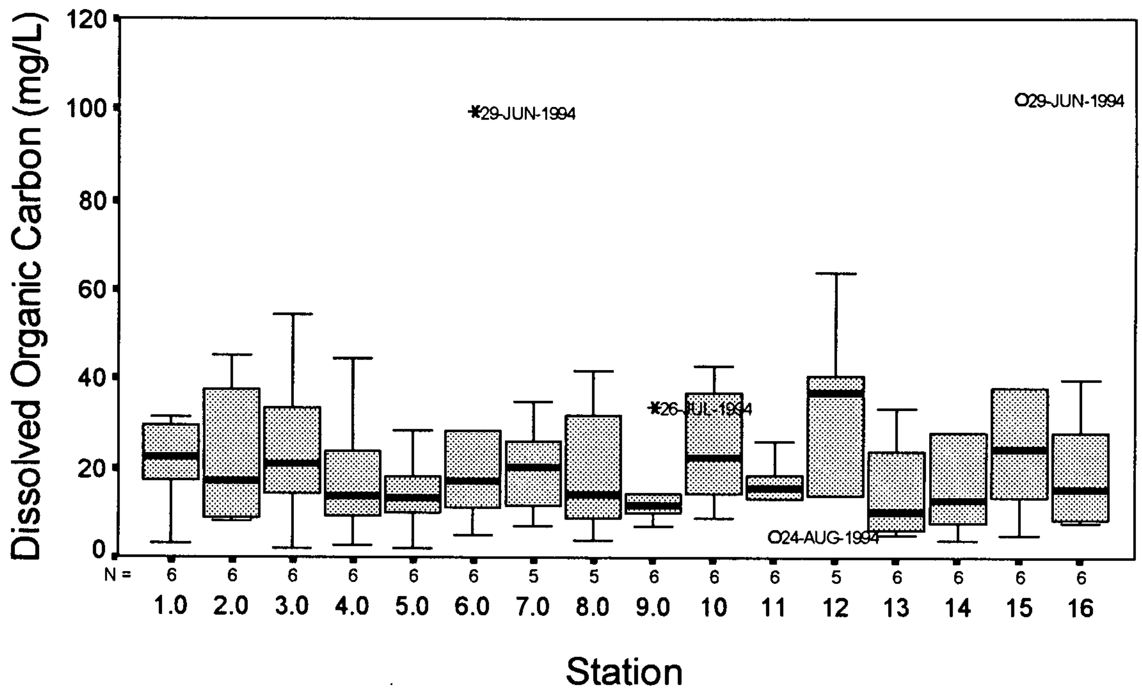


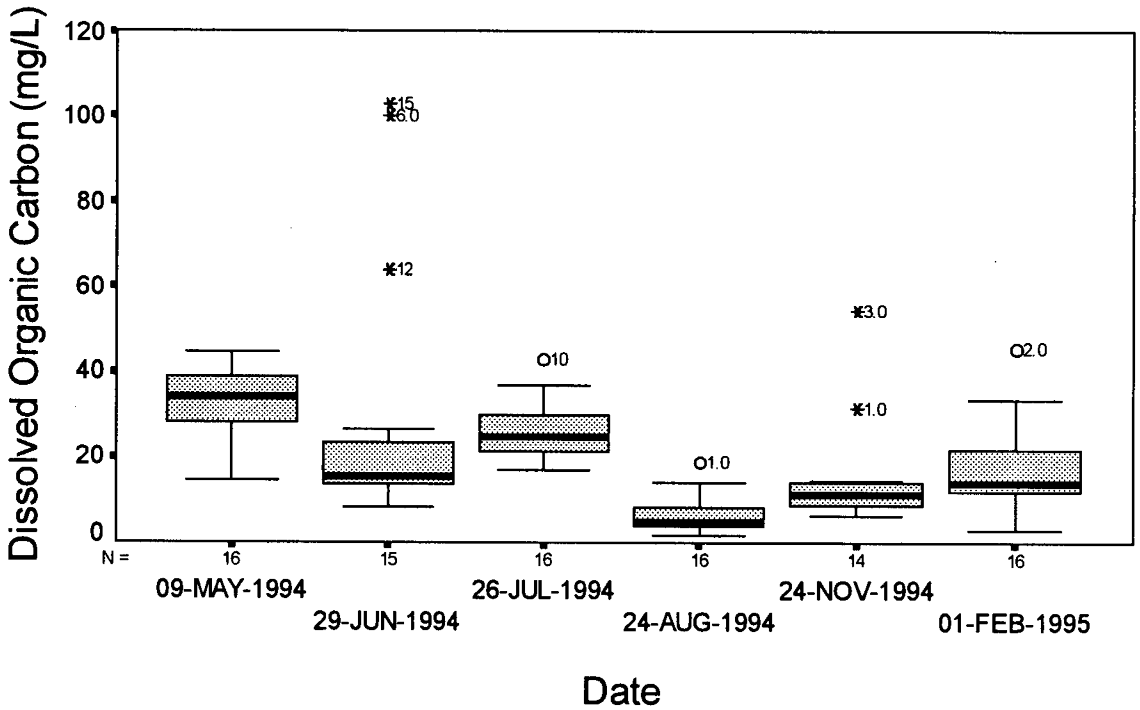
Appendix E: Box Plots of Water Quality Results by Station and by Sampling Date
Conductivity



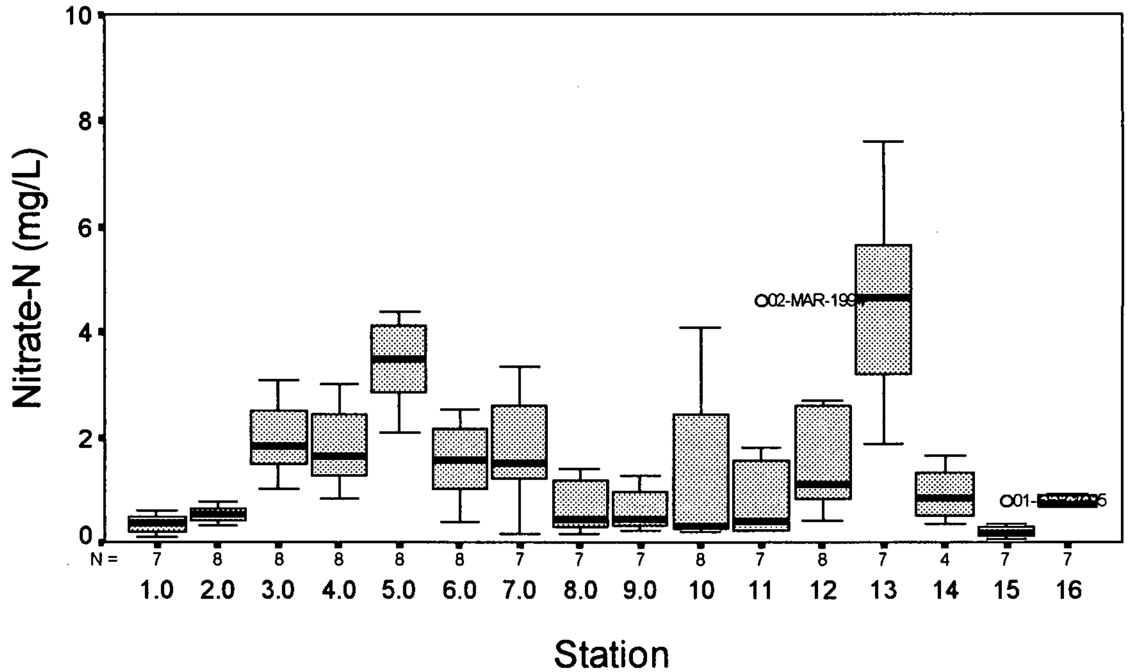


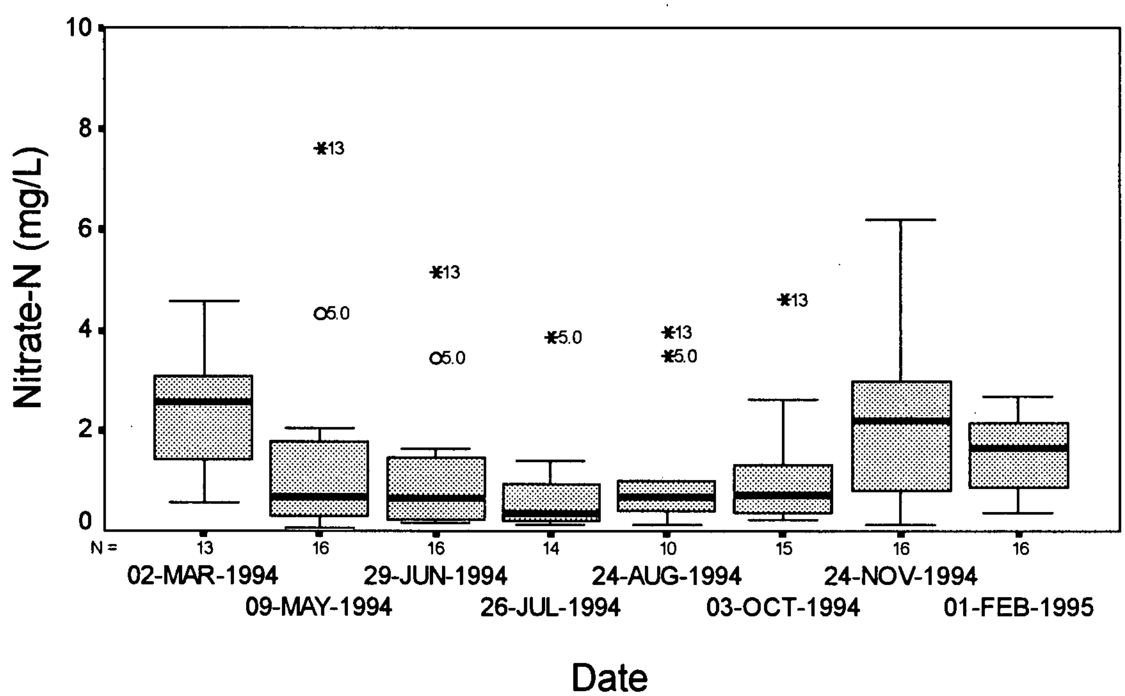
Appendix E: Box Plots of Water Quality Results by Station and by Sampling Date
Dissolved Organic Carbon



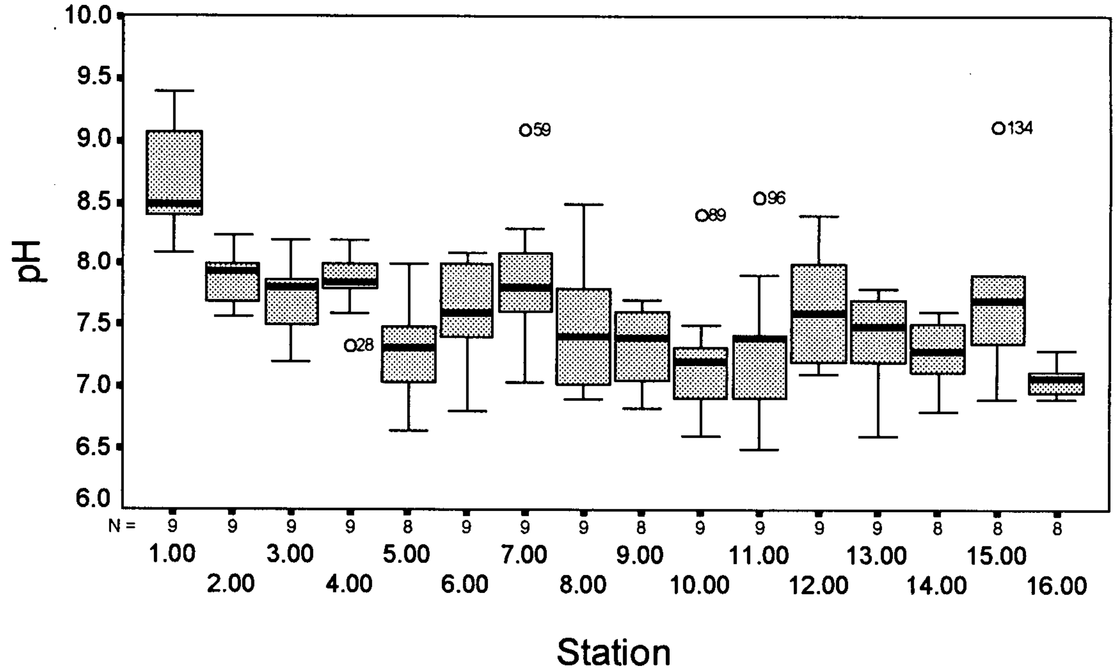


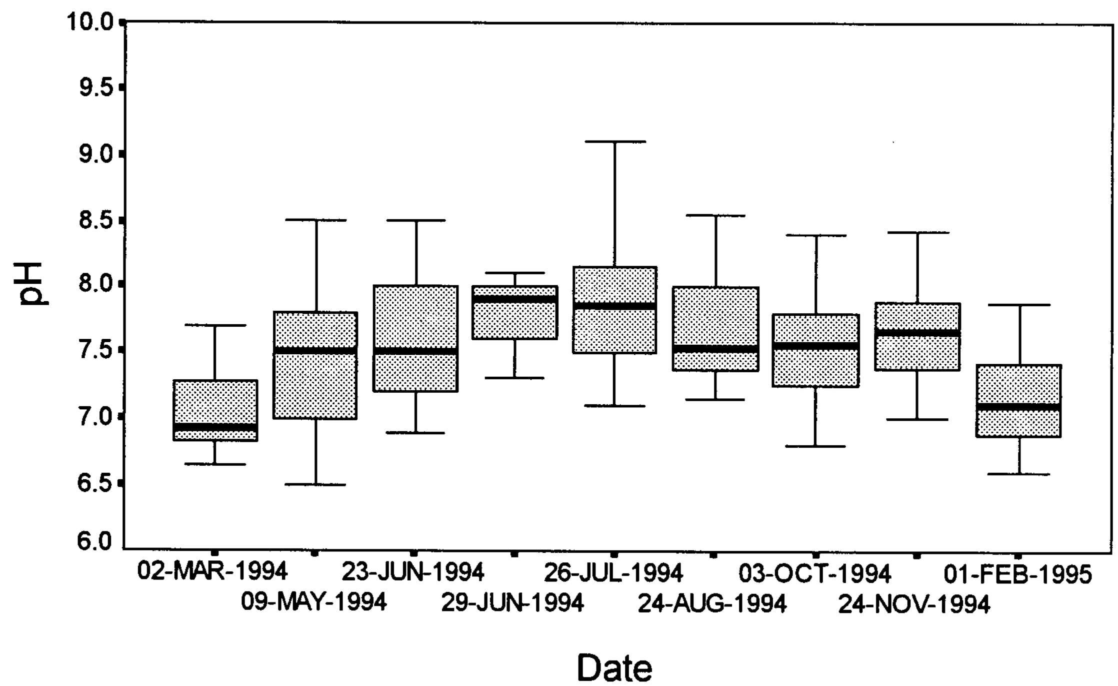
Appendix E: Box Plots of Water Quality Results by Station and by Sampling Date
Nitrate-N



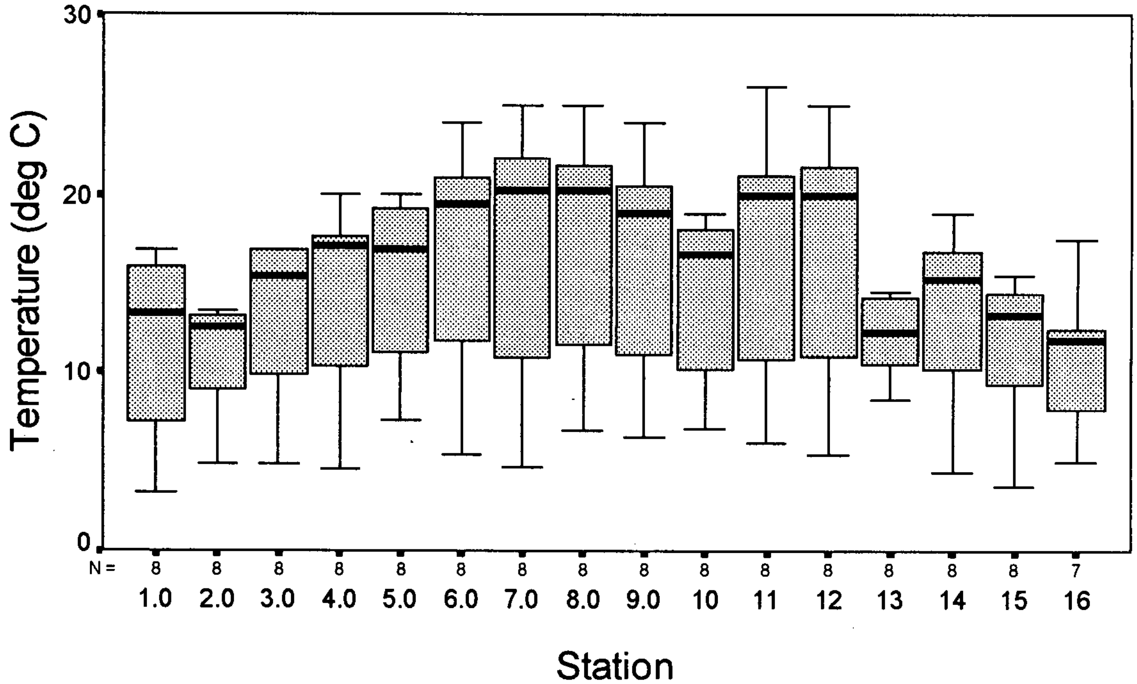


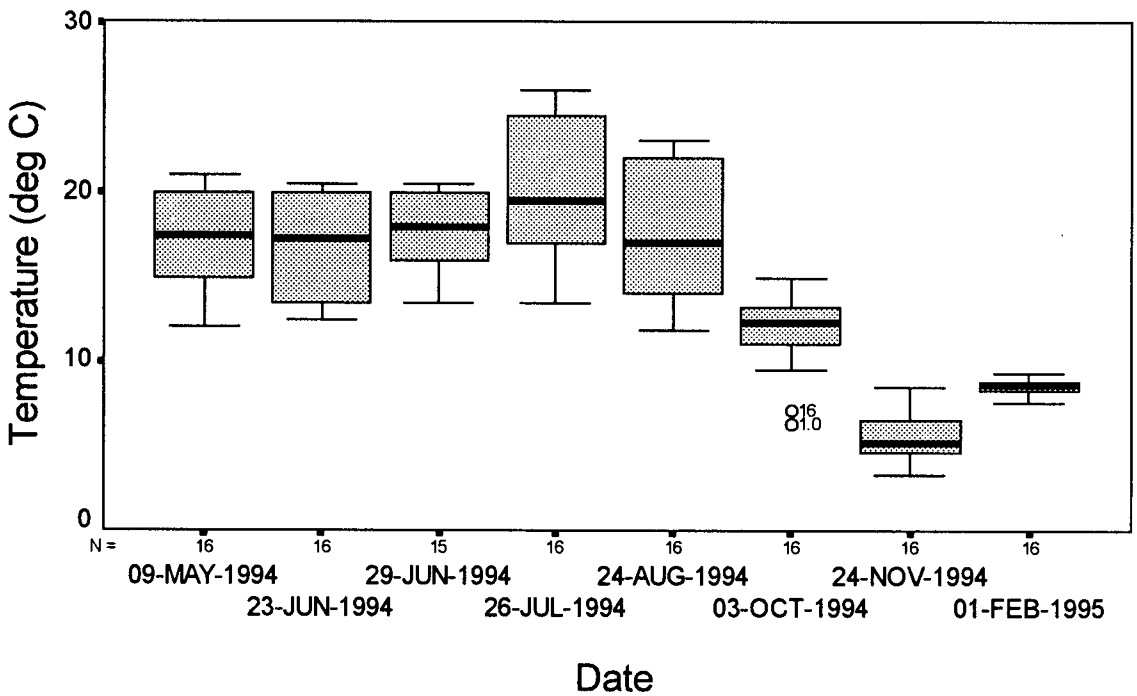
Appendix E: Box Plots of Water Quality Results by Station and by Sampling Date
pH



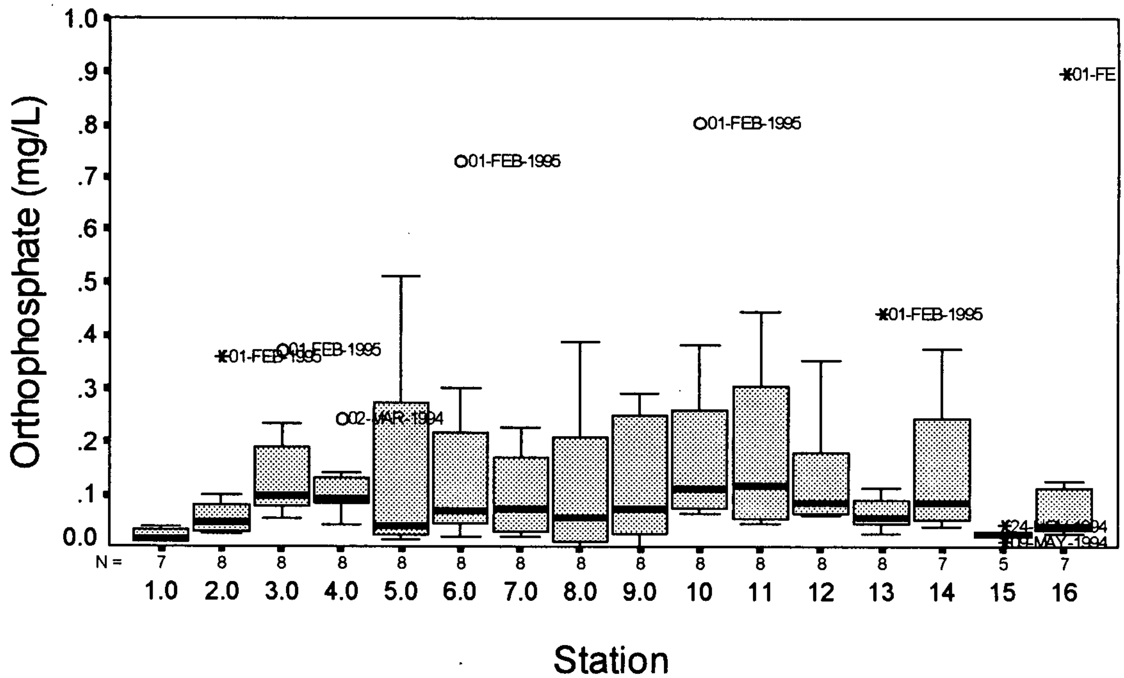


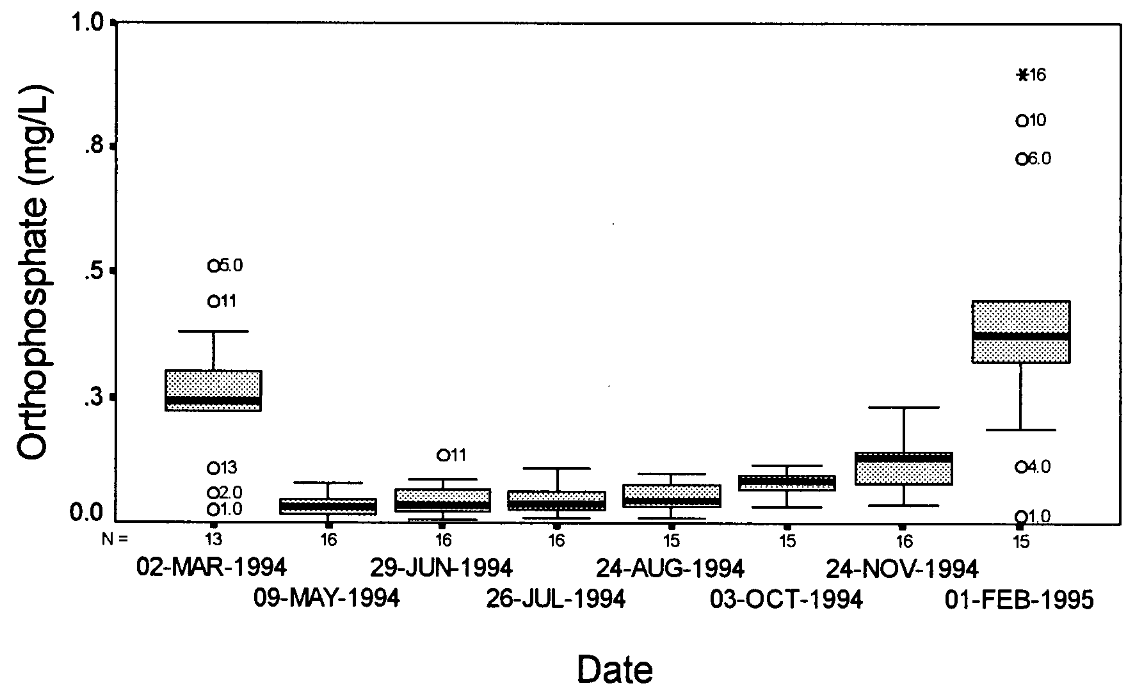
Appendix E: Box Plots of Water Quality Results by Station and by Sampling Date
Temperature



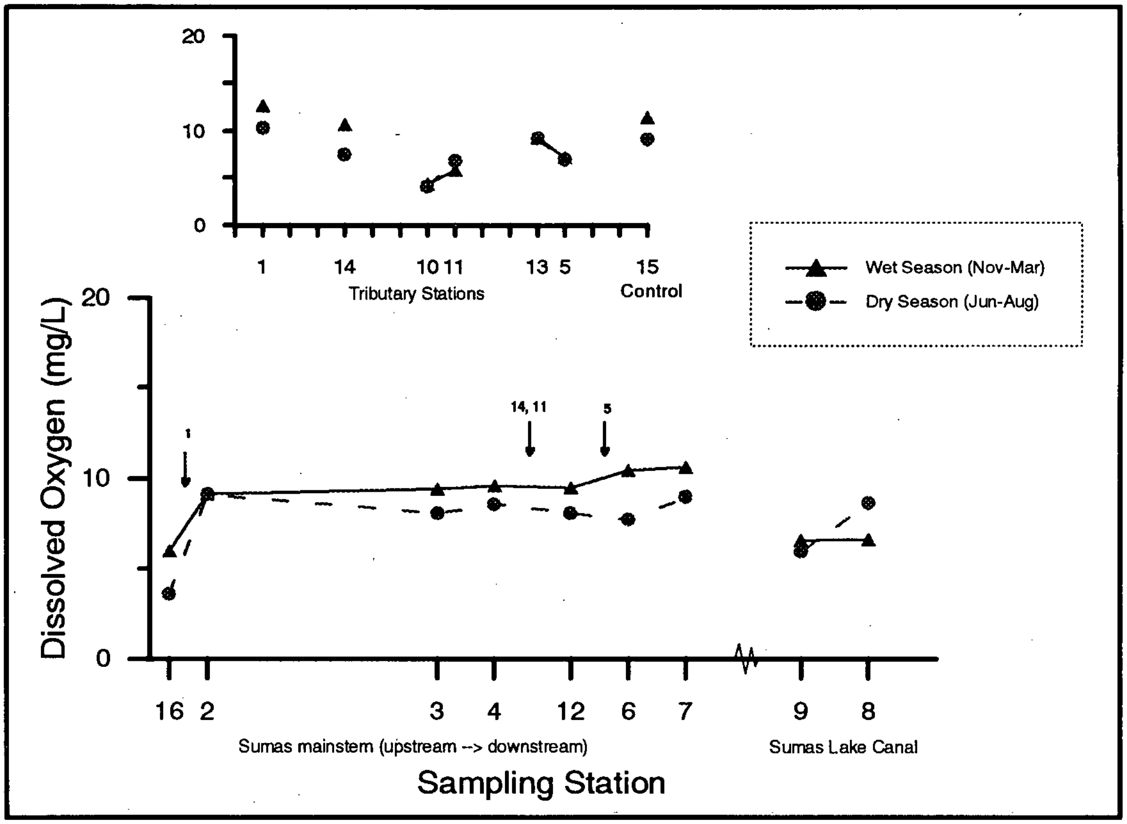


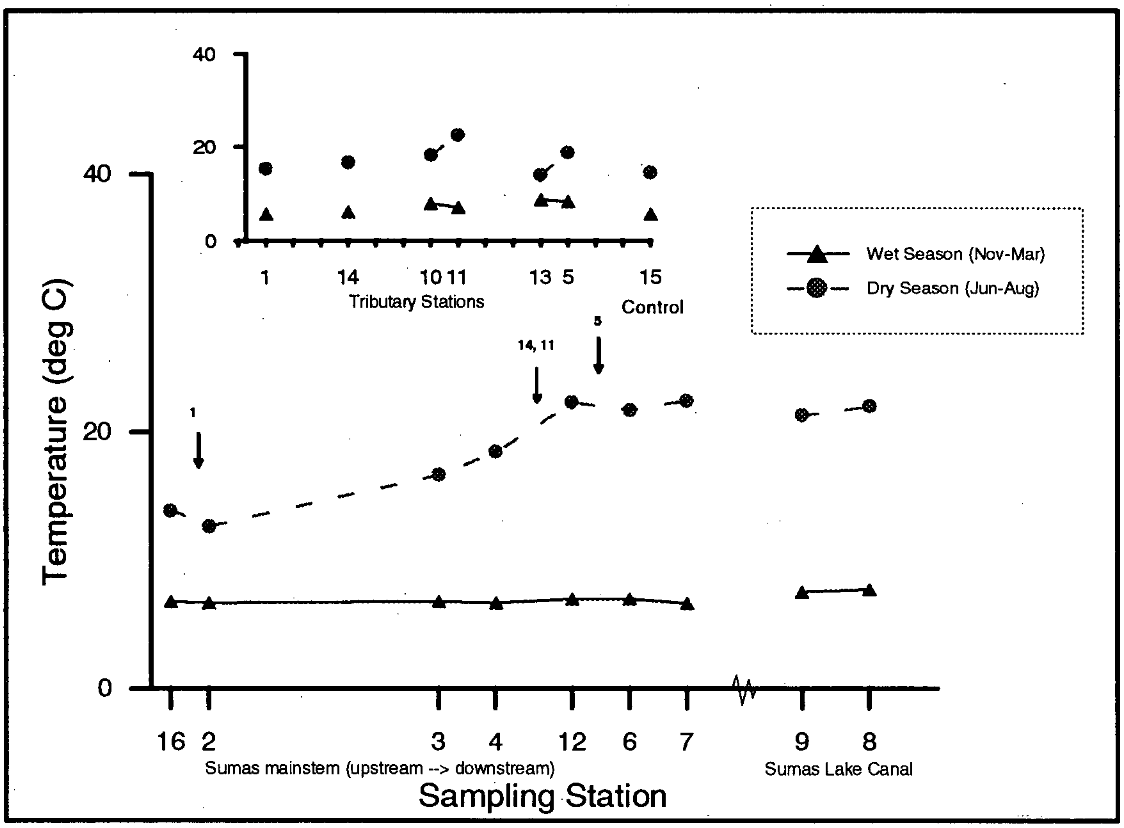
Appendix E: Box Plots of Water Quality Results by Station and by Sampling Date
Orthophosphate



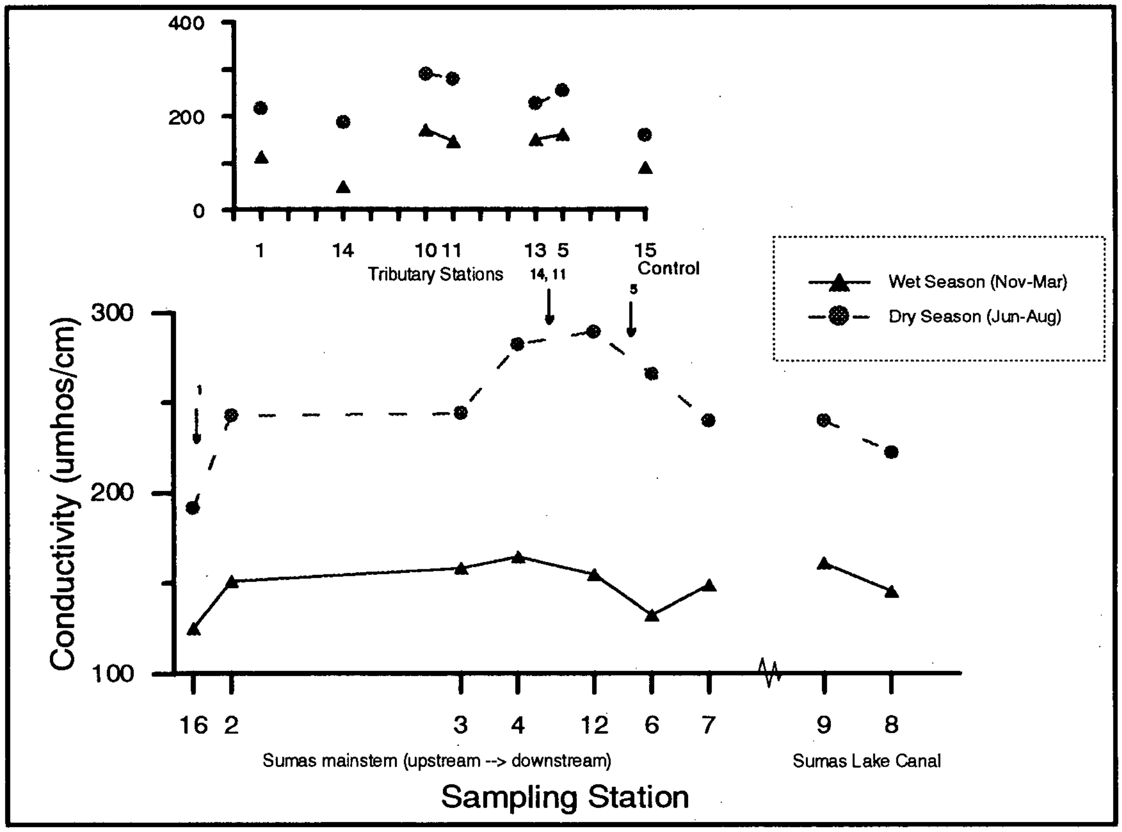


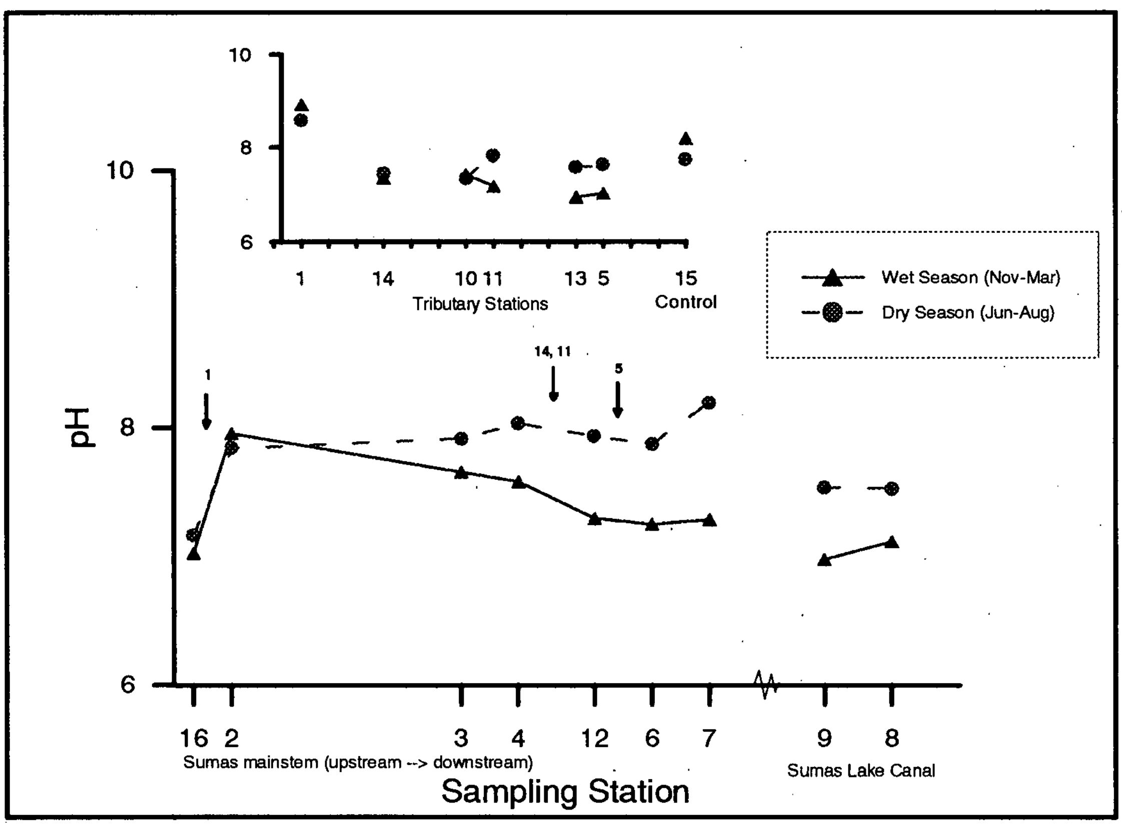
Appendix F: Wet Season/Dry Season Water Quality Results



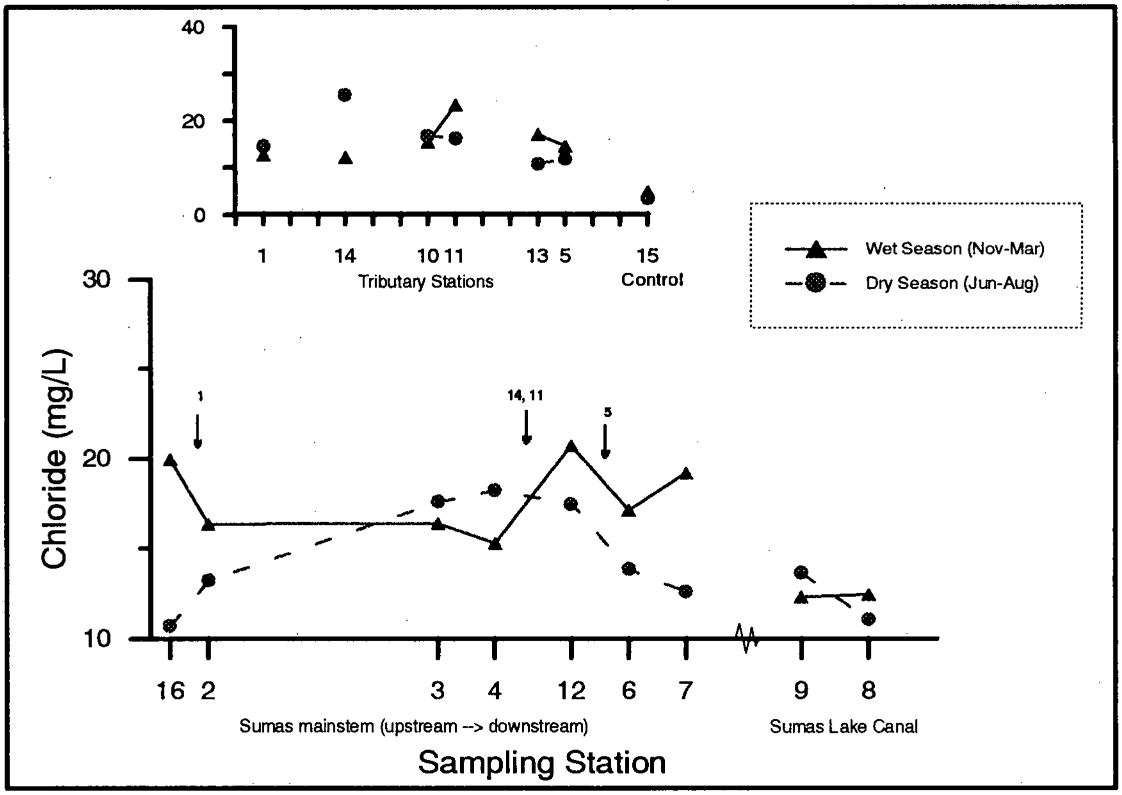


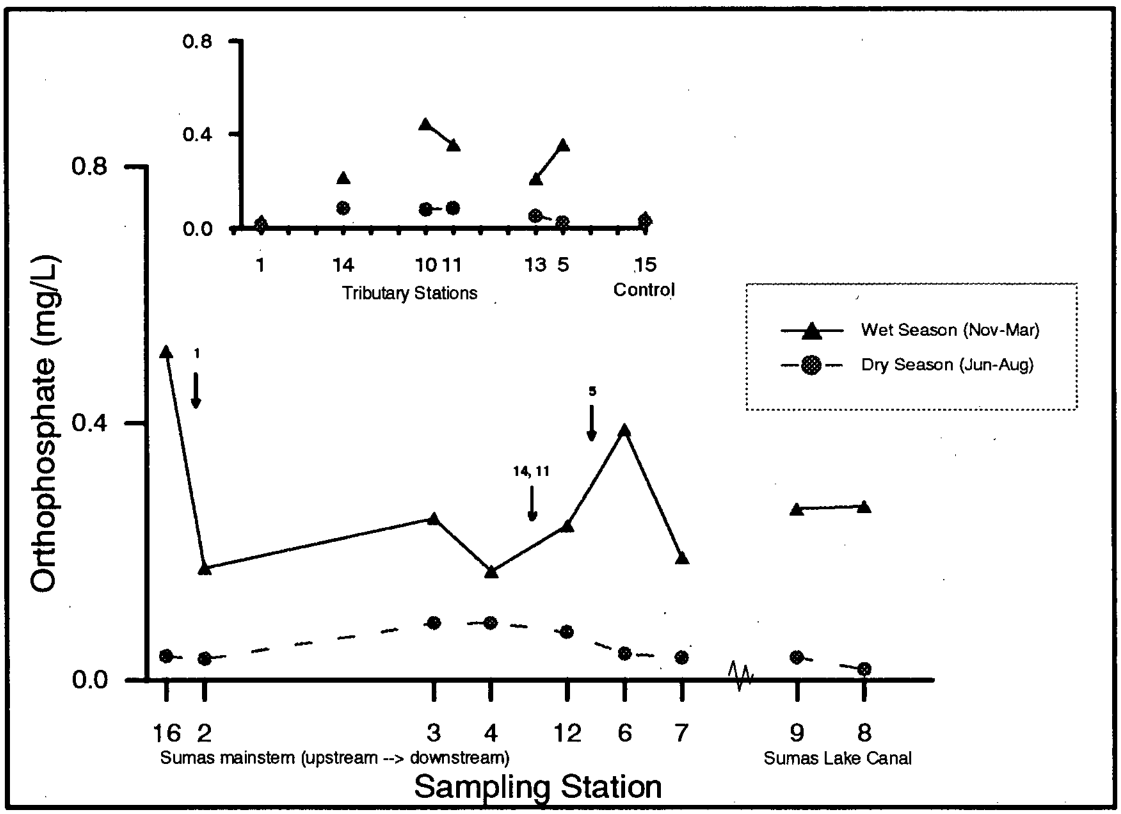
Appendix F: Wet Season/Dry Season Water Quality Results



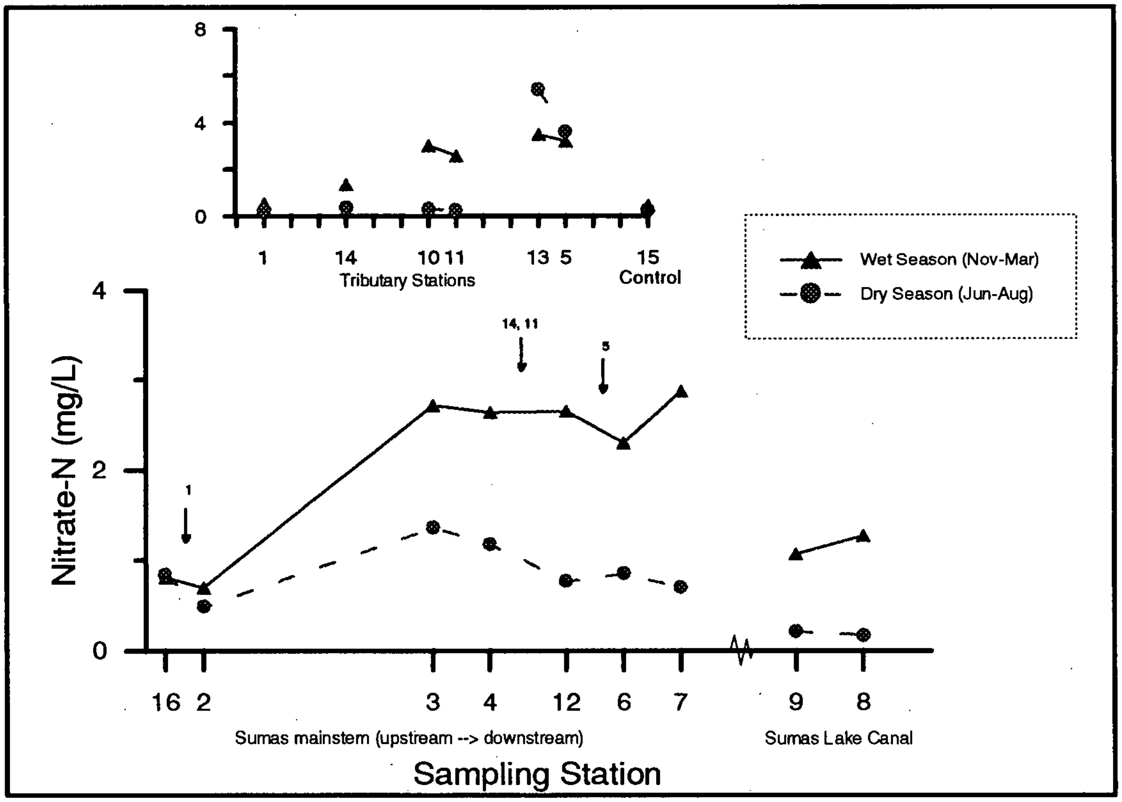


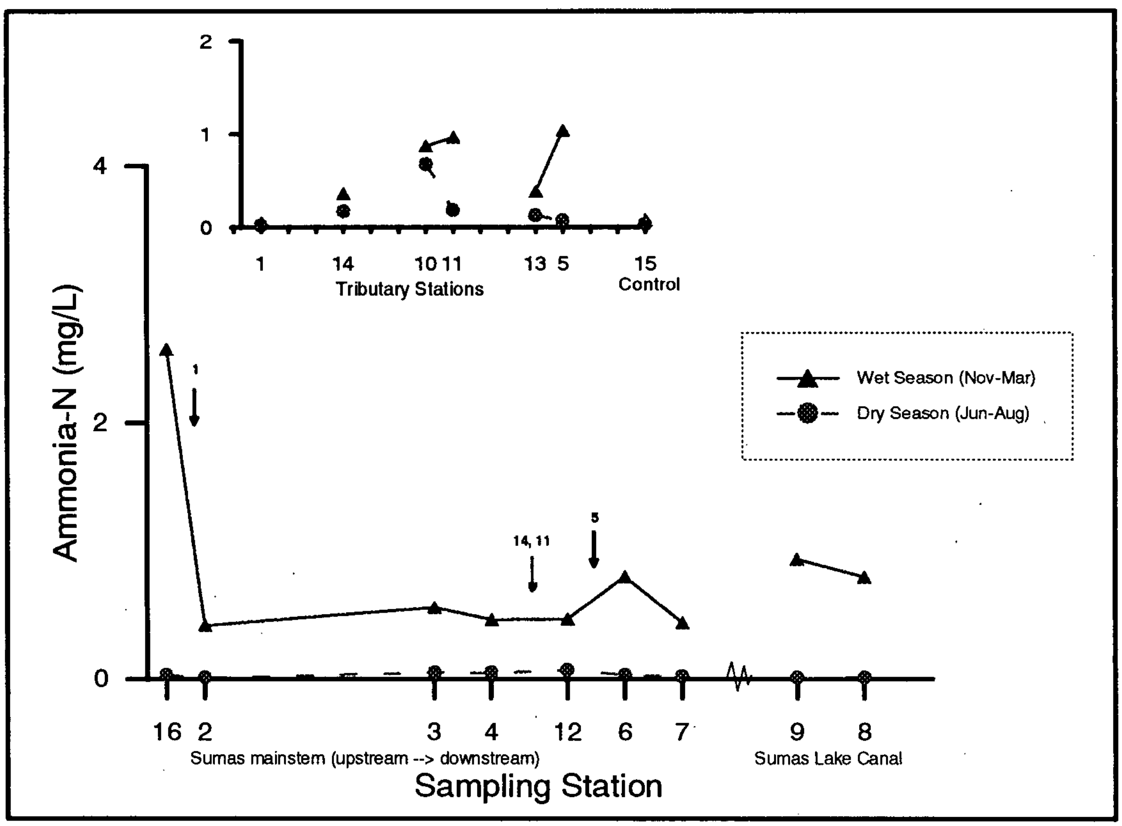
Appendix F: Wet Season/Dry Season Water Quality Results



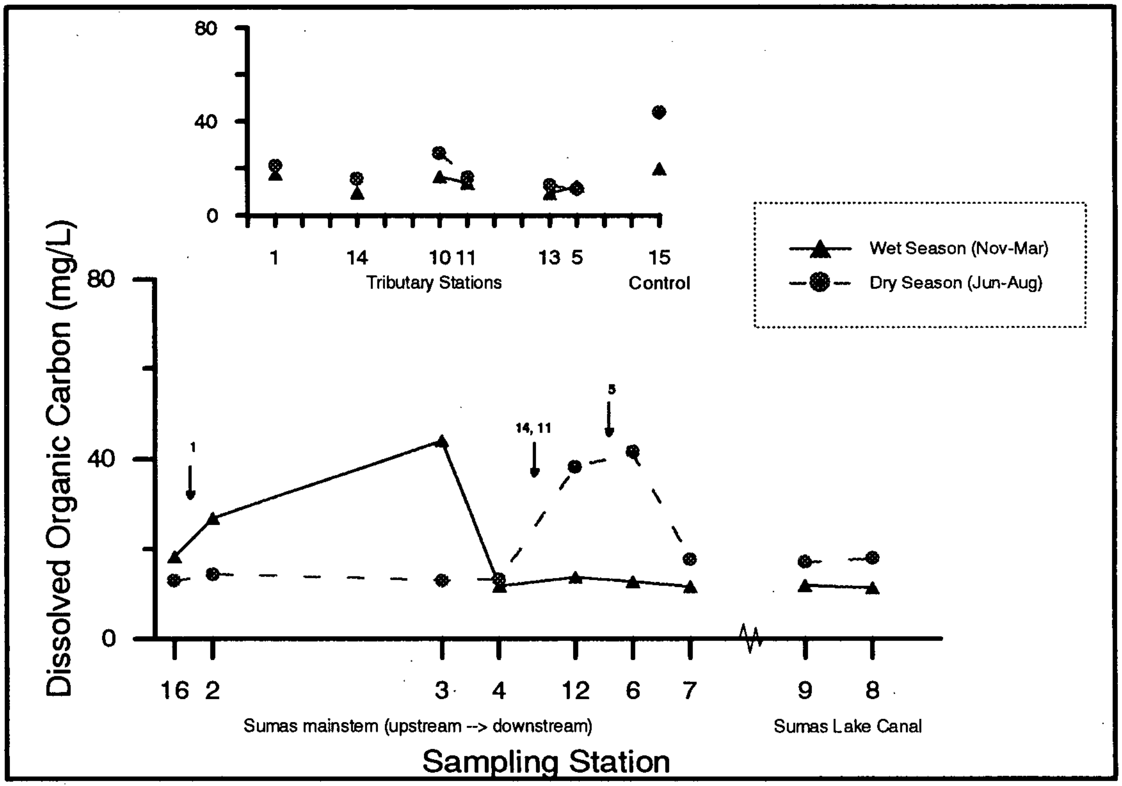


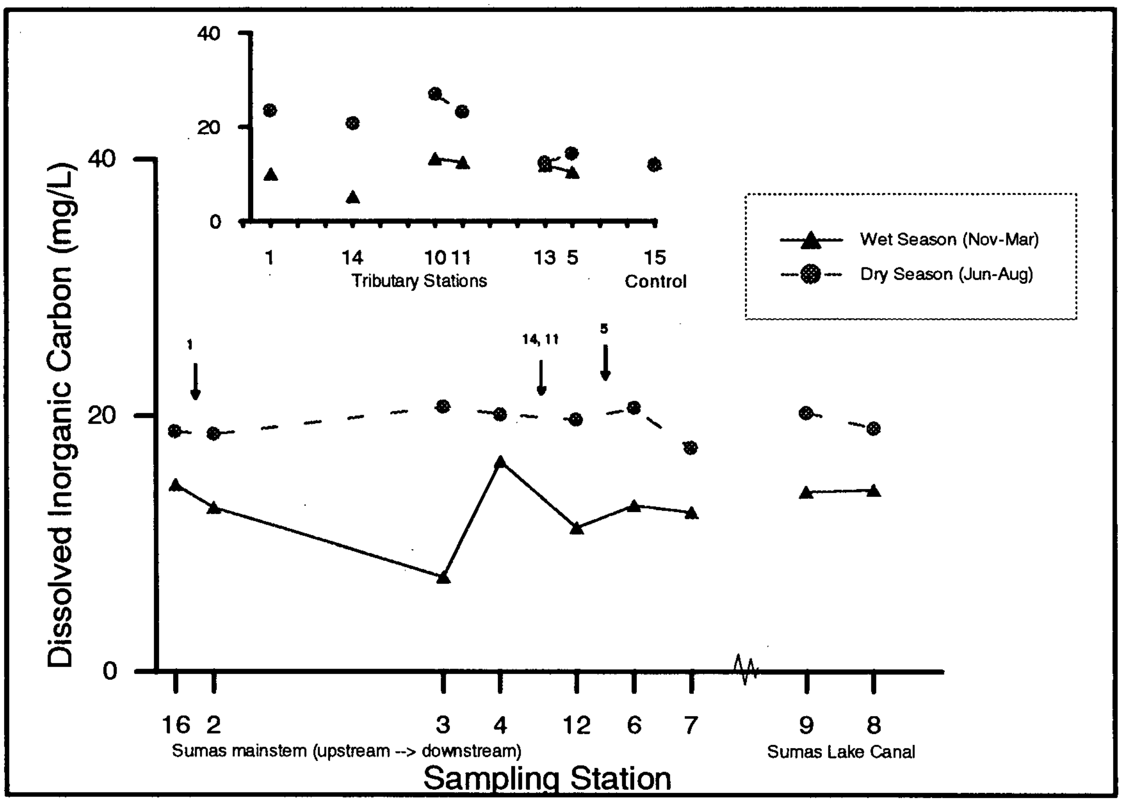
Appendix F: Wet Season/Dry Season Water Quality Results



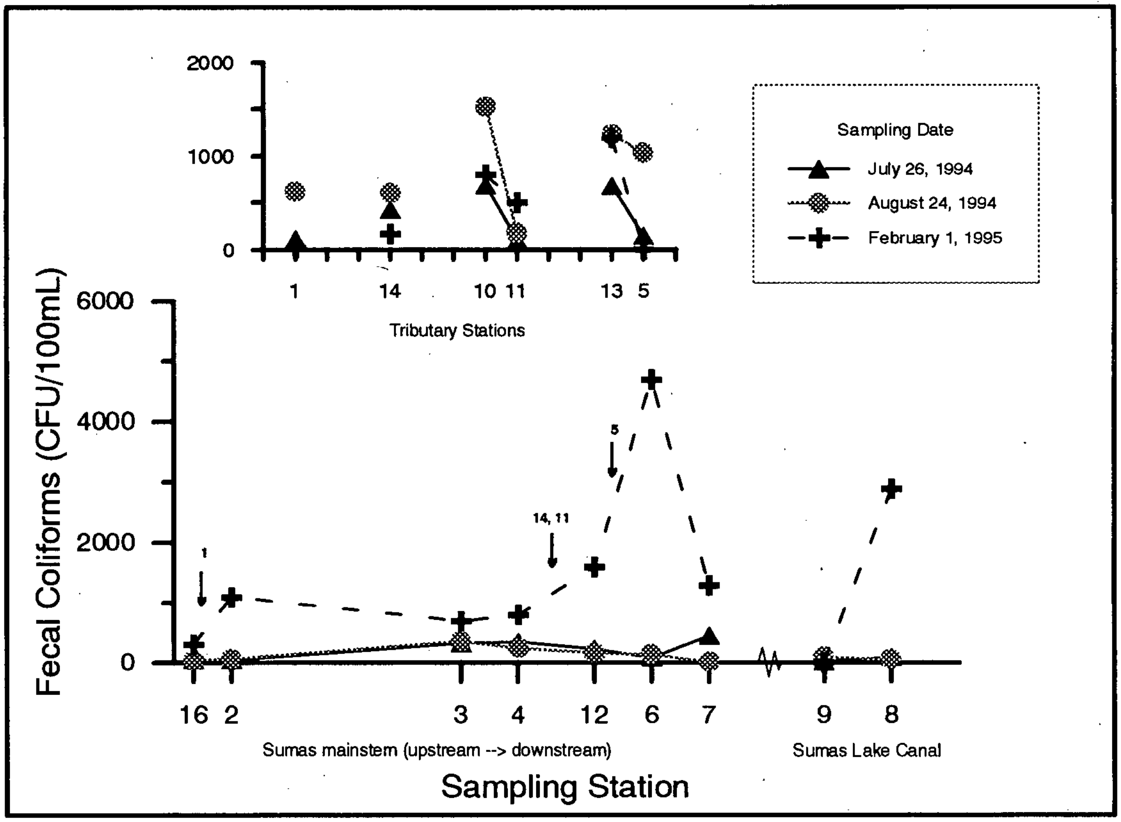


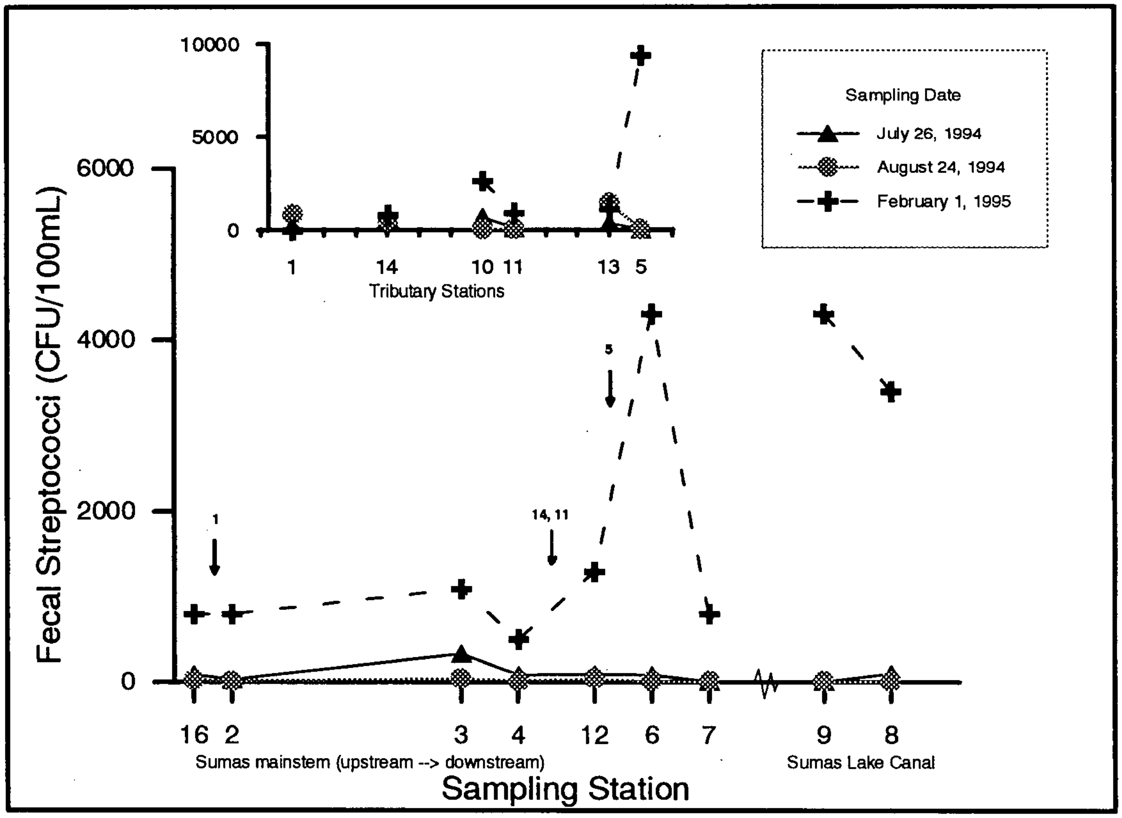
Appendix F: Wet Season/Dry Season Water Quality Results



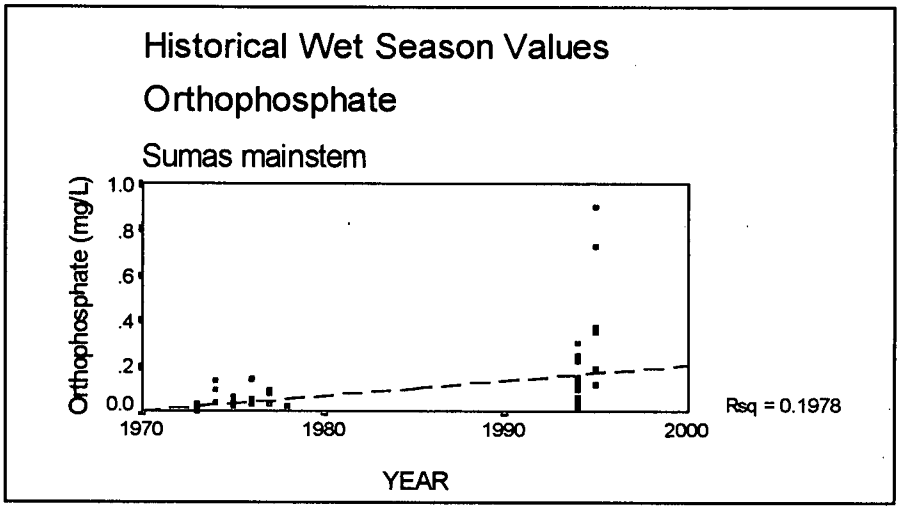


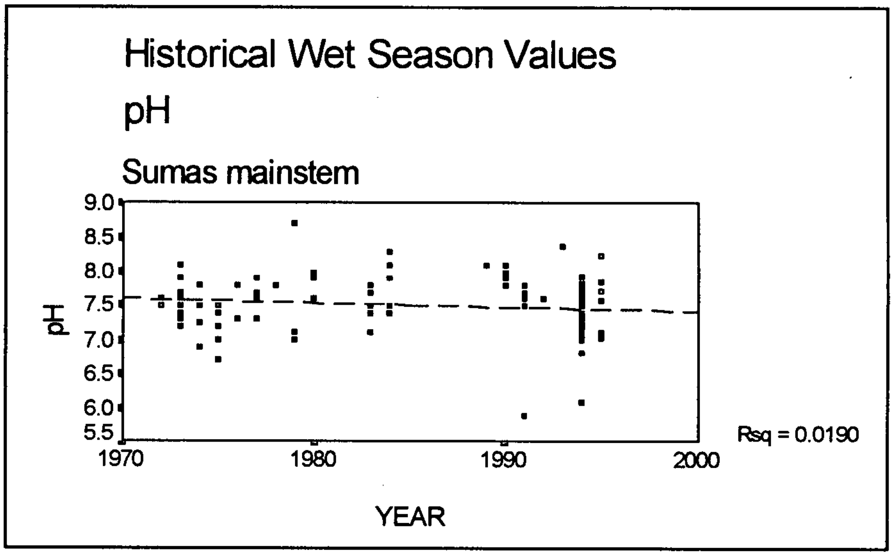
Appendix F: 3 Sampling Dates, Fecal Coliform Results

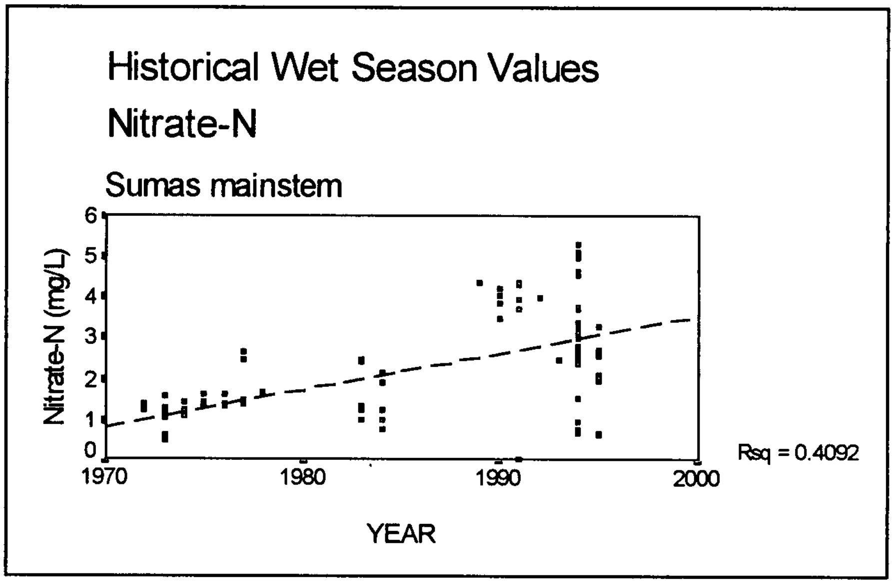




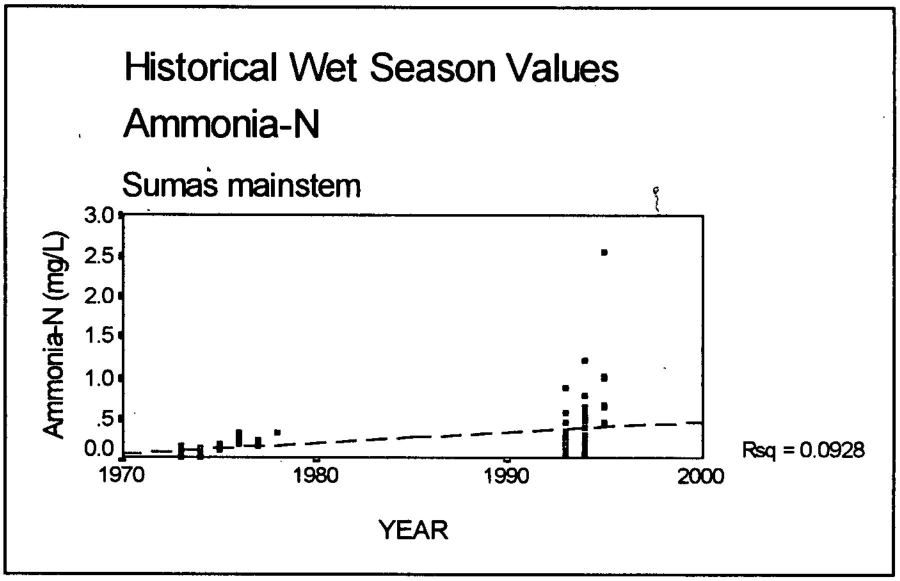
Appendix G: Historical Wet Season Water Quality. All stations on the mainstem are plotted. Wet Season = November through March.

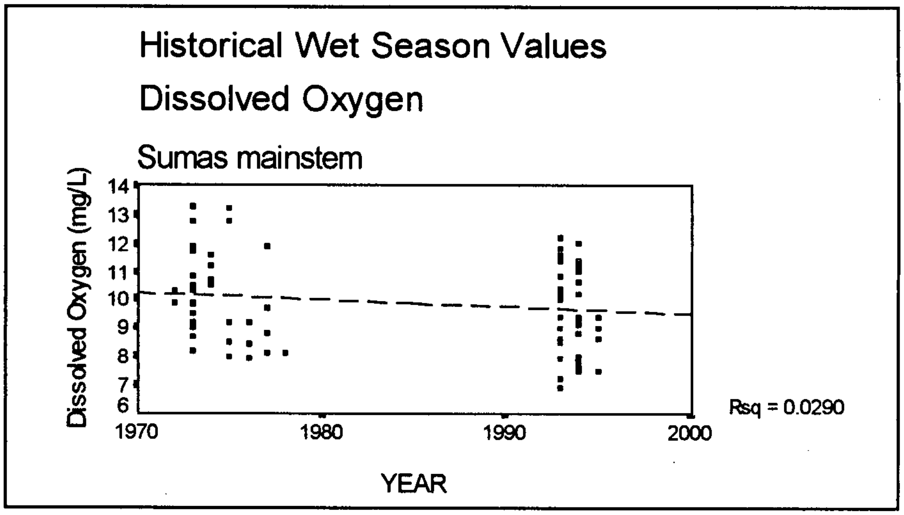


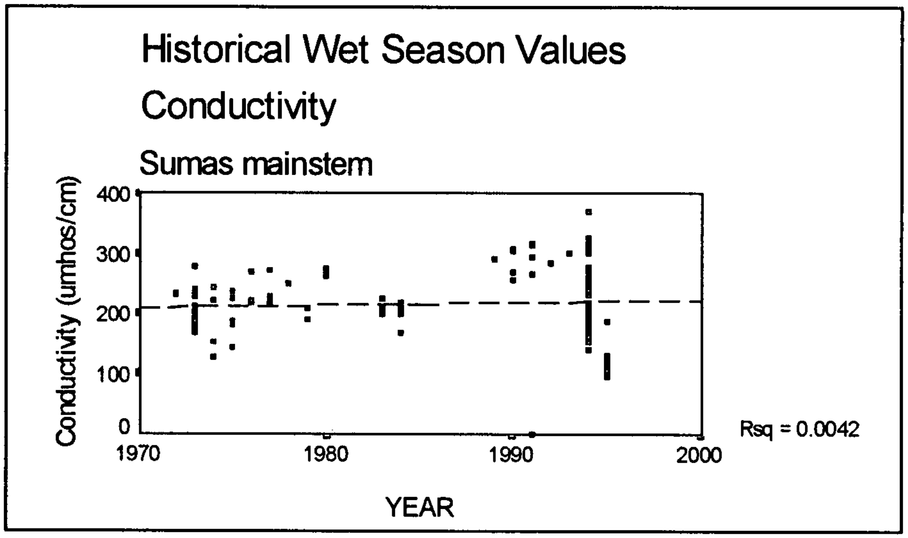




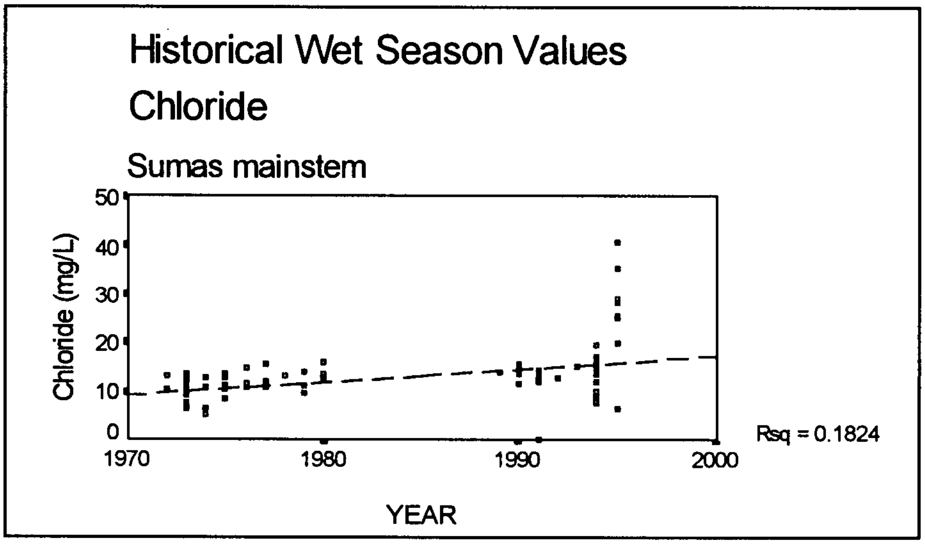
Appendix G: Historical Wet Season Water Quality. All stations on the mainstem are plotted. Wet Season = November through March.



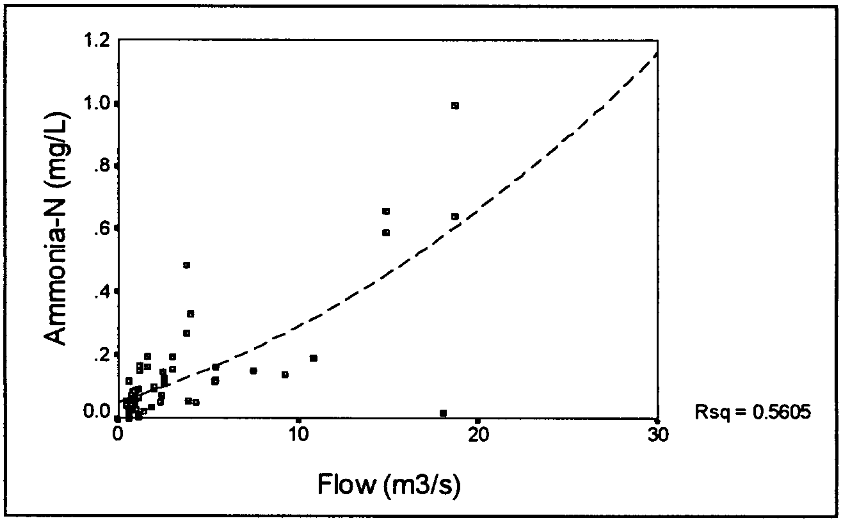


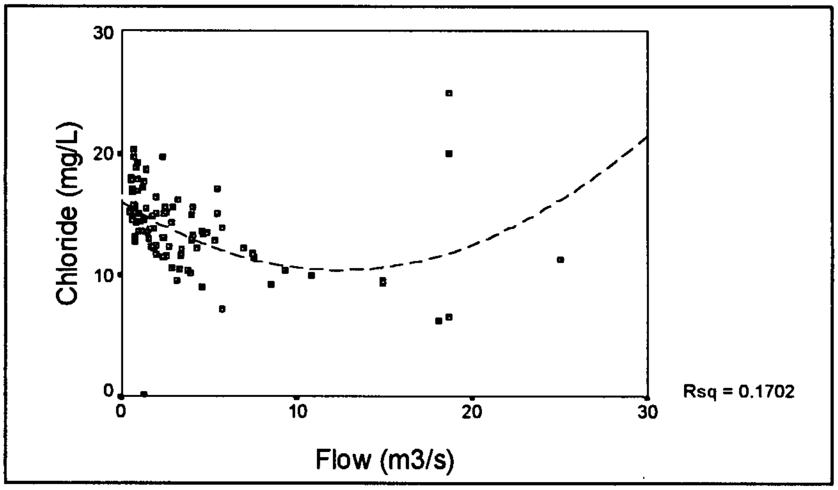


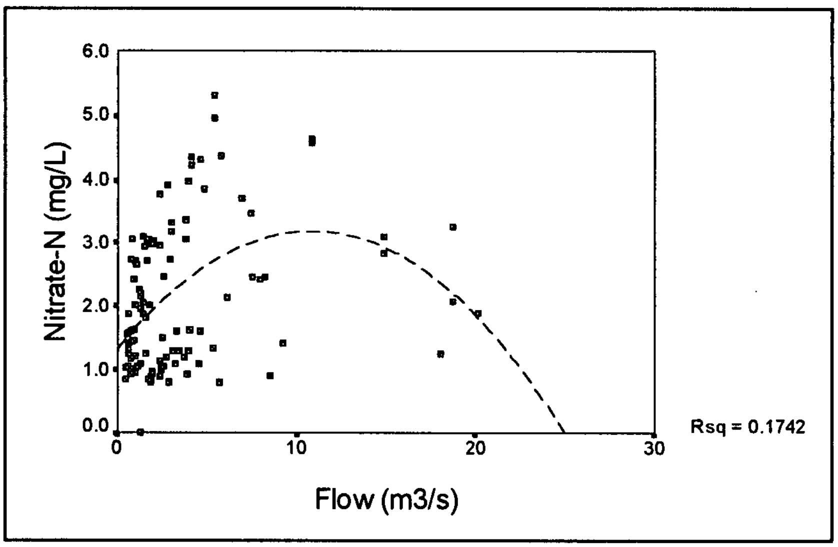
Appendix G: Historical Wet Season Water Quality. All stations on the mainstem are plotted. Wet Season = November through March.



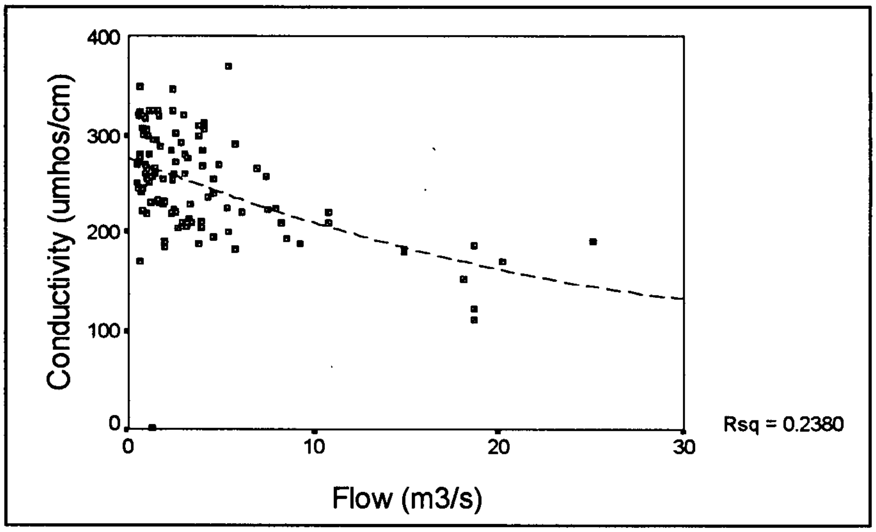
Appendix H: Scatterplots of Historical Water Quality vs. Discharge. All seasons at stations 3 and 4 only are plotted. Discharge is as measured at station 3 (U.S. border).

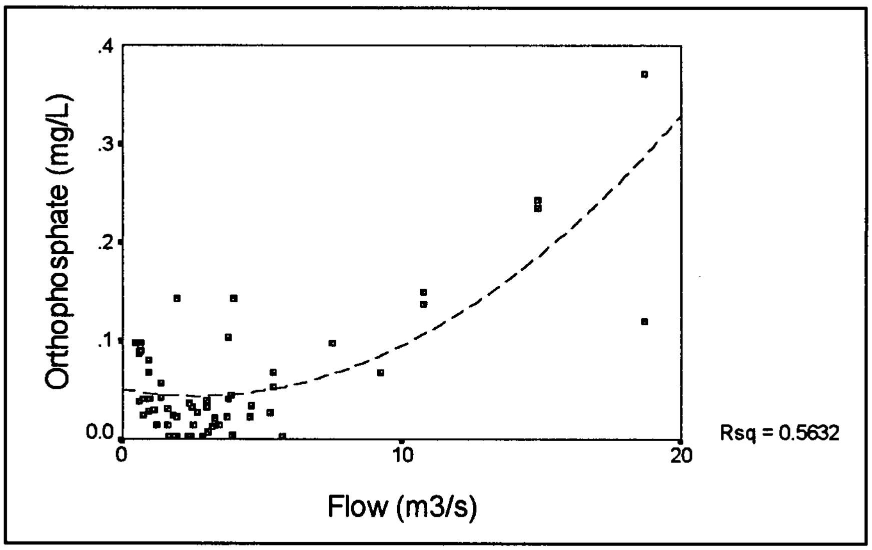






Appendix H: Scatterplots of Historical Water Quality vs. Discharge. All seasons at stations 3 and 4 only are plotted. Discharge is as measured at station 3 (U.S. border).





Appendix I Nitrogen Model Methodology by Brisbin (1995)

The following description of the nitrogen model (see figure at end of this appendix) is adopted from Brisbin (1995):

The model relies on a number of input variables: livestock inventory; unit livestock nutrient production; manure management practices and associated nutrient losses; agricultural land base inventory; unit crop nutrient uptake; inorganic fertilizer use; and soil-atmosphere nitrogen exchange factors.

The model utilizes these variables in a series of calculations to estimate the losses of nutrients to the atmosphere, surface water and groundwater. The calculations are described by the following steps:

1) Unit livestock nutrient production estimates are applied to livestock inventory values to generate total manure nutrient production by livestock type and commodity.

2) Nutrient loss factors (the percentage of the nutrient "lost" during a particular component of the manure management process, to be applied to the total amount of the nutrient entering that component of the system) for various manure management system components are prorated by the distribution of the management system components to generate composite loss factors for each commodity group. The composite loss factors are then applied to the total manure nutrient production for each commodity group to generate estimates of nutrient losses which occur at different steps of the manure management process and a net application of manure to land. The net application to land includes that "applied" by livestock on pasture.

Losses during the manure management process include losses to the atmosphere, losses to surface water, losses to groundwater and export. The model estimates losses which occur during housing and collection, from yard areas and pasture, from storage and during land application. Export losses refer to nutrients which are utilized in such a manner that they are not applied to the agricultural land of the area to which the model is being applied.

3) Unit crop uptake and inorganic fertilizer application values are applied to the land base inventory and a value for crop nutrient uptake minus inorganic fertilizer application is calculated.

4) An estimate of the soil-atmosphere nitrogen exchange is made utilizing estimates of a

background net input to soil plus estimates of a return flow from agricultural activities which is calculated as a percentage of the total losses to the atmosphere during the manure management process (denitrification losses are not used in this calculation).

5) The values for total manure nutrient production (amount excreted) and manure management losses are combined with the crop - inorganic fertilizer application balance and the soil-atmosphere balance to generate an estimate of the surplus (or deficit) applied to the soil.

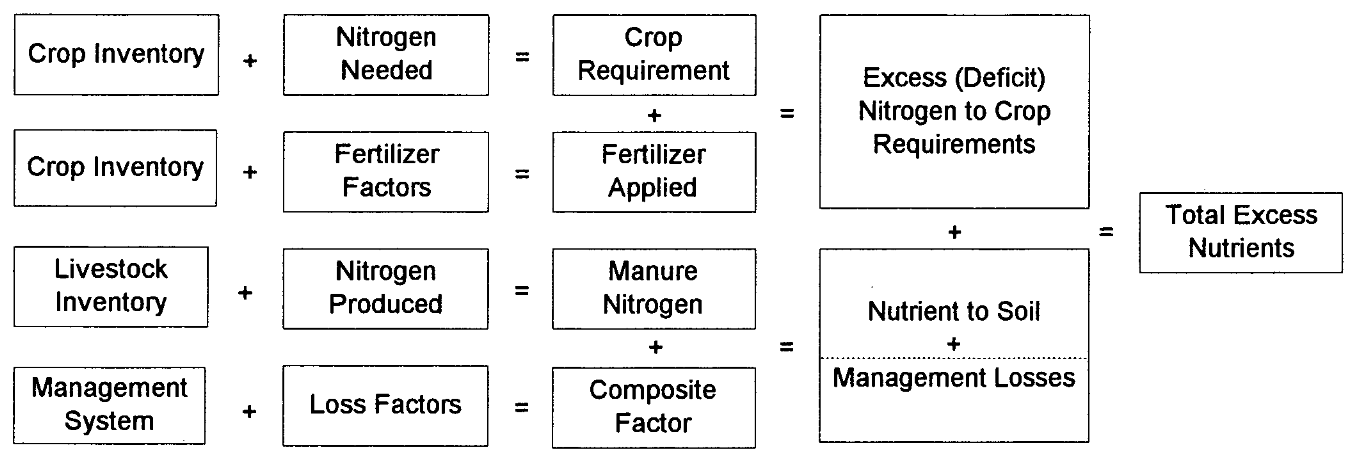
A surplus value does not necessarily mean that excessive amounts of nutrients are being applied to the soil. The term "surplus" in this case means only that the nutrients produced in manure less manure management losses plus inorganic fertilizer applications plus net input from the atmosphere exceed crop nutrient uptake. "Losses" of nutrients from soils is part of the various nutrient cycles and cannot be eliminated from agricultural systems; "no surplus" is simply not attainable. Surplus applications, as defined in this study, must be interpreted as excessive or not and this interpretation must consider their ultimate destination (surface water or groundwater) and the sensitivity of that destination to nutrient loading.

6) Surplus applications to the land are then partitioned into losses to denitrification, surface water and groundwater using various soil release factors. Denitrification losses are calculated as a percentage of the "net manure application". "Deep losses" (nutrients which move below the rooting zone) are calculated as the surplus application less denitrification losses and are split between losses to surface water and losses to groundwater.

The model has the ability to estimate the exchange of nutrients within the soils (releases from organic matter within the soil and immobilization within the soil). However, in this study it was assumed that the net of this exchange would be zero; the amount released from the soil equals the amount immobilized by the soil. When the model is applied to a particular geographic area it is being assumed that the rate of mobilization (mineralization) within that geographic area equals the rate of immobilization within the area; this does not imply that the two rates are equal for all locations within that area, only that they are equal over the entire area.

Nutrient exchanges in the soil can be very significant over the short term; however over a long period of time a soil system will tend to approach an equilibrium where annual rates of immobilization equal rates of mobilization.

Appendix I (continued) Schematic of Nitrogen Model Methodology (adopted from Brisbin (1995))



Appendix J

Summary of Nitrogen Balance for the Canadian Portion of the Sumas Watershed

Balance Inputs and Outputs	WMS farms	WMS farms	WMS farms	Brisbin		Brisbin	Census	Comments
Units are kg N/year unless otherwise noted		+ averages	+ census	Large farms	Small farms	Total	1991	
Farmed area (ha)	5491	12060	6485	7032	660	7692	7593	non-farmed area is assumed to be in dynamic equilibrium, inputs=uptake
Cropped area (ha)	4905	10749	5637	6687	543	7230	6636	
Manure produced	2061505	3533859	*	1892000	171	1892171	2155667	based on Brisbin's N production for each animal type
Manure exported	76752	116808	*	36000	0	36000	46788	estimate of 30% of broiler manure exported by Brisbin, 15% used for census (broiler numbers not distinguished from layers)
Management losses	926365	1617001	*	883000	75000	958000	993530	uses air, runoff, infiltration loss factors derived from Brisbin and applied to N production
Net Manure Application	1053008	1778931	*	973000	95000	1068000	1128995	application factors derived from Brisbin tables and applied to N production
Crop requirements	946369	1602562	*	1383000	106000	1489000	1449634	uses N uptake rates by crop type from Brisbin
Fertilizer applied	630309	1209841	*	1154000	78000	1232000	1118531	inorganic fertilizer application rates from Brisbin
Net crop (fertilizer applied-require	-316060	-392721	*	-229000	-28000	-257000	-331103	
Net atmospheric input	314043	571606	*	309000	25000	334000	256110	9 kg/ha/yr background+30% of volatilized from manure
Applied surplus (deficit) (kg)	1050990	1957815	*	1053000	92000	1145000	1054001	net applied + net crop + net atmospheric input
kg/farmed ha	191	162	*	150	139	149	139	
kg/cropped ha	214	182	*	157	170	158	159	
Denitrification	105301	177893	*	146000	14000	160000	112899	10% of net manure applied is assumed to be lost through denitrification
Surplus N	945689	1779922	981448	907000	78000	985000	941102	*Surplus N (after denitrification) - this quantity is used as an index in this thesis*
kg/farmed ha	172	148	151	129	118	128	123	*this quantity is used as an index in this thesis*
kg/cropped ha	193	166	174	135	144	136	141	*this quantity is used as an index in this thesis*

**This calculation used results from the WMS-only balance and the census-only balance. They were combined using GIS queries and spatial summations to reach a final Surplus N*

Appendix K Variables Used in the Spearman Rank Correlation
(94 variables and 11 cases written)

Variable Name	Description
CA	Contributing Area Number, not used in correlation ID only

Water Quality

PHWET	Wet Season pH
PHDRY	Dry Season pH
CONDWET	Wet Season Conductivity
CONDDRY	Dry Season Conductivity
DOWET	Wet Season Dissolved Oxygen
DODRY	Dry Season Dissolved Oxygen
ORTHOPWE	Wet Season Ortho-P
ORTHOPDR	Dry Season Ortho-P
CLWET	Wet Season Chloride
CLDRY	Dry Season Chloride
AMMONWET	Wet Season Ammonia-N
AMMONDRY	Dry Season Ammonia-N
NITWET	Wet Season Nitrate-N
NITDRY	Dry Season Nitrate-N

Land Activity Intensity

EA_N	Total Surplus Nitrogen, calculated using WMS and Census data
EA_N_GIS	Surplus nitrogen per total hectares
EA_N_FM	Surplus nitrogen per farmed hectares
EA_N_CRP	Surplus nitrogen per cropped hectares
WMS_N	Total surplus nitrogen, calculated using WMS data and averages
WMS_N_GI	Surplus nitrogen per total hectares
WMS_N_FM	Surplus nitrogen per farmed hectares
WMS_N_CR	Surplus nitrogen per cropped hectares
AUETOT	Total Animal Unit Equivalents
AUEDENS	Animal Unit Equivalents per farmed hectare
PLTRYTOT	Total number of poultry
DCOWTOT	Total number of dairy cows

PIGTOT	Total number of pigs
NO_FARMS	Total number of farms

Land Use Types

LU1TOT	Total hectares agriculture
LU2TOT	Total hectares forest
LU3TOT	Total hectares none perceived land use
LU4TOT	Total hectares park/wetlands/recreation
LU5TOT	Total hectares residential
LU6TOT	Total hectares industrial/commercial
LU1PRCNT	% area agriculture
LU2PRCNT	% area forest
LU3PRCNT	% area none perceived land use
LU4PRCNT	% area park/wetlands/recreation
LU5PRCNT	% area residential
LU6PRCNT	% area industrial/commercial

Surficial Soil Texture (approx. first 25 cm)

SURF1TOT	Total hectares organic
SURF2TOT	Total hectares clay
SURF3TOT	Total hectares loam
SURF4TOT	Total hectares silt
SURF5TOT	Total hectares sand
SURF6TOT	Total hectares gravel
SURF1PRC	% area organic
SURF2PRC	% area clay
SURF3PRC	% area loam
SURF4PRC	% area silt
SURF5PRC	% area sand
SURF6PRC	% area gravel

Subsurface Soil Texture (approx. below 25 cm)

SUB1TOT	Total hectares organic
SUB2TOT	Total hectares clay
SUB3TOT	Total hectares loam
SUB4TOT	Total hectares silt
SUB5TOT	Total hectares sand
SUB6TOT	Total hectares gravel
SUB1PRCN	% area organic
SUB2PRCN	% area clay

SUB3PRCN	% area loam
SUB4PRCN	% area silt
SUB5PRCN	% area sand
SUB6PRCN	% area gravel

Soil Drainage Capability

DRN1TOT	Total hectares excessive
DRN2TOT	Total hectares well
DRN3TOT	Total hectares moderately well
DRN4TOT	Total hectares imperfect
DRN5TOT	Total hectares poor
DRN6TOT	Total hectares very poor
DRN1PRCN	% area excessive
DRN2PRCN	% area well
DRN3PRCN	% area moderately well
DRN4PRCN	% area imperfect
DRN5PRCN	% area poor
DRN6PRCN	% area very poor

Parent Material

PM2TOT	Total hectares colluvium
PM3TOT	Total hectares outwash
PM4TOT	Total hectares alluvium
PM5TOT	Total hectares glacio-fluvial
PM6TOT	Total hectares lacustrine
PM7TOT	Total hectares glacial till
PM10TOT	Total hectares organic
PM2PRCNT	% area colluvium
PM3PRCNT	% area outwash
PM4PRCNT	% area alluvium
PM5PRCNT	% area glacio-fluvial
PM6PRCNT	% area lacustrine
PM7PRCNT	% area glacial till
PM10PRCN	% area organic

Appendix L Indice Values by Contributing Area - Canadian Portion of the Sumas Watershed

CA	ea_N	ea_N_gis	ea_N_fm	ea_N_crp	wms_N	wms_N_gi	wms_N_fm	wms_N_cr	AUEtot	AUEdens	pltrytot	dcowtot	pigtot	no_farms
4	72286	150	142	163	101338	210	120	137	1405	2.9	27000	1103	2711	17
5	168924	92	228	264	203737	111	235	260	2448	1.3	95000	1585	8511	20
6	0	0	0	0	0	0	0	0	0	0.0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0.0	0	0	0	0
8	102811	85	184	200	192065	159	150	166	1819	1.5	147000	1554	1651	29
9	269933	46	115	140	575467	98	129	152	7537	1.3	298800	6320	10560	105
10	29715	46	144	168	100628	156	154	177	1207	1.9	17000	945	3022	19
11	43903	235	318	327	68120	364	332	354	832	4.5	0	515	3511	5
12	100055	79	94	98	236772	186	146	158	3028	2.4	24300	2905	0	33
13	23519	14	112	224	32741	20	57	67	715	0.4	104000	334	3022	15
15	0	0	0	0	0	0	0	0	0	0.0	0	0	0	0

CA	lu1tot	lu2tot	lu3tot	lu4tot	lu5tot	lu6tot	lu1prcnt	lu2prcnt	lu3prcnt	lu4prcnt	lu5prcnt	lu6prcnt
4	437.28		37		0.92	7.48	0.91		0.08		0.00	0.02
5	1025.16	545.56	80.32	5.24	110.32	67.32	0.56	0.30	0.04	0.00	0.06	0.04
6	78.72	796.4	2.92	4.2	0.16	6.6	0.09	0.89	0.00	0.00	0.00	0.01
7	42.8	308.44	6.04	57.92			0.10	0.69	0.01	0.13		
8	1084.12	24.88	5.24	55.88	32.08		0.90		0.02	0.00	0.05	0.03
9	3708.84	1862.4	96.44	4.52	153	27.4	0.63	0.32	0.02	0.00	0.03	0.00
10	437.16	185.64	11.12		9.52		0.68	0.29	0.02		0.01	
11	186.12						0.99					
12	1208.04		36.48	1.32		19.64	0.95		0.03	0.00		0.02
13	549.2	49.28	156.36	21.12	556.64	342	0.33	0.03	0.09	0.01	0.33	0.20
15	0.12	54.44				11.6	0.00	0.82				0.18

CA	surf1tot	surf2tot	surf3tot	surf4tot	surf5tot	surf6tot	surf1prcnt	surf2prcnt	surf3prcnt	surf4prcnt	surf5prcnt	surf6prcnt
4	2.4		59.92	411.08	4.08		0.00		0.12	0.85	0.01	
5	169.68	29.52	271.12	1294.76	68.84		0.09	0.02	0.15	0.71	0.04	
6		4.6	1.6	693.6	177.64	11.04		0.01	0.00	0.77	0.20	0.01
7		44.36	0.28	75.56	273.68	5.4		0.10	0.00	0.17	0.62	0.01
8			288	222.08	688.12				0.24	0.18	0.57	
9		3	802.36	3319.6	1731.92			0.00	0.14	0.57	0.30	
10	1.08	2.2	163.12	426.8	21.52		0.00	0.00	0.25	0.66	0.03	
11			100.12	83.36	4.88				0.53	0.44	0.03	
12		1.56	128.8	983.04	132.08				0.00	0.10	0.77	0.10
13	202.88		2.8	1182	276.04	12	0.12		0.00	0.71	0.16	0.01
15				66.16						1.00		

Appendix L Indice Values by Contributing Area - Canadian Portion of the Sumas Watershed

CA	sub1tot	sub2tot	sub3tot	sub4tot	sub5tot	sub6tot	sub1prcnt	sub2prcnt	sub3prcnt	sub4prcnt	sub5prcnt	sub6prcnt
4		62.32	94.36		183.32	137.48		0.13	0.20	0.38	0.28	
5		395.96	873	29.52	396.36	139.08		0.22	0.48	0.02	0.22	0.08
6		1.6	336.16	4.6	326.76	219.36		0.00	0.37	0.01	0.36	0.24
7			39.56	44.36	37.96	277.4			0.09	0.10	0.09	0.62
8			114.6		1076.6	7			0.09		0.89	0.01
9		239.96	2186.88	3	3270.04	157		0.04	0.37	0.00	0.56	0.03
10		164.2	227.36	2.2	200	20.96		0.26	0.35	0.00	0.31	0.03
11		100.12	26.04		61.64	0.56		0.53	0.14		0.33	0.00
12		128.8	602.04	1.56	385.24	127.84		0.10	0.47	0.00	0.30	0.10
13	25.32	150.12	98.16	12.24	476.6	913.28	0.02	0.09	0.06	0.01	0.28	0.55
15			4.52		35.8	25.84			0.07		0.54	0.39

CA	drn1tot	drn2tot	drn3tot	drn4tot	drn5tot	drn6tot	drn1prcnt	drn2prcnt	drn3prcnt	drn4prcnt	drn5prcnt	drn6prcnt
4		4.08	137.48	172.84	160.68	2.4		0.01	0.28	0.36	0.33	0.00
5		183.2	624.64	389.44	437.44	199.2		0.10	0.34	0.21	0.24	0.11
6		224.36	633.56	16.88	9.08	4.6		0.25	0.71	0.02	0.01	0.01
7		278.28	51.8	3.8	21.04	44.36		0.63	0.12	0.01	0.05	0.10
8		1.24	7	146.8	1043.16			0.00	0.01	0.12	0.86	
9		142.08	2124.2	1106.92	2480.68	3		0.02	0.36	0.19	0.42	0.00
10		0.56	196.16	251.6	163.12	3.28		0.00	0.30	0.39	0.25	0.01
11		4.32	0.56	83.36	100.12			0.02	0.00	0.44	0.53	
12		88.24	127.84	811.8	216.04	1.56		0.07	0.10	0.64	0.17	0.00
13	155.48	901.28	332.52	4.12	67.44	214.88	0.09	0.54	0.20	0.00	0.04	0.13
15		25.84	34.16		6.16			0.39	0.52		0.09	

CA	pm2tot	pm3tot	pm4tot	pm5tot	pm6tot	pm7tot	pm10tot	pm2prcnt	pm3prcnt	pm4prcnt	pm5prcnt	pm6prcnt	pm7prcnt	pm10prcn
4			203.68		273.8					0.42		0.57		
5	43.52	126.08	400.88	0.76	599.28	611.64	51.76	0.02	0.07	0.22	0.00	0.33	0.33	0.03
6	171.68	36.64	31.16		15.44	633.56		0.19	0.04	0.03		0.02	0.71	
7	272.8		53.56		21.12	51.8		0.61		0.12		0.05	0.12	
8			122.8		1075.4					0.10		0.89		
9	16.16		672.68		3184.68	1983.36		0.00		0.11		0.54	0.34	
10			76.4		363.12	175.2				0.12		0.56	0.27	
11			26.6		161.76					0.14		0.86		
12			710.28		535.2					0.56		0.42		
13		913.28	28.8	220.12	6.92	332.52	174.08		0.55	0.02	0.13	0.00	0.20	0.10
15		25.84		6.16		34.16			0.39		0.09		0.52	

Appendix L Indice Values by Contributing Area - Whole Watershed

CA	wms_N	ave_N	wms_N_f	ave_N_fm	AUEtot	AUEdens	lu1tot	lu2tot	lu3tot	lu4tot	lu5tot	lu6tot	lu1prcnt	lu2prcnt	lu3prcnt	lu4prcnt	lu5prcnt	lu6prcnt
4	101338	112128	120	133	1405	2.9	437.28	0	37	0	0.92	7.48	0.91	0	0.08	0	0.00	0.02
5	203737	149367	235	172	2448	1.3	1025.16	545.56	80.32	5.24	110.32	67.32	0.56	0.30	0.04	0.00	0.06	0.04
6	0	0	0	0	0	0.0	78.72	796.4	2.92	4.2	0.16	6.6	0.09	0.89	0.00	0.00	0.00	0.01
7	0	0	0	0	0	0.0	42.8	308.44	6.04	57.92	0	0	0.10	0.69	0.01	0.13	0	0
8	192065	169409	150	133	1819	1.5	1084.12	24.88	5.24	55.88	32.08	0	0.90	0	0.02	0.00	0.05	0.03
9	575467	873969	129	196	7537	1.3	3708.84	1862.4	96.44	4.52	153	27.4	0.63	0.32	0.02	0.00	0.03	0.00
10	253370	287730	185	211	3837	2.8	1151	455	18	0	15	4	0.70	0.28	0.01	0.00	0.01	0.00
11	68120	57689	332	281	832	4.5	186.12	0	0	0	0	0	0.99	0	0	0	0	0
12	236772	228570	146	141	3028	2.4	1208.04	0	36.48	1.32	0	19.64	0.95	0	0.03	0.00	0	0.02
13	32741	83194	57	145	715	0.4	549.2	49.28	156.36	21.12	556.64	342	0.33	0.03	0.09	0.01	0.33	0.20
15	0	0	0	0	0	0.0	0.12	54.44	0	0	0	11.6	0.00	0.82	0	0	0	0.18
2	-21881	-21881	-29	-29	150	0.2	742	1152	24	27	174	26	0.35	0.55	0.01	0.01	0.08	0.01
3	436339	436339	67	67	10140	1.6	6467	1416	342	81	645	194	0.65	0.14	0.03	0.01	0.07	0.02
14	57466	57466	107	107	1170	2.2	538	1430	155	29	181	24	0.21	0.56	0.06	0.01	0.07	0.01
16	11964	11964	13	13	720	0.8	893	1022	20	16	138	49	0.41	0.47	0.01	0.01	0.06	0.02

CA	sub1tot	sub2tot	sub3tot	sub4tot	sub5tot	sub6tot	sub1prcnt	sub2prcnt	sub3prcnt	sub4prcnt	sub5prcnt	sub6prcnt
4	0	62.32	94.36	0	183.32	137.48	0	0.13	0.20	0.38	0.28	0
5	0	395.96	873	29.52	396.36	139.08	0	0.22	0.48	0.02	0.22	0.08
6	0	1.6	336.16	4.6	326.76	219.36	0	0.00	0.37	0.01	0.36	0.24
7	0	0	39.56	44.36	37.96	277.4	0	0	0.09	0.10	0.09	0.62
8	0	0	114.6	0	1076.6	7	0	0	0.09	0	0.89	0.01
9	0	239.96	2186.88	3	3270.04	157	0	0.04	0.37	0.00	0.56	0.03
10	6.24	164	349	409	499	154	0.00	0.10	0.22	0.25	0.31	0.10
11	0	100.12	26.04	0	61.64	0.56	0	0.53	0.14	0	0.33	0.00
12	0	128.8	602.04	1.56	385.24	127.84	0	0.10	0.47	0.00	0.30	0.10
13	25.32	150.12	98.16	12.24	476.6	913.28	0.02	0.09	0.06	0.01	0.28	0.55
15	0	0	4.52	0	35.8	25.84	0	0	0.07	0	0.54	0.39
2	23.40	0.00	898.36	207.44	680.28	289.04	0.01	0.00	0.43	0.10	0.32	0.14
3	576.48	0	2684.08	2791.52	2593.6	1231.72	0.06	0	0.27	0.28	0.26	0.12
14	14.80	0	1195.52	369.96	405.84	560.12	0.01	0	0.47	0.15	0.16	0.22
16	10.16	0	965.2	112.56	810.08	270.6	0.00	0	0.44	0.05	0.37	0.12

CA	drn1tot	drn2tot	drn3tot	drn4tot	drn5tot	drn6tot	drn1prcnt	drn2prcnt	drn3prcnt	drn4prcnt	drn5prcnt	drn6prcnt
4	0	4.08	137.48	172.84	160.68	2.4	0	0.01	0.28	0.36	0.33	0.00
5	0	183.2	624.64	389.44	437.44	199.2	0	0.10	0.34	0.21	0.24	0.11
6	0	224.36	633.56	16.88	9.08	4.6	0	0.25	0.71	0.02	0.01	0.01
7	0	278.28	51.8	3.8	21.04	44.36	0	0.63	0.12	0.01	0.05	0.10
8	0	1.24	7	146.8	1043.16	0	0	0.00	0.01	0.12	0.86	0
9	0	142.08	2124.2	1106.92	2480.68	3	0	0.02	0.36	0.19	0.42	0.00
10	26	323	306	252	359	315	0.02	0.20	0.19	0.16	0.22	0.20
11	0	4.32	0.56	83.36	100.12	0	0	0.02	0.00	0.44	0.53	0
12	0	88.24	127.84	811.8	216.04	1.56	0	0.07	0.10	0.64	0.17	0.00
13	155.48	901.28	332.52	4.12	67.44	214.88	0.09	0.54	0.20	0.00	0.04	0.13
15	0	25.84	34.16	0	6.16	0	0	0.39	0.52	0	0.09	0
2	179.72	887.68	364.00	0.00	631.40	35.72	0.09	0.42	0.17	0.00	0.30	0.02
3	258.32	3024.88	1817.76	0	2870.4	1906.04	0.03	0.31	0.18	0.00	0.29	0.19
14	50.44	1596	585.88	0	102.88	211.04	0.02	0.63	0.23	0.00	0.04	0.08
16	219.16	1006.76	644.84	0	287.68	10.16	0.10	0.46	0.30	0.00	0.13	0.00

Appendix L Indice Values by Contributing Area - Whole Watershed

CA	pm1tot	pm2tot	pm3tot	pm4tot	pm5tot	pm6tot	pm7tot	pm10tot	pm1prcnt	pm2prcnt	pm3prcnt	pm4prcnt	pm5prcnt	pm6prcnt	pm7prcnt	pm10prcn
4	0	0	0	203.68	0	273.8	0	0	0	0	0	0.42	0	0.57	0	0
5	0	43.52	126.08	400.88	0.76	599.28	611.64	51.76	0	0.02	0.07	0.22	0.00	0.33	0.33	0.03
6	0	171.68	36.64	31.16	0	15.44	633.56	0	0	0.19	0.04	0.03	0	0.02	0.71	0
7	0	272.8	0	53.56	0	21.12	51.8	0	0	0.61	0	0.12	0	0.05	0.12	0
8	0	0	0	122.8	0	1075.4	0	0	0	0	0	0.10	0	0.89	0	0
9	0	16.16	0	672.68	0	3184.68	1983.36	0	0	0.00	0	0.11	0	0.54	0.34	0
10	33	196	0	709	6	363	269	6	0.02	0.12	0.00	0.44	0	0.23	0.17	0.00
11	0	0	0	26.6	0	161.76	0	0	0	0	0	0.14	0	0.86	0	0
12	0	0	0	710.28	0	535.2	0	0	0	0	0	0.56	0	0.42	0	0
13	0	0	913.28	28.8	220.12	6.92	332.52	174.08	0	0	0.55	0.02	0.13	0.00	0.20	0.10
15	0	0	25.84	0	6.16	0	34.16	0	0	0	0.39		0.09		0.52	0
2	0.44	560.00	375.64	671.76	0.00	0.00	467.28	23.40	0.00	0.27	0.18	0.32	0.00	0.00	0.22	0.01
3	85.72	777.72	2489.6	4879	0	0	970.92	576.48	0.01	0.08	0.25	0.49	0.00	0.00	0.10	0.06
14	41.44	548.48	219.6	480.2	6.68	0	1217.04	14.8	0.02	0.22	0.09	0.19	0.00	0.00	0.48	0.01
16	0	525.68	308.4	807.92	0	0	516.44	10.16	0.00	0.24	0.14	0.37	0.00	0.00	0.24	0.00

Appendix M   Spearman Rank Correlation Coefficients for Canadian Portion of Sumas Watershed Water Quality vs. Landuse Indices by Contributing Area

	(2) Surplus N/farmed ha	Surplus N/cropped ha	AUE/ farmed ha	pig #	Agricultural Area - %	No Activity Perceived Area - total	No Activity Perceived Area - %	Park/Recreation/ Wetlands Area - total	Industrial/ Commericial Area - %
Ammonia-N, W (1)	0.70, 0.76	0.75		0.67					
Ammonia-N, D									
Nitrate-N, W							0.63		
Nitrate-N, D							0.61		
Ortho-P, W									
Ortho-P, D								-0.61	
Dissolved Oxygen, W	-0.81, -0.84	-0.73, -0.84	-0.61	-0.76	-0.61				
Dissolved Oxygen, D	-0.63	-0.63							0.63
Conductivity, W						0.7	0.62		
Conductivity, D			0.64						
Chloride, W									
Chloride, D			0.67		0.65				

Notes:
(1) W=wet season, D=dry season
(2) two coefficients may be given as two methods were used to calculate N surplus indices; one using census data, the other using Waste Management Survey averages, giving slightly different numbers
(3) n=11 for all coefficients
(4) $p < 0.05$ for all coefficients

Appendix M Spearman Rank Correlation Coefficients for Canadian Portion of Sumas Watershed Water Quality vs. Soil Indices by Contributing Area

	SURFACE TEXTURE				SUBSURFACE TEXTURE					DRAINAGE				
	Organic- total area	Organic- %	Loam- total area	Loam- %	Clay- total area	Clay- %	Loam- %	Silt- %	Sand- %	Well- %	Imperfect- total area	Imperfect- %	Poor- total area	Poor- %
Ammonia-N, W (1)			0.7	0.8	0.61		0.7				0.65			
Ammonia-N, D						0.81								
Nitrate-N, W	0.75	0.75						0.65	-0.85					
Nitrate-N, D	0.74	0.74						0.79	-0.78					
Ortho-P, W				0.72										
Ortho-P, D						0.64								
Dissolved Oxygen, W			-0.79	-0.89	-0.61	-0.63				0.71			-0.67	-0.67
Dissolved Oxygen, D			-0.61	-0.71	-0.61	-0.63	-0.7			0.61	-0.7	-0.69		
Conductivity, W	0.61	0.61			0.72	0.64					0.69			
Conductivity, D						0.75	0.61					0.84		
Chloride, W														
Chloride, D												0.81		

Notes:

(1) W=wet season, D=dry season
(2) n=11 for all coefficients
(3) $p < 0.05$ for all coefficients

Appendix M Spearman Rank Correlation Coefficients for Canadian Portion of Sumas Watershed Water Quality vs. Soil Indices by Contributing Area (continued)

PARENT MATERIAL

	Very poor- total area	Very poor- %	Outwash- %	Alluvium- total area	Alluvium- %	Glacio-Fluvial- total area	Glacio-Fluvial- %	Lacustrine total area	Lacustrine %	Organic- total area	Organic- %
Ammonia-N, W (1)								0.63			
Ammonia-N, D											
Nitrate-N, W	0.73	0.82								0.67	0.67
Nitrate-N, D	0.72	0.83								0.67	0.67
Ortho-P, W											
Ortho-P, D											
Dissolved Oxygen, W								-0.61	-0.67		
Dissolved Oxygen, D											
Conductivity, W				0.63							
Conductivity, D					0.71						
Chloride, W											
Chloride, D			-0.67		0.74	-0.72	-0.72				

Appendix M **Significant Relationships by Spearman Rank Correlation for Canadian Portion of Sumas Watershed**
Landuse Indices vs. Soil Indices by Contributing Area

	SURFACE TEXTURE												SUBSURFACE TEXTURE				
	Organic- total area	Organic- %	Clay- total area	Clay- %	Loam- total area	Loam- %	Silt- total area	Silt- %	Sand- total area	Sand- %	Gravel- toal area	Gravel- %	Organic- total area	Organic- %	Clay- total area	Clay- %	Loam- total area
Surplus N					+		+				-						+
Surplus N/farmed ha					+	+					-					+	
Surplus N/cropped ha					+	+					-					+	
AUE total					+		+				-				+		+
AUE/farmed ha						+					-					+	
poultry #																	
pig #					+	+						-			+		
cow #					+		+				-				+		+
farm #					+		+										+
Agricultural Area - total					+		+										+
Agricultural Area - %														+			
Forest Area - total			+	+													
Forest Area - %				+													
No Activity Perceived Area - total	+	+					+								+		
No Activity Perceived Area - %	+	+															
Park/Recreation/Wetlands Area - total									+	+							
Park/Recreation/Wetlands Area - %									+	+	-	-					
Residential Area - total	+	+					+										
Residential Area - %	+	+					+										
Industrial/Commericial Area total							+										
Industrial/Commericial Area %																	

Appendix M

Significant Relationships by Spearman Rank Correlation for Canadian Portion of Sumas Watershed
Landuse Indices vs. Soil Indices by Contributing Area (continued)

								DRAINAGE									
	Loam- %	Silt- total area	Silt- %	Sand- total area	Sand- %	Gravel- total area	Gravel- %	Well- total area	Well- %	Mod. Well total area	Mod. Well %	Imperfect- total area	Imperfect- %	Poor- total area	Poor- %	Very poor- total area	Very poor- %
Surplus N				+								+		+	+		
Surplus N/farmed ha						-	-		-			+	+	+	+		
Surplus N/cropped ha						-	-		-			+	+	+	+		
AUE total				+								+	+	+	+		
AUE/farmed ha						-	-	-	-				+		+		
poultry #				+													
pig #																	
cow #				+													
farm #				+								+		+			
Agricultural Area - total				+								+		+			
Agricultural Area - %							-		-		-		+		+		
Forest Area - total		+								+	+						
Forest Area - %							+				+		-		-		
No Activity Perceived Area - total				+						+						+	
No Activity Perceived Area - %																	
Park/Recreation/Wetlands Area - total		+															
Park/Recreation/Wetlands Area - %		+				+	+	+	+							+	
Residential Area - total				+						+							
Residential Area - %				+													
Industrial/Commericial Area total																	
Industrial/Commericial Area %																	

Appendix M

Significant Relationships by Spearman Rank Correlation for Canadian Portion of Sumas Watershed
Landuse Indices vs. Soil Indices by Contributing Area (continued)

PARENT MATERIAL

	Colluvium-total area	Colluvium-%	Outwash-total area	Outwash-%	Alluvium-total area	Alluvium-%	Glacio-Flu total area	Glacio-Flu %	Lacustrine total area	Lacustrine %	Glacial Till total area	Glacial Till %	Organic-total area	Organic-%
Surplus N					+				+					
Surplus N/farmed ha									+	+				
Surplus N/cropped ha									+	+				
AUE total					+									
AUE/farmed ha						+				+	-	-		
poultry #														
pig #														
cow #														
farm #					+				+					
Agricultural Area - total					+				+					
Agricultural Area - %			-	-		+				+	-	-		
Forest Area - total	+	+									+	+		
Forest Area - %	+	+								-	+	+		
No Activity Perceived Area - total													+	+
No Activity Perceived Area - %													+	+
Park/Recreation/Wetlands Area - total														
Park/Recreation/Wetlands Area - %														
Residential Area - total													+	+
Residential Area - %													+	+
Industrial/Commericial Area total			+	+			+	+					+	+
Industrial/Commericial Area %			+	+			+	+					+	+

Appendix M Spearman Rank Correlation Coefficients
Water Quality vs. Water Quality by Contributing Area

	Ammonia-N, W (1)	Ammonia-N, D	Nitrate-N, W	Nitrate-N, D	Ortho-P, W	Ortho-P, D	Dissolved Oxygen, W	Dissolved Oxygen, D	Conductivity, W	Conductivity, D	Chloride, W	Chloride, D
Ammonia-N, W (1)					0.87		-0.76	-0.80				
Ammonia-N, D			0.60			0.63						
Nitrate-N, W		0.64		0.60					0.59			
Nitrate-N, D			0.75									
Ortho-P, W	0.80						-0.68	-0.80				
Ortho-P, D		0.66										0.80
Dissolved Oxygen, W	-0.72				-0.65			0.58				
Dissolved Oxygen, D	-0.87				-0.75		0.71					
Conductivity, W										0.71		
Conductivity, D		0.63				0.75		-0.64	0.62			0.56
Chloride, W						0.62						
Chloride, D						0.77				0.92		

(1) W=wet season, D=dry season
(2) Bottom left: Canadian portion analysis; Top right: Whole watershed analysis