IMPACTS OF URBAN HILLSLOPE DEVELOPMENT AND AGRICULTURE ON HYDROLOGY AND WATER QUALITY IN THE CHILLIWACK CREEK WATERSHED, BRITISH COLUMBIA

by

JENNIFER RAE MACDONALD

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ABSTRACT

The Lower Fraser Valley (LFV) has one of the most rapidly growing urban populations in Canada, and as a result water pollution problems associated with non-point source (NPS) pollution from urban expansion and agricultural intensification are increasing rapidly in this region. At the same time, the increasing demand for housing combined with the protection of agricultural land in the valley has pushed development onto the hillslopes. The transition from natural forest cover to impervious surfaces alters the hydrologic system, and increases the rate and volume of stormwater runoff that reaches the receiving watercourses. Due to the sensitivity of hillslope environments, and because upland activities may have damaging consequences downstream, development on these hillslopes presents many unique challenges for stormwater management.

This research project uses a watershed approach to examine the impacts of land use (agriculture and urban development) on hydrological processes and surface water quality in a mixed land use setting. In Chilliwack, forest land on the hillslope is being converted into urban developments, and plans are under way to house up to 50,000 people on the hillslopes in Chilliwack over the next 25 years. The impact of this conversion on hydrology and water quality was examined in streams draining recently completed urban development (up to 2000 houses) by comparing the results with streams originating from undisturbed forested land.

Using samples collected at twenty stations, a baseline was established for water quality and trace metals in sediments for various sub-watersheds in the study area. These results indicate that the lowland agricultural activities are the major source of NPS pollution in the watershed. Nutrient levels are elevated during the wet season, and many of the agricultural tributaries show evidence of eutrophication in the summer season. Trace metals associated with agricultural operations (Cu, Fe, Mn, Cd and Zn) were also elevated in the sediment of agricultural streams. Spatially, ammonia, orthophosphate and trace metals increased in the downstream direction along Interception Ditch (a large agricultural drainage ditch) indicating the effects may be cumulative.

Results from the hillslope urban sites indicated that the hydrologic impacts of the development are the most important at this stage. Peak runoff was shown to be up to 1416% higher and lag times were up to 30 hours shorter in the suburban hillslope catchment (26% TIA) than for the forested catchment (4% TIA). While the impact on water and sediment quality was minimal, concentrations of orthophosphate, dissolved magnesium and potassium did show significantly elevated concentrations compared to the forested tributaries.

Currently, the City of Chilliwack is experimenting with a number of innovative stormwater management designs (e.g. on-site detention ponds, infiltration galleries) in attempts to infiltrate much of the stormwater into the soil in these hillslope developments, before it reaches the streams. It is suggested that incorporating these low impact designs and source control methods may be more effective at mitigating the impacts of development than conventional stormwater management systems.

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ABBREVIATIONS

Places and Institutions

B.C.	British Columbia
BCMELP	British Colombia Ministry of Environment, Lands and Parks
DFO	Department of Fisheries and Oceans
EC	Environment Canada
EPA	Environmental Protection Agency
FRAP	Fraser River Action Plan
FVRD	Fraser Valley Regional District
GVRD	Greater Vancouver Regional District
LFV	Lower Fraser Valley
MWLAP	Ministry of Water Land and Air Protection

Chemical Symbols and Formulas

Al	Aluminum
Ca	Calcium
Cd	Cadmium
Co	Cobalt
Cr	Chromium
Cu	Copper
Fe	Iron
K	Potassium
Mg	Magnesium
Mn	Manganese
Na	Sodium
Ni	Nickel
P	Phosphorus
Pb	Lead
Zn	Zinc

Other Abbreviations

ALR	Agricultural Land Reserve
BAP	bio-available phosphorus
BMP	Best Management Practices
CV	coefficient of variation
DPS	degree of phosphorus saturation
DO	dissolved oxygen
EIA	effective impermeable area
GIS	Geographic Information System
HMP	hexametaphosphate
HOF	hortonian overland flow
ICP-AES	Inductively Coupled Plasma – Atomic Emission Spectrometry
IQR	interquartile range
ISQG	interim sediment quality guidelines
IR	infrared
LID	low impact development
MAC	maximum acceptable concentration
MAR	mean annual daily rainfall
MIT	minimum interevent time
MMT	methylcyclopentadienyl manganese tricarbonyl
NPS	non-point source
OCP	Official Community Plan
PEL	probable effect level
SEL	severe effect level
SOF	saturated overland flow
TEL	tetraethyl lead
TIA	total impervious area
TIN	triangular irregular network
TP	total phosphorus
WBM	Water Balance Model
YSI	Yellow Springs Instrument

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1 INTRODUCTION

Our water resources are greatly affected by human activities. Alteration of the land surface for a variety of uses has induced changes to natural processes, modified water pathways and led to the deterioration of watercourses throughout the world (Peters et al., 1997). The Lower Fraser Valley (LFV) in British Columbia has some of the most productive agricultural land in Canada. It also has a rapidly growing urban population. As a result, water pollution problems associated with non-point source pollution (NPS) from urban expansion and agricultural intensification are increasing rapidly in this region. In addition, as impervious surfaces replace natural land cover, the changes in the hydrologic system increase stormwater runoff. In order to properly manage and protect aquatic systems it is important to have a clear understanding of the impacts of this land use intensification on water resources at the watershed level.

Land use trends and ongoing concerns in the Chilliwack Creek watershed are representative of what is happening in the LFV: urban expansion into the forested hillslopes, agricultural intensification in the lowland and aquatic degradation due to NPS pollution and cumulative effects. The land use distribution of the Chilliwack Creek watershed provides an excellent opportunity to investigate water management issues in a mixed land use setting. Although watersheds are increasingly managed under the concept of multiple uses, studies concerning the effect of land use on water quality, even in mixed land use watersheds, generally focus on investigating the impact of only a single type of land use. Research on the interaction between, or the cumulative effects of multiple land use activities, distributed in both time and space, is rare (Sidle and Hornbeck, 1991). Evidence is increasing that the combined effects of several land use activities may have more devastating effects on water quality than the impact of individual land uses (Sidle and Sharpley, 1991; MacDonald, 2000). Furthermore, upland activities may interact with natural processes and/or other land use effects and have damaging consequences downstream.

With Chilliwack's population expected to nearly double by 2025 and the protection of agricultural land in the valley, there is a demand to convert the forested upland area into residential housing. While the negative impacts of watershed urbanization on streams have been well documented, there have been very few investigations on the specific case of hillslope urbanization in the LFV. Hillslopes are sensitive environments and there is a greater potential for downstream impacts such as flooding, and an increased risk of slope instability when they are developed. For this reason, conventional stormwater management practices, which are designed to remove runoff from impervious surfaces as efficiently as possible and which deliver stormwater to receiving waters much faster and in greater volumes than natural conditions, may not be adequate to mitigate the effects of development in hillslope areas.

Currently, the City of Chilliwack is experimenting with a number of innovative stormwater management designs (e.g. detention ponds, on-site infiltration galleries) in an attempt to infiltrate much of the stormwater into the soils in these hillslope developments before it reaches the streams. The collection of baseline data during pre-development and in the early stages of urbanization will allow for comparison with data collected in later years to evaluate the effectiveness of this new stormwater management policy, and suggest modifications if necessary.

1.1 Study Goals and Objectives

The research project will use a watershed approach to examine impacts of land use (agriculture and urban hillslope development) on hydrological processes and surface water quality in a mixed land use setting. Forest land on the hillslope is being converted into suburban residential developments, and plans are under way to house up to 50,000 people on the hillslopes in Chilliwack over the next 25 years. As development of the hillslopes progresses, it will become increasingly important to better understand the hydrological effects and pollutant loadings of these urban hillslope systems, and in turn how best to mitigate these negative impacts. To provide information how hillslope developments in the LFV will impact hydrology and water quality, this study compares data collected in streams draining a new urban hillslope development (up to 2000 houses) with data collected in streams originating from undisturbed forested land. At the same time, the impact from these two upland land uses on the agricultural lowland will be investigated.

The specific objectives of the study are:

1) To establish baseline information for the watershed in terms of streamflow, land use, sediment and water quality, which is an essential pre-requisite for future impact assessment of the continuing urban hillslope development;
2) To investigate how the recent hillslope urbanization has altered streamflow response to different storm events, using the forested hillslope as a control;
3) To determine seasonal and spatial variability in water and sediment quality in the watershed, and compare the surface water and sediment quality of small streams draining undisturbed upland forest, recently competed residential developments in the same physical setting, and agricultural streams in the lowland;
4) To investigate how cumulative impacts of the different land use activities propagate along the mainstem downstream, and to determine whether the upstream urbanization is affecting downstream water quality;
5) To compare the use of buffers versus contributing areas for examining the relationships between land use indices and water/sediment quality in a mixed land use setting.

2 LITERATURE REVIEW

Trends in the Lower Fraser Valley (LFV), and elsewhere in North America, suggest that agricultural activities are intensifying and that urban areas are continuing to expand to support the constantly growing populations. As the landscape is altered new stresses are place on the aquatic systems from both contaminant inputs and hydrologic changes. Both agricultural and urban areas have been recognized as important sources of runoff and non-point source (NPS) pollution (Leopold, 1968; Choe et al., 2002; Sharpley et al., 1994). Runoff from agricultural land was identified as the primary cause of water quality problems in over 40% of surveyed rivers in the United States (EPA, 2002a). Contaminated stormwater runoff is recognized as a leading source of water quality problems in urban settings; however the hydrologic impacts from urbanization can often be more harmful than the pollutants it carries (BCMELP, 1992). This chapter provides some background information on the issues of agricultural and urban NPS pollution, as well as the hydrologic changes that result from urbanization.

2.1 Agricultural Non-Point Source Pollution

In Canada, modern agricultural practices have been developed to produce a higher yield from a smaller land base resulting from greater inputs of fertilizer and pesticides. Furthermore, over the years there has been a steady increase in the livestock population coupled with a decrease in the number of livestock farms (Statistics Canada, 2002; Smith, 2004). For instance, in the LFV the number of dairy cows has increased by 70% over the last 10 years, and the area now has the largest number of dairy cows per farm in Canada. The increased number of chickens per farm has been particularly dramatic, with a 52% increase between 1996 and 2001 (Schreier et al., 2004). In areas of intensive agricultural production, the higher inputs of fertilizer and manure applied to the land often exceed the crop requirements and the ability of the soil to assimilate it (Zebarth et al., 1999; Chadwick and Chen, 2002; Schreier et al., 2004). This is particularly problematic in areas where the spreading of manure is used as a means for disposal. Inadequate storage capacities often result in manure applications at times when there is low crop demand, for example in the late fall when high rainfall exacerbates the risk of surface water contamination. A recent study of the LFV region analyzed nutrient dynamics in agricultural systems in order to determine areas of excess nutrient applications. It was determined that 65% of the areas in the LFV had surplus nitrogen in excess of 100 kg/ha/year and phosphorus surplus applications were in excess of 50 kg/ha/year. (Schreier et al., 2004). This condition can result in an increase in nutrient/contaminant loss in runoff that may then contribute to eutrophication and contamination of the receiving waterways.

The transfer of pollutants from fields to surface water may occur as direct runoff, or by infiltration through the root zone and discharge as seepage of subsurface flow. The extent to which pollutants are transferred from fields to surface and groundwater is influenced by chemical speciation, availability to crops, soil properties, and factors controlling hydrologic processes (topography, drainage characteristics, climate) in addition to land management practices such as manure and fertilizer application rates, timing and method of application, and the time interval between applications (Muhammetoglu et al., 2002; Gburek et al., 2000; Sharpley et al., 1994). For example, if manure is spread over the soil surface rather than incorporated through tillage, particularly if heavy rainfall occurs within a few days of application, the risk of surface and groundwater contamination increases (Daniel et al., 1994; Giting et al., 1998). Soil-bound pollutants (e.g. ammonia, phosphorus, trace metals) are generally lost through surface runoff. Higher losses occur in areas with a reduced soil infiltration capacity, steeper topography, increased concentrations at the soil surface, and a limited riparian zone. For more soluble contaminants (such as nitrate) the factors which enhance water pollution include high fertilizer or manure application rates, cropping systems with low uptake efficiency, and tile drainage systems (Nielsen et al., 1982; Zebarth et al., 1999).

This study focuses on nutrients and trace metal contamination; however there are a number of other contaminants that can contribute to agricultural non-point source pollution of waterways such as soil/sediment particles, pathogens, pesticides, fertilizers, hormones and antibiotic residues. A more detailed discussion of the chemistry, potential sources and the environmental impacts of nutrient and trace metals in aquatic systems is found in Chapter 7.

2.2 Impacts of Urbanization

2.2.1 Hydrological Characteristics of Stormwater Runoff

In undeveloped areas, such as forested hillslopes, rainwater is stored in surface depressions or absorbed by soil and vegetation though various environmental processes including evapotranspitration (ET) and infiltration. Hewlett (1982) states that the majority of precipitation (up to 70% in temperate regions) leaves as evaporation. Precipitation that infiltrates the soil surface travels through the soil as either shallow *subsurface flow* or deep seepage that replenishes groundwater (Ziemer and Lisle, 1998). This groundwater storage ultimately maintains baseflow during dry periods. Because infiltration capacities of natural systems are generally high due to the high organic matter content and the activity of microorganisms which create an open soil structure (Dunne and Leopold, 1978), subsurface flow accounts for nearly all the water that is delivered to the stream channel (Harr, 1977). This water moves very slowly and only those parts of the catchment located near the stream itself generally contribute to stormflow (Booth, 2000). During a rainfall event, the water table rises and soils can become saturated increasing the area contributing to rapid stormflow. In these saturated areas subsurface flow emerges as return flow; this and any additional rainfall runs off as saturated overland flow (SOF). Zones of SOF generally occupy small areas which expand during wet periods – a phenomenon known as the variable source area concept of storm runoff (Dunne and Leopold, 1978; Zeimer and Lisle, 1998; Booth, 2000). These areas generally occur where shallow subsurface flow converges in topographic depressions or accumulates in areas of decreasing hillslope gradient (e.g. in valleys near the stream channel). The size of these saturated areas influences the amount of stormflow that is generated. Hortonian overland flow (HOF), which occurs when rainfall falls on the land surface more rapidly than the soil can absorb it causing the excess rainfall to run over the land surface, is another mechanism by which stormflow can occur. Water from HOF flows above ground at substantially higher rates than subsurface flow; however, because infiltration rates generally exceed rainfall intensities in the Pacific coastal region, HOF does not generally occur in undeveloped forest areas (Zeimer and Lisle, 1998). When the landscape is altered, the type and magnitude of runoff processes are changed.

As urban development progresses, the catchment surface undergoes a transformation from pervious to impervious as vegetation is cleared, soil is compacted and the land is graded, and impervious buildings and streets are constructed. These changes reduce interception, evapotranspiration, and the water storage capacity of the land (Savini and Kammerer, 1961; Burges et al., 1998; Konrad and Booth, 2002). The major change influencing runoff processes results from covering parts of the land surface with impervious surfaces (e.g. roofs, sidewalk, streets, and parking lots). This reduces the infiltration capacity of these areas to zero and converts what was once subsurface flow directly to HOF, accelerating stormwater runoff to ditches and streams following storm events – even for the short, low intensity storms which would generally not produce runoff under natural conditions. Consequently, the precipitation that falls reaches the stream within a few minutes, instead of what had been a delay of hours to days. This, in turn, increases the severity of flooding – with increases in the volume of runoff and the magnitude of peak flow (Carter, 1961; Leopold, 1968; Arnold and Gibbons, 1996; Konrad and Booth, 2002). While these effects are seen during both small, frequently occurring events and large, infrequent events, they are generally most pronounced during the smaller events (Schueler, 1994). These effects of urbanization are further exacerbated by the higher efficiency of water transport to stream channels provided by stormwater drainage pipes (Walsh, 2000; Arnold and Gibbons; 1996). Flooding is particularly problematic where urbanization is occurring in upland areas as the generation of stormwater can significantly alter the flow regime in the entire watercourse downstream. The decreased infiltration also reduces groundwater recharge, which not only threatens water supplies but reduces the groundwater available to supply baseflow – thus lowering low flows during dry weather. (Arnold and Gibbons, 1996, Dunne and Leopold, 1978).

The hydrologic consequences of urban development have deleterious effects on the receiving waterways, and often lead to wider, straighter channels and scouring of the stream bed as the stream tries to deal with the additional flow (Schueler, 1992; Booth, 1990). The enhanced runoff and more frequent flooding also cause erosion from construction sites and of stream banks and channels (Arnold and Gibbons, 1996). Furthermore, the prevalence of large woody debris, which has long been recognized as a key factor in creating complex channel conditions and habitat diversity, has been shown to decline with urbanization (Stephens et al., 2003; Horner, 1998). These factors, in turn, reduce the diversity and availability of in-stream habitat – as pool and riffle sequences and overhead cover are lost, and the streambed is covered by a uniform blanket of eroded sand and silt from the sediment loaded runoff (Schueler, 1992; Arnold and Gibbons, 1996; Walsh, 2000). Engineering responses to flooding (e.g. stream diversions, channelization, damming, culverts and piping) further destroy stream beds and related habitat (Arnold and Gibbons, 1996). Finally, the reduction in tree cover surrounding the stream results in water temperature fluctuations, which will stress fish (Arnold and Gibbons, 1996).

2.2.2 Urban Runoff Water Quality

The urbanization-induced hydrological changes also have the potential to cause significant water quality problems in the local receiving waters. Stormwater runoff exhibits degraded water quality as it picks up pollutants that have accumulated on impervious surfaces, which are then transported directly to streams. Moreover, the decrease in infiltration reduces filtration of pollutants through soil and the uptake by plants, thereby further increasing the pollutant load entering the receiving waters. The highest pollutant loads are usually seen during the initial periods of stormwater runoff - a phenomenon known as the 'first flush' (Lee et al., 2002). These pollutants pose a toxicity risk to aquatic organisms, particularly in the summer when low flows have been substantially reduced due to reduced groundwater recharge.

Constituents in urban stormwater runoff include suspended solids, bacteria, heavy metals, nutrients, pathogens, pesticides, organic matter, oils and grease; and they are derived from various sources. Paved areas such as highways and streets in urban areas are considered "stormwater intensive" land uses since they are highly impervious, and accumulate pollutants from vehicular activity (e.g. tire and break wear, vehicle emissions) (Marsalek et al., 1999). About a third of all pervious areas (e.g. lawns, parks) in the urban landscape receive high rates of irrigation, fertilizers and insecticide applications (Schueler, 1995). Because these pervious areas are frequently interlaced with impervious surfaces these pollutants often migrate to the impervious areas, which increase their potential to end up in nearby waterways. Lawn fertilizer, road dirt, soils, leaf fall, grass clipping, animal wastes, and detergents were identified as the primary sources of phosphorus in urban and suburban settings (Washbusch et al., 1999). Erosion from construction sites is a significant source of sediment pollution in streams. On a unit area basis, construction sites export sediment at 20 to 1000 times the rate of other land uses (CWP, 2000).

2.2.3 Ecological Impacts of Urbanization in the Lower Fraser Valley

Both the hydrologic disruption and degradation of water quality associated with urban development can have significant ecological impacts. Urban sprawl has resulted in habitat loss and a decline in fish population in many of the small streams and wetlands in the LFV, which are critical spawning and rearing habitat for several salmonid species (BCMELP, 2000; Stephens et al., 2003; Slaney, 1996). In the LFV, 71% of streams are considered threatened or endangered, and a further 15% have been lost altogether as a result of urban growth (BCMELP, 2000; Stephens et al., 2003).

2.2.4 Imperviousness as an Environmental Indicator

Numerous studies have shown a link between impervious surface area and the degradation of aquatic systems, with strong correlations found between hydrology, loadings from NPS pollution, thermal pollution, habitat structure, and biological integrity and diversity (Schueler, 1992; Booth et al., 1993; Schueler, 1994; Arnold and Gibbons, 1996). Consequently, catchment imperviousness is often used as an environmental indicator of aquatic system degradation in urban areas. Schueler (1994) reviewed the various studies that related imperviousness to changes in aquatic systems and concluded that "this research, conducted in many geographic areas, concentrating on many different variables, and employing widely different methods, has yielded a surprisingly similar conclusion – stream degradation occurs at relatively low levels of imperviousness (~10%)". While stream degradation begins at 10% imperviousness, it becomes completely degraded above the 30% threshold (Schueler, 1994; Arnold and Gibbons, 1996). A study in the Puget Sound region of Washington State found that water quality impacts were less important than hydrological or riparian zones changes in the degradation of stream health. It was determined that the impacts of poor water quality and concentrations of metals in sediments did not show significant impact on aquatic biological communities until above 50% total impervious surface area.

2.3 Stormwater Management

2.3.1 History of Stormwater Management

Proper management of stormwater runoff is a key component of protecting property, water quality and aquatic ecosystems. Traditionally, stormwater management has been achieved through engineered drainage systems in which a series of gutters, drains and storm sewers collect rainwater from roads and transport it though pipes into nearby streams. The main goal is to remove runoff as quickly as possible from developed areas to prevent on-site flooding. In the early 1970s, the use of stormwater detention ponds was introduced as an additional method of detaining water in order to reduce peak flows in receiving waters. Detention ponds consist of a storage area into which stormwater runoff is directed and then released gradually through a constricted outlet pipe. Detention ponds also have the additional benefit of providing some treatment of contaminated stormwater runoff through adsorption of contaminants to sediments, sedimentation, plant uptake and microbial processes (Pettersson, 1998). However, neither of these approaches fully prevents aquatic degradation or flooding risks. For example, while detention ponds slow down the water and reduce peak runoff rates, they do not reduce the total runoff volume. Instead, the total volume is spread out over a longer period of time, which can result in erosive streamflow over longer periods of time (Stephens et al., 2002).

As stormwater runoff in the Lower Fraser Valley becomes more problematic as urban areas expand onto the surrounding hillslopes, municipalities are starting to change the way in which they approach stormwater management. Instead of piping water directly to streams, Chilliwack and other municipalities in the Greater Vancouver Regional District (GVRD) are making an effort to incorporate low impact development (LID) practices and source control alternatives to mitigate effects of stormwater runoff. These low impact and source control alternatives are discussed in the next section.

2.3.2 Low Impact Development (LID) and Source Control Measures

Catchment imperviousness and the design of drainage infrastructure are the primary determinants of the quantity and quality of urban stormwater runoff delivered to receiving streams. Low impact development is a new approach to land planning which uses certain source control technologies and design practices to ensure that a site's post development hydrologic functions mimic those in its pre-development state (Nataluk and Dooley, 2003). Some of the basic principles include: 1) preserving the natural evapotranspiration capacity through conservation, landscaping and green roofs; 2) using designs that limit the creation of impervious areas; 3) incorporating source control strategies that preserve natural infiltration capacity by infiltrating rainfall near the source; and 4) re-using rainwater for irrigation and for indoor uses.

As previously mentioned, the amount of impervious surface area in a catchment has been linked to flooding and stream degradation. Therefore, limiting the impervious coverage can reduce runoff and partially mitigate these problems. There are many strategies which could be used to reduce the amount of impervious surface areas when designing new residential developments. Stone et al. (2004) suggest that the most effective approach to reducing the area of residential impervious surfaces is to decrease lot size. For example, it was shown that a reduction in the average lot size of new development from 4000 to 2000 m^2, a reduction in the frontage from 21 to 15 m, and a reduction in the front yard setback from 12 to 8 m would reduce total parcel impervious area by approximately 30%. Designing residential areas with narrower streets and street designs which reduce the size and number of intersections would also help decrease the volume of stormwater runoff as streets are a significant portion of the impervious surface within residential subdivisions (Stone, 2004). It has been estimated that the elimination of parking on one side of the street can reduce stormwater runoff by 25 percent (CWP, 1998). Other practices include shared driveways, use of alternative/pervious pavements, and center islands in cul-de-sacs. *Permeable pavement* is an alternative to the common asphalt pavement. There are several types of porous paving materials, through which up to 80% of intercepted stormwater can infiltrate (Brattebo and Booth, 2003). These pavements tend to function better in low traffic areas such as parking lots, driveways and sidewalks since they are easily clogged, impeding their performance. Maintenance requires annual high powered vacuuming of the area to remove sediments (Nataluk and Dooley, 2003).

However, implementing these urban design practices that reduce impervious coverage is not enough to protect downstream watercourses, since low levels of impervious coverage (10%) can cause significant damage (CH2MHill, 2002b). Source control measures provide a means to further reduce the runoff volume from impervious surfaces, as well as improve the quality of stormwater before it reaches the stream. These options can be implemented on a small site scale and are generally designed to capture and infiltrate small storm events and the first portion of larger storms on site, thereby reducing the volume of overland runoff. In terms of water quality, the first flush of pollutants that gets washed off the impervious surfaces at the beginning of rainfall events will be filtered and receive some treatment as they infiltrate into the ground. Some of the structural and non-structural options that can be implemented on a small site scale are described below.

Lawns and landscaped areas have reduced infiltration capacity as the surface soils layers are often removed and heavily compacted, and replaced by a thin layer (often less than 50 mm) of imported topsoil. Runoff from these pervious areas can be virtually eliminated by providing 300 mm layer of landscaped absorbent soil, even where the hydrologic conductivity of the underlying soil is low (CH2MHill, 2002b).

Re-directing runoff from impervious surfaces to areas where it can infiltrate (generally near the source) is another method by which stormwater runoff can be reduced. The effectiveness of the method will vary significantly depending on the type of surface over which the runoff is dispersed (CH2MHill, 2002b), and can be enhanced by creating infiltration facilities that are designed to retain runoff and provide time for water to infiltrate:

- *Infiltration galleries/trenches or soak-away pits* are excavated areas filled with aggregate material to hold water until it can infiltrate into the ground. They are generally designed to retain the first flush and have been shown to be effective at pollutant removal and recharging groundwater tables. Maintenance is important to avoid clogging and groundwater contamination can be a concern if proper studies are not undertaken prior to implementation (Brydon, 2004; Shammaa et al., 2001). *Exfiltration galleries/trenches* function in a similar manner except that once the water has filtered though the soil media it is collected in an underlying drain system and conveyed to the stormwater system (Nataluk and Dooley, 2003).

- *Bioretention areas* are shallow depressions that are filled with soil and vegetation to promote infiltration, evapotranspiration, filtration and uptake of nutrients and other pollutants (EPA, 2000). The planting soils used contain some clay which adsorbs pollutants such as hydrocarbons, heavy metals and nutrients. Often an organic layer is included to promote the degradation of petroleum based pollutants through the action of microorganisms. The nutrients and metals will eventually lower the cation exchange capacity of the soils (its ability to absorb pollutant particles through ion attraction), and consequently, the soil needs to be replaced after 5 to 10 years (Nataluk and Dooley, 2003).

Infiltration galleries would be slightly more effective than a bioretention facility (of the same size) due to the higher storage capacity of gravel over absorbent soil. The effectiveness of these two systems could be enhanced by placing an infiltration chamber under the gallery or designing for surface ponding in a bioretention area, as both increase storage capacity (CH2MHill, 2002b).

Additional opportunities to manage stormwater exist as the water is conveyed to the stream. *Grass swales* are vegetated channels designed to convey water away from streets and structures and provide an effective replacement for the tradition curb and gutter system in residential subdivisions. They generally function as a mechanism to slow runoff and as filtration/infiltration tools. Often they are used to convey water to a subsequent infiltration or bioretention area and function as a pre-treatment mechanism that filters sediment from stormwater. In general, grass channels are most effective when flow depth is shallow and slow (EPA, 2000). Periodic mowing and removal of sediment are their main maintenance requirements. The performance of swales is dependent on not only channel length, but also longitudinal slope and the use of dams to slow flows and allow for greater infiltration (EPA, 2000). *Grass filter strips* can be used as pre-treatment devices to intercept stormwater and remove sediment before water enters infiltration devices. They are most effective on minimal slopes (<2%) and under shallow flow conditions (Nataluk and Dooley, 2003).

Stormwater runoff can also be avoided by redirecting rooftop runoff (that would normally be conveyed into gutter and storm sewers) onto vegetated areas such as grass swales, bioretention areas and French drains (excavated pits with aggregate stone). Alternatively, rainwater can be harvested in rain barrels or cisterns and later used in irrigation of lawns. This would have the added benefit of reducing municipal water consumption (Fergusson, 1998).

These smaller scale infiltration techniques can be implemented in combination, and in series, with stormwater detention ponds in order to maximize the opportunities to mitigate stormwater runoff issues. In addition, there are several non-structural Best Management Practices (BMP) that can increase the effectiveness of stormwater management. These include reducing the use of contaminants (e.g. phosphate detergents, de-icing agents, and fertilizers), street sweeping, and maintenance of structural BMPs.

2.3.3 Effectiveness of Source Control Methods

The effectiveness of these source controls varies with their design, with precipitation patterns, and with soil type, among other factors (CH2MHill, 2002b). Currently, limited research has been conducted on the effectiveness of LID in retaining predevelopment hydrology and reducing pollutant loadings cause by stormwater runoff on developed sites. Still there are a few studies that have tried to analyze the effectiveness of various LID practices based on runoff and pollutant removal capabilities. Table 2.1 presents the contaminant removal efficiencies for various LID practices for several parameters. These results were originally presented in reports by Urbonas (2000) and EPA (2000), each of which draws data from various studies.

Table 2.1 Contaminant Removal Ranges in Percent for Several LID Practices

Type of LID	TSS	TP	TN	NH_4^+	NO_3^-	Zn	Pb	Cu	Fe	Mn
Porous Pavement	80-95	65	75-85	n/a	n/a	98	80	n/a	n/a	n/a
Grass lined swale	20-40	0-15	0-10	n/a	n/a	0-20	n/a	n/a	n/a	n/a
Grass Buffer Strip	10-20	0-15	0-15	n/a	n/a	0-20	n/a	n/a	n/a	n/a
Infiltration Basin	0-98	0-75	0-70	n/a	n/a	0-99	0-99	n/a	n/a	n/a
Biorentention systems	n/a	16-87	49-75	49-75	15-26	64-98	70-97	43-97	n/a	n/a
Asphalt w/ grass swale	n/a	(-94)	42	45	44	46	59	23	52	40
Permeable Pavement w/grass swale	91	3	9	85	66	75	85	81	92	92

Overall, the removal rates for metals were greater than the removal rates for nutrients. However, it can also be seen from Table 2.1 that there were wide ranges in the reported percent removals for metals. This is due to the variation in site conditions (terrain slopes, soil stability, detention time, incoming pollutant loads, soil condition, geology, local climate) and site-specific design details (Urbonas, 2000). Despite this, when properly designed for site local conditions it is very likely that these LID designs will remove pollutants from stormwater to some degree.

Less information was found on the effectiveness in terms of runoff. Sabouring (1999) showed that total runoff volumes from grassed swales were 6-30% less than conventional systems. Another study showed that a parking lot with swales and permeable pavement had 80-90% less runoff than basins without swales, and 60-80% less runoff than basins with concrete or asphalt and swales, for rainfall events less than 2 cm. There were fewer differences between pavement types during larger storms, but basins with swales still showed about 40% less runoff compared to basins without swales (Kuo et al., 1999).

The most appropriate source control options and design features for any given development (or re-development) site must be evaluated based on site specific conditions, such as soil type, land use type, rainfall, and groundwater characteristics (CH2MHill, 2002b). However, there appears to be limited scientific research on what variables affect the efficiency of the different designs, which LIDs function most effectively under what conditions, and how their performance will vary over time. The GVRD recently completed a study that attempted to answer some of these questions (CH2MHill, 2002b). To do this, they developed the Water Balance Model (WBM) , an "interactive model that can simulate the performance of impervious controls, absorbent landscaping, infiltration facilities, green roofs and rainwater harvesting under various development scenarios" (Stephens et al., 2003). Since then the model has been enhanced to make it more user-friendly with the goal that it can be used as a decision support tool to evaluate land use planning decisions and their ability to meet stormwater management objectives at both the individual development site and watershed scale (Stephens et al., 2003).

3 THE CHILLIWACK CREEK WATERSHED: DESCRIPTION OF THE STUDY AREA

This research project was conducted in the Chilliwack Creek watershed, located in the Lower Fraser Valley, British Columbia (B.C.). This watershed was chosen for the following reasons: it encompasses several different land uses, each of which has the potential to negatively impact water quality and alter hydrology; there had been no previous comprehensive survey of surface water quality within the watershed (what minimal sampling that had been done did not include the upland area where development is beginning); the issues in the watershed are representative of what is happening in the LFV (i.e. urban expansion on the hillslopes, agricultural intensification in the lowland, and aquatic degradation due to NPS pollution and cumulative effects); and finally, the distribution of agriculture, forest and urban land uses in the watershed allows for an assessment of upland-lowland interactions and cumulative effects. The watershed has a number of tributary streams that are dominated by each of the three land uses (urban, forest, and agriculture); the residential urban developments and forests dominate the upland portion of the watershed, while agriculture is dominant in the lowland. Water quality and the hydrologic response of the suburbanized section of the hillslope is used as an indication of what is likely to be experienced by the forested portion of the hillslope if it is developed using conventional designs.

This chapter will give a description of the study area with respect to its physical setting and climatic conditions, soils and geology, surface water and groundwater resources, and land use. An overview of the development that is currently underway and planned for the hillslopes in the Chilliwack area is also given. Finally, the innovative stormwater management approach Chilliwack is taking in order to address the issues and concerns of this hillslope development is outlined.

3.1 Physical Setting

The Chilliwack Creek watershed is located in the City of Chilliwack, approximately 100 km east of Vancouver. It is situated at the eastern end of the Fraser Valley Regional District (FVRD) with the Fraser River to the north and the Cascade mountains to the south. Figure 3.1 shows the study area with respect to the entire Chilliwack Creek watershed. Although the study area itself does not cover the entire Chilliwack Creek watershed, for simplicity it will be referred to as such throughout this thesis. The study area has a catchment area of 55.4 km^2 representing 65% of the entire watershed (84.7 km^2). Chilliwack Creek originates in Sardis and flows north through Chilliwack, eventually entering the Fraser River east of Chilliwack Mountain.

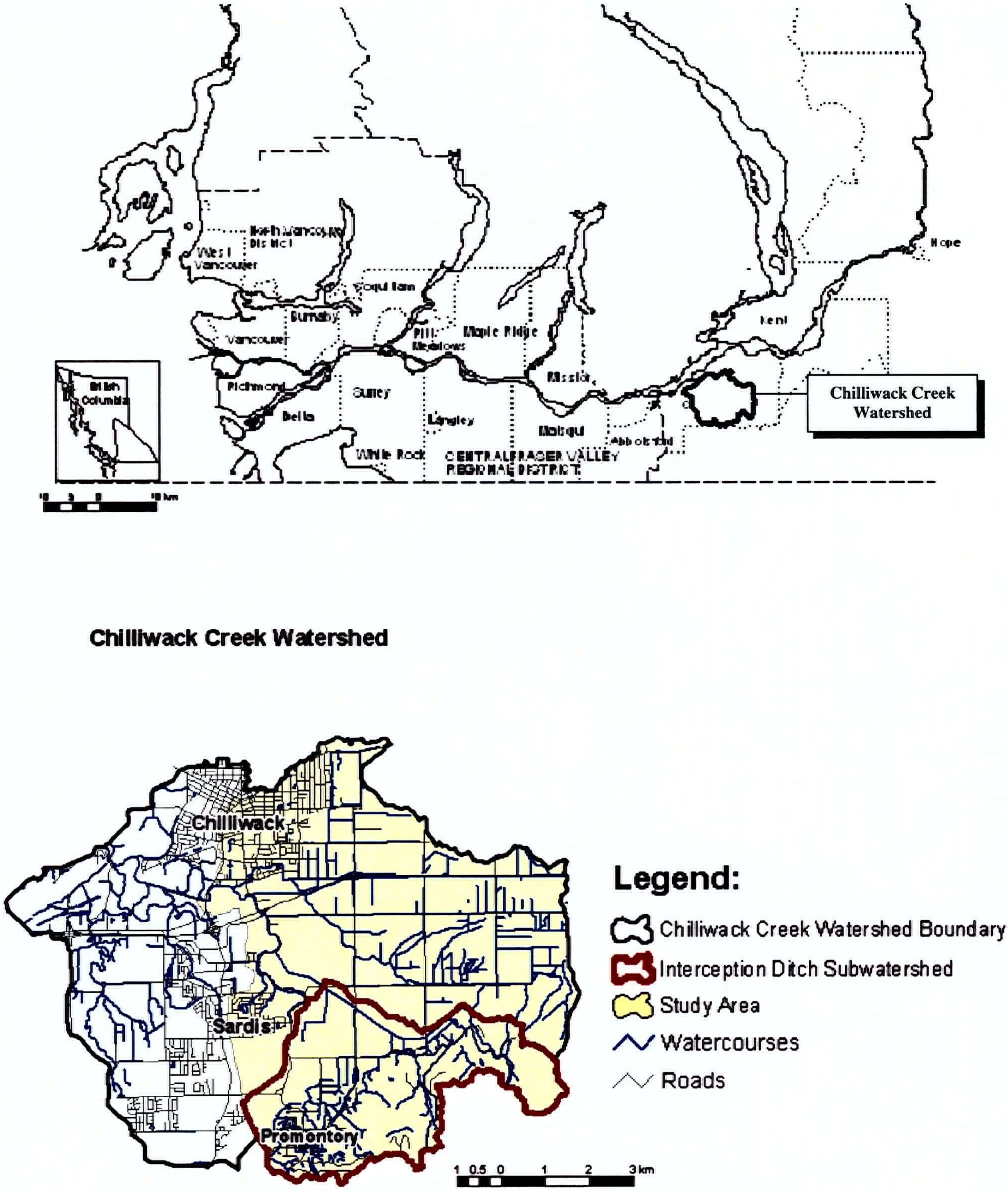


Figure 3.1 Location of the Chilliwack Creek Watershed within the Lower Fraser Valley, British Columbia

This study focuses primarily on a sub-catchment of the Chilliwack Creek watershed known as Interception Ditch (Figure 3.1). This sub-catchment can be divided into three somewhat distinct areas based on land use. The flat lands at the base of the hillslope are primarily agricultural, while the hillslope has both a forested area and a recently constructed urban area. The western end of the hillslope currently has a small residential development (Promontory) which is continuing to be developed, while the remaining hillslope is forested but is slated to be developed in the future. Water from all of these areas eventually drains into Interception Ditch, a large constructed drainage ditch, which flows into Chilliwack Creek.

3.1.1 Topography and Slope

The Chilliwack Creek watershed is comprised of the low-lying valley of the Fraser River floodplain (~10 masl), and the slopes of Mt. Thom (~480 masl) and Lookout Ridge (706 masl) as well as Ryder Lake Uplands (338 masl). The hillslope area has an average slope of 14°. However, some portions of the watershed are steeper with slopes of up to 62°. The transition zone between the hillslope and lowland valley is generally abrupt. This change in slope drastically changes the flow regime as fast flowing water from the hillsides is suddenly contained in the flat slower flowing ditches of the lowland. The lower velocities in the ditches result in lower flow capacities, and cause frequent flooding during heavier rainfall events. The topography of the watershed is depicted in Figure 3.2.

3.1.2 Geology and Soils

The surficial geology of the Chilliwack area is described and mapped by Armstrong (1980). The soils and surficial geology in the area can be divided into four regions:

- ***The hillsides (eastern section)*** are underlain by Mesozoic and upper Paleozoic sedimentary and metamorphic bedrock from the Pre-Tertiary era. In the eastern portion of the study area, this bedrock is overlain by thin (less than 2 m thick), medium-textured, glacial and eolian sediments. The Lonzo Creek soil series covers most of this region of the hillslope.

- ***The Promontory region*** of the hillslope is underlain by late Pleistocene Sumas drift (till and glacial-fluvial deposits) and is locally capped by up to several meters of loess. The depth to bedrock in this area commonly exceeds 30 m. Marble Hill, Abbotsford, and Ryder soils dominate this section of the hillslope.

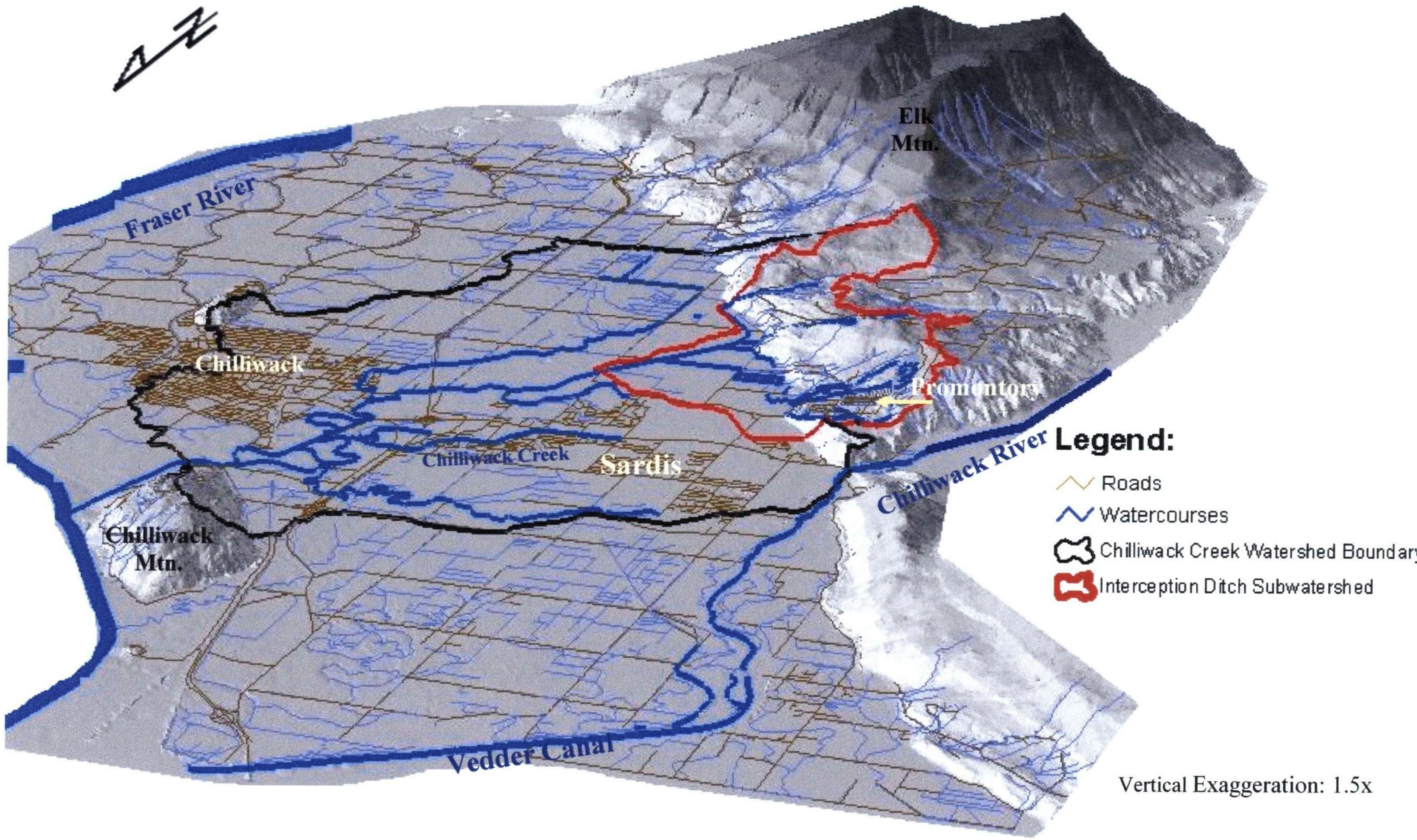


Figure 3.2 Topography of the Chilliwack Creek Watershed

- ***The floodplain*** consists of alluvial and floodplain sediments underlain by quaternary sand and gravel deposits that extend to depths of over 400 m (Monahan and Levson, 2003) Some of these floodplain deposits are derived from the Fraser River, and some are from the Chilliwack River during the post-glacial period. The floodplain soils derived from these deposits consist of laterally and vertically accreted silt loam and silty clay loams. Towards Chilliwack Creek medium-textured deposits from local streams become important, forming different soils: Lickman, Bates, and McElvee.

- ***The lowlands at the base of hillslope near Promontory (southwestern section)*** consists of gravel deposits from the alluvial fan where the Chilliwack/Vedder River enters the Fraser Lowland have prograded over older deposits in the Fraser River valley (Dakin, 1994). These deposits are over 35 m thick at the mountain front (Dakin, 1994). Sardis and Hopedale soils dominate this portion of the watershed.

A number of areas in the watershed, predominantly the area adjacent to the toe of the slope and sections of the floodplain, have experienced regular flooding in the past. In these areas, bog, swamp and shallow lake deposits (lowland peat, organic silt loam, silty clay loam) cover older floodplain deposits. These deposits form organic soils - primarily Annis soil and Banford muck.

A map of the surficial materials defined by geologic origin (parent material), dominant texture and drainage is shown in Figure 3.3. Figure 3.4 is a map depicting the distribution of soils types in the watershed. Table A.2 describes the some characteristics of the major soils in the study area (Appendix A).

3.1.3 Climate

The Chilliwack Creek watershed experiences a temperate climate, with cool dry summers and mild wet winters. In the winter, the Pacific westerlies bring in moist air and low pressure systems from the coast. As a result, about three quarters of the annual precipitation for the Lower Fraser Valley falls between October and March, and almost all of this falls as rain (Swain et al., 1997). During the summer, the presence of a high pressure system off the coast results in mostly clear skies and low rainfall. Summer storms are usually brief and intense. The months of July and August typically have the lowest amount of rainfall, and greatest evapotranspiration (Swain et al., 1997). As a result, little rainfall contributes to streamflow or replenishes groundwater during these months. The climate of the Chilliwack area is discussed further in Chapter 6.

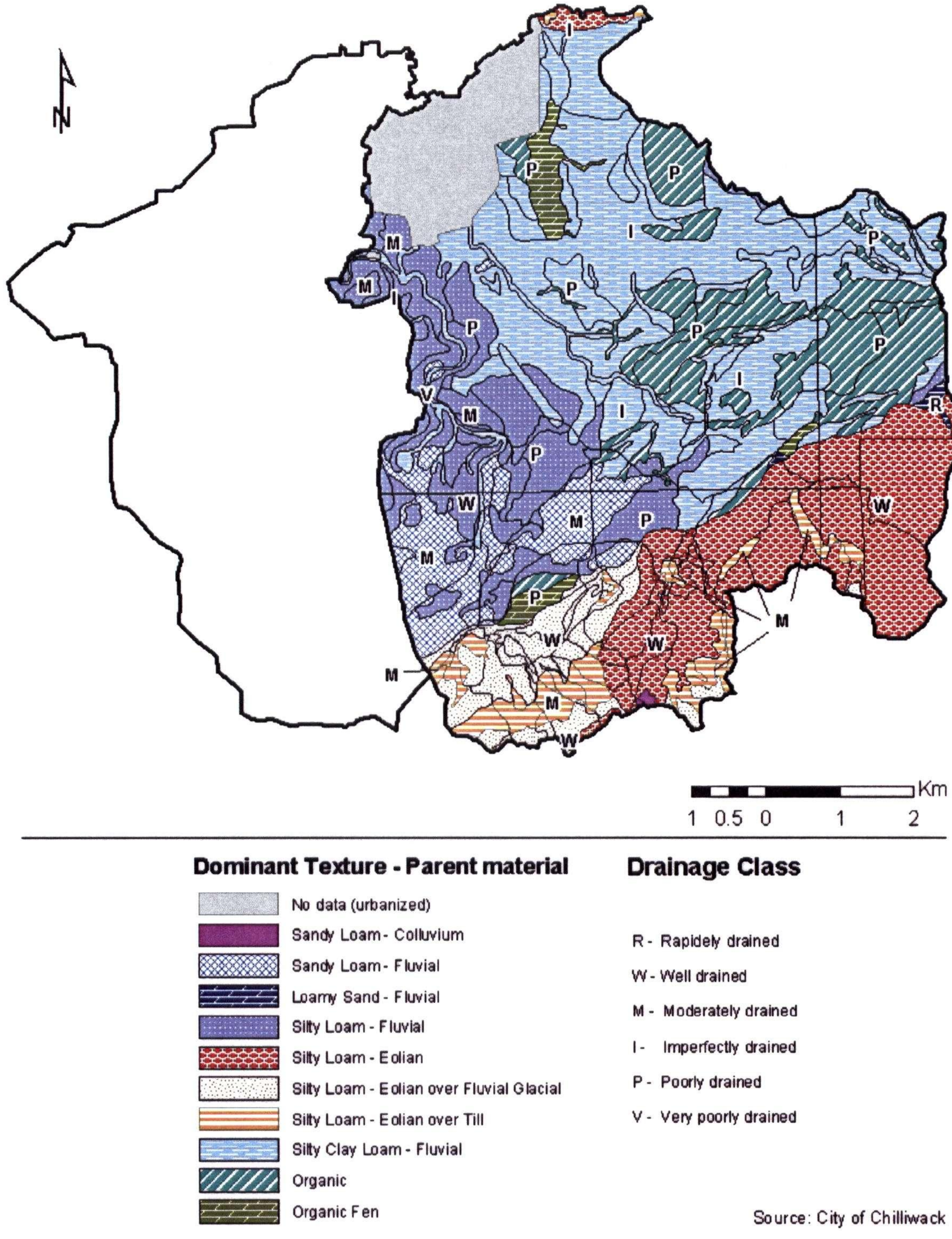


Figure 3.3 Surficial Geology for the Chilliwack Creek Watershed: Dominant Texture, Parent Material and Drainage Class

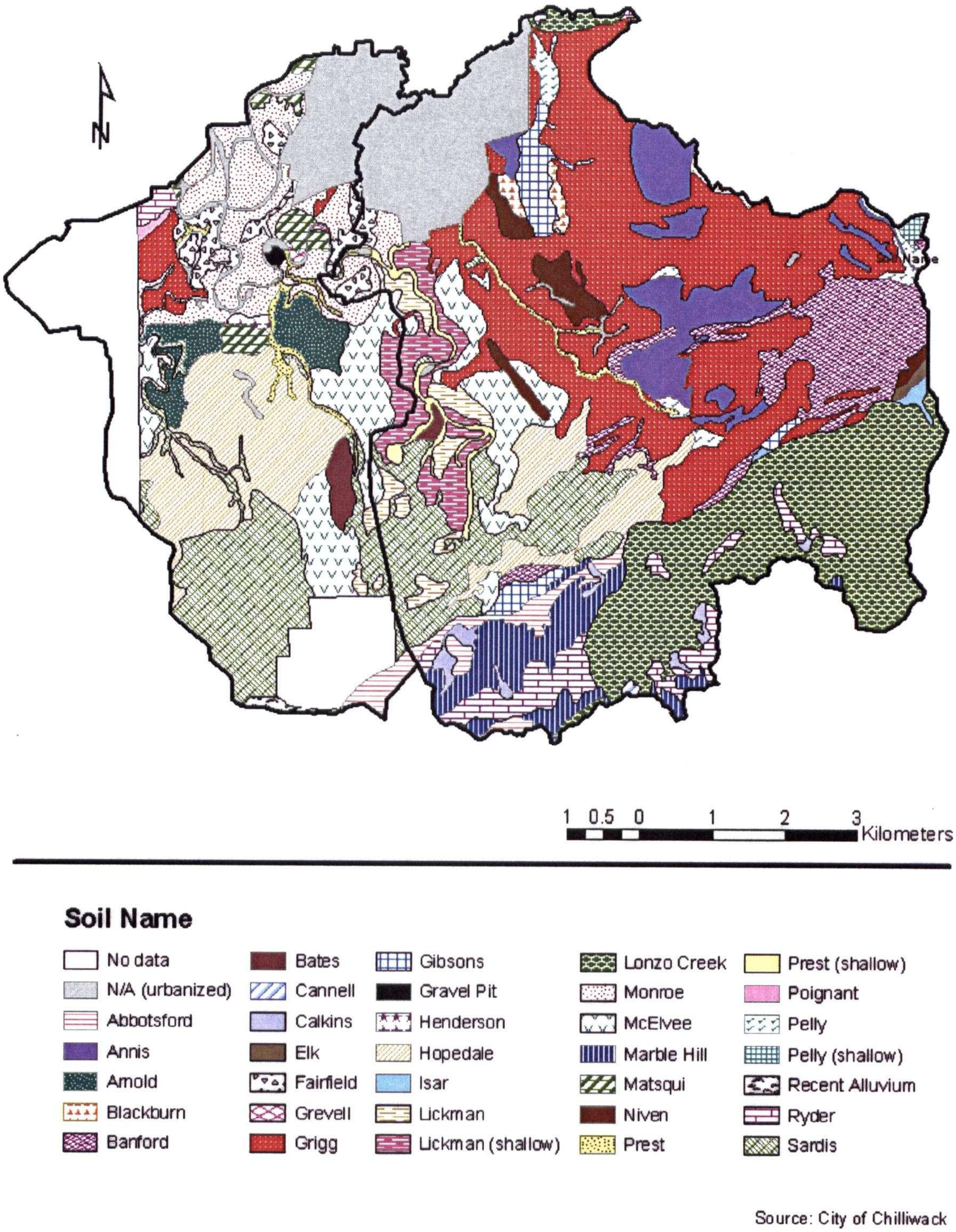


Figure 3.4 Soils of the Chilliwack Creek Watershed

3.2 Watercourse Characteristics

3.2.1 Stream and Drainage Network

The stream network for the Chilliwack Creek watershed is shown in Figure 3.5. As Chilliwack Creek flows from Sardis through Chilliwack towards the Fraser River it is joined by a number of major tributaries: Interception Ditch, Luckakuck Creek, Semiault Creek, and Atchelitz Creek. All but Atchelitz Creek are included in the study area. Characteristics and potential pollution sources for each major tributary are summarized in Table 3.1

Chilliwack Creek and Luckakuck Creek are former channels of the Chilliwack/Vedder River (Rood and Hamilton, 1995). Most of the substrate is silt, except near areas of upwelling where gravels are found (FRAP, 1999). The flows of these two creeks, as well as flows in Atchelitz Creek, result in part from groundwater inflow and seepage (Rood and Hamilton, 1995). Together Chilliwack and Atchelitz Creeks form a wetland area of approximately 145 ha. The wetland area is classified as having approximately 70% stream water and 30 % floodplain marsh (FRAP, 1999).

Semiault Creek originates in the agricultural region east of Chilliwack Creek, and its flow consists predominantly of surface runoff from the adjacent fields. Interception Ditch is a large constructed drainage ditch which receives water from the hillslope area and also drains part of the agricultural area adjacent to the hillslope.

Surface water extraction for irrigation and industrial licenses affects flow in all of these streams. Rood and Hamilton (1995) suggest that over forty percent of the summer low flows in Chilliwack and Luckakuck Creeks are consumed by water demands. Summer low flow problems have also been reported in Atchelitz Creek. Recent summer water use has been rated as more excessive than average, and as a result the groundwater table has been dropping in the vicinity of this watercourse (FRAP, 1999). In addition, it has been stated that irrigation withdrawals on Semiault Creek consume 100% of the naturalized summer 7-day mean low flow (FRAP, 1999).

There have been significant impacts to streams within the Chilliwack Creek watershed as a result of population growth and intensification of human activity (both urbanization and agricultural activities). Most of the natural vegetation and riparian zones have been removed, and the streams and ditches have been channelized along various reaches to support agriculture and control flooding. In addition, water quality degradation has resulted from agricultural runoff and urban stormwater runoff and from erosion.

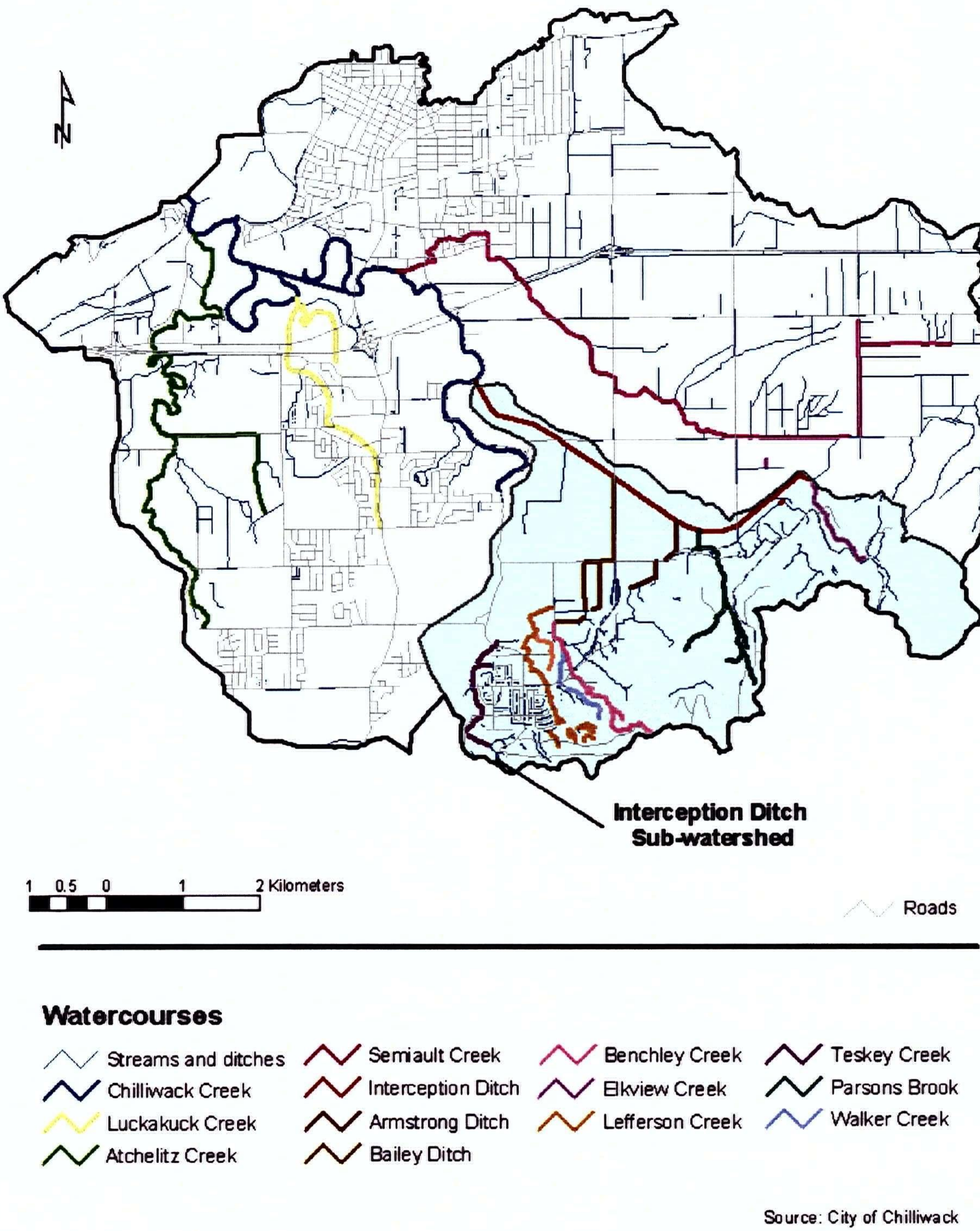


Figure 3.5 Stream Network for the Chilliwack Creek Watershed

The catchment area of Luckakuck creek has experienced considerable urbanization, so that at present approximately 21% of the sub-watershed is effectively an impermeable area (EIA). Both industrial and residential developments are encroaching on the creek and riparian vegetation has been removed from all but a few reaches (Rood and Hamilton, 1995). There is also industrial development along the lower reaches of Chilliwack Creek and Atchelitz Creek; these streams receive stormwater from a number of bulk petroleum facilities and cooling effluent from various food processing plants. Industrial activities on Atchelitz creek also include a canning factory, a food processing plant, and a sawmill (FRAP, 1999).

Agricultural activities are also affecting the watercourses in various portions of the watershed. The upper reaches of Atchelitz Creek, the mid-sections of Chilliwack Creek, and the entire length of Semiault Creek and Interception Ditch are the most severely affected areas. Bank erosion and sedimentation in ditches and channels, low flows, water quality issues (low DO, high ammonia and coliform levels), removal of riparian vegetation are ongoing concerns in these areas.

Hillslope streams are characterized by relatively high gradients, with relatively good quality water in the undisturbed forests. Most of these streams eventually drain into Interception Ditch. Further development of the hillslopes will greatly increase the EIA of the upstream system, potentially altering the flow regime of the system. Depending on stormwater management practices, this may have severe consequences for the downstream lowland agricultural land.

Table 3.1 Major Watercourse Characteristics within the Chilliwack Creek Watershed

	Chilliwack Creek	Semiault Creek	Luckakuck Creek	Atchelitz Creek	Interception Ditch
Status (FRAP 1997)	Endangered	Endangered	Endangered	Endangered	Not surveyed
Trend (FRAP 1999)	Declining				
Watercourse Environmental Issues (FRAP 1997)	• Riparian zone loss • channelized • significant water diversions • significant water quality problems • urbanization has significantly altered stream basin	• channelized • significant water quality problems • significant water diversions • urbanization has significantly altered stream basin	• riparian zone loss • EIA > 10% • significant water quality problems • urbanization has significantly altered stream basin	• riparian zone loss • significant water quality problems	Not surveyed
Possible Pollution Sources	• adjacent agriculture • urban development • industrial discharges	• adjacent agriculture	• adjacent agriculture • urban development • industrial discharges	• adjacent agriculture • industrial discharges	• adjacent agriculture • Bailey landfill
Water Licence Demand (Rood and Hamilton 1995)					
Domestic (gal/day)	19,300	16,000	500	0	
Irrigation (ac-ft)	1,357	293	317	263	
Industrial Use (gal/day)	1,517,043	4,723	1,500,500	10,000	

3.2.2 Fish Habitat

Chilliwack Creek and its tributaries support populations of a variety of fish species including: coho salmon (*Oncorhynchus kisutch)* and chum salmon (*Oncorhynchus keta);* steelhead trout (*Oncorhynchus mykiss),* rainbow trout and cutthroat trout (*Onchohynchus clarki clarki).* Non-salmonid species include various carp, sturgeons, sculpins, suckers, sticklebacks, and calico bass. The rare and endangered salish sucker (*Catostomus sp.*) has also been recorded in the system (FRAP, 1999). The salmonid species spawn in the upper reaches of Luckakuck, Atchelitz and parts of Chilliwack Creek. Semiault Creek and Interception Ditch support no spawning; and fish in these tributaries consist primarily of coarse fish species.

This thesis does not focus on fish; however land use activities in the watershed can affect fish habitat and productivity. As most of the lowland streams flow through agricultural areas, many of the constraints are related to agriculture. The primary concerns include: 1) decreased stream flows due to loss of recharge areas and the number of water withdrawal licenses on these stream; 2) decreased spawning habitat due to sedimentation and siltation resulting from bank erosion; and 3) the removal of fish habitat elements (gravel substrate, riparian areas, large organic debris etc.) due to regular clearing of waterways (FRAP, 1999). Notable water quality problems have also been evident. Low dissolved oxygen, high phosphorus and ammonia values, high water temperature and fecal coliform counts have been recorded. In addition, the Chilliwack pump station causes fish passage problems. Table 3.1 summarizes some of the pressures and concerns that the Department of Fisheries and Oceans (DFO) has noted for the various watercourses.

Ongoing industrial and residential development is also increasing the risk of altering the hydrology and degrading water quality from stormwater runoff, contaminated discharges, and riparian vegetation removal.

Riparian habitat provides important benefits to fish populations. Many of the streams draining the hillsides and uplands contribute important nutrients into fish bearing streams. Protecting riparian areas in the upland headwaters is therefore essential in minimizing potential environmental disruption caused by development.

3.2.3 Flooding Issues and Natural Hazards

The portion of the watershed located in the lowland is subject to frequent flooding resulting from heavy rainfall or snowmelt (spring freshet) from the Fraser River, and from winter storm and flood flows from the Chilliwack River/Vedder Canal basin. The 200-year flood zone covers most of the valley to the north, and some of the lands to the south of the Trans-Canada Highway, and is susceptible to flooding. The area has experienced major flooding as recently as 1984. Since then a system of dikes was built to protect adjacent land from the Chilliwack/Vedder River and the Fraser River from flooding. In addition to the dyking system, the Chilliwack Pump Station located at the end of Chilliwack Creek pumps out water during high flows.

The security against flooding provided by the dykes is being reduced as gravel originating from upstream is transported and deposited in the confined channel. As the beds of the Fraser or Chilliwack rivers rises (aggrades), the water surface level also rises for a given flow; and as a result, the level of flood protection afforded by the dykes along the river is reduced. It is known that in some places along the Fraser River, the dykes are now insufficiently high to assure protection against the water levels for which the dyke system was designed (i.e. the 1894 flood record) (UMA, 2001; Church et al., 2001). As a result, gravel (minimum of 685,000 cubic meters) is being removed on an almost annual basis to minimize the risk of flooding.

The hillside and uplands areas may also be subject to natural hazards such as flooding, erosion and instability, particularly if urban development alters stream flow and increases erosion potential. Erosion of upland areas creates serious downstream consequences, such as local flooding, impediment to farmland drainage, and potential loss of property on the hillsides.

3.3 Groundwater Resources

Groundwater is the principal source of drinking water in the City of Chilliwack. Two major aquifers have been identified in the Chilliwack Regional District: Sardis-Vedder and Rosedale (Table 3.2).

The Sardis-Vedder aquifer is a shallow (~10 m), unconfined aquifer that covers an area of 25 km^2, and is up to 60 m thick in places (Dakin, 1994). The aquifer is comprised of a sandy, gravel alluvial fan formed by the Chilliwack River where the river exits the Cascade Mountains, and becomes known as the Vedder River (Rood and Hamilton, 1995). It is capped with a thin, relatively permeable layer of sand and silty sand.

Flow in the aquifer is relatively fast (3380 L/s or 107,000,000 m^3/yr) and occurs in a radial direction within the fan (IRE, 2001). A portion of this water is extracted by pumping wells and a portion discharges as springs. These springs contribute to the headwaters of a number of streams including Luckakuck Creek, Chilliwack Creek, and Atchelitz Creek. It is likely that flows in many of the smaller tributaries are maintained by groundwater recharge during the late summer (Hamilton and Rood, 1995). Recharge for the aquifer comes from both infiltration of precipitation (12,352,810 m^3/yr) and leakage from the perched bed of the Vedder River (Dakin 1994; IRE, 2001).

The Sardis-Vedder aquifer is the most important source of drinking water for the City of Chilliwack with five wells producing more than half of the drinking water for the community. The aquifer is very productive with sufficient capacity to accommodate further population growth. However, because the Sardis-Vedder aquifer is very shallow, unconfined and overlain by extremely permeable soil, the aquifer is highly vulnerable to contamination. In 1997, the City of Chilliwack implemented a groundwater protection plan to ensure that no significant land use change occurs in the aquifer recharge area and within the capture zones of the well.

Chilliwack's secondary supply source, the Rosedale aquifer, was abandoned in 1997 due to high iron and manganese levels (City of Chilliwack, 2004). The high organic content and low flushing rates in this aquifer are the likely causes of the high dissolved iron and manganese concentrations. This aquifer was formed by Fraser River deposits and underlying glacio-fluvial sediments (Dakin, 1994).

Table 3.2 Summary Information for the Sardis Vedder and Rosedale Aquifers (based on Dakin, 1994)

Aquifer	Area (km^2)	Average Thickness (m)	Estimated Recharge (10^6 m^3/yr)	Annual Abstraction (10^6 m^3)	Recharge Source
Sardis-Vedder	25	25	15	8	• Precipitation • significant recharge from Chilliwack/Vedder River
Rosedale	28	40	10	2	• Precipitation • surface water recharge from Fraser River

3.4 Human Activity / Land Use

The City of Chilliwack has both an urban sector and a substantial rural presence. A large portion of the watershed is comprised of the flat Fraser River floodplain and much of the land base surrounding the urban communities is part of the B.C. Agricultural Land Reserve (ALR). Traditionally agriculture has been the main economic activity within the watershed. Farms (primarily dairy/beef or forage crops) surround the stream channel and most of the lower agricultural area of the basin has been ditched and removed of its riparian vegetation. Currently, the headwaters and upper portions of the watershed area are primarily forested with new residential developments being built.

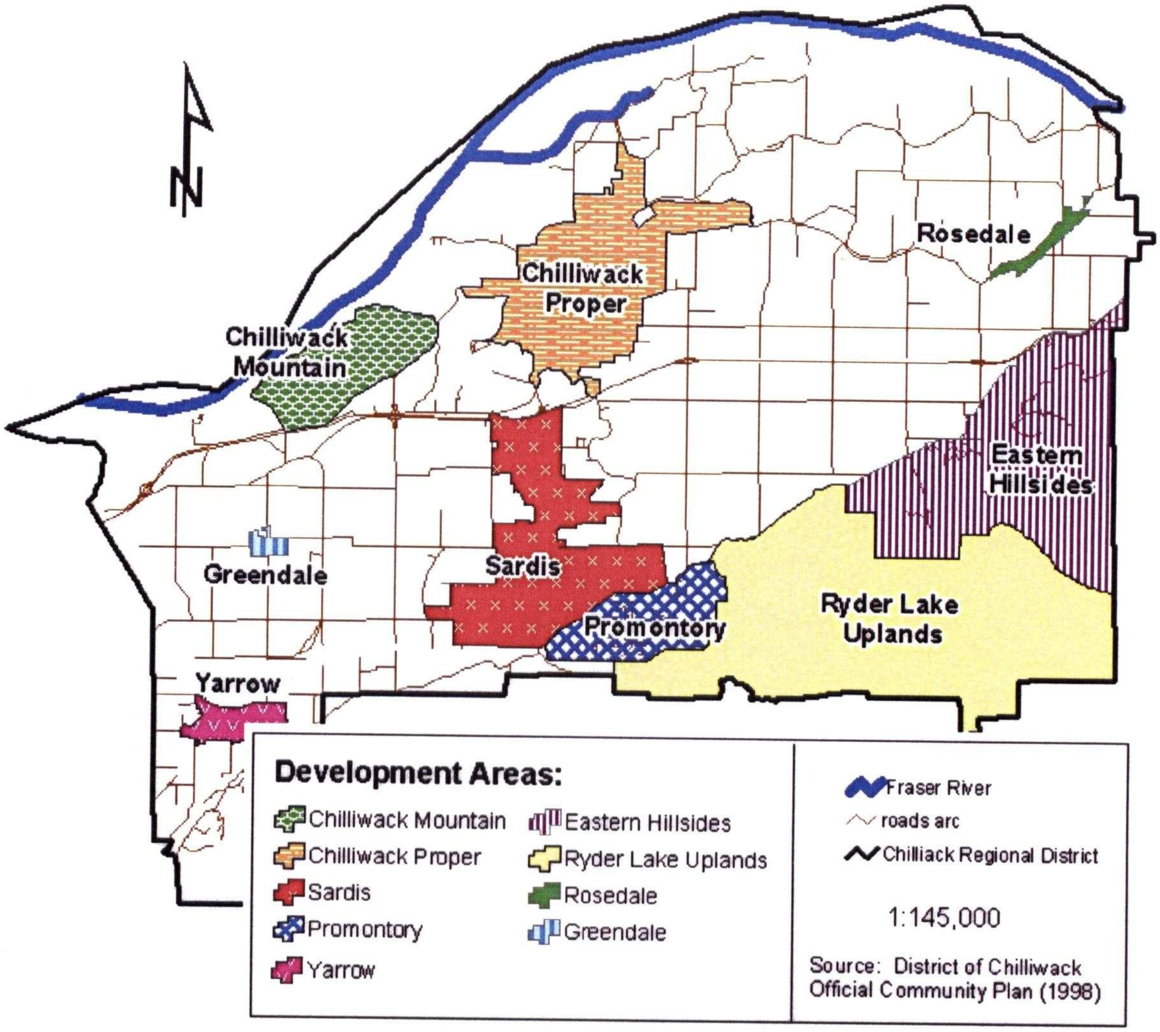
The study area itself reflects this mixed land use setting, and supports a number of different land uses in various sections of the catchment. Current land use, its spatial distribution and the changes in land use since 1995 are discussed in more detail in Chapter 5.

3.4.1 Population Trends and Spatial Distribution

The Lower Fraser Valley (LFV) is one of the fastest growing regions in Canada. The population in City of Chilliwack has grown from 41,471 residents in 1981 to 62,927 residents in 2001 (City of Chilliwack 2004), at an average annual growth rate of about 2.5%. It is estimated that by about 2010 the population will reach 85,000 (Official Community Plan (OCP) target). Currently, over eighty-two percent of the population lives in urban communities or surburban neighbourhoods, and the balance in the rural hillsides and farming areas (City of Chilliwack, 2004) (Figure 3.6).

Population growth is guided by the city's Official Community Plan, produced in 1998. Because urbanization in the valley floor is restricted by the presence of the ALR lands, essentially establishing an urban containment boundary, the OCP has directed future growth towards two main areas in planning for this 85,000 population milestone: 1) densification and infilling of the existing urban corridor; and 2) development of selected hillside and upland areas (namely Promontory, Chilliwack Mountain and Eastern Hillsides).

- **Promontory**: Promontory is a hillside community situated near the southern end of Sardis-Vedder with a current population of about 2,800. It is still in an active phase of development, and upon completion is expected to hold a population of 7,000. Over the next ten years it is expected to accommodate just under nine percent of the growth in the district.
- **Chilliwack Mountain**: Another suburban hillside community, located west of Chilliwack Proper on Chilliwack Mountain. Currently the area consists of rural homes, and much of the hillside remains under forest cover. However, the present population of about 1,000 is expected to triple by 2026.



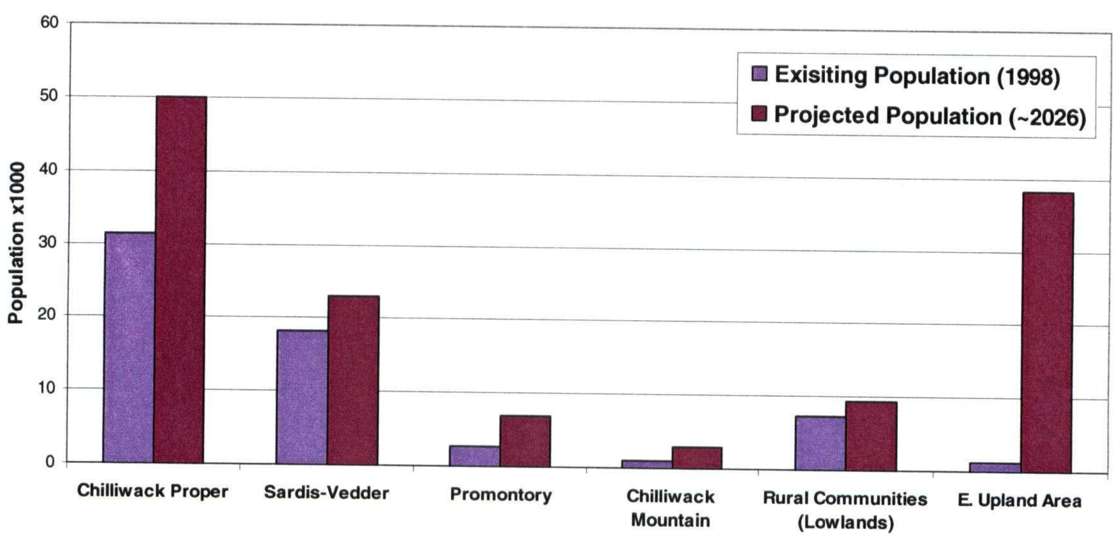


Figure 3.6 Predicted Population Trends for Various Regions in the City of Chilliwack, 1998-2026

- **Eastern Uplands Area:** This area includes both Ryder Lake and the Eastern Hillsides. The *Eastern Hillsides* is a 1320 ha area adjoining the eastern boundary of the municipality. Suburban subdivisions in this area currently hold 900 residents, but according to the development plan for the area it could have a built-out capacity of 8,000. Overall, about sixteen percent of the city's population growth over the next ten years is expected to be in this area. *Ryder uplands* is likely to be the last area slated for development. At present the plan is to maintain it as a long-term community development reserve, with a low development density. However, once the Eastern Hillsides has reached its development capacity this area will likely be developed to accommodate a suburban residential community in order to meet housing demands. Long term plans call for five development areas, 1500 ha of developed land and a population of about 60,000 (City of Chilliwack, 2004).

3.5 Hillslope Development: Issues and Concerns

The hillside and upland area slated for development is a sensitive environment, and may be subject to natural hazards such as flooding, erosion and slope instability. In addition, the area is located upstream of rich agricultural lowlands, which may pose liability issues for the municipality. According to B.C. drainage law, the municipality is liable for any runoff and flooding impacts resulting from urbanization. Consequently, there are a number of issues and concerns that need to be addressed if development of the hillsides is to proceed (CH2MHill, 2002):

- Any increase in impervious surface on the hillslope will increase flow volume and velocity of stormwater to the low lying farm land. This could result in flooding along the natural and constructed drainage system, or could aggravate existing flooding problems both on-site or downstream;
- Increased flow rates and volumes could destabilize the existing balance of the natural geomorphic drainage systems (e.g. increase stream bank erosion) resulting in bank or slope failures, destruction of habitat, downstream sedimentation leading to a decreased channel capacity which could impede farmland drainage, and smothering of spawning beds;
- Alteration of the natural topography and native vegetation could result in unstable soil conditions in slopes/embankments, or may increase water temperature;
- Alteration of the groundwater interflow could adversely change downstream baseflows and/or impair existing water rights; and
- Rapid and direct transport of contaminants associated with urban activities may degrade water quality in the streams.

3.5.1 Stormwater Management Innovations in the City of Chilliwack

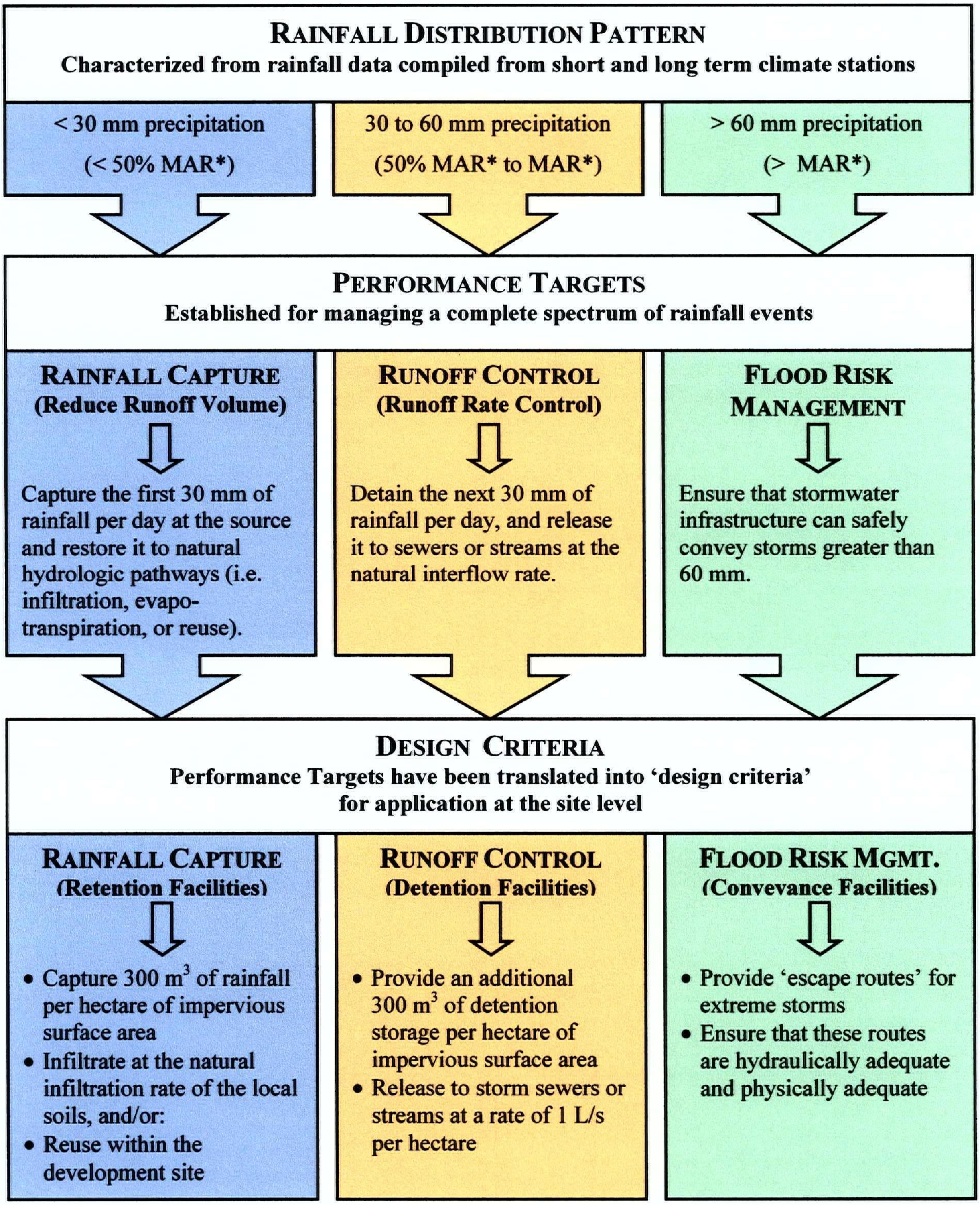
With the pressure to develop on the steeper hillsides, the potential for downstream impacts and the resulting liability issues, the municipality has moved away from tradition stormwater management practices and has instead adopted an innovative integrated master drainage plan that requires land developers in the uplands to protect the natural water balance. In 2002, the City of Chilliwack completed their "*Policy and Design Criteria Manual for Surface Water Management*" which provides guidance on how to design on-site drainage systems that reduce runoff volume at the source. This manual uses concepts from, and was developed as a case study to the B.C. guidebook on stormwater management (*Stormwater Planning: A Guidebook for BC*). As a result, Chilliwack has become recognized as a leader within British Columbia in promoting and implementing changes in the philosophy of, approach to and standards for stormwater management (Stephan and Pringle, 2004).

Conventional stormwater management practices are limited in that they generally focus only on controlling peak flows (by piping rainwater runoff to streams) during the larger infrequent storm events, while they neglect to manage runoff volumes from smaller events (CH2MHill, 2002a). However, many of the impacts to the aquatic system are dominantly controlled by the cumulative effects of smaller storm events rather than by rare, high magnitude storm events (McClintock et al., 1995). Chilliwack's innovative stormwater management approach is to manage for the complete spectrum of rainfall events, from the small frequent events to the extreme events (see Figure 3.7). The overall objective is to use a combination of source control and traditional stormwater management practices to decrease the volume of runoff that flows to the stream, thereby creating a situation that approximates the water balance of a naturally vegetated watershed (CH2MHill, 2002a):

- **Rainfall Capture (retention/runoff volume reduction):** The small frequently occurring rainfall events, which account for the bulk of the total rainfall volume, are to be captured and infiltrated (or re-used) at the source (on building lots and within road right-of-ways). The goal is to control runoff volume so that the watershed behaves as though it has less than ten percent impervious surface area.

- **Runoff Control (detention/runoff rate reduction):** The intermediate events are to be detained and released to watercourses or drainage systems at a rate that approximates the natural forested condition (~1 L/s/ha).

- **Flood Risk Management (conveyance):** Extreme events (e.g. 100-year rainfall event) are to be safely conveyed to downstream watercourses.



* MAR = mean annual daily rainfall

Figure 3.7 Chilliwack's Integrated Stormwater Management Strategy for Managing a Complete Spectrum of Rainfall Events (Source: CH2MHill, 2002a)

3.5.2 Demonstration Projects

There are now a number of innovative development projects within the Chilliwack Creek watershed where source control and low impact design technologies have been applied. Source control strategies for future development may include absorbent landscaping, infiltration facilities and extended detention, preservation of significant natural areas, green roofs, rainwater capture/reuse, and/or pervious cascading swale channel systems on the hillside. Low impact design technologies used may include smaller lot sizes, narrower roads, and elimination of curbs, gutters, storm drain and sidewalks.

Table 3.3 Summary of Low Impact Design Demonstration Projects in the City of Chilliwack

	Project	Location	Source Control/Low impact development technology
Industrial/ Commercial	Stream International	Chilliwack	- exfiltration gallery adjacent to stream - stormwater retention/detention trench
	Chevron Gas Bar	Sardis	- exfiltration gallery under pavement and landscaping
Residential Developments	Fetterly Place	Promontory	- storm sewer with partial exfiltration trench - soakaway pit on each lot - detention pond at outlet Note: conventional sub-division (i.e. curb and gutter)
	Byrant Place	Eastern Hillsides	- full exfiltration trench - on lot soakaway pits - detention pond - no curb and gutter
	Russel Heights	Promontory (multi-family)	- runoff from lots is directed to a large green area for infiltration - road runoff is directed to an exfiltration gallery that will provide detention for medium storms (large storms will bypass the infiltration gallery)
	Peach Road subdivisions		- runoff goes into yards and then drains to a surface swale for infiltration - water runs down the road to an infiltration gallery - detention pond is being build to handle the largest storms - small lots, narrow roads - no storm drain
	Suncor Developments		- road runoff flows to an infiltration gallery - narrow roads, no sidewalks - no curb and gutter
	West Point (Copper Ridge)		- exfiltration gallery adjacent to small hillside stream
	Edward Street Apartments		- exfiltration gallery under pavement

The city plans to install monitoring stations at some of the residential housing projects to monitor both runoff volume and water quality (temperature, dissolved oxygen, turbidity, and pH). Practical experience and performance from these demonstration projects will enable constant improvement to land development and rainwater management practices.

4 METHODOLOGY

This project used a variety of data sources in its analysis: surface water quality data obtained from the analysis of grab samples, sediment quality data obtained from the analysis of two sets of streambed sediment samples, continuous streamflow and precipitation data recorded from existing hydrometric stations and tipping buckets set up by the City of Chilliwack, and land use information created using a Geographical Information System (GIS). The following sections describe in more detail the methods used for data collection and analysis.

4.1 Sampling Methodology

As previously mentioned, the Chilliwack Creek watershed was chosen for this study because it has sufficient tributary streams that are dominated by three different land uses (urban, forest, and agriculture). Urban development and forests dominate the hillslopes, while agriculture is dominant in the lowland which allows for an assessment of upland-lowland interactions and cumulative effects.

A total of twenty sampling sites were selected for this study (Figure 4.1). Six of these sites (G1, U3, U4, M10, F13 and F14) were selected to be adjacent to the existing streamflow gauges in order to investigate the relationship between water quality and water quantity. The remaining sampling locations were chosen to ensure adequate distribution throughout the stream network, and to make sure there was sufficient representation from areas with different land use activities – namely, agriculture, urban and forest. During the preliminary survey on 13-May-2002 only fourteen stations were investigated. A site located downstream along Chilliwack Creek was added later that month as a potential indicator of the combined overall water quality of the stream network before it entered the Fraser River. In addition, five sites were also subsequently added to ensure that there would be sufficient data from each of the urban, forest and agricultural land use categories for statistical analysis.

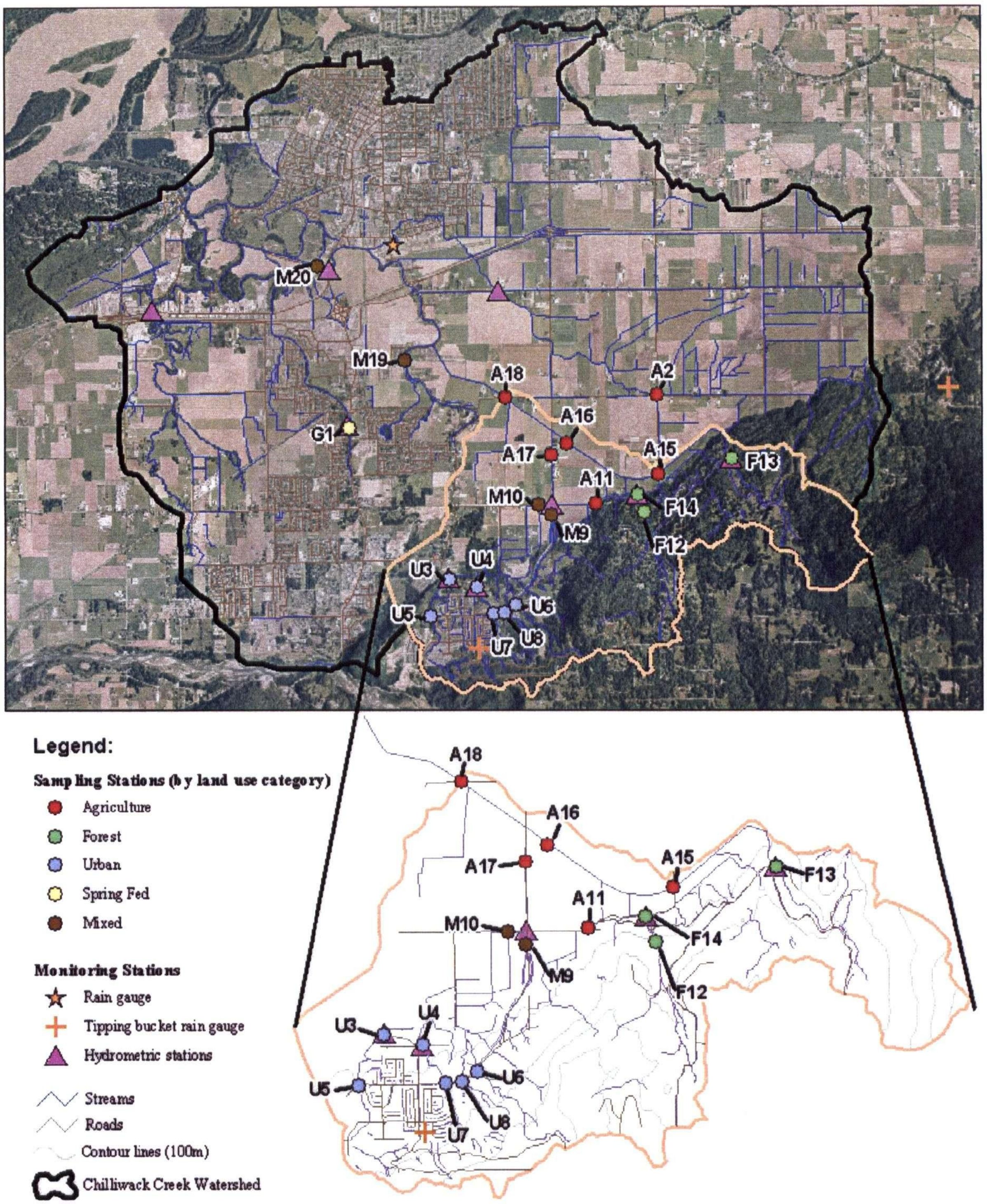


Figure 4.1 Water and Sediment Sampling Stations, Chilliwack Creek Watershed 2002-2003

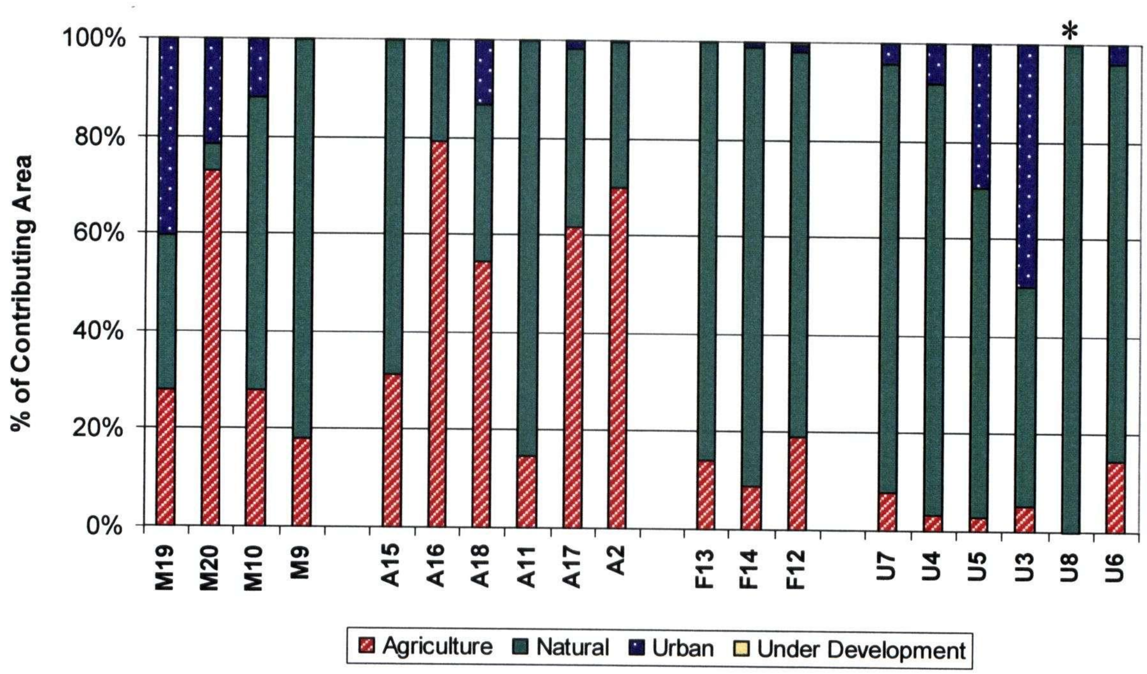
Each sampling site was classified into one of five land use categories: agriculture, urban, forest, mixed, or spring-fed. Note that the 'urban' category for sampling stations refers to hillslope tributaries that drain the new residential development of Promontory; and that any streams draining urban lowland areas are included in the 'mixed' category. Classification was determined based on the dominant land use immediately upstream of the stations, and is summarized in Table 4.1. For clarification, the land use classification of each station is indicated by the letter preceding the sampling station number (A = agriculture, U = urban, F = forest, G = spring fed, M = mixed). In total, six sites were classified as urban influenced, six as agriculturally influenced sites, three sites were considered forested, and four sites were classified as mixed land use.

From Figure 4.2 it is obvious that the percentage of urban, forest, and agricultural land varies not only between land use categories, but between sampling stations of the same land use category. Within the agriculture category, stations A2, A16 and A18 are the most intensively used agricultural areas. Station A11 is located directly adjacent to a tree farm operation, and was included in the agriculture land use group despite having less than twenty percent of its contributing area under agriculture. It should also be noted that if we consider the entire area upstream of a sampling site both stations A17 and A18 receive water from the sub-urban residential area of the hillslope; and consequently, are not solely influenced by agriculture. Urban stations U5 and U3 have a larger percentage of their drainage area covered by urban activities than the other urban sampling stations (U4, U7, U8 and U6). The three forested sites (F12, F13, and F14) were relatively undeveloped and, consequently, were chosen as control sites to represent streamwater quality before any form of contamination would be introduced to the stream by land use activities. Any agricultural activity contributing to these stations is predominantly small hobby farms. Station G1, located on Luckakuck Creek, is spring fed and was therefore used as a measure of the general groundwater chemistry in the area.

Table 4.1 Watercourse Classification for Sampling Stations

(Sampling stations are arranged upstream to downstream for each watercourse).

SAMPLING STATION	WATERCOURSE	LAND USE
M19	Chilliwack Creek	Mixed
M20	Chilliwack Creek	Mixed
A15	Interception Ditch	Agriculture
A16	Interception Ditch	Agriculture
A18	Interception Ditch	Agriculture
F13	Elkview Creek	Forest
F14	Parson's Brook	Forest
F12	Parson's Brook	Forest
A11	Armstrong Ditch	Agriculture
M9	Teskey Way Ditch	Mixed
A17	Teskey Way Ditch	Agriculture
M10	Bailey Ditch	Mixed
U7	Lefferson Creek	Urban
U4	Lefferson Creek	Urban
U5	Teskey/Thorton Creek	Urban
U3	Teskey/Thorton Creek	Urban
U8	Walker Creek	Urban
U6	Benchley Creek	Urban
A2	Semiault Creek	Agriculture
G1	Luckakuck Creek	Spring fed



* estimated to have ~ 10% imperviousness during sampling period (2002-2003)

Figure 4.2 Percent of Land Use Activity within each Contributing Area (based on 2002 land use map)

4.2 Field Methods

4.2.1 Surface Water

The field sampling took place over the period of one hydrologic cycle to include both wet and dry conditions. Streamwater grab samples were taken on nine dates (approximately monthly to bi-monthly) between May 2002 and July 2003, primarily during baseflow conditions. In addition, samples were collected during a storm event on 16-Oct-2003. Over this storm event, a series of four samples were taken (approximately every 75 minutes) at four different sampling stations (A2, U3, F12 and A18) within the catchment. Station M20 was sampled once near the end of the storm sampling.

Grab samples were taken in acid washed polyethylene bottles, and stored in a cooler with ice until analysis. Nitrate-N + nitrite-N (NO_3^- -N + NO_2^- –N), orthophosphate-P (PO_4^{3-} – P), and ammonia-N (NH_3- N) were then analyzed in the lab within 24 hours of being sampled. On three of the eight sampling dates (27-May-2002; 1-May-2003; and 9-July-2003), part of each grab sample was separated and later analyzed for various trace elements: aluminum (Al), calcium (Ca), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), sodium (Na), nickel (Ni), phosphorus (P), lead (Pb) and zinc (Zn). Preparation and laboratory techniques are described in Section 4.3.1.

Parameters that were measured *in situ* include specific conductivity and water temperature using a Yellow Springs Instrument Co. (YSI) Model #30M/50 FI meter, and dissolved oxygen (DO) using a YSI Model #58 meter. pH was analyzed in the lab using a Beckmann 44 pH meter. Due to problems with broken probes, data for all these parameters could not be collected on every sampling date. Table 4.2 shows the parameters measured on each sampling date.

4.2.2 Sediments

Samples of stream bed sediments were collected twice during the dry season, on 10-Oct-2002 and 9-July-2003. The sampling was done twice in order to observe any variation between years, and because the first sampling did not include four stations (A2, M10, M19 and M20). At each site, sediment samples were collected from the surface sediment layer using a 4 m pole with an aluminum pot attached at one end. Each sample was then place in a plastic bag, and refrigerated in the lab until analysis for trace elements, particle size, orthophosphate and degree of phosphorus saturation (DPS) was completed (see section 4.4.2 for details on the laboratory analysis).

Table 4.2 Summary of Water Quality and Sediment Parameters Measured on Each Sampling Date

PARAMETER	ANALYTICAL EQUIPMENT [6]	Sampling Date								
		13-May-02 [2]	27-May-03	21-Aug-02 [1]	10-Oct-02 [1]	12-Nov-02	12-Dec-02	03-Mar-03	01-May-03	09-Jul-03
WATER:										
Nitrate-N	Lachat		X	X	X	X	X	X	X	X
Ammonia-N	Lachat		X	X	X	X	X	X	X	X
Orthophosphate-P	Lachat			X	X	X				
Specific Conductivity	Probe (DM)	X	X	X	X	X	X	X	X	X
pH	Probe (DM)		X	X	X	X	X	X	X	X
Temperature	Probe (DM)	X	X	X[3]			X	X	X	X
Dissolved Oxygen	Probe (DM)	X	X	X[3]				X		X
Trace Elements (Dissolved)	ICP	X							X	X
SEDIMENT:										
Trace Elements (Total)	ICP				X[5]					X
Particle-Size										X
Orthophosphate	Lachat									X
Total Carbon	LECO				X[5]					X
Total Nitrogen	LECO				X[5]					X

[1] No data for site A11 (stream dry)
[2] Preliminary sampling date (no data collected for stations U5, U7, F12, A15, A17, M20)
[3] No data for stations A2, M10, F13, A15, A16, A17, A18, A19
[4] Ammonium oxalate extractable elements
[5] No sampling for stations A2, M10, M19 and M20
[6] Lachat – Lachat QuickChem FIA+ 8000 Flow Injection Analyzer,
ICP – Vista Pro CCD Simultaneous Inductively Coupled Plasma – Atomic Emission Spectrometry,
LECO – LECO CNS-2000 furnace
[7] DM – direct measurement

4.2.3 Precipitation and Streamflow Data

Flow data from a number of hydrometric stations throughout the watershed was obtained from the City of Chilliwack. The dates of operation for each hydrometric station can be found in Table B.1 (Appendix B), and the locations of these stations are shown in Figure 4.1. Each streamflow sampling site has an automated ISCO 4150 Flow Logger, which collects data at 15 minute intervals. The sensor on the meter uses Doppler technology to measure the average velocity of the flow in the stream, while an integral pressure transducer measures the liquid depth to determine the flow area. The flow logger then calculates the flow rate by multiplying the area of flow in the stream by its average velocity (ISCO, 2004).

Table B.1 also gives the channel characteristics and type of conversion used in the flow calculation for each station.

Precipitation data were obtained from one of two sources. Table B.2 shows the record period and sampling frequencies for the different rain gauges (Appendix B). Daily data were obtained from an Environment Canada climate station (station # 1101530) rain gauge which is located at the Chilliwack Airport in the lowland valley. In addition, the City of Chilliwack operates two tipping buckets (Promontory and Marble Hill) which are located on the hillslope; these tipping buckets collect continuous data at five minute intervals. Unfortunately, the data records from the tipping buckets are incomplete and sporadic; consequently, any analysis performed with the Promontory and Marble Hill data sets should be interpreted with caution. Due to the major gaps in the data, use of upland precipitation records has been restricted to investigating storm events where the data exists, and no effort has been made to determine annual or monthly rates at these stations.

4.3 Laboratory Analysis

4.3.1 Surface Water Samples

4.3.1.1 Nutrients (Nitrate, Ammonia and Orthophosphate)

In the lab on the day after sampling, the water samples were filtered through Whatman #42 (2.5 μm) ashless paper to remove any particulate matter. Dissolved nutrients ($NO_3^- + NO_2^-$ - N, PO_4-P^{3-} and NH_3-N) were analyzed on a Lachat QuickChem 8000 Flow Injection Analyzer. Total ammonia as nitrogen (NH_3-N), nitrate as nitrogen (NO_3^--N), and orthophosphate as phosphorus (PO_4^{-3}-P) were analyzed the day after sampling in the UBC Soils Department laboratory. Prior to analysis, the water samples were filtered using Whatman #42 ashless paper to remove any particulate matter. Dissolved nutrients were analyzed on a Lachat QuickChem 8000 Flow Injection Analyzer using method #12-107-04-1-B for NO_3^--N (detection limit 0.10 mg/L), method #10-107-06-2-A for NH_4^+-N (detection limit 0.10 mg/L), method #10-115-01-1-A for PO_4 (detection limit 0.02 mg/L). A brief description of these methods can be found in Appendix C.

4.3.1.2 Dissolved Elements in Water

Samples used in the analysis of dissolved elements were filtered through Whatman #42 ashless paper, and concentrated trace metal grade HNO_3 (~ 0.5 mL HNO_3 per 50 mL sample) was then added as a preservative. Each sample was analyzed in the UBC Soils Department laboratory using a Varian Vista Pro (RadialTorch) CCD Simultaneous Inductively Coupled Plasma – Atomic Emission Spectrometry (ICP-AES). Table C.2 in Appendix C lists the calculated detection limits for each of the elements analyzed.

4.3.2 Sediment Samples

All sediment samples were wet-sieved with distilled water using Tyler stainless steel sieves. A random sub-sample of the original sampled sediment was sieved using No. 230 mesh size to obtain the < 63μm fraction. This fraction represents the clay and silt sized particles which tend to be the greatest accumulators of metals. The < 63μm fraction was then placed in a glass beaker and dried at approximately 75°C until the sediment was completely dry. The dried samples were then gently ground using a mortar and pestle (so as not to destroy the structure of the particles and to create additional surface area). The samples were then stored in plastic containers until analysis. Similarly, a separate sub-sample of the original sediment was sieved using No. 9 mesh to separate the fraction smaller than 2 mm. This was also dried at 75°C, ground using a mortal and pestle and stored in plastic containers until analysis.

4.3.2.1 Physical Properties

Textural analysis was performed on the < 2mm dried sediment fraction using a simplified method for particle size determination discussed by Kettler et al. (2001). The rapid method outlined in this paper, which does not take into account the presence of particulate organic matter, was used because it was assumed that geological sediments have not had time to develop or accumulate an influential amount of organic material. In this method, 45 mL of sodium - hexametaphosphate (HMP)[1] ($(NaPO_4)_6$) at an aqueous concentration of 3% by weight was added to 15 grams of the dried sediment sample in a 100 mL Berkman centrifuge tube. The centrifuge tube was then placed on a reciprocating shaker for two hours. The purpose of the sodium in HMP is to complex any Ca^{2+} in solution and to replace Ca^{2+} with Na^+ on the sediment particle. Sodium has a larger hydrated radius than calcium; this results in the dispersal of individual soil particles and the breakdown of soil aggregates (Kettler, 2001). Na^+ may also dissolve any organic matter binding particles (Lavkulich, pers. com. 2003). The phosphorus in the HMP binds to both Al and Fe (which are both major binding agents in soils) and precipitates them out of the solution. After dispersion, the sediment slurry was sieved through a standard 0.053 mm mesh (no. 270) sieve to separate the sand faction. The slurry was sieved until the liquid passing through the sieve appeared clear. The particles that did not pass through the sieve (the sand fraction) were collected and rinsed into a weigh boat and dried at 55°C to a constant weight. The percentage of sand is then calculated based on its fraction of the original mass. The solution and particles (silt and clay) that passed through the 0.0053 mm mesh were collected in glass beakers. The solution was then stirred with a glass stirring rod to ensure suspension of all sediment particles and left undisturbed for three hours. During this time the silt particles settled out leaving the clay particles in suspension. After three hours the solution of suspended clay particles was decanted and discarded. The settled silt fraction was rinsed into a weigh boat and dried at 55°C to constant weight. The percentage of

[1] Calgon (detergent grade HMP) was used

silt was calculated based on its fraction of the original mass. The percentage of clay was calculated as the difference of 100 percent minus the sum of the percent sand and percent silt.

4.3.2.2 Total Carbon and Nitrogen

The dried < 2 mm sediment fraction was passed through a 1 mm mesh (no. 16) sieve. Carbon and nitrogen content in the sediments were determined using a LECO CNS-2000 furnace. Approximately 0.5 g of sediment was placed in the sample holder. In the combustion chamber the furnace heat (1350°C) and oxygen gas cause the sample to combust; which converts any elemental carbon and nitrogen into CO_2, N_2 and NO_x gas. These gases are then passed through the infrared (IR) cells to determine the carbon content, and a thermal conductivity cell to determine the nitrogen content.

4.3.2.3 Phosphorus

Bioavailable phosphorus (measured as orthophosphate-P) was also analyzed. "Bioavailable P was determined using the Bray-Kurtz P-1 method (0.025N HCl + 0.03N NH_4F). 20ml of extractant was added to 2.00 g of sediment and shaken for 5 minutes. The samples were then filtered through Whatman #42 filter paper and analyzed using a Lachat 8000-series QuikchemAE FIA colorimeter that employs the molybdate blue method (Murphy and Riley, 1962) to determine orthophosphate concentrations" (Li, 2003).

4.3.2.4 Trace Elements in Sediments

Analysis for total trace metal concentrations in sediment was performed on the < 0.63 µm dried sediment fraction. The U.S. Environmental Protection Agency (EPA) 200.2 metal digestion method was used for the digestion (Smoley, 1992). In the method, 1.00 g of well mixed <0.63µm dried sediment fraction was placed in a 125 mL glass beaker. An aqua regia solution (4 mL of 1:1 nitric acid (HNO_3) and 10 mL of 1:4 hydrochloric acid (HCl)) was added to the sample using a calibrated pipette. Metals were then extracted from the sediment samples by covering the beaker with a watch glass and refluxing the sample in the dilute acid mixture for about 1 hour in an oven at approximately 80°C. The digested samples were cooled and then filtered through Whatman #42 filter paper. The filtered solution was then quantitatively transferred to a 100 mL volumetric flask and diluted to volume with deionized water. The digested sediment samples were analyzed on a Varian Vista Pro (Radial Torch) CCD Simultaneous ICP-AES. The sediments were analyzed for the following elements: Al, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, and Zn. Final concentrations found in the sediments are presented as mg/kg dry weight for the silt/clay fraction. Table D.1 located in Appendix D lists the detection limits for the analysis.

4.4 Quality Analysis and Quality Control

4.4.1 Site Variability

To obtain an estimate of intra-site sampling variability, water samples were collected in triplicate at one or two stations selected at random on two of the eight water sampling days. The coefficient of variation (CV) for each set of triplicates was calculated, and the overall average CV was calculated as a measure of the intra-site variability for each parameter. Raw data and the results for replicate analysis are given in Appendix E. All parameters had an average CV below 8%, with the exception of ammonia-N. The exceptionally high (48.90%) CV value for ammonia may be due to sample contamination or natural variability. Within site variability was not measured for sediments.

4.4.2 Method Accuracy of Water and Sediment Analysis

The accuracy of the water sample analysis was determined by measuring a series of standards (samples with known concentrations) every ten samples analyzed on the Lachat and ICP-AES during each sampling run.

The accuracy of the digestion technique for trace elements was determined using measurements of trace element concentrations in certified reference sediments. MESS-1 marine reference sediment was analyzed twice with the October sampling set, while Priority PollutnT™/CLP (Lot No. DO35-540) reference sediment was analyzed once with the July 2003 sampling set. Only certified values for Cr, Cu, Ni and Zn were available for the MESS-1 sediments. Results indicate that sediment sampling recoveries for all elements were within performance limits for July 2003 analysis. For the October 2002 sediments, chromium, nickel, copper and zinc were all outside the 8% error range, with Cr (67.2%) and Ni (32.7%) having very poor recoveries. See Appendix E for a complete list of results.

4.4.3 Method Precision for Water and Sediment Analysis

Replicate samples were sub-sampled from the dried and sieved sediment samples, and analyzed to provide an indication of the precision of the various analytical methods used. Precision was measured by calculating the percent difference between duplicate values, and then calculating the overall average percent difference for each parameter. Raw data and precision results for trace elements, orthophosphate (Bray-Kurtz P-1), and particle size can be found in Appendix E.

In July 2003, copper and iron showed the highest variability in analytical results with an average percent difference between replicates of 17.3% and 12.2% for copper and iron, respectively. The high percent difference calculated for copper and iron for these data was primarily due to the presence of a high duplicate at site M9, which gave a percent difference of 33.4 and 24.2, respectively. Still, the high variability in duplicate analysis for these two metals suggests a lower confidence in Fe and Cu results. The average percent difference of all other elements ranged from 0.63% for zinc to 5.91% for sodium in July 2003, and from 2.35% for phosphorus to 8.61% for sodium in October 2002. In general, the October 2002 sediments showed a higher variability in the analytical results for most elements, with the exception of copper and iron. Method precision results for textural analysis showed that there was higher variability in calculating the silt and clay fractions than the sand fraction.

4.5 Geographic Information System (GIS) Methodology

4.5.1 GIS Database Creation

A GIS was used to document the biophysical resources in the watershed. For this study, ArcGIS© Desktop 8.2 (a product of ESRI Inc.) was used to aggregate and synthesize this database, and then to analyze spatial trends. The digital layers of the different watershed characteristics entered into the GIS database were obtained from a variety sources, shown in Table 4.3 below.

The stream network, soils, roads, orthophotos, and a TIN (triangulated irregular network) showing the topography were obtained from the City of Chilliwack in digital form. Separate coverages were created for a number of other features, such as the location of sampling stations, hydrometric stations and precipitation monitoring sites in the watershed. Locations of these stations were approximated, using the orthophoto, road and watercourse layers as a guide.

Table 4.3 Data Sources for the GIS Database

Layer	Source
Stream network	Digital, City of Chilliwack
Roads	Digital, City of Chilliwack
Topography (TIN)	Digital, City of Chilliwack
Watershed/Contributing Areas	Manually digitized from TIN, contours and drainage pipes/outlets
Drainage pipes, outlets *et cetera*	Digital, City of Chilliwack
Soils	Digital, City of Chilliwack
Land Use (1995, 2000)	Manually digitized from orthophotos
Land Use (2002)	Manually digitized from orthophotos and digital map provided by the City of Chilliwack
Sampling sites	Manually digitized
Hydrometric stations	Digital, City of Chilliwack
Orthophotos (1995)	Triathlong Inc. (digital)
Orthophotos (2000)	Digital, City of Chilliwack

Land use maps were based on the orthophotos and the land use map provided by the City of Chilliwack. The 1995 and 2000 land use information was digitized from 1:20,000 scale color orthophotos of the respective years. Current land use information was taken from a digital land use map for 2002 provided by the City of Chilliwack. However, due to inconsistencies in the polygons (i.e. overlaps, gaps) a new 2002 land use map was created. To do this, the 2000 land use map was altered using land use information from the 2002 digital map file. See Table 5.1 for a summary of the land use categories used to characterize the watershed and Figure 5.1 for a map of the current (2002) land use.

Information on soils and surficial materials specific to the watershed was based on a 1:25,000 digital soil map provided by the City of Chilliwack. This map was originally digitized from 1962 *Soil Survey Map of the Chilliwack Area* (Comar, Sprout and Kelley, 1962). For simplicity, each soil unit was split into surface and subsurface layers and defined by geologic origin (parent material), dominant surface and subsurface texture, drainage and perviousness. The parent materials in the watershed included organic material, colluvial, eolian or fluvial deposits, and indicate the way by which the soil was carried, sorted and deposited. The surface texture was defined as the texture of the topmost discrete soil unit with a thickness of at least 10 cm. The subsurface layer was defined as the major textural class below the surface layer. Appendix A shows the classification categories for the soil and surficial material attribute data.

4.5.2 Contributing Area and Buffer Area Delineation

In order to examine the relationship between land use and water quality, the contributing area for each sampling station was delineated. On the hillslope, delineation was based primarily on topography; however topographical features, such as larger roads where ditches can redirect runoff from the adjacent land, were taken into account. In the urbanized section of the hillslope storm drains can alter the natural drainage pattern by collecting water from the land and releasing it to the stream at specific points. As a result runoff does not always follow the topography of the catchment. In order to overcome this difficulty the location of drainage pipes and outfall locations (obtained from a digital file provided by the City of Chilliwack) were also used in determining the contributing areas in this part of the hillslope. In the lowland agricultural area, the topography is relatively flat, and the Triangular Irregular Network (TIN) was not always detailed enough to clearly delineate the drainage areas based on topography. When topographical data was not clear, the midpoints between watercourses were used to determine the contributing areas. A map of the contributing areas is shown in Figure 4.3, and Table F.1 lists the receiving watercourse and the size of the drainage area for each of the contributing areas.

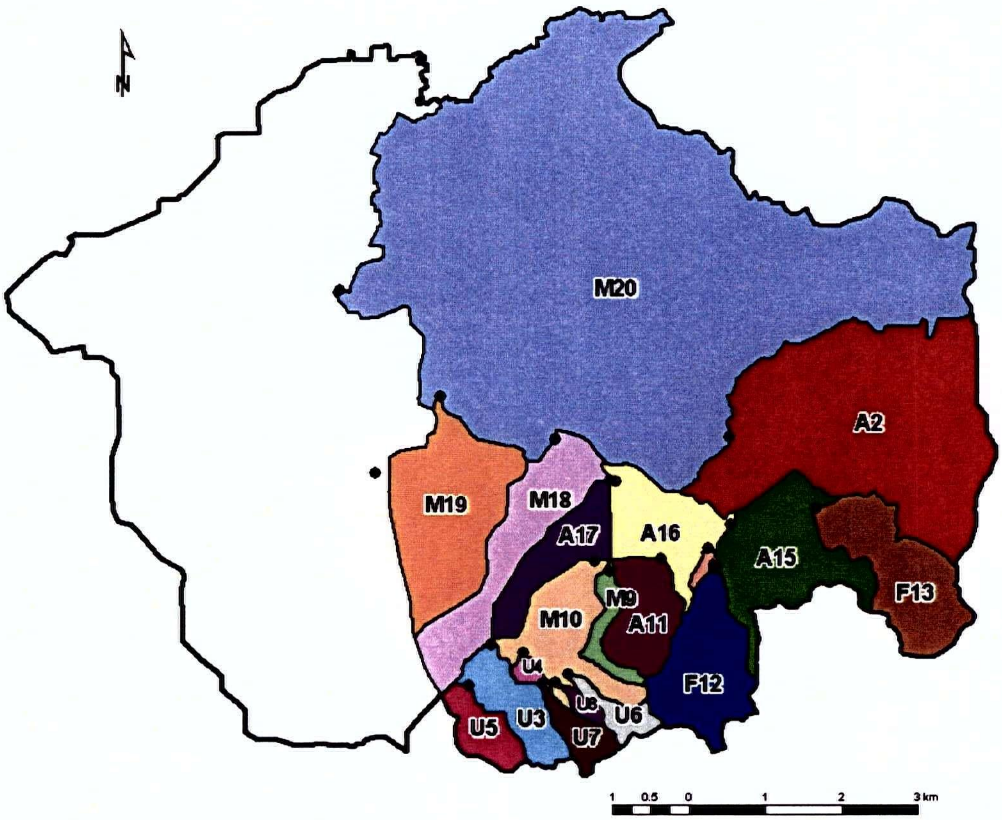


Figure 4.3 Map Showing the Contributing Areas for the Sampling Stations in the Chilliwack Creek Watershed

No contributing area was delineated for station G1 because it receives a significant portion of its water from the Sardis-Vedder aquifer. Groundwater movement does not necessarily follow topography since it is subject to the hydraulic properties of the aquifer, input to (recharge) and outflow from (discharge) the aquifer system, and the geological factors that may block or create flow paths. Consequently, the boundaries of surface water and groundwater drainage areas do not always coincide, and delineating contributing areas for the aquifer requires an understanding of the aquifer properties that is beyond the scope of this thesis.

Water quality results from the sampling stations were also correlated with land use within a buffer zone surrounding the streams. The buffer tool in ArcMap© was used to create three different sized buffers (50 m, 100 m and 200 m) around the stream network. A map of the land use within the 100 m buffer is shown in Figure 8.1. Using the geoprocessing wizard in ArcMap©, land use information was extracted from the various land use coverages, and summarized by contributing area, buffer zones and the watershed as a whole. Both the total area upstream of the sampling station (cumulative area), as well as the area between sampling stations (independent area) were calculated for each station (see Appendix A).

4.6 Water and Sediment Quality: Data Analysis Methods

The *SPSS for Windows 12* software program was used for all statistical data analysis. Based on normality tests it was found that the water quality and sediment data were skewed (i.e. non-normally distributed) for most parameters. In addition, for some land use categories, the sample size was very small. For these reasons, non-parametric statistical techniques were used for all data analysis. These methods are less powerful than parametric procedures; however, they can be used when the assumptions required for parametric statistics are not met (Townend, 2002).

4.6.1 Statistical Analysis of Water Quality Data

Water quality results were divided into 'wet season' (November 2002 to early May 2003) and 'dry season' (May to August 2002, and July 2003) based on differences in flow and precipitation. In total, there were four sampling dates for each of the two seasons. For each parameter an average value was calculated for both the wet and dry season and used to determine seasonal trends. The Mann-Whitney U test was used to determine if there were significant differences between the wet and dry season data. This test is the non-parametric alternative to the unpaired t-test, and tests whether two groups have the same median. Data for dissolved ions were only measured on three sampling dates, and a Kruskal-Wallis test (the non-parametric equivalent to the analysis of variance (ANOVA)) confirmed that the medians of the different dates were statistically similar ($\alpha > 0.05$). Therefore, results for dissolved ions were not separated into wet and dry season, and no seasonal analyses were performed for the dissolved ions.

Graphs and box plots were created in order to visualize spatial and seasonal trends. In these graphs, the wet and dry season averages are plotted for stations along the Interception Ditch mainstem to the mouth of Chilliwack Creek. Boxplots have the advantage of displaying the full range of data without requiring the parametric assumption of normality. In addition, they are useful in determining critical values at specific locations or on specific dates, which may be masked by the use of wet and dry season means. The boxplots for each variable are shown in Appendix C for each site over the sampling dates, for each sampling date by site. Boxplots by land use category are also shown. Boxplots represent the range from the lower bound of the second quartile to upper bound of the third quartile (a distance describes as the 'interquartile range' (IQR)), with the line between them marking the median. Data within a distance of 1.5 times the IQR of either the bound is noted by the extended whiskers. Measurements beyond more than 1.5 times the IQR from the median are considered outliers and are denoted by individual data circles "o". Values greater than 3 times the IQR are considered extreme values (represented by an asterisk "*").

For each parameter, water quality data were grouped by land use category (previously defined in Section 4.2), and a Mann-Whitney U test was used to make pair-wise comparisons (for wet season and dry seasons separately and for both seasons combined) between the three dominant land use categories (agriculture, urban, and forest). When making multiple comparisons, a correction is needed to adjust for the increased chance of making a Type 1 Error (concluding that there is a significant difference between the populations of two groups when really there is not) in at least one case. Therefore, the Bonferroni method was use to adjust the level at which a result was considered 'significantly different'. This method divides the significance level that would normally be used ($\alpha = 0.05$) by the number of possible pairwise comparisons (3) for a new significance level of $\alpha = 0.017$.

4.6.2 Statistical Analysis of Sediment Quality Data

A similar approach to that used for the analysis of water quality data was taken for the analysis of the sediment data. Boxplots were created for each parameter by land use categories (see Appendix D). The downstream graphs plotted the data for the two sampling dates along the mainstem and its tributaries. Sediment data was tested (by land use category and all data combined) using a Wilcoxon Signed Rank test (α=0.05) to determine if the levels of metals had changed significantly between the two sampling dates. Stations A2, M10, M19 and M20 were omitted from this part of the analysis because they were not sampled in October. The Wilcoxon Signed Rank test was chosen over the Mann-Whitney U test because the samples were assumed to be dependent due to the fact that comparisons were being over time. Mann-Whitney U tests (α=0.0167 using the Bonferroni adjustment) were used to make pair-wise comparisons between land use categories (for both dates individually and for the pooled data set).

4.6.3 Relationships between Land Use, Sediment, and Water Quality

As previously described, land use indices were calculated for each contributing area and within three different width buffer zones (50 m, 100 m and 200 m). A Spearman's Rank correlation test (1-tailed, α=0.05) was used to determine the relationship between these land use indices and the various water and sediment quality parameters. This test measures both linear and non-linear correlations and can be used even for small sample sizes (Helsel and Hirsch, 1992). A strong positive or negative correlation suggests a relationship between two variables, but does not determine whether changes in one of the variables actually cause changes in the other. This cause-and-effect relationship needs to be established separately (Townend, 2002). Correlations were carried out separately for each season, as well as for the combined data. Results were considered significant at $p < 0.05$.

4.7 Water Quantity: Data Analysis

Individual storm events between 2001 and 2003 were delineated for both the Marble Hill and Promontory precipitation data. A number of rainfall characteristics were then calculated for each storm event: total precipitation (in mm); duration (in hrs); peak intensity (5 min, 15 min, 30 min, 1 hour, 3 hour and 6 hour) (in mm/hr); and antecedent dry period (in hrs). See Tables B.6 and B.7 in Appendix B. Storm classes were created based on total rainfall and peak 15-minute intensity (see Table 6.1 for classification), and the percentage of storms in each class was then calculated.

For each storm event, the lag time (in hrs) from peak rainfall to peak runoff, and the peak runoff rate (in mm/hr) were calculated at each of the flow monitoring stations. Only storms with a total rainfall greater than 10 mm were used in this part of the analysis since it was assumed that runoff from smaller storms would be insignificant.

The Wilcoxon Signed Rank test was then used to determine if statistically significant differences (α=0.05) existed between the different catchments for each storm response characteristics. Chilliwack and Semiault were omitted from this analysis. Boxplots were also created using all storms events at each station. It should be noted that, although they are shown in the same graph, the storm events represented in the boxplots are not identical for each station. Finally, hydrographs were created for six individual storm events to visualize the differences in the response of the different catchments. These events are described in section 6.3.2.2.

4.7.1 Delineation of Storm Events

Continuous rainfall data (Promontory and Marble Hill) for a three-year period (2001-2003) was separated into a record of individual storm events, using a minimum interevent time[1] (MIT) of 6 hours. Any period with less than 0.5 mm of rainfall over a 1 hour period was considered to be insignificant. The time series of 15 minute precipitation data from the Promontory tipping bucket was separated into 93, 66 and 51 independent events for 2001, 2002 and 2003 respectively; while the data from the Marble Hill tipping bucket was differentiated into 99, 69 and 52 individual events for the same three years.

4.7.2 Calculating Storm Response Characteristics

In this study, peak runoff rate calculations were based on the total streamflow volumes. Since baseflow was not separated and subtracted from the total streamflow volume to derive direct runoff, peak runoff

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[1] Minimum interevent time (MIT) is defined such that "rainfall pulses separated by a time less than this value are considered part of the same event" (Bedient and Huber, 1992)

rate may be more accurately considered to be peak discharge per unit area. In small, urbanized streams baseflow is often neglected because it represents such a small fraction of the total flow. However, in natural streams and larger rivers baseflow may be a significant fraction of streamflow due to the contribution along banks from the water table (Bedient and Huber, 1992).

The equations used to calculate the lag time and peak runoff rate are defined below. A graphical depiction of the input variables is shown in Figure 4.4

Lag Time (in hrs) was defined as the time from peak rainfall to peak runoff:

$$\text{Lag Time (LT)} = t(Q_p) - t(P_p)$$

Peak Runoff Rate (in mm/hr) was defined as the peak discharge per unit area.

$$\text{Peak Runoff Rate } (R_p) = Q_p / A$$

note: multiply value in m/s by (3600*1000) to get a value in mm/hr (runoff rate)

multiply value in m^3s^{-1}/m^2 by 10^5 to get a value in m^3s^{-1}/km^2 (peak discharge per unit area)

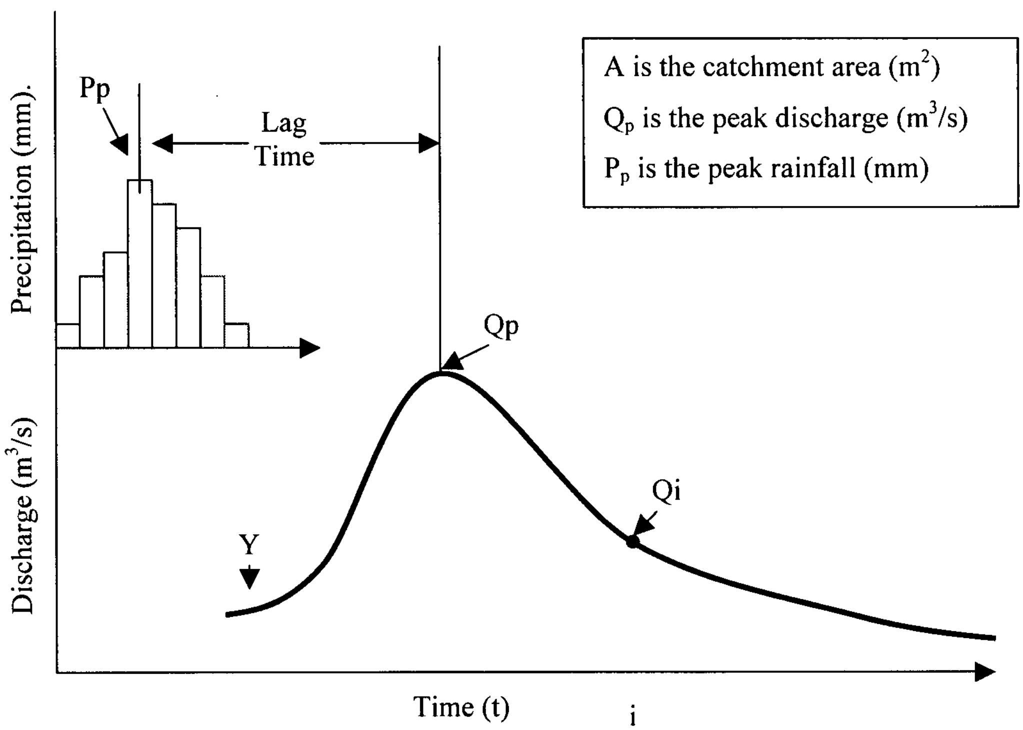


Figure 4.4 Graphical Representation of Storm Response Characteristics

The results of this study are discussed in the next four chapters. First, the current land use and trends over the last 8 years are discussed in Chapter 5. Chapter 6 focuses on the climatic conditions in the watershed and the spatial and seasonal variability in streamflow, as well as the extent to which the Promontory development has contributed to changes in streamflow. Next, the overall surface water and sediment quality is discussed in Chapter 7, with a focus on spatial and temporal trends. Because water and sediment samples were taken from three distinct land use areas, analysis was done to determine if the water and sediment quality from the different areas had any distinct chemical signatures, and to determine the impact of the new hillslope development. The next chapter (Chapter 8) uses the GIS database and water quality and sediment data to examine the interactions between water quality, sediment quality and land use. A brief discussion and summary of the results are found in Chapter 9. Conclusions and management recommendations are found in Chapters 10 and 11.

5 LAND USE IN THE CHILLIWACK CREEK WATERSHED

Land use in the study area was characterized for 1995, 2000 and 2002 with the aid of GIS. Table 5.1 describes the land use categories that were used to characterize the watershed. Note that because a more detailed land use map was already available there are additional subcategories for the 2002 land use map. Once incorporated into the GIS database, the GIS program was used to make quantitative comparisons in land use changes. This chapter will discuss the current land use in the watershed, and identify trends in land use change over the past seven years.

5.1 Current Land Use

Figure 5.1a shows the various land use activities in the study area for the year 2002. The study area contains a mixture of different land use activities that are not evenly distributed throughout the watershed (see Figure 5.1).

The eastern and upper portions of the hillslope are the least developed regions in the watershed; rural residences and hobby farms are scattered throughout the primarily forested hillslopes. Promontory, a new low-density residential development, is located on the lower western portion of the hillslope. This development accounts for 13% of the 'residential' land use in the study area.

The lowland area covers approximately 75% (4154 ha) of the land base in the watershed. About 72% (2990 ha) of the lowland valley is part of the Agricultural Land Reserve (ALR), and is some of the most productive agricultural lands in the province. Soil capability for agriculture is frequently Class 2 and 3 in the valley, and upland soil capability is generally Class 4, 5 and 6 (City of Chilliwack, 1998). Dairy farming/beef cattle production and crop farming are the most common agricultural land uses in the watershed. While the data collected did not distinguish between the type of crop cover (all crops were grouped under 'arable'), based on observations during field excursions it was obvious that corn and forage are the most commonly grown crops. In the lowland agricultural area, cattle and arable land account for 49 and 47% of the agricultural practices, respectively. There is also a small presence of poultry operations, as well as greenhouse and horticultural developments in this region of the watershed. This agricultural land base confines the urban centers of Chilliwack and Sardis to the eastern sections of the Chilliwack watershed. Overall, urban land use covers about fifteen percent of the land base in the study area. Of this, 72% is found in the urban-corridor, 16% in the lowland agricultural area, 11% in the Promontory development, and less than 1% on the remaining hillslope (Ryder Uplands) (see Table A.4 in Appendix 5). Tables A.4 and A.5 in Appendix A summarize the land use in the watershed. Although the data are not discussed by individual contributing areas, this data can also be found in Appendix A.

Table 5.1 List and Description of Land Use Categories (*indicates additional sub-categories used for 2002 land use map only)

LAND USE	LAND USE	SUBCATEGORY	DESCRIPTION
AGRICULTURE	Arable*		Land cultivated under crops, grain, fruits/berries, or pasture.
	Livestock*	Cattle	Land used for cattle (dairy or beef)
		Poultry	Land used for poultry production.
	Horticulture*		Land used to produce flowers or trees, excluding greenhouses.
	Greenhouse*		Includes all areas under greenhouse production.
	Hobby Farm*		Includes field area of hobby farms.
	Unused Agricultural Land*		Agricultural land that is not currently under cultivation.
URBAN	Transportation		Includes all major roads (highways), and railways. Smaller roads were split down the middle and included with adjacent land uses.
	Residential	Low Density*	
		High Density*	
	Industrial/Commercial (I/D) and Institutional (Inst.)	I/D Low Density*	
		I/D Medium Density*	
		I/D High Density*	
		Other*	Includes non-residential, non-commercial/industrial activities such as the airport and municipal dump.
		Inst. Med/Low Density*	
		Inst. High Density*	
GREENSPACE	Open Space[1]	Rural Residential (Estate)	Includes any rural house on the hillslopes, as well as residential homes in the agricultural lowlands (including any adjacent land not being used for agriculture).
		Recreation	Includes grass areas, playing fields, and parks not included under 'wilderness parks'.
		Shrubs	Large areas of shrub vegetation, including vegetation along streams. Minor landscaping was not included.
		Unused Open Space	Areas of land that are unused and that are not forested.
		Clearcuts	Areas that have been logged/cleared for non-development purposes. May be partially re-vegetated.
	Forest	Wilderness Parks	All parks that are primarily forested/natural vegetation.
		Forest	Includes all forested land on the hillslope, as well as larger clusters of trees.
UNDER DEVELOPMENT	Cleared for Development		Includes areas that have been cleared of vegetation for development purposes, but have yet to be developed.
WATER	Water		Areas under water (lakes, ponds, large rivers). Small creeks, streams and ditches are not included.

[1]The open space category was created to represent all non-agricultural clearing, and consists of any open space that is covered in grass or low lying shrubs, including parks and playing field, unused open space, as well as areas that have been clearcut. Rural residential land use was also classified as 'open space' because most of the land area associated is usually grassy open space, and because it was assumed that the inputs would different than from either urban or agricultural land uses.

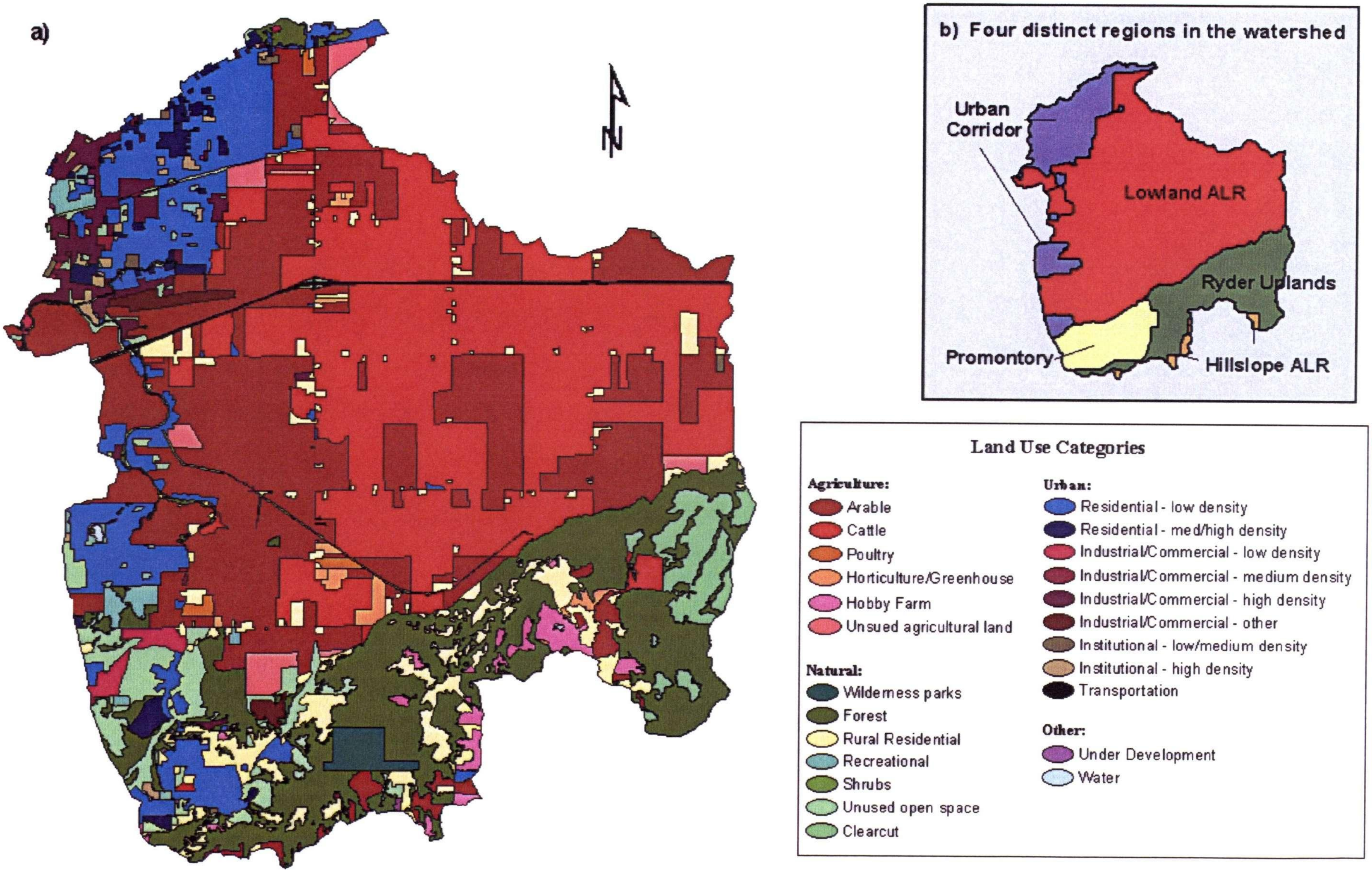


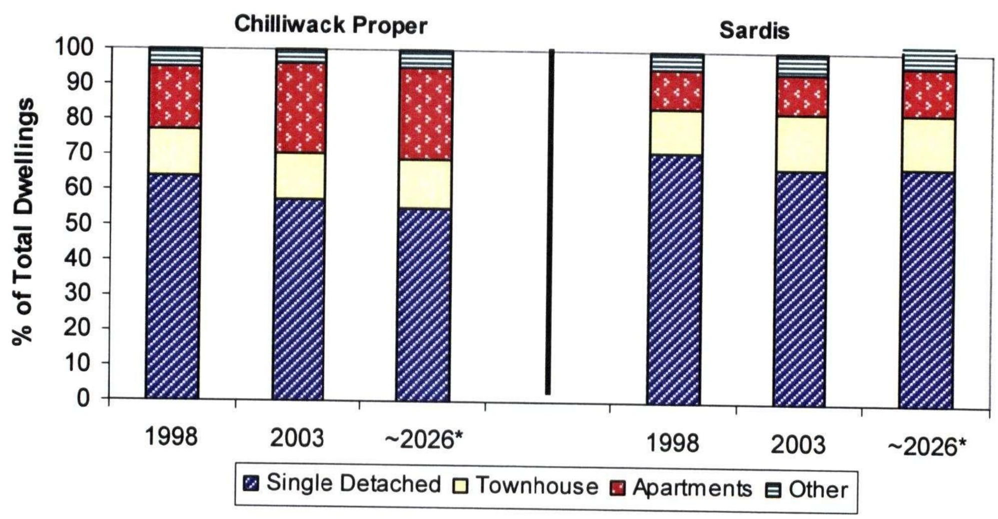
Figure 5.1 Land Use in the Chilliwack Creek Watershed Study Area, 2002

5.2 Trends in Land Use

Land use activity, spatially illustrated for 1995, 2000 and 2002 in Figure 5.3, has changed only marginally when the entire watershed is considered (Table A.5). The two largest land uses (agricultural and forest) both decreased slightly over the seven year period (by 4% and 5%, respectively). Urban residential and rural residential land uses have increased by 27% and 5%, respectively.

In general, the presence of the ALR has ensured that land in lowland valley remains agricultural in nature, and consequently, there has been very little change in land use activities in this region. However, a few small residential areas have been built in the lowland (e.g. at the confluence of Interception Ditch and Chilliwack Creek). While the area of agricultural land has not increased, due to the high quality of the valley agricultural land and the proximity to a large urban population and food processing plants, agricultural activities in the regions are becoming increasingly intensive. Agricultural intensification results in greater inputs of nutrients, pesticides and other contaminants, and a greater potential for ground and surface water contamination.

Small areas of undeveloped land in the urban corridor are continually being developed, particularly in Sardis and on Little Chilliwack Mountain. Past trends show that there has been a gradual shift from predominantly single family homes to a greater mix of single and multiple family housing; and future estimates suggest that this trend will continue (Figure 5.2).



*Based on OCP Scenario of 85,000 population threshold.

Figure 5.2 Housing Development in the Chilliwack Urban Corridor by 'Type' of Dwelling (City of Chilliwack, 2003)

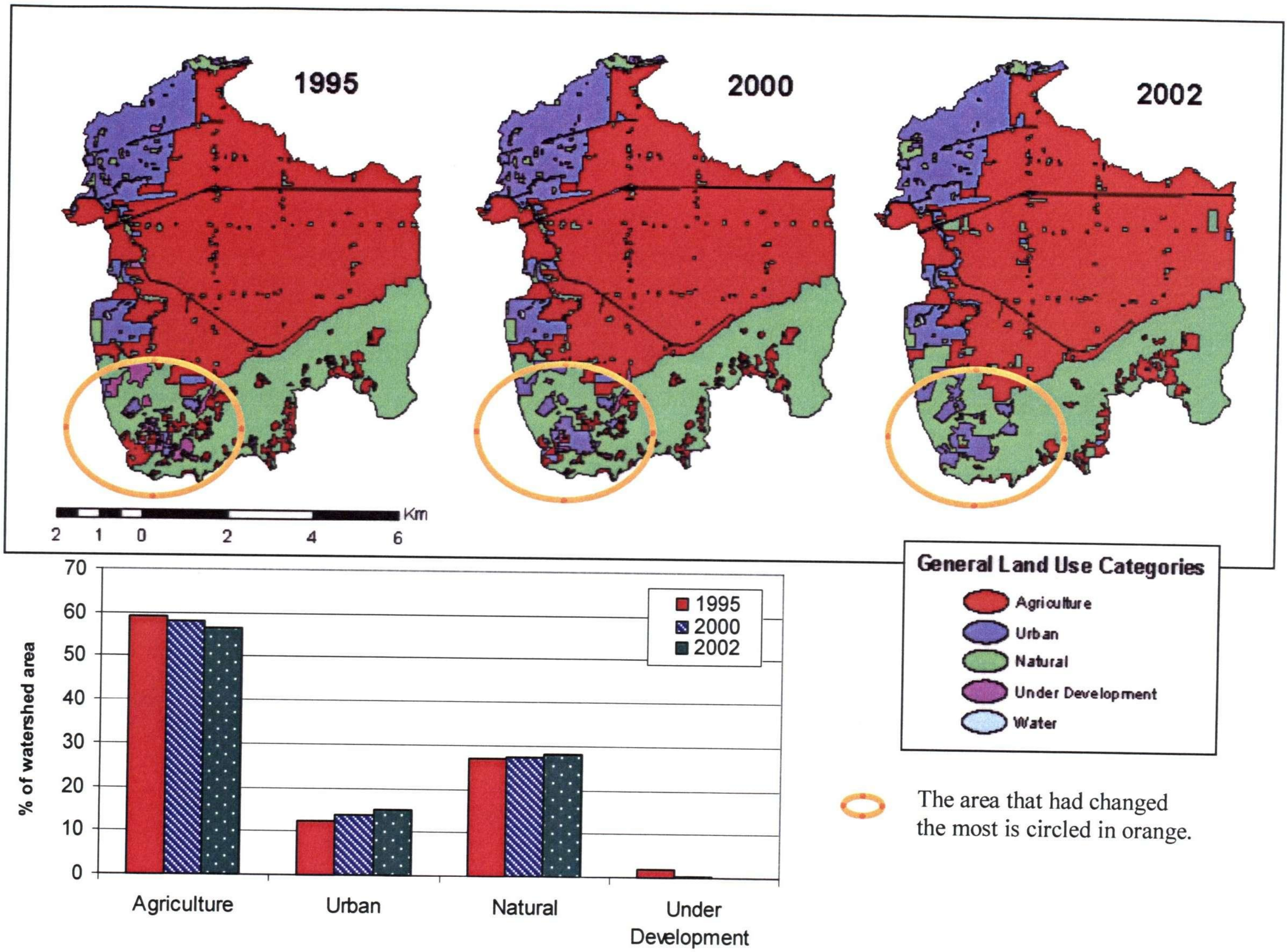


Figure 5.3 Land Use Changes (1995-2002) in the Chilliwack Creek Watershed

The most substantial land use changes in the watershed were in the Promontory hillslope development area (see Figure 5.3). In 1995, the suburban community in the Promontory region was in the initial stages of development, with 18.4 ha of existing residential area and 47.7 ha of land that had been cleared for development purposes. By 2002, most of the land that had visibly been cleared for development was residential housing or unused open space. Overall, the land base dedicated to residential homes had increased by a factor of 4.3 to 78.2 ha, while the area of unused open space increased by a factor of 2.5 (or 33.9 ha). Figure 5.4 shows a detailed breakdown of these changes.

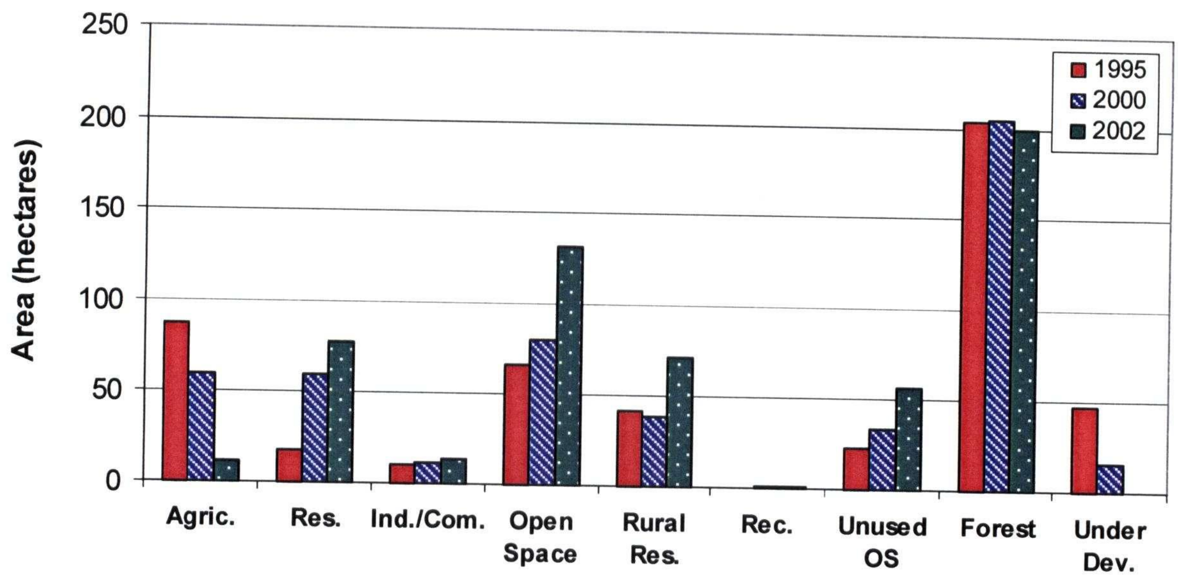


Figure 5.4 Land Use Changes 1995-2000: Promontory Development Region of the Chilliwack Creek Watershed Study Area

Currently, most of the housing developments in the Promontory development are large, single family dwellings (Figure 5.5). In addition, the subdivisions were generally built with wide roads and driveways, resulting in a significant increase in the impervious surface area. Urban development on the hillslope has been rapid and is expected to affect the area through increased contaminant inputs and re-engineering of the hillslope tributaries. Interception Ditch and the downstream agricultural area are particularly at risk as increases in the effective impermeable area in the upstream systems could potentially alter their flow regime depending on stormwater management practices.

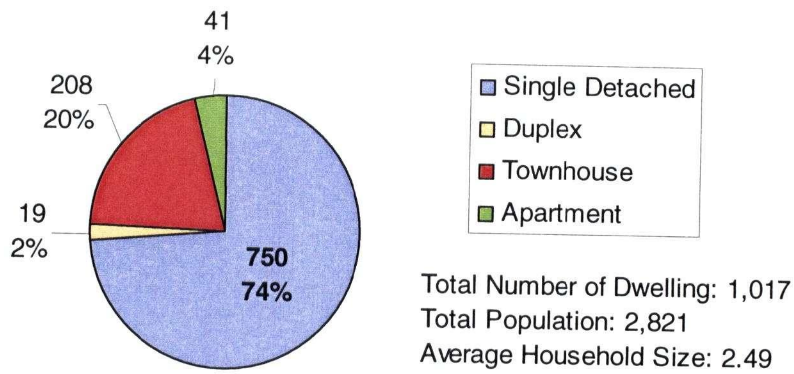


Figure 5.5 2003 Dwelling and Populations Estimates for Promontory

5.3 Impervious Surface Area

Impervious surface area is a useful indicator for water management of urban areas because it is easy to measure. Numerous studies have shown a link between impervious surface area and the degradation of aquatic systems, with strong correlations found between hydrology, loadings from NPS pollution, biological integrity (Schueler, 1992; Booth et al., 1993; Schueler, 1994; Arnold and Gibbons, 1996). In this study, the total impervious surface area (TIA) for each contributing area was determined indirectly from a land use/land cover map. The calculation involved three steps: 1) calculating the amount of each land use category within the contributing area, 2) multiplying each total area within each category by an 'imperviousness factor' typical for that category (see Appendix A for the imperviousness factors used), and 3) summing the results for all land use categories to get an overall TIA value. The accuracy of the results will be influenced by the selection of appropriate imperviousness factors and accuracy and scale of land use mapping.

The total impervious area of each contributing area is summarized in Table A.7 and illustrated in Figure 5.6. Within the watershed the %TIA per contributing area ranges from about 2 to 40 percent, with the lowest values predominantly in the agricultural area and forested sections of the hillslopes. The contributing areas for Teskey Creek and Chilliwack Creek have %TIA near 30 %, the value at which streams become completely degraded (Besbier et al., 2000; Arnold and Gibbons, 1996). Another four contributing areas (A18, U4, M19 and U5) have values above 10% TIA (the threshold above which stream degradation has been shown to begin). The %TIA within buffer zones was generally similar, except at station A18. While this station had over 10% TIA in the contributing area, only 4 % of the buffer zone is impervious surface area. It should also be noted that %TIA for stations M10 and A17, which are below the hillslope development, are considerable greater when the entire cumulative area above the station is considered.

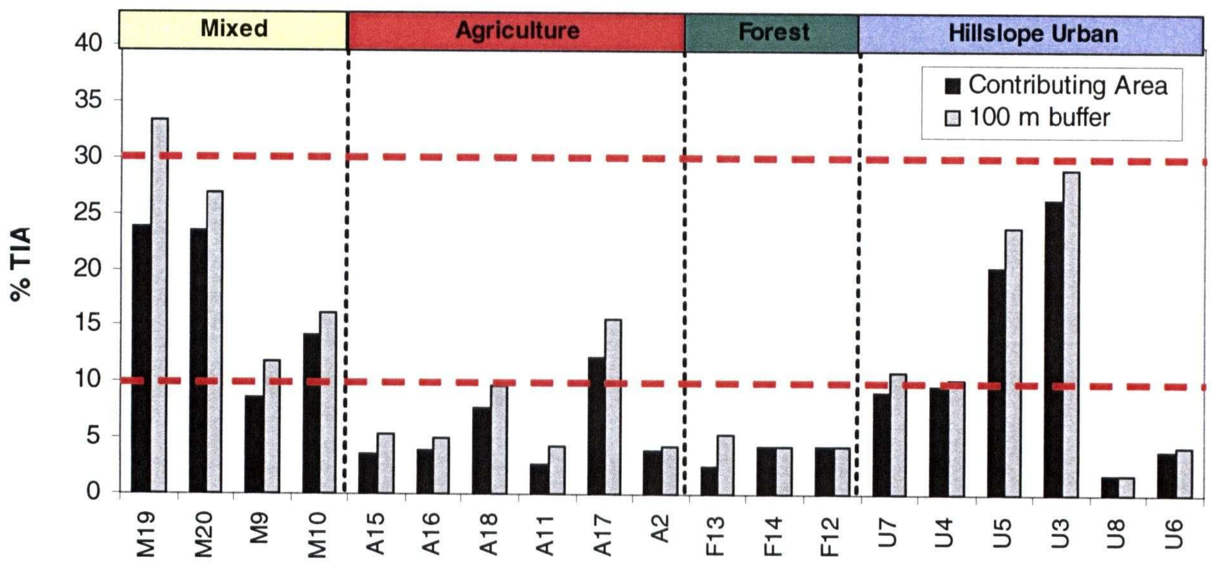


Figure 5.6 Percent Total Impervious Area by Total Upstream Contributing Area

6 CLIMATE AND HYDROLOGY

The hydrology of an area reflects the interactions between climate, physiographic factors, geology and vegetation, as well as human activity (Moore, 1991). Water inputs to the surface are determined by the climate (e.g. amount, intensity and distribution of rainfall), while the other factors control the subsequent partitioning of inputs into overland flow, soil moisture, groundwater and streamflow (Moore, 1991). Modifications of land surface (particularly during urbanization) can produce changes to the hydrologic characteristics of the land surface and modify pathways and rates of water flow. As a watershed is developed, its surfaces are made less pervious and natural channels straightened or hardened (lined with concrete); as a result there is typically more rapid runoff leading to higher peak discharge and total runoff volumes (Leopold, 1968; Anderson, 1968; Dunne and Leopold, 1978). Ultimately, these hydrologic impacts associated with urban development have serious adverse effects on the environment including: channel erosion and widening, loss of groundwater recharge, decreasing ecological diversity of the aquatic community, and downstream flooding (Booth, 1990; Konrad, 2000; Schueler, 1992; Schueler, 1994).

Our knowledge of hydrologic response is strongest in homogenous catchments, yet many resource management problems are focused on heterogeneous drainage basins where land surface characteristics are changing over time (Zhang and Smith, 2003). The continuing urban development of the hillslopes in the Chilliwack Creek watershed is especially important in terms of stormwater management problems, and it is therefore critical to understand and manage the hydrologic impacts of this drastic change in land use. This chapter will discuss both the climatic factors and trends that may influence streamflow in the Chilliwack Creek watershed, as well as the spatial and seasonal variability in streamflow. Of particular interest is the extent to which land use changes taking place on the hillslopes are contributing to changes in streamflow.

6.1 Climatic Characteristics

6.1.1 Temperature

Temperature data collected at the Chilliwack regional airport (Environment Canada climate station # 1101530) were obtained from the National Climate Data and Information Archives operated by Environment Canada (EC). Figure 6.1 shows the minimum, mean and maximum normal monthly temperatures for the 1971-2001 period. The mean annual temperature is 10.5°C at the Chilliwack regional airport (11 masl). January is the coldest month with mean a temperature of 2.3°C. July and August are the warmest months with mean temperatures of 18.5°C and 18.4°C, respectively.

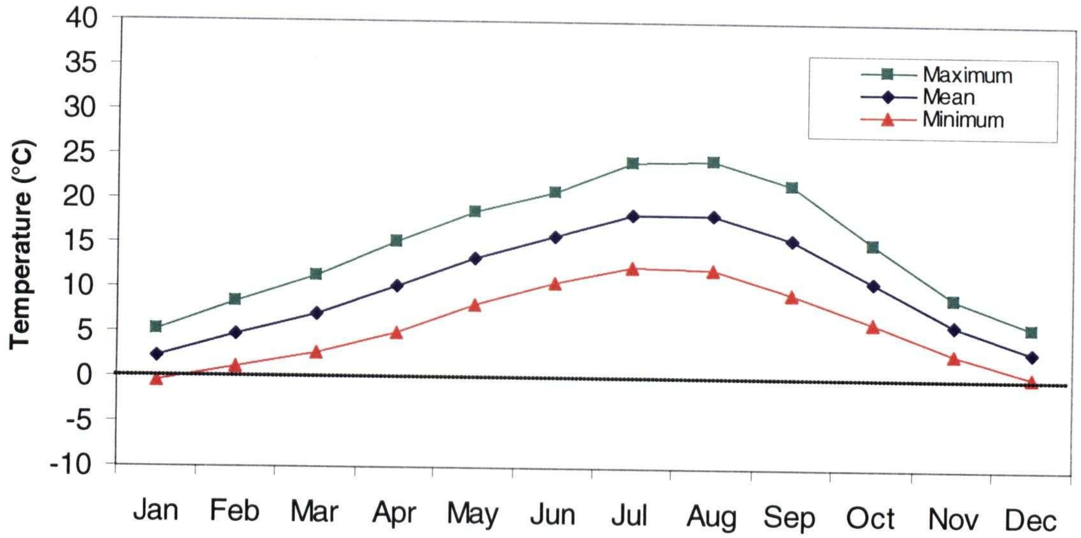


Figure 6.1 Monthly Mean Maximum and Minimum Temperatures for the 1971-2000 Normal Period, Chilliwack Climate Station (EC, 2003)

There also appears to be a warming trend between 1911 and 2001 of about 2.1°C (Figure 6.2). Moore (1991) found a similar increase in temperature at the Agassiz climate station from about 1970 on. Without further analysis, it is not possible to say whether this shift is climate related (e.g. global warming) or whether it is due to other influences.

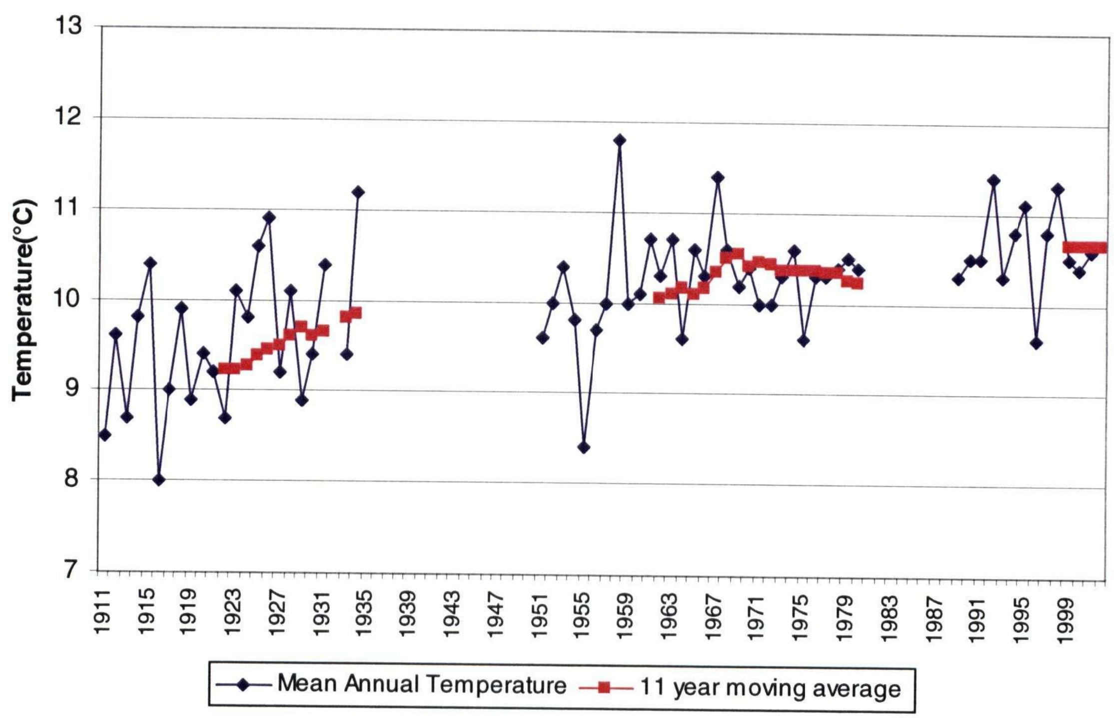


Figure 6.2 Mean Annual Temperature (°C) and 11-Year Running Means for the Chilliwack Climate Station (EC, 2003)

6.1.2 Precipitation

6.1.2.1 Temporal Trends

As shown in Figure 6.3 below, precipitation exhibits substantial inter-annual variability; and as a result, it is difficult to define trends in the data with any certainty. However, although not statistically verified there appears to be a slight increase in precipitation as well as year to year variability since the early 1900s.

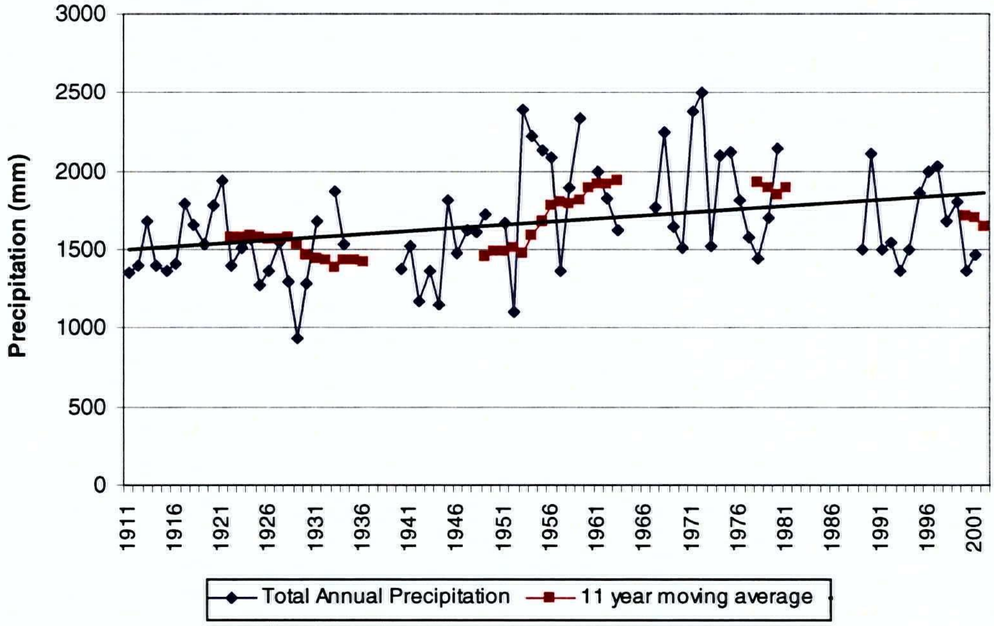


Figure 6.3 Total Annual Precipitation and 11-Year Average for the Chilliwack Climate Station (EC, 2003)

6.1.2.2 Seasonal Variations

Monthly precipitation averaged over a thirty-year period (1971-2000) is shown in Figure 6.4. The 30-year mean annual rainfall at the Chilliwack airport was 1787.8 mm, with a maximum of 271.8 mm in December and a minimum of 54.3 mm in July. An average of 72% of the precipitation at this station falls between the months of October and March; however, this trend was not observed during the sampling period itself (May 2002 to July 2003). The summer and fall of 2002 was an exceptionally dry period, which was followed by an extremely wet period. These extremes can be seen in the cumulative precipitation graph in Figure 6.5. In this figure the flatter sections represent periods with little precipitation, and the steeper sections show the wetter periods. October, in particular, had much lower precipitation than the 30-year average for that month. For this reason the dry period included October sampling. Total precipitation for August 2002 (22.5 mm), July 2003 (22.0 mm) and August 2003 (9.9 mm) were also much lower than the 30-year mean. Conversely, October 2003 (364.7 mm) and November 2003 (278.7 mm) had considerably more precipitation than the corresponding 30-year averages (Figure 6.6). Overall, the study period was a period of great variability and extremes.

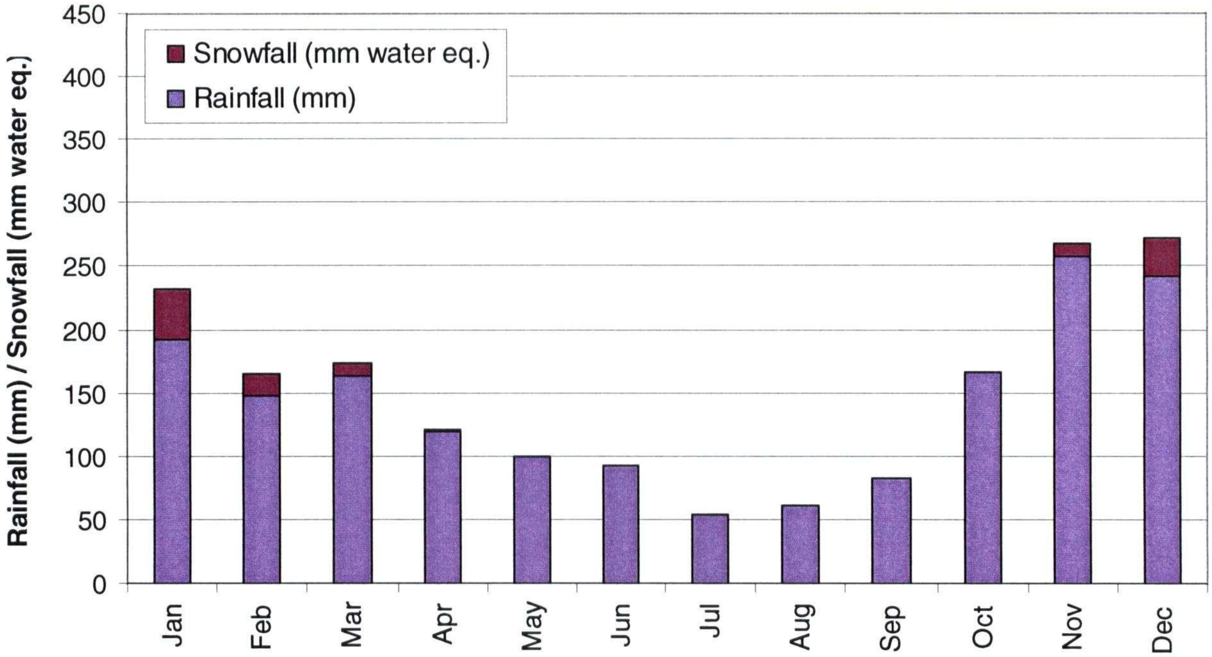


Figure 6.4 Mean Monthly Precipitation for the 1971-2000 Normal Period, Chilliwack Climate Station (EC, 2003)

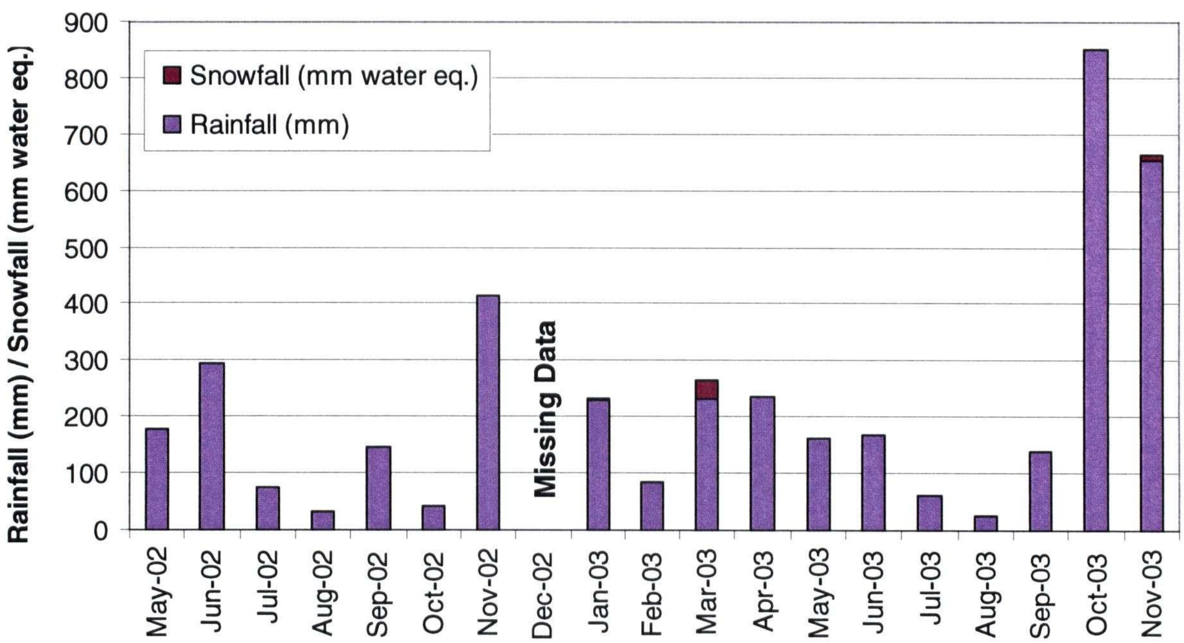


Figure 6.5 Total Monthly Precipitation for the Study Period (May 2002 to November 2003), Chilliwack Climate Station (EC, 2003)

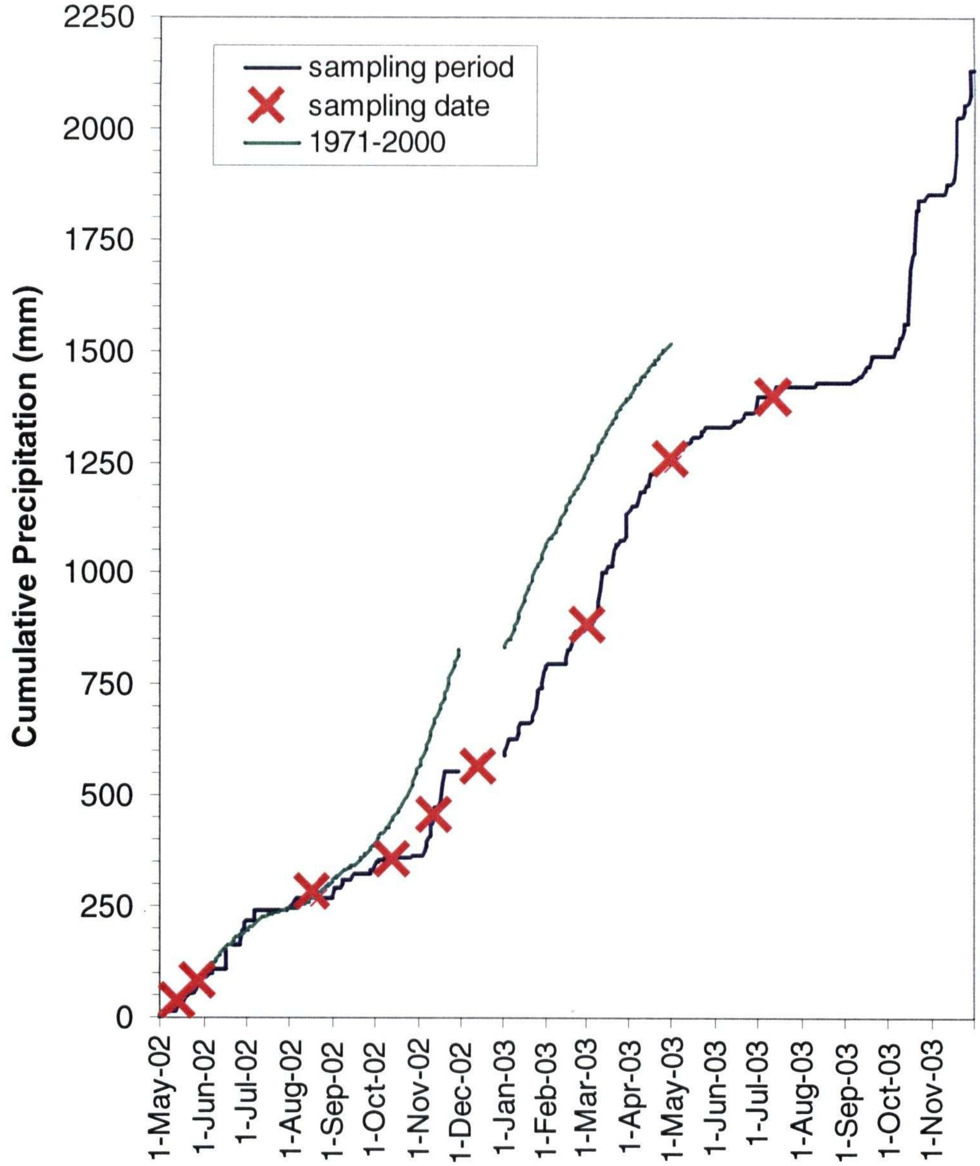


Figure 6.6 May 2002 – November 2003 Cumulative Precipitation; and Average Cumulative Precipitation. Chilliwack Climate Station (EC, 2003)

6.1.2.3 Spatial Variability

Figure 6.7 shows daily rainfall hyetographs for the different stations throughout the watershed over the study period. Using the Wilcoxon sign test, significant differences were found between the three stations. Unexpectedly, precipitation recorded at the Chilliwack climate station was significantly greater ($p<0.05$) than the precipitation recorded at both upland stations (Promontory and Marble Hill). The difference may attributed be to the fact that tipping buckets are located on the north facing slope, to an undercatch of the tipping buckets or to actual variability in storms. Precipitation at Marble Hill was found to be slightly greater ($p<0.05$) than precipitation at the Promontory station.

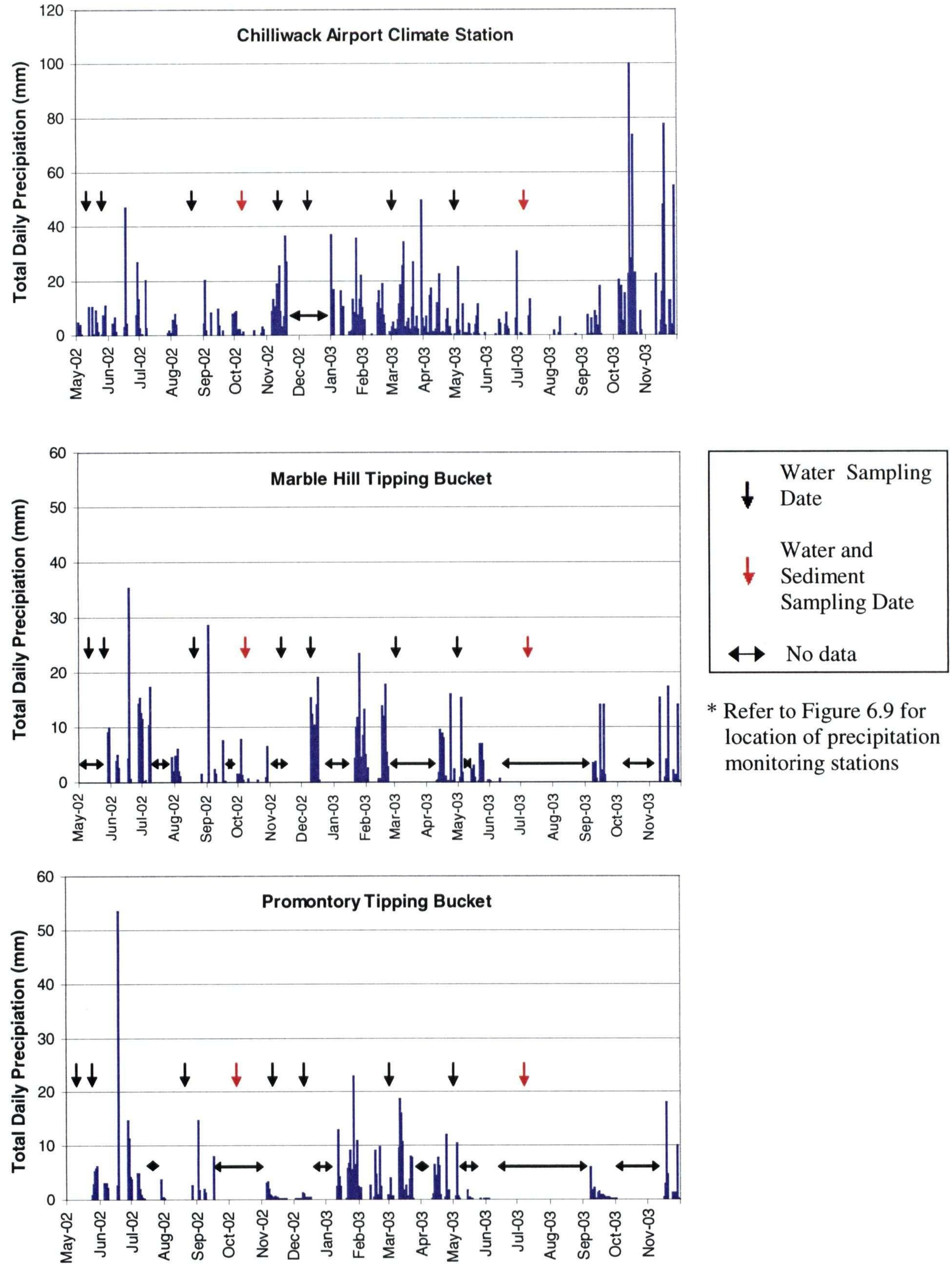
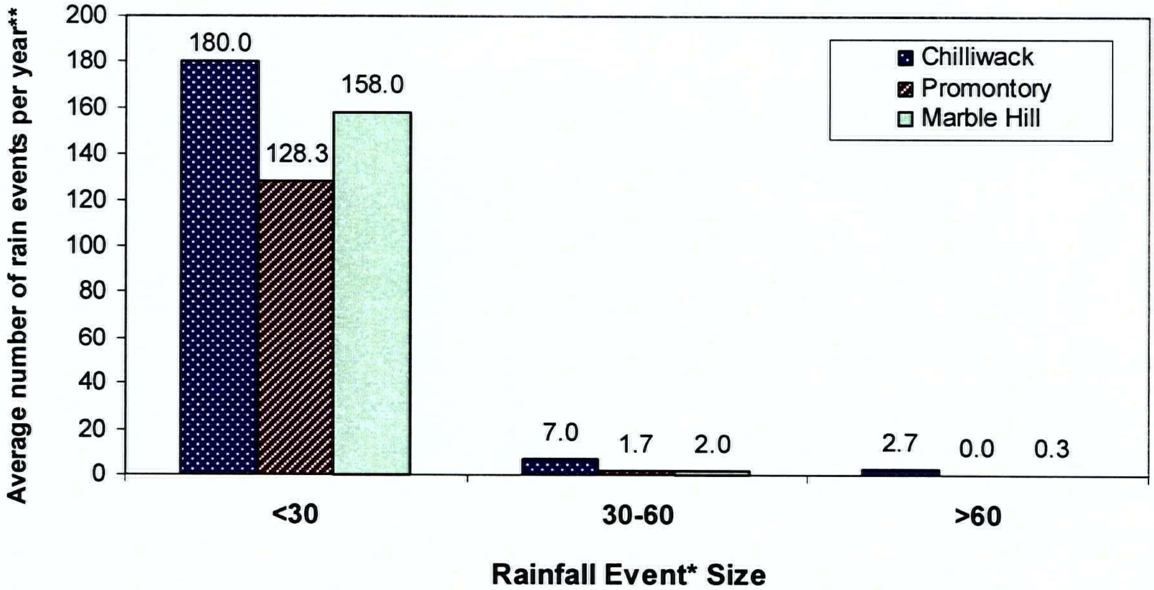


Figure 6.7 Daily Precipitation at the Various Monitoring Stations throughout the Watershed for the Study Period (May 2002 to November 2003)

6.1.2.4 Distribution of Daily Precipitation

The City of Chilliwack's performance targets for stormwater retention, detention and conveyance are based on the regional mean annual daily rainfall (MAR), which has been calculated to be 60 mm (CH2MHill, 2002a). As previously mentioned daily rainfall that is less than 50% MAR (< 30 mm) is captured on site; the next 30 mm is detained and released at the natural interflow rate; and storms greater than the MAR (≥ 60 mm) are conveyed directly to the streams (Figure 3.7).

Daily precipitation data from 2000, 2001 and 2003 were used to calculate the average annual distribution of daily precipitation relative to the three categories described above (< 30 mm, 30-60 mm, and > 60 mm). The percent of the total annual volume for each category was also calculated (Figure 6.8). Precipitation data for 2002 were excluded from the analysis because the data for December were missing at the Chilliwack climate station. Note that values were calculated for all three rain gauges; however, Promontory and Marble Hill values come from incomplete data sets. Still, it is obvious that under Chilliwack's new stormwater management plan most of the total rainfall is to be retained at the source and relatively little rainfall is to be conveyed to the outlet of a development site. Similar results were found in the study by CH2MHill (2002a).



* rainfall event defined as total daily rainfall depth	** Average of 2000, 2001 and 2003 rainfall data

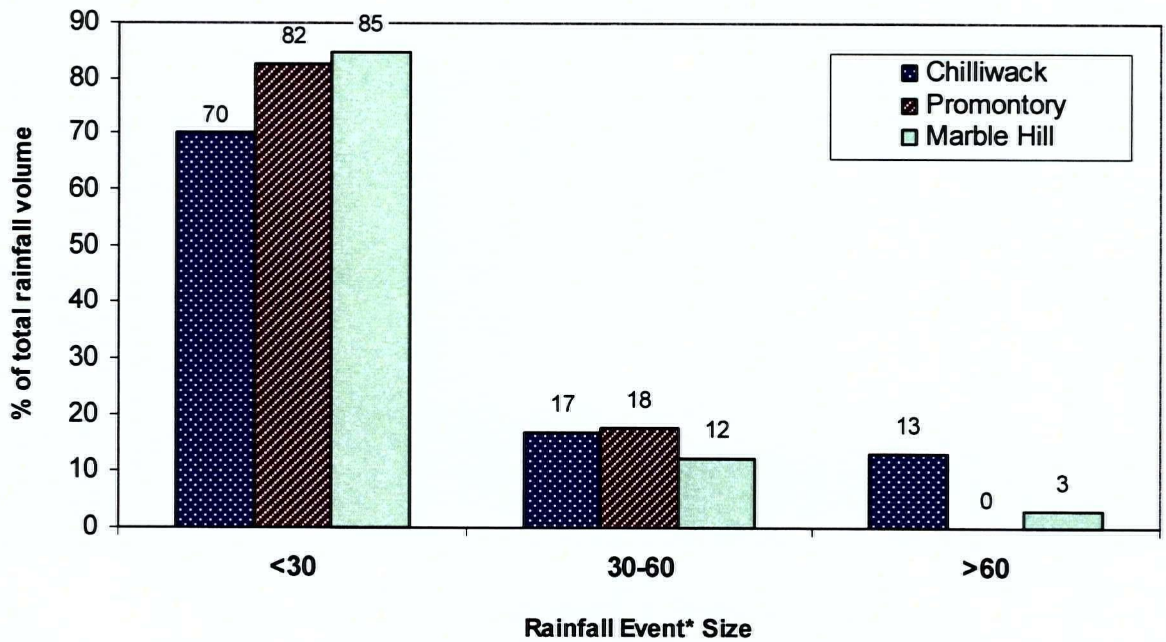


Figure 6.8 Distribution of the Number of Annual Rainfall Events (top graph); and the Distribution of the Annual Rainfall Volume (bottom graph)

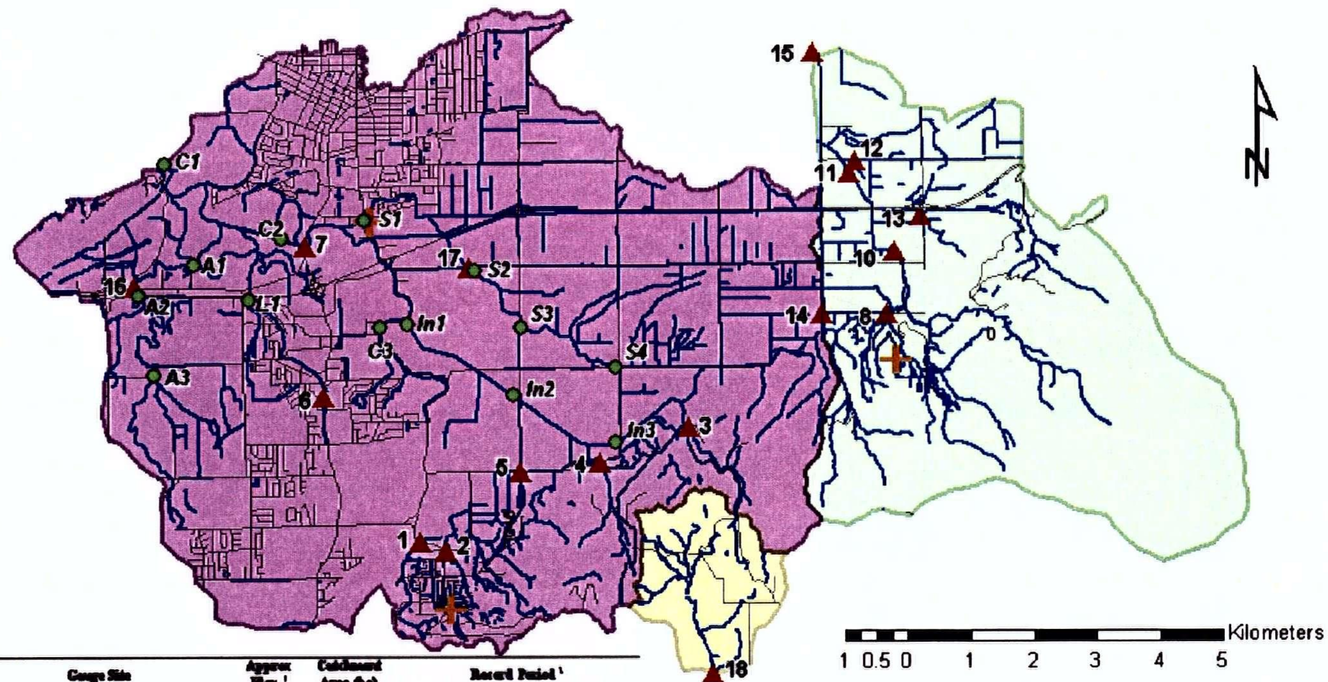
6.2 Streamflow Distribution

Continuous streamflow measurements have been made at eighteen stations throughout the Chilliwack regional district, at varying times since about 1997 (Figure 6.9). In addition, a baseflow discharge survey was performed in October 2002 at various points along Interception Ditch, Semiault Creek, Chilliwack Creek, Atchelitz Creek and Luckakuck Creek (O'Byrne, 2002).

This study focuses on the eight hydrometric stations that are within the study area itself. Each of these eight hydrometric stations has a drainage area of less than 3 km^2, with the exception of the Chilliwack Creek station (55.4 km^2) and the Semiault Creek station (10.2 km^2). Land use properties vary between the catchments. Teskey and Lefferson have experienced urbanization over the past eight years. These catchments contain impervious surfaces distributed throughout the primarily residential developments. Some of the more recent development areas were developed using low impact design technologies; however this study was done when conventional design practices were being used. Parsons and Elkview drain relatively undeveloped catchments and are used as control stations for the study. Bailey station lies at the base of the hillslope and receives water from both the urbanized upstream catchments as well as from a less developed area of the hillslope. Luckakuck Creek is spring fed, but stormwater outlets from the Sardis area are discharged into the stream above the hydrometric station. The Semiault Creek station drains the large section of the lowland agricultural area. The final station lies downstream of all these areas towards the mouth of the Chilliwack Creek.

6.2.1 Variability in Streamflow

Daily discharge varies greatly over the year. In general, the winter portion of the hydrograph is characterized by a succession of storm peaks corresponding to the passage of frequent storms, superimposed on a high base flow. Conversely, summer base flow is significantly lower. Discharge from the base flow survey carried out in October 2002 is shown in Appendix B (Table B.3). Base flow values range from 0.007 m^3/s at station C3 to 2.880 m^3/s at station C1 (both along Chilliwack Creek). For all watercourses, base flow increases in the downstream direction with one exception: the furthermost downstream station along Semiault Creek (S1) is almost ten times lower (0.063 m^3/s) than station S2 upstream (0.582 m^3/s). Water withdrawls for irrigation during the summer months is likely a major cause of the lower baseflow observed downstream. During the study period, maximum daily flows range from 0.048 m^3/s at Lefferson to 4.193 m^3/s at the Chilliwack station (Table B.4 in Appendix B). The variation in daily discharge per unit catchment area for the different sub-catchments is shown in Figure 6.10 and summarized in Table B.5 (Appendix B). It was not possible to calculate or compare monthly or annual discharge for the different stations because the data series was incomplete and had an unequal distribution of gaps between the different data sets.



	Gauge Site	Approx Elev.[1]	Catchment Area (ha)	Record Period[1]
1	Teskey Creek @ Promontory Rd.	38 m asl	64.52	November 30, 1999 to December 11, 2003
2	Lefferson Creek @ Uplands Rd.	70 asl	166.40	October 21, 1999 to December 18, 2002
3	Elkview Creek @ Wincott Rd.	130 m asl	216.55	October 15, 1999 to December 11, 2003
4	Parson's Brook @ Lindell Rd.	20 m asl	204.77	November 30, 1999 to December 20, 2002
5	Bailey Ditch @ Prest Rd.	10 m asl	436.86	November 20, 1999 o December 18, 2002
6	Luckakuck Creek @ Eden Dr.	10 m asl	N/A	April 12, 2001 to June 10, 2003
7	Chilliwack Creek @ Yale Rd.	10 m asl	5541.93	February 8, 2003 to December 31, 2003
8	Marble Hill Creek	45 m asl		April 17, 1998 to December 31, 2003
9	Ford Creek	10 m asl		November 22, 1997 to December 31, 2003
10	Elk Creek @ weir	10 m asl		January 24, 1998 to December 31, 2003
11	Elk Creek @ Springbank Farms	10 m asl		February 11, 1997 to December 8, 2003
12	Elk Creek at Brown Ditch	10 m asl		March 28, 2000 to December 31, 2003
13	Ford Creek	10 m asl		November 12, 1997 to December 31, 2003
14	Big Ditch	10 m asl		April 18, 1998 to December 8, 2003
15	Hope Slough	10 m asl		May 10, 2000 to May 26, 2002
16	Atchelitz Creek	10 m asl	1347.00	February 6, 2003 to December 31, 2003
17	Semmihault Creek @ Prairie Central Rd.	10 m asl	1016.00	January 1, 2003 to December 31, 2003
18	Ryder Creek	130 m asl	1553.00	December 20, 2001 to December 31, 2003

1) 10 m asl was used for all lowland stations
2) Incomplete data over the record period, at most stations

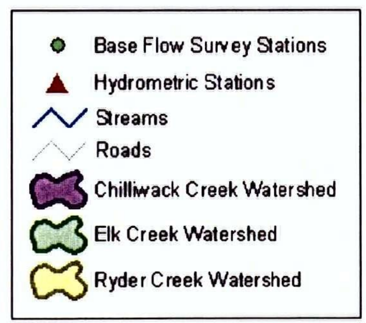


Figure 6.9 Location of Streamflow Measurements within the Chilliwack Creek, Elk Creek and Ryder Creek Watersheds

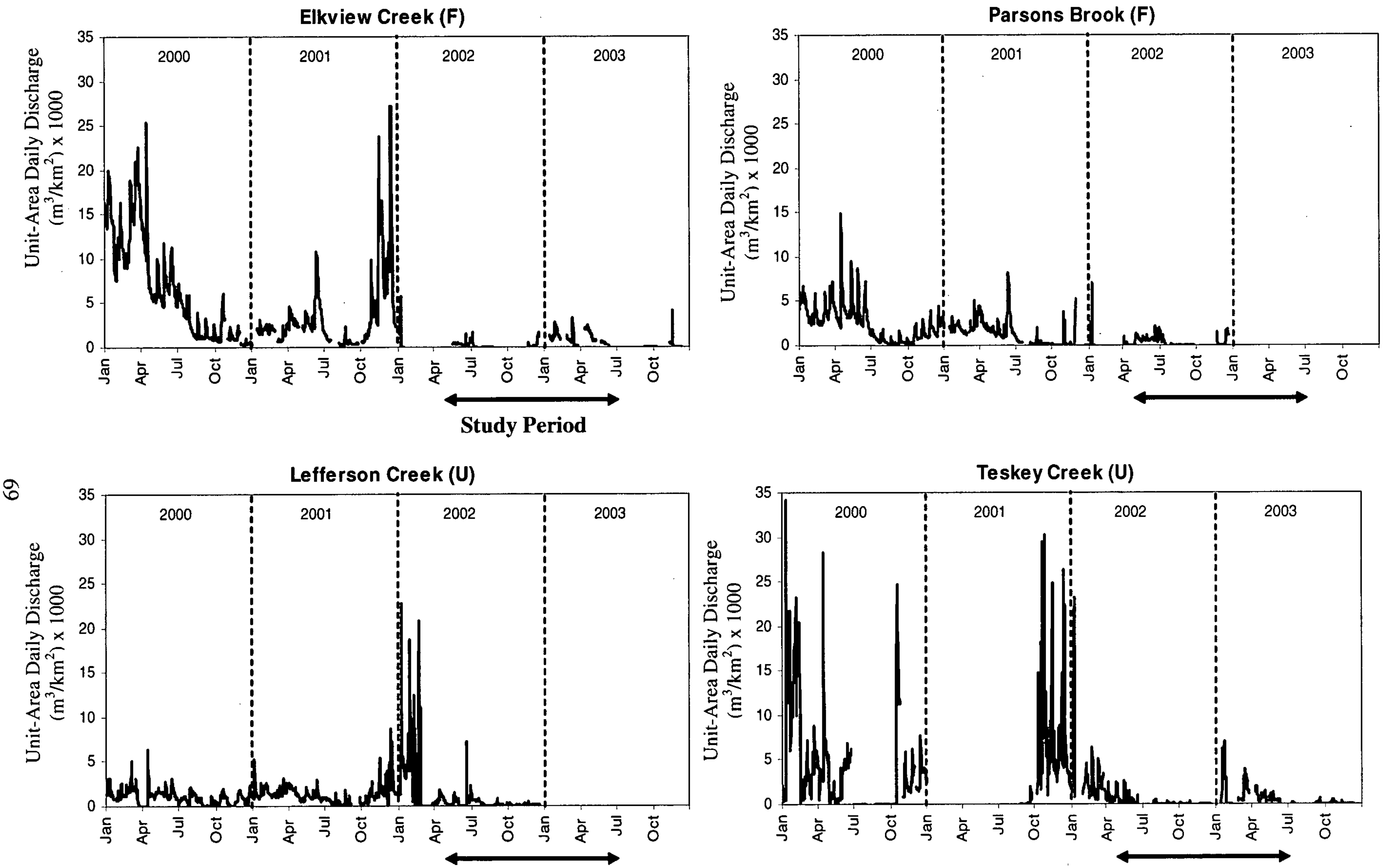


Figure 6.10 2000-2003 Total Daily Runoff (mm) for the Various Sub-Catchments in the Chilliwack Creek Watershed.

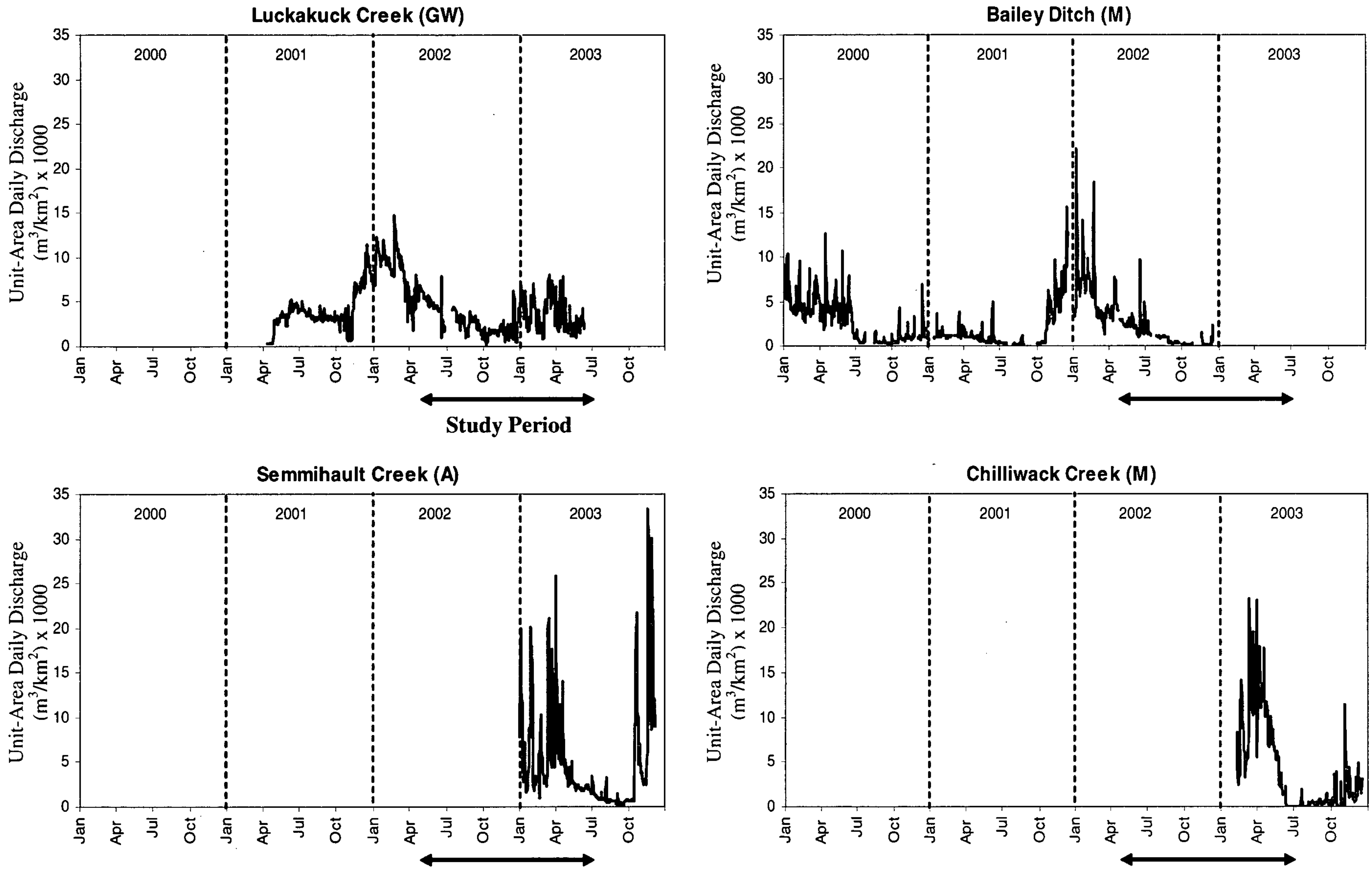


Figure 6.10 (cont.) 2000-2003 Total Daily Runoff (mm) for the Various Sub-Catchments in the Chilliwack Creek Watershed

6.3 Hydrologic Response to Storm Events

A stream's response to a rainfall event is influenced by many factors, including the intensity and duration of the storm, the topography of the basin, land use and land cover properties, and the hydrologic conditions preceding the storm event (e.g. antecedent soil moisture). In this section the storms are first classified based on the precipitation data. The hydrologic response of the Chilliwack Creek basin is then examined, with particular emphasis placed on contrasting the response of the suburbanized and the forested sub-catchments.

6.3.1 Distribution of Storm Events

The gaps in the precipitation record at both Marble Hill and Promontory stations preclude the determination of complete annual distributions. Instead, the cumulative frequency distribution graphs were created for each of the storm variables (shown in Figure B.8, Appendix B). These graphs represent storms that fall within the available data from the combined 2001-2003 record period. The cumulative distributions were generally similar for Marble Hill and Promontory.

Three storm classes were then defined (minor, intermediate and major) in relation to total rainfall and peak 15-minute intensity (Table 6.1). Table 6.2 presents the seasonal distribution of storm classes at both tipping bucket sites.

Table 6.1 Definition of Minor, Intermediate, and Major Storm Classes in Relation to Total Rainfall (mm) and Peak 15-minute intensity (mm/hr)

		Peak 15 minute Rainfall Intensity (mm/hr)		
		< 5	5 – 10	≥ 10
Total Rainfall (mm)	<10	Minor		
	10 - 30		Intermediate	
	≥ 30			Major

Table 6.2 Distribution of Storm Events in Three Storm Classes (Minor, Intermediate, Major) at Two Sites (Promontory and Marble Hill) for the Wet and Dry season

SITE	YEAR	TOTAL		MINOR		INTERMEDIATE		MAJOR		% DATA RECORD MISSING	
		WET	*DRY*	*WET*	*DRY*	*WET*	*DRY*	*WET*	*DRY*	*WET*	*DRY*
PROMONTORY	2001	57.0% (53)	43.0% (40)	50.5% (47)	34.4% (32)	6.5% (6)	7.5% (7)	0.0% (0)	1.1% (1)	17.3%	24.2%
	2002	65.2% (43)	34.8% (23)	60.6% (40)	33.3% (22)	4.5% (3)	0.0% (0)	0.0% (0)	1.5% (1)	11.2%	37.4%
	2003	94.1% (48)	5.9% (3)	82.4% (42)	5.9% (3)	11.8% (6)	0.0% (0)	0.0% (0)	0.0% (0)	27.7%	62.6%
	Overall average	68.6% (144)	31.4% (66)	61.4% (129)	27.1% (57)	7.1% (15)	3.3% (7)	0.0% (0)	1.0% (2)	18.7%	41.4%
MARBLE HILL	2001	62.6% (62)	37.4% (37)	56.6% (56)	31.3% (31)	6.1% (6)	6.1% (6)	0.0% (0)	0.0% (0)	11.2%	26.8%
	2002	56.5% (39)	43.5% (30)	44.9% (31)	34.8% (24)	10.1% (7)	7.2% (5)	1.4% (1)	1.4% (1)	45.4%	25.2%
	2003	75.0% (140)	25.0% (80)	65.4% (121)	21.2% (66)	9.6% (18)	3.8% (13)	0.0% (1)	0.0% (1)	47.0%	62.6%
	Overall average	63.6% (140)	36.4% (80)	55.0% (121)	30.0% (66)	8.2% (18)	5.9% (13)	0.5% (1)	0.5% (1)	34.5%	38.2%

Note: The top number represents the percentage of all storms belonging to a specific class; the bottom number in parenthesis is the total number of storms belonging to a specific class.

On average, 68.6 % of all storms occurred in the wet period whereas 31.4 % occurred during the dry season at the Promontory site. The majority (84.9%) of storms were minor events, while major events were infrequent (1.0 % of all storms). Over the three year record period, only two major events were captured. However, the Chilliwack climate station recorded 5 days with a total rainfall accumulation over 30 mm during the period of missing data at Promontory (Table B.9 in Appendix B), suggesting that a number of major rainfall events may not have been captured by the tipping bucket gauges. The storm class distribution within each season varied slightly between the two sites. However it is suspected that this variability is, at least in part if not primarily, due to the unequal distribution in data gaps between the two sites. The percent of record missing for both sites is shown in the last two columns of Table 6.2.

Table 6.3 gives the median and range of storm characteristics for each class, based on three years of data (2001 to 2003) from the Promontory tipping bucket rain gauge. A more detailed breakdown and additional statistics are given in Appendix B (Table B.10).

Table 6.3 Summary of "Average" Storm Characteristics for a Three Year Period (2001 to 2003). Based on data from the Promontory tipping bucket.

		Total Precip. (mm)	Peak Intensity (mm/hr)			Duration (hrs)	Ant. Dry Period (hrs)	N
			5 min	15 min	60 min			
MINOR	*Median*	3.3	3.60	2.00	2.00	4.38	31.88	187
	Range	0.4-40.6	1.2-40.8	1.0-14.0	1.0-4.0	0.3-34.5	6.3-653.0	
INTERMEDIATE	*Median*	17.3	8.40	7.00	4.50	15.00	47.75	22
	Range	10.8-80.2	6.0-79.2	5.0-27.0	3.0-8.0	2.8-46.5	8.5-215.3	
MAJOR	*Median*	49.2	28.80	20.00	14.00	22.50	173.00	2
	Range	44.6-53.7	20.4-37.2	16.0-24.0	9.0-19.0	6.3-38.8	117.0-229.0	

6.3.2 Storm Response Characteristics

Storms with a total rainfall accumulation greater than 10 mm were investigated in further detail. For each event, a number of storm response variables were calculated. The magnitude of the event is represented by peak discharge. Response time is represented by the lag to peak value, which was computed as the time difference between the peak discharge and peak rainfall. The storm response variables for individual storm events are listed in Appendix B, and summarized for the eight hydrometric stations in Table 6.4 below.

Table 6.4 Summary of Storm Response Variables for the Various Hydrometric Stations in the Chilliwack Creek Watershed

Station		Peak Discharge (m^3/s)	Peak Runoff Rate (mm/hr)	Lag Time (hrs)
Parsons (F)	*Median*	0.110	0.194	14.00
	Range	0.029-0.241	0.052-0.423	2.28-31.75
Elkview (F)	*Median*	0.134	0.223	14.00
	Range	0.041-0.732	0.067-1.217	0.25-31.25
Lefferson (U)	*Median*	0.024	0.152	1.25
	Range	0.009-0.288	0.059-1.803	0.00-12.25
Teskey (U)	*Median*	0.421	0.92	0.38
	Range	0.076-1.724	0.165-3.731	0.00-7.00
Luckakuck (GW)	*Median*	0.220	0.267	2.75
	Range	0.129-0.681	0.156-0.827	0.25-13.00
Bailey (M)	*Median*	0.385	0.317	6.25
	Range	0.031-1.058	0.025-0.872	1.00-38.25
Semiault (A)	*Median*	3.052	0.710	8.88
	Range	0.808-5.162	0.187-1.196	5.25-47.25
Chilliwack (M)	*Median*	3.479	0.806	9.00
	Range	0.905-4.816	0.180-1.617	4.00-17.75

6.3.2.1 Between Catchment Comparisons

The storm response variables were compared across six of the sub-catchments using a Wilcoxon sign test. Chilliwack and Semiault were omitted from this analysis. The results of the significance tests are provided in Appendix B (Table B.19).

The Teskey catchment showed significantly shorter lag times than all the other catchments, while both the forested catchments (Parsons and Elkview) had significantly longer lag times than other catchments. It is interesting to note that the Luckakuck catchment showed significantly shorter lag times than all stations except Teskey and Lefferson. Trends for lag times at the different catchments can be seen in Figure 6.11.

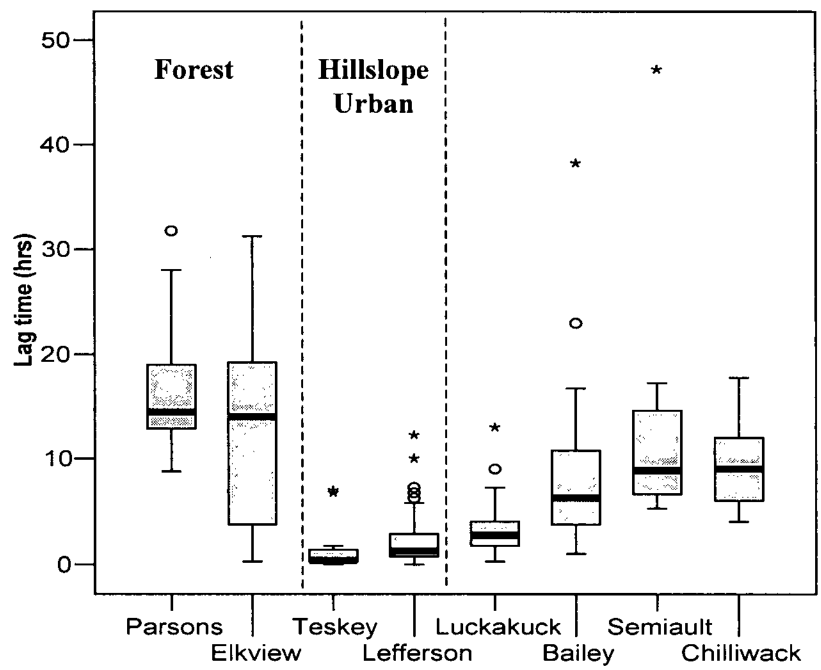


Figure 6.11 Lag Time: Boxplots for the Different Sub-Catchments within the Chilliwack Creek Watershed

Peak runoff rates were highest at the Teskey catchment. Lefferson had significantly lower peak runoff rates than all catchments with the exception of Elkview and Parsons. All other stations had statistically similar peak runoff rates, with one exception: Bailey had significantly lower peak runoff rates than Elkview. Boxplots comparing peak runoff at the various catchments are shown in Figure 6.12.

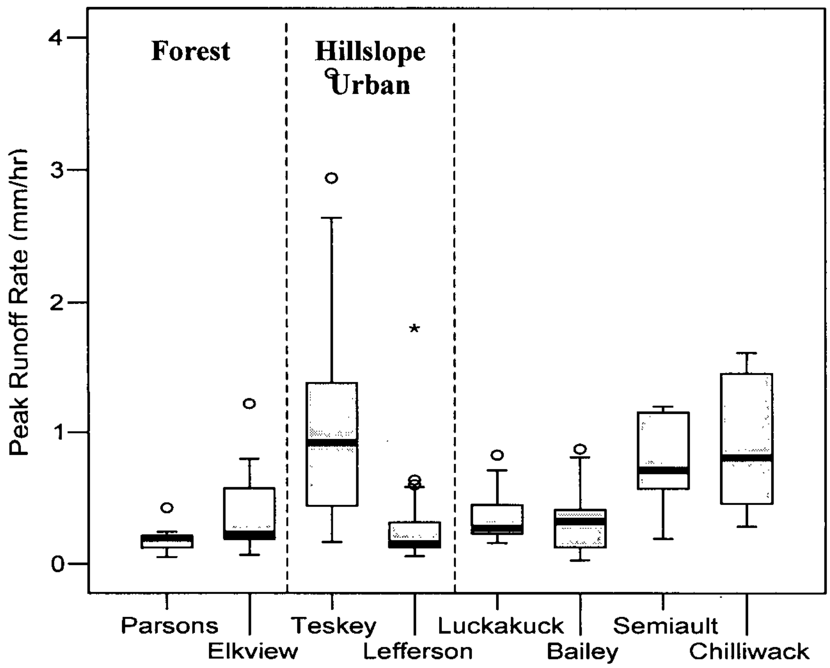


Figure 6.12 Peak Runoff Rate: Boxplots for the Different Sub-Catchments within the Chilliwack Creek Watershed

In summary, the two forested catchments (Parsons and Elkview) did not show any significant differences from each other; while the two urban stations (Lefferson and Teskey) were significantly different for all the variables. Teskey (the most urbanized catchment) had a shorter lag time, and higher peak discharge and peak runoff rate than Parsons (the least developed catchment). Significant differences ($p<0.05$) were also found between Elkview (forested) and Teskey (U) for all variables.

6.3.3 Hydrograph Comparison of Individual Storm Events

A subset of six storm events is used to further investigate the response of the various sub-catchments. The storms were selected to represent a range of rainfall conditions (Table 6.5). In total, two minor, three intermediate, and one major storm were selected. The following section will outline the characteristics of these storm events and the response of each catchment. A complete table of response variables for each storm event is given in Appendix B. The hydrographs not presented in this section can also be found in Appendix B.

Table 6.5 Rainfall Summaries for the Six Selected Storm Events Based on Data from the Promontory Tipping Bucket Rain Gauge

Event	Duration (hrs)	Total Rain (mm)	Ant. Dry Period (hrs)	Peak Rain (mm)	Peak Intensities (mm/hr)			Fraction of Storm Total Rainfall exceeding rainfall rates of (mm/hr)[1]:				Storm Class
					5 min	15 min	60 min	% > 2.5	% > 5	% > 10	% > 25	
8Mar-01	19.00	18.1	60.25	1.3	7.2	5.2	3.6	7.9	1.3	0	0	Intermediate
26-Oct-01	25.50	32.5	25.5	0.9	4.8	4.0	3.3	8.8	0	0	0	Minor
3-Nov-01	30.50	40.6	14.75	1.1	6.0	4.4	3.4	11.5	0	0	0	Minor
8-Dec-01	14.75	22.1	30.50	0.9	18.0	6.8	3.2	18.6	1.7	0	0	Intermediate
7-Jun-02	6.25	53.7	229.0	5.8	37.2	24.0	18.9	72.0	56.0		40.0	Major
10-Mar-03	17.00	18.9	10.25	0.9	7.2	5.6	4.0	14.7	0	0	0	Intermediate

[1] Fractions based on 15 minute rainfall intensity

Minor Storm Events: October 26, 2001 and November 13, 2001

Of the 6 storm events, the two minor storms had the longest rainfall durations and 15-minute rainfall intensities below 4.5 mm/hr. Total rainfall accumulation for both storms is on the upper range for minor storm events. The 26-October-2001 storm produced rainfall accumulation of 32.5 mm during a 25.5 hour period, while the 13-November-2001 storm event produced a slightly higher (40.6 mm) rainfall accumulation over a 30.5 hour period. A summary of values for a few key response variables is shown in Table 6.6, and the hydrograph for each storm event is shown in Figure 6.13.

Table 6.6 Lag Time and Peak Runoff Rate for Each Catchment for Two Minor Storm Events

	Hillslope Stations				Downstream Stations			
	Parsons	Elkview	Teskey	Lefferson	Luckakuck	Semiault	Bailey	Chilliwack
Land Use:	*Forest*	*Forest*	*Urban*	*Urban*	*Spring-Fed*	*Agriculture*	*Mixed*	*Mixed*
26-Oct-01 Storm Event								
Peak Runoff Rate (mm/hr)	n/a	0.58	3.73	0.22	0.25	n/a	0.36	n/a
Lag Time (hrs)	n/a	19.25	6.75	6.75	13.00	n/a	38.25	n/a
13-Nov-01 Storm Event								
Peak Runoff Rate (mm/hr)	n/a	1.22	1.88	0.31	0.39	n/a	0.50	n/a
Lag Time (hrs)	n/a	10.75	0.00	10.00	0.25	n/a	10.75	n/a

Intermediate Storm Events: March 18, 2001; December 8, 2001 and January 25, 2003

The intermediate storms had the lowest total rainfall accumulations of the six storm events at 18.1 mm, 22.1 mm and 18.95 mm. Antecedent dry conditions ranged from short (10.25 hrs) for the 18-March-2003 event to relatively long (60.25 hrs) for the 18-Mar-2001 event. However, it should be noted that the antecedent condition prior to the small event (<10 mm) which preceded the March event was 189 hrs. A summary of the response variables is presented in Table 6.7. The hydrograph for the 18-Mar-01 storm event is shown in Figure 6.13.

Table 6.7 Lag Time and Peak Runoff Rate for Each Catchment for Three Intermediate Storm Events

	Hillslope Stations				Downstream Stations			
	Parsons	**Elkview**	**Teskey**	**Lefferson**	**Luckakuck**	**Semiault**	**Bailey**	**Chilliwack**
Land Use:	*Forest*	*Forest*	*Urban*	*Urban*	*Spring-Fed*	*Agriculture*	*Mixed*	*Mixed*
18-Mar-01 Storm Event								
Peak Runoff Rate (mm/hr)	0.18	0.20	n/a	0.34	n/a	n/a	0.38	n/a
Lag Time (hrs)	14.00	16.00	n/a		n/a	n/a	3.75	n/a
8-Dec-01 Storm Event								
Peak Runoff Rate (mm/hr)	n/a	0.74	1.44	0.41	0.51	n/a	0.59	n/a
Lag Time (hrs)	n/a	3.00	1.50	0.00	0.25	n/a	6.25	n/a
10-Mar-03 Storm Event								
Peak Runoff Rate (mm/hr)	n/a	0.19	0.75	n/a	0.39	0.75	n/a	1.62
Lag Time (hrs)	n/a	2.75	1.25	n/a	3.25	17.25	n/a	15.25

Major Storm Event: June 17, 2002

The minor and intermediate storms described above were the product of modest rainfall accumulation over medium to long duration during the wet season. In contrast, the 17-June-2002 storm is a short duration, high intensity rainfall event during the dry season. This shortest storm event produced the highest rainfall accumulation at 53.7 mm delivered over a period of 6.25 hours. Peak rainfall rates exceeded 37 mm/hr at the 5 minute interval, and forty percent of the total rainfall fell at rates exceeding 25 mm/hr at the 15-minute interval. This summer storm also had the longest antecedent dry period at 229 hours (almost four times longer than any of the other storms described). The 17-June-2002 event was the largest storm in the 2001-2003 Promontory record; however the missing portion of the record includes two storms with daily precipitation totals greater than 60 mm (110.3 mm on 16-October-2003, and 73.8 mm on 20-October-2003) as measured at the Chilliwack climate station. The storm response for the various catchments are summarized in Table 6.8, and shown in Figure 6.14. It is interesting to note that for this event Lefferson has a much higher peak runoff and total runoff than Teskey, which is opposite of the usual trends.

Table 6.8 Lag Time and Peak Runoff Rate for Each Catchment for a Major Storm Event

	Hillslope Stations				Downstream Stations			
	Parsons	**Elkview**	**Teskey**	**Lefferson**	**Luckakuck**	**Semiault**	**Bailey**	**Chilliwack**
Land Use:	*Forest*	*Forest*	*Urban*	*Urban*	*Spring-Fed*	*Agriculture*	*Mixed*	*Mixed*
26-Oct-01 Storm Event								
Peak Runoff Rate (mm/hr)	0.24	0.21	0.38	1.80	0.71	n/a	0.71	n/a
Lag Time (hrs)	12.75	2.00	0.50	1.00	2.75	n/a	9.75	n/a

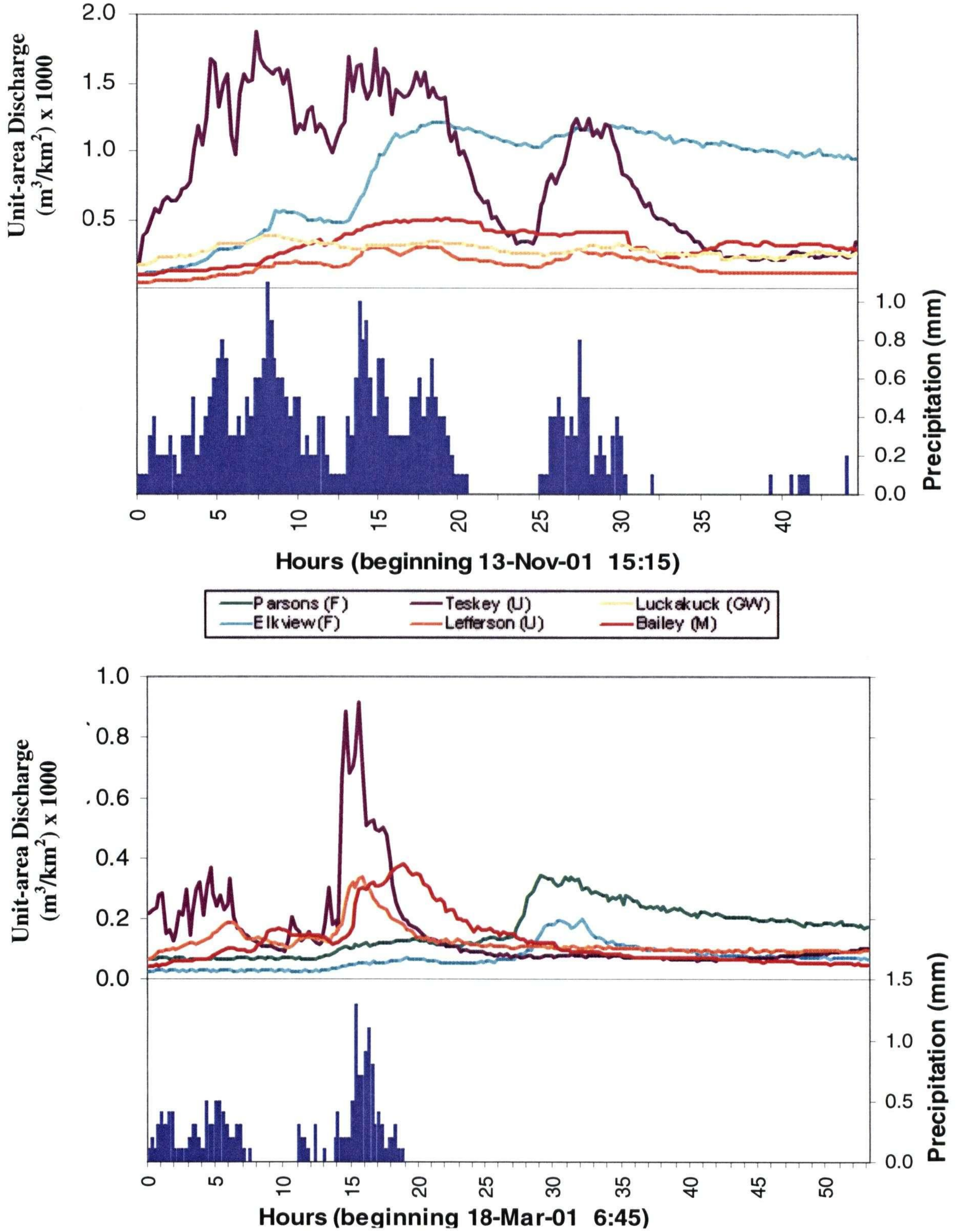


Figure 6.13 Hydrograph for a Minor (12-Nov-01) and Intermediate Storm Event (18-Mar-01)

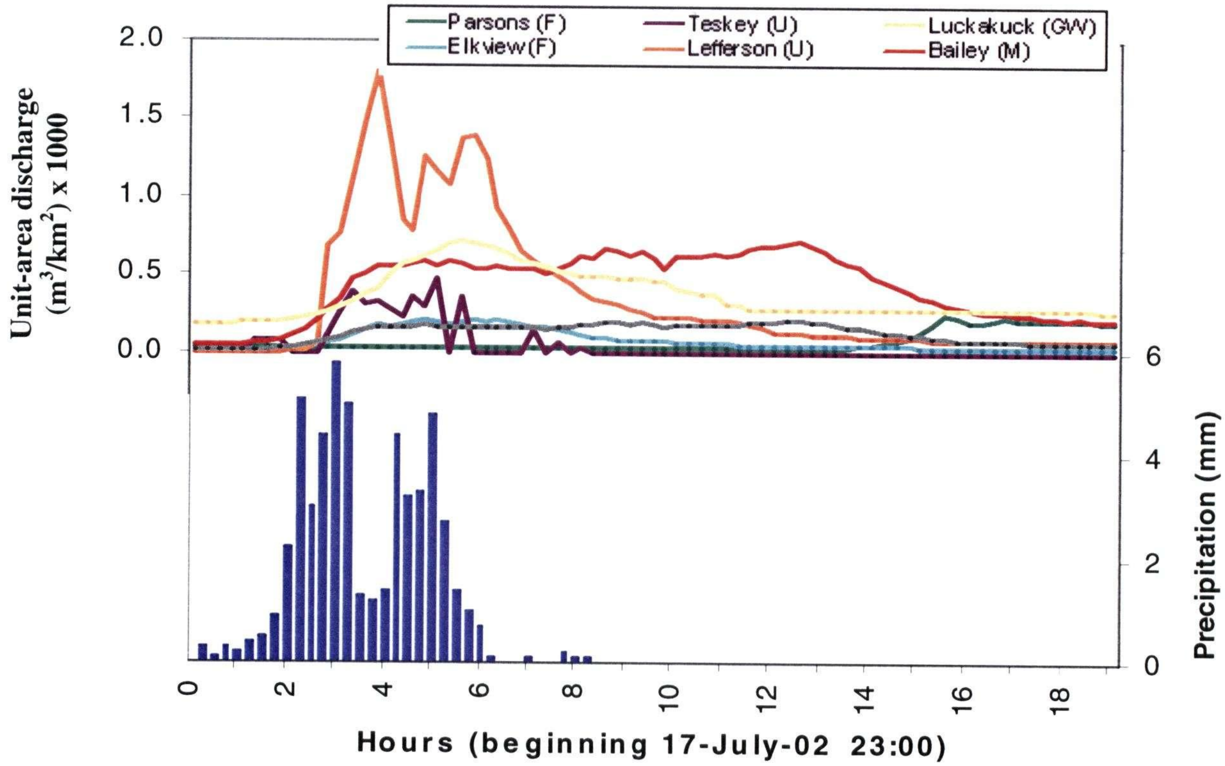


Figure 6.14 Hydrograph for a Major Storm Event (17-Jul-02)

6.3.4 Comparison between Forest and Urban Hillslope Catchments

Land use on the hillslope has been changing over the last 10 years. Because the hydrologic data record is only a few years long it was not possible to detect the effects of changing land use within the same catchment. Instead a comparison of the urbanized section of the hillslope and the forested area was used to examine the potential effects of urbanization. The Parsons and Teskey catchments were chosen because they were determined to be the best examples of a forested and developed hillside catchment, respectively. The differences between Parsons and Teskey catchments for lag time and peak runoff rate are shown in Table 6.9 for each storm class separately and for all storms combined.

Table 6.9 Differences in Lag Time, Peak Runoff and Total Runoff between the Teskey (Urban) and Parsons (Forested) Catchments, for Three Storm Classes

		Minor	Intermediate	Major	All Storms
	N =	*5*	*6*	*1*	*13*
Lag Time (hrs)[1]	*Max diff.*	31.75	19.5	12.25	31.75
	Min diff.	13.5	8.5		8.5
	Mean diff.	19.65	13.29		15.85
Peak Runoff Rate[2]	*Max diff.*	1214%	1519%	159%	1519%
	Min diff.	106%	116%		106%
	Mean diff.	411%	524%		447%

[1] Values represent how much longer the response time is at Parsons than at Teskey (in hours)

[2] Percentage represents the value at Teskey expressed as a percent of the value at Parsons. Note that a value greater than 100% indicates that the value at Teskey is greater than Parsons; and a percentage less than 100% indicates that the value at Parsons is greater.

These results indicate that:

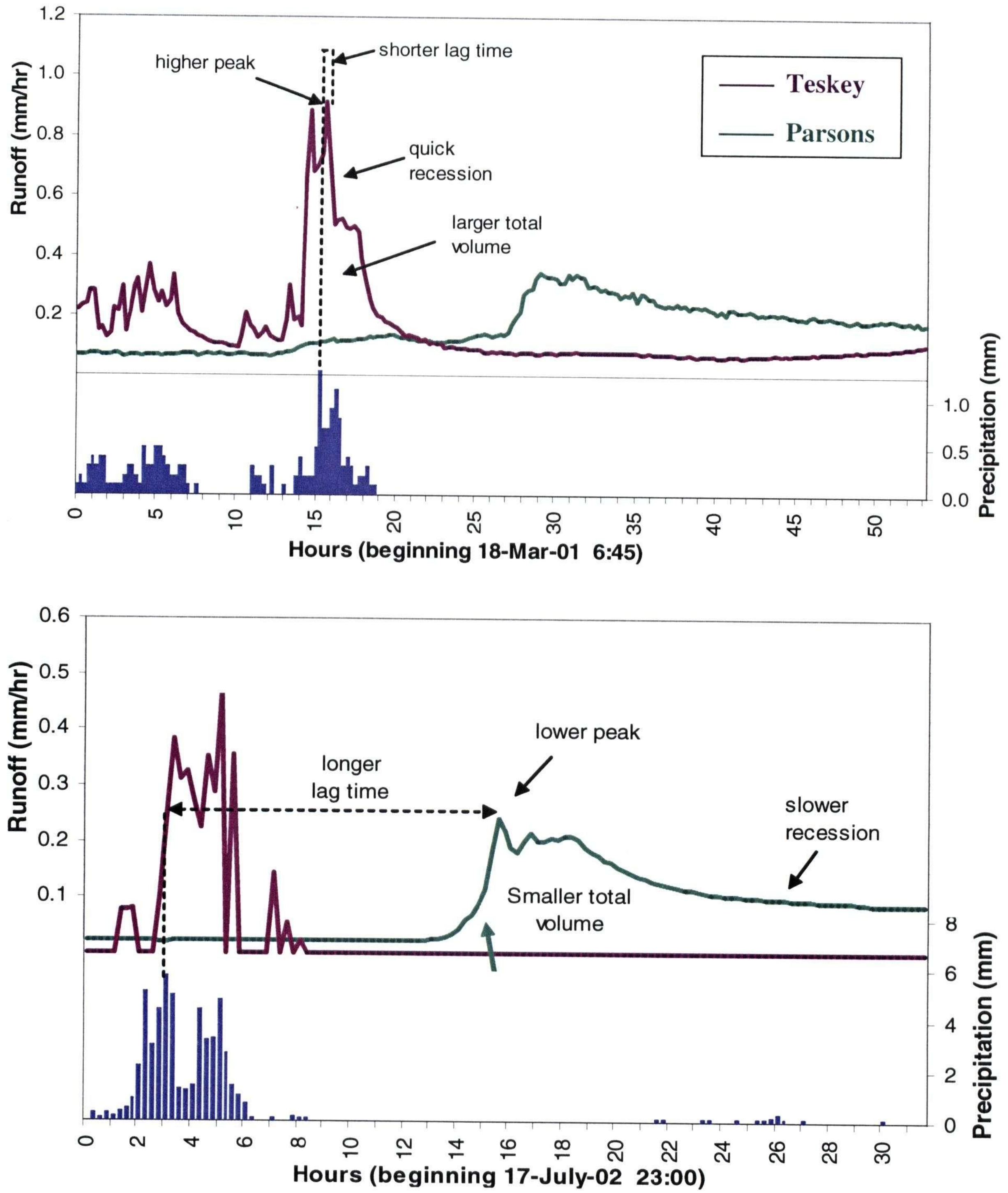
a) Lag time was much longer at Parsons than at Teskey (between 8.5 and 31.75 hours longer over all storm events); and

b) Peak runoff rates at the Teskey station were higher than at the Parsons station - up to 15 times greater during an intermediate storm event. Not all events were significantly greater; peak runoff rates showed less than a 16% increase for some minor and intermediate events.

The results for one major event were included in Table 6.9; however, it should be noted that there is some uncertainty as to the validity of these results. Unexpectedly, peak runoff rate showed relatively little difference between Teskey and Parsons for this storm event. Lefferson (the other urban station, which usually has the lowest peak runoff rate) had a much higher peak runoff rate than both Teskey and Parsons. Peak runoff values at Lefferson were 4.7 and 5.7 times greater than at Teskey (respectively), and 7.5 times and 5.0 times greater than at Parsons according to the available data.

Hydrograph Comparison:

Figure 6.15 below shows graphically the difference between the storm response at Teskey and the storm response at Parsons for two different storm events: an intermediate storm event on 18-Mar-2001 and a major storm event on 17-Jun-2002. The top graph highlights the response typical of an urbanized catchment, and the bottom graph highlights the response typical of a forested catchment.



Catchment		Area (ha)	TIA (%)	
			CA	100m buffer
Parsons	Forested	204.77	26.3	29.0
Teskey	Urban	64.52	4.3	4.2

Annotation: The top graph highlights the 'typical' characteristics of an urbanized catchment. The bottom graph highlights the 'typical' characteristics of a forested catchment.

Figure 6.15 Comparison of Teskey (urban) and Parsons (forested) Hydrographs for Two Storm Events

6.4 Data/Analysis Considerations

In using this approach to identify the hydrological response of the different catchments (and ultimately the hydrologic consequences of urbanization of the hillslope) there are a number of concerns in the data and analysis that must be mentioned: 1) the length of the hydrological records is relatively short; 2) there is an unequal distribution of gaps between the different stations, and therefore it is difficult to compare estimates and results may be unreliable; 3) the natural variability of hydrological systems is generally high; 4) land use impacts are compounded by the complexity of hillslope processes, and potentially, by climate variability (as a result, differences in streamflow cannot be attributed solely to land use, but may also reflect differences in geology, topography, storm patterns *etc*); and 5) rainfall may not be uniformly distributed over the catchment.

While this is a somewhat crude method, the analysis does provide a first approximation of the magnitude of storm events for the different catchments in the watershed.

7 WATER AND SEDIMENT QUALITY

For this study, measurements of ambient water quality, both in the water column and in the sediments, were used to define the status of water quality in the watershed, to identify and quantify trends in water quality and to evaluate overall impacts of various sources of pollution. Specific parameters and streamwater constituents were used as indicators[1] to provide a representative picture of water quality. The indicators themselves may not negatively affect the aquatic environment; they may, however, suggest the presence of harmful constituents or potential for future degradation (Hayman, 2000). The major polluting sources expected from the different land use activities within the watershed determined the choice of parameters. Table C.1 lists the chosen parameters and the land uses that may impact the parameters (Appendix C).

It should be noted that this study focuses on chemical indicators, which by themselves cannot fully answer questions about the ecological response to a pollutant. Often by the time chemical concentrations reach a detectable level at the basin scale substantial insult to the ecosystem may have already occurred (Cairns, 1993). Also, knowledge of chemical concentration is not always representative of biological availability. Biological indicators, on the other hand, are continually exposed to the effects of various stressors and are therefore able to integrate the indirect and interactive effects of many different stressors over time (Chapman and Kimstach, 1996). As a result, they can identify impairments of aquatic life from unknown or unregulated chemicals and non-chemical impacts that chemical monitoring is unlikely to reveal.

The following section briefly discusses each variable measured with respect to its origins, possible sources and its behavior and transformation in the aquatic system. Next, this chapter examines the current water quality conditions of the watercourses in the Chilliwack Creek watershed by looking at the spatial and temporal trends in the collected water quality and sediment data, and by comparing the collected data to water quality and sediment guidelines. The data from the sampling stations were grouped into three categories according to the dominant land use in the area immediately upstream of the sampling sites (agriculture, forest and urban as outlined in Table 4.1); statistical methods were then used to compare these groups. The focus of this chapter is to determine if surface water quality is different in the agricultural, urban and forested areas of the watershed. However, the specific relationship between land use and water quality is not emphasized here since it is explored in depth in a subsequent chapter.

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[1] Indicators are characteristics of the environment that, when measured, provide information about the current status of specific pollutants in the ecosystem, suggest potential for future degradation and identify responses to both anthropogenic and other stresses (Cairns et al., 1993).

7.1 Sediment and Water Quality Indicators

7.1.1 Nutrients

When present in excess, nitrogen and phosphorus are the nutrients of most concern for water quality. Nutrient enrichment, particularly phosphorus since it is generally the limiting nutrient for plant productivity, contributes to excessive growth of aquatic vegetation and algae - a process known as eutrophication (Correll, 1998). This excess growth can ultimately lead to depressed oxygen levels when this plant material decomposes. In addition, certain blue-green algae associated with eutrophic waters form toxins, which can pose a health risk to both livestock and humans (Sharpley et al., 1994). Accelerated eutrophication causes a general deterioration of water quality and often limits the use of surface water for drinking, industry, recreation and fisheries purposes (Hayman, 2000). This section focuses on the sources, fate and chemistry of these nutrients in a watercourse.

7.1.1.1 Nitrogen (Nitrate, Nitrite and Ammonia)

Nitrogen is an important nutrient for many aquatic organisms, particularly aquatic plants, as it is a vital component of amino acids and proteins (Hatch et al., 2002). It occurs in many forms in the environment and takes part in many biochemical reactions. However, when present in excess of local requirements, nitrogen can lead to pollution of watercourses. In the context of water pollution, nitrogen occurs in three forms that are of known concern: ammonia (NH_3, which dissolves to form NH_4^+), nitrite (NO_2^-) and nitrate (NO_3^-) (Waite, 1984).

Most nitrogen enters the aquatic system naturally from the atmosphere and the soil through a process called nitrogen fixation. Nitrogen fixation is primarily performed by algae and various nitrogen fixing bacteria. Nitrogen can also enter the aquatic system due to ammonification, a process where bacteria break down organic matter to create ammonia. Consequently, increased concentrations of ammonia could be a useful indicator of organic pollution from sewage sludge or manure runoff. Ammonia can be found in two forms in water: as un-ionized ammonia NH_3, or as the ammonium ion NH_4^+. At a neutral pH typical of most natural waters the latter predominates. However, high temperatures and higher pH (pH>8) can cause a shift from the ammonium ion to the more toxic un-ionized ammonia form (Burt et al.,1993; Sharpley et al., 1994). Ammonia concentrations greater than 2.5 mg/L have been shown to be toxic to many aquatic organisms (Eghball and Billey, 1999). Ammonia (NH_3) is also the predominant form of nitrogen under anoxic conditions, such as those found within sediments.

When sufficient oxygen is available, ammonia that enters the watercourse is rapidly oxidized to nitrate by the activities of microorganisms. This process, known as nitrification, occurs in two steps: ammonia is first converted to the intermediate form nitrite, which is then oxidized to nitrate. While nitrite is quite toxic to aquatic life, the usually rapid oxidization of nitrite to nitrate prevents high concentrations from accumulating in aquatic systems. However, under conditions of high temperature and poor aeration ammonia oxidation exceeds nitrite oxidation, and nitrite can accumulate (Hatch et al., 2002). Under anaerobic conditions nitrate can be reduced to nitrite, and in most cases further reduced to nitrogen gas (N_2). This process is called denitrification, and it is how nitrogen is lost from the system (Burt et al., 1993).

Nitrification of ammonia to nitrate is a key process which mobilizes nitrogen and promotes its loss from agricultural fields to watercourses (Hatch et al., 2002). Nitrate is relatively stable, very soluble and because of its negative charge does not become fixed on clay or organic matter. It therefore remains highly mobile and is the major source of nitrogen pollution to watercourses. On the other hand, ammonia is positively charged and tends to be relatively immobile. However, in soils subject to erosion it can occasionally be removed and reach watercourses in overland flow.

Although nitrogen occurs naturally in unpolluted waters, it is generally found in low concentrations (0.07 to 2.3 mg/L) (Stednick, 1991). Concentrations of nitrogen in streams are increased through human sources such as municipal sewage discharge, leaching or runoff of inorganic nitrate fertilizers through soil in suburban and rural areas, agricultural runoff of manure or inorganic fertilizers, and leaking of septic tanks.

Nitrate pollution has been considered a hazard to human health for many years for two reasons. First, concentrations exceeding 10 mg/L were associated with methomeglobemia (blue-baby syndrome), and secondly, the ingestion of large amounts of nitrate was thought by some to cause stomach cancer (Addiscott et al., 1991). However, recent medical research has questioned some of the reasoning behind this established view (Addiscott et al., 1999; Hatch et al., 2002).

7.1.1.2 Phosphorus (Orthophosphate)

Phosphorus (P) is an essential nutrient for algae and plants, yet it is also one of the scarcest elements available in both terrestrial and aquatic ecosystems in terms of its demand (Leinweber et al., 2002). While phosphorus is present in numerous different forms, only orthophosphate (PO_4^{3-}) can be assimilated by bacteria, algae and plants (Correll, 1998). Dissolved orthophosphate occurs in one of three forms, depending on the pH; $H_2PO_4^-$ and HPO_4^{2-} are the inorganic anions that predominate in the normal pH range of natural waters, while H_3PO_4 is more abundant in acidic environments (Waite, 1984).

Phosphorus in soils and water originates naturally from the weathering of phosphate bearing rock and decomposition of organic matter (Chapman and Kimstach, 1996). Anthropogenic sources that contribute to elevated P levels include domestic wastewaters (particularly those containing detergents) and runoff from agricultural lands on which manure or inorganic fertilizers have been applied. A major cause for excessive phosphorus concentrations on farmland is excessive manure and fertilizer application. The nitrogen to phosphorus ratio of manure (2:1 to 6:1) is typically lower than what crops require (7:1 to 11:1) (Gburek et al., 2000); however, most farmers apply manure to their fields based on nitrogen demands.

Phosphorus is delivered to aquatic systems from the land surface in both dissolved and particulate forms. Since P is strongly adsorbed into the soil profile, runoff and erosion are the main mechanisms by which this P is transported (Parry, 1998; Sharpley et al., 1994; Correll, 1998). In cultivated soils losses of particulate P can be extremely high and constitute most of the P transferred in runoff (60-90%), whereas runoff from grass or forest lands carries little sediment and is, therefore, dominated by the dissolved form (Daniel et al., 1998; Sharpley et al., 1992).

Once in the watercourse, particulate phosphorus input into watercourses may be deposited in the bottom sediments or it may release P and organic P into solution, and eventually hydrolyzed to orthophosphate (Waite, 1984; Daniel et al., 1998). Orthophosphate can follow one of two pathways: formation of insoluble metal-complexes and biological uptake. The phosphate can complex with aqueous cations, particularly iron, aluminum and calcium, to form insoluble molecules which precipitate out into the sediments (Waite, 1984). These phosphates-metal complexes are no longer available for plant uptake. Consequently, the concentration of available phosphorous in the aquatic system is in part a function of the factors (primarily pH and dissolved oxygen concentration) affecting the solubility of these metal complexes. For instance, under anoxic conditions Fe^{3+} is reduced to Fe^{2+} and phosphate is released back into the water column. Orthophosphate can also be taken up by plants where it is converted into organic phosphorus (as polyphosphates). Eventually, when the plant dies this immobilized P in the plant tissues is release back into solution when bacteria re-hydrolyze the polyphosphate back to orthophosphate (Waite, 1984)

In most natural waters orthophosphate levels range from 0.005 to 0.02 mg/L (Chapman and Kimstach, 1996). Phosphorus itself is not toxic at concentrations found in natural waters (Campbell and Edwards, 2001; Doljilo and Best, 1993) and consequently, surface impacts of phosphorus loads do not pose a risk to human health but do create environmental and aesthetic concerns. Hence, water quality guidelines are set in to prevent eutrophication rather than direct phosphorus toxicity. For British Columbia, the drinking water quality guideline has been set at 0.01 mg/L total P. No guideline has been set for the protection of aquatic life in streams.

7.1.2 General Water Chemistry

7.1.2.1 pH

pH is a "determining factor in almost every natural (chemical or biological) process", and as a result it is an important variable to measure in water quality assessments (Stednick, 1991). The pH range of most natural waters is between 6.5 and 8.5, and is primarily dependent on the concentration of carbonates and carbon dioxide in the water body. As a result, pH levels may be higher during the daytime, particularly in eutrophic waters when aquatic plants are actively removing carbon dioxide from the water through photosynthetic activity (Doljilo and Best, 1993). The geology of the catchment and the soil types in the drainage area also influence pH. For example, drainage waters from forests are usually more acidic because of the presence of humic and fulvic acids (Doljilo and Best, 1993). pH also affects the equilibrium between soluble and solid species of trace elements. In general, trace elements tend to become more soluble at lower pHs – and consequently, lowering the pH levels can allow the release of toxic metals that may otherwise be attached to the sediment and unavailable to water system (Chapman and Kimstach, 1996). Once these metals are mobilized they are potentially more available for uptake by aquatic life.

7.1.2.2 Temperature

Temperature influences almost every biological, chemical and physical process in a waterbody, and consequently, the concentration of many water quality constituents (Chapman and Kimstach, 1996). As temperature increases, the solubility of gases (N_2, O_2, CO_2) in water decreases. Also, higher temperatures generally increase the rate of biochemical processes involved in metabolism, growth and reproduction. (Doljilo and Best, 1993). In warmer waters, increased respiration can lead to increases in oxygen consumption and increased decomposition of organic matter. This increased metabolic oxygen demand in conjunction with the reduced solubility of oxygen in water at higher temperature can cause an oxygen deficit which can be harmful to aquatic life. Furthermore, temperature affects the solubility and toxicity of many chemical compounds (such as pesticides and trace metals) and therefore can influence the effects of pollutants on aquatic life. Streamwater temperature may also be an indication of groundwater influence, particularly in the dry season when groundwater makes a greater contribution to streamflow.

7.1.2.3 Specific Conductivity

Specific conductivity is a measure of the water body's ability to conduct an electric current. The current is conducted in solution by the movement of ions. In natural waters, the ions in solution (essentially, Na+, Mg^{2+}, Ca^{2+}, K^+, Cl^-, SO_4^{2-}, HCO_3^- and CO_3^{2-}) are formed predominantly by the dissociation of inorganic compounds, mostly mineral salts. Organic compounds dissolve very little and consequently contribute little to conductivity. Specific conductivity has no significant health implications. It is, however, sensitive to the amount of salts dissolved in water and can be used as a convenient, rapid method of estimating total dissolved solids and salinity in a watercourse. These dissolved solids and salts can have implications for domestic and agricultural water use (Stedick, 1991; Doljilo and Best, 1993).

Conductivity in streams is affected by the geology of the area through which the water flows. For example, streams that run through granite bedrock will have a much lower conductivity than those that flow through limestone, shale or through clay soils. Higher conductivity readings can also result from pollution sources such as urban or agricultural runoff. Other factors that can affect conductivity include temperature and discharge; warmer water and low flow conditions generally contribute to conductivity readings.

7.1.2.4 Dissolved Oxygen

Dissolved oxygen (DO) content is another vital parameter of any water body because it is essential for most forms of life. Dissolved oxygen concentrations below 5 mg/L may adversely affect the function and survival of biological communities, and concentrations below 2 mg/L can lead to fish mortality. The solubility of heavy metals is also influenced by the dissolved oxygen content of the water body – solubility of most metals decreases under low oxygen conditions. A number of factors may influence the concentration of DO in water, including turbulence, biological activity and temperature. Water gains oxygen from the atmosphere. Therefore, physical movement, such as rapids, promotes dissolving of oxygen in water. Secondly, respiration by aquatic plants, and the decomposition of organic matter consume oxygen from the water. Consequently, water discharges high in organic matter and nutrients can lead to decreases in the dissolved oxygen content as a result of the increased microbial activity. Accordingly, DO is a good indicator of the degree of pollution by organic matter. The solubility of oxygen also decreases as temperature increases. Variation in DO can occur seasonally or daily in relation to temperature and biological respiration (related to photosynthesis and the decomposition of organic matter). Both an increase in temperature and increase in respiration will lead to decreases in DO concentrations.

7.1.3 Major Ions in Water

While waters contain a vast array of chemical constituents, a relatively small number of elements make up the majority of the species found in most natural waters. The major cations are the alkaline and alkali earth metals, which exist largely as free ions (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}). The major anions (Cl^{-}, HCO_3^{-} and SO_4^{2-}) were not measured in this study. Concentrations of major ions are naturally very variable in surface waters, and mainly depend upon the natural geology of the catchment and the factors influencing the weathering process of rocks and soils (Doljido and Best, 1993; Chapman and Kimstach, 1996). Potassium (K) is generally found in low concentrations in natural waters since potassium bearing minerals (e.g. microcline $KALSi_3O_8$, leucite $KALSi_2O_6$, silvine KCl, kainite $KCl{\cdot}MgSO_4{\cdot}3H_2O$, carnallite $KClMgCl_2{\cdot}6H_2O$, glacerite $K_3NA(SO_4)_2$) are relatively resistant to weathering (Doljido and Best, 1996). However, because potassium is an essential element for plant growth potassium salts are widely used as fertilizer; and consequently can enter watercourses with agricultural runoff. Sodium (Na) minerals (e.g. halite NaCl, thenardite Na_2SO_4, albite $NaSi_3O_8$) tend to be highly soluble, and consequently, the natural level of sodium in water is considerably higher than potassium. Increased concentrations may arise from the use of salts on roads and from sewage and industrial effluents. Because elevated sodium in soil can degrade soil structure and thereby restrict water movement, sodium is commonly measured where water is to be used for irrigation (Chapman and Kimstach, 1996). Magnesium (Mg) is present in ferromagnesium minerals and some carbonate rocks (e.g. dolomite $CaMg(CO_3)_2$, and magnesite $MgCO_3$), while calcium (Ca) is readily dissolved from rocks rich in Ca minerals - particularly carbonates (calcite $CaCO_3$, dolomite $CaMg(CO_3)_2$, limestone) and sulphates (e.g. gypsum $CaSO_4{\cdot}2H_2O$). Calcium concentrations can fall when Ca carbonate precipitates due to increased water temperatures, photosynthetic activity or loss of CO_2 in the system (Chapman and Kimstach, 1996). Together, calcium (Ca) and magnesium (Mg) salts are responsible for the hardness of water, and when heated they form insoluble scales in water heaters and coilers reducing their efficiency. The amount of hardness in the water can also modify the toxicity of some cations due to competition between the toxic cation and the Ca and Mg ions at the exchange sites in the aquatic organisms.

7.1.4 Metals in Water and Sediment

7.1.4.1 Sources of Metals in Urban and Agricultural Areas

Trace metals are naturally present in freshwater systems from erosion and the weathering of rocks and soils. However, with the increasing urbanization and agricultural intensification over the last few decades metals introduced into the aquatic environment are increasingly coming from anthropogenic sources such as direct discharge of effluent from domestic or industrial activities, wet and dry atmospheric deposition, and mining (Chapman and Kimstach, 1996). In many areas, recent metal accumulation has been occurring at a much faster than the historical rate. This section focuses on sources of metal pollution in agricultural runoff and urban stormwater.

In agricultural watersheds the primary sources of metals are fertilizers and manure. Some trace metals are essential micronutrients for animals and are frequently added to livestock and poultry feed as growth promoters and antibiotics (Smith, 2004; McBride and Spiers, 2001; Nicholson et al., 1999). Zinc (as zinc oxide or zinc sulphate) and copper (as copper sulphate) are the most common feed supplements. As a result, manure can contain high levels of copper and zinc, as well as other metals such as iron, manganese and lead. Zinc sulphate is also used as a plant fertilizer, zinc chloride is used as a pesticide and organic zinc compounds are used as fungicides (Ohnesorge and Wilhelm, 1991; Smith, 2004). In general, livestock and poultry manure contribute most to the input of Cu and Zn, whereas fertilizers are the dominant source of Cd in agricultural (both arable and livestock) systems (de Vries, 2002). Atmospheric deposition is generally a larger contributor of Pb than agricultural sources, although it is used in pesticides and can be found in livestock manure (deVries, 2002).

Stormwater runoff mobilizes large quantities of contaminants from the urban environment (Characklis and Wiesner, 1997; Davis et al., 2001), including trace metals (Choe et al., 2002). A number of studies have found various levels of metals in runoff from urban areas, particularly highway runoff (Wu et al., 1998, Sansalone and Buchberger, 1997, Marsalek et al., 1999). Common metals associated with urban runoff include: copper, zinc, iron, lead manganese, nickel, arsenic and chromium. Generally the levels follow the order: Zn (20-5000 ug/L) > Cu ~ Pb (5-200 ug/L) > Cd (<12 ug/L) (Davis et al., 2001).

In urban areas, trace metals are introduced into the environment through construction materials and chemicals; however motor vehicles are recognized to be the primary source of most metals (Gibb et al., 1991; Davis et al., 2001; Sansalone and Buchberger, 1997). Transport related sources of metals include gasoline (Pb, Mn), diesel fuel (Cd), exhaust emissions (Pb, Ni), lubricating oils (Pb, Ni, Zn), grease (Zn, Pb), tire wear (Cd, Zn), asphalt paving wear (Ni), break lining wear (Cu) (Legret and Pagotto, 1999; McCallum, 1995). Due to the significant reduction in the use of tetraethyl lead (TEL) as a gasoline additive (15 mg//L since 1989 instead of 40 mg/L) there has been a decrease in the lead content in surface waters (Legret and Pagotto, 1999). The natural levels in gasoline (~10 mg/L) may still contribute lead (Lee and Jones-Lee, 1993). This reduction of Pb based gasoline additives was associated with an increase in the use of methylcyclopentadienyl manganese tricarbonyl (MMT) as an alternative octane enhancer (Egyed and Wook, 1996). Consequently, MMT fuel additive is suggested to be a potential source of Mn accumulation in urban streams (Mielke et al., 2002). Other sources of metals include wires and pipes (Cu, Zn), the corrosion of iron and steels products (Fe), and lead based paints (Pb). Galvanized roofs have been shown to be a significant source of Zn.

7.1.4.2 Chemistry and Fate of Trace Metals in the Aquatic Environment

Elements in aquatic systems may be present in many forms such as dissolved ions, dissolved organic or inorganic complexes, precipitated as metal oxides, hydroxides, carbonates and sulphides, or adsorbed onto clays and humic materials. In general, only a small proportion of the total metal load in aquatic systems is actually found in the dissolved fraction, while bottom sediments often become contaminated with metals. This is because sediments have a remarkable ability to remove metal ions from the water column through various processes (e.g. ions exchange, precipitation, chelation), collectively known as sorption. Clay minerals, hydroxides and oxides (particularly those of Fe, Al and Mn), as well as particulate organic matter (POM) are the most important constituents in these sorption processes. Humic substances contain a large amount of hydroxyl and carboxylic functional groups, which can act as cation binding sites when they dissociate in water to release protons. Similarly, the hydroxyl groups on the edges of phyllosilicate clays can donate protons to aqueous solution in return for metal uptake. Metal adsorption onto these sites is pH dependent (Evans, 1999). At the broken edges of clay particles, negatively charged oxygen atoms provide additional binding sites. Clay minerals may also have a permanent structural charge (as a result of structural imperfections caused by isomorphic substitution or non-ideal occupancy in the octahedral sheets) which can act as additional sites for ion-exchange (Evans, 1999). Under oxic conditions, the surfaces of oxide and hydroxide minerals can donate protons to aqueous solution in return for metal uptake. Under reducing conditions, the adsorption mechanism of oxides reverses, resulting in re-mobilization of sorbed metals (Stumm and Morgan, 1970). Consequently, increasing the organic matter and clay content in sediments provides more sites for metal adsorption thus reducing the amount of metal that is found in the dissolved fraction.

Texture has been cited by many investigators as the most important factor affecting trace metal concentrations. The fine-textured sediment, which contains an appreciable amount of organic matter, Fe and Mn oxides, and clay minerals, tends to accumulate higher concentrations of metals due to the higher adsorptive capacity of these constituents (Fergusson, 1990; Salomons and Förstner, 1984).

The speciation of trace metals in natural waters has an important influence on their mobility/transport, chemical reactivity (behavior), and biological availability and toxicity. Research has shown that the biological availability and behavior of trace metals in aquatic systems is closely related to chemical forms rather than the total metal concentration. Small dissolved metal species and free metal ions, in particular, are believed to be most easily absorbed in biota from the water column (Pagenkopf, 1983; Gundersen and Steinnes, 2001), and therefore most likely to result in adverse effects. In most unpolluted waters, concentrations of free metals are low due to the abundance of natural ligands, adsoption sites and near neutral condition; however, changes in water chemistry and metal loadings can significantly increase the free metal ion concentration. Factors that can influence the proportion of metals in each fraction include the physical properties of sediment (texture, organic matter content, type of clay present), chemical conditions (pH, water hardness, and redox conditions), metal concentration and the presence of other ligands (Evans, 1999; Salomons and Förstner, 1991; Gundersen and Steinnes, 2001).

In general, pH seems to have the greatest effect on the solubility of metals, with a greater metal retention in sediment and lower solubility of metal cations as pH increases. This occurs because as pH decreases, cations compete with extra hydrogen (H^+) and aluminum (Al^{3+}) for positions on exchange sites (Förstner and Salmons, 1991). The extent of adsorption of metals typically goes from near zero to near 100% over a relatively small pH range (this 'adsorption edge' is dependent on the type of metal). As a result, a small shift in the pH of surface water can cause a sharp increase or decrease in the dissolved metal levels (Salomons and Förstner, 1984).

Changes in redox (oxidation/reduction) conditions in aquatic systems can influence the availability of metals by changing the oxidation state of the metal ion and its solubility (Evans, 1999). Iron and manganese oxides are particularly susceptible to oxidation and reduction reactions; with the solubility of Fe and Mn increasing under reducing conditions.

The amount of metal in sediment may decrease if the concentration of anions in solution (e.g. chloride, biocarbonate, nitrate) is increased, through the addition of salts for example, as the binding sites in the sediment constituents will have to compete with the anions in solution for the metallic cation. (Salomons and Förstner, 1984).

Sediment dynamics will have an influence on the degree of variability within river systems. 'Hot spots' are created where a combination of pollutant loading and sediment dynamics produce sites with high impact potential (Rhoads and Cahill, 1999). In general, concentrations in urban streams generally decline as distance from a point source (e.g. stormwater outfall) increases. The highest concentrations in the downstream reaches generally occur in areas that promote the accumulation of fine sediment (e.g. regions of low velocity such as vegetated area (Rhoads and Cahill, 1999).

7.2 Water Quality Results

The analysis of the water quality results is presented in this section. As previously mentioned, surface water samples from twenty stations throughout the watershed were collected between May 2002 and July 2003 as well as during a storm event in October 2003 (see Figure 4.1 for the location of the sampling stations). Analytical results for streamwater (nitrate-N, orthophosphate-P, ammonia-N, major ion and trace element concentrations) as well as field measurements of streamwater specific conductivity, pH, dissolved oxygen, temperature are presented in Appendix C, and summarized in Tables 7.1 and 7.2 for the complete data set and for sites grouped by land use categories (agriculture, urban, forest). Natural background levels in streamwater, and results from other studies in the Lower Fraser Valley (LFV) are also included in these tables for comparison.

7.2.1 Spatial and Temporal Trends in Water Quality Parameters

The spatial and seasonal variability in each of the water quality parameters is addressed using series of graphs. In these graphs, the wet and dry season averages are plotted for stations from the headwaters of the Interception Ditch mainstem to the mouth of Chilliwack Creek in the upstream to downstream direction (represented by the solid lines). The Chilliwack Creek mainstem (M19 to M20) is also shown (represented by the dashed lines). It should also be noted that in these graphs the first station along the 'Interception Ditch mainstem' is a forested tributary station (Parsons Brook, F13); the next three stations are along the ditch itself, and the final station is at the mouth of Chilliwack Creek. For the Chilliwack Creek mainstem, the upstream station is the most intensive urban sampling site in this study (M19). Values for selected forested, urban and agricultural tributaries are shown in a separate graph; arrows on the mainstem graph indicate where a tributary enters the stream. Figure 7.1 shows the location of the sampling stations on the two mainstems (Interception Ditch and Chilliwack Creek) and the stations along the tributaries. The locations of a few key points of confluence are also shown on the map: 1) the point where the streams draining the 'urban hillslope' (UH) enter Interception Ditch (between station A16 and A18); 2) the point of confluence for the forested hillslope tributary (FH) with Interception Ditch (between station A15 and A16); and 3) the point where Interception Ditch enters Chilliwack Creek.

Table 7.1 Overall Surface Water Chemistry of the Chilliwack Creek Watershed, and Comparison with Natural Background Levels and Other Studies in the Lower Fraser Valley (LFV)

			pH	Dissolved Oxygen (mg/L)	Sp. Cond. (µS/cm)	Temperature (°C)	Nitrate-N (mg/L)	Ammonia-N (mg/L)	Ortho-P (mg/L)
2002-2003, Chilliwack Creek Streamwater Sampling									
ALL SITES		***Mean***	7.4	9.2	245	11.9	0.75	0.27	0.09
		Range	6.0-9.0	3.9-15.2	97-550	4.6-22.6	bd – 5.68	0.05-5.23	bd – 0.16
AGRICULTURAL SITES		***Mean***	7.27	9.2	275	12.6	0.75	0.43	0.11
		Range	7.0-9.0	6.0-12.6	130-550	6.1-22.6	bd – 5.68	0.05-4.23	bd – 0.16
URBAN SITES		***Mean***	7.6	9.5	213	11.2	0.51	0.13	0.08
		Range	7.0-8.0	3.9-12.8	97-373	4.6-16.6	0.06-1.35	bd – 0.71	bd – 0.13
FOREST SITES		***Mean***	7.6	9.7	217	11.9	0.64	0.16	0.06
		Range	7.0-8.0	4.5-12.6	110-322	5.0-18.7	0.23-1.11	bd – 0.60	bd – 0.08
Background Concentrations in Streamwater									
Natural levels in freshwaters			6.0-8.5[b]	bd -18.4 [a] typically > 10	10-1000[b]		0.002-6.6 [a]	<0.001-0.490 [a] typically <0.1	0.005-0.020[b]
FORESTED CONTROL SITES IN LFV STUDIES	Aggasiz (control site) [e]		5.8 (5.2-6.0)	10.7 (5.7-17.4)	25 (10-45)	8.2 (2.7-15.9)	1.500 (0.006-0.498)	0.063 (0.002-0.241)	0.009 (0.003-0.014)
	Vedder Mountain 2003-2004 (Sumas Watershed)[c]		7.7 7.3-7.9	10.5 4.4-14.0	111 70-148	7.7 2.6-14.8		0.013 bd-0.410	All bd
	Upper Elk Creek (Chilliwack hillslope region 1998-2001)[d]			10.2 6.2-14.5		10.8 2.5-20.2		0.008 0.005-0.504	
Streamwater Concentrations, mean and range (Impacted watersheds in the Lower Fraser Valley)									
AGRICULTURAL WATERSHEDS	Sumas River (Abbotsford)[c]		7.4 6.6-8.7	7.9 2.7-12.3	277 186-358	10.3 3.9-23.9	2.26 0.46-4.92	0.230 bd-1.260	0.0350 bd-0.120
	Lower Elk Creek (Chilliwack 1998-2001) [d]			12.0 6.5-13.2		6.8 0.8-13.9		0.006 0.005-0.440	

[a] CCREM (1987) cited in Berka (1996)
[b] Chapman and Kimstach (1996)
[c] Smith (2004)
[d] Schreier et al. (2004)
[e] Addah (2002)

* bd = below detection, taken as detection limit for analysis

Table 7.2 Major Ions and Trace Metals in Water for the Chilliwack Creek Watershed, and Comparison with Natural Background Levels and Other Studies in the Lower Fraser Valley (LFV)

	(mg/L)	Fe	Mn	Ca	K	Mg	Na
2002-2003, Chilliwack Creek Streamwater Sampling							
ALL SITES	***Mean***	0.369	0.073	28.0	1.26	5.36	6.79
	Range	bd – 1.685	bd – 0.380	13.7 - 53.1	bd – 2.71	1.90-9.65	2.92-13.90
AGRICULTURAL SITES	***Mean***	0.796	0.134	30.3	1.18	5.06	6.56
	Range	0.210-1.685	bd – 0.252	16.2-53.1	bd – 2.42	2.60-7.90	3.64-9.00
URBAN SITES	***Mean***	0.095	0.017	24.2	1.30	6.70	7.16
	Range	bd – 0.330	bd – 0.058	15.6-29.5	0.78-2.23	5.34-9.65	22.93-13.90
FOREST SITES	***Mean***	0.087	0.018	20.8	0.70	2.68	7.68
	Range	bd – 0.185	bd – 0.042	13.7-27.1	bd -0.87	1.90-3.22	4.20-9.98
Background Concentrations in Streamwater							
Natural ranges of (dissolved) concentrations in streamwater[c]		0.055[e]	0.006[e]	0.06-210	0.1-6.3	0.05-80	0.06-350
Global average (MCNC)[d]				8.0	1.0	2.4	3.7
PRISTINE STREAMS DRAINING COMMON ROCK TYPE[f]	Granite			0.78	0.3	0.38	2.0
	Sandstone			1.8	0.82	0.75	1.2
	Shale			8.1	0.78	2.9	2.4
	Carbonate			51	0.51	7.8	0.8
FORESTED CONTROL SITES IN LFV STUDIES	Vedder Mtn. 2003-2004 (Sumas Watershed)[a]	All bd	All bd	14.38 9.3-193-.4	All bd	3.1 2.2-4.1	
	Lower Elk Creek (Chilliwack hillslope region 2000, means)[b]	0.133 (spring) 0.053 (fall)	0.005(spring) 0.036(fall)				
Streamwater Concentrations, mean and range (Impacted watersheds in the Lower Fraser Valley)							
AGRICULTURAL WATERSHEDS	Sumas River (Abbotsford)[a]	0.355 0.05-1.14	0.052 bd-0.161	17.1 7.7-25.7	2.39 0.07-5.80	19.66 12.6-28.1	
	Hope Slough (Chilliwack 2000, means)[b]	0.696 (spring) 0.717 (fall)	0.146(spring) 0.116(fall)				

*bd – below detection   [a] Smith (2004)   [b] Schreier et al. (2004)
[c] Chapman and Kimstach (1996) after avergaes from a survey of 250 pristine streams in France (Meybeck, 1986) and from 75 sites world-wide (Meybeck 1987);
[d] MCNC (most common natural concentrations) corresponding to median value obtained in 60 major rivers (Meybeck 1979) ;
[e] Yeats and Bewers (1982) cited in Salomons and Förstner (1984)
[f] Meybeck and Helmer (1989) cited in Chapman and Kimstach (1992) ; based on 75 unpolluted rivers in monolithological watersheds (rock type proportion close to the estimated global proportion of Meybeck (1987)

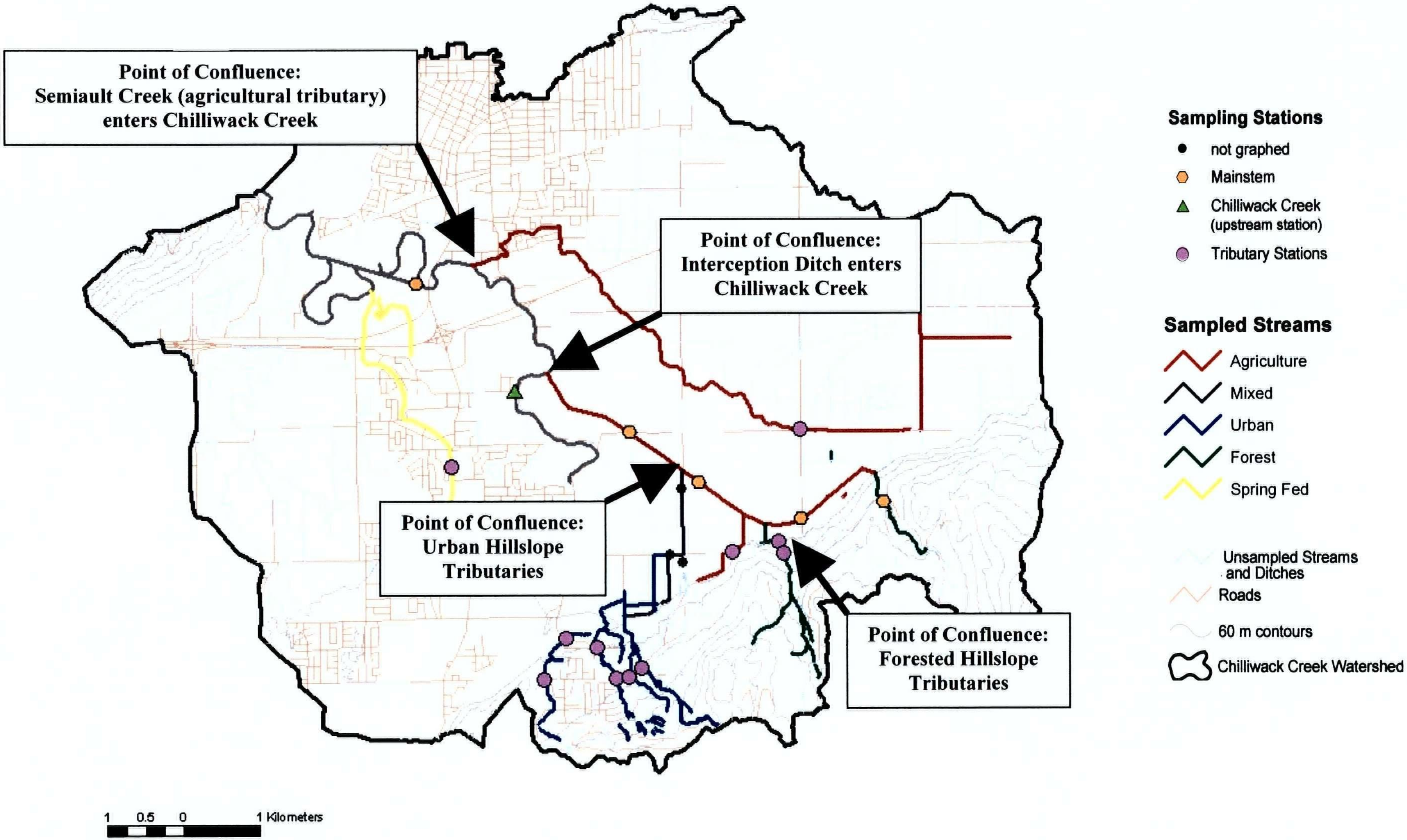


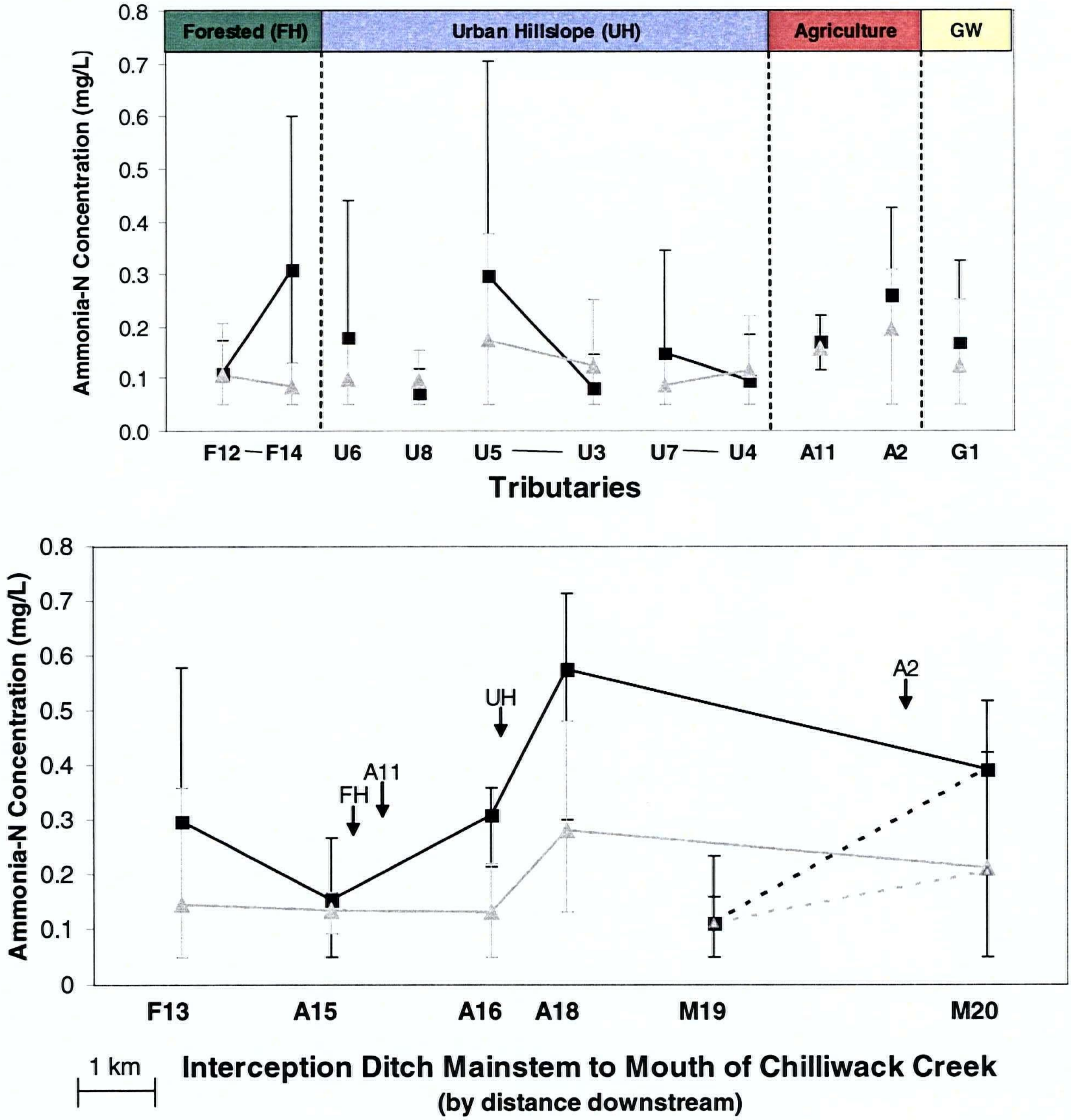
Figure 7.1 Location of Sampling Stations along the Interception Ditch and Chilliwack Creek Mainstems, and Selected Tributaries

7.2.1.1 Variations in Ammonia-N

Throughout the 2002-2003 sampling season, ammonia (NH_4^+-N) concentrations ranged from below detection (0.10 mg/L) to 5.23 mg/L. The highest value was measured in Bailey Ditch (M10) on 12-Dec-02, and exceeded the *B.C. Approved Water Quality Guidelines* for the protection of aquatic life. On this date, ammonia concentrations at stations A16 (3.41 mg/L), A17 (4.23 mg/L) and A18 (1.77 mg/L) also exceeded the maximum permissible total concentration for the protection of aquatic life. Furthermore, in July 2003 the ammonia concentration at station A18 was very near the average 30-day concentration guideline for ammonia-N (<0.15 mg/L at pH = 8.8 and temperature = 22°C).

Ammonia concentrations varied spatially along the Interception Ditch and Chilliwack Creek, as shown in Figure 7.2. Concentrations are low at the upstream station of Chilliwack Creek with a significant increase in ammonia-N concentration when agricultural tributaries (Semiault Creek and Interception Ditch) enter the mainstem. Interception Ditch shows a similar downstream trend with low concentrations in the (forested) headwaters and an increase in the downstream direction as agricultural influence intensifies. This increase was most pronounced between stations A16 and A18, where Teskey Way Ditch (a ditch with both urban and agricultural influence) drains into the mainstem. Concentrations at M10 and A17 (Teskey Way Ditch) are high suggesting that that this portion of the watershed may be contributing ammonia-N to Interception Ditch. These two stations are located downstream of the urban hillslope tributaries as well as some agricultural land. It should be noted that station M10 may also receive water from the Bailey landfill site, but from the sampling sites in this study there is no way to differentiate if the high levels at M10 are due to upstream agricultural activities or leakage from the landfill site.

An exception to the spatial pattern described above occurred on 12-Dec-02 when concentrations peaked at station A16 (3.41 mg/L). The high concentrations detected on 12-Dec-2002 at station A16, A17, A18 and M10 likely resulted from runoff caused by a moderate rainfall (>20 mm) immediately prior to and during the sampling. All other concentrations measured during the sampling period were below 0.900 mg/L. This result suggests that there is a high potential for rapid and higher losses of nitrogen to occur during rainfall events. Figure 7.2 shows the wet and dry season trends excluding the 12-Dec-02 sampling data.



Legend: ▲ Grey triangles represent dry season means.
■ Black squares represent wet season means (excl. 12-Dec-02)
— Solid line represents Interception Ditch Mainstem
- - - Dashed line represents Chilliwack Creek

FH= forested hillslope tributaries (Elkview Creek); UH = urban hillslope tributaries

Notes: Error bars represent the range of measured values.
Arrows indicate the approximate location of tributaries draining into the mainstem.

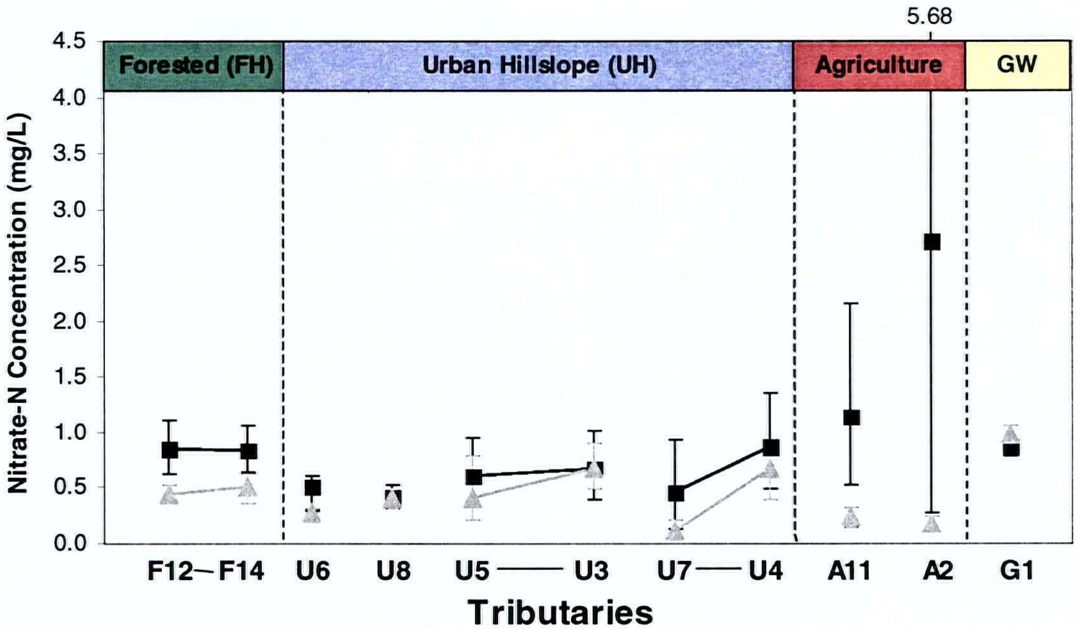
Figure 7.2 Spatial and Seasonal Variations in Streamwater Ammonia-N in the Chilliwack Creek Watershed

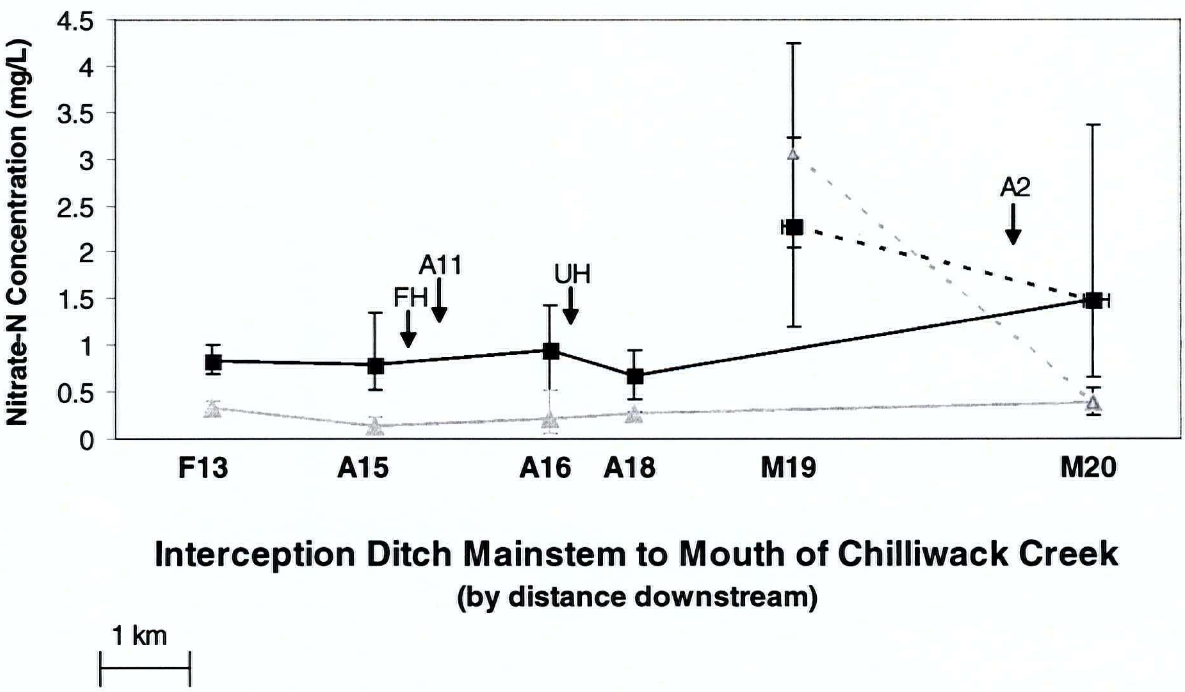
Seasonally, ammonia-N concentration in the mid and lower sections of Chilliwack Creek and Interception Ditch were higher in the wet season than in the summer season. In agricultural areas, surface runoff and erosion are the major sources of ammonia to streams. In the wet season, surface runoff increases and biological uptake decreases because plants are not growing; this leads to increased inputs to streams. The opposite occurs in the dry season because there is less runoff and because plants and organisms are actively absorbing ammonia. In addition, the warmer water temperatures during the dry season would encourage nitrification (conversion of ammonia to nitrate). Tributaries that were less influenced by temperature and algae and vegetation growth, namely shaded hillslope tributaries, showed minimal seasonal variation.

7.2.1.2 Variations in Nitrate-N

During the sampling period, the mean nitrate-N concentration was 0.75 mg/L. Values below detection limit were measured in the middle section of Interception Ditch (A15 and A16) during the dry season (October and July, respectively). The highest values were consistently recorded in Semiault Creek (A2) during the wet season. In general nitrate concentrations in the watershed are low; and all values were below *BC Water Quality Guidelines* for drinking water (10 mg/L) and aquatic habitat (200 mg/L). However it should be noted that, during the wet season, Semiault Creek (intensive agriculture) and Chilliwack Creek had nitrate-N concentrations that were above the 3 mg/L level that is indicative that the stream is impacted by anthropogenic influence (Schreier, pers. comm., 2004).

The spatial and seasonal variability in nitrate-N during low flow (dry) and high flow (wet) conditions for Interception Ditch, Chilliwack Creek and selected tributaries is illustrated in Figure 7.3. Nitrate-N concentrations along Interception Ditch varied only slightly between stations, remaining consistently below 1.43 mg/L along the length of the stream. The trends described were most pronounced on the December sampling date, which occurred just after a storm event when discharge was still increasing. Chilliwack Creek showed the opposite trend with nitrate-N concentrations decreasing downstream. It should be noted that concentrations at the mouth of Chilliwack Creek were, on average, double the concentrations measured in Interception Ditch. Semiault Creek, which flows through the main agricultural area in the watershed, had high nitrate concentrations, and empties into Chilliwack Creek prior to station M20. However, due to the consistently high nitrate-N concentrations recorded at the upstream station (M19), it is uncertain how much this agricultural area is influencing nitrate levels in Chilliwack Creek.





Legend: ▲ Grey triangles represent dry season means. — Solid line represents Interception Ditch Mainstem
■ Black squares represent wet season means - - - Dashed line represents Chilliwack Creek

FH= forested hillslope tributaries (Elkview Creek); UH = urban hillslope tributaries

Notes: Error bars represent the range of measured values.
Arrows indicate the approximate location of tributaries draining into the mainstem.

Figure 7.3 Spatial and Seasonal Variations in Streamwater Nitrate-N in the Chilliwack Creek Watershed

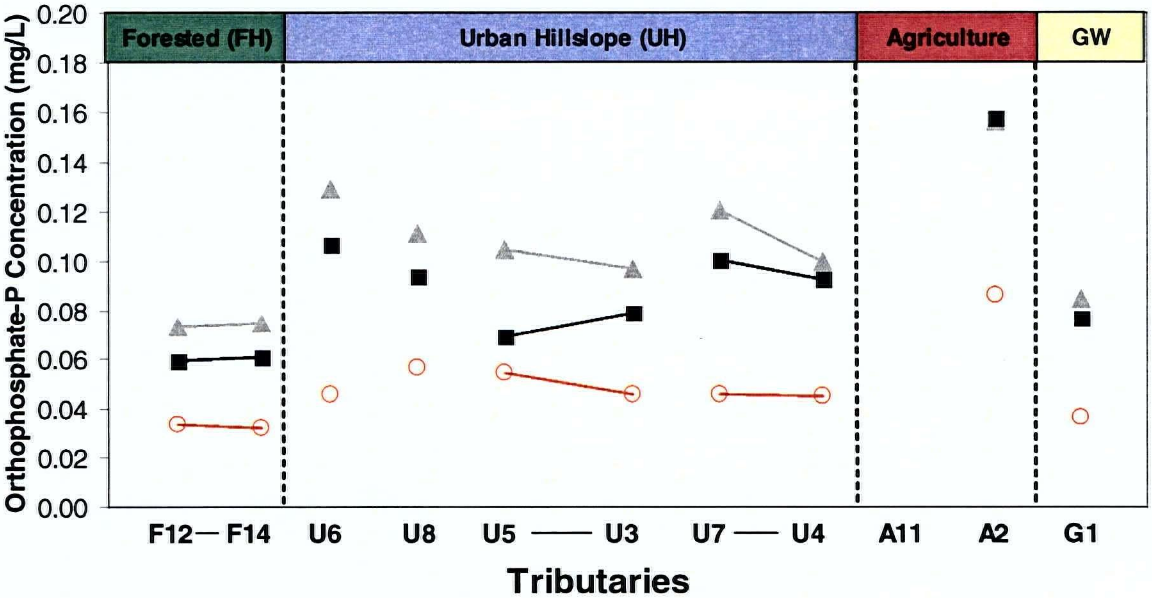
Wet season values were higher and more variable than dry season values throughout the watershed, reflecting the effects of higher stormwater runoff volume and lower biological uptake. In the wet season, the lowest levels of nitrate were consistently found in tributaries with minimal to no agricultural activity, whereas in the dry season the lowest nitrate levels were often found in streams influenced by agriculture. Seasonal variation was greatest for the agricultural sites, and smallest for the urban hillslope streams. This is particularly evident at station A2, the most intensively agricultural sampling site, which exhibited some of the highest nitrate-N values in the watershed in the wet season, but also had some of the lowest values observed in the dry season.

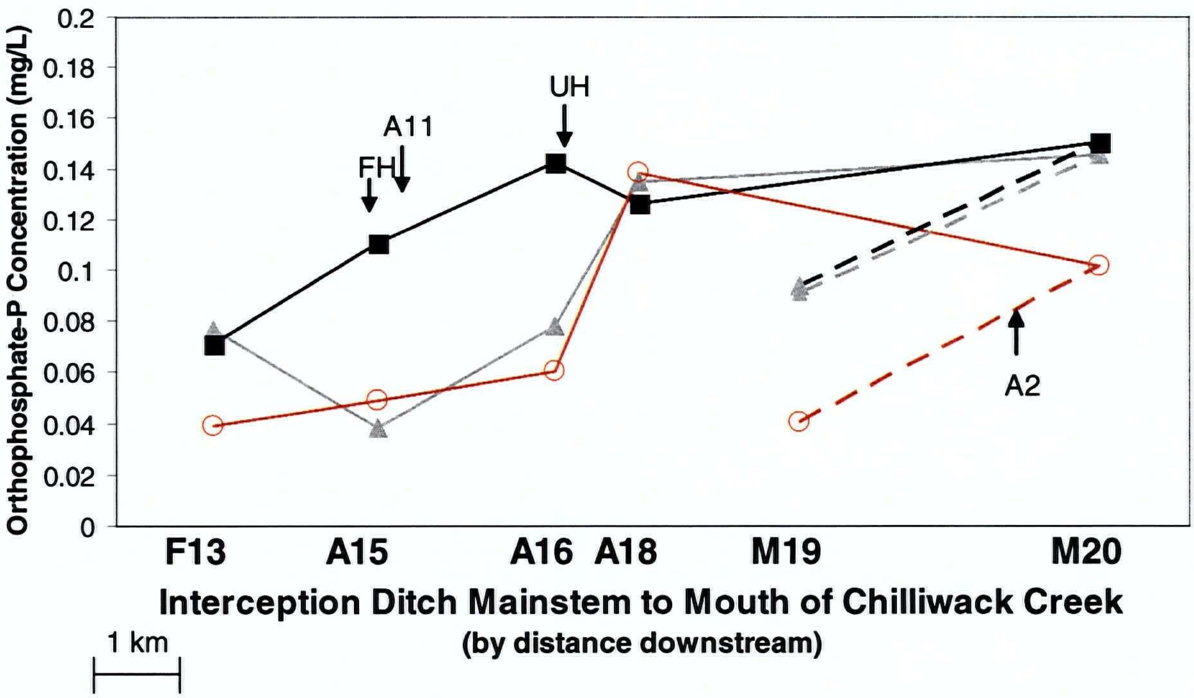
One exception to this seasonal trend was seen at the upper station along Chilliwack Creek (M19). At this site, nitrate-N concentrations were higher during the dry season. This station maintained relatively high levels of nitrate-N during both the wet and the dry season (2.36 mg/L and 2.98 mg/L, respectively). There are a number of stormwater outfalls that drain into Chilliwack Creek above this sampling site, and it is assumed that these contribute significant amounts of nitrate year round, overwhelming the effects of other contributing factors.

7.2.1.3 Variations in Orthophosphate-P

Three sample sets (12-Dec-2002, 3-Mar-2003 and 1-May-2003) were not used because of problems with the laboratory analytical technique. Of the remaining sampling sets, almost all values for 27-May-2002 and 9-July-2003 were below detection. Values for 12-Nov-2002 (wet season) and for 21-Aug-2002 and 10-Oct-2002 (dry season) are plotted in Figure 7.4.

Overall, orthophosphate-P levels ranged from below detection (0.02 mg/L) to 0.16 mg/L. The highest value was detected at station A17 in August 2002. The spring-fed station (G1) and the forested control stations (F12, F13, and F14) generally had the lowest orthophosphate-P concentrations in the watershed, suggesting anthropogenic sources may be responsible for higher phosphate concentrations in the rest of the watershed. In contrast, August and/or October orthophosphate levels in Semiault Creek, in the lower sections of both Interception Ditch and Chilliwack Creek, and in some of the urban hillslope tributaries were above levels cited as critical for causing accelerated eutrophication in lakes (0.1 mg/L) (Schreier, pers. comm., 1994). There is no water quality guideline for phosphorus in streams.





Legend: ▲ Grey triangles represent 21-Aug-03 concentrations — Solid line represents Interception Ditch Mainstem
■ Black squares represent 10-Oct-02 concentrations - - - Dashed line represents Chilliwack Creek
O Orange circles represent 12-Nov-02 concentrations

FH= forested hillslope tributaries (Elkview Creek); UH = urban hillslope tributaries

Notes: Arrows indicate the approximate location of tributaries draining into the mainstem.

Figure 7.4 Spatial and Seasonal Variations in Streamwater Orthophosphate-P in the Chilliwack Creek Watershed

In contrast to nitrogen, orthophosphate-P values were consistently lower in November (wet season date) than in October/August (dry season dates) in Chilliwack Creek and all tributaries, regardless of land use. This is the opposite of the seasonal trends found in other studies in the LFV (Schendel, 2001; Wernick, 1996; Berka, 1994). This difference may be attributed to dilution as November samples were taken after a high rainfall period. Dilution was noted for other water quality parameters (e.g. specific conductivity) on this date.

Concentrations were generally low in the headwaters and increased along Interception Ditch before leveling off towards the mouth of Chilliwack Creek. In August and November there is a pronounced increase between A16 and A18. A different spatial trend was observed along Interception Ditch in October, where the most pronounced increase occurred in the lower reaches (i.e. the headwaters to A16). Along Chilliwack Creek, concentrations increased in the downstream direction as agricultural tributaries (Interception Ditch and Semiault Creek) enter the stream and residential activities increase.

7.2.1.4 Variations in Specific Conductivity

Specific conductivity measurements ranged from 97 to 550 μS/cm. The highest values were consistently measured in Semiault Creek (A2) and Bailey Ditch (M10). The lowest value was measured at station U3 (Teskey Creek) on 12-Nov-02. Luckakuck Creek (G1) also had very low values over the entire sampling period suggesting that the groundwater has a lower specific conductivity than surface water.

While the difference is minimal, some seasonal variability can be observed in most tributaries and in the lower sections of Interception Ditch (Figure 7.5). As expected, winter conductivity readings are lower because there is more water in the stream, which leads to dilution. This dilution effect is most evident in the Nov-2002 measurements taken under very high flow conditions. It is interesting to note that while Dec-2002 readings were also taken under high flow conditions, conductivity values are high. This could be attributed to the time the sampling took place during the storm event; December samples were probably taken when contaminants were still being flushed into the stream before dilution occurred. These higher conductivity values further emphasize the idea that sediment and manure are entering the stream during runoff events. Streams that were less influenced by land use had similar conductivity values year round.

Specific conductivity increased along Interception Ditch with progression downstream. These increases are probably due to the introduction of salts to the watercourse from agricultural sources (such as inorganic fertilizers and animal manures). Nitrate-N is relatively constant along Interception Ditch. However, both ammonia-N and orthophosphate-P increase in concentration with progression downstream.

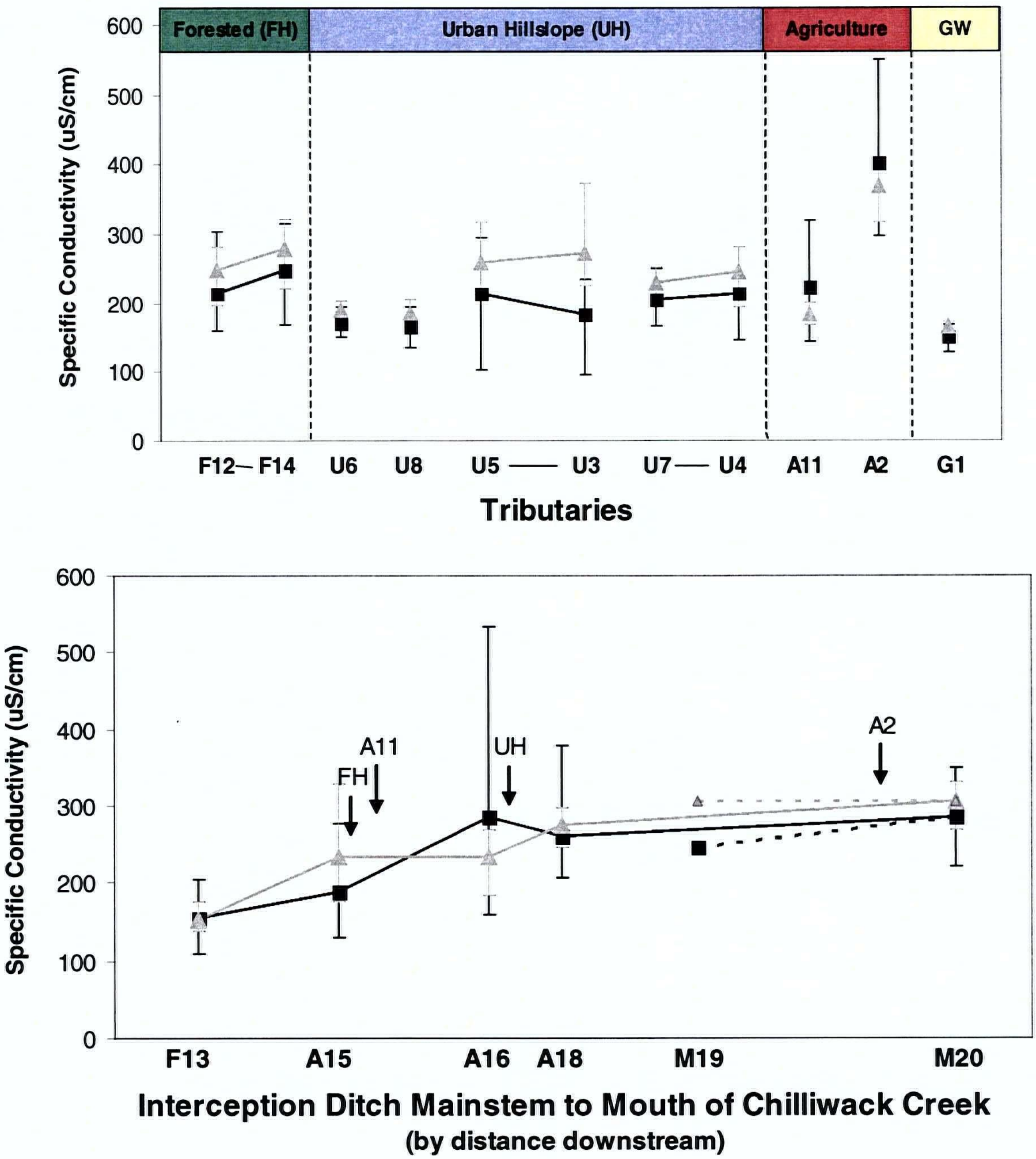
There was little to no variation along Chilliwack Creek, and concentrations were similar to those measured in Interception Ditch suggesting contributions from both urban and agricultural activities in this stream.

Differences in conductivity between the forested tributaries suggest that the geology through which Elkview Creek (F13) and Parsons Brook (F12, F14) flows may be different from one another. Elkview Creek has a very low conductivity (values are lower than the most other streams in the watershed year round) due to the fact that the water draining into Elkview Creek flows over quartz-rich metamorphic rocks which do not readily dissolve and therefore contribute less dissolved ions to the drainage water. Since shale, which contains more soluble ions, dominates much of the upland area drained by Parson's Brook, water in this stream is expected to have a higher conductivity.

7.2.1.5 Variations in pH

Measured pH values ranged from 6.3 to 8.8, with a mean value of 7.4. The highest pH was measured at station A16 in July 2003. Benchley Creek (U6) and Walker Creek (U8) also had mean pH values above 7.8. The lowest pH was consistently measured at the spring station (G1) indicating that the groundwater generally had a lower pH than surface water. This lower extreme value is the only value that did not meet B.C and Canadian water quality guidelines for the protection of aquatic life (6.5-9.0).

Seasonally, pH values were higher during the summer season in the lower and mid sections of Interception Ditch, in Semiault Creek and in Teskey Way Ditch (A17). pH in streams usually decreases with increasing temperature, which is opposite to the seasonal variation measured along Interception Ditch. This is possibly due to liming of the lowland agricultural fields, or to the fact that these stations have more aquatic plants in the summer period, which consume CO_2 during photosynthesis, causing an increase in pH. With the exception of a drop between A16 and A18, pH along Interception Ditch and Chilliwack Creek mainstems showed little variation.



Legend: ▲ Grey triangles represent dry season means. ■ Black squares represent wet season means

—— Solid line represents Interception Ditch Mainstem

- - - Dashed line represents Chilliwack Creek

FH= forested hillslope tributaries (Elkview Creek); UH = urban hillslope tributaries

Notes: Error bars represent the range of measured values.
Arrows indicate the approximate location of tributaries draining into the mainstem.

Figure 7.5 Spatial and Seasonal Variability in Streamwater Conductivity in the Chilliwack Creek Watershed

7.2.1.6 Variations in Temperature

Water temperatures of the hillslope streams ranged from 4.6°C to 6.6°C in March to maximum temperatures between 13.7°C and 18.7°C in August. One exception to this occurs at station F12 which shows a high December temperature of 16.9°C. This result was considered anomalous and discarded from further analysis. Lowland stations had a higher temperature range (with minimum March temperature between 6.1°C and 10.2°C for all stations, to a maximum temperature of 22.6°C at station A16 in July). Canopy cover and ambient temperature largely governed the variability in stream temperature within the watershed. Both the urban and forested hillslope tributaries were shaded by canopy, whereas the agricultural watercourses had little to no vegetated riparian zones that could offer shade cover. Luckakuck Creek is the exception because it is spring fed. This stream was one of the coolest streams in the summer and one of the warmest streams in the winter reflecting groundwater inputs to the stream.

During both the summer and winter, water temperatures along Interception Ditch increase from station F13 towards A16. In the summer temperatures decrease slightly towards station A18, while in the winter they continue to increase over this stretch. One possible explanation is that the stream may be influenced in part by groundwater between these stations.

7.2.1.7 Variations in Dissolved Oxygen

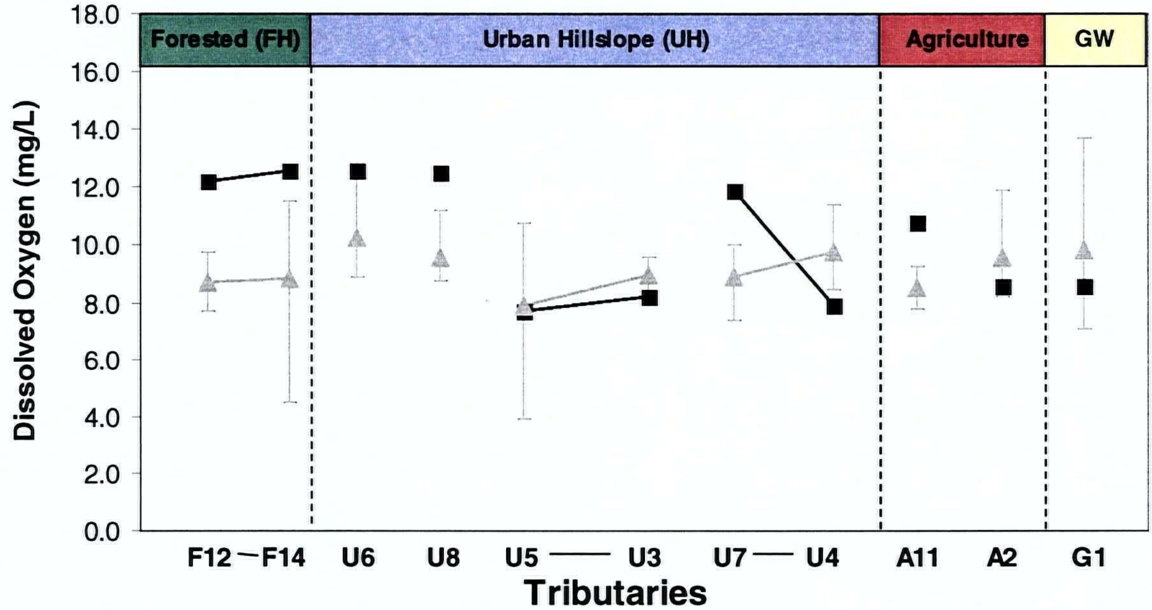
Due to equipment problems dissolved oxygen (DO) was only measured on five of the eight sampling dates (Table C.10 in Appendix C). Both DO concentrations and percent saturation (standard saturation concentration tables) were considered. Percent saturation was included because it corrects for temperature effects, and therefore gives a better description of the actual oxygen demand in the water at a specific site. Figure 7.6 shows the fluctuations in the wet and dry season mean DO concentrations. However, it should be noted that 3-Mar-2003 was the only wet season sampling date for which DO was measured, and that this date is not be representative of the entire wet season.

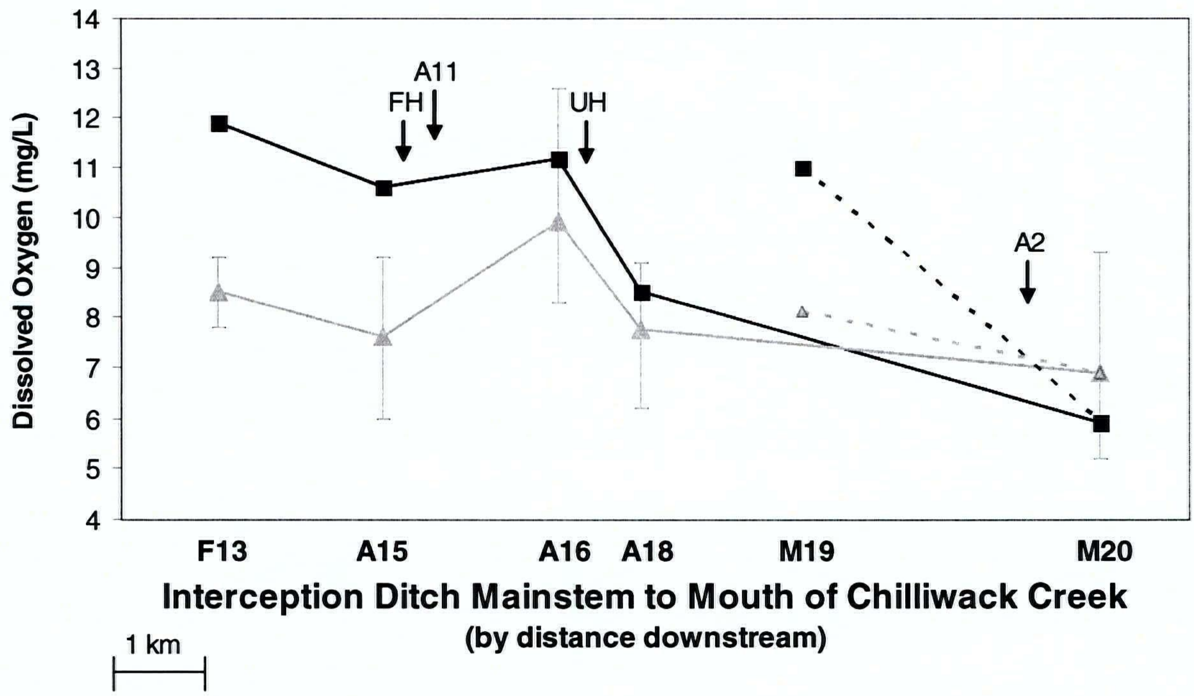
Dissolved oxygen levels were quite variable throughout the sampling period ranging from concentrations of 3.5 mg/L (39% DO saturation) at station U5 to supersaturated levels of 15.2 mg/L (>150% DO saturation) at station M9, in August. Station F14 is the only site that consistently had values above saturation, with the exception of one low value of 47% recorded in August 2002. Over the sampling period, two stations (U5 and F14) had concentrations below the 5.0 mg/L guideline for adult and juvenile salmonids. With the exception of station A17, every station was below the 9 mg/L guideline for salmonid embryos at least once during the sampling season.

Seasonal differences in DO concentrations were seen in the headwaters of both Chilliwack Creek and Interception Ditch, and in most hillslope tributaries. The higher wet season values at these locations can be attributed to turbulence (higher flows causing increased riffle action) and cooler temperatures in the stream, which promote the dissolving of oxygen in water. Lower biological activity and decomposition rates, combined with increased flushing of organic matter from the system also characterize the wet season; and both of these factors reduce the oxygen demand within the aquatic system (Addah, 2002).

While the difference is minimal, the opposite trend was observed in the lower reaches of the Chilliwack Creek and Interception Ditch mainstem. These locations are located in the lowland areas where streamflow is slower. In addition, the abundance of aquatic vegetation present at these sites would release oxygen to the water during photosynthesis; this phenomenon would be emphasized in the dry season when productivity is at its peak.

Both DO concentration and %DO saturation showed similar spatial patterns along the Interception Ditch and Chilliwack Creek mainstems. DO concentrations in the headwaters were somewhat higher than concentrations downstream year-round, with one exception. A peak, which is more pronounced in the summer, occurs at station A16 along Interception Ditch. Note also that at its mouth, Chilliwack Creek consistently had the lowest DO levels during both the wet (5.9 mg/L, 53%) and dry season (6.9 mg/L, 69%).





Legend: ▲ Grey triangles represent dry season means. ■ Black squares represent wet season means

—— Solid line represents Interception Ditch Mainstem
- - - Dashed line represents Chilliwack Creek

FH= forested hillslope tributaries (Elkview Creek); UH = urban hillslope tributaries

Notes: Error bars represent the range of measured values.
Arrows indicate the approximate location of tributaries draining into the mainstem.

Figure 7.6 Spatial and Seasonal Variations in Dissolved Oxygen Concentrations in the Chilliwack Creek Watershed

7.2.1.8 Variations in Dissolved Elements (Major Ions and Trace Metals) in Water

Dissolved streamwater concentrations of 6 elements were considered for all sites: calcium (Ca); iron (Fe); potassium (K), magnesium (Mg), manganese (Mn), and sodium (Na). In addition to these, a further 8 elements (Cd, Cr, Co, Cu, Ni, P, Pb, and Zn) were analyzed but were below their respective detection limits for all sites on all sampling dates. Aluminum was also consistently found below detection limit (0.05 ppm) except in Armstrong Ditch (A11, 0.42 ppm) and in Interception Ditch (A16, 0.06 ppm) on 3-May-2003. Due to the lack of data, these elements are not considered further. A tabular summary of the data is provided in Appendix C, and Table 7.2 shows a statistical summary of the data obtained from the analysis of major ions and trace metals in streamwater for the watershed.

Based on the graphs in Figures 7.7 through 7.12, no overall temporal trend is evident for any of the 6 elements. As previously mentioned, a Kruskal-Wallis test showed that for each element there was no significant difference between the median concentrations of the three sampling sets (dates).

Spatial Variability of Major Ions (Ca, Mg, Na, K) in Water

The lowest concentrations of Ca, K and Mg in the watershed were consistently detected in Elkview Creek (F13). Parson's Brook (F12, F14), Armstrong Ditch (A11) and the upper reaches of Interception Ditch (A15) also had low K and Mg levels. The highest Ca levels were found in Semiault Creek (A2), while Bailey Ditch (M10) and the upper station on Teskey Creek (U5) showed some of the highest Mg levels. Station M19 consistently had the highest K concentrations measured in the watershed, with relatively high concentrations of Ca and Mg also detected at this site. Bailey Ditch (M10), Teskey Way Ditch (A17) and Chilliwack Creek (M20) also showed some of the highest concentrations for all major ions, except Na.

Sodium behaved slightly differently than the other major ions. For example, Parson's Brook, which had low concentrations of most ions, showed some of the highest sodium concentrations in the watershed. Upper Thorton/Teskey Creek (U5) had the highest Na levels, while Walker Creek (U8), Benchley Creek (U6), Luckakuck Creek (G1), and the lower reaches of Lefferson Creek (U7) had the lowest levels of Na.

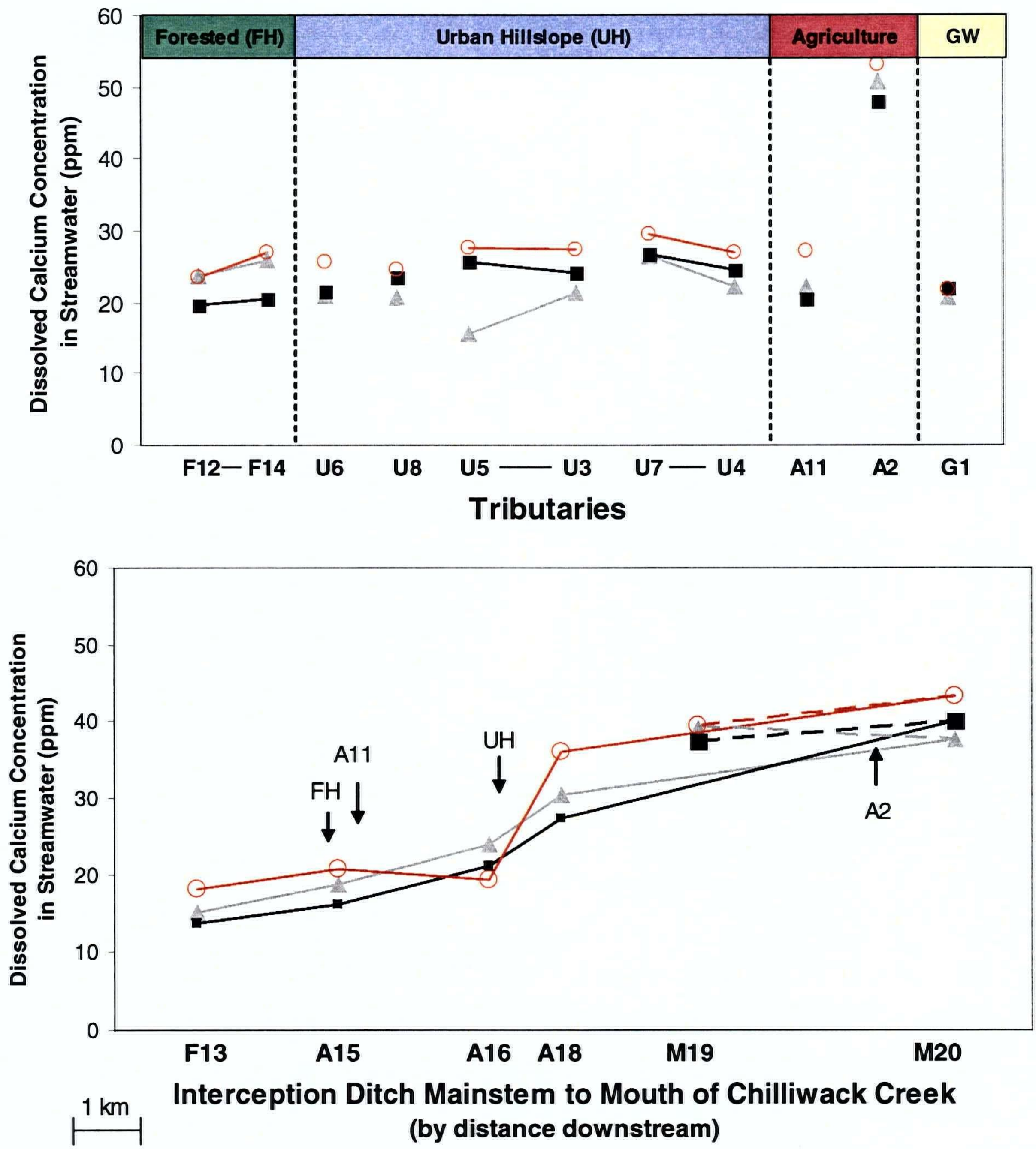
Finally, little to no variability can be seen in Luckakuck Creek (G1) for any of the major ions, and concentrations at this site are generally low and comparable to concentrations detected at the forested control stations (F12, F13, and F14).

Spatial trends with progression downstream were also evident (Figure 7.7 to 7.10). All cations showed a definite increase in concentration along the Interception Ditch mainstem from its headwaters to where it joins Chilliwack Creek. The area of Interception Ditch with the most substantial increase occurs downstream of station A16, where Teskey Creek enters the Ditch. (Note that streams draining into Teskey Creek flow through residential developments, agricultural land, and past the Bailey landfill site). The high ion concentrations in Teskey Way Ditch (21.45 ppm, 7.44 ppm and 2.00 ppm, for Ca, Mg, and K at station A17, respectively) may partially explain the substantial increase along this stretch of Interception Ditch. Concentrations in Chilliwack Creek were equal (Na, Mg) or greater (Ca, K) than concentrations in lower reaches Interception Ditch. Spatially, Ca concentrations decreased and Mg concentrations increased along Chilliwack Creek.

Spatial Variations in Trace Metals (Fe, Mn) in Water

Manganese (Mn) concentrations ranged from below detection (0.005 ppm) to 0.38 ppm, with a mean value of 0.07 ppm. The highest Mn concentration was measured in Bailey Ditch (M10) in May 2003. In addition, Semiault Creek (A2), Chilliwack Creek (M20), and the downstream section of Interception Ditch (A18, A16) all had concentrations above 0.10 mg/L on at least two of the three sampling dates. Iron (Fe) concentrations ranged from below detection (0.05 ppm) to 1.69 ppm, with a mean value of 0.37 ppm. As with Mn levels, Bailey Ditch (M10), Armstrong Ditch (A11), and the downstream section of Interception Ditch (A18, A16) had relatively high Fe levels. Semiault Creek (A2), which is intensively agricultural, showed the highest Mn concentrations, but had low Fe concentrations.

Spatially, concentrations of Fe and Mn were low in the headwaters and increased along Interception Ditch; however, the trend from Interception Ditch to the mouth of Chilliwack Creek differed. Manganese concentrations are greater at the mouth of Chilliwack Creek than concentrations measured along Interception Ditch, while iron concentrations in Chilliwack Creek remain much lower than those in Interception Ditch. Concentrations of the two metals also increase along Chilliwack Creek which may be due to contributions of the agricultural tributaries that enter the stream. Fe and Mn concentrations in the hillslope tributaries and in Luckakuck Creek (G1) were consistently low (concentrations are nearly always below or very near detection limit). These spatial variations of Fe and Mn are shown in Figures 7.11 and 7.12, respectively.

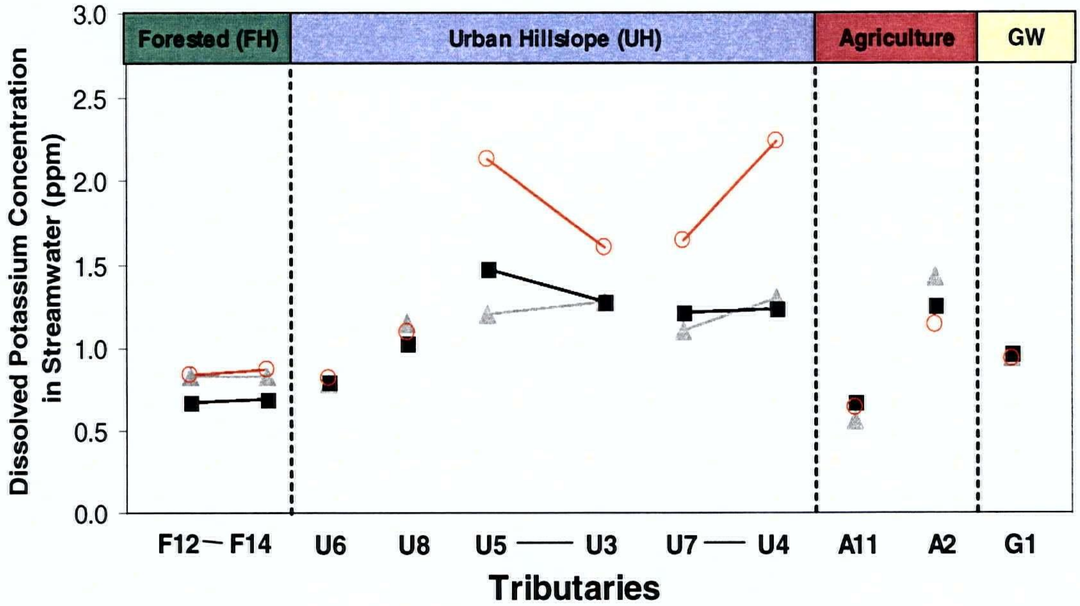


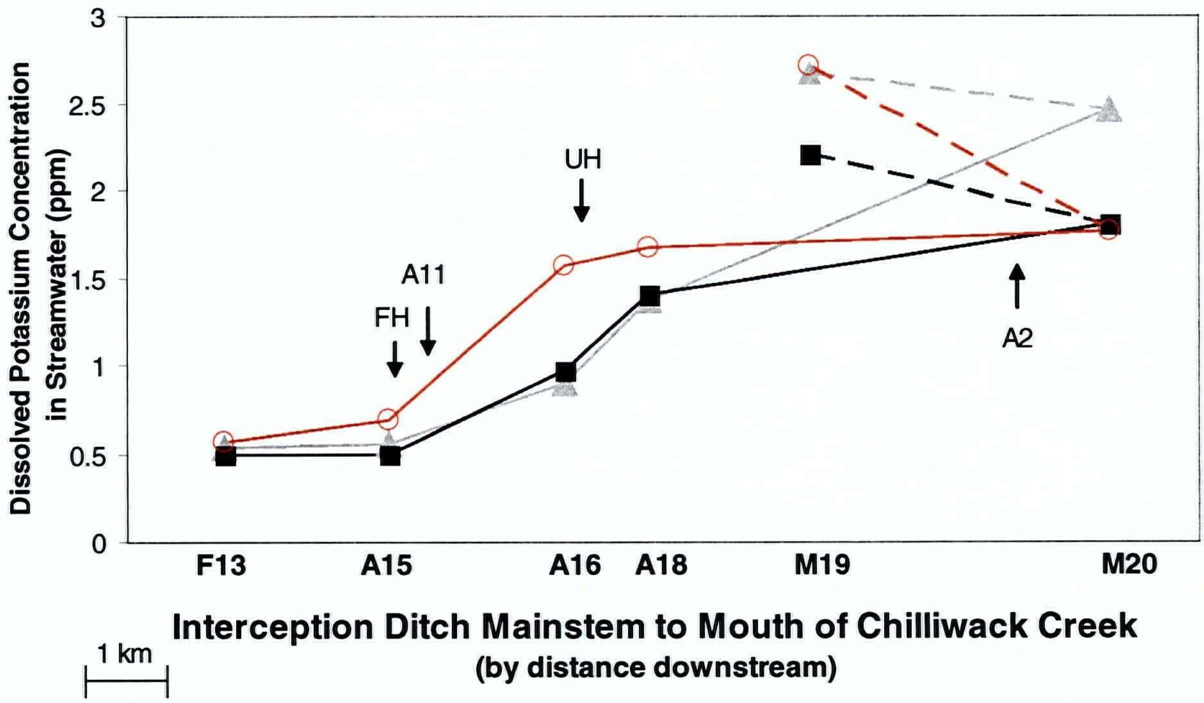
Legend: ▲ Grey triangles represent 27-May-02 concentrations — Solid line represents Interception Ditch Mainstem
■ Black squares represent 3-May-02 concentrations - - - Dashed line represents Chilliwack Creek
O Orange circles represent 9-Jul-03 concentrations

FH= forested hillslope tributaries (Elkview Creek); UH = urban hillslope tributaries

Notes: Arrows indicate the approximate location of tributaries draining into the mainstem.

Figure 7.7 Spatial and Temporal Variations in Dissolved Calcium (Ca) in the Chilliwack Creek Watershed



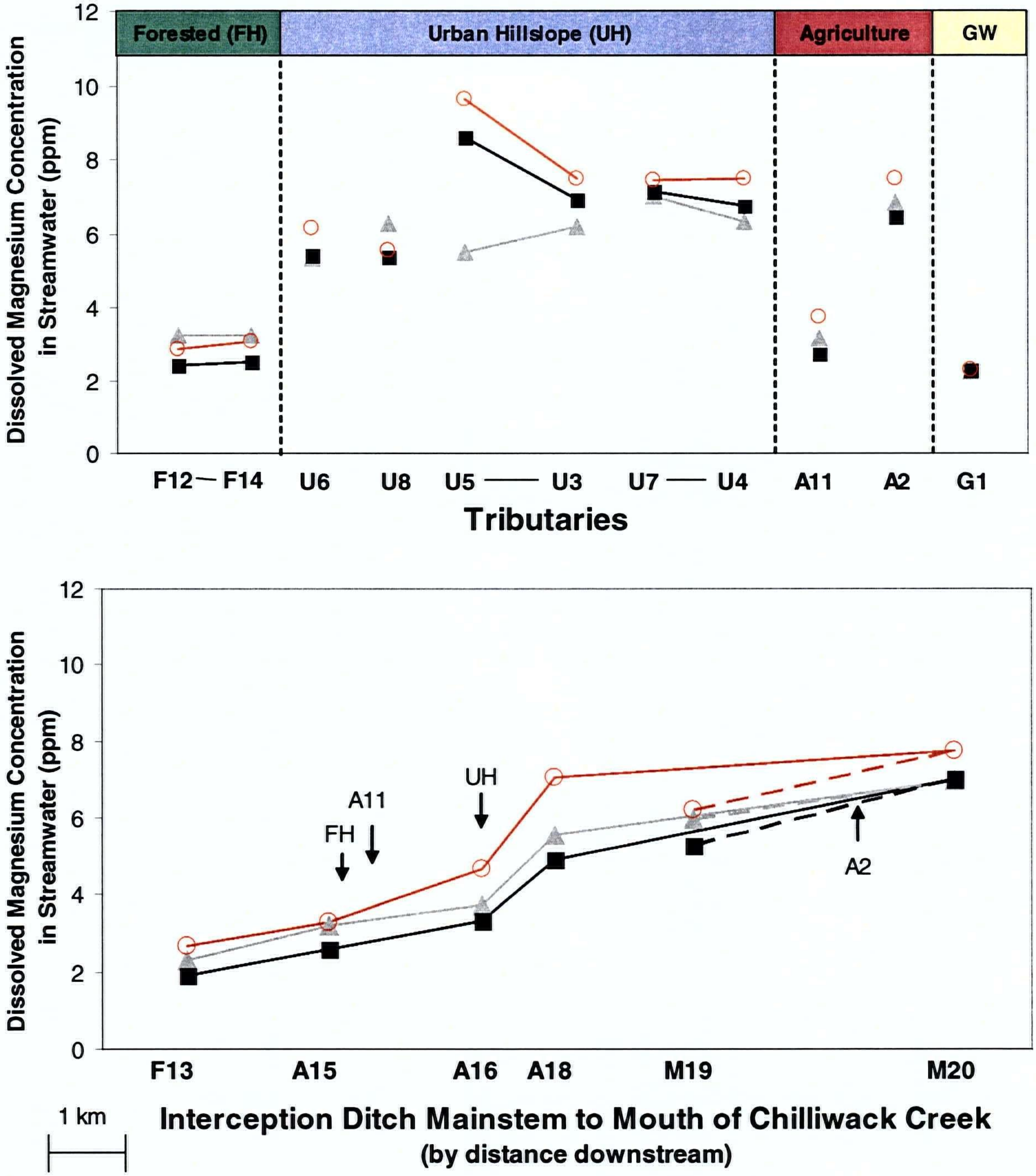


Legend: ▲ Grey triangles represent 27-May-02 concentrations — Solid line represents Interception Ditch Mainstem
■ Black squares represent 3-May-02 concentrations - - - Dashed line represents Chilliwack Creek
○ Orange circles represent 9-Jul-03 concentrations

FH= forested hillslope tributaries (Elkview Creek); UH = urban hillslope tributaries

Notes: Arrows indicate the approximate location of tributaries draining into the mainstem.

Figure 7.8 Spatial and Temporal Variations in Dissolved Potassium (K) in the Chilliwack Creek Watershed



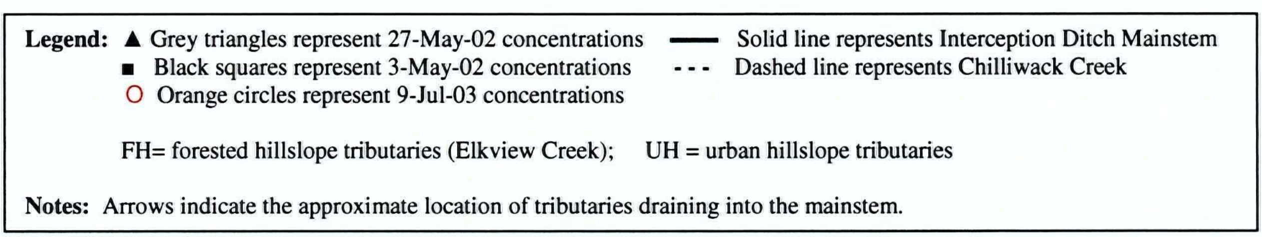
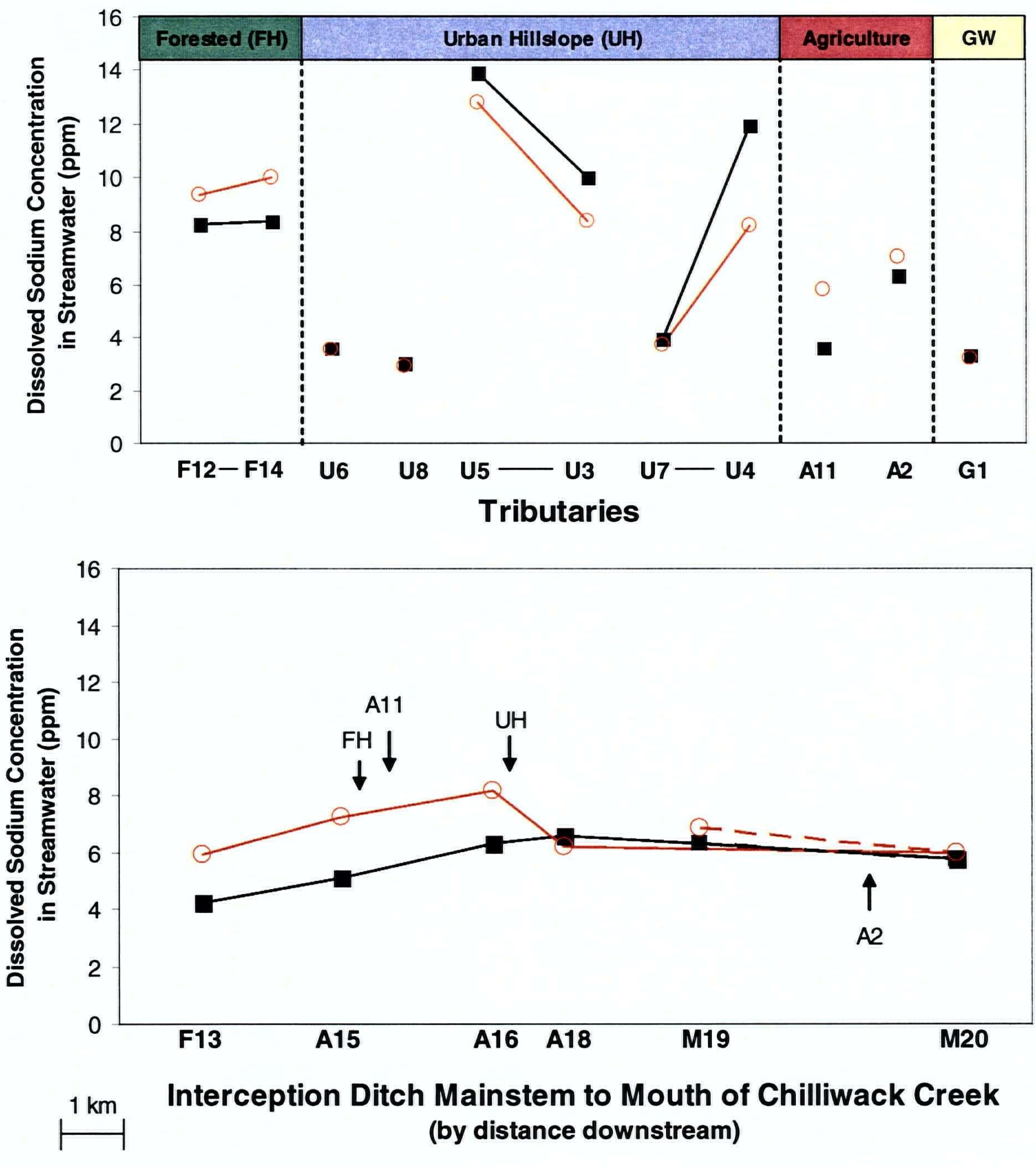


Figure 7.9 Spatial and Temporal Variations in Dissolved Magnesium (Mg) in the Chilliwack Creek Watershed

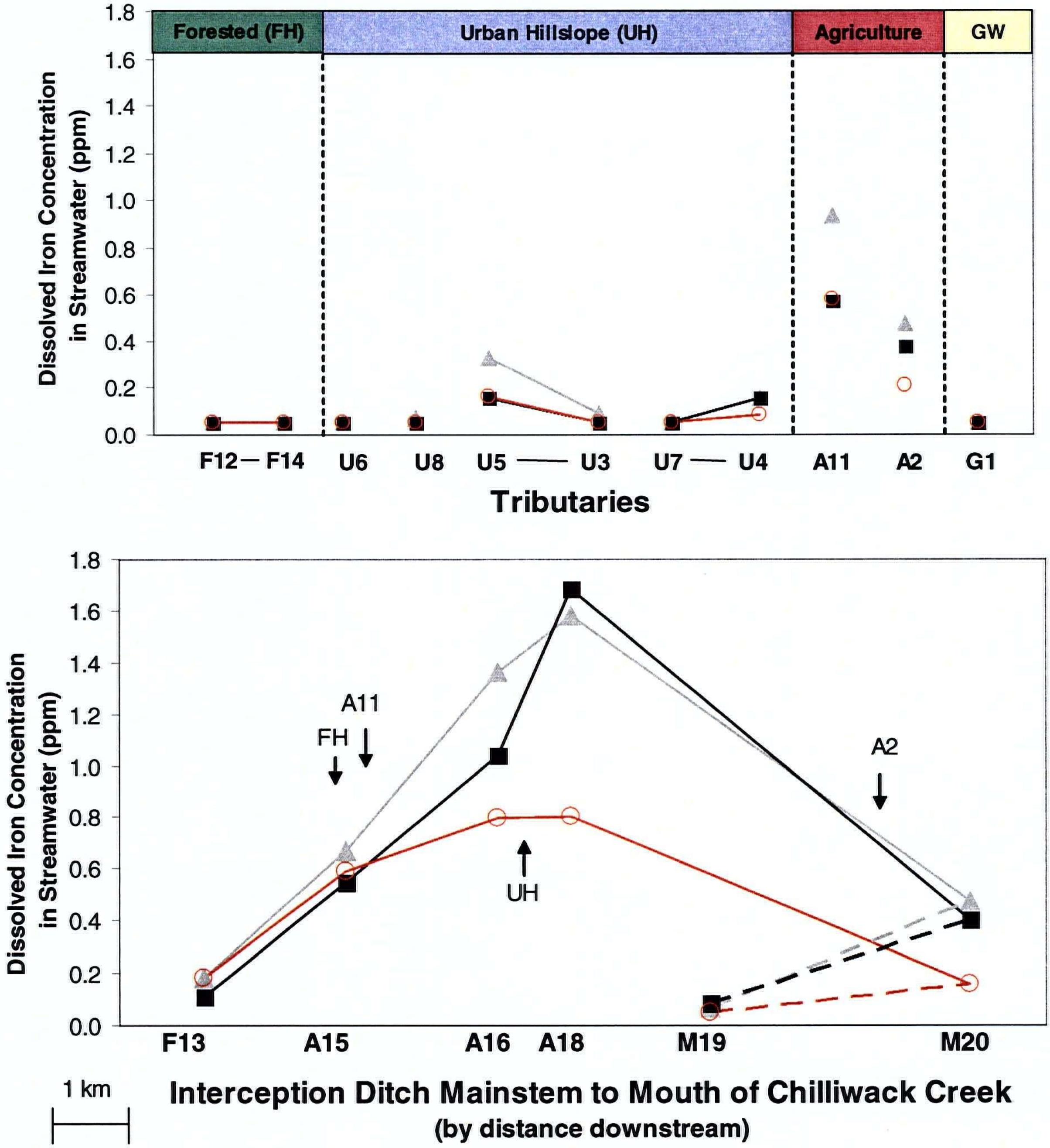


Legend: O Orange circles represent 12-Nov-02 concentrations —— Solid line represents Interception Ditch Mainstem
■ Black squares represent 10-Oct-02 concentrations - - - Dashed line represents Chilliwack Creek

FH= forested hillslope tributaries (Elkview Creek); UH = urban hillslope tributaries

Notes: Arrows indicate the approximate location of tributaries draining into the mainstem.

Figure 7.10 Spatial and Temporal Variations in Dissolved Sodium (Na) in the Chilliwack Creek Watershed



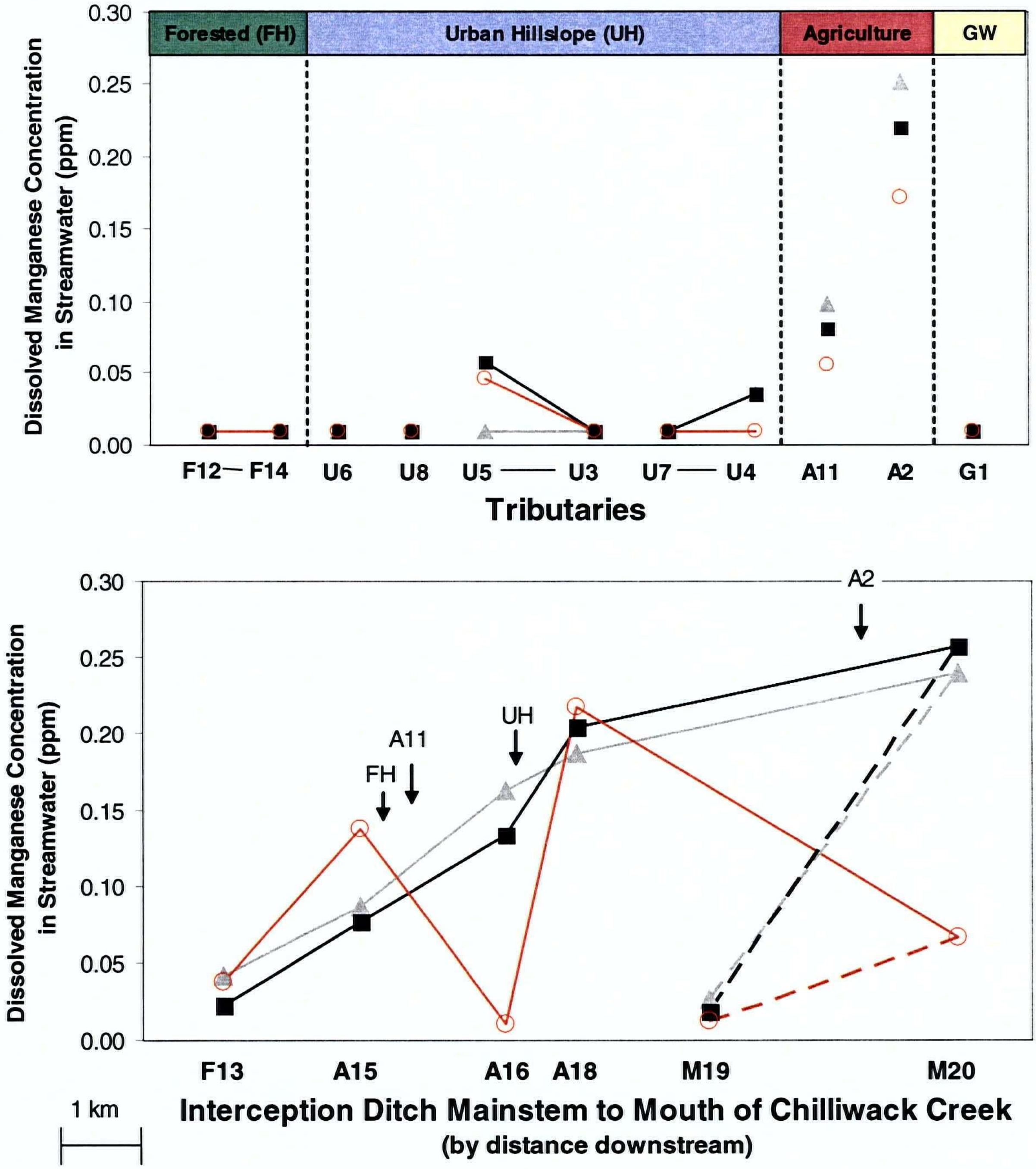
Legend: ▲ Grey triangles represent 27-May-02 concentrations
■ Black squares represent 3-May-02 concentrations
O Orange circles represent 9-Jul-03 concentrations

—— Solid line represents Interception Ditch Mainstem
- - - Dashed line represents Chilliwack Creek

FH= forested hillslope tributaries (Elkview Creek); UH = urban hillslope tributaries

Notes: Arrows indicate the approximate location of tributaries draining into the mainstem.

Figure 7.11 Spatial and Temporal Variations in Dissolved Iron (Fe) in the Chilliwack Creek Watershed



Legend: ▲ Grey triangles represent 27-May-02 concentrations —— Solid line represents Interception Ditch Mainstem
■ Black squares represent 3-May-02 concentrations - - - Dashed line represents Chilliwack Creek
O Orange circles represent 9-Jul-03 concentrations

FH= forested hillslope tributaries (Elkview Creek); UH = urban hillslope tributaries

Notes: Arrows indicate the approximate location of tributaries draining into the mainstem.

Figure 7.12 Spatial and Temporal Variations in Dissolved Manganese (Mn) in the Chilliwack Creek Watershed

7.2.2 Comparison between Land Use Categories: Water Quality Parameters

In this section the differences in water chemistry of streams draining the three dominant types of land uses are compared. An examination of the differences between sites grouped by land use will help distinguish the relative contributions of the different land uses for the various contaminants. Specific emphasis is placed on the difference between streams draining the upland urban area and the forested hillslopes since this would provide an idea as to what happens to aquatic systems as the hillslope is developed (i.e. converted from forest to urban). An overview of the differences in water chemistry between the three land uses is presented in Tables 7.3 and 7.4 below.

For each parameter, a Mann-Whitney U test was used to make pair-wise comparison between land use categories for wet and dry season data separately, and for both seasons combined. Due to their small sample sizes (n=3), dissolved elements were omitted from the wet and dry season analysis but were included in the statistical analysis of the combined seasonal data.

Table 7.3 Overview of Mann-Whitney Comparison between Land Use Categories for Water Quality Parameters (Wet and Dry Seasons)

		NH_4^+-N	NO_3^--N	PO_4^{3-}-P	pH	Temp	Sp. Cond.	DO
Dry Season	Agriculture vs Forest	A>F*	F>A	A>F				
	Agriculture vs Urban	A>U*	U>A*	A>U*		A>U*	A>U	
	Forest vs Urban			U>F				
Wet Season	Agriculture vs Forest	A>F		A>F*	A<F			F>A*
	Agriculture vs Urban	A>U	A>U		U>A	A>U	A>U	
	Forest vs Urban		F>U	U>F*				

All values significant at the α=0.0167 level unless otherwise noted by '*'
* Significant at the α=0.05 level

Table 7.4 Overview of Mann-Whitney Comparisons Between Land Use Categories for Major Ions and Trace Metals in Water (Seasons Combined)

		Ca	K	Mg	Na	Fe	Mn
Seasons Combined	Agriculture vs Forest	A>F*	A>F*	A>F		A>F	A>F
	Agriculture vs Urban			U>A*		A>U	A>U
	Forest vs Urban		U>F	U>F			

All values significant at the α=0.0167 level unless otherwise noted by '*'
* Significant at the α=0.05 level

Seasonal trends may differ depending on the land use of the surrounding area due to differences in environmental conditions and processes. Table 7.5 summarizes the seasonal differences in water chemistry for individual parameters.

Table 7.5 Overview of Mann-Whitney Comparison Between Wet and Dry Season Values for Water Quality Parameters

	NH_4^+-N	NO_3^--N	PO_4^{3-}-P	pH	Temp	Sp. Cond.	DO
Agriculture	X	X	O		O		
Urban		X	O		O	X	
Forest		X	O		O		X

*Symbology for statistically significant differences ($\alpha = 0.05$): 'X' = wet > dry; 'O' = wet < dry

Time series graphs were created in order to visualize the trends in water quality parameters for the different land use categories over the sampling period. The data series in these graphs represent trends for agriculture, urban, and forest, based on the mean for each land use category. Values for stations M19 and G1 were also plotted on this graph to represent water quality of a more intensive urban stream and a spring-fed stream, respectively. These graphs do not show the variability within land use categories; however deviation from the observed trend is noted when it was thought to be important.

It should be emphasized that any differences found between the land use categories are not necessarily the result of different inputs from the various land activities. Other abiotic and biotic factors that may influence water quality at a given site include: 1) flow characteristics of the stream (Arheimer et al., 1996); 2) the mechanism of water flow from the land (i.e. the proportion of surface runoff and groundwater, flow paths, and type of runoff event) (Chapman and Kimstach, 1996; Jordan et al., 1997); 3) internal river processes including biological and chemical transformations (Arheimer and Lidén, 2000); 4) geology of the drainage area; 5) topography (Herpe and Troch, 2000) and 5) mixing of water from different tributaries with different water quality (Chapman and Kimstach, 1996).

<u>**Nitrate-N:**</u>

Within the dry season (summer), nitrate-N concentrations in the agricultural streams were significantly lower than the nitrate-N concentrations of the forested tributaries ($p<0.017$) and urban tributaries ($p<0.05$). Agricultural watercourses tend to have more aquatic vegetation and algae growth in the summer; therefore, any nitrate that is on the land or that runs off into nearby watercourses is actively being taken up by the plants and aquatic biota that are growing at this time of year. In addition, the action of nitrifying bacteria is increased at higher temperatures (Heathwaite, 1993); thus, in warmer waters, typical of unshaded agricultural streams in the dry summer season, nitrification (conversion of ammonia to nitrate) is increased.

In the wet season, the urban hillslope streams had the lowest nitrate-N concentrations of the three main land use categories. The agricultural area had the highest nitrate-N levels, particularly on sampling dates that occurred during or immediately following a rain event (12-Nov-02 and 12-Dec-02); however, agriculture and forest concentrations were not statistically different. The lack of significant difference could be attributed to natural variability, differences in site conditions or possible unknown sources. Other studies in the LFV have shown that small hobby farms and leakage from septic tanks in rural areas can contribute nitrate to surface waters (Wernick, 1996; Cook, 1994). However, a more detailed study would have to be done to confirm this possibility.

The more intensive urban station (M19) along Chilliwack Creek had high nitrate-N levels during most of the year. As previously mentioned, storm outfalls are thought to contribute nitrate to the stream year round. The low values in November and December are likely a dilution effect from high stormwater runoff volumes. Nitrate-N concentrations at the spring-fed station were consistently around 1 mg/L throughout the year, below the 3 mg/L that is considered indicative of impacted groundwater (Schreier et al., 1996).

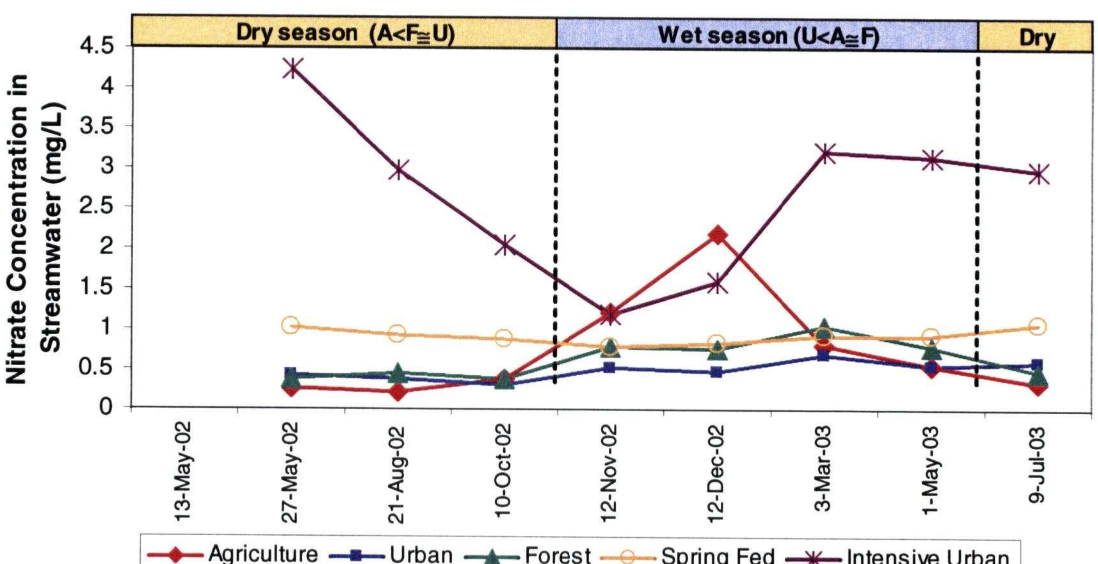


Figure 7.13 Nitrate-N Comparisons by Land Use Category

Ammonia-N:

Agricultural ammonia-N concentrations were significantly higher than either the urban or forested ammonia-N concentrations in the wet season. The largest differences between agricultural and hillslope areas occur on dates where significant rainfall occurred (12-Nov-02 and 12-Dec-02). Armstrong Ditch (A11) and the furthest upstream station along Interception Ditch (A15) are exceptions. These two agricultural stations had concentrations comparable to those measured in forest and urban hillslope tributaries. Stormwater outfalls at station M19 do not appear to be contributing ammonia-N to the stream.

Unlike nitrate-N, ammonia concentrations in Luckakuck Creek were not constant year round. The difference in the pattern seen for the two nutrients suggests that ammonia levels in Luckakuck Creek may be influenced by land use, while nitrate-N is not.

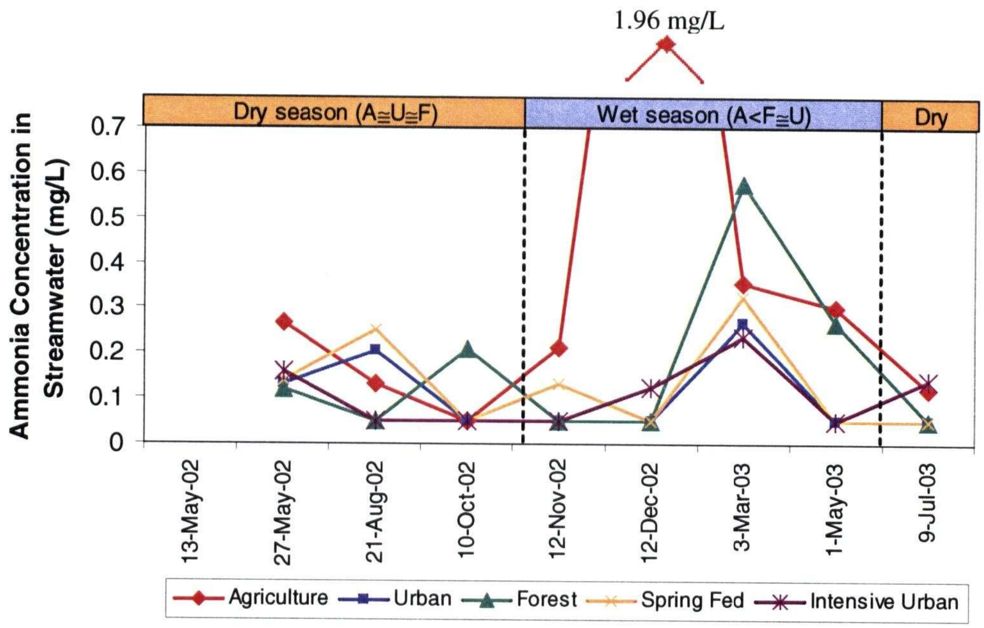


Figure 7.14 Ammonia-N Comparison By Land Use Category

Orthophosphate:

Agricultural and urban sampling sites had significantly higher orthophosphate-P levels than the forested sites, both in November ($p<0.05$) and for the combined August/October data ($p<0.017$) Still, it appears that agricultural sampling station had higher concentrations than the urban sampling stations, particularly in the wet season. Station A15 was the only agricultural site that had similar concentrations to any urban or forest sites.

Specific Conductivity:

The agricultural streams had significantly higher wet season specific conductivity values compared to the urban streams. This implies that agricultural activities in the watershed are a larger contributor of inorganic salts to the watercourses than the urban activities on the hillslope. This is supported by the fact that no significant difference was found between urban and forest. It is suspected that the urban area is not yet large enough to see significant impacts from the introduction of salts typical in urban runoff (such as road salt and fertilizers). Specific conductivity of both the urban and forest areas are primarily influenced by the geology of the hillslope area. The influence typical of a more intensified urban area can be seen in the higher conductivity values observed at station M19 during the dry season when dilution was not an issue.

Some variability among the agricultural stations did exist. The major agriculturally influenced station A2 (Semiault Creek) consistently had some of the highest specific conductivity values during both the wet and the dry season, as did station A17. In contrast, Armstrong Ditch station (A11) had much lower conductivity values, particularly in the dry season. The fact that this station receives much of its water from the hillslope area may explain the lower values observed at the site.

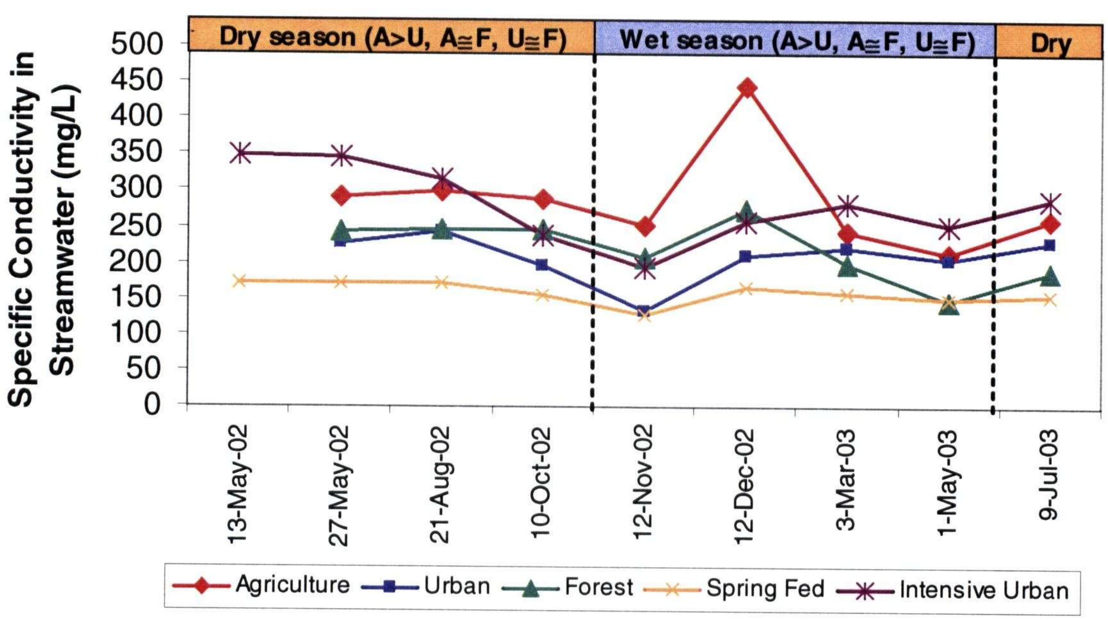


Figure 7.15 Specific Conductivity Comparisons by Land Use Category

Dissolved Oxygen:

During the wet season, both DO concentration and %DO saturation were significantly greater in the forest area when compared to the agricultural area. The higher runoff velocity on the hillslopes creates turbulence, which promotes the dissolving of oxygen from the air to the stream. Therefore, the difference in topography between the forest tributaries and lowland agricultural streams may partially explain the higher DO concentrations of the forested tributaries. Since the urban land use is also on the hillslope it is reasonable that there was no significant difference between forest and urban sites. No significant difference was found during the dry season, when runoff is at its lowest.

pH:

Schendel's (2001) study in the adjacent (Elk Creek) watershed showed soils in the area were generally acidic (3.23 to 6.25), but that the forested hillslope soils were more acidic than the soils sampled in the lowland agricultural area. However, this does not translate to the watercourses. During the wet season, pH values were significantly lower in the agricultural streams than in the hillslope tributaries (forest and urban). No significant difference was found between the urban and forested hillslope tributaries. The higher acidity of the agricultural watercourses is probably due to the addition of chemical fertilizers and manure inputs during runoff events. During the dry season, all land use categories had statistically similar ($p>0.017$) pH values

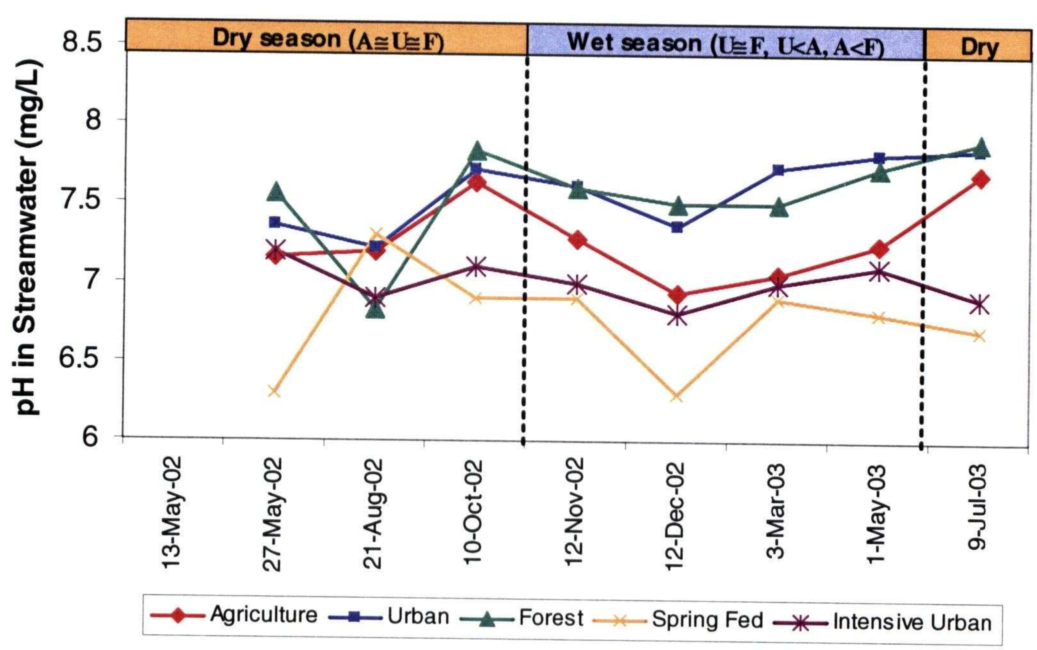


Figure 7.16 pH Comparisons by Land Use Category

Major Ions in Water (Ca, Mg, K, Na):

When comparing concentrations for major ions, it can be observed that calcium is the major ion with the broadest range and highest mean concentration (13.7-53.1, 28.0 mg/L). Overall, the following sequence, going from least to most abundant, can be established: K<Mg<Na<<Ca when all sites are considered. When separated by land use the sequence is the same, although the relative difference in concentration differs. For example, for forested sites, Mg concentrations are much lower than Na concentrations (Table 7.2, Figure 7.17).

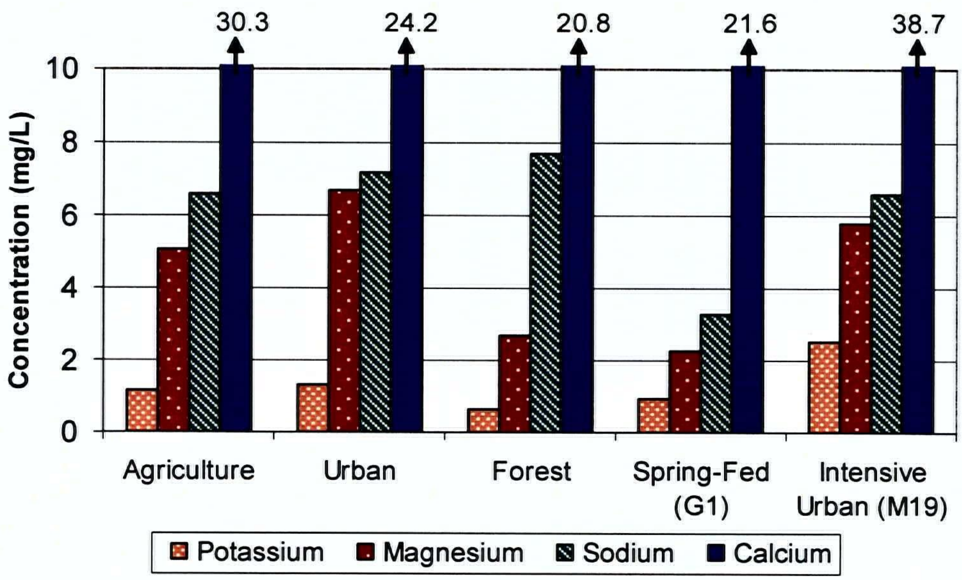


Figure 7.17 Major Ions (K, Mg, Na, Ca) Comparison by Land Use Category

The magnesium and potassium cations appear to be strongly influenced by land use. Overall, tributaries on the forested hillslope had significantly lower ($p<0.017$) concentrations of Mg and K. These results are similar to the spatial trends found in soils of Elk Creek (an adjacent watershed). Schendel's (2001) study of Elk Creek soils found that Ca, Mg, and K concentrations were significantly lower in the upland areas than the lowland areas, while Na was not found to exhibit any spatial trends. Differences between land use could be due to fertilizer application to urban lawns and agricultural fields. It is interesting to note that at the 0.05 level magnesium concentrations of the urban streams are also significantly greater than concentrations in agricultural streams. It is uncertain what the source of these elevated levels is, but they could be a result of construction activities in this portion of the watershed.

While concentrations of K and Mg at the agricultural sites were generally higher than concentration detected at the forest sites, some variability did exist. Agriculture stations that are closer to the hillslope (A15 and A11) had concentrations similar to forested sites, whereas downstream stations along Interception Ditch (A16, A18), station A17, and sites which do not receive drainage waters directly from the hillslopes (A2), had much higher concentrations.

Trace Metals in Water (Fe, Mn) :

For trace metals, iron concentrations were higher than manganese concentrations. The difference between the two is significantly larger for agriculture sites (0.66 mg/L), than for forest (0.07 mg/L) or urban (0.08 mg/L) sites.

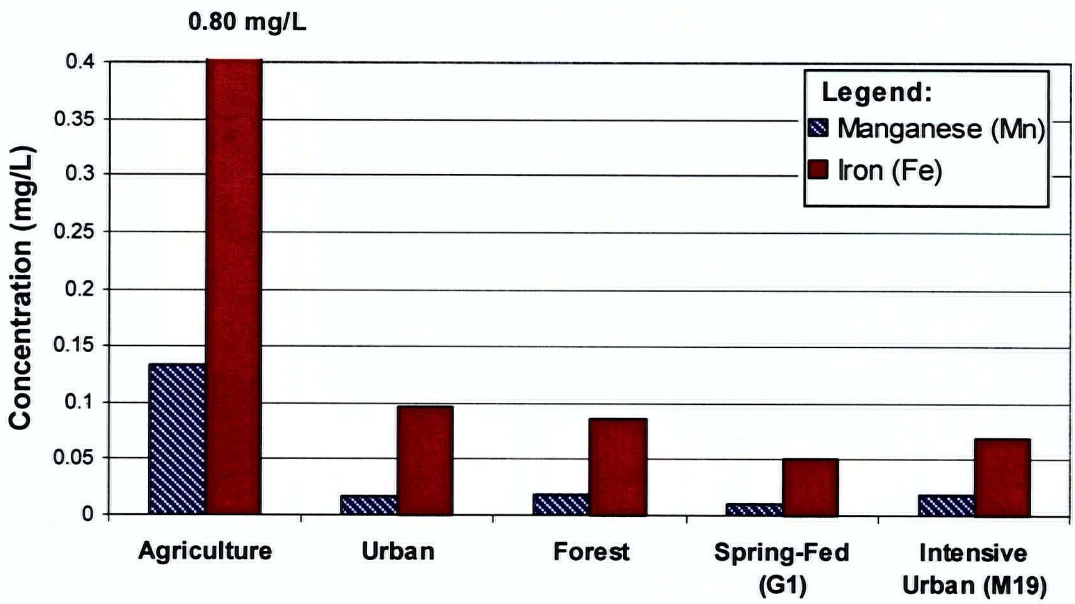


Figure 7.18 Dissolved Trace Metals (Fe, Mn) Comparison by Land Use Category

Both iron and manganese concentrations were the highest for the agricultural land use category (Table 7.4). Metals such as Mn and Fe are added to animal feed as nutrient supplements, and as a consequence animal manures can contain high concentrations of these metals and surface water can be at risk of metals leaching from fields receiving livestock manure. The occurrence of iron and manganese in aqueous solution is also largely dependent on environmental conditions, particularly conditions that influence oxidation and reduction reactions (Chapman and Kimstach, 1996). The lower pH in the agricultural streams could promote the release of iron from sediments.

7.2.3 Variations with Discharge

A Spearman's rank correlation was used to determine the relationship between water quality indicators and streamflow. This was done separately for each monitoring station that was adjacent to a hydrometric station; however no significant relationships were found. It is thought that the lack of data, particularly during high flow, most likely inhibited determining any relationships between water quality parameters.

7.2.3.1 Influence of Storm Events on Water Chemistry

Water samples were collected at two agricultural sites (A2, A18), one urban site (U3), and one forested site (F14) during a storm event on 16-Oct-2003, and analyzed for nitrate and dissolved trace elements. Samples were collected four times at each station, approximately every 75 minutes. In addition, one sample was also taken at the mouth of Chilliwack Creek (station M20) near the end of the sampling period. Considering that the hydrologic response of urban watersheds is typically fast, and that runoff frequently occurs in surges (which would be accompanied by pulses in contaminants to the streams), this is considered somewhat 'sparse' sampling, particularly if loads are to be determined (Macdonald et al., 1997).

Although samples were analyzed for the presence of a number of metals, only Al, Mn, Ca, Fe, K, Mg and Na were consistently present in concentrations above detection at all stations (Table C.13 in Appendix C). In contrast to baseflow sampling, Al was also above detection for all sites, and Zn was above detection at station A2 (Semiault Creek).

The sampled event was the first large storm (>100 mm) of the winter rainy season following an unusually long dry season. Unfortunately, the sampling period only covered the initial stages of the storm; the majority of the runoff occurred after sampling ended (Figure 7.19). In addition there is no precipitation data from the tipping buckets, and only two of the hydrometric stations (Semiault and Teskey) were operational at the time. The 'urban' sampling set, taken at station U3, is located in the same spot as the Teskey flow station. There were no hydrometric stations directly adjacent to either of the 'agricultural' sampling stations. The hydrometric station along Semiault Creek is located approximately 3.3 km downstream of the sampling station A2 (and therefore is probably not entirely representative of flow at point of sampling). Over the sampled period of the storm, the Teskey Creek hydrograph shows a minor peak shortly before the main storm runoff began; flow at the Semiault station only begins to increase near the end of sampled period. Despite missing the major storm peak, when the water quality data are plotted with the progression of the storm event there is evidence that the storm runoff is already influencing water chemistry (Figure 7.20 and 7.21).

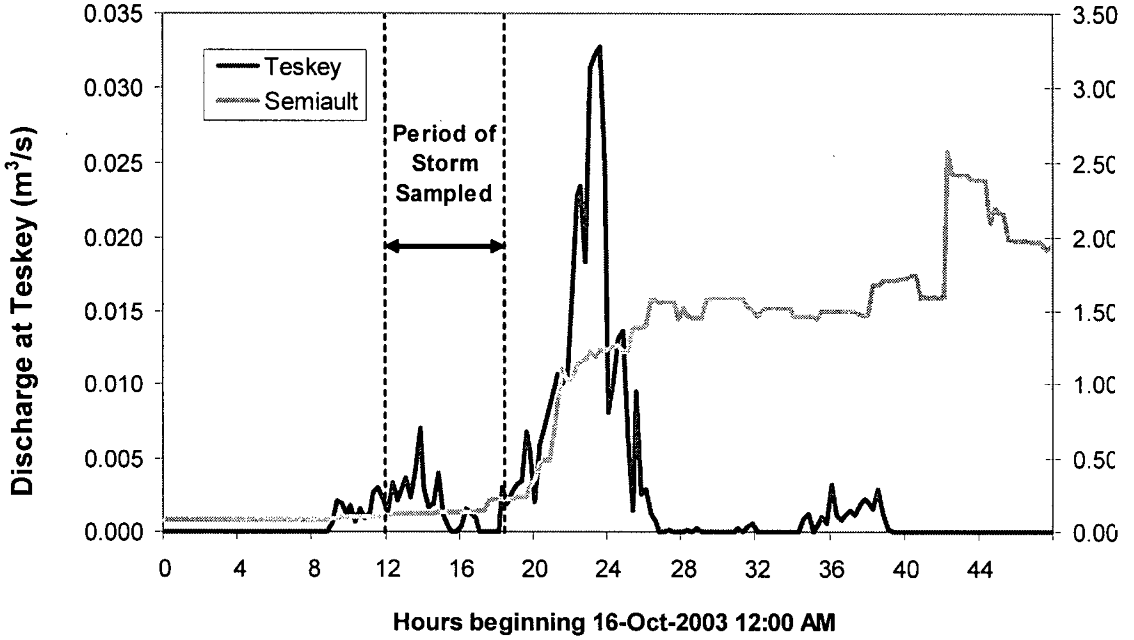


Figure 7.19 Storm Hydrograph for the 16-Oct-2003 Storm Event

Nitrate and metals linked to agricultural activities, particularly animal manure (Mn, Zn), showed significant increases in concentration at the agricultural stations during the storm event.
In Semiault Creek (A2), nitrate, manganese and zinc showed particularly strong increasing trends reaching maximum concentrations of 7.20 mg/L, 0.35 mg/L and 0.06 mg/L, respectively. Station A18 showed a similar trend (but with lower concentrations) for Mn and nitrate. Overall, concentrations were greater than the concentrations recorded during monthly (baseflow) sampling, and it is thought that concentrations would continue to increase throughout the storm until dilution started.

Fe and Al data trends observed at the urban station (U3) and the downstream agricultural station (A18) were remarkably similar. Samples from both stations showed an increase in concentration until 5 hours (±1 hour) after the onset of the storm, followed by a decline to initial levels. This corresponds to about a 3 hour lag time (±1 hour) between peak runoff and peak concentrations. Peak concentrations of 0.75 mg/L Fe and 0.78 mg/L Al were measured at the urban site, and higher peak concentrations of 1.24 mg/L Fe and 1.12 mg/L Al were recorded at the downstream agricultural station A18. At station A2 dissolved aluminum and iron concentrations are lower and continually increase over the course of the sampling to maximum concentrations of 0.41 mg/L Fe and 0.43 mg/L Al. As expected, concentrations at the forest station remained low with minimal change over the storm event.

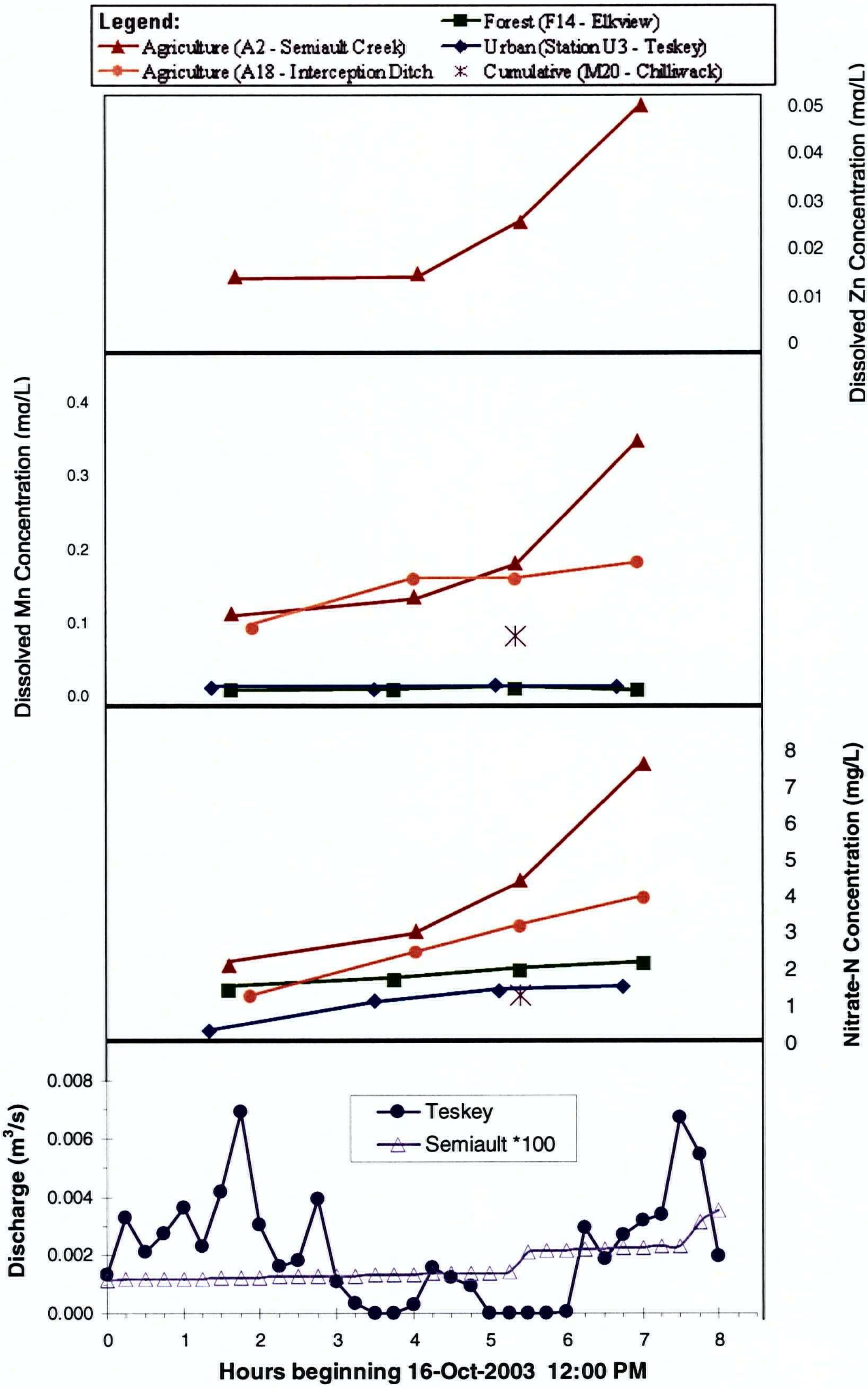


Figure 7.20 Response of Zinc (Zn), Manganese (Mn) and Nitrate During the 16-October-2003 Storm Event

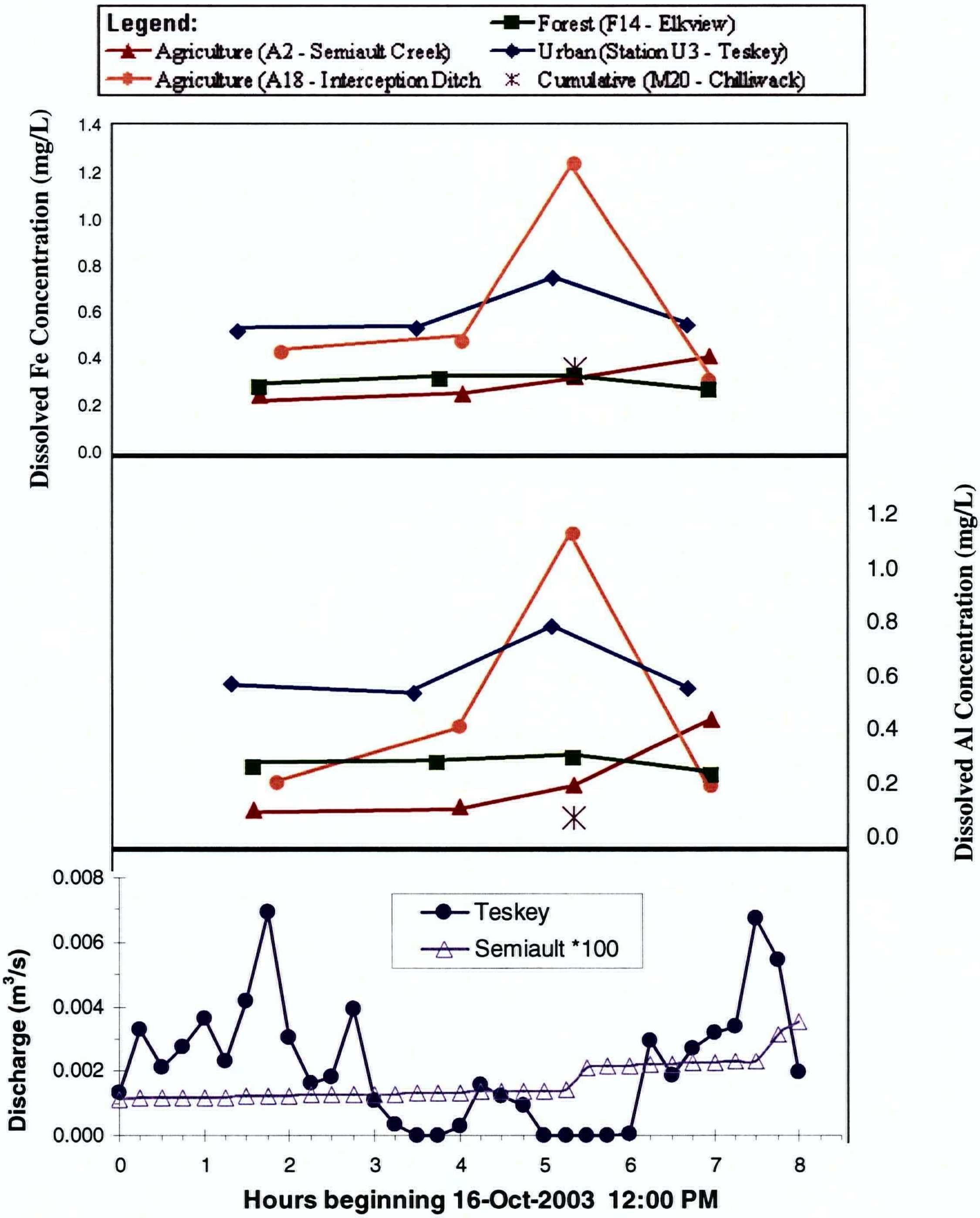


Figure 7.21 Response of Aluminum (Al) and Iron (Fe) During the 16-October-2003 Storm Event

7.3 Results for Sediment Parameters

Streambed sediments were collected in October 2002 and again in July 2003, and analyzed for carbon and nitrogen content, and for trace elements. The July sediment sample set was further analyzed for bio-available phosphorus (as orthophosphate) and texture. Results for all these properties are shown in Appendix D.

7.3.1 Sediment Properties: Particle Size

The smaller sediment size fractions have a relatively higher adsorptive capacity, and thus, it is expected that this finer fraction (generally <0.063 mm) will have a higher concentration of metals. This silt and clay component also has been shown to have a greater potential to become re-suspended. Consequently, this fraction is important in understanding site contamination. Figure 7.22 shows the percentages of sand, silt and clay at each site on the July-2003 sampling date.

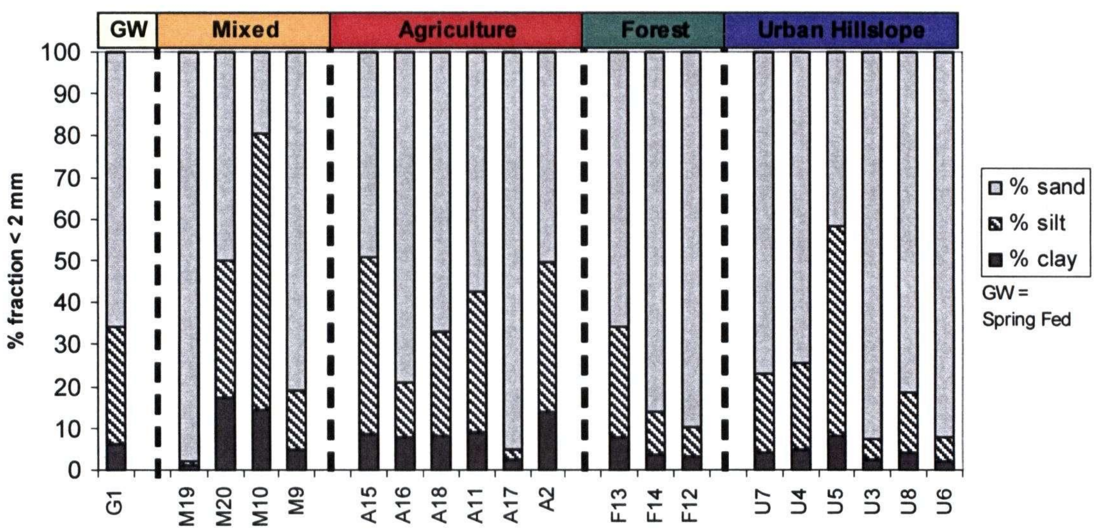


Figure 7.22 Percentages of Sand, Silt and Clay at Each Sampling Station

Overall, particle sizes were quite variable throughout the watershed. The clay fraction ranged from 1.3 to 17.3%, the silt fraction from 0.9 to 66.1%, and sand fraction from 19.3 to 97.7%. While the sand, silt and clay content of the sediment did not show any significant differences between the three major land use categories (forest, urban, agriculture), sediments sampled from upland streams appeared to have a higher sand content. Topography is one of the main factors controlling sediment transport at the catchment scale; the steeper grade of the hillslope area through which these stream flows is steep enough to move finer sediments downstream even under summer flow conditions. Two exceptions are Elkview Creek (F13) and upper Teskey Creek (U5) which showed lower percent sand (65.8% and 41.8%, respectively) than the other hillslope stations. Sampling station F13 is at the transition between the hillslopes and the flat agricultural land; as a result, water at this point slows rather abruptly and finer sediments will begin to settle out.

In contrast, significant clay-silt fractions (<0.053 mm) were found in most lowland streams (Semiault Creek (49.7%), Armstrong Ditch (42.5%), Interception Ditch (21.3 to 50.7%), and the mouth of Chilliwack Creek (50.1%)). The largest percent fines (<0.053 mm, clay + silt) was found in Bailey Ditch (M10) with 80.7%. Sampling was done in the low flow period when water in these lowland streams and agricultural ditches tends to be stagnant, which allows the fine particles to settle out. Station M19 and A17 are exceptions, and had the highest percentages of sand (>95%) in the sediment collected in the watershed.

7.3.2 Variations in % Carbon and % Nitrogen

Percent carbon and percent nitrogen in the sediment were used as a measure of the organic matter content. Percent total carbon (%C) varied from 0.35% at station U3 to 7.04% at station G1. Nitrogen content ranged from 0.03% to 0.51%, and was correlated strongly with percent carbon (r = 0.955). As with carbon, the highest %N was measure in Luckakuck Creek (G1).

Carbon and nitrogen showed similar trends. In general, the carbon and nitrogen content in the sediment collected from the lowland agricultural area did appear elevated compared to that of the sediment collected from the upland areas. This is reflected in the Mann-Whitney tests for comparison between land use categories for %N.

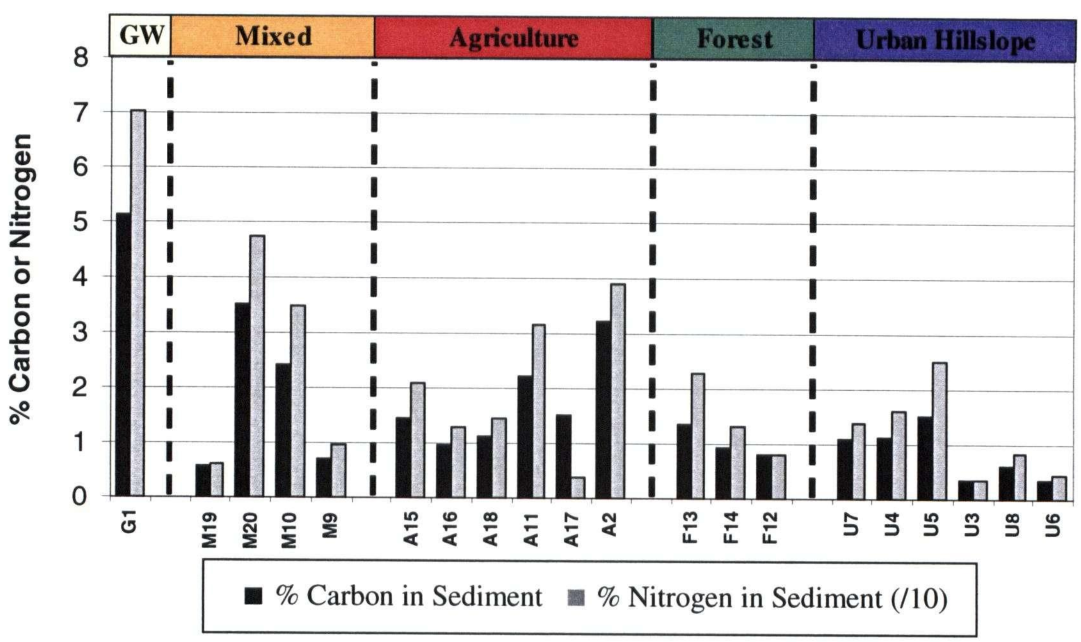


Figure 7.23 %Carbon and %Nitrogen for July 2003 Sediment Samples

7.3.3 Metals in Sediment

Sediment samples were taken at the end of the dry season (extended period of low flow conditions), and therefore the total trace metal concentration in sediments was used as an indicator of accumulated metal contamination over the previous year. The initial chemical analysis for sediments focused on the total concentration of twenty-two elements (Al, As, Ba, B, Ca, Cd, Cr, Co, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, Se, Si, Sr and Zn) at each sampling site. A complete tabular summary of the sediments metal data is provided in Appendix D. Of these, concentrations of four elements (As, B, Mo, Se) were consistently below their respective detection limit and will not be considered further. Phosphorus is discussed separately in a subsequent section.

7.3.3.1 Temporal Trends

An overview of the differences in metals between the two sampling dates is shown in Table 7.6 Sediment samples taken in October 2002 generally had higher metal concentrations than samples taken in July 2003, for both the agricultural and urban land use categories. However, these differences may simply reflect the natural variability in trace metals due to the physical and chemical properties of the sediment, variability in streamflow, and in-stream conditions. The urban area is in a development stage, and therefore soils and land in the area are continually being disturbed as new developments are built. Therefore, it is also possible that while low flow sampling is stable in the undisturbed forested hillslope, the development of the urban area on the hillslope may be impacting trace metal concentrations.

Table 7.6 Overview of Total Metal Concentrations in Sediments Showing a Significant Difference Between October 2002 and July 2003 Sediment Sampling Sets

Land Use	Elements showing a significant difference at $\alpha = 0.05$
Agriculture*	Al, Cr, Cd, Cu, Fe, K, Mg, Ni, Zn, Co
Urban	Al, Cd, Co, Cr, Fe, K, Mg, Na, Ni, P, Ca
Forest	None
Combined Data*	Al, Cr, Cu, Fe, K, Mg, Ni, Zn, Co, Na, Mn, Ca

* excludes station A2 since samples were only collected in July 2003

7.3.3.2 Spatial Trends

The range and mean of trace metal concentrations measured in the streambed sediment of Chilliwack Creek and its tributaries are presented in Table 7.7. These data are separated by land use, and compared to background concentrations and concentrations of these elements found in sediments for other studies in the Lower Fraser Valley. Because concentrations of metals in sediment may be enriched through natural processes (such as weathering), and consequently, influenced by the composition of local soils and geology, information on background concentrations can help in determining the extent to which human activities have contributed to the concentrations of sediment associated metals. As with water quality data, results are presented graphically to visualize changes in metal concentrations from the upstream to downstream direction for the Interception Ditch and Chilliwack Creek mainstems and their tributaries. Both the October 2002 and July 2003 samples are shown.

Most metals are not above natural background concentrations when compared to the data for Vancouver region sediments (Table 7.7), and match values measured at reference sites from other studies in the LFV. However, if we compare the data to the reference sites from Smith (2004) located on Vedder mountain, Cd, Mn, Zn, Fe, Mg, Ca, Na, and K all showed higher concentrations than those measured at this reference site.

This thesis will focus on the results of iron (Fe), copper (Cu), zinc (Zn), cadmium (Cd), manganese (Mn), magnesium (Mg), sodium (Na) and potassium (K), as these elements exhibited the most interesting spatial variation throughout the watershed.

Table 7.7 Metal Concentrations in Sediment for the Chilliwack Creek Watershed, and Comparison with Natural Background Levels and Other Studies in the Lower Fraser Valley (LFV)

2002-2003, Chilliwack Creek Streambed Sediment Sampling (mg/kg)[j]		Al	Fe	Mg	Ca	Na	K	Si	Sr	Ba
ALL SITES	**Mean**	11250	33898	5370	4373	171	509	1355	32.3	137
	Range	6927-17014	15328-89488	2204-22565	2568-9900	89-309	232-1176	904-2082	20.2-51.8	59 – 294
AGRICULTURAL SITES	**Mean**	12009	43825	5512	4270	208	550	1366	32.1	166
	Range	8188-15245	22027-89488	2854-8387	3362-6525	130-303	232-1006	1037-2082	23.9-43.4	109-294
URBAN SITES	**Mean**	10859	22153	4083	3991	134	459	1300	28.4	117
	Range	6927-15964	15328-30322	2204-6207	2568-5356	89-209	347-655	1079-1836	20.2-41.3	91-145
FOREST SITES	**Mean**	12642	30671	5289	4111	123	331	1451	40.5	121
	Range	9517-17014	22283-44339	3090-8106	2861-5222	100-156	246-460	936-1900	28.7-50.5	79-185
Background Concentrations										
Western US sediments (<63μm fraction)[a]										
Mean sediments[b]		7.2%	4.1%	1.4%	60%	0.6%	2.0%	24.5%	230	460
Upper Illinois R. Basin low order streams median (<63 μm fraction)[c]			2.9%							
NTS 92G Vancouver map sheet (<177 μm fraction), mean and range[d]			2.02% (0.4-10.5)%							
FORESTED CONTROL SITES IN LFV STUDIES	Vedder Mtn 2004 (Sumas Watershed)[e]	12195	20964	10296	5929	181	202	616		
Streambed Sediment Concentrations (Impacted watersheds in the LFV)										
AGRICULTURAL WATERSHEDS	Sumas River (Abbotsford)[e]	9514 (5238-12318)	48693 (39866-73763)	63297 (8628-126150)	4354 (2967-6028)	551.4 (231-911)	487.8 (359-725)	634 (427-878)		
	Agassiz/Harrison Hot Springs[h], mean and range		5% (1.9-8.7)%							
RURAL RESIDENTIAL/ AGRICULTURAL WATERSHED	Salmon River (Langley), Aug 1991[g] mean and range	6400 (45600-84400)	48700 (33100-114000)	7540 (4930-11800)	12189 (6830-16800)	14636 (9560-19600)			32.2 (16.0-79.8)	
URBAN WATERSHED	Burnette River[i] (Vancouver), median and range		2.0% (5962-48651)	3424 (247-8087)						

[a] Combest (1991) cited in Cook (1994)
[b] Wedepohl (1968) cited in Salomons and Förstner (1984)
[c] Colman and Sazolon (1992) cited in Cook (1994)
[d] BCMOEMPR (1990) cited in Cook (1994)
[e] unpublished data, I. Smith (pers. comm..)
[g] Cook (1994)
[h] Addah (2002), dry season data only, omitting spring and control stations
[i] McCallum (1995)
[j] all concentration are in mg/kg dry weight, unless otherwise noted

Table 7.7 (cont.) Metal Concentrations in Sediments for the Chilliwack Creek Watershed, and Comparisons with Natural Background Levels and Other Studies in the Lower Fraser Valley (LFV)

2002-2003, Chilliwack Creek Streambed Sediment Sampling (mg/kg)[j]		**Cd**	**Co**	**Cr**	**Cu**	**Mn**	**Ni**	**P**	**Pb**	**Zn**
ALL SITES	***Mean***	4.0	12.7	29.2	38.9	763	27.9	1150	45.1	120
	Range	2.5-11.2	10.0-27.7	18.4-64.9	17.9-80.8	142-1805	16.2-45.1	500-5110	25.8-76.2	54-265
AGRICULTURAL SITES	***Mean***	4.9	13.6	28.6	40.9	591	28.2	1426		149
	Range	2.9-11.2	10.0-27.7	20.1-35.9	29.0-56.6	226-1318	17.9-34.5	958-2884		84-218
URBAN SITES	***Mean***	2.7	11.3	27.9	26.8	952	27.3	716		81
	Range	2.5-3.2	10.0-14.4	18.4-35.7	17.9-33.5	446-1656	16.2-37.2	620-849		54-119
FOREST SITES	***Mean***	3.8	15.6	27.5	44.2	838	31.7	702		114
	Range	2.5-5.1	10.0-24.0	20.7-34.6	24.9-63.1	359-1446	20.2-45.1	500-862		65-154
Background Concentrations										
Western US sediments (<63μm fraction)[a]				20-210	0-110				9-52	49-510
Mean sediments[b]		0.17	14	72	45	770	52	670	19	95
Upper Illinois R. Basin low order streams median (<63 μm fraction)[c]				56	23		26		27	100
NTS 92G Vancouver map sheet (<177 μm fraction)[d]			8 (1-32)	44 (12-515)	26 (2-415)	322 (53-2100)	7 (1-165)	7 (1-140)		48 (10-1000)
FORESTED CONTROL SITES IN LFV STUDIES	Vedder Mtn 2004 (Sumas Watershed)[e]		15.7	51.2	61.1	443	33.6	620	Bd	47.4
Streambed Sediment Concentrations (Impacted watersheds in the LFV)										
AGRICULTURAL WATERSHEDS	Sumas River (Abbotsford)[e]		38.2 (11.2-69.3)	111.9 (39.6-186)	28.5 (17.1-45.2)	1770 (261-7232)	571.9 (80.2-1148)	1539.7 (312-3296)	25.5 (Bd-29.6)	81.1 (53-109)
	Agassiz/Harrison Hot Springs[h], mean and range				54 (30-148)	442 (189-1296)			54 (30-149)	145 (0-737)
RURAL RESIDENTIAL/ AGRICULTURAL ATERSHED	Salmon River (Langley???)[g] mean and range		26.6 (21.1-30.9)	124 (115-140)	43.1 (26.9-84.0)	177 (53-684)	27.2 (16.2-43.3)	166 (64-373)	39.1 (10.8-67.4)	170 (92-344)
URBAN WATERSHED	Burnette River[i] (Vancouver), median and range	(<3 – 17)		28 (5-141)	56 (25-279)	807 (194-3402)	14 (<6 – 52)		63 (22-407)	143 (60-391)

[a] Combest (1991) cited in Cook (1994)
[b] Wedepohl (1968) cited in Salomons and Förstner (1984)
[c] Colman and Sazolon (1992) cited in Cook (1994)
[d] BCMOEMPR (1990) cited in Cook (1994)
[e] unpublished data, I. Smith (pers. comm..)
[g] Cook (1994)
[h] Addah (2002), dry season data only, omitting spring and control stations
[i] McCallum (1995)
[j] all concentration are in mg/kg dry weight, unless otherwise noted

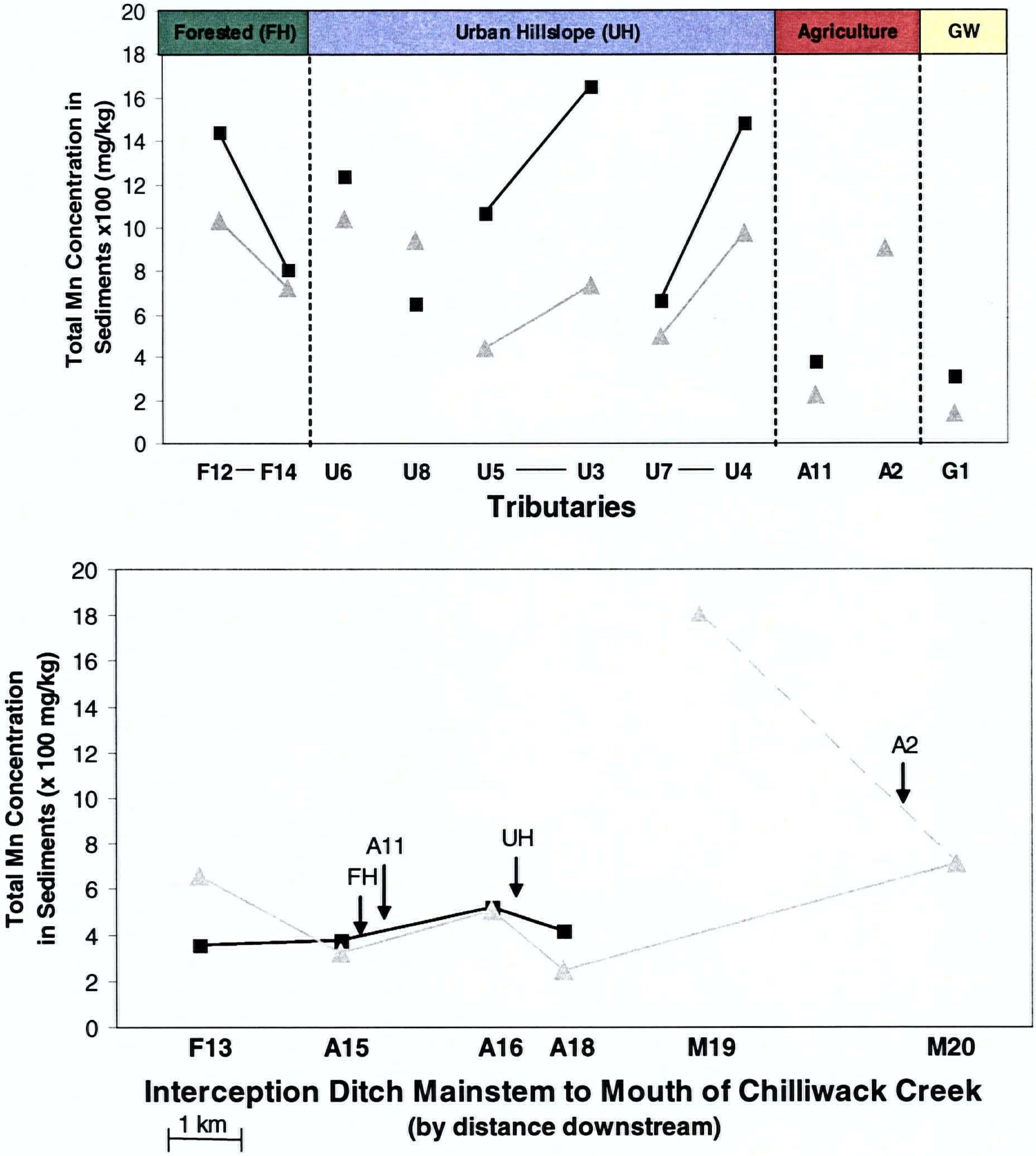
Manganese

Manganese concentrations in the watershed ranged from 142 to 1805 mg/kg, with a mean of 763 mg/kg. The lowest Mn concentrations were measured in Luckakuck Creek (G1, mean 227 mg/kg), Armstrong Ditch (A11, mean 304 mg/kg), Bailey Ditch (M10, mean 343 mg/kg) and along Interception Ditch. The highest Mn concentration (1805 mg/kg) was recorded at station M19. This station is located below a number of outfalls which drain water from an area that is more intensively urbanized than the Promontory area. The increase in impermeable surface area and traffic intensity of this urban area could be responsible for these higher Mn concentrations (as manganese based fuel additives get flushed into the stream during storm events). A number of stations in the Promontory region also showed high Mn levels including Benchley Creek (U6, mean 1138 mg/kg), and the lower station along Teskey Creek (U3, mean 1199 mg/kg) and Lefferson Creek (U4, mean 1232 mg/kg).

Spatially, Mn in sediment was higher in the headwaters (Oct sampling set only) than along Interception Ditch (see Figure 7.24). Concentrations increased along Interception Ditch itself (with a peak between station A16 and A18 where low dissolved Mn concentrations were recorded in water samples on the same date); concentrations then increase past A18 towards the mouth of Chilliwack Creek. High Mn concentrations were recorded at the upstream (intensive urban) station along Chilliwack Creek, and decreased at the mouth (M20). It is interesting to note the sites with high Mn in sediment generally had lower Mn in water, and vice versa.

Lead

Lead concentrations at most sites were below the detection limit (<25 mg/kg), with a few exceptions. Notably, the highest lead concentrations were recorded in Luckakuck Creek (G1) with a mean of 73.1 mg/kg. Sampling stations along Chilliwack Creek (M19, M20) also showed higher lead levels in sediments, with concentrations of 56.5 mg/kg and 50.2 mg/kg, respectively. Concentrations above detection were also recorded in Teskey Way Ditch at station M9, in the lower reaches of Teskey Creek (U3), and in Parson's Brook (F12, F14) in July 2003; however, these levels were below the interim sediment quality guideline for lead (ISQG) (35 mg/kg).



Legend: ■ Black squares represent 10-Oct-02 samples — Solid line represents Interception Ditch Mainstem
▲ Grey triangles represent 09-Jul-02 samples. - - - Dashed line represents Chilliwack Creek

FH= forested hillslope tributaries (Elkview Creek); UH = urban hillslope tributaries

Notes: Error bars represent the range of measured values.
Arrows indicate the approximate location of tributaries draining into the mainstem.

Figure 7.24 Spatial and Temporal Variations of Total Manganese (Mn) Concentrations in Streambed Sediments in the Chilliwack Creek Watershed

Iron, Copper, Zinc and Cadmium

The lowest concentrations of these metals were found in the urban hillslope tributaries (Benchley Creek, Walker Creek, Teskey Creek, and Lefferson Creek), Parsons Brook (F13), Armstrong Ditch[1] (A11), and in the upstream section of Interception Ditch (A15). Metal concentrations at the spring-fed station were also generally low, with the exception of Cu (42.5 mg/kg), which had values comparable to the agricultural stations. Apart from iron, which is found in high concentrations in local rocks and soils, concentrations of these metals in these tributaries were consistently below sediment quality guidelines.

Iron (Fe), copper (Cu), zinc (Zn) and to a lesser extent cadmium (Cd) are metals typically associated with agricultural activities. It is not surprising, therefore, that the high concentrations of these metals were found in streams associated with agricultural activities: Semiault Creek (A2), Chilliwack Creek (M19, M20), Bailey Ditch (M10), and station A17 had high levels of all four metals. Fe and Cd, in particular, seem to be associated with agricultural activities, with the highest concentrations of Fe (89 488 mg/kg) and Cd (11.2 mg/kg) recorded in Semiault Creek (the most intensive agricultural station).

When plotted in an upstream to downstream direction, as shown in Figures 7.25 to 7.28, these four metals showed similar trends. Concentrations along the mainstem generally increased from station F13 to the mouth of Chilliwack Creek (M20), with a drop exhibited between station A16 and A18 for the July 2003 sampling date. The drop is not likely an error since it is found for all four metals, but instead may be due to variability in physical or chemical properties of the sediment or differences in the site conditions (e.g. reducing conditions). For example, there was a peak in the DO and pH of streamwater at station A16 on the July 2003 sampling date. The increasing downstream trend suggests a potential cumulative impact of agriculture on these metals in sediment. Concentration of Fe and Cu also increased along Chilliwack Creek reaching concentrations of 882449 mg/kg (Fe) and 80.8 mg/kg (Cu) at the mouth, while Zn and Cd were high along the entire length of the stream. The difference in trends along Chilliwack Creek suggest that agricultural tributaries are the main contributor of Fe and Cu to Chilliwack Creek, while urban activities are the primarily source of Zn and Cd.

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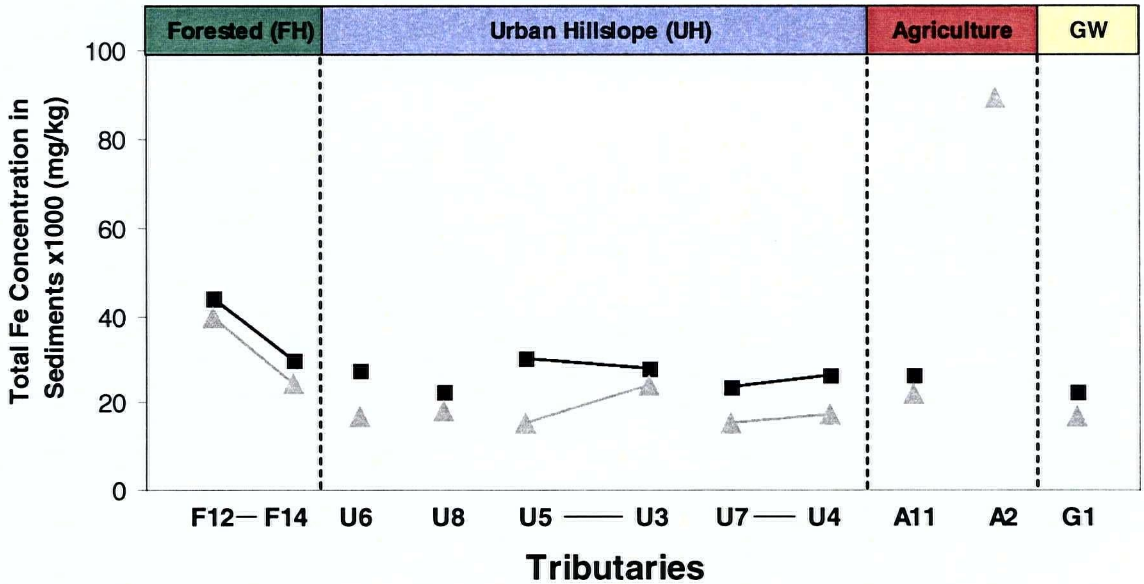
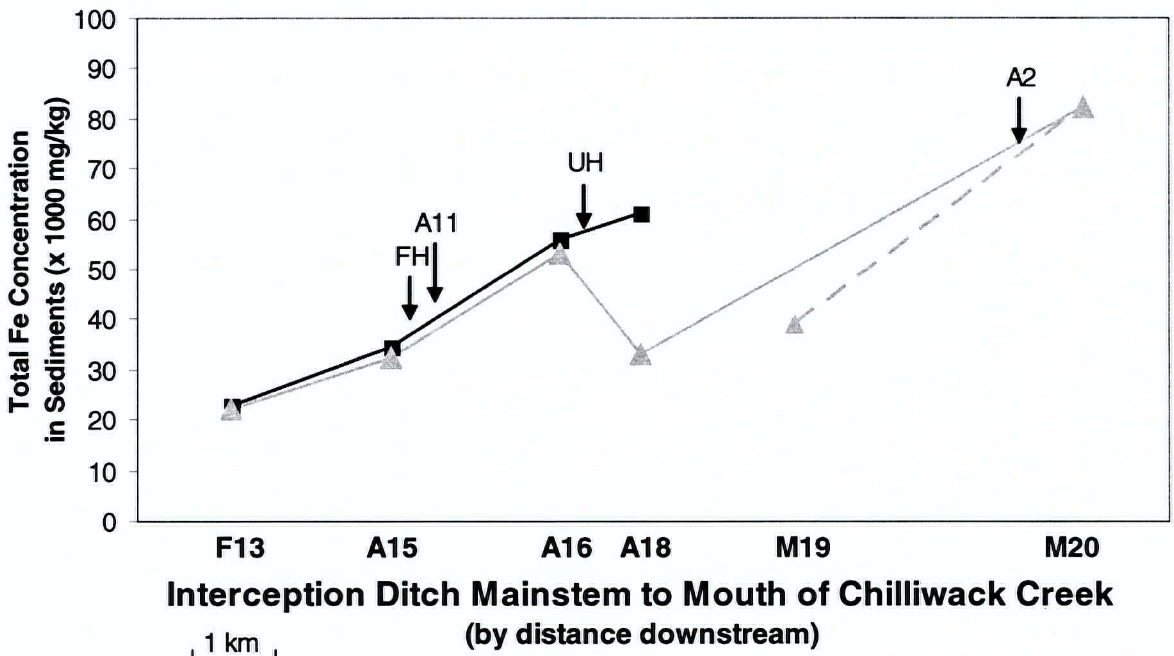
[1] A11 showed a very high Zn concentration in October, but a much lower value was observed in July. Without further sampling it is uncertain whether the high concentration was due to error, or a due to a source that was not present in July 2003



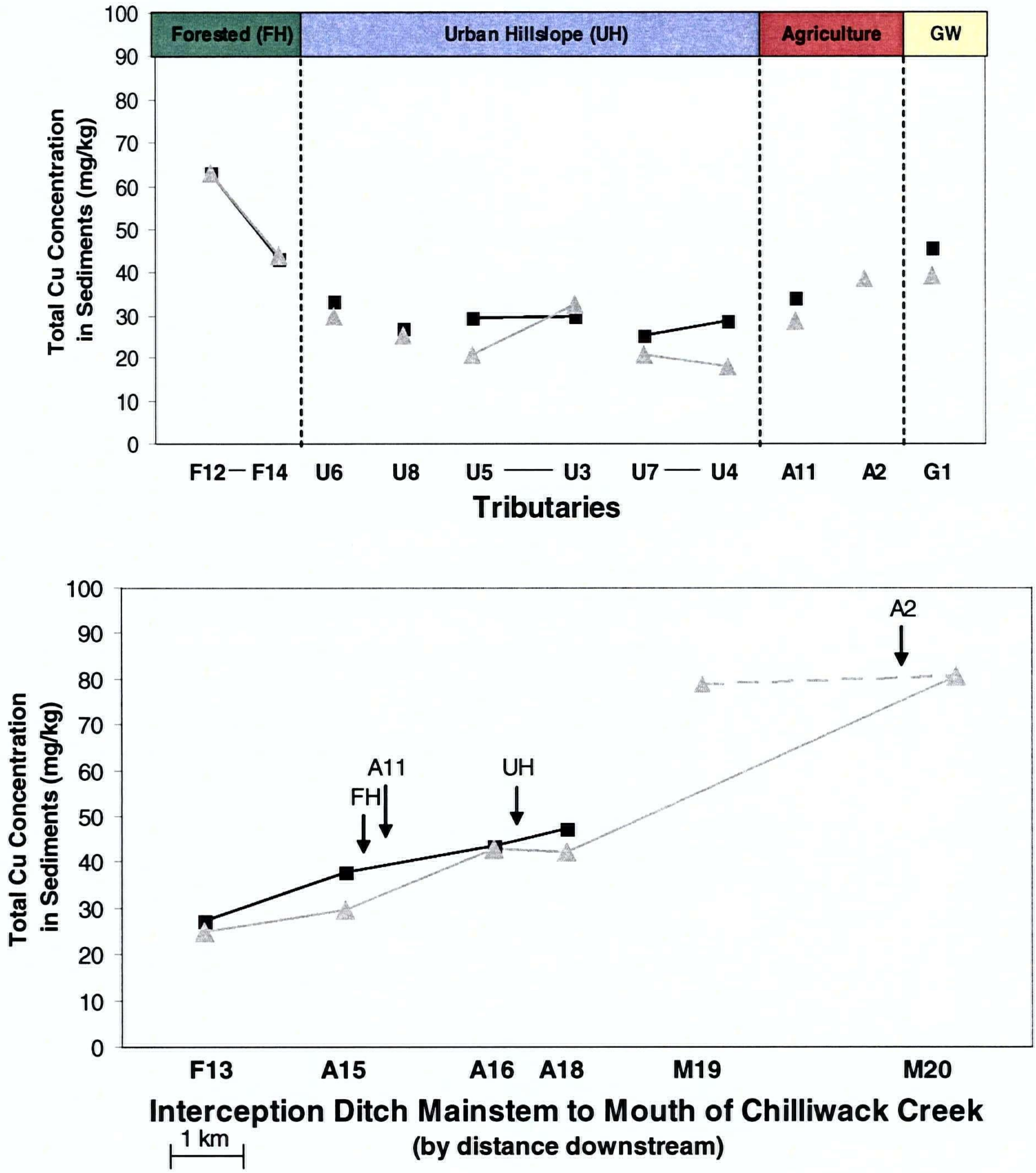


Legend: ■ Black squares represent 10-Oct-02 samples —— Solid line represents Interception Ditch Mainstem
▲ Grey triangles represent 09-Jul-02 samples. - - - Dashed line represents Chilliwack Creek

FH= forested hillslope tributaries (Elkview Creek); UH = urban hillslope tributaries

Notes: Arrows indicate the approximate location of tributaries draining into the mainstem

Figure 7.25 Spatial and Temporal Variations of Total Iron (Fe) Concentrations in Streambed Sediments in the Chilliwack Creek Watershed

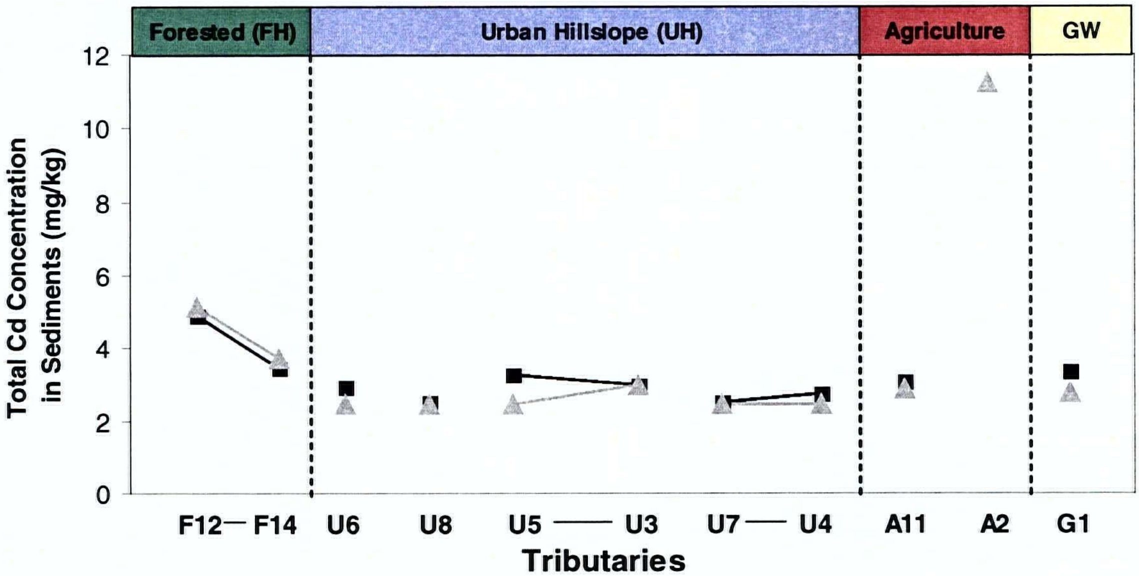


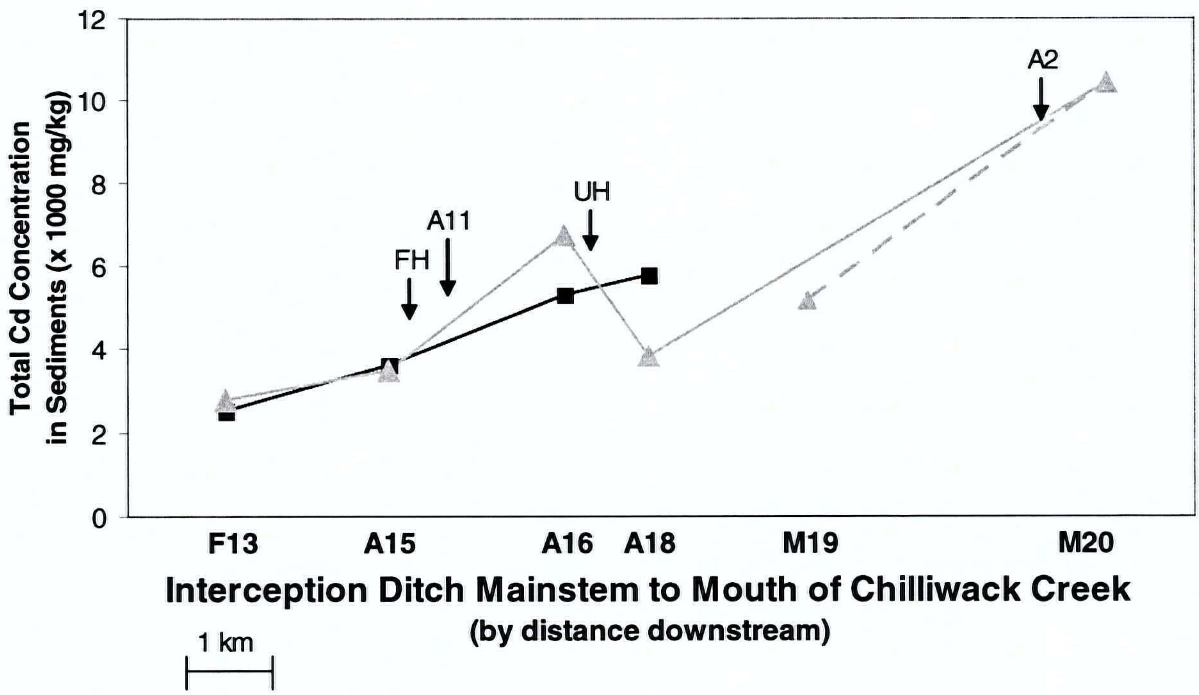
Legend: ■ Black squares represent 10-Oct-02 samples — Solid line represents Interception Ditch Mainstem
▲ Grey triangles represent 09-Jul-02 samples. - - - Dashed line represents Chilliwack Creek

FH= forested hillslope tributaries (Elkview Creek); UH = urban hillslope tributaries

Notes: Arrows indicate the approximate location of tributaries draining into the mainstem

Figure 7.26 Spatial and Temporal Variations of Total Copper (Cu) Concentrations in Streambed Sediments in the Chilliwack Creek Watershed



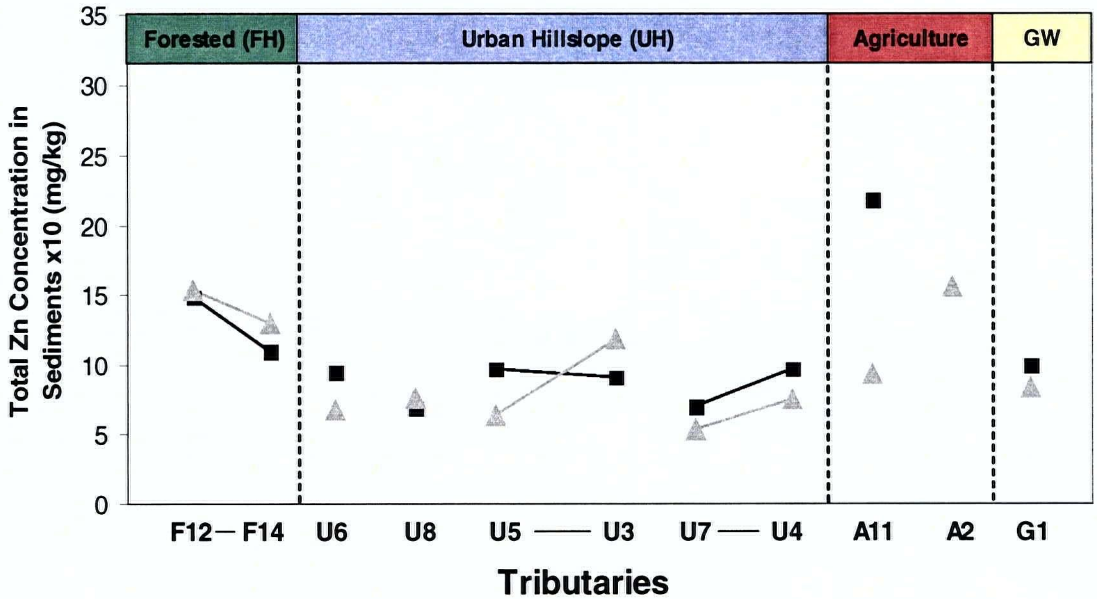


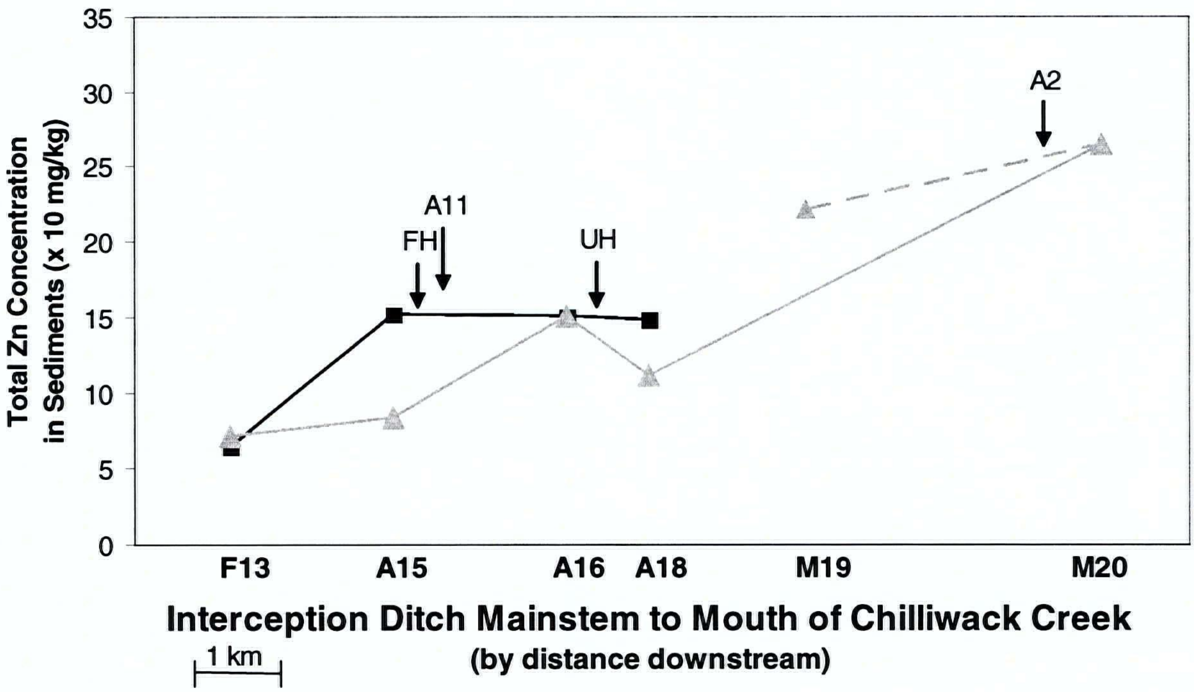
Legend: ■ Black squares represent 10-Oct-02 samples — Solid line represents Interception Ditch Mainstem
▲ Grey triangles represent 09-Jul-02 samples. - - - Dashed line represents Chilliwack Creek

FH= forested hillslope tributaries (Elkview Creek); UH = urban hillslope tributaries

Notes: Arrows indicate the approximate location of tributaries draining into the mainstem.

Figure 7.27 Spatial and Temporal Variations of Total Cadmium (Cd) Concentrations in Streambed Sediments in the Chilliwack Creek Watershed





Legend: ■ Black squares represent 10-Oct-02 samples —— Solid line represents Interception Ditch Mainstem
▲ Grey triangles represent 09-Jul-02 samples. - - - Dashed line represents Chilliwack Creek

FH= forested hillslope tributaries (Elkview Creek); UH = urban hillslope tributaries

Notes: Arrows indicate the approximate location of tributaries draining into the mainstem.

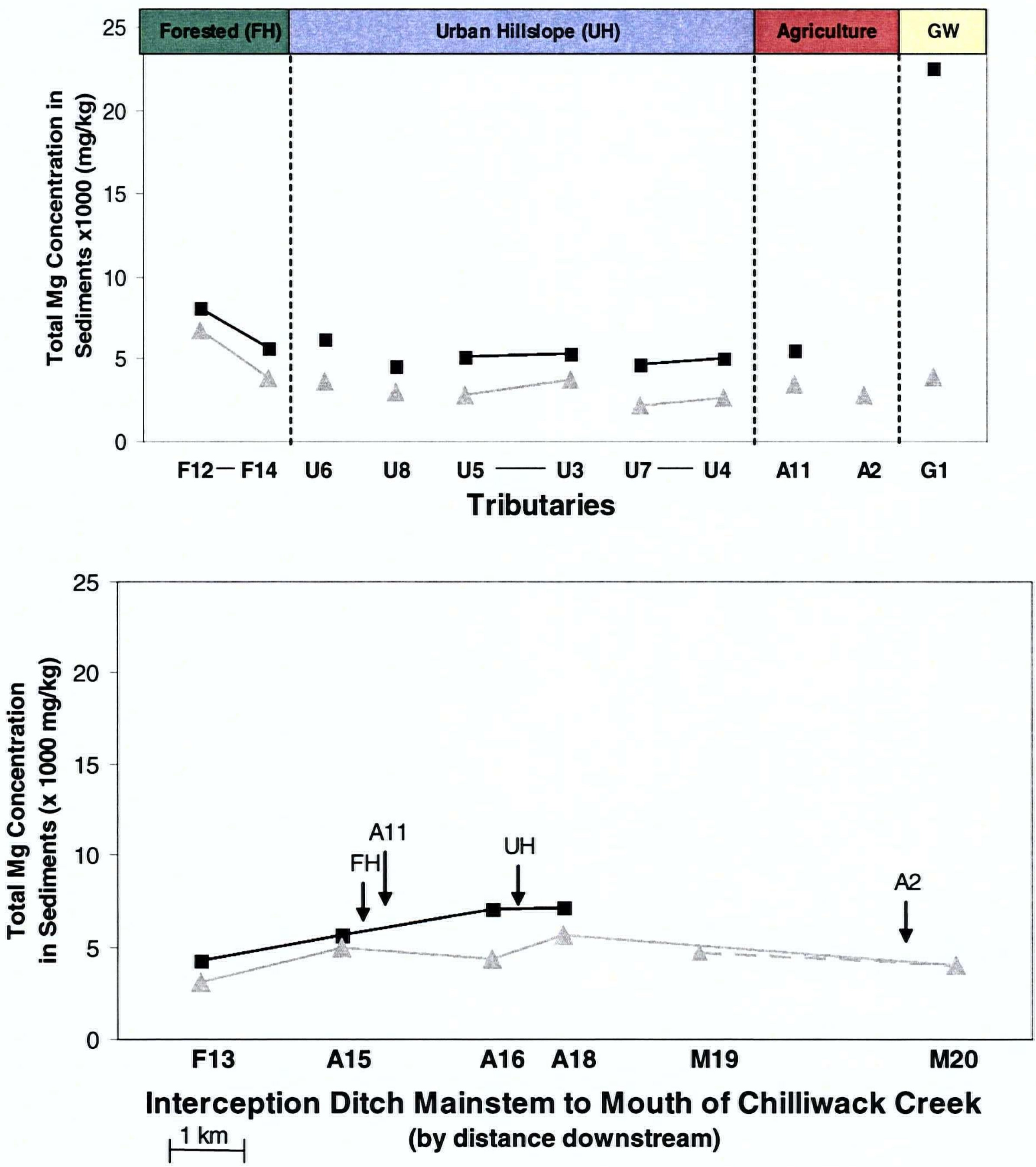
Figure 7.28 Spatial and Temporal Variations of Total Zinc (Zn) Concentrations in Streambed Sediments in the Chilliwack Creek Watershed

Magnesium, Potassium, and Sodium

The highest sediment concentrations of these three metals (K: 1176 mg/kg, Mg: 22565 mg/kg, Na: 309 mg/kg) were measured in Luckakuck Creek (G1) in October 2002. However, July concentrations were 1.9 (Na) to 5.7 (Mg) times lower than the October concentrations at this station.

Throughout the rest of the watershed Mg ranged from 2204 to 8386 mg/kg, K from 232 to 1006 mg/kg, and Na from 89 to 303 mg/kg. Magnesium concentrations were slightly higher in upper Parsons (F12) and the lower reaches of Interception Ditch and Chilliwack Creek (M20), while potassium concentrations were higher at stations M19, A17 and M10. High Na concentrations were recorded in Armstrong Ditch (A11), Teskey Way Ditch (A17), and upper reaches of Chilliwack Creek (M19).

Spatially, concentrations for all three elements were generally low in the headwaters and increased in the downstream direction along Interception Ditch, and then remained constant or decreased slightly towards the mouth of Chilliwack Creek (Figures 7.29 through 7.31). Slight variations to this trend were observed in October including a sharper increase in Na between A15 and A16, and a slight drop in Mg levels at A16. K and Na concentrations decreased from M19 to M20 along Chilliwack Creek.

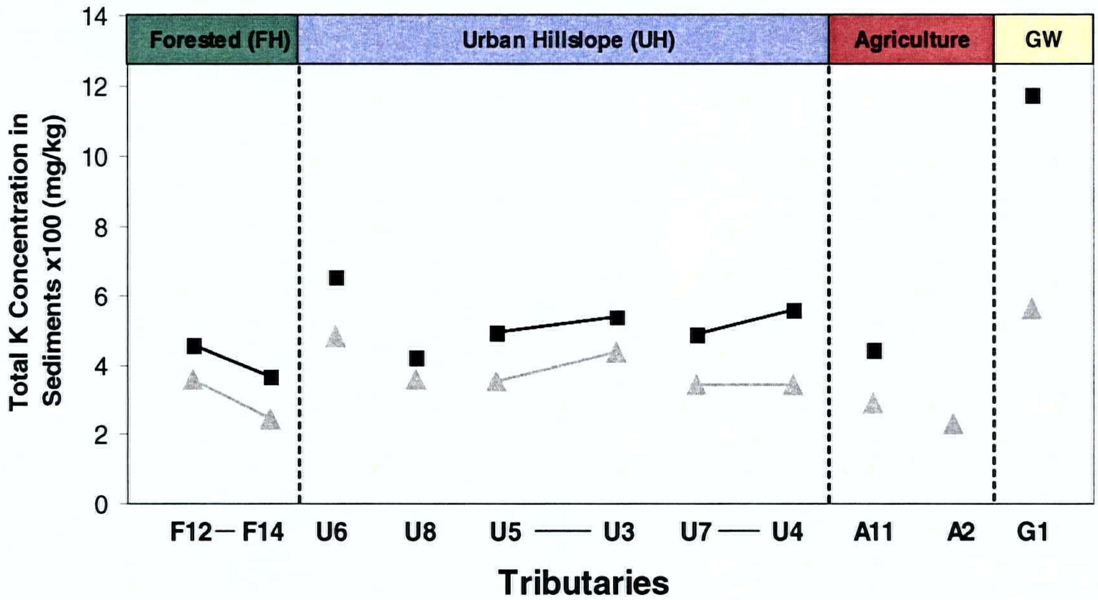


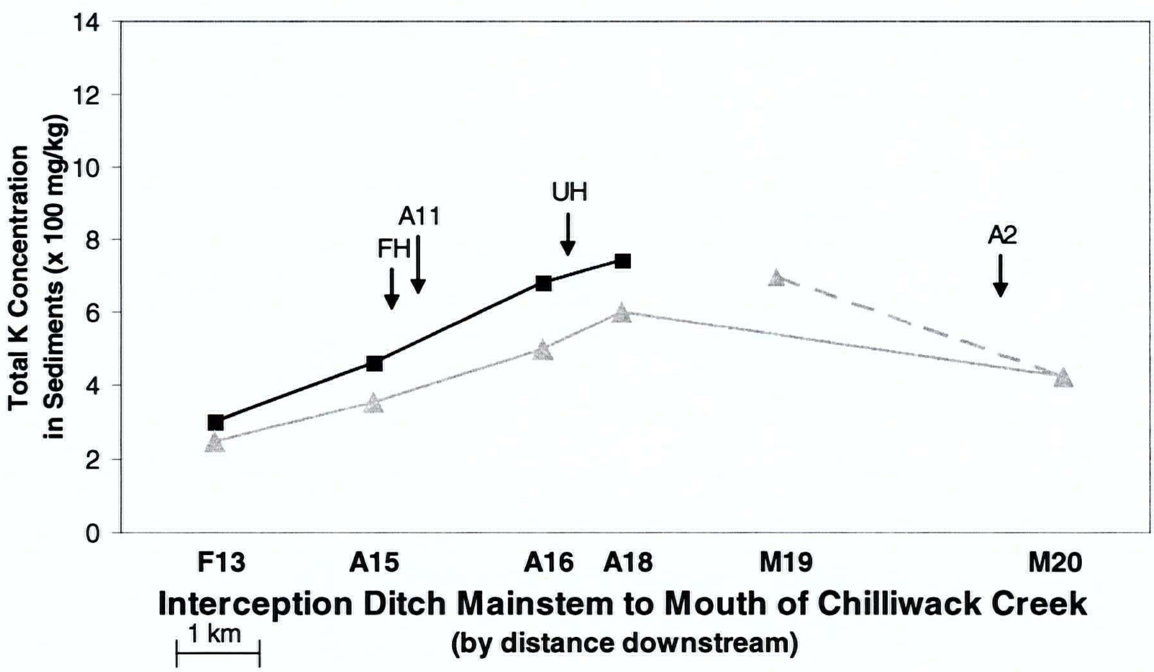
Legend: ■ Black squares represent 10-Oct-02 samples —— Solid line represents Interception Ditch Mainstem
▲ Grey triangles represent 09-Jul-02 samples. - - - Dashed line represents Chilliwack Creek

FH= forested hillslope tributaries (Elkview Creek); UH = urban hillslope tributaries

Notes: Arrows indicate the approximate location of tributaries draining into the mainstem.

Figure 7.29 Spatial and Temporal Variations of Total Magnesium (Mg) Concentrations in Streambed Sediments in the Chilliwack Creek Watershed



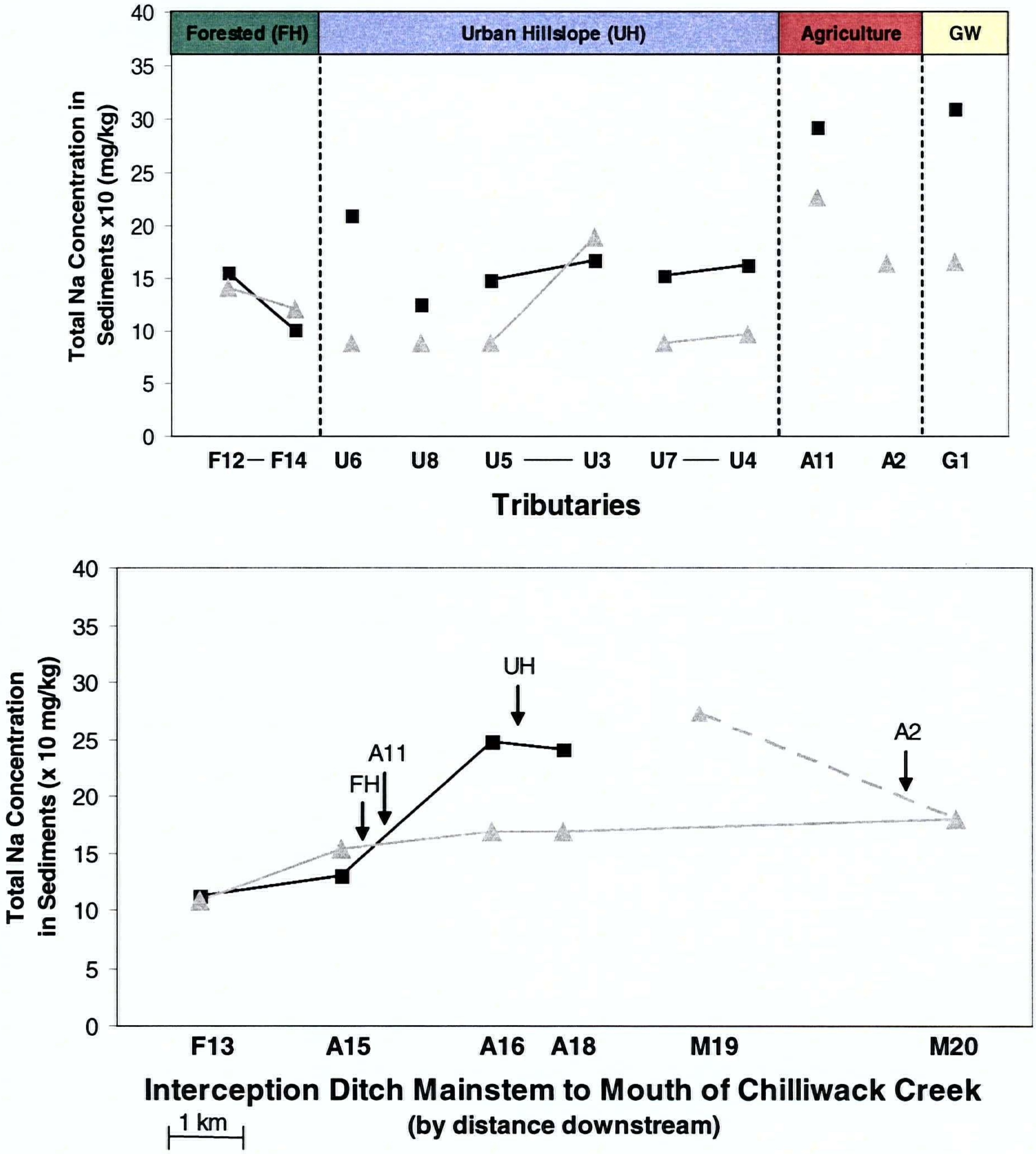


Legend: ■ Black squares represent 10-Oct-02 samples — Solid line represents Interception Ditch Mainstem
▲ Grey triangles represent 09-Jul-02 samples. - - - Dashed line represents Chilliwack Creek

FH= forested hillslope tributaries (Elkview Creek); UH = urban hillslope tributaries

Notes: Arrows indicate the approximate location of tributaries draining into the mainstem.

Figure 7.30 Spatial and Temporal Variations of Total Potassium (K) Concentrations in Streambed Sediments in the Chilliwack Creek Watershed



Legend: ■ Black squares represent 10-Oct-02 samples — Solid line represents Interception Ditch Mainstem
▲ Grey triangles represent 09-Jul-02 samples. - - - Dashed line represents Chilliwack Creek

FH= forested hillslope tributaries (Elkview Creek); UH = urban hillslope tributaries

Notes: Arrows indicate the approximate location of tributaries draining into the mainstem.

Figure 7.31 Spatial and Temporal Variations of Total Sodium (Na) Concentrations in Streambed Sediments in the Chilliwack Creek Watershed

7.3.4 Phosphorus in Sediment

Sediments were analyzed for two different forms of phosphorus: bio-available phosphorus (BAP) measured as orthophosphate-P and total phosphorus (TP). The analytical results are listed in Appendix D.

7.3.4.1 Bio-Available Phosphorus

Bio-available phosphorus (or orthophosphate) concentrations ranged from below detection limit (for 7 of 20 sites) to 29.9 ppm in Luckakuck Creek. From Figure 7.33 it appears that sediment samples from streams in the upland residential area (U3-U8) had slightly higher BAP concentrations. However, a series of Mann-Whitney tests did not show any statistically significant differences between agriculture, forest and urban land use types. A number of non-urban streams also showed higher BAP concentrations, including Teskey Way Ditch (A17: 28.5 ppm), Parson's Brook (F14: 24.3 ppm; F12: 14.0 ppm), Luckakuck Creek (G1: 29.9 ppm), Armstrong Ditch (A11: 12.6 ppm) and Chilliwack Creek (M19: 27.2 ppm).

7.3.4.2 Total Phosphorus

Total phosphorus (TP) ranged from 500 mg/kg to 5110 mg/kg throughout the watershed, with a mean of 1150 mg/kg. The hillslope tributaries (both forest and urban) generally had low TP concentrations, while concentrations in the lowland agricultural ditches were higher (particularly in Semiault Creek and at station A16 along Interception Ditch). Spatially, TP concentrations increased from the headwaters of Interception Ditch to the mouth of Chilliwack Creek, with a drop between A16 and A18 (after confluence with urban hillslope tributaries). While concentrations in the upper reaches of Chilliwack Creek (M19) are comparable to concentrations along Interception Ditch (reflecting that some phosphorus is originating from urban sources), TP increases in the downstream directions as tributaries draining the large agricultural area in the lowland (e.g. Semiault Creek and Interception Ditch) enter the Chilliwack Creek. These trends are shown in Figure 7.33 below.

When land use types were compared, TP in the sediments from the agricultural lowland streams were significantly higher than from hillslope tributaries (both forest and urban). This was expected as agriculture is known to contribute phosphorus to watercourses.

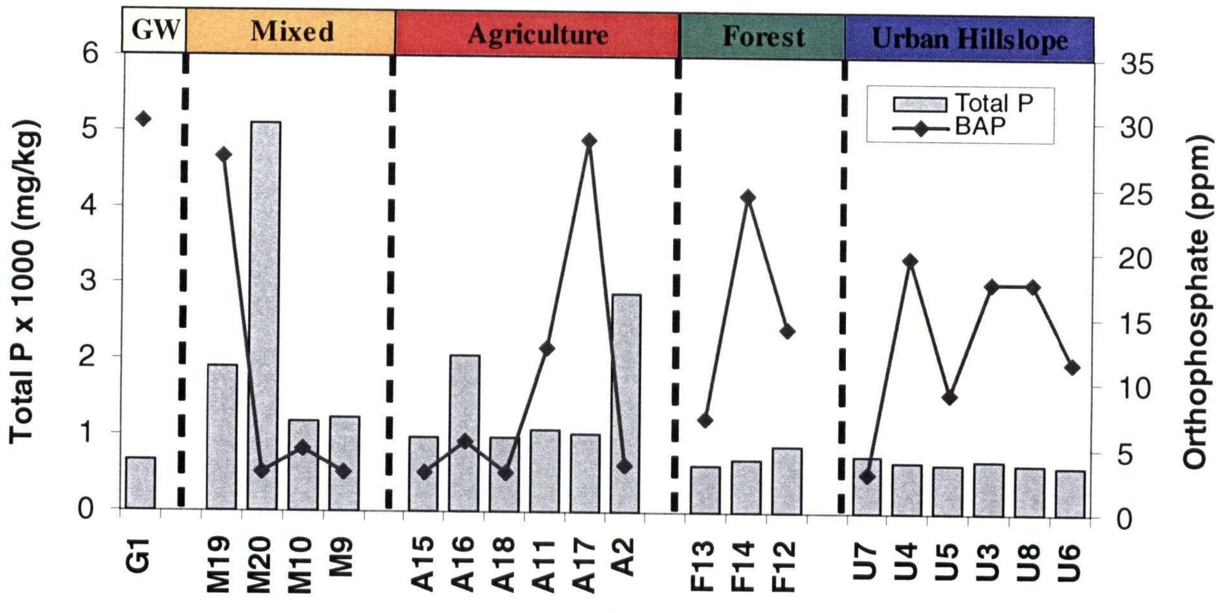


Figure 7.32 Total P and Bio-Available (orthophosphate) Concentrations in Sediment, July 2003 Sampling

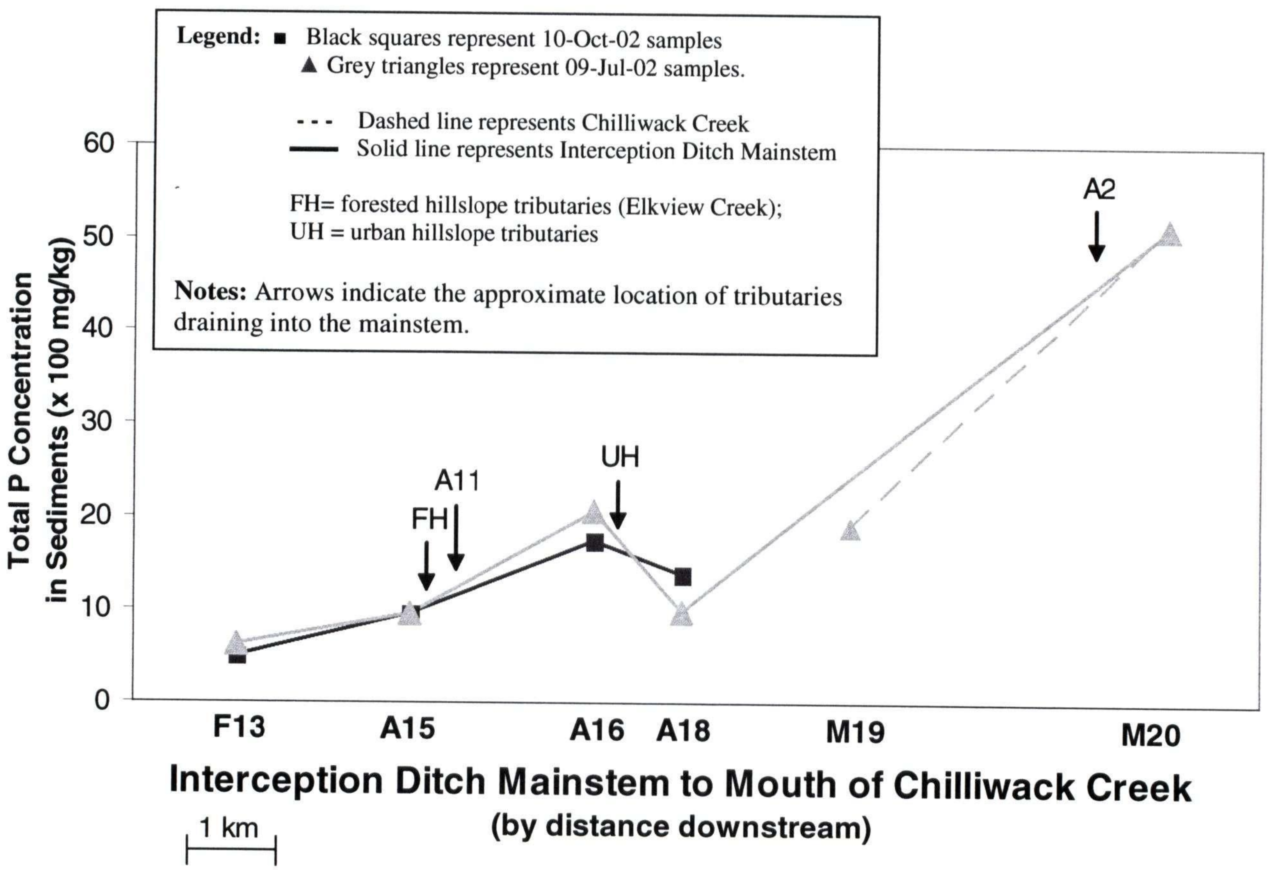


Figure 7.33 Spatial Trends in Total Phosphorus Concentration in Streambed Sediments along Interception Ditch and Chilliwack Creek

7.3.5 Comparison between Agriculture, Urban and Forest Land Uses: Sediment Parameters

For each element, the Oct-2002 and July-2003 data sets were pooled and a Mann-Whitney U test was used for pair-wise comparisons to determine if differences existed between urban, forest and agriculture land use categories. An overview of the results is summarized in Table 7.8.

Table 7.8 Overview of Mann-Whitney Comparisons between Land Use Categories for Trace Elements in Sediment

			Parameters showing a significant difference at α=0.05:	
			Combined 2002/2003	***July 2003***
Agriculture	>	Forest	**Na*, P***, %N	Na, P
Agriculture	<	Forest	-	-
Agriculture	>	Urban	**Cd*, Fe*, P*, Zn*, Cu*, Mg*, Na***, %N	**Cd*, Fe*, P*, Zn***, Co, Cu, Mg, Na, %N
Agriculture	<	Urban	Mn	Mn
Urban	>	Forest	**Cd***	Cd, Fe
Urban	<	Forest	K	-

* indicates significant difference at α=0.0176 level (Bonferroni adjustment)

Combined 2002/2003: n (forest) = 6 ; n (agriculture) = 10 ; n (urban) = 12
July 2003: n (forest) = 3 ; n (agriculture) = 6; n (urban) = 6

Zinc (Zn), iron (Fe), copper (Cu), cadmium (Cd), magnesium (Mg), sodium (Na) and phosphorus (P) all showed significantly higher levels in agriculture compared to the urban catchments. Interestingly, Na, P and %N were the only parameters that had lower levels at the forest sites compared to the agricultural sites. Also worthy of noting is the fact that with there were minimal significant differences between urban and forest land use categories. Higher concentrations of Cd and Fe and lower K concentrations were found at the forested sites compared to the urban sites. Nickel (Ni), calcium (Ca), cobalt (Co), chromium (Cr), and aluminum (Al) showed no significant differences between land use categories. Boxplots by land use category are shown in Appendix D.

7.4 Comparison of Water and Sediment Quality to Provincial and Federal Guidelines During Baseflow and Stormflow Conditions

Comparing the streamwater and sediment results to the various water quality and sediment criteria provides some indication of the health of the aquatic system. Overall, the water quality throughout the watershed appears to be moderately good. According to water quality and sediment guidelines Semiault Creek and Interception Ditch are the most degraded watercourses, while Luckakuck Creek and the hillslope tributaries have the best conditions for aquatic life.

However, it is important to note that provincial and federal guidelines generally do not take into account the potential for cumulative impacts of contaminants (Addah, 2002); and sediment criteria do not account for the confounding effects of the physiochemical attributes of the sediment (such as particle size, organic matter content, chemical species and complexes) or for metal bioavailability which may change the potential for toxic effects at a specific site (McCallum, 1995; CCME, 2001). As a result, concentrations below acceptable levels may still be having an impact on the watercourse

7.4.1 Water Quality Compared to Provincial Water Quality Guidelines

Water quality results are compared with *BC Water Quality Guidelines for the Protection of Aquatic Life* in Table 7.9. While wet and dry season means for nitrate, ammonia, pH and iron are below the provincial guidelines at all sampling stations within the watershed, about half the stations do not meet the guidelines for dissolved oxygen or temperature. Furthermore, a large number of stations have at least one value throughout the sampling season that does not meet guideline values. This suggests that critical levels may be occurring during different times of the year, at certain locations.

Al was consistently below detection limit, except within Armstrong Ditch in May 2002. On this date, a value of 0.41 mg/L was recorded, which is above the B.C. water quality guideline (max 0.1 mg/L dissolved Al at pH>6.5).

Table 7.9 Sampling Stations within the Chilliwack Creek Watershed Exceeding B.C. Water Quality Guidelines for the Protection of Aquatic Life during the Wet and Dry Seasons (MWLAP, 1998)

Water Quality Parameter	BC Water Quality Guidelines[1]	Stations Exceeding Water Quality Guidelines
Nitrate - N	≤ 40 mg/L (avg) 200 mg/L (max)	None
	10 mg/L (max)[4]	None
Orthophosphate	No criteria	
Ammonia (Total)	1.07-27.0 mg/L (max)[3] (depends on pH and temperature)	Dry season: None Wet season: M10, A16, A17, A18
Dissolved Oxygen	5.0 mg/L (inst. min) (adult/juvenile life stages)	Dry season: U5, F14 Wet season: None
	9.0 mg/L (inst. min) (buried embryo/alevin life stages)	Dry season: All stations below criteria except A17 Wet season: G1, A2, U3, U4, U5, A18, M20
pH	6.5-9.0	Dry and Wet season: G1
Temperature	12°C (incubation maximum for fall and spring)	Dry season: All stations Wet season: All stations above criteria except U8
	19°C (max daily temperature)	Dry season: A18, A16 Wet season: None
Sp. Conductivity	No criteria	
Calcium (Total)[2]	4 mg/L, high sensitivity to acid inputs 4-8 mg/L, moderate sensitivity > 8 mg/L, low sensitivity	Low sensitivity for all stations.
Manganese (Total)	0.7 -1.9 mg/L (depends on $CaCO_3$)	None
Iron (Total)[2]	0.3 mg/L (max)	Dry season: A2, M9, M10, A11, A15, A1, A17, A18, M20 Wet season: A2, U5, M9, M10, A11, A15, A1, A17, A18, M20
Sodium (Total)	No criteria	
Potassium (Total)	No criteria	
Magnesium (Total)	No criteria	

[1] Refers to Guideline for the Protection of Aquatic Life unless otherwise noted
[2] Working Guideline
[3] Values determined using rages of pH and temperatures observed within the Chilliwack Creek watershed.
[4] Drinking water guideline

Ammonia concentrations exceeded the maximum permissible total concentration on one sampling date (12-Dec-2002) for a number of sites: M10 (Bailey Ditch), A16 and 18 (Interception Ditch), and A17. Exceedence on this date was likely due to runoff caused by a large storm event occurring just prior to sampling. While the sampling scheme did not capture it, it is possible that ammonia concentrations may have exceeded guidelines during other intense runoff events which promote loss of nitrogen to streams, particularly in agricultural areas where nitrogen is applied to fields and is more available to be lost to steams. Lower concentrations of ammonia may also be toxic depending on how long they are maintained. In July 2003, the ammonia concentration at station A18 was above the average 30-day guideline of ammonia-N (>0.15 mg/L at pH = 8.8 and temperature = 22°C). Because samples were only taken once a month, it cannot be determined whether concentrations were maintained around this level for a 30-day period. However, temperatures at this site (and other sites along Interception Ditch and Chilliwack Creek) increase substantially in the summer, and pH values are usually above 7.5. It is, therefore, feasible that the water would remain toxic to aquatic life during the summer months.

All stations were out of compliance with the provincial water quality guidelines for temperature at least once over the sampling period. Overall, almost all watercourses in the Chilliwack Creek watershed are limited in their ability to support the incubation of salmonid embryos. Luckakuck Creek is the only watercourse that is able to consistently maintain temperatures below the 12°C guideline for incubation. This is likely due to influence of the cooler groundwater inputs in the stream during the summer season. During the wet season, Armstrong Ditch, Parson's Brook, station A15, as well as all the urban hillslope tributaries were also able to maintain temperatures below the 12°C guideline. Overall, Interception Ditch appears to be an area of relatively high temperatures, in particular, stations A18 and A16, where temperatures above the daily maximum (19°C) were recorded during the summer. As a result, based on the high temperatures recorded along Interception Ditch it is unlikely that it would be able to support a viable fish population.

With respect to dissolved oxygen, station A17 is the only site for which DO levels did not fall below the 9.0 mg/L minimum requirement of DO for buried embryo development at any time during the sampling period. Wet season data are restricted to one sampling date (03-March-2003), and therefore it is difficult to make conclusions as to what is happening over the wet period. However, based on the available data there is the potential that a number of streams may be able to support embryonic fish development at this time. The downstream site along Chilliwack Creek (M20) is the most impacted by an oxygen deficit. Two sites did not meet the minimum DO level required for adult and juvenile fish: Elkview Creek (F14) and Teskey Creek (U5). Overall, DO levels appear to be more critical during the dry season then the wet season.

The spring-fed station is the only sampling station that did not meet provincial for pH. pH at this station dropped to 6.3 on two occasions. It is assumed that the lower value at this station is likely the result of the influence of geology on the water chemistry, rather than the result of land use activities.

In general, agriculturally influenced streams - Semiault Creek (A2), Armstrong Ditch (A11), Interception Ditch (A15, A16, A18), Chilliwack Creek (M20), Bailey Ditch (M10) and station A17 had iron concentrations above the BC Water Quality Guideline (0.3 mg/kg) on at least two of the three sampling dates. Values above the criteria were also detected at stations M9 and U5.

COMPLIANCE DURING STORMFLOW CONDITIONS:

At least one storm sample for all stations (except M20) exceeded the guidelines for dissolved Al (max 0.1 mg/L at pH>6.5) and total Fe (0.3 mg/L). Zinc was only above detection at station A2. Concentrations of the latest sample during the storm event (0.05 mg/L) exceeded water quality guidelines for 'total' Zn (0.04 mg/L at hardness of 100 mg/L $CaCO_3$). Nitrate concentrations did not exceed any guidelines for water quality; however concentrations were near the 10 mg/L guideline for drinking water quality at station A2, and it is expected that concentrations would continue to increase over the course of the storm and exceed this limit.

7.4.2 Sediment Quality Compared to Federal Sediment Quality Guidelines

For sediments, the comparison with *Canadian Sediment Quality Guidelines for the Protection of Aquatic Life* reveals a number of stream stations exceeding the different criteria for levels of cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), nickel (Ni), lead (Pb) and zinc (Zn) (Table 7.10). Ni, Cu, Fe and Cd concentrations were above the lowest effect level (LEL) for all stations, including the forested control stations. This suggests that the natural background levels of these metals may be high, rather than an influence of the surrounding land use on sediment toxicity. Similar to high streamwater iron concentrations observed at the agriculturally influenced station, sediment iron concentrations were above the severe effect level (SEL) for stations A2 (Semiault Creek), A11 (Armstrong Ditch), U5 (lower Teskey Creek), M9 (Teskey Way Ditch), A16 and A18 (Interception Ditch), F12 (Parson's Brook) and M20 (Chilliwack Creek). Cadmium concentrations above the probable effect level (PEL) and zinc concentrations above the ISQG were found at most of these same sites. Cd and Zn concentrations above these levels were also found at M10 and A17. It is thought that agriculture may be leading to Fe and Cd toxicity in these sediments. Chilliwack Creek maintained some of the highest metal concentrations overall, particularly station M19, which lies directly below an outfall draining a relatively dense urban area. While it is not possible to determine if the metal concentrations were impacting the aquatic system without further testing, this site is the most likely to be impacted as it has some of the highest concentrations of Pb, Cd, Zn, Mn, and Cu recorded in the watershed. This site is also the only site for which chromium exceeded the sediment quality guideline. The aquatic environment of Semiault Creek is also likely to be impacted, with Cd, Fe, Zn, Cu above sediment guidelines as well as high concentrations of Co.

Table 7.10 Sampling Stations within the Chilliwack Creek Watershed Exceeding Canadian Sediment Quality Guidelines for the Protection of Aquatic Life (CCME, 2003)

Sediment Quality Parameter	Canadian Sediment Quality Guidelines (mg/kg) $^{\omega}$	Stations Above Canadian Sediment Quality Guidelines
Cadmium	0.6 (TEL)	All stations above guideline
	3.5 (PEL)	M9, F12, A15, A16, A17, A18, A2, M10, M19, M20
Chromium	37 (ISQG)	M19
	90 (PEL)	None
Copper	35.7 (ISQG)	All stations above guideline except U3, U4, U6, U7, U8, F13
	197 (PEL)	None
Iron	2100 (LEL)	All stations above guideline
	4380 (SEL)	A2, U5, M9, A11, F12, A16, A18, M20
Nickel	16 (LEL)	All stations above guideline
	75 (SEL)	None
Lead	31 (LEL)	G1, M19, M20
	250 (SEL)	None
Zinc	123 (ISQG)	A2, M9, A11, F12, F14, A15, A16, A17, A18, M19, M20
	315 (PEL)	None
No guidelines are available for Al, Ba, Ca, Co, K, Mg, Na, P, Si, Si		

8 LAND USE AND WATER INTERACTIONS

The various land use types and their changing pattern affect both the hydrologic regime and water quality of the adjacent watercourses. This chapter discusses the relationship between the different land uses and both the water and sediment quality. To examine these relationships, the watershed was divided into sub-watersheds (contributing areas) by delineating the area draining each sampling station, as described in chapter 4. A map of these contributing areas in the watershed is shown in Figure 4.3. Next, the proportion of land with a given land use (referred to hereafter as 'land indices') within each individual (independent) contributing area was calculated (as a percent of the total contributing area) using GIS. In addition, because water quality at a given station may be influenced by land uses farther upstream than the immediate contributing area, land use indices were also calculated for the cumulative contributing area. This cumulative contributing area comprises the total watershed area upstream of a given sampling stations (that is, all the contributing areas upstream of the water sampling station).

Furthermore, because areas closer to the stream may have a greater influence on water quality, land indices were also calculated for buffer zones of three different widths (50 m, 100 m and 200 m) parallel to the stream channel. By using buffers as opposed to contributing areas, only the land use directly adjacent to the stream is related to water quality, minimizing the incorporation of irrelevant or less influential land uses. Other studies that have attempted to relate land use indices to water quality parameters have found that, in agricultural areas, the buffer zone technique gave better results than the use of contributing areas (Addah, 2002).

A Spearman's Rank correlation test performed on land use indices and water (and sediment) quality parameters revealed significant correlation between several parameters. These results are presented below for urban, natural and agricultural land uses separately. A full summary of the results is shown in Appendix F. Note that a positive correlation coefficient indicates that as the percent of land use increases, the concentration of the water (or sediment) parameter also increases. Conversely, a negative correlation indicates that as the percent of land use increases, the concentration of the parameter decreases.

Overall, there were minimal differences between relationships found using the independent versus the cumulative land indices. There were also minimal differences between the three different sized contributing areas. Results from correlations using the independent contributing areas and 100 m buffers correlations are discussed here. A summary of selected land use indices for each (independent) contributing area and 100 m buffer is shown in Table 8.1, and a map of the 100 m land use buffers is provided in Figure 8.1.

Table 8.1 Characteristics of Land Use within Each Contributing Area

Watercourse	Station	% Land Use within Contributing Areas: Total agric.	Arable	Cattle	Open Space	Forest	Ind./ Com.	Res.	High density urban	Low density urban
Interception Ditch	A15	31.4	10.3	4.3	19.8	48.7	0.0	0.0	0.0	0.0
	A16	79.1	22.7	39.4	8.4	12.5	0.0	0.0	0.0	0.0
	A18	54.3	51.0	0.4	22.6	9.9	1.7	11.5	5.4	7.7
Teskey Way Ditch	A17	61.8	40.3	20.8	22.6	14.1	0.0	1.5	0.0	1.5
Semiault Creek	A2	69.9	26.7	42.1	14.8	15.1	0.2	0.0	0.0	0.0
Armstrong Ditch	A11	14.8	10.8	2.4	17.8	67.4	0.0	0.0	0.0	0.0
Elkview Creek	F12	19.0	10.89	0.00	22.64	56.31	0.09	1.39	0.00	1.39
	F14	8.88	0.00	0.06	10.24	80.04	0.84	0.00	0.00	0.00
Parsons Brook	F13	14.1	6.54	1.84	17.70	68.25	0.00	0.00	0.00	0.00
Teskey Creek	U3	5.2	2.7	1.6	21.6	23.4	1.1	48.7	0.0	48.7
	U5	2.9	1.2	0.0	33.9	33.8	3.7	25.4	9.5	23.2
Lefferson Creek	U4	3.3	0.0	0.0	80.9	7.5	0.0	8.3	0.0	8.3
	U7	8.0	7.5	0.5	30.0	57.8	0.0	4.2	2.7	1.5
Benchley Creek	U6	14.6	14.6	0.0	16.1	65.2	0.0	4.1	0.0	4.1
Walker Creek	U8	0.0	0.0	0.0	21.6	78.4	0.0	0.0	0.0	0.0
Teskey Way Ditch	M9	18.3	17.2	0.0	44.1	37.6	0.0	0.0	0.0	0.0
Bailey Ditch	M10	28.2	13.9	0.0	25.5	34.5	7.1	4.8	1.4	10.4
Chilliwack Creek	M19	27.9	27.1	0.8	24.1	7.3	8.6	31.5	1.2	39.1
	M20	72.8	32.3	38.7	4.9	0.7	6.4	14.3	7.6	13.6

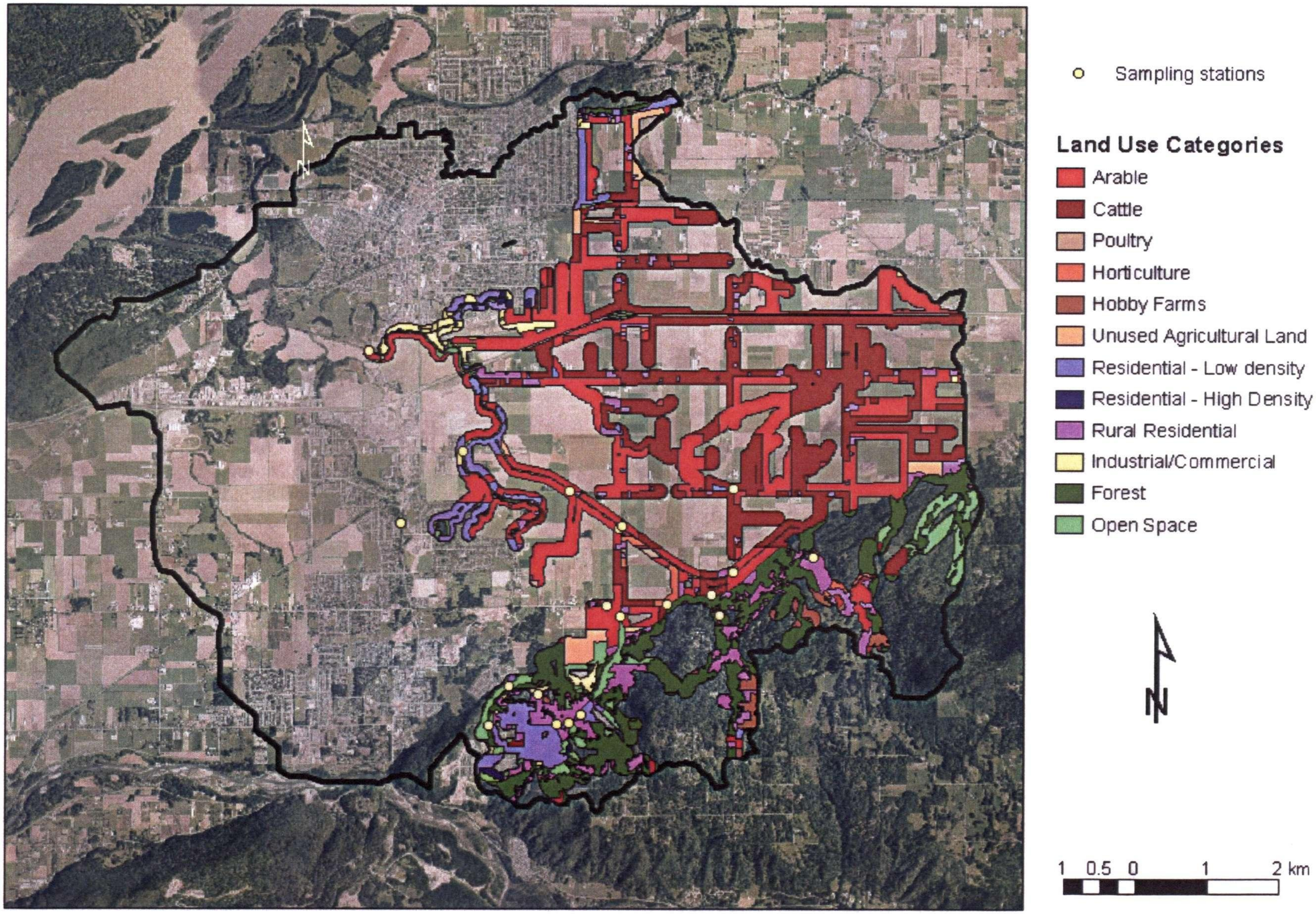


Figure 8.1 Chilliwack Creek Watershed Land Use 100 m Land Use Buffers

8.1 Correlations with Agricultural Land Uses

Agricultural land use was subdivided into different activity types: arable, cattle, poultry, horticulture (tree farms), greenhouse, unused (fallow), and hobby farms for the land use analysis (Table 5.1). The 'total agriculture' category represents the sum of all these agricultural land uses. A summary of results for arable, cattle and total agricultural operation are presented in Table 8.2, and the complete results are provided in Appendix F. Only a few relationships were found between water and sediment results for other agricultural activities (Appendix F).

The results showed that nutrients (nitrate, ammonia, orthophosphate), conductivity, temperature, dissolved Fe and Mn, were positively correlated with total agricultural land and percent arable land. The relationships were generally consistent between the wet and dry season, with the exception of nitrate (for which no relationship was seen in the dry season). pH was the only water quality parameter that had a negative relationship, and this was only significant in the dry season. The percent land dedicated to cattle (%cattle) generally showed these same relationships in the wet season (with the exception of orthophosphate where no relationship was seen), but in the dry season only the relationship with pH and with ammonia were significant. It is interesting to note that for wet season nitrate, the relationship was stronger for %cattle and total agriculture than for %arable. Overall, the relationships were slightly stronger in the wet season and there was relatively little difference between the relationships found using contributing areas versus 100 m buffer zones.

A number of metals in sediments (Cd, Co, Cr, Cu, Fe, Ni, Zn, and P) were consistently correlated with %total agricultural land and %arable land. Of these Cd, Cu, Fe, Zn and P concentrations had the strongest relationships ($r > 0.6$). Weaker relationships with K, Ca, Mg, and Na were also found for both %total agricultural and %arable land, with a few exceptions. Percent cattle showed fewer significant relationships with metals in sediment, and no relationship with K, Mg or Ca. It is interesting to note, that in contrast to total P, the bio-available P in sediment (orthophosphate) was negatively correlated to total agricultural land. As with the water quality correlations, there was minimal difference between the results using contributing areas and results using 100 m buffer zones.

Table 8.2 Spearman's Rank Correlation Coefficients for Independent Contributing Areas and 100 m Buffers: Agricultural Land Use Indices versus Water and Sediment Quality Parameters

Independent Area Correlations			AGRICULTURE					
			Total		Arable		Cattle	
			CA	*Buffer*	*CA*	*Buffer*	*CA*	*Buffer*
WATER QUALITY PARAMETERS	Ammonia-N	*wet*	**0.69**	**0.71**	**0.56**	**0.63**	**0.47**	**0.45**
		dry	**0.50**	**0.68**	**0.50**	**0.61**	**0.39**	0.35
	Nitrate-N	*wet*	**0.55**	**0.50**	0.33	**0.39**	**0.54**	**0.60**
		dry	-0.25	-0.15	-0.17	-0.21	-0.26	-0.02
	Orthophosphate-P	*wet*	**0.54**	**0.54**	**0.61**	**0.59**	0.19	0.16
		dry						
	Specific Conductivity	*wet*	**0.74**	**0.61**	**0.67**	**0.61**	**0.40**	**0.45**
		dry	**0.46**	**0.38**	**0.46**	0.33	0.24	0.36
	DO	*wet*	-0.18	-0.31	-0.19	-0.21	-0.25	-0.26
		dry	-0.20	-0.23	-0.18	-0.16	-0.18	-0.13
	pH	*wet*	-0.04	-0.23	-0.22	-0.29	-0.03	0.04
		dry	**-0.69**	**-0.73**	**-0.66**	**-0.74**	**-0.51**	**-0.48**
	Temperature	*wet*	**0.83**	**0.77**	**0.87**	**0.80**	**0.42**	0.34
		dry	**0.61**	**0.57**	**0.46**	**0.52**	0.25	0.20
	Iron (Fe)		**0.64**	**0.76**	**0.55**	**0.72**	**0.46**	**0.43**
	Manganese (Mn)		**0.73**	**0.81**	**0.60**	**0.71**	**0.56**	**0.53**
	Calcium (Ca)		0.35	0.28	**0.50**	0.33	0.19	0.22
SEDIMENT PARAMETERS	Cadmium (Cd)		**0.84**	**0.65**	**0.71**	**0.70**	**0.51**	**0.54**
	Cobalt (Co)		**0.62**	**0.42**	**0.46**	**0.42**	**0.43**	**0.55**
	Chromium (Cr)		**0.47**	0.33	**0.51**	**0.42**	0.16	0.18
	Copper (Cu)		**0.70**	**0.50**	**0.67**	**0.57**	0.32	**0.43**
	Iron (Fe)		**0.83**	**0.67**	**0.65**	**0.68**	**0.48**	**0.51**
	Nickel (Ni)		**0.49**	0.31	**0.49**	0.32	0.11	0.20
	Zinc (Zn)		**0.68**	**0.53**	**0.61**	**0.60**	**0.49**	**0.62**
	Phosphorus (P)		**0.81**	**0.61**	**0.71**	**0.68**	**0.59**	**0.58**
	Calcium (Ca)		**0.40**	0.23	**0.53**	0.38	0.23	0.33
	Potassium (K)		0.37	0.33	**0.57**	**0.42**	-0.10	-0.01
	Magnesium (Mg)		**0.61**	**0.53**	**0.59**	**0.55**	0.12	0.20
	Sodium (Na)		**0.63**	**0.62**	**0.63**	**0.71**	**0.64**	**0.70**
	% Nitrogen		**0.42**	**0.50**	0.23	0.31	**0.49**	**0.46**
	Orthophosphate		**-0.48**	-0.30	**-0.43**	-0.13	-0.05	

* Values in bold indicate significant correlations at α =0.05 for a one-tailed test

8.2 Correlations with Natural Land Cover

As shown in Table 5.1, the 'natural' land use category is subdivided into forest and open space. Open space encompasses all non-agricultural clearings (e.g. parks, playing fields, clearings) and was designed to represent land that was not forested but was also not being used for agriculture. This was done because it was assumed that this land base would have different inputs than agricultural fields or forests. Rural residential land (which includes both the building and surrounding land) was also included in this category since most of the land is cleared space. A summary of the results for 'total natural', forest and open space categories is presented in Table 8.3. Complete correlations results are located in Appendix F.

Correlations between both the percent total natural area (%natural) and percent forested land (%forest) with water and sediment parameters were generally similar using contributing areas or 100 m buffers. Temperature, conductivity and ammonia were negatively correlated with %forest and %natural land use in both the wet and dry season. Negative relationships were also seen with other nutrients (nitrate and orthophosphate) and dissolved oxygen (DO) in the wet season, and with pH in the dry season. All major ions (Ca, Mg, Na, K) and trace metals (Fe, Mn) were negatively correlated with these two land indices. %open space only showed significant correlations with conductivity (wet and dry), pH (dry), and temperature (wet), but these were only seen using the 100 m buffer method.

Negative relationships were also found between metals (Cd, Co, Cu, Fe, Ni, Cr, and P) in sediments and %natural land use. Similar to relationships with agriculture, the strongest correlations were found with Cd, Cu, Fe, Zn and P ($r > 0.6$). Negative correlations with Ca, K, Mg and Na were also found. Similar correlations were found for %forest with the exception of Co, Cr, Ni, Ca, and Mg; however, relationships with Co and Ca are seen when the cumulative index is used (Appendix F). It is interesting to note that for %natural and %forest a few more significant correlations were found using the contributing area method, while significant correlations with %open space were only found using the 100 m buffer.

Table 8.3 Spearman's Rank Correlation Coefficients for Independent Contributing Areas and 100 m Buffers: Natural Land Cover Indices versus Water and Sediment Quality Parameters

	Cumulative Area Correlations		NATURAL					
			Total		**Forest**		**Open Space**	
			CA	*Buffer*	*CA*	*Buffer*	*CA*	*Buffer*
WATER QUALITY PARAMETERS	Ammonia-N	*wet*	**-0.46**	**-0.44**	-0.29	-0.28	-0.24	-0.02
		dry	**-0.52**	**-0.66**	**-0.42**	**-0.59**	-0.22	-0.01
	Nitrate-N	*wet*	**-0.48**	**-0.52**	**-0.41**	-0.35	**-0.41**	**-0.39**
		dry	-0.22	-0.22	-0.37	-0.18	0.34	-0.03
	Orthophosphate-P	*wet*	**-0.45**	**-0.40**	**-0.45**	**-0.41**	-0.10	-0.14
		dry						
	Specific Conductivity	*wet*	**-0.62**	**-0.51**	**-0.64**	**-0.44**	-0.06	-0.15
		dry	**-0.81**	**-0.67**	**-0.86**	**-0.58**	0.10	-0.26
	DO	*wet*	**0.53**	**0.61**	**0.63**	**0.66**	-0.11	-0.02
		dry	**0.39**	**0.50**	0.20	0.34	0.06	0.08
	pH	*wet*	0.23	**0.52**	0.31	**0.60**	-0.12	-0.09
		dry	**0.61**	**0.74**	**0.51**	**0.66**	0.22	0.30
	Temperature	*wet*	**-0.58**	**-0.57**	**-0.46**	**-0.45**	-0.29	-0.30
		dry	-0.37	-0.28	-0.32	-0.28	0.03	0.12
	Iron (Fe)		-0.36	**-0.47**	-0.25	-0.36	-0.11	0.03
	Manganese (Mn)		**-0.53**	**-0.61**	**-0.44**	**-0.52**	-0.22	-0.09
	Calcium (Ca)		**-0.55**	**-0.51**	**-0.74**	**-0.58**	0.15	-0.14
	Potassium (K)		**-0.57**	**-0.49**	**-0.74**	**-0.47**	0.28	-0.18
	Magnesium (Mg)		**-0.43**	-0.36	**-0.62**	**-0.44**	0.33	0.05
	Sodium (Na)		-0.32	-0.23	**-0.52**	-0.28	**0.48**	0.28
SEDIMENT PARAMETERS	Cadmium (Cd)		**-0.70**	**-0.62**	**-0.60**	**-0.51**	-0.32	**-0.45**
	Cobalt (Co)		**-0.68**	**-0.52**	**-0.57**	-0.37	-0.1[illegible]	**-0.46**
	Chromium (Cr)		**-0.46**	**-0.40**	-0.30	-0.26	-0.17	**-0.56**
	Copper (Cu)		**-0.69**	**-0.52**	**-0.52**	-0.28	-0.27	**-0.53**
	Iron (Fe)		**-0.62**	**-0.56**	**-0.51**	**-0.46**	-0.34	**-0.43**
	Manganese (Mn)		-0.10	0.01	-0.23	-0.03	0.02	-0.31
	Nickel (Ni)		**-0.59**	**-0.40**	-0.32	-0.10	**-0.40**	**-0.73**
	Zinc (Zn)		**-0.72**	**-0.61**	**-0.64**	**-0.47**	-0.24	**-0.49**
	Phosphorus (P)		**-0.59**	**-0.54**	**-0.57**	**-0.51**	-0.22	-0.34
	Calcium (Ca)		**-0.57**	-0.38	**-0.50**	-0.25	-0.15	**-0.52**
	Potassium (K)		-0.37	-0.30	-0.37	-0.22	0.22	-0.16
	Magnesium (Mg)		**-0.44**	-0.36	-0.22	-0.11	-0.05	-0.25
	Sodium (Na)		**-0.64**	**-0.70**	**-0.53**	**-0.54**	-0.19	0.32
	% Nitrogen		-0.31	**-0.39**	-0.22	-0.33	-0.21	0.10

* Values in bold indicate significant correlations at α =0.05 for a one-tailed test

8.3 Correlations with Urban Land Uses

Urban land use was divided in two ways. First, urban categories were grouped based on the type of urban use (industrial/commercial versus residential). Second, total urban land use was grouped based on the density of use (high density versus low density). A summary of the correlation results is shown in Table 8.4, and the complete results of the correlations test are provided in Appendix F.

Urban land use activities are concentrated in two regions of the watershed: the urban centers of Chilliwack and Sardis (part of which are within the contributing areas for stations M19 and M20), and the urban hillslope development of Promontory. In both areas, the percentage of low intensity urban is much larger than high intensity urban within the individual contributing areas, and the percentage of residential is much larger than industrial land uses (Table 8.1). The correlations presented did not include stations M19 and M20 (which are more intensively urbanized). This was done in order to determine if any relationships could be found with the residential hillslope development.

The percent of both low density (%low density) land use, and percent residential (%residential) showed similar results to each other and to the results found for total urban land use (%urban): positive correlations with nitrate in the dry season, negative correlations with ammonia in the wet season, and positive correlations with dissolved K and Mg. In sediment, Cd, Fe and Ca showed negative relationships with %residential land use. A number of (weak) correlations were found using the 100 m buffer that were not found using the contributing area methods. These were: positive correlations with pH in the dry season, and negative correlations with wet season ammonia, dissolved Fe and Mn, and sediment-bound Co, Cu and Zn.

Correlation results for the percent high density (%high density) and commercial/industrial (%C/I) are slightly different, and there were significantly more correlations between %C/I and water quality parameters. Relationships that were not found with %low density or %residential include negative correlations with dissolved sodium and dry season DO, and positive correlations with dry season ammonia and both orthophosphate and conductivity in the wet season With the exception of a weak positive relationship with copper, no associations with sediment-bound metals were found.

Table 8.4 Spearman's Rank Correlation Coefficients for Independent Contributing Areas and 100 m Buffers: Urban Land Use Indices versus Water and Sediment Quality Parameters

Independent Area Correlations			Urban									
			Total		Commercial/Ind.		Residential		High Density		Low Density	
			CA	*Buffer*	*CA*	*Buffer*	*CA*	*Buffer*	*CA*	*Buffer*	*CA*	*Buffer*
WATER QUALITY PARAMETERS	Ammonia-N	*wet*	-0.07	**-0.38**	**0.39**	0.20	-0.11	**-0.44**	0.33	0.20	-0.07	**-0.44**
		dry	0.09	-0.11	**0.50**	**0.46**	0.14	-0.20	**0.42**	0.17	0.18	-0.20
	Nitrate-N	*wet*	-0.16	-0.15	0.32	0.20	-0.28	-0.24	-0.18	-0.11	-0.22	-0.24
		dry	**0.55**	0.37	0.26	0.31	**0.47**	**0.45**	-0.05	0.05	**0.57**	**0.47**
	Orthophosphate-P	*wet*	0.05	-0.20	**0.42**	0.24	0.10	-0.28	**0.39**	0.10	0.13	-0.28
		dry										
	Specific Conductivity	*wet*	0.02	-0.23	**0.48**	0.25	-0.05	-0.32	0.19	0.09	0.00	-0.32
		dry	**0.47**	0.19	**0.69**	**0.56**	0.34	0.09	0.26	0.20	**0.39**	0.08
	DO	*wet*	**-0.48**	-0.32	**-0.44**	**-0.59**	-0.38	-0.20	**-0.41**	-0.29	**-0.39**	-0.19
		dry	-0.09	0.08	-0.37	-0.24	-0.24	-0.01	**-0.56**	-0.37	-0.20	0.01
	pH	*wet*	-0.01	0.06	-0.29	-0.32	-0.10	0.11	**-0.46**	-0.20	-0.08	0.12
		dry	0.22	**0.42**	-0.29	-0.15	0.19	**0.51**	-0.20	0.09	0.15	**0.51**
	Temperature	*wet*	-0.18	-0.36	0.29	-0.06	0.02	-0.36	0.19	-0.10	0.03	-0.36
		dry	-0.05	-0.36	0.32	0.02	-0.03	-0.37	0.25	0.02	-0.02	-0.37
	Iron (Fe)		-0.15	**-0.43**	0.24	0.14	-0.10	**-0.46**	0.26	0.02	-0.04	**-0.46**
	Manganese (Mn)		-0.12	-0.33	0.38	0.30	-0.12	**-0.44**	0.29	0.11	-0.08	**-0.45**
	Calcium (Ca)		0.35	0.15	0.38	**0.38**	0.23	-0.02	0.33	0.23	0.25	[illegible]
	Potassium (K)		**0.79**	**0.53**	**0.51**	**0.57**	**0.69**	**0.47**	**0.57**	**0.54**	**0.70**	**0.46**
	Magnesium (Mg)		**0.68**	**0.58**	0.36	**0.64**	**0.58**	**0.45**	**0.57**	**0.64**	**0.57**	**0.43**
	Sodium (Na)		**0.49**	0.30	**0.56**	**0.48**	0.30	0.30	0.11	0.21	0.34	0.30
SEDIMENT PARAMETERS	Cadmium (Cd)		-0.24	-0.35	0.37	0.12	**-0.39**	**-0.55**	-0.19	-0.29	-0.37	0.28
	Cobalt (Co)		-0.13	-0.23	0.30	0.07	-0.31	**-0.39**	-0.34	-0.34	-0.29	-0.22
	Copper (Cu)		0.04	-0.33	**0.38**	-0.04	-0.20	**-0.42**	-0.20	-0.35	-0.16	**-0.41**
	Iron (Fe)		-0.28	-0.35	0.33	0.13	**-0.41**	**-0.55**	-0.23	-0.32	-0.37	-0.13
	Nickel (Ni)		0.13	0.19	0.25	-0.17	0.09	0.21	**-0.51**	-0.35	0.14	**-0.47**
	Zinc (Zn)		0.04	-0.03	0.27	0.03	-0.09	-0.14	-0.17	-0.30	-0.05	-0.35
	Phosphorus (P)		-0.13	-0.35	0.26	0.01	-0.27	**-0.48**	**-0.42**	**-0.50**	-0.24	-0.20
	Calcium (Ca)		-0.30	-0.37	0.18	0.09	**-0.40**	**-0.55**	-0.07	-0.12	**-0.39**	-0.35
	Potassium (K)		0.09	-0.06	0.04	-0.13	-0.03	-0.11	**-0.41**	**-0.48**	-0.02	**-0.46**

* Values in bold indicate significant correlations α=0.05 for a one-tailed test

8.4 Comparison Between Land Use Components

A subset of the results was chosen for comparison, and is shown in Table 8.5. The land indices were chosen because they were most representative of the comparisons throughout this thesis. Overall, the correlation results support the findings in the previous chapter. Agricultural land uses were associated with increases in both nutrients and trace metals (in water and sediment). The impacts of residential land use on water and sediment quality were less pronounced. The only parameters that showed relationships unique to %residential land use were dissolved magnesium and potassium. Forest cover was generally associated with lower concentrations of nutrients and metals.

Table 8.5 Overview of Spearman's Ranks Correlations ($p<0.05$) Between Land Use and Various Water and Sediment Quality Parameters

		Agriculture *(%total agriculture)*	**Urban** *(%residential)*	**Forest** *(%forest)*
Nutrients in Water	*Wet season*	NH_4, NO_3, PO_4		(- PO_4)
	Dry season	NH_4	NO_3	(-NH_4, NO_3)
Physical Water Parameters	*Wet season*	cond., temp.		DO, (- cond., temp.)
	Dry season	cond., temp., (-pH)		pH (-cond, temp)
Ions and Metals	*Water (dissolved)*	Fe, Mn	K, Mg	(- Fe, Mn, Ca, K, Mg)
	Sediment (total)	Cd, Co, Cr, Cu, Fe, Zn, P, Ni, Ca, Mg, Na	(-Cd, Fe, P)	(- Cd, Cu, Fe, Zn, P, K, Na)

8.5 Correlations with Impervious Surface Area

Percent total impervious surface area (%TIA) did not correlate well with water or sediment quality parameters. In the wet season, specific conductivity and dissolved Mn, Ca, K and Mg were all positively correlated with %TIA. A negative relationship with dissolved oxygen was the only relationship found in the dry season.

9 DISCUSSION

The objectives of this project were to provide information on the current status of the watershed in terms of hydrology as well as water and sediment quality, to determine the impact that the new hillslope development is having on the hydrology and water quality of the hillslope and lowland agricultural area, and to investigate the links between both surface water and sediment quality and land use. Changes in land use were identified, water and sediment samples were collected and analyzed, precipitation and flow data were examined, and comparisons were made between the three primary land uses (agriculture, urban, and forest).

9.1 Climate and Hydrology

9.1.1 Climate Variability

Climate variability is an important parameter affecting the hydrologic regime of a watershed; and precipitation is the key climate variable of concern to stormwater management (Watt et al., 2003). Precipitation during the sampling period was characterized by extremes - a long dry period followed by a wet season with record rainfalls. October 2002 had significantly less precipitation (24.0 mm) than the 30-year average (167.3 mm). In contrast, October 2003 was extremely wet with a total monthly precipitation of 364.7 mm. Of this, 254.6 mm fell over a six day period (and 100.3 mm fell during the storm event on 16-Oct-03). This is consistent with the increasing climatic variability noted in the literature. Precipitation data for southwestern British Columbia suggest that precipitation frequency, intensity and duration are changing compared to the mid 20th century, and climate change has been implicated as the primary contributor to these observed trends (Stephens et al., 2002a). Environment Canada models project increasing fall and winter precipitation, decreasing late spring-early summer precipitation, and more intense rainstorms (Stephens et al., 2002a). Other studies have also reported that the frequency of heavy and extreme precipitation events is increasing (Houghton et al., 2001).

In terms of stormwater management, the increased seasonal rainfall and more frequent heavy rainfall events mean that there will be more runoff to manage in the future. Typically, stormwater management infrastructures are designed to convey a particular historical rainfall pattern; however assumptions about climate are generally static and based on limited historical data (Watt et al., 2003). If rainfall inputs increase as a result of climate change, the designs that worked in the past may not be adequate in the future. For example, storage volumes for detention ponds designed to reduce peak outflows to predevelopment conditions are based on a specific design rainfall event. As precipitation increases the storage volume required would be larger for the same design rainfall.

9.1.2 Distribution of Storm Events

An examination of the precipitation records for Chilliwack show that the majority (88.6%) of the storm events recorded were minor events, and that total daily rainfall was usually below 30 mm. Total daily rainfall exceeded 60 mm on 1 of 68 days (over the three year period that was measured) and, on average, accounted for about 13% of the total annual rainfall volume. In contrast, 70% of the total annual rainfall volume over this same period was generated by events of less than 30 mm. The implication for stormwater management, based on these data, would be that strategies which incorporate low impact designs and source control methods (which are designed to capture and infiltrate precipitation from these small events on-site) may be more effective at mitigating the impacts of development than conventional stormwater management systems (which are generally designed to control peak runoff rate for a few large storm events; and are often not designed to mitigate for runoff rate and increases in runoff volume from the smaller, frequently occurring storms). If Chilliwack's new stormwater management plan is effective, over 75% of the rainfall will be captured and detained on site, greatly reducing the rate and volume of runoff reaching nearby streams.

9.1.3 Overview of Storm Response for the Different Sub-Watersheds

The Chilliwack Creek watershed has a range of land use properties, which results in a heterogeneous mix of hydrologic response properties for the various sub-catchments. This section will discuss the general response of the individual sub-catchments based on the hydrographs and storm characteristic results presented in Chapter 6.

9.1.3.1 Forested Systems: Parsons Brook and Elkview Creek

The drainage area for both Elkview Creek and Parsons Brook is mostly rural and undeveloped (forested) land. Therefore, it is reasonable that the hydrographs exhibit a longer time to peak discharge followed by a slow recession as is generally seen in the hydrographs for the Parsons. While Elkview Creek showed significantly longer lag times than the other catchments, a number of the hydrographs for individual storm events exhibited a much shorter time peak than Parsons. A possible explanation for the shorter lag time is that a road runs directly adjacent to Elkview Creek. Direct runoff from the impervious road surface would decrease the travel time to the stream, while precipitation falling in the forested parts of the catchment would infiltrate and flow much slower as subsurface stormflow, and continue to reach the stream much later causing the slower recession. In summary, the response at Parsons Brook is more typical of a forested catchment while the response at Elkview Creek may be influenced in part by a small section of impervious surface directly adjacent to the stream.

9.1.3.2 Urban Systems: Teskey Creek and Lefferson Creek

Storm flow peaks for both of the semi-urbanized catchments closely mimic precipitation patterns, and display a shorter time to peak than the other stations. In addition, the peak runoff rate at Teskey Creek (which has a higher proportion of impervious area) is markedly higher than most of the other stations. This suggests that much of the rainfall is reaching the stream as direct surface runoff from impervious surface areas in the Promontory development. In contrast, peak runoff rate at Lefferson is generally lower than most stations. Although this catchment is currently being developed, the area of impervious surface is lower than it is for Teskey Creek. In addition, the gauge itself is on a buffered area of the stream with steep slopes on either side. Consequently, the lower storm runoff rates at Lefferson may be because the area developed (i.e. the impervious surface area) is still insufficient to increase surface runoff. If this is the case, the shorter lag time is possibly the result of overland flow down the steep slopes at either side of the stream gauge; and not due to urbanization. One exception was observed during the major storm event on 17-Jul-02 storm event.

9.1.3.3 Agricultural Systems: Semiault Creek

Peak runoff rates were generally high, with moderate response times. The median peak runoff rate (0.710 mm/hr) of this agricultural catchment is up to 3.7 times the median peak runoff rates in the undeveloped catchments. Agricultural drainage systems (like those found in the Semiault Creek catchment) have been shown to increase outflow from fields by 5 to 20% depending on the system, site conditions and soils (Schreier et al., 2002; Ritter and Shirmohanmmadi, 2001). Agricultural practices have also been shown to reduce the infiltration capacity of the soil which would increase surface runoff. This is the result of a number of factors, such as soil compaction, sealing of the soil surface by sediment laden runoff, and the reduction of organic matter content that maintains a soil texture that is conductive to infiltration (Brady and Weil, 1996).

9.1.3.4 Groundwater Influenced System: Luckakuck Creek

Flow at the Luckakuck Creek station can be characterized as having: 1) a slightly higher baseflow ; 2) a relatively short lag time; and 3) a somewhat muted/stable response overall. This stream originates as a spring and is influenced by groundwater from the Sardis-Vedder aquifer, which contributes to baseflow in the stream. The soils above the aquifer are very permeable and consequently less surface runoff is expected in this area. In addition, groundwater accretion resulting from a particular storm is normally released over an extended period of time (Viessman and Lewis, 1996). Consequently, the more stable response observed is reasonable. Part of the watershed surrounding the stream above this station is urbanized; yet it does not seem to be increasing peak flows significantly. The short lag time, however, may be influenced by the stormwater outfall above this station.

9.1.3.5 Downstream (Mixed) Systems: Bailey Ditch and Chilliwack Creek

The timing and magnitude of the streamflow from the upstream tributaries play a role in determining the hydrologic response at the downstream stations. For example, the Chilliwack Creek hydrograph shows both a rapid and extended response. The station itself lies in an urban section of the stream, and the initial rapid response is likely from immediate stormwater runoff from impervious surfaces near the station. As water from the upper portions of the watershed reach the station the stream continues to respond. The blips in the hydrograph (see Figure B.1) following rainfall are likely due to contributions from different portions of the watershed. Bailey station, which lies downstream of the Promontory development peaks slightly after the urban catchments and has a more gradual response.

9.1.4 Comparison of the Hydrologic Effects between Forested and Urban Sub-Catchments

Urbanization, with the accompanying loss of vegetation, replacement of soil with impervious surfaces, and routing of stormwater runoff directly to stream channels, has a significant impact on many of the processes that control streamflow (McCuen, 1998). A number of major effects of urbanization on hydrologic processes have been identified in the literature: 1) a higher proportion of precipitation appears as surface runoff (i.e. increased runoff volumes and higher runoff/rainfall ratios); 2) the catchment response time to precipitation is accelerated and the lag time between precipitation and runoff is decreased; 3) peak flow magnitudes are generally increased; and 4) low flow is typically decreased due to reduced contributions from groundwater storage (Rose and Peters, 2001). The Promontory development on the hillslope is still relatively small, and the impacts are not as large as would be observed in a more intensive urban catchment. Still, some of the effects listed above are evident.

9.1.4.1 Lag Time

Catchment response time appears to be related to its land use/land cover properties. The median lag time of the suburbanized catchments, Teskey (64.5 ha) and Lefferson (166.4 ha), are extremely short, and more than 12 hours faster than the lag time of the forested catchments, Parsons (204.8 ha) and Elkview (216.2 ha). In addition, variability for the urban catchments is minimal compared to the variability observed in the forested catchments (Figure 6.11). A possible explanation for the low variability within the urbanized catchments is that impervious surfaces reduce the infiltration capacity to zero so that more runoff occurs as overland flow. When this happens, some of the factors influencing the runoff process (e.g. antecedent soil moisture) have a lesser influence on the timing of storm flow. In contrast, in undeveloped catchments the timing (and magnitude) of streamflow, is more dependent on storm and catchment characteristics. The part of the drainage basin that is contributing rapid storm runoff to the channel tends to expand through an entire storm season, making any changes in stream flow more intense and the lag time shorter for similar-sized storm occurring later in the wet season (Hewlett and Hibbert, 1967; Booth, 2000). For example, a summer storm with a longer antecedent dry period would be more likely to have a longer lag time because the soil will be able to absorb more precipitation, and more water will flow to the stream as subsurface flow and less as rapid overland flow.

9.1.4.2 Peak Runoff Rate

The box plots shown in Figure 6.13 and the sign test results indicate that peak runoff rates for the analyzed storm events at the Teskey station (0.165-3.731 mm) were up to 15 times higher than at the undeveloped hillslope stations (e.g. Parsons and Elkview). Higher peak flows and higher volumes of water discharged to streams during storm events are common consequences of urban development, and have been noted in literature for many years (Anderson, 1968; Leopold, 1968; Carter, 1961). It is interesting to note, however, that for some storm events there was a minimal difference, and in some instances total runoff volume was higher at Parsons (forested stream) than at Teskey. On closer inspection, these events occurred soon after another storm event while runoff was still increasing. As a result, the response seen in the forested catchment is a combination of the response of the previous storms and the actual event being measured, resulting in a much higher streamflow. Response in the more urban catchments is immediate, and therefore not influenced by the previous event. Conversely, the largest differences between the forest and urban catchments were observed for intermediate sized events (e.g. 1-Jun-01) following periods with relatively little rain, when forests have a larger storage capacity for water. During wetter periods, the soils in undeveloped basins become saturated and additional rainfall is converted to runoff as much as it does in an urban basin (Konrad, 2003).

9.2 Water and Sediment Quality

9.2.1 Impacts of Agricultural Land Uses

Water and sediment sampling revealed a number of impacts that appear to be related to agricultural activities. These include: elevated nutrient concentrations in lowland watercourses, evidence of eutrophication, depressed oxygen levels in streams and ditches, and the enrichment of streambed sediment with trace metals associated with animal feeds and fertilizers.

9.2.1.1 Nutrients in Water and Sediment

Nutrient results indicate that most of the streams in the lowland agricultural area have levels above those of the forested control sites for nitrate in the wet season, and for orthophosphate and ammonia throughout the year. While none of the samples exceeded the B.C. Water Quality Guidelines, Semiault Creek consistently had the highest levels of nitrate and reached a concentration of 5.68 mg/L in December 2002. Chilliwack Creek was the only other waterway where the nitrate concentration rose above the 3 mg/L level that is indicative of impact by anthropogenic activities (Schreier, pers comm., 2004). For ammonia, the B.C. Water Quality Guidelines are based on the risk to aquatic fish, and are set for both continuous exposure (30-day average) to ammonia and for maximum acceptable concentrations (MAC). These guidelines vary with pH and temperature, which affect both the toxicity of ammonia and the form in which it occurs (Mueller and Helsel, 1999; Nordin and Pommen, 1986). Concentrations at the downstream station along Interception Ditch (A18) were above the 30-day average guideline (>0.15 mg/L at pH = 8.8 and temperature = 22°C) on 9-July-2003. While samples were not taken over a 30 day period, it does not seem implausible that average concentrations may be sustained above this level for the duration of the month. Ammonia concentrations also exceeded the MAC at a number of stations in December 2002: Bailey Ditch (M10, 5.233 mg/L), Teskey Way Ditch (A17, 4.23), and Interception Ditch (A16, 3.41 mg/L, A18, 1.77 mg/L).

Semiault Creek and the downstream regions of Interception Ditch and Chilliwack Creek experienced seasonal trends for both ammonia and nitrate. In general, concentrations were found to be higher and more variable in the wet season, with the highest concentration recorded during winter and fall runoff events (e.g. December 2002, October 2003). This further supports the assumption that nutrient influx to the streams is primarily from overland runoff and that there is the potential for higher nitrogen loads to be transported to the stream during winter rainfall events. While manure and fertilizers are applied to agricultural fields in the summer months there is less runoff and higher biological uptake of nutrients both by crop and aquatic plants. This may account for the lower nitrate and ammonia levels the agricultural waterways at this time of the year.

The fact that ammonia and nitrate concentrations in Bailey Ditch are relatively high year-round suggests that this portion of the watershed may be contributing nitrogen to Interception Ditch. The contributing area for Bailey Ditch includes the Bailey Landfill site, but the site is also downstream of a number of agricultural operations.

Waterways surrounded by agricultural operations also had significantly higher levels of orthophosphate than the forested reference sites. There are no provincial or federal guidelines for phosphate in streams. However, to control eutrophication the EPA recommends that total phosphorus should not exceed 0.1 mg/L in streams (Mueller and Helsel, 1999). Concentrations of orthophosphate exceeded 0.1 mg/L in Semiault Creek, Bailey Ditch and in the downstream sections of Interception Ditch and Chilliwack Creek in August 2002 and October 2002. In Semiault Creek, and in the lower reaches of Interception Ditch and Chilliwack Creek, the total P concentration in sediments was also greater than in the forested tributaries; however the BAP was lower. While bound to sediments, phosphorus is not available to plants or organisms, and does not pose an immediate threat of eutrophication. However, if physical conditions (such as pH, temperature, DO) change to favor the dissolution of the phosphate complexes, the sediment-bound phosphorus may be re-released to the water column.

Where concentrations of these nutrients are high, they warrant concerns about toxicity to fish and accelerated eutrophication (which can lead to decreased oxygen levels in the water). Eutrophication (excess algal growth and plant proliferation) can reduce the potential use of water for recreation, industry, and drinking purposes. Furthermore, the conversion of ammonium to nitrate in streams will remove oxygen from water and adversely affect fish populations in the streams.

9.2.1.2 Dissolved Oxygen (DO)

Although DO levels were below the provincial water quality guidelines in several agricultural streams during the summer months, DO levels were not found to be significantly different than the forested sites. Semiault Creek and the lowest regions of Interception Ditch had DO levels below 9 mg/L (the minimum requirement for buried embryo/alevin life stages) on all sampling dates except July 2003. The downstream region of Chilliwack Creek was the most impacted by oxygen deficit, with concentrations below 6.2 mg/L on three of the four sampling dates. The flow in these streams is relatively stagnant, which combined with higher summer temperatures and nutrient concentrations likely contributed to the low DO levels at these sites.

9.2.1.3 Specific Conductivity

B.C. Working Water Quality Guidelines indicate that specific conductivity should not exceed 700 μS/cm for drinking water, and 700 to 5000 μS/cm for irrigation purposes (depending on soil and crops) (MWLAP, 1998). These levels were not exceeded at any station throughout the sampling period. However Semiault Creek consistently had the highest levels in the watershed reaching levels of 550 μS/cm in December 2002. Other streams surrounded by agricultural activities (Interception Ditch, Bailey Ditch and Teskey Way Ditch) also had higher conductivity values on this date. This is likely an indication that sediment and manure are entering the stream during runoff events.

9.2.1.4 Temperature

Spot measurements of temperature (i.e. sampling once per station on each sampling date) are limited in their usefulness since diurnal fluctuations cannot be determined. In addition, the data on temperature do not allow for the determination of abrupt changes in stream temperature which have been shown to be harmful to some aquatic species. Still, Interception Ditch (A16 and A18) and Semiault Creek have relatively high temperatures in the summer months, which is likely the result of a combination of the stagnant nature of these watercourses and the minimal shade cover. Increased temperatures reduced the solubility of oxygen, which combined with the elevated metabolic oxygen demand, may impact many fish species. In addition, temperature influences other parameters (such as pH) and can therefore influence the solubility of other chemical species and their effect on aquatic life (MWLAP, 1998).

9.2.1.5 pH

pH levels in the watershed are within provincial guidelines (6.5-9.0). However, the results indicate that many of the agricultural streams have significantly lower wet season pH values in comparison to the forested tributaries. Manure and fertilizer tend to be acidic, and consequently, runoff from agricultural fields and manure storage areas could be the cause of the lower pH values noted in the receiving waterways (Sharpley et al., 1998; Smith, 1994). This lowering of pH is of concern because the additional hydrogen ions compete with metal cations for positions on sediment exchange sites. As a result, more metals are found in the water (bioavailable fraction) which increases the risk of toxicity to aquatic plants and organisms.

9.2.1.6 Metals in Water and Sediment

The following elements are of interest in agricultural watercourses because they are frequently found in manure and fertilizers and once in waterways they may present toxicity problems for aquatic biota: Cu, Zn, Cr, Mn, Cd, and Fe (McBride and Spiers, 2001; Nicholson et al., 1999; deVries, 2003; Here and Tessies, 1996). Concentrations of sediment-bound Cu, Zn, Fe and Cd in agricultural streams were not found to be significantly different than in the forested streams; this is likely due to the high concentrations observed in Elkview Creek. However, concentrations of these metals do appear to be elevated, and are generally higher than the rest of the hillslope tributaries. Significantly higher levels of dissolved iron and manganese were found in the agricultural streams in comparison to both the urban and forested tributaries.

Zinc was not found to be above detection limit (>0.01mg/L) for any of the water samples during monthly sampling. However, during first major runoff event after the summer months (October 2003 storm samples) Zn levels rose slightly above 0.03 mg/L (the Canadian Water Quality Guideline for the Protection of Aquatic Life) in Semiault Creek. In sediment, Zn concentration exceeded the ISGQ (123 mg/L) at all agricultural sites.

Water sampled did not have detectable levels (> 0.05 mg/L) of dissolved Cu; however sediment results indicated that concentrations exceeded the lowest effect level (LEL) for Cu in all watercourses.

In the agricultural sites, the highest concentrations (> 40 ppm) were found in the lower reaches of Interception Ditch. Cu and Zn are of greater concern when found together since their toxicity increase when present together in the aquatic environment (Anderson, 1988).

Fe and Mn are often found in association in nature, and natural background concentrations are generally high in the region. In agricultural areas of the watershed Fe concentrations were elevated in both water and sediments, while high Mn concentrations were only detected in water. The likely sources are agricultural runoff, and release from Fe and Mn bearing minerals. The mean Fe levels in water at the agricultural sites (0.80 mg/L) was over 8 times greater than mean levels for the forest (0.10) and urban (0.09) sites. The *B.C. Water Quality Guidelines for the Protection of Aquatic Life* for Fe in water is 0.03 mg/L, and Fe concentrations in all agricultural watercourses exceeded this level on all sampling dates with one exception; Semiault Creek had a level of 0.21 mg/L in July 2003. On this date the highest Fe concentrations in sediments were recorded at this site (89488 ppm). High dissolved Fe levels (>1.6 mg/L), as well as sediment-bound Fe levels greater than the severe effect level (SEL) (4380 ppm) were noted in the lower reaches of Interception Ditch. Peak Mn concentrations (>0.2 mg/L) were also measured in Semiault Creek and the lower sections of Interception Ditch. It is interesting to note that Semiault Creek, which had the highest concentrations of sediment-bound Fe and dissolved Mn, had the lowest dissolved Fe concentrations. The occurrence of these metals in water and sediment are influenced by pH, dissolved oxygen, and redox potential. As dissolved oxygen and redox potential decrease, Fe and Mn oxides become soluble, but Mn oxides are more easily dissolved than Fe oxides (Singh and Steinnes, 1994). Manganese oxides are capable of oxidizing Fe^{2+}, and therefore Mn^{2+} is found in solution before dissolved Fe^{2+} as the redox potential progressively decreases (Stumm and Morgan, 1970).

Cadmium has cumulative and highly toxic effects in all chemical forms (EPA, 2004). Water samples did not have detectable levels of Cd. Sediment samples, however, had concentrations above the severe effect level at all agricultural stations. Cd levels in Semiault Creek were double the concentrations at most of the other agricultural sites. The lower reaches of Interception Ditch also had elevated concentrations of Cd. The likely sources are manure and phosphate fertilizers applied to adjacent agricultural fields. Zinc and copper (which are also found in higher concentrations in these areas) are known to increase cadmium's toxicity.

It is encouraging that most metals were not found in detectable concentrations in the water column. However, the high concentrations in sediment could pose a risk to aquatic biota should the metals be released into the dissolved state.

9.2.2 Impacts of Urban Land Uses

9.2.2.1 Intensive Urban (M19)

While this study focused primarily on the potential impact of the new suburban residential hillside development (Promontory), station M19 provides an idea of the impact from the more intensive urban activities in the lowland area. Station M19 is located on the upper reaches of Chilliwack Creek below a number of stormwater outfalls that drain a relatively dense urban area. Results obtained from this station show elevated streamwater concentrations of nitrate, magnesium, calcium and the highest potassium concentrations in the watershed. Stormwater discharges are likely also responsible for the relatively high specific conductivity values and low pH values measured at this station. The most significant impact at this station appears to be elevated metal concentrations in the sediments. Concentration of Ca, Cr, and Mn were the highest measured in the watershed. Pb, Fe, Cu, Cd, Na, K, Ni and Zn also showed elevated concentrations compared to other stations within the watershed. A number of metals had concentrations that were above their respective LEL (Cu, Pb, Fe, Ni), PEL (Cd) or interim sediment quality guideline (Zn). This indicates possible toxic impacts to aquatic organisms, and significant degradation of the aquatic ecosystem in this area. However, due to the lack of sampling stations along this creek, it is not certain how localized the effects of stormwater discharges to the watercourse are (i.e. it is not known how far downstream these conditions persist). Overall, metal concentrations at this station are within the range found by McCallum (1995) in a stormwater study conducted in the Brunette watershed (a heavily urbanized watershed in the LFV).

9.2.2.2 Sub-Urban Residential Hillslope Development: Comparison with Forested Control Area

Comparison of water and sediment conditions between forest and urban tributaries on the hillslope provides some indication as to whether the new hillslope development (Promontory) is impacting the water quality of the hillslope tributaries. Streamwater orthophosphate concentrations, dissolved Mg and K concentrations, and K levels in bed sediments were significantly higher in the residential sections of the hillslope. Potassium chloride is a major component in fertilizers, which may be the cause of higher potassium levels in the hillslope streams. Lawn fertilizers, animal wastes, grass clipping, and household detergents have all been identified as sources of phosphorus in residential areas (Washbusch et al., 1999). The potential source of magnesium is less clear; however, Mg is found in construction materials (e.g. cement) and may reach streams with stormwater runoff, or it may be released when soil is disturbed during construction activities.

Enrichment of sediments with trace metals was not apparent in the urbanized section of the hillslope. This was unexpected since urban areas have often been associated with non-point source pollution from impervious surfaces, particularly with metals and phosphates (Washbusch et al., 1999; Characklis and

Weisner, 1997). The Promontory development is still relatively small and primarily residential, and it is thought that stream impacts associated with urban activities and urban stormwater runoff may not yet be sufficiently evident. Still, a difference in the trace metal content between the 2002 and 2003 sediment samples was evident in the developed section of the hillslope, suggesting that some changes may be occurring in the area as development proceeds.

Construction sites are not thought to be important sources of metal contamination, unless the soil is already contaminated (EPA, 2002b). Since much of the Promontory area is still being developed, it may have been more useful to have measured a pollutant associated with the construction phase of urban development, such as sediment. It has been shown that sediment runoff rates from construction sites are typically 10 to 20 times greater than those of agricultural land, and 1000 to 2000 times greater than forested areas (EPA, 2004).

9.2.3 Conditions in the Forested Area

Water and sediment quality for Elkview Creek (F13) and Parsons Brook (F12, F14) were generally reflective of what was expected at the control stations, with a few exceptions. The forest hillslope tributaries exhibited the lowest concentrations of streamwater orthophosphate, dissolved ions (Ca, K, Mg), most trace metals and showed the highest wet season DO concentrations. Relatively low concentrations of dissolved metals (Fe, Mn) were also found. The lack of a significant difference between wet season nitrate concentrations of the forest and agricultural sites might reflect a high natural contribution leached from forest soils, contribution from small hobby farms located on the hillslope, and/or leakage of septic systems from rural residential areas.

Geological sources are likely responsible for much of the Co, Ca, Al, Ni and Cr observed in the watershed since little spatial variability is observed. None of these elements were found in concentrations above the detection limit for water, and concentrations of Co, Cr and Ca in the streambed sediments were generally below the average background levels in B.C. (see Table 7.7). However, concentrations of Ni were above the lowest effect level (16 ppm) at all sites throughout the watershed. Parsons Brook (F13) had some of the lowest concentrations in sediments for most metals. In contrast, the upper station on Elkview Creek (F12) had the highest concentrations of Al, Co, Ni, Ca in the watershed (with the exception of Chilliwack Creek), as well as elevated concentrations of Cr, Zn, Cd, Cu and Mn. Cu levels were higher in Elkview Creek (> 60 ppm at F14) than in any of the agricultural streams, but all other hillslope sites had levels near average levels (26 ppm) in the Vancouver region (see Table 7.7). Elkview Creek was also one of the few sites that had concentrations of Pb that were above detection in July 2003. Cd, Zn and Pb are often found in association in natural environments (MWLAP, 1998), which may indicate that the elevated concentrations of Cd and Zn at this site are at least in part from geological materials. The high concentrations of all these metals recorded at this site may be attributed to higher rates of weathering of the exposed bedrock and shale above this site.

Differences in the geology of the area draining Elkview Creek and Parsons Brook account for some of the variations in water quality between the two streams. Elkview Creek generally had the lower conductivity values and concentrations of dissolved ions (Ca, K and Mg) in the watershed, and higher Na concentrations than Parsons. However, these differences were relatively small compared to the more land use impacted regions in the watershed.

9.2.4 Cumulative Effects (Downstream Trends)

Rarely does a single land use dominate a drainage basin; rather the effect of land use throughout the watershed is a conglomeration of all the individual land uses in the watershed. In the Chilliwack Creek watershed, the different land uses are distributed so that forested areas are located on the upland hillslopes, agricultural is below in the valley bottom, and the urban centers are located the furthest downstream. The new residential development of Promontory is also located in the hillslope with tributaries draining into the agricultural reaches. As a result, differences in the characteristics of the landscape are often difficult to separate from those of the land use itself. In addition, it is difficult to separate the effects of progressive changes in stream processes from land use effects when land use patterns change along the stream (Grove, 2001). Still, downstream trends along Interception Ditch and Chilliwack Creek give some indication of the spatial cumulative effects in the watershed.

Distinctive downstream trends of nutrients and various elements (dissolved and sediment-bound) were observed in the watershed. In water, concentrations of ammonia, orthophosphate, dissolved elements (Ca, K, Mg, Fe, Mn), conductivity values and temperature were generally low in the headwater and increased along Interception Ditch with progression downstream. Dissolved oxygen showed the opposite trend, decreasing downstream. Sediments concentrations of Fe, Cu, Cd, Zn, K, Na (which are all found in manure and fertilizers) increased along Interception Ditch. The spatial patterns are thought to reflect the cumulative effects of agricultural activities. It is possible that Elkview Creek (which had high concentrations of these metals in sediment and drains into Interception Ditch) is contributing to the higher concentrations in the lower reaches of Interception Ditch. However, the fact that Ni, Co, Cr, and Al (which are not associated with agricultural but were also found in higher concentrations in Elkview Creek) did not show increases along Interception Ditch suggests that agricultural operations are likely responsible for the observed increasing trends.

Determining the impact of the Promontory development on water and sediment quality in the lowland is complicated by the fact that the variables measured (particularly trace metals and phosphate) have both urban and agricultural sources. However, since concentrations in the urban area were generally below background concentrations, this area of the watershed is not likely contributing to pollution of the lowland streams. As the hillslope development continues to expand, it will likely begin to impact water and sediment quality downstream. Measuring a parameter unique to urban activities (e.g. hydrocarbons) would help to distinguish the urban impact in the agricultural system.

The impact of both agricultural and urban activities can be seen in the high metal concentrations in sediments, extremely low DO levels and high specific conductivity measured in the lower reaches of Chilliwack Creek (site M20). Agricultural tributaries seem to be the primary source of the Fe and Cd found at this site since high levels are not seen at the intensive urban site upstream. Most of the iron at this site is held up in sediment. In contrast, Mn and Pb (which are not found in high concentrations in the sediments collected in agricultural streams) are elevated in the upper section of Chilliwack Creek suggesting urban activities are their main source throughout the stream. A combination of inputs from agricultural tributaries and urban activities likely contributed to the high Cu, Zn and phosphorus levels measured at station M20.

9.2.5 Influence of Storm Events on Water Quality

The relative contribution of contaminants from storm events versus those resulting from background flows is an important consideration in the development of stormwater management strategies. Characklis and Wiesner (1997) showed that "even unremarkable storm events can contribute the equivalent of weeks or even months of background contaminant loading in a 24 hour period". In agricultural areas, large quantities of manure are applied to the fields in the fall to ensure sufficient winter storage. At this time of the year, conditions (e.g. greater rainfall, minimal vegetation, and exposed soil) promote erosion and large amounts of manure and associated contaminants (metals, nutrients) are transferred to the stream with surface runoff (particularly during the first major runoff event of the wet season). While this study could not look at storm loadings in detail, data was collected during the first major runoff event after the dry summer period.

Data from monthly grab samples showed that concentrations were generally higher and more variable during high flow periods (wet season). This was most obvious on 12-Dec-02 when sampling occurred during the initial stages of a runoff event Spikes in nitrate, ammonia and conductivity were seen in Bailey Ditch (which receives water from urban and agricultural land, and may also be influenced by runoff from the Bailey landfill site), along Interception Ditch and Semiault Creek. It was previously suggested that these high concentrations were likely attributable to runoff from agricultural activities.

Additional sampling from the initial stages of a large storm event in October 2003 provided further evidence of the impacts of storms events. Nitrate and metals (Mn, Zn) often associated with agricultural activities (particularly livestock manure) showed significant increases in concentration at the agricultural stations during the storm event. Al and Fe also showed variations with the storm progression. It is thought that the source may not be anthropogenic, but rather natural (e.g. soil components). Both of these metals are found in high concentrations in local soils; therefore flushing out of mobile pools of weathered elements held in the soil may be responsible for the increases at these sites. The difference in response between stations may be due to differences in flow/catchment characteristics upstream of the site. Concentrations of both Al and Fe reached a maximum at the 5 hour (±1 hr) point, about 3 hours after peak runoff flow. Another possible source of the Al and Fe is re-suspension of bed sediment, or soil erosion (which may account for the longer than expected lag time).

While it is acknowledged that these observations come from a limited number of samples, the results suggest that storm water runoff may be an important mechanism in transporting nutrients and dissolved metals to streams in the lowland agricultural area, and to a lesser extent in the recent urban development on the hillslope.

It should be noted that a weakness of this study, and of many water quality investigations, is the use of concentration values which do not take into account the influence of discharge on water quality. Associating discharge with water quality variables is useful for a number of reasons. Firstly, investigating the relationship between flow and a particular water quality parameter can give an idea as to the origin of the parameter (Albek, 2003). For example, surface runoff generally carries soils and associated metals and contaminants, subsurface runoff leaches DOC and nutrients from the soils, and groundwater often provides most of the major ions associated with weathering (Chapman and Kimstach, 1996). Secondly, knowing the hydrologic flow at a sampling station would allow for estimates of contaminant loadings for specific water quality variables to be made. However, a major part of contaminant transport to streams takes place during high flow events (Sandén et al., 1997). Not only are contaminants transported with surface runoff during a precipitation event, studies have shown that some contaminants can be re-suspended during storm events. Consequently, water quality data collected on a monthly basis are inadequate for the assessment or modeling of many water quality problems as storm event samples are underrepresented or missed.

9.3 Relationships between Land Use and Water and Sediment Quality

The use of contributing areas and 100 m buffer zones gave similar results when used to correlate land uses with water and sediment quality. This was somewhat unexpected since other studies have found that using buffer zones gave better relationships than the use of contributing areas (Addah, 2002), particularly in agricultural areas where topography is generally flat and does not encourage runoff. It may be that in the Chilliwack watershed, the drainage system (including the smaller agricultural tributaries and ditches) are very effective at collecting runoff and transporting it to Interception Ditch or Semiault Creek. If this is the case, land outside the 100 m buffer region would have an impact on water quality.

Correlation results showed that agricultural land use activities significantly increase the nutrient concentrations in the watercourses. The strongest relationships were found with ammonia in the wet season, suggesting contaminated runoff as a major source of nutrients to streams. The relationship with nitrate was weaker and only found in the wet season. Other studies in the LFV suggest that the use of contributing areas may be inappropriate for determining relationships with nitrate (Berka, 1996; Wernick, 1996). It is thought that nitrate values are less influenced by nearby land uses due to the nitrification (conversion of ammonia to nitrate). Percent total agricultural land and percent total arable land were the best indicators of water pollution from agricultural activities. In addition to nutrients, these indices were positively correlated to conductivity in the wet season, and negatively correlated with pH in the dry season. In terms of metals, both were also good indicators of higher levels of Cd, Co, Cr, Cu, Fe, Zn, P, Ni in sediment, and of Fe and Mn in water. The strongest correlations were found with Cd, Cu, Fe, Zn and P which are frequently added to livestock feed as growth promoters, and as a result are also found in manures (Nicholson et al., 1999; McBribe and Spiers, 2001; and Sharpley et al., 1998).

As expected, correlations with %forest showed that an increase in forested area within a contributing area resulted in water quality conditions reflective of the control stations. The lower anthropogenic inputs of nutrients and metals typical of forested regions are reflected in the negative correlations with orthophosphate, conductivity and most metals (in both water and sediment) associated with agriculture. Since most forested areas occurred on the steeper hillslopes, it is not surprising that an increase in forest is associated with higher DO levels and lower temperatures where flows are generally higher and more turbulent and canopy cover typically shades the tributaries. It is interesting to note that during the wet season, no relationship was found with nitrate or ammonia. This is consistent with the previous finding that there was no significant difference between nitrate-N concentrations in agriculture versus forest sites; it was suggested that septic systems from rural residences or hobby farm activities may be contributing nitrate to the stream.

Only a few relationships were found between urban land use indices and the water/sediment parameters. There was a similar lack of significant relationships found between %TIA and the water/sediment parameters. These results are inconsistent with findings from other studies which generally show increases in metals, and to a lesser extent nutrients, from impermeable surface areas and urban centers. However, the major urban centers were excluded from the analysis and consequently, the hillslope development of Promontory made up the majority of the urban land included in the correlations. This residential area is relatively small compared to other urban areas, and thus contaminant inputs are likely not as apparent. In addition, the collected water and sediment data (previously discussed) suggest that agriculture is a much larger contributor of nutrients and trace metals to the watercourse at this point. Since many of the contaminants associated with urban activities are seen in elevated concentrations in the agricultural part of the watershed, even if the Promontory development was contributing metals or nutrients to the streams, the correlations would likely be masked by the higher levels observed in agriculture. Dissolved Mg and K were the only parameters that showed relationships that were unique to the %residential land.

There are a number of limitations inherent in the assumptions made when using contributing areas to evaluate land use-water quality interactions. First, in using the contributing area method the spatial variability in pollutant loading to streams from the different land use activities within a contributing area is considered to be random (i.e. no effort is made to distinguish the distance of a land use from the sampling stations, or its relative importance). However, pollutant loads to the stream from different land use activities may be correlated over space. For example, no distinction is made between land uses located near the stream or sampling station and land use activities located further away, which would likely have a lesser impact on water quality at the station. It would be interesting to look at the possibility of incorporating geostatistical methods (which could quantify this spatial correlation) into the technique. Unfortunately, this would prove difficult due to complexity of the system. There are numerous factors affecting the transport of the contaminants to the stream, and the fate of contaminants in the stream, and each contaminant would behave differently. A second assumption is that all runoff and contaminants originate within the contributing area itself. However, the fact that water flows downstream implies that if the distance between sampling locations is not great enough, the observations will not be independent. Other factors which could influence the accuracy of the associations between variables include: errors in the mapping of the land use, and in the delineation of contributing areas. Finally, the percent of land use does not give any measure of the intensity of the land use activities. A number of studies have shown that land use indices which reflect the intensity (such as stocking density or rate of fertilizer application) are better indicators than the type and area of land use.

10 SUMMARY AND CONCLUSIONS

10.1 Land Use

The Chilliwack Creek watershed has a number of land uses distributed in four relatively distinct areas. Agricultural is the predominant land use in the lowland valley, and is dominated by dairy farms and horticultural activities. The agricultural land reserve (ALR) limits the urban expansion of the urban centres of Chilliwack and Sardis, where seventy six percent of the population currently lives. This has led to a gradual shift from predominantly single family homes to a greater mix of single and multiple family housing. However, urban infilling and densification are expected to reach a maximum in the near future. As a result, the most substantial changes in land use in the watershed took place in the Promontory development area of the hillslope. Hillslope communities are expected to absorb approximately 37% of the regions growth over the next four to seven years. At present, the drastic shift from forest to low density residential sub-divisions has resulted in an increase in impervious surface area, which has altered the hydrology of these catchments. The %TIA (total impervious surface area) for Teskey Creek is currently 26% (near 30%, the value at which streams become significantly degraded), and the %TIA for Lefferson Creek is just below 10% (the value where stream degradation has been shown to begin). As development of the hillslope continues, the natural equilibrium of the existing watercourses on both the hillside area and of the receiving ditch system in the lowland areas will be affected. The increased imperviousness and hydraulic efficiency of streamflow in these urban hillslope tributaries will cause an increase in stormwater discharge which, depending on stormwater management practices, could increase stream bank erosion and cause flooding downstream.

10.2 Climate and Hydrology

The analysis of rainfall distribution over a 3 year period revealed that on average less than 2% of storm events (based on daily rainfall) exceeded 60 mm, and 70% of the total annual rainfall volume was generated by events of less than 30 mm. This suggests that stormwater management strategies which incorporate source control methods (such as on-site infiltration) to deal with runoff volume of smaller events would be more effective at mitigating the impacts of development than conventional stormwater management systems. Under Chilliwack's new stormwater management plan over 75% of the rainfall would be captured and detained on site, which if effective, would greatly reduce the rate and volume of runoff reaching nearby streams.

The comparison of storm response characteristics between the urban and forested sub-catchments suggests that the Promontory development has altered the hydrologic response of the Teskey sub-catchment. Results indicate that under the conventional development practices used in the Promontory development to this point, the peak runoff rate is up to 1416% higher and the lag time is up to 31 hours shorter at Teskey (26%TIA) than at Parsons (forested, 4%TIA). For the intermediate events, the peak runoff rate is 4.2 times greater and the lag time is 13.3 hours shorter at Teskey, on average.

While the Promontory development on the hillslope is still relatively small, it is already beginning to impact the hydrology of the system, even for minor (low rainfall and intensity) events that are the majority of the storms.

10.3 Water and Sediment Quality

Lowland agricultural activities and the intensive urban centers were found to be the major source of NPS pollution in the watershed. Agricultural streams had significantly higher concentrations of ammonia and orthophosphate year round than forested tributaries, as well as elevated nitrate levels in the wet season. Nutrient input to the streams seemed to be greatest during winter rainfall events, which flush manure and fertilizer residues from fields into the adjacent waterways. Ammonia concentrations exceeded provincial guidelines directly after a large event in December, and nitrate levels reached 7.6 mg/L during the first large rainstorm in the fall 2003. Evidence of eutrophication is most pronounced in the more intensively agricultural streams which had higher nutrient concentrations - namely Semiault Creek (A2) and the lower reaches of Interception Ditch (A16, A18). Minimum dissolved oxygen concentrations recorded at these stations are below the 9.0 mg/L guideline for salmonid embryos during the summer months. The highest concentrations of Fe, Cu, Zn, Na, P and Cd in sediments, and Fe and Mn in water, were generally found in the agricultural area. Sodium, which is associated with agricultural manures, was also found in higher concentrations in the sediments of agricultural waterways. Semiault Creek, which had the most intensively used agricultural land base, is the most degraded agricultural watercourse with Cd, Fe, Zn and Cu sediment concentrations above their lowest effect level, and high concentrations of Co.

The worst overall sediment quality was seen in upper reaches of Chilliwack Creek, likely due to runoff from nearby impermeable surface areas. The upstream station contributes high concentrations of Mn, Cr, Pb, Fe, Cu, Cd, Ni, K and Zn that accumulate in the sediment and may adversely affect habitat and biota should the metals undergo changes to the bioavailable state. Concentrations of copper, zinc, iron, nickel, cadmium and zinc all exceeded the provincial guidelines for sediments.

Distinctive spatial patterns of specific conductivity, DO, nutrients (ammonia and orthophosphate), dissolved elements (Ca,K, Mg, Fe, and Mn) in water, and Fe, Cu, Cd, Zn, K, P and Na in sediments were observed in the watershed. Concentrations of DO were generally high in the headwaters and decreased along Interception Ditch with progression downstream; all other parameters showed the opposite trend, increasing downstream. These spatial patterns are thought to reflect the cumulative effects of agricultural activities. Poor water and sediment quality in the lower regions of Chilliwack Creek (site M20) reflect the cumulative effects of upstream urban and agricultural activities. Station M20 showed extremely low DO levels (<6.2 mg/L) and high specific conductivity for most of the year, as well as high levels of most metals and phosphorus in sediments. Agricultural tributaries appear to be the primary source of Fe and Cd, while urban activities are the likely sources of Mn and Pb.

At this point, the impact of the Promontory development on water quality appears to be minimal. Tributaries draining the development area did show significantly higher concentrations of orthophosphate and potassium (dissolved and sediment-bound) as compared to the forested tributaries, suggesting the residential lawns and activities may be contributing fertilizers and household detergents to the streams. Dissolved magnesium concentrations were also elevated in this area, possibly due to construction activities.

A geologic source is likely responsible for much of the Co, Al, Ni and Cr observed in the watershed. Elkview Creek had the highest concentrations of these elements in the watershed (with the exception of Chilliwack Creek), as well as elevated concentrations of Cr, Zn, Cd, Cu and Mn, which were attributed to higher rates of weathering over the visibly exposed bedrock above this site.

10.4 Relationships between Land Use and Water and Sediment Quality

Land use indicators were calculated for each sampling site by delineating contributing areas and 100 m buffers around the sites using a GIS. The use of contributing areas and 100 m buffer zones was found to yield similar results when used to correlate land uses with water and sediment quality Percent total agricultural and percent arable land were the best indicators of water quality degradation from agricultural activities as they were significantly correlated to high levels of nutrients (NO_3^--N, NH_4^+-N, PO_4^{3-}), higher specific conductivity, high concentrations of dissolved Fe and Mn and most ions, high levels of sediment-bound Cd, Cu, Fe, Zn and P, and to low pH values. The percent of forest cover was the best indicator of water and sediment quality, having the opposite correlations to percent total agricultural. With the exception of increased dissolved K and Mg, residential areas were not found to influence water or sediment quality. It is thought that this is due to the small size of the hillslope development, and the larger agricultural inputs.

11 Recommendations

Stormwater management will become increasingly important in Chilliwack and other areas in the Lower Fraser Valley as development continues to expand into the surrounding hillslopes. Increased climatic variability and surface modifications (land use changes) are the key issues to consider when dealing with runoff management issues. Hillslope developments present additional challenges as slope stability and increased stormwater runoff pose a threat to downstream areas. As can be seen in this study, water and sediment quality impacts of the Promontory development are minimal to this point. However the hydrology in the system has already been affected. By incorporating low impact and source control methods in the design of any new development further impacts of future developments can be eliminated (or at least reduced), thereby, freeing up resources in the future to address the remediation of existing pollution concern in the agricultural area. Below are some recommendations that would be useful in minimizing the impact of hillslope development in the future, and improve the current state agricultural NPS pollution in the watershed.

Incorporate LID and source control methods into the design of new developments:

Traditional stormwater management approaches (such as curb and gutter) are effective at eliminating on-site flooding by quickly conveying runoff to a BMP (e.g. detention pond) or stream. However, they often result in an increase in runoff volume, downstream flooding, and provide a mechanism for further degradation of receiving waters (erosion, water quality and habitat degradation). Source control and low impact development (LID) approaches should be incorporated in the overall management strategy to help achieve stormwater and pollution reduction. These principles are based on controlling stormwater at the source using a combination of a number of integrated micro-scale infiltration, retention and detention areas that are distributed throughout the development site, and a reduction in impervious surfaces (Coffman, 2000). There are many strategies which could be used to reduce the amount of impervious surface areas when designing new residential developments including smaller lot sizes, narrower streets, the use of alternative pavements (e.g. porous paving materials) in driveways and sidewalks, and alternative street designs to the traditional grid patterns. Where possible runoff should be directed to pervious areas (e.g. grass swales, biorentention areas, and infiltration trenches) in order to disconnect the impervious surfaces from the streams. These functional landscapes/pervious areas allow stormwater to infiltrate into the underlying soil promoting pollutant treatment (through adsorption, filtration and sedimentation), groundwater recharge and runoff volume reduction (through infiltration).

Encourage residents to manage their stormwater:

Rainwater harvesting from rooftop runoff for later use in watering lawns and gardens can help reduce runoff flow to surface waters. This practice could be encouraged by offering rain barrels to residents at a subsidized price.

Preserve environmentally sensitive features and buffer strips:

Hillslopes are sensitive environments, and factors such as drainage conditions, slope stability and riparian areas are even more important to consider in development planning. A complete inventory of these sensitive natural environmental features should be conducted so that these areas can be protected when designing the development.

There are a number of small streams in the upland that drain into the valley. Riparian buffers should be maintained along all these streams to minimize downstream flooding, erosion and deleterious effects on the aquatic habitat. Wide riparian buffers will also help infiltrate stormwater and filter pollutants before they reach the stream, and allow the incorporation of detention ponds and wetland within the buffer zone.

Consider pollutant removal in the design of detention ponds:

Stormwater ponds are generally constructed to control flooding; however they have been shown to be a useful tool in removing some of the pollutants in stormwater runoff before they are flushed into the natural watercourse (Brydon, 2004; Bartone et al., 1999; Kennedy and Mayer, 2002). Thus, when detention ponds are built they should incorporate features known to enhance contaminant removal in the ponds, such as vegetation, wetland soil types, and continuous baseflow. Proper maintenance and cleaning to remove contaminants will also be important in their long term management.

Consider climatic variability in design of the stormwater management plan:

The increase in seasonal rainfall and more frequent heavy rainfall events (that has been predicted in other studies) should be considered when dealing with stormwater management issues. Stormwater management practices should be designed with future rainfall patterns in mind, and not based on historical data to ensure that they can adequate deal with the higher runoff volumes in the future.

Facilitate adoption of LID through public education and developer incentives:

There are a number of challenges in implementing LID including the risk associated with the performance uncertainty of these new development practices. Homeowners are often concerned that without conventional controls, such as curb and gutters, they will need to deal with issues such as basements flooding and property damage. Furthermore, many people view the reduction of street width or construction of detention ponds as undesirable and unsafe. Consequently developers are worried about market acceptance, higher costs and liability issues. In Chilliwack development costs for the LID residential projects are approximately $800 higher per lot than for conventional systems (due to requirements for redundant stormwater facilities in case the LID facilities don't perform as expected) (PSAT, 2003). Providing incentives for developers in conjunction with public education on stormwater issues and LID would help overcome some of these obstacles.

Use Chilliwack as a case-study for evaluating LID practices:

Low impact development (LID), which incorporates source control methods, is a relatively new concept in stormwater management and not yet widely implemented. Chilliwack is currently in the process of experimenting with these techniques in some of their newer hillslope developments projects, and as a result, could be used as a case-study. Hydrologic, water and sediment quality data from this study provides a baseline for pre-development and for the early stages of development using conventional practices in the watershed. Comparing adjacent development sites, one built using traditional stormwater control measures and the other using LID practices, would provide a needed assessment of the effectiveness of these LID methods in retaining pre-development hydrology and as a mechanism for preventing or reducing pollutant in stormwater runoff from development sites. Currently, limited research has been conducted on the various LID practices – and consequently, there is very little scientific data available for making decisions about which Best Management Practices (BMP) function most effectively under what conditions, or what variables directly affect the efficiency of the different designs. In addition, the effects of infiltration methods on slope stability should be investigated.

Encourage infilling and densification in Chilliwack and Sardis:

While LID practices and infiltration methods will likely help minimize some of the environmental impacts of hillslope development, as development continues in the area the risk of potential contaminant and hydrologic impacts increase. Infilling and densification in the low elevation urban center of Chilliwack and Sardis should be encouraged in order to reduce urban encroachment on hillslopes.

Implement BMPs for sedimentation and erosion during the construction-phase:

There will be significant amount of construction activity in the upland portion of the watershed as development continues. It is recommended that best management policies be implemented prior to any land clearing in order to limit the impact to the watercourse and aquatic system, particularly from sedimentation. These policies should include a detailed sediment and erosion control plan and monitoring during the course of clearing to ensure that the plan is properly implemented, as well as long-term monitoring for disturbed sites until green-up is established. More information can be obtained by referring to Best Management Practices Guide for Stormwater, Appendix H: Construction Site Erosion and Sediment Control Guide (GVSDD, 1999).

Implementation of agricultural waste and nutrient management practices:

The use of best management practices should be encouraged to reduce agricultural NPS pollution. In particular, manure and fertilizer application should be managed to ensure that nutrients and trace metals do no build up within the soil. This could include: relocating excess manure, reduced applications of inorganic fertilizers, improved manure handling (i.e. better timing of manure applications) and storage, and improved feeding strategies.

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Appendix A: Land Use Information

Table A.1 Codes for Soils Maps and Tables

Drainage and Perviousness: dominant soil drainage class and perviousness class (Ministry of Environment and Parks 1987)

Code	Drainage Class	Code	Perviousness Class
R	Rapidly drained	R	Rapidly pervious
W	Well drained	M	Moderately pervious
M	Moderately drained	S	Slowly pervious
I	Imperfectly drained		
P	Poorly drained		

Unified Texture: Soil texture based on the Unified Soil Classification System (Asphalt Institute 1978)

Code	Texture Class
GW	Well-graded gravels or gravel sand mixtures, little of no fines
GP	Poorly graded gravels or gravel sand mixtures, little of no fines
SP	Poorly graded sands or gravelly sands, little or no fines
SM	Silty sands, sand-silt mixtures
ML	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
CH	Inorganic clays of high plasticity
PT	Peat and other highly organic soils

Table A.2 Soil Characteristics (descriptions taken from Luttmerding 1981)

	Soil Name	Soil Classification	Soil Material	CSSC Texture		Unified Texture		Perv.	Drainage
				Surface	Subsurface	Surface	Subsurface		
	Floodplain Deposits:								
Fluvial	Annis	Rego Gleysol	15 to 40 cm of organic material over moderately fine textured floodplain deposits	Organic	Silty Clay	PT	CL	P	S
Fluvial	Blackburn	Orthic Humic Gleysol	Moderately fine textures, vertically accreted floodplain deposits.	Silty Clay Loam	Silt Loam	Cl	CL	P	M
Fluvial	Fairfield	Gleyed Eluviated Melanic Brunisol	Medium to moderately fine textured, laterally accreted floodplain deposits	Silt Loam	Loamy Sand	ML	SP	I	M
Fluvial	Grigg	Gleyed Gray Luvisol	Medium to moderately fine textreud deltaic deposits over sand	Silty Clay Loam	Sitly Clay	ML	CH	I	M
Fluvial	Monroe	Eluviated Eutric Brunisol	Medium textured. laterally accreated floodplain deposits	Silt Loam	Silt Loam	ML	ML	M	M
Fluvial	Niven	Rego Gleysol	Moderalty fined textured floodplain deposits over organic deposits	Silty Clay Loam	N/A	ML	PT	P	M
Fluvial	Pelly	Orthic Humic Gleysol	Medium to moderately fine textured, vertically accreted floodplain deposits	Silty Clay Loam	Silt Loam	ML	ML	P	S
Fluvial	Pelly (shallow variation.)	Orthic Humic Gleysol	Medium to moderately fine textured, vertically accreted floodplain deposits	Silty Clay Loam	Sandy Loam	ML	SM	P	S
Fluvial	Prest	Rego Gleysol	Medium to moderately fine texture floodplain deposits	Silty Clay Loam	Silty Loam	CL	ML	V	M
Fluvial	Prest (shallow variation.)	Rego Gleysol	Medium to moderately fine texture floodplain deposits	Silty Clay Loam	Loamy Sand	CL	SM	V	M

Table A.2 (cont.) Soils Characteristics (descriptions taken from Luttmerding 1981)

	Soil Name	Soil Classification	Soil Material	CSSC Texture		Unified Texture		Perv.	Drainage
				Surface	Subsurface	Surface	Subsurface		
	Alluvial Deposits:								
	Hopedale	Rego Gleysol	15 to 50 cm of medium-textured local stream deposits over sand	Silt Laom	Loamy Sand	ML	SP	P	M
	Sardis	Orthic Regosol	Coarse to moderately coarse textured local stream deposits	Sandy Loam	SandSM	GP	M	R	
	Bates	Gleyed Eluviated Melanic Brunisol	Medium-textured local stream deposits	Silt Loam	Loamy Sand	ML	SM	I	M
	Lickman	Eluviated Eutric Brunisol	Medium-textured local stream deposits	Silt Loam	Fine Sandy Loam	ML	SM	W	M
	Lickman (shallow variation.)	Eluviated Eutric Brunisol		Silt Loam	Loamy Sand	ML	SM	W	M
	McElvee	Rego Gleysol	Medium-textured local stream deposits	Silt loam	Loamy sand	ML	SM	P	M
	Fan Deposits:								
	Elk	Rego Humic Gleysol	Medium to moderately coarse textured alluvial fan deposits	Silt Loam	Loamy Sand	ML	GP	P	R
	Isar	Orthic Regosol	Coarse textured alluvial fan deposits	Loamy Sand	Sand	GW	GW	R	R
EOLIAN	**Eolian over Till:**								
	Calkins	Rego Humic Gleysol	More than 20 cm of medium textured eolian deposits over glacial outwash deposits or glacial till	Silt Loam	Loamy Sand	ML	SM	P	M
	Lonzo Creek	Orthic Humo-Ferric Podzol	15 to 50 cm of medium-textured eolian deposits over moderately coarse textured glacial till	Silt Loam	Loam	ML	SM	W	M
	Ryder	Orthic Humo-Ferric Podzol	More than 50 cm of medium-textured eolian deposits over glacial till	Silt Loam	Sandy Laom	ML	SM	M	M

Table A.2 (cont.) Soils Characteristics (descriptions taken from Luttmerding 1981)

	Soil Name	Soil Classification	Soil Material	CSSC Texture		Unified Texture		Perv.	Drainage
				Surface	Subsurface	Surface	Subsurface		
	Eolian over Glacial-fluvial:								
Eolian	Abbotsford	Orthic Humo-Ferric Podzol	20 to 50 cm of medium textured eolian deposits over gravelly glacial outwash	Silt Loam	Sand	ML	GP	R	W
Eolian	Calkins	Rego Humic Gleysol	More than 20 cm of medium textured eloian deposits over glacial outwash deposits or glacial till	Silt Loam	Loamy Sand	ML	SM	P	M
Eolian	Marble Hill	Orthic Humo-Ferric Podzol	More than 50 cm of medium textured eloian deposits over gravelly glacial outwash deposits	Silt Loam	Loamy Sand	ML	GP	W	M
	Organic Deposits:								
Organic	Banford	Terric Humisol	40 to 60 cm of well decomposed organic material over medium and moderately fine textured floodplain deposits	Organic	Silty Clay Loam	PT	ML	P	M
Organic	Gibsons	Terric Mesisol	40 to 160 cm of partially decomposed organic material over floodplain deposits	Organic	Silt Clay Loam	PT	ML	P	M
	Shallow Colluvial Deposits (<1m) over Bedrock:								
Colluvium	Cannell	Orthic Humo-Ferric Podzol	10 to 20 cm of moderately coarse textured glacial till or colluvium over bedrock	Sandy Loam	Bedrock	SM	N/A	W	R

Table A.3 Area (m²) of Various Land Uses Within Each (Independent) Contributing Area for 2002

Land Use	Sampling Stations									
	M19	M20	A15	A16	A18	F13	F14	F12	A11	M9
AGRICULTURE	**890,307**	**19,423,244**	**734,259**	**1,255,929**	**1,244,997**	**304,212**	**7,836**	**372,253**	**175,563**	**75,301**
Arable	864,721	8,623,475	243,494	360,334	1,168,864	141,632	0	213,304	127,970	70,922
Livestock	25,586	10,360,555	102,221	683,046	72,318	39,933	53	0	28,354	0
Cattle	*25,586*	*10,325,477*	*102,221*	*625,963*	*8,485*	*39,933*	*53*	*0*	*28,354*	*0*
Poultry	*0*	*35,078*	*0*	*57,084*	*63,834*	*0*	*0*	*0*	*0*	*0*
Horticulture (Tree Farms)	0	32,457	4,784	193,451	3,815	70,992	0	0	4,023	0
Greenhouse	0	21,276	0	17,890	0	0	0	0	0	0
Hobby Farm	0	0	383,760	1,207	0	51,655	7,783	158,948	2,670	0
Unused Agricultural Land	0	385,482	0	0	0	0	0	0	12,546	4,379
URBAN	**1,276,732**	**5,746,834**	**0**	**226**	**301,910**	**0**	**740**	**29,150**	**0**	**0**
Transportation	0	230,567	0	0	0	0	0	0	0	0
Residential	***1,003,460***	***3,810,746***	***0***	***0***	***262,561***	***0***	***0***	***27,289***	***0***	***0***
Residential - Low Density	992,507	3,346,824	0	0	138,122	0	0	27,289	0	0
Residential – Med/High Density	10,954	463,922	0	0	124,439	0	0	0	0	0
Industrial/Commercial (I/D)	***273,271***	***1,705,520***	***0***	***226***	***39,349***	***0***	***740***	***1,861***	***0***	***0***
I/D – Low Density	245,827	56,584	0	0	39,349	0	0	0	0	0
I/D – Medium Density	10,446	27,770	0	0	0	0	0	0	0	0
I/D – High Density	9,842	1,103,573	0	0	0	0	0	0	0	0
I/D – Other (e.g. airport, dump)	0	206,825	0	0	0	0	0	0	0	0
Institutional – Med/Low Density	0	94,682	0	226	0	0	740	1,861	0	0
Institutional – High Density	7,156	216,088	0	0	0	0	0	0	0	0
NATURAL	**1,000,657**	**1,491,851**	**1,615,440**	**331,180**	**744,673**	**1,861,303**	**79,689**	**1,546,944**	**1,011,885**	**336,915**
Open Space	***767,482***	***1,301,459***	***467,097***	***132,799***	***518,831***	***383,308***	***9,038***	***443,689***	***211,433***	***181,895***
Rural Residential (Estate)	51,735	648,092	460,768	105,403	78,043	242,815	9,038	406,033	172,462	55,175
Parks/Playing Fields/Grass Areas	251,788	219,885	0	0	19,975	0	0	0	0	0
Shrubs	2,890	70,423	6,328	27,396	17,284	0	0	0	0	0
Unused Open Space	461,069	363,059	0	0	403,530	0	0	37,656	38,971	126,720
Clearcuts	0	0	0	0	0	140,493	0	0	0	0
Forest	***233,176***	***190,392***	***1,148,344***	***198,381***	***225,842***	***1,477,995***	***70,651***	***1,103,255***	***800,452***	***155,020***
Wilderness Parks	0	0	0	0	0	0	0	135,754	152,251	43,125
Forest	233,176	190,392	1,148,344	198,381	225,842	1,477,995	70,651	967,500	648,201	111,895
UNDER DEVELOPMENT	**0**	**14,653**	**0**	**0**	**0**	**0**	**0**	**11,044**	**0**	**0**
WATER	**21,601**	**17,421**	**6,353**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
TOTAL	3,189,297	26,694,003	2,356,052	1,587,335	2,291,580	2,165,515	88,264	1,959,390	1,187,449	412,216

Table A.3 (cont.) Area (m^2) of Various Land Uses Within Each (Independent) Contributing Area for 2002

Land Use	Sampling Stations									
	A17	M10	U7	U4	U5	U3	U8	U6	A2	G1
AGRICULTURE	718,377	463,092	35,856	4,178	18,523	52,958	0	53,816	5,561,801	SPRING FED STATION (NO CONTRIBUTING AREA DELINEATED)
Arable	468,075	229,211	33,491	0	7,751	27,405	0	53,816	2,126,476	
Livestock	241,188	483	2,365	0	0	16,651	0	0	3,347,397	
Cattle	*241,188*	*483*	*2,365*	*0*	*0*	*16,651*	*0*	*0*	*3,347,397*	
Poultry	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	
Horticulture (Tree Farms)	9,113	0	0	0	0	0	0	0	0	
Greenhouse	0	0	0	0	0	0	0	0	0	
Hobby Farm	0	4,731	0	4,178	10,772	8,902	0	0	0	
Unused Agricultural Land	0	228,667	0	0	0	0	0	0	87,928	
URBAN	17,369	195,236	18,825	10,531	187,563	507,215	26	15,089	16,829	
Transportation	0	0	0	0	0	0	0	57	0	
Residential	***17,369***	***78,118***	***18,825***	***10,531***	***163,688***	***495,741***	***26***	***15,032***	***0***	
Residential - Low Density	17,369	78,118	6,550	10,531	125,968	495,741	26	15,032	0	
Residential – Med/High Density	0	0	12,275	0	37,720	0	0	0	0	
Industrial/Commercial (I/D)	***0***	***117,119***	***0***	***0***	***23,875***	***11,474***	***0***	***0***	***16,829***	
I/D – Low Density	0	0	0	0	0	0	0	0	0	
I/D – Medium Density	0	0	0	0	0	0	0	0	0	
I/D – High Density	0	23,582	0	0	0	0	0	0	0	
I/D – Other (e.g. airport, dump)	0	93,536	0	0	0	0	0	0	0	
Institutional – Med/Low Density	0	0	0	0	0	11,474	0	0	16,829	
Institutional – High Density	0	0	0	0	23,875	0	0	0	0	
NATURAL	425,848	984,821	393,773	111,858	436,701	458,487	118,929	298,665	2,379,350	
Open Space	***262,208***	***418,601***	***134,482***	***102,326***	***218,876***	***220,215***	***25,696***	***59,054***	***1,175,095***	
Rural Residential (Estate)	97,327	192,561	81,609	102,326	84,103	93,407	18,815	52,876	146,169	
Parks/Playing Fields/Grass Areas	20,993	0	0	0	14,437	1,281	0	0	0	
Shrubs	104	0	0	0	0	0	0	0	0	
Unused Open Space	143,785	219,649	52,873	0	120,336	125,174	6,881	6,178	0	
Clearcuts	0	6,391	0	0	0	353	0	0	1,028,925	
Forest	***163,641***	***566,220***	***259,291***	***9,532***	***217,825***	***238,271***	***93,233***	***239,611***	***1,204,255***	
Wilderness Parks	0	23,715	0	0	0	0	0	0	0	
Forest	163,641	542,504	259,291	9,532	217,825	238,271	93,233	239,611	1,204,255	
UNDER DEVELOPMENT	0	0	0	0	2,498	0	0	0	0	
WATER	0	0	0	0	0	0	0	0	0	
TOTAL	1,161,594	1,643,149	448,453	126,568	645,284	1,018,659	118,955	367,570	7,957,980	

Table A.4 Total Area (m^2) of Various Land Uses by Region

	Hillslope		Lowland	
	Promontory	**East Hillslope**	**ALR**	**Urban**
Agriculture	**115,250**	**1,351,357**	**24,169**	**29,925,895**
Arable	69,025	512,850	24,143	14,179,067
Livestock	16,651	157,699	0	14,745,801
Cattle	16,651	157,699	0	14,589,805
Poultry	0	0	0	155,996
Horticulture/Greenhouses	0	75,776	0	282,026
Hobby Farms	29,574	605,032	0	0
Unused Agricultural Land	0	0	27	719,002
Urban	**915,116**	**30,116**	**6,014,955**	**7,379,041**
Transportation	57	0	9,853	230,567
Residential	*782,210*	*27,289*	*4,555,829*	*5,093,885*
Industrial/Commerical	*132,849*	*2,827*	*1,449,273*	*2,054,588*
Natural	**3,306,167**	**8,132,009**	**1,133,903**	**4,190,792**
Open Space	*1,313,220*	*2,462,868*	*790,480*	*3,257,494*
Rural Residential	718,466	1,255,793	0	1,124,497
Recreational	15,718	0	306,834	512,640
Shrubs	0	0	7,374	124,424
Unused Open Space	572,292	37,656	476,273	1,495,933
Clearcuts	6,744	1,169,419	0	0
Forest	*1,992,947*	*5,669,141*	*343,423*	*933,298*
Wilderness Parks	242,908	111,938	0	0
Forest	1,750,039	5,557,203	343,423	933,298
Under Development	**2,498**	**11,044**	**14,653**	**14,653**
Water	**0**	**6,353**	**35,669**	**39,021**
Total	**4,339,031**	**9,530,879**	**7,223,350**	**41,549,403**

Table A.5 Total Area (m²) of Various Land Uses within the Chilliwack Creek Watershed

Land Use	Total Area (m²)			% of watershed			% Change in Land Use Area*	
	1995	2000	2002	1995	2000	2002	1995-2000	2000-2002
AGRICULTURE	**32,604,109**	**32,139,571**	**31,392,502**	**58.8**	**58.0**	**56.65**	**-1.42**	**-2.32**
Arable			14,760,942			26.64		
Livestock			14,920,150			26.92		
Cattle			*14,764,155*			*26.64*		
Poultry			*155,996*			*0.28*		
Horticulture (Tree Farms)			318,636			0.57		
Greenhouse			39,166			0.07		
Hobby Farm			634,606			1.15		
Unused Agricultural Land			719,002			1.30		
URBAN	**6,874,113**	**7,775,379**	**8,324,274**	**12.40**	**14.03**	**15.02**	**13.11**	**7.06**
Transportation	264,234	238,121	230,624	0.48	0.43	0.42	-9.88	-3.15
Residential	4,653,636	5,217,729	5,903,385	8.40	9.42	10.65	12.12	13.14
Residential – Low Density			*5,254,077*			*9.48*		
Residential – Med/High Density			*649,308*			*1.17*		
Industrial/Commercial	1,956,244	2,319,529	2,190,264	3.53	4.19	3.95	18.57	-5.57
I/D – Low Density			*341,759*			*0.62*		
I/D – Medium Density			*38,216*			*0.07*		
I/D – High Density			*1,136,997*			*2.05*		
I/D – Other (e.g. airport, dump)			*300,361*			*0.54*		
Institutional – Med/Low Density			*125,812*			*0.23*		
Institutional – High Density			*247,120*			*0.45*		
NATURAL	**14,854,040**	**15,207,304**	**15,628,969**	**26.80**	**27.44**	**28.20**	**2.38**	**2.77**
Open Space	5,542,213	6,052,532	7,033,582	10.00	10.92	12.69	9.21	16.21
Rural Residential (Estate)	*1,899,262*	*2,076,931*	*3,098,757*	*3.43*	*3.75*	*5.59*	*9.35*	*49.20*
Parks/Playing Fields/Grass Areas	*134,259*	*169,001*	*528,358*	*0.24*	*0.30*	*0.95*	*25.88*	*212.64*
Shrubs	*127,538*	*127,538*	*124,424*	*0.23*	*0.23*	*0.22*	*0.00*	*-2.44*
Unused Open Space	*2,174,696*	*2,423,800*	*2,105,880*	*3.92*	*4.37*	*3.80*	*11.45*	*-13.12*
Clearcuts	*1,206,458*	*1,255,262*	*1,176,163*	*2.18*	*2.27*	*2.12*	*4.05*	*-6.30*
Forest	9,311,827	9,154,772	8,595,386	16.80	16.52	15.51	-1.69	-6.11
Wilderness Parks	*354,846*	*354,846*	*354,846*	*0.64*	*0.64*	*0.64*	*0.00*	*0.00*
Forest	*8,956,982*	*8,799,927*	*8,240,541*	*16.16*	*15.88*	*14.87*	*-1.75*	*-6.36*
UNDER DEVELOPMENT	**1,041,677**	**251,685**	**28,195**	**1.88**	**0.45**	**0.05**	**-75.84**	**-88.80**
WATER	**45,374**	**45,374**	**45,374**	**0.08**	**0.08**	**0.08**	**0.00**	**0.00**
TOTAL	**55,419,314**	**55,419,314**	**55,419,314**	**100**	**100**	**100**	**0.00**	**0.00**

* A negative % difference indicates a <u>decrease</u> in the area devoted to that land use (e.g. less area in 2000 than in 1995)

Table A.6 Imperviousness Factors by Land Use/Land Cover Category

(used to Calculate Total Impervious Surface Area)

Description	Imperviousness Factor
Agriculture	3 %
Forest	1 %
Shrubs	3 %
Grass	3 %
Open Space	3 %
Constructed Cover (buildings, roads)	100%
Industrial/Commercial - Light Density	70 %
Industrial/Commercial - Med Density	80 %
Industrial/Commercial - High Density	90 %
Institutional - Light density	70 %
Institutional - med density	80 %
Residential (low density/single family)	47 %
Residential (med/high density)	80 %
Residential (med/high density)	80 %
Clearcut	3 %
Bare surface (exposed soil)	3 %
Bare surface (compacted surface)	10 %
Water	0 %

*Values based on values in Zandbergen et al (2000)

Table A.7 Percent Total Impervious Surface Area (%TIA) by Contributing Area

	Contributing Area	Cumulative Contributing Area	100 m Buffer	Cumulative 100 m Buffer
M19	23.8	23.8	33.3	33.3
M20	39.7	23.5	42.6	27.0
M9	8.5	8.5	11.8	11.8
M10	6.7	14.2	6.2	16.1
A15	4.6	3.6	5.3	5.3
A16	5.3	3.9	5.8	5.0
A18	11.3	7.7	3.6	9.7
A11	2.7	2.7	4.2	4.2
A17	6.4	12.3	10.0	15.6
A2	3.9	3.9	4.4	4.4
F13	2.5	2.5	5.4	5.4
F14	4.6	4.3	6.8	4.3
F12	4.3	4.3	4.2	4.2
U7	9.1	9.1	10.9	10.9
U4	11.9	9.7	8.5	10.2
U5	20.3	20.3	23.9	23.9
U3	30.1	26.3	31.9	29.0
U8	1.7	1.7	1.8	1.8
U6	4.0	4.0	4.2	4.2

Appendix B: Climate and Hydrology Data

Table B.1 Channel Characteristics, Conversion Type and Dates of Operation for Streamflow Gauges in the Chilliwack Creek Watershed

SITE	LOCATION	DATES MONITORED	CONVERSION TYPE	CHANNEL SHAPE	CHANNEL CHARACTERISTICS
U3	Teskey Creek at Promontory Road	August 22, 1997 - ongoing	Manning Formula	Round	Diameter = 1.4 m Slope = 0.05 Roughness = 0.025
F14	Parsons Brook at Lindell Road	March 15, 1999 - ongoing	Area Velocity	Round	Diameter = 1.5 m
G1	Luckakuck Creek at Eden Drive	March 13, 2001 – ongoing	Area Velocity	Rectangular	Width = 5.020 ft
U4	Lefferson Creek at Uplands Road	August 22, 1997 – December 18, 2002	Area Velocity	Round	Diameter = 0.610 m
M10	Bailey Ditch at Prest Road	August 22, 1997 – December 18, 2002	Area Velocity	Round	Diameter = 1.4 m
F13	Elkview Creek at Wincott Road	March 16, 1999 – ongoing	Manning Formula	Round	Diameter = 0.7 m Slope = 0.052 Roughness = 0.028
M20	Chilliwack Creek near Yale Rd.	January 1, 2003 – ongoing	Not available	Not available	Not available
N/A	Semiault Creek at Prairie Central Rd.	January 1, 2003 – ongoing	Not available	Not available	Not available

Table B.2 Record Period for Precipitation Gauges in the Chilliwack Region

Gauge Site	Approx. Elevation	Gauge Type	Sampling Interval	Record Period*	Responsible Agency
Promontory	158 m asl	ISCO Tipping Bucket	5 minutes	January 2000 to November 2003	City of Chilliwack
Marble Hill	163 m asl	ISCO Tipping Bucket	5 minutes	June 1999 to November 2003	City of Chilliwack
Chilliwack Airport (# 1101530)	11 m asl	Rain Gauge	Daily $^{\alpha}$	January 1879 to December 2003 $^{\beta}$	Environment Canada

*All records have missing sections of data

$^{\alpha}$ Measurements for 24 hour period beginning at 8 am

$^{\beta}$ Missing data from December 2002; 2003 data is raw non-quality controlled data

Table B.3 October 2002 baseflow Discharge Survey Results; Chilliwack Creek Watershed (O'Byrne 2002). Stations are listed from upstream to downstream within each watercourse.

STREAM	GAUGE SITE	LOCATION	DESCRIPTION/ COMMENTS	CATCHMENT AREA (HA)	BASE FLOW (M^3/S)
Atchelitz Creek	A3-1	At Sumas Central Road, at the inlet to two culverts on the south side of the road	Low base flow conditions	540.0	0.037
	A3-2	At Sumas Central Road, across road culvert (900 mm diameter wood stave pipe 20.6 m long)	Lowest flow seen at this station	221.2	0.050
	A2	Between Hwy No. 1 and Luckakuck Way bridges		1016	0.435
	A1	At Atchelitz Road, back of houses off point upstream of Atchelitz Rd. ditch entering the creek	Low flow to no flow	1347	0.731
Luckakuck Creek	L1	South side of Luckakuck Way, Stream bed upstream of multiplate culvert, rectangular channel		617	0.280
Chilliwack Creek	C3	At Knight Road	Low trickle flow	448	0.007
	C2	Downstream of Yale Rd, downstream of first farm access bridge	Diversion Creek only (no measurements for old channel split flow)	5459	0.490*
	C1	Concrete apron of pump station flood box at dyke	Site conditions allowed for high accuracy measurement**	8550	2.880
Interception Ditch	In3	At Banford Rd, downstream of culverts, recently dredged clean channel	Low flow to no flow	427.8	0.118
	In2	At Prest Rd., downstream of culverts and Bailey Ditch entering from the south	Low flow to no flow, channel recently dredged	1466	0.160
	In1	At Chilliwack River Rd., upstream inlet of twin multiplate culverts		1684	0.540
Semiault Creek	S4	At Banford Road, downstream of bridge		733	0.091
	S3	At Prest Rd., under bridge in a narrowing of thaweg		1096	0.175
	S2	Downstream of confluence of Prairie Central Rd. and Semiault Creek, upstream side of old Hop Yard driveway		1553	0.582
	S1	At Young Rd. outlet of box culvert		3080	0.063

* Accounts for only part of the flow that should be present. Substantial flows also flow through the old original channel route at least equal to that entering the diversion channel

** Conditions at other sites allowed a moderate level of survey control

Table B.4 Summary of Daily Discharge (m^3/s) for the Chilliwack Creek Watershed

Year	Station	N	% year missing	Mean	Median	St. Dev	Min	Max
2000	Bailey	336	8.2%	0.144	0.131	0.122	0.005	0.643
	Lefferson	366	0.0%	0.007	0.007	0.006	0.000	0.042
	Luckakuck	0	100.0%	n.d.	n.d.	n.d.	n.d.	n.d.
	Parsons	360	1.6%	0.059	0.057	0.049	0.002	0.352
	Elkview	358	2.2%	0.164	0.137	0.143	0.002	0.633
	Teskey	357	2.5%	0.073	0.052	0.107	0.000	0.6579
	Semiault	0	100.0%	n.d.	n.d.	n.d.	n.d.	n.d.
	Chilliwack	0	100.0%	n.d.	n.d.	n.d.	n.d.	n.d.
2001	Bailey	286	21.6%	0.089	0.050	0.117	0.004	0.790
	Lefferson	344	5.8%	0.009	0.008	0.007	0.000	0.058
	Luckakuck	263	27.9%	0.137	0.117	0.071	0.009	0.392
	Parsons	286	21.6%	0.031	0.029	0.031	0	0.195
	Elkview	312	14.5%	0.087	0.055	0.111	0.005	0.682
	Teskey	120	67.1%	0.113	0.074	0.131	0.000	0.584
	Semiault	0	100.0%	n.d.	n.d.	n.d.	n.d.	n.d.
	Chilliwack	0	100.0%	n.d.	n.d.	n.d.	n.d.	n.d.
2002	Bailey	306	16.2%	0.149	0.110	0.157	0.002	1.121
	Lefferson	348	4.7%	0.007	0.001	0.019	0.000	0.151
	Luckakuck	344	5.8%	0.161	0.137	0.111	0.008	0.506
	Parsons	193	46.3%	0.010	0.002	0.013	0.000	0.052
	Elkview	133	63.6%	0.010	0.004	0.018	0.000	0.144
	Teskey	263	27.9%	0.018	0.002	0.042	0.000	0.448
	Semiault	0	100.0%	n.d.	n.d.	n.d.	n.d.	n.d.
	Chilliwack	278	23.8%	0.151	0.087	0.165	0.002	1.121
2003	Bailey	0	100.0%	n.d.	n.d.	n.d.	n.d.	n.d.
	Lefferson	0	100.0%	n.d.	n.d.	n.d.	n.d.	n.d.
	Luckakuck	161	55.9%	0.119	0.106	0.062	0.028	0.277
	Parsons	0	100.0%	n.d.	n.d.	n.d.	n.d.	n.d.
	Elkview	162	55.6%	0.018	0.014	0.020	0.000	0.103
	Teskey	217	40.5%	0.013	0.002	0.024	0.000	0.135
	Semiault	341	6.6%	0.542	0.307	0.635	0.000	3.916
	Chilliwack	313	14.2%	0.711	0.239	0.903	0.000	4.193
Study Period (May 2002 - July 2003)	Bailey	190	58.4%	0.060	0.050	0.060	0.002	0.486
	Lefferson	228	50.1%	0.002	0.001	0.004	0.000	0.048
	Luckakuck	385	15.8%	0.106	0.092	0.058	0.008	0.277
	Parsons	163	64.3%	0.011	0.008	0.013	0.000	0.052
	Elkview	222	51.4%	0.016	0.010	0.017	0.000	0.081
	Teskey	290	36.5%	0.011	0.002	0.021	0.000	0.135
	Semiault	212	53.6%	0.553	0.346	0.523	0.090	3.033
	Chilliwack	174	61.9%	1.121	1.016	1.015	0.000	4.193

*n.d. = no data

Table B.5 Summary of Daily Runoff Rate (mm/day) for the Chilliwack Creek Watershed

Year	Station	N	% year missing	Mean	Median	St. Dev	Min	Max
2000	Bailey	336	8.2%	2.854	2.582	2.411	0.106	12.715
	Lefferson	366	0.0%	1.040	1.024	0.832	0.000	6.318
	Luckakuck	0	100.0%	n.d.	n.d.	n.d.	n.d.	n.d.
	Parsons	360	1.6%	2.496	2.387	2.067	0.085	14.850
	Elkview	358	2.2%	6.558	5.484	5.723	0.089	25.269
	Teskey	357	2.5%	3.797	2.687	5.571	0.000	34.163
	Semiault	0	100.0%	n.d.	n.d.	n.d.	n.d.	n.d.
	Chilliwack	0	100.0%	n.d.	n.d.	n.d.	n.d.	n.d.
2001	Bailey	286	21.6%	1.751	0.994	2.305	0.071	15.618
	Lefferson	344	5.8%	1.316	1.161	1.049	0.000	8.713
	Luckakuck	263	27.9%	3.999	3.406	2.082	0.253	11.407
	Parsons	286	21.6%	1.302	1.233	1.303	0.000	8.213
	Elkview	312	14.5%	3.452	2.186	4.441	0.183	27.218
	Teskey	120	67.1%	5.890	3.852	6.801	0.000	30.309
	Semiault	0	100.0%	n.d.	n.d.	n.d.	n.d.	n.d.
	Chilliwack	0	100.0%	n.d.	n.d.	n.d.	n.d.	n.d.
2002	Bailey	306	16.2%	2.937	2.176	3.113	0.035	22.177
	Lefferson	348	4.7%	1.080	0.113	2.862	0.000	22.714
	Luckakuck	344	5.8%	4.699	3.995	3.237	0.245	14.732
	Parsons	193	46.3%	0.417	0.073	0.534	0.000	2.178
	Elkview	133	63.6%	0.386	0.170	0.728	0.000	5.732
	Teskey	263	27.9%	0.911	0.126	2.160	0.000	23.248
	Semiault	0	100.0%	n.d.	n.d.	n.d.	n.d.	n.d.
	Chilliwack	278	100.0%	n.d.	n.d.	n.d.	n.d.	n.d.
2003	Bailey	0	100.0%	n.d.	n.d.	n.d.	n.d.	n.d.
	Lefferson	0	100.0%	n.d.	n.d.	n.d.	n.d.	n.d.
	Luckakuck	161	55.9%	3.471	3.083	1.810	0.823	8.082
	Parsons	0	100.0%	n.d.	n.d.	n.d.	n.d.	n.d.
	Elkview	162	55.6%	0.722	0.547	0.783	0.000	4.124
	Teskey	217	40.5%	0.661	0.120	1.244	0.000	7.004
	Semiault	341	6.6%	4.605	2.614	5.403	0.000	33.301
	Chilliwack	313	14.2%	3.954	1.328	5.025	0.000	23.326
Study Period (May 2002 - July 2003)	Bailey	190	58.4%	1.189	0.996	1.187	0.035	9.615
	Lefferson	228	50.1%	0.261	0.088	0.574	0.000	7.196
	Luckakuck	385	15.8%	3.090	2.667	1.679	0.245	8.082
	Parsons	163	64.3%	0.484	0.331	0.551	0.000	2.178
	Elkview	222	51.4%	0.631	0.389	0.664	0.000	3.221
	Teskey	290	36.5%	0.560	0.101	1.114	0.000	7.004
	Semiault	212	53.6%	4.705	2.944	4.452	0.766	25.792
	Chilliwack	174	61.9%	6.234	5.651	5.646	0	23.326

*n.d. = no data

Table B.6 Precipitation Summaries for Storm Events (2001-2003) based on Promontory Rain Gauge Data.

Event	Duration (hrs)	Total Precip. (mm)	Ant. Dry Period (hrs)	Peak Intensity (mm/hr)						Storm Class
				5 min	15 min	30 min	1 hour	3 hour	6 hour	
3-Jan-01 17:30	3.25	5.7	182.75	4.80	4.00	3.40	3.00	1.90	0.95	Minor
4-Jan-01 10:00	25.00	34.8	13.25	10.80	8.00	7.20	6.50	4.67	3.57	Intermediate
8-Jan-01 15:15	6.50	5.2	76.25	4.80	3.20	2.80	2.00	1.20	0.85	Minor
18-Jan-01 15:00	3.25	2.3	233.25	1.20	1.20	1.20	1.20	0.77	0.38	Minor
21-Jan-01 3:00	11.50	17.2	56.75	6.00	5.20	4.20	3.40	2.37	1.95	Intermediate
24-Jan-01 20:45	1.75	0.8	78.25	1.20	0.80	0.80	0.60	0.43	0.37	Minor
31-Jan-01 2:45	1.75	0.8	106.5	1.20	0.80	0.60	0.50	0.33	0.20	Minor
2-Feb-01 0:45	9.75	4.4	44.25	6.00	3.60	2.20	2.10	1.03	0.55	Minor
4-Feb-01 0:15	3.75	4.8	37.75	3.60	2.80	2.40	1.90	1.53	0.82	Minor
4-Feb-01 17:00	7.75	4.3	13	8.40	4.80	2.80	1.80	0.77	0.58	Minor
8-Feb-01 13:45	2.75	0.9	85	1.20	0.80	0.80	0.60	0.30	0.15	Minor
22-Feb-01 2:30	2.25	2.6	322	2.40	2.40	2.20	1.70	0.87	0.43	Minor
24-Feb-01 10:30	4.75	2.1	53.75	2.40	1.60	1.40	1.10	0.50	0.35	Minor
8-Mar-01 2:45	20.25	11.3	275.5	3.60	3.60	3.00	2.80	1.50	0.95	Minor
13-Mar-01 2:45	9.00	4.2	99.75	2.40	2.00	1.80	1.80	1.10	0.58	Minor
15-Mar-01 14:45	3.75	3.9	51	2.40	2.00	1.60	1.50	1.23	0.65	Minor
18-Mar-01 6:45	19.00	18.1	60.25	7.20	5.20	4.20	3.60	2.47	1.55	Intermediate
25-Mar-01 6:00	2.25	2	148.25	2.40	2.00	1.40	1.10	0.67	0.33	Minor
25-Mar-01 21:45	13.25	10	13.5	4.80	3.20	2.80	2.30	1.27	0.93	Minor
27-Mar-01 13:45	7.00	9.8	26.75	4.80	4.00	3.40	2.80	2.03	1.53	Minor
28-Mar-01 5:45	0.75	0.4	9	1.20	1.20	0.80	0.50	0.23	0.12	Minor
29-Mar-01 14:15	9.00	4.6	31.75	4.80	4.00	3.20	2.10	1.07	0.55	Minor
31-Mar-01 5:15	10.25	5.4	30	4.80	3.60	2.60	1.50	0.77	0.50	Minor
1-Apr-01 12:00	1.75	2.3	20.5	3.60	2.80	2.00	1.60	0.77	0.38	Minor
5-Apr-01 13:00	5.50	4	95.25	1.20	1.20	1.20	1.10	0.97	0.68	Minor
6-Apr-01 3:45	1.25	0.6	9.25	1.20	0.80	0.60	0.50	0.20	0.10	Minor
29-Apr-01 7:45	17.00	7.3	554.75	2.40	2.00	1.60	1.00	0.70	0.52	Minor
30-Apr-01 9:15	4.25	1.8	8.5	3.60	2.80	2.00	1.30	0.43	0.30	Minor
30-Apr-01 21:45	4.25	2.8	8.25	2.40	2.40	2.00	1.50	0.80	0.57	Minor
1-May-01 19:45	0.75	0.6	17.75	2.40	1.60	1.00	0.60	0.20	0.10	Minor
4-May-01 16:15	7.00	7.8	67.75	4.80	4.40	3.60	2.40	1.47	1.20	Minor
12-May-01 20:45	3.25	2.7	189.5	6.00	4.40	3.40	1.90	0.87	0.45	Minor
14-May-01 1:45	21.75	17.8	25.75	3.60	2.40	2.20	2.10	1.57	1.32	Minor
15-May-01 7:00	1.25	0.6	7.5	1.20	1.20	0.80	0.50	0.30	0.23	Minor
15-May-01 21:15	9.25	10.7	13	3.60	3.20	2.80	2.50	2.17	1.23	Minor
19-May-01 12:00	0.75	1.3	77.5	7.20	4.00	2.20	1.30	0.43	0.22	Minor
28-May-01 12:00	3.75	10.9	215.25	79.20	26.80	13.60	7.60	3.50	1.83	Intermediate
1-Jun-01 8:30	14.25	21.7	88.75	9.60	7.20	6.40	5.30	3.63	2.70	Intermediate
6-Jun-01 5:00	10.25	7	102.25	9.60	6.00	4.20	2.60	1.60	0.82	Minor
8-Jun-01 19:15	12.75	10.8	52	8.40	8.00	7.20	4.50	1.60	1.13	Intermediate
9-Jun-01 20:30	11.75	10.8	12.5	2.40	2.40	2.40	2.30	1.53	1.12	Minor
10-Jun-01 19:15	21.50	16.4	11	2.40	1.60	1.60	1.50	0.97	0.87	Minor
12-Jun-01 7:15	7.25	6	14.5	2.40	2.40	2.00	1.90	1.27	0.92	Minor
24-Jun-01 15:15	1.00	0.6	288.75	1.20	0.80	0.80	0.60	0.43	0.33	Minor
26-Jun-01 11:45	0.25	1.3	43.5	8.40	5.20	2.60	1.30	0.43	0.22	Minor
27-Jun-01 13:15	1.75	2.1	25.25	3.60	2.00	1.60	1.60	0.70	0.35	Minor
28-Jun-01 3:30	1.00	0.6	12.5	2.40	1.20	1.00	0.60	0.23	0.12	Minor
15-Jul-01 13:00	6.25	2.1	416.5	2.40	1.60	1.20	0.90	0.40	0.35	Minor
16-Jul-01 11:30	0.50	0.8	16.25	6.00	2.80	1.60	0.80	0.33	0.17	Minor
21-Aug-01 9:00	38.75	44.6	117	20.40	16.00	11.00	9.10	5.27	2.95	Major
23-Aug-01 10:15	14.25	17.4	10.5	10.80	9.60	8.80	6.50	3.73	2.15	Intermediate
1-Sep-01 4:30	6.00	12	196	8.40	7.60	5.40	4.20	2.73	2.00	Intermediate
3-Sep-01 2:45	5.75	2.4	40.25	4.80	2.40	1.80	1.00	0.53	0.40	Minor
3-Jan-01 17:30	3.25	5.7	182.75	4.80	4.00	3.40	3.00	1.90	0.95	Minor

Table B.6 (cont.) Precipitation Summaries for Storm Events (2001-2003) based on Promontory Rain Gauge Data

Event	Duration (hrs)	Total Precip. (mm)	Ant. Dry Period (hrs)	Peak Intensity (mm/hr) 5 min	15 min	30 min	1 hour	3 hour	6 hour	Storm Class
5-Sep-01 15:15	0.25	3.4	54.75	40.80	13.60	6.80	3.40	1.13	0.57	Minor
19-Sep-01 2:00	1.50	2.7	322.5	4.80	4.00	3.00	2.40	0.93	0.47	Minor
21-Sep-01 2:15	6.00	6	46.75	2.40	2.40	1.80	1.40	1.27	1.00	Minor
7-Oct-01 23:00	6.50	2.7	398.75	2.40	2.00	1.60	1.30	0.63	0.42	Minor
9-Oct-01 9:00	1.00	1.7	27.5	2.40	2.40	2.40	1.70	0.60	0.30	Minor
10-Oct-01 8:45	8.25	13.7	22.75	4.80	4.00	3.60	3.50	2.37	1.70	Minor
12-Oct-01 2:45	9.75	9.7	33.75	3.60	2.40	2.00	1.70	1.20	1.05	Minor
13-Oct-01 18:45	11.00	4.7	30.25	2.40	2.40	1.80	1.10	0.60	0.45	Minor
16-Oct-01 10:30	4.50	5	52.75	3.60	3.60	2.80	2.40	1.47	0.83	Minor
18-Oct-01 10:00	11.50	7	43	2.40	1.60	1.60	1.50	1.23	0.82	Minor
21-Oct-01 8:00	9.75	12.8	58.5	3.60	3.20	2.80	2.40	1.87	1.58	Minor
22-Oct-01 3:15	25.00	19	9.5	8.40	5.60	4.20	3.40	1.93	1.35	Intermediate
24-Oct-01 4:30	8.75	5.6	24.25	2.40	1.60	1.40	1.30	0.77	0.63	Minor
24-Oct-01 19:45	11.00	8.2	6.5	2.40	1.60	1.40	1.40	1.00	0.87	Minor
26-Oct-01 8:15	25.50	32.5	25.5	4.80	4.00	3.60	3.30	2.47	2.07	Minor
30-Oct-01 14:15	19.50	15.6	76.5	8.40	7.20	4.40	2.90	1.83	1.08	Intermediate
1-Nov-01 19:45	1.00	0.6	34	1.20	1.20	1.00	0.60	0.23	0.23	Minor
2-Nov-01 4:30	1.25	2	7.75	6.00	4.00	3.40	1.90	0.70	0.37	Minor
4-Nov-01 7:15	14.75	17.6	49.5	3.60	3.20	3.00	2.80	2.33	1.88	Minor
5-Nov-01 11:00	1.25	0.6	13	2.40	1.20	0.80	0.60	0.20	0.13	Minor
12-Nov-01 23:00	1.50	0.8	178.75	1.20	0.80	0.60	0.60	0.30	0.15	Minor
13-Nov-01 15:15	30.50	40.6	14.75	6.00	4.40	4.00	3.40	2.57	2.27	Minor
15-Nov-01 12:00	4.25	5.9	14.25	6.00	4.80	3.40	2.40	1.77	1.00	Minor
16-Nov-01 9:45	2.25	2.8	17.5	4.80	4.00	3.60	2.30	0.97	0.48	Minor
19-Nov-01 8:00	13.75	13.3	68	3.60	2.40	2.40	2.10	1.77	1.48	Minor
20-Nov-01 6:15	1.75	1.8	8.5	4.80	3.60	2.40	1.30	0.63	0.32	Minor
20-Nov-01 17:45	1.50	1.2	9.75	2.40	2.00	1.40	1.00	0.50	0.32	Minor
22-Nov-01 13:00	16.00	6.2	41.75	2.40	1.60	1.20	1.00	0.67	0.47	Minor
25-Nov-01 14:00	2.50	1.1	57	1.20	0.80	0.60	0.60	0.40	0.23	Minor
27-Nov-01 0:30	3.00	1.4	32	2.40	1.20	0.80	0.60	0.47	0.27	Minor
28-Nov-01 8:45	7.25	6.4	29.25	2.40	2.00	2.00	1.50	1.07	0.93	Minor
29-Nov-01 2:30	6.75	7.8	10.5	7.20	6.40	4.80	3.40	1.53	1.27	Minor
1-Dec-01 12:15	12.75	12.4	51	18.00	16.00	14.40	8.30	2.93	1.67	Minor
4-Dec-01 15:30	3.25	7.2	62.5	4.80	4.00	3.60	3.50	2.37	1.22	Minor
6-Dec-01 3:00	12.75	8.5	32.25	10.80	9.20	5.40	3.00	1.47	1.07	Minor
6-Dec-01 22:00	2.75	1.5	6.25	2.40	1.60	1.00	0.80	0.50	0.30	Minor
8-Dec-01 7:15	14.75	22.1	30.5	18.00	6.80	3.80	3.20	2.87	2.33	Intermediate
10-Dec-01 13:30	2.00	1.3	39.5	1.20	1.20	1.00	0.80	0.47	0.25	Minor
12-Dec-01 15:30	37.50	55.6	48	8.40	7.20	6.20	4.90	3.80	2.97	Intermediate
15-Dec-01 14:45	34.50	31.2	33.75	4.80	4.40	4.20	3.80	2.43	1.47	Minor
12-Jan-02 4:30	5.75	6.9	627.25	3.60	3.20	2.80	2.40	1.90	1.15	Minor
19-Jan-02 14:30	18.00	12.6	172.25	3.60	2.00	1.80	1.60	1.40	1.15	Minor
21-Jan-02 11:00	4.50	1.1	26.5	1.20	1.20	1.00	0.60	0.20	0.18	Minor
23-Jan-02 11:30	19.50	15.6	44	3.60	2.80	2.40	1.80	1.33	1.08	Minor
24-Jan-02 17:45	11.50	15.2	10.75	4.80	4.00	3.60	3.00	2.60	2.02	Minor
25-Jan-02 15:00	4.25	5.4	9.75	4.80	3.60	2.80	2.30	1.40	0.92	Minor
31-Jan-02 13:30	5.00	10.8	138.25	4.80	4.00	3.60	3.40	3.03	1.83	Minor
1-Feb-02 5:00	9.75	3.2	10.5	2.40	1.20	0.80	0.70	0.57	0.47	Minor
3-Feb-02 10:15	1.25	1.1	43.5	2.40	1.60	1.40	1.00	0.53	0.28	Minor
6-Feb-02 6:15	11.75	7.9	66.75	2.40	2.00	1.80	1.60	1.27	1.00	Minor
8-Feb-02 0:00	5.25	3	30	2.40	1.60	1.20	0.80	0.60	0.53	Minor
8-Feb-02 23:45	1.00	0.8	18.5	2.40	1.60	1.20	0.80	0.30	0.15	Minor
10-Feb-02 15:45	2.50	6	39	4.80	3.60	3.60	3.40	2.00	1.00	Minor

Table B.6 (cont.) Precipitation Summaries for Storm Events (2001-2003) based on Promontory Rain Gauge Data

Event	Duration (hrs)	Total Precip. (mm)	Ant. Dry Period (hrs)	Peak Intensity (mm/hr) 5 min	15 min	30 min	1 hour	3 hour	6 hour	Storm Class
17-Feb-02 17:15	14.25	5.7	167	2.40	2.00	1.60	1.30	0.87	0.45	Minor
19-Feb-02 3:15	1.00	1.9	19.75	7.20	5.20	3.60	1.90	0.63	0.32	Minor
21-Feb-02 3:45	46.50	80.2	47.5	6.00	5.20	4.80	3.70	2.83	2.65	Intermediate
23-Feb-02 14:45	1.50	1.2	12.5	2.40	1.60	1.20	1.00	0.40	0.20	Minor
5-Mar-02 0:15	11.50	6.5	224	4.80	3.60	3.00	2.70	1.30	0.87	Minor
9-Mar-02 23:15	2.50	1.5	107.5	1.20	1.20	1.00	0.80	0.50	0.27	Minor
10-Mar-02 13:15	2.50	2.9	11.5	3.60	2.40	2.20	1.80	0.97	0.48	Minor
11-Mar-02 1:15	12.75	16.3	9.5	4.80	4.40	3.80	3.10	2.10	1.52	Minor
11-Mar-02 20:15	1.00	0.5	6.25	1.20	0.80	0.80	0.50	0.17	0.10	Minor
12-Mar-02 6:45	1.00	0.6	9.5	2.40	1.60	0.80	0.60	0.20	0.10	Minor
13-Mar-02 2:15	1.50	0.8	18.5	1.20	0.80	0.80	0.70	0.33	0.25	Minor
14-Mar-02 4:00	1.25	0.8	24.25	2.40	1.60	1.40	0.70	0.37	0.20	Minor
14-Mar-02 11:30	2.00	0.9	6.25	1.20	0.80	0.60	0.60	0.37	0.18	Minor
15-Mar-02 18:15	2.50	2.1	28.75	2.40	1.60	1.40	1.20	0.70	0.35	Minor
21-Mar-02 15:00	1.00	0.9	138.25	1.20	1.20	1.20	0.90	0.30	0.15	Minor
27-Mar-02 21:30	6.50	2	149.5	1.20	1.20	1.00	0.70	0.43	0.30	Minor
1-Apr-02 1:30	1.75	4.1	93.5	4.80	4.80	4.00	3.50	1.37	0.68	Minor
5-Apr-02 19:00	1.00	0.7	111.75	1.20	1.20	1.00	0.70	0.27	0.17	Minor
6-Apr-02 4:00	1.50	1.5	8	2.40	2.40	1.80	1.20	0.57	0.33	Minor
6-Apr-02 14:45	8.00	9.1	9.25	3.60	2.80	2.40	2.10	1.73	1.32	Minor
9-Apr-02 9:15	20.25	12.1	58.5	10.80	8.80	7.40	6.10	2.50	1.42	Intermediate
12-Apr-02 2:15	5.75	3.3	44.75	2.40	1.20	1.20	1.00	0.77	0.55	Minor
12-Apr-02 21:45	12.00	8.4	13.75	3.60	2.40	2.20	1.90	1.23	0.83	Minor
13-Apr-02 18:15	8.75	11.4	8.5	8.40	4.80	4.20	3.00	1.93	1.62	Minor
15-Apr-02 10:45	1.00	0.5	31.75	1.20	0.80	0.60	0.50	0.23	0.12	Minor
15-Apr-02 23:45	1.50	0.7	12	1.20	0.80	0.60	0.50	0.30	0.15	Minor
16-Apr-02 22:15	7.25	6.8	21	3.60	2.80	2.20	1.70	1.17	1.05	Minor
17-Apr-02 19:00	0.75	0.5	13.5	2.40	1.20	1.00	0.50	0.17	0.08	Minor
22-Apr-02 17:30	1.00	1.1	117.75	2.40	2.00	1.80	1.10	0.37	0.18	Minor
19-May-02 23:30	10.75	8.7	653	4.80	4.00	3.40	3.00	1.77	1.13	Minor
22-May-02 2:15	5.00	3.1	40	3.60	2.00	1.40	1.20	0.63	0.55	Minor
26-May-02 19:00	2.00	2.4	107.75	4.80	4.40	3.00	1.80	0.80	0.42	Minor
27-May-02 18:30	2.75	4.7	21.5	9.60	8.00	6.00	3.40	1.57	0.90	Minor
28-May-02 11:00	13.50	5.2	13.75	10.80	4.00	2.00	1.50	0.77	0.42	Minor
29-May-02 12:15	7.25	5.7	11.75	8.40	6.80	4.40	2.50	1.07	0.72	Minor
5-Jun-02 2:15	2.25	2.4	150.75	4.80	3.20	2.60	1.50	0.87	0.45	Minor
6-Jun-02 6:15	4.75	3	25.75	3.60	2.80	2.40	1.90	0.73	0.50	Minor
7-Jun-02 10:30	3.25	2.9	23.5	9.60	4.40	2.60	1.70	0.93	0.52	Minor
8-Jun-02 2:30	7.25	2.1	12.75	3.60	2.80	2.00	1.30	0.47	0.25	Minor
17-Jun-02 22:45	6.25	53.7	229	37.20	24.00	22.80	18.90	14.30	8.93	Major
18-Jun-02 23:45	1.25	0.8	18.75	1.20	1.20	1.00	0.70	0.30	0.17	Minor
27-Jun-02 10:00	4.25	7.6	201	8.40	5.20	4.20	3.00	2.10	1.27	Minor
27-Jun-02 21:15	5.50	4.5	7	3.60	2.80	2.00	1.50	1.07	0.77	Minor
28-Jun-02 14:30	16.75	16.6	11.75	4.80	3.20	2.80	2.30	1.60	1.33	Minor
29-Jun-02 16:00	12.00	9.8	8.75	4.80	3.60	2.80	2.50	1.80	0.93	Minor
1-Jul-02 2:15	5.25	3.4	22.25	4.80	4.00	2.60	1.40	0.77	0.58	Minor
7-Jul-02 15:45	9.00	5.1	152.25	1.20	0.80	0.80	0.70	0.67	0.60	Minor
27-Aug-02 10:45	0.50	2.6	466	14.40	8.00	5.20	2.60	0.87	0.43	Minor
2-Sep-02 6:30	10.75	14.1	139.25	4.80	4.40	3.60	3.20	2.27	1.85	Minor
3-Sep-02 9:15	1.50	1.5	16	2.40	2.00	1.60	1.20	0.50	0.25	Minor
8-Sep-02 20:45	4.75	2.8	130	2.40	1.60	1.00	1.00	0.70	0.48	Minor
16-Sep-02 2:15	17.25	7.5	168.75	3.60	2.40	1.80	1.50	1.17	0.87	Minor
5-Nov-02 20:15	2.75	2.8	456.75	2.40	1.60	1.40	1.30	0.97	0.53	Minor

Table B.6 (cont.) Precipitation Summaries for Storm Events (2001-2003) based on Promontory Rain Gauge Data

Event	Duration (hrs)	Total Precip. (mm)	Ant. Dry Period (hrs)	Peak Intensity (mm/hr) 5 min	15 min	30 min	1 hour	3 hour	6 hour	Storm Class
11-Jan-03 19:30	19.00	15	164.5	4.80	4.00	4.00	3.30	2.07	1.40	Minor
13-Jan-03 21:45	4.00	6.7	31.25	3.60	3.60	3.00	2.60	2.10	1.12	Minor
21-Jan-03 15:15	5.75	5.2	181.5	2.40	1.60	1.60	1.30	1.13	0.88	Minor
22-Jan-03 9:15	3.00	3.5	12.25	4.80	2.80	2.20	1.70	1.17	0.63	Minor
22-Jan-03 22:00	11.25	11.7	9.75	6.00	5.60	5.40	4.20	2.33	1.52	Intermediate
24-Jan-03 2:30	2.25	1.6	17.25	2.40	1.60	1.20	0.90	0.67	0.35	Minor
24-Jan-03 19:00	1.25	0.8	14.25	2.40	1.60	1.20	0.80	0.33	0.18	Minor
25-Jan-03 15:45	18.50	28.5	19.5	13.20	9.20	7.00	5.70	3.80	2.35	Intermediate
27-Jan-03 9:00	5.25	3	22.75	2.40	1.60	1.60	1.30	0.70	0.52	Minor
29-Jan-03 9:30	7.00	5.4	43.25	2.40	2.40	2.20	1.50	1.17	0.85	Minor
30-Jan-03 16:45	8.50	12.6	24.25	6.00	4.00	3.80	3.50	2.23	1.63	Minor
2-Feb-03 2:00	2.00	1.5	48.75	4.80	2.40	1.40	0.90	0.50	0.27	Minor
11-Feb-03 11:45	1.00	2.7	223.75	31.20	10.40	5.20	2.70	0.90	0.45	Minor
16-Feb-03 2:15	10.25	8.5	109.5	2.40	2.40	2.00	1.70	1.13	10.7	Minor
17-Feb-03 1:00	9.25	4.5	12.5	3.60	2.80	2.20	1.70	0.93	0.55	Minor
20-Feb-03 7:00	10.25	7.5	68.75	3.60	2.40	2.40	2.00	1.37	0.92	Minor
21-Feb-03 16:30	1.50	1.2	23.25	2.40	2.00	1.60	1.00	0.40	0.25	Minor
2-Mar-03 9:30	8.00	3.4	207.5	1.20	1.20	1.20	1.00	0.53	0.42	Minor
10-Mar-03 6:00	7.50	9.1	180.5	3.60	2.40	2.40	2.20	1.83	1.38	Minor
10-Mar-03 23:45	17.00	18.9	10.25	7.20	5.60	4.00	3.40	2.53	2.03	Intermediate
12-Mar-03 6:45	25.75	26	14	3.60	2.80	2.80	2.20	1.90	1.45	Minor
14-Mar-03 1:45	2.50	1.5	17.25	2.40	1.60	1.20	1.00	0.50	0.25	Minor
15-Mar-03 6:00	0.75	0.5	25.75	1.20	1.20	0.80	0.50	0.20	0.10	Minor
16-Mar-03 18:30	2.75	1.6	35.75	2.40	1.60	1.20	0.90	0.53	0.28	Minor
17-Mar-03 20:00	2.50	2	22.75	3.60	2.80	2.20	1.40	0.70	0.40	Minor
18-Mar-03 11:45	1.00	0.5	13.25	1.20	0.80	0.80	0.50	0.17	0.08	Minor
20-Mar-03 7:45	0.75	0.9	43	2.40	2.00	1.60	0.90	0.30	0.15	Minor
20-Mar-03 15:30	14.00	4.7	7	3.60	2.80	1.80	1.00	0.63	0.45	Minor
21-Mar-03 18:00	15.25	13.1	12.5	8.40	6.40	4.40	3.00	1.43	1.07	Intermediate
23-Mar-03 4:15	6.50	3.3	19	3.60	2.40	1.60	1.00	0.73	0.52	Minor
15-Apr-03 14:45	6.25	4.3	556	7.20	3.60	2.40	1.60	1.03	0.70	Minor
16-Apr-03 14:30	15.75	13.8	17.5	4.80	3.20	2.80	2.10	1.80	1.33	Minor
19-Apr-03 22:00	1.00	0.8	63.75	1.20	1.20	1.00	0.80	0.27	0.13	Minor
24-Apr-03 3:00	20.50	12.1	100	2.40	2.00	1.60	1.40	1.07	0.73	Minor
27-Apr-03 6:00	1.25	0.7	54.5	1.20	0.80	0.60	0.60	0.30	0.15	Minor
4-May-03 0:00	24.00	10.4	160.75	4.80	3.20	2.20	1.90	0.80	0.75	Minor
7-Sep-03 1:00	4.00	5.5	97	3.60	3.20	2.80	2.40	1.70	0.92	Minor
7-Sep-03 20:30	0.75	0.5	15.5	1.20	0.80	0.60	0.50	0.17	0.10	Minor
15-Nov-03 20:30	1.25	0.8	215.25	1.20	1.20	1.00	0.70	0.33	0.17	Minor
16-Nov-03 10:00	18.00	12.1	12.25	6.00	4.00	2.60	1.80	1.50	0.95	Minor
17-Nov-03 18:00	36.25	72.7	14	7.20	6.00	5.80	5.60	4.33	3.50	Intermediate
19-Nov-03 19:30	1.00	0.5	13.25	2.40	1.20	0.80	0.50	0.17	0.08	Minor
23-Nov-03 17:45	4.50	3.3	93.25	2.40	2.40	2.00	1.40	0.80	0.55	Minor
25-Nov-03 12:45	1.50	3.7	38.5	7.20	6.00	4.80	3.30	1.23	0.62	Minor
28-Nov-03 2:00	23.00	33.3	59.75	4.80	3.60	3.20	2.80	2.43	2.18	Minor
2-Dec-03 20:15	2.75	11.7	91.25	12.00	10.00	8.80	7.80	3.90	1.95	Intermediate
4-Dec-03 18:30	6.75	3.5	43.5	2.40	1.60	1.40	1.30	0.63	0.53	Minor
5-Dec-03 10:45	5.50	2.5	9.5	2.40	1.60	1.40	1.10	0.57	0.42	Minor
6-Dec-03 1:00	4.00	7.3	8.75	4.80	4.40	3.80	3.30	2.30	1.22	Minor
7-Dec-03 21:00	0.75	0.5	40	1.20	1.20	0.80	0.50	0.27	0.13	Minor
8-Dec-03 8:00	1.50	1.3	10.25	2.40	2.00	1.40	1.10	0.47	0.25	Minor

Table B.7 Precipitation Summaries for Storm Events (2001-2003) based on Marble Hill Rain Gauge Data

Event	Duration (hrs)	Total Precip (mm)	Ant. Dry Period (hrs)	Peak Intensity (mm/hr) 5 min	15 min	30 min	1 hour	3 hour	6 hour	Storm Class
18-Jan-01 15:15	3.00	2.8	540.5	1.20	1.20	1.20	1.20	0.73	0.37	Minor
21-Jan-01 3:45	12.50	14.7	57.5	6.00	5.20	4.20	3.40	2.37	1.95	Intermediate
28-Jan-01 23:15	13.00	8.5	175	0.00	0.00	0.00	0.00	0.00	0.00	Minor
30-Jan-01 7:00	7.00	3.3	18.75	1.20	0.80	0.60	0.50	0.33	0.23	Minor
31-Jan-01 0:30	4.75	3.1	10.5	1.20	0.80	0.60	0.50	0.40	0.27	Minor
2-Feb-01 1:00	9.75	4.5	43.75	6.00	3.60	2.20	2.10	1.00	0.52	Minor
4-Feb-01 0:30	3.25	3.3	37.75	3.60	2.80	2.40	1.90	1.53	0.80	Minor
4-Feb-01 17:30	6.75	3.3	13.75	8.40	4.80	2.80	1.80	0.77	0.58	Minor
8-Feb-01 13:00	1.00	0.9	84.75	1.20	0.80	0.80	0.60	0.30	0.15	Minor
14-Feb-01 23:15	1.25	0.6	153.25	1.20	1.20	0.60	0.40	0.23	0.12	Minor
17-Feb-01 13:00	1.25	1.5	60.5	1.20	0.40	0.20	0.10	0.03	0.02	Minor
22-Feb-01 2:00	3.25	2	107.75	2.40	2.40	2.20	1.70	0.90	0.45	Minor
24-Feb-01 6:45	5.50	3.1	49.5	2.40	1.60	1.40	1.10	0.50	0.35	Minor
8-Mar-01 2:15	20.75	16.7	278	3.60	3.60	3.00	2.80	1.50	0.95	Minor
13-Mar-01 2:45	3.00	3.2	99.75	2.40	2.00	1.80	1.80	1.10	0.58	Minor
14-Mar-01 0:15	0.75	0.6	18.5	1.20	0.40	0.20	0.10	0.03	0.02	Minor
15-Mar-01 15:00	3.50	3.3	38	2.40	2.00	1.60	1.50	1.23	0.63	Minor
16-Mar-01 16:00	0.50	0.6	21.5	0.00	0.00	0.00	0.00	0.00	0.00	Minor
18-Mar-01 1:00	24.50	25.5	32.5	7.20	5.20	4.20	3.60	2.47	1.55	Intermediate
25-Mar-01 6:15	1.50	1.8	148.75	2.40	1.60	1.20	1.00	0.63	0.32	Minor
25-Mar-01 22:00	13.00	7.9	14.25	4.80	3.20	2.80	2.30	1.27	0.92	Minor
27-Mar-01 13:30	7.25	8.8	26.5	4.80	4.00	3.40	2.80	2.03	1.53	Minor
28-Mar-01 7:00	1.00	0.5	10.25	1.20	0.80	0.40	0.20	0.07	0.03	Minor
29-Mar-01 13:30	9.50	6.2	29.5	4.80	4.00	3.20	2.10	1.07	0.55	Minor
31-Mar-01 5:30	10.00	5.7	30.5	4.80	3.60	2.60	1.50	0.77	0.48	Minor
31-Mar-01 23:15	0.75	0.5	7.75	1.20	0.40	0.20	0.20	0.07	0.03	Minor
5-Apr-01 11:15	18.25	11	107.25	1.20	1.20	1.20	1.10	0.97	0.70	Minor
8-Apr-01 7:45	2.00	1.4	50.25	0.00	0.00	0.00	0.00	0.00	0.00	Minor
10-Apr-01 3:30	2.75	1.5	41.75	0.00	0.00	0.00	0.00	0.00	0.00	Minor
13-Apr-01 4:30	4.25	2.3	70.25	0.00	0.00	0.00	0.00	0.00	0.00	Minor
13-Apr-01 19:30	0.25	1.1	10.75	0.00	0.00	0.00	0.00	0.00	0.00	Minor
17-Apr-01 1:30	0.75	0.5	77.75	0.00	0.00	0.00	0.00	0.00	0.00	Minor
18-Apr-01 14:00	2.00	5.4	35.75	0.00	0.00	0.00	0.00	0.00	0.00	Minor
22-Apr-01 18:15	13.75	7.8	98.25	0.00	0.00	0.00	0.00	0.00	0.00	Minor
24-Apr-01 19:30	0.75	0.5	35.5	0.00	0.00	0.00	0.00	0.00	0.00	Minor
12-May-01 20:30	3.25	3.4	432.25	6.00	4.40	3.40	1.90	0.87	0.45	Minor
14-May-01 2:00	21.75	28.5	26.25	3.60	2.40	2.20	2.10	1.57	1.32	Minor
15-May-01 6:30	7.00	1.9	6.75	1.20	1.20	0.80	0.50	0.33	0.23	Minor
15-May-01 21:00	10.00	13.3	7.5	3.60	3.20	2.80	2.50	2.17	1.23	Minor
19-May-01 12:00	1.00	2.5	77	7.20	4.00	2.20	1.30	0.43	0.22	Minor
28-May-01 12:00	3.00	3.3	215	79.20	26.80	13.60	7.60	3.50	1.83	Minor
1-Jun-01 10:00	19.00	18.4	91	9.60	7.20	6.40	5.30	3.63	2.70	Intermediate
2-Jun-01 14:30	4.00	8.9	9.5	2.40	1.60	0.80	0.40	0.23	0.15	Minor
5-Jun-01 14:30	0.25	4.9	68	0.00	0.00	0.00	0.00	0.03	0.02	Minor
6-Jun-01 5:30	10.75	3.9	14.75	9.60	6.00	4.20	2.60	1.60	0.82	Minor
8-Jun-01 19:00	13.00	12.6	50.75	8.40	8.00	7.20	4.50	1.60	1.13	Intermediate
9-Jun-01 18:00	12.25	7	10	2.40	2.40	2.40	2.30	1.53	1.12	Minor
10-Jun-01 17:30	23.50	22.4	11.25	2.40	1.60	1.60	1.50	0.97	0.87	Minor
12-Jun-01 1:30	5.25	7	8.5	1.20	0.80	0.40	0.40	0.53	0.80	Minor
24-Jun-01 19:00	8.50	2.3	300.25	1.20	0.40	0.40	0.30	0.17	0.10	Minor
25-Jun-01 11:45	0.25	4	8.25	0.00	0.00	0.00	0.00	0.03	0.05	Minor
27-Jun-01 13:15	2.25	3.4	49.25	3.60	2.00	1.60	1.60	0.70	0.35	Minor
28-Jun-01 3:30	1.00	0.6	12	2.40	1.20	1.00	0.60	0.23	0.12	Minor
15-Jul-01 13:00	6.50	2.3	416.5	2.40	1.60	1.20	0.90	0.40	0.35	Minor

Table B.7 (cont.) Precipitation Summaries for Storm Events (2001-2003) based on Marble Hill Rain Gauge Data

Event	Duration (hrs)	Total Precip (mm)	Ant. Dry Period (hrs)	Peak Intensity (mm/hr)						Storm Class
				5 min	15 min	30 min	1 hour	3 hour	6 hour	
16-Jul-01 19:00	1.00	0.8	23.5	1.20	0.40	0.20	0.10	0.03	0.02	Minor
21-Aug-01 9:00	39.00	36.9	109	8.40	6.80	5.20	4.70	3.10	1.87	Intermediate
23-Aug-01 11:00	14.50	18.6	11	18.00	14.40	13.00	9.10	4.47	2.53	Minor
1-Sep-01 4:45	7.00	13.1	195.25	8.40	5.60	4.20	3.40	2.70	2.10	Intermediate
3-Sep-01 7:15	1.25	1.3	43.5	2.40	2.00	1.80	1.20	0.50	0.28	Minor
7-Oct-01 22:30	7.00	3	86	2.40	1.60	1.60	1.30	0.57	0.43	Minor
9-Oct-01 0:00	1.00	0.9	18.5	2.40	2.00	1.60	0.90	0.30	0.17	Minor
9-Oct-01 9:00	1.25	0.7	8	1.20	0.80	0.80	0.70	0.27	0.13	Minor
10-Oct-01 9:00	8.00	10.6	22.75	3.60	2.80	2.60	2.00	1.80	1.35	Minor
12-Oct-01 3:00	11.50	8.6	34	2.40	1.60	1.40	1.10	0.97	0.88	Minor
13-Oct-01 17:30	12.00	8.6	27	3.60	3.60	3.20	2.80	1.60	0.95	Minor
16-Oct-01 11:00	3.25	3.6	53.5	2.40	2.00	2.00	1.90	1.17	0.63	Minor
18-Oct-01 10:30	11.25	9.2	44.25	2.40	2.00	2.00	1.90	1.50	1.13	Minor
19-Oct-01 15:45	1.00	0.6	18	1.20	0.80	0.80	0.60	0.20	0.10	Minor
21-Oct-01 8:15	9.50	13.7	39.5	2.40	2.40	2.00	1.90	1.80	1.70	Minor
22-Oct-01 4:15	17.50	11.6	10.5	2.40	1.60	1.20	1.10	1.03	0.93	Minor
26-Oct-01 18:15	20.50	11.9	92.5	1.20	1.20	1.20	1.10	0.87	0.73	Minor
30-Oct-01 14:30	18.50	14.2	71.75	7.20	6.40	4.40	3.60	1.87	1.12	Intermediate
1-Nov-01 19:00	1.00	0.6	34	1.20	1.20	1.00	0.60	0.23	0.22	Minor
2-Nov-01 3:45	0.75	0.9	7.75	3.60	2.00	1.40	0.90	0.33	0.17	Minor
4-Nov-01 7:00	13.75	18	50.5	6.00	4.00	3.80	3.30	2.67	2.00	Minor
12-Nov-01 22:00	2.75	2.2	193.25	2.40	2.00	1.60	1.40	0.73	0.37	Minor
13-Nov-01 14:15	31.25	57.8	13.5	7.20	6.80	5.60	5.20	4.33	3.58	Intermediate
15-Nov-01 7:00	1.00	0.5	9.5	1.20	0.80	0.60	0.50	0.20	0.65	Minor
15-Nov-01 11:30	4.00	5.2	3.5	4.80	4.00	2.60	2.30	1.63	0.87	Minor
16-Nov-01 8:45	2.50	5	17.25	3.60	3.60	3.20	2.60	1.67	0.83	Minor
19-Nov-01 5:00	16.25	11.8	65.75	2.40	2.40	2.00	1.60	1.23	1.13	Minor
20-Nov-01 4:15	2.50	1.7	7	3.60	3.20	2.20	1.20	0.63	0.32	Minor
20-Nov-01 16:45	1.75	1.4	10	2.40	2.00	1.60	1.20	0.57	0.37	Minor
21-Nov-01 1:00	1.00	0.8	6.5	2.40	1.60	1.20	0.80	0.30	0.17	Minor
22-Nov-01 12:45	16.25	11.7	34.75	3.60	3.20	2.80	2.40	1.43	1.02	Minor
25-Nov-01 13:45	1.50	0.7	56.75	1.20	0.80	0.60	0.60	0.33	0.18	Minor
26-Nov-01 23:45	3.25	3.3	32.5	3.60	2.80	2.40	2.10	1.10	0.57	Minor
27-Nov-01 13:45	0.75	0.7	10.75	7.20	2.40	1.40	0.70	0.23	0.12	Minor
28-Nov-01 8:15	7.00	4.5	17.75	1.20	1.20	1.20	1.10	0.83	0.68	Minor
29-Nov-01 1:30	10.50	9.6	10.25	3.60	2.80	2.00	1.50	1.23	1.02	Minor
1-Dec-01 0:45	26.00	23.4	36.75	8.40	6.80	5.60	4.90	3.90	2.78	Intermediate
4-Dec-01 12:45	1.25	1.6	58	2.40	2.40	2.20	1.50	0.53	0.27	Minor
6-Dec-01 13:00	1.25	1.3	47	2.40	2.00	1.60	1.20	0.43	0.23	Minor
8-Dec-01 4:30	16.50	29	38.25	7.20	5.60	4.60	4.10	3.47	2.80	Intermediate
10-Dec-01 13:00	1.75	1.4	40	1.20	1.20	1.20	1.00	0.50	0.27	Minor
12-Dec-01 12:15	39.75	57.8	45.5	9.60	9.20	8.40	7.10	4.90	3.72	Intermediate
15-Dec-01 13:30	34.75	31.2	33.5	6.00	4.40	3.60	3.20	2.57	1.97	Minor
19-Dec-01 4:15	2.00	3.2	52	4.80	4.00	3.60	2.60	1.07	0.53	Minor
28-Dec-01 4:00	1.00	0.5	213.75	1.20	0.80	0.60	0.50	0.33	0.18	Minor
1-Jan-02 16:45	10.25	5.8	107.75	2.40	2.00	1.60	1.30	1.00	0.70	Minor
5-Jan-02 22:15	1.25	1.2	91.25	2.40	2.00	1.60	1.10	0.40	0.20	Minor
6-Jan-02 14:15	48.75	105.2	14.75	31.20	27.60	26.20	21.20	13.17	7.82	Major
10-Jan-02 12:15	1.25	0.8	45.25	1.20	0.80	0.80	0.70	0.30	0.17	Minor
1-Feb-02 14:15	11.25	4.7	528.75	1.20	1.20	1.20	1.00	0.57	0.53	Minor
2-Feb-02 10:45	4.25	5.4	9.25	3.60	2.80	2.40	2.00	1.47	0.90	Minor

Table B.7 (cont.) Precipitation Summaries for Storm Events (2001-2003) based on Marble Hill Rain Gauge Data

Event	Duration (hrs)	Total Precip (mm)	Ant. Dry Period (hrs)	Peak Intensity (mm/hr) 5 min	15 min	30 min	1 hour	3 hour	6 hour	Storm Class
3-Feb-02 9:45	1.25	1.2	18.75	2.40	2.00	1.40	1.10	0.53	0.30	Minor
5-Feb-02 12:15	1.75	2.1	49.25	3.60	2.80	2.40	1.90	0.70	0.35	Minor
6-Feb-02 6:00	17.75	10.1	16	7.20	5.20	3.00	1.50	0.90	0.88	Intermediate
7-Feb-02 22:45	7.00	5.8	23	2.40	1.60	1.40	1.10	0.93	0.88	Minor
10-Feb-02 15:00	2.75	7.8	57.25	6.00	5.60	5.00	4.70	2.60	1.30	Minor
17-Feb-02 16:30	13.75	4.9	166.75	3.60	2.00	1.60	1.30	0.60	0.38	Minor
19-Feb-02 2:15	1.00	1.3	20	2.40	2.00	1.60	1.30	0.43	0.23	Minor
19-Feb-02 12:15	2.25	2.3	9	2.40	2.40	2.20	1.70	0.87	0.47	Minor
21-Feb-02 3:15	45.00	106.8	36.75	6.00	5.60	5.00	4.80	4.13	3.78	Intermediate
23-Feb-02 15:00	1.25	0.7	14.75	2.40	1.60	0.80	0.60	0.33	0.17	Minor
4-Mar-02 23:30	5.25	5.3	223.25	4.80	4.00	3.00	2.00	1.13	0.90	Minor
9-Mar-02 22:45	2.50	1.5	114	2.40	1.20	0.80	0.70	0.50	0.27	Minor
10-Mar-02 12:45	2.50	3.1	11.5	2.40	2.40	2.00	1.70	1.03	0.53	Minor
11-Mar-02 1:45	11.75	21.8	10.5	6.00	5.60	4.40	3.90	2.67	2.07	Intermediate
11-Mar-02 19:30	0.75	1.1	6	3.60	2.40	1.80	1.10	0.47	0.25	Minor
12-Mar-02 6:00	1.00	1	9.75	3.60	1.60	1.40	1.00	0.33	0.17	Minor
13-Mar-02 1:45	4.00	1.6	18.75	1.20	1.20	1.00	0.80	0.37	0.32	Minor
13-Mar-02 14:15	1.75	2.1	8.5	3.60	2.80	2.40	1.60	0.70	0.42	Minor
14-Mar-02 3:30	8.75	1.8	11.5	1.20	1.20	1.00	0.70	0.40	0.20	Minor
15-Mar-02 15:15	4.50	1.6	27	1.20	0.80	0.80	0.70	0.33	0.27	Minor
16-Mar-02 12:15	2.00	1.9	16.5	3.60	2.40	2.40	1.60	0.63	0.32	Minor
21-Mar-02 16:15	4.00	5.4	122	4.80	3.60	3.40	2.80	1.63	1.00	Minor
22-Mar-02 7:00	4.00	8.5	10.75	6.00	5.20	4.80	4.40	2.67	1.42	Minor
27-May-02 19:30	5.75	3.7	152.5	2.40	1.60	1.40	1.20	0.70	0.62	Minor
28-May-02 15:00	9.00	7.6	13.75	16.80	5.60	3.00	2.00	1.43	0.75	Minor
29-May-02 13:00	8.25	9.5	13	12.00	9.60	8.40	5.80	2.40	1.48	Minor
5-Jun-02 2:30	3.00	2.3	149.25	3.60	2.40	1.80	1.10	0.77	0.48	Minor
6-Jun-02 6:30	5.00	4.7	25	6.00	4.80	4.00	2.90	1.30	0.78	Minor
7-Jun-02 11:00	5.25	2.5	23.5	4.80	3.20	2.00	1.20	0.57	0.42	Minor
8-Jun-02 2:15	1.50	1.8	10	3.60	2.80	2.60	1.70	0.63	0.35	Minor
17-Jun-02 6:00	2.00	1.4	218.25	2.40	1.20	1.00	0.80	0.47	0.25	Minor
17-Jun-02 20:30	11.00	36	12.5	20.40	15.60	13.00	10.40	7.37	5.77	Major
18-Jun-02 23:30	1.25	0.6	16	1.20	0.80	0.80	0.50	0.27	0.15	Minor
27-Jun-02 10:00	8.50	13.5	201.25	8.40	7.20	5.40	3.80	3.30	2.15	Intermediate
28-Jun-02 14:30	16.25	20.7	20	9.60	7.60	5.80	3.60	2.03	1.65	Intermediate
29-Jun-02 16:45	12.25	16.4	10	7.20	5.60	4.00	3.60	2.57	2.07	Intermediate
1-Jul-02 2:30	6.00	7.5	21.5	13.20	10.00	7.60	4.70	2.00	1.25	Minor
7-Jul-02 16:30	19.50	27.6	152	7.20	5.60	5.40	5.10	3.17	2.70	Intermediate
29-Jul-02 0:45	5.25	3.3	492.75	2.40	2.00	1.60	1.00	0.77	0.57	Minor
30-Jul-02 23:30	1.50	3.6	41.5	7.20	5.60	4.00	2.50	1.20	0.62	Minor
2-Aug-02 7:45	2.50	4.3	54.75	4.80	4.40	4.00	3.20	1.43	0.78	Minor
4-Aug-02 2:15	1.75	2.4	40	4.80	2.80	2.60	1.80	0.83	0.52	Minor
4-Aug-02 14:00	0.75	2.1	10	7.20	5.60	4.00	2.10	0.70	0.43	Minor
5-Aug-02 20:15	5.00	2.4	29.5	2.40	1.60	1.40	1.00	0.43	0.40	Minor
27-Aug-02 14:30	0.25	1.6	517.25	19.20	6.40	3.20	1.60	0.53	0.27	Minor
2-Sep-02 6:45	15.00	28.6	136	9.60	7.60	6.80	6.30	4.90	3.67	Intermediate
3-Sep-02 7:45	1.00	0.9	10	2.40	1.60	1.40	0.90	0.43	0.25	Minor
8-Sep-02 21:00	5.25	3.2	132.25	2.40	2.40	1.60	1.20	0.77	0.53	Minor
16-Sep-02 3:15	12.75	6.7	169	3.60	2.80	2.20	1.90	1.27	0.95	Minor
30-Sep-02 8:30	1.25	1.1	328.5	2.40	2.00	1.40	1.10	0.40	0.20	Minor
2-Oct-02 22:15	9.00	9.2	60.5	3.60	2.80	2.40	2.20	1.47	1.27	Minor

Table B.7 (cont.) Precipitation Summaries for Storm Events (2001-2003) based on Marble Hill Rain Gauge Data

Event	Duration (hrs)	Total Precip (mm)	Ant. Dry Period (hrs)	Peak Intensity (mm/hr)						Storm Class
				5 min	15 min	30 min	1 hour	3 hour	6 hour	
10-Oct-02 2:45	0.75	0.5	163.5	1.20	1.20	0.80	0.50	0.17	0.08	Minor
28-Oct-02 2:45	12.25	6.1	431.25	3.60	2.40	1.80	1.40	0.67	0.58	Minor
19-Nov-02 13:45	5.25	7.6	526.75	4.80	3.20	2.80	2.70	1.93	1.28	Minor
10-Dec-02 7:00	2.00	3.1	492	3.60	2.80	2.60	2.40	1.03	0.52	Minor
10-Dec-02 16:45	8.00	12.3	7.75	7.20	6.00	5.40	4.80	3.23	1.85	Intermediate
11-Dec-02 14:45	7.00	11.7	14	4.80	4.00	4.00	3.60	2.47	1.90	Minor
12-Dec-02 13:00	13.50	14.2	15.25	8.40	7.20	5.80	4.60	2.50	1.53	Intermediate
13-Dec-02 19:00	6.50	4.2	16.5	3.60	3.60	2.60	1.80	1.03	0.68	Minor
14-Dec-02 8:00	4.50	4.5	6.5	2.40	2.40	1.80	1.50	1.27	0.77	Minor
14-Dec-02 17:00	16.00	15.4	4.5	7.20	6.40	6.00	5.80	3.23	1.95	Intermediate
16-Dec-02 5:00	21.00	21.8	20	10.80	8.80	6.60	5.40	2.60	1.78	Intermediate
17-Dec-02 9:00	8.50	5.1	7	2.40	2.00	2.00	1.80	1.20	0.72	Minor
21-Jan-03 16:30	6.75	4.1	95	2.40	1.60	1.40	1.30	0.97	0.65	Minor
22-Jan-03 10:00	23.50	21.2	10.75	6.00	5.60	5.20	4.30	3.03	1.88	Intermediate
24-Jan-03 2:15	4.25	2.4	16.75	1.20	1.20	1.00	0.90	0.63	0.42	Minor
24-Jan-03 19:30	1.00	0.8	13	2.40	1.60	1.20	0.80	0.37	0.18	Minor
25-Jan-03 16:30	17.75	30.9	20	9.60	8.00	6.00	4.80	3.27	2.40	Intermediate
27-Jan-03 9:15	5.50	4.3	23	4.80	3.60	2.60	1.60	0.83	0.72	Minor
29-Jan-03 10:15	11.25	8.3	43.5	3.60	3.60	3.40	2.50	1.50	1.00	Minor
30-Jan-03 17:15	8.75	16.8	19.75	6.00	4.40	3.80	3.50	2.67	2.10	Minor
1-Feb-03 20:30	10.75	2.7	42.5	2.40	2.00	1.60	0.90	0.37	0.35	Minor
13-Feb-03 17:00	0.25	0.7	273.75	8.40	2.80	1.40	0.70	0.23	0.12	Minor
16-Feb-03 3:15	10.00	12.9	58	4.80	4.40	4.00	2.90	2.03	1.75	Minor
17-Feb-03 0:45	10.25	11.9	11.5	7.20	6.00	5.20	3.90	2.07	1.30	Intermediate
19-Feb-03 16:30	31.50	19.3	53.5	4.80	4.40	4.20	3.60	2.60	1.77	Minor
21-Feb-03 7:00	15.50	5.4	7	2.40	2.40	2.00	1.30	0.67	0.47	Minor
22-Feb-03 4:45	1.50	0.7	6.25	1.20	1.20	0.80	0.60	0.27	0.15	Minor
22-Feb-03 20:45	2.50	1.9	14.5	3.60	2.80	1.80	1.30	0.63	0.32	Minor
9-Apr-03 12:45	1.25	0.6	349.5	2.40	1.60	1.00	0.60	0.20	0.10	Minor
12-Apr-03 11:45	4.50	1.7	69.75	2.40	1.60	1.20	0.80	0.37	0.28	Minor
13-Apr-03 9:15	7.75	9.2	17	6.00	4.80	4.40	3.80	2.37	1.40	Minor
14-Apr-03 20:15	1.50	3.5	27.25	12.00	8.00	5.40	3.20	1.20	0.60	Minor
15-Apr-03 13:45	8.00	8.8	16	4.80	4.80	4.20	2.50	1.37	1.25	Minor
16-Apr-03 18:00	13.50	12.8	20.25	4.80	4.00	3.60	2.60	1.97	1.47	Minor
18-Apr-03 3:15	0.75	0.8	19.75	3.60	2.40	1.60	0.80	0.30	0.15	Minor
24-Apr-03 3:45	20.25	16	143.75	2.40	2.40	2.20	1.80	1.47	1.12	Minor
27-Apr-03 1:15	5.50	1.6	49.25	1.20	1.20	0.80	0.50	0.30	0.28	Minor
4-May-03 5:00	19.75	15.7	166.25	7.20	5.60	4.00	2.60	1.67	1.48	Intermediate
5-May-03 8:15	1.25	0.9	7.5	2.40	1.20	1.20	0.90	0.33	0.17	Minor
14-May-03 13:15	2.50	1.9	219.75	2.40	1.60	1.40	1.20	0.63	0.33	Minor
16-May-03 20:30	2.75	2.3	52.75	2.40	1.60	1.40	1.10	0.80	0.45	Minor
22-May-03 2:30	9.50	5.8	123.25	2.40	2.40	2.00	1.70	0.97	0.72	Minor
24-May-03 15:45	4.00	6.9	51.75	8.40	6.00	4.80	3.90	2.10	1.15	Minor
25-May-03 5:15	2.75	3.7	9.5	3.60	2.40	2.00	1.80	1.23	0.63	Minor
7-Sep-03 2:15	2.50	2.8	330.25	4.80	3.20	2.20	1.40	0.93	0.48	Minor
10-Sep-03 17:15	3.75	2.8	84.5	3.60	2.80	1.80	1.30	0.80	0.52	Minor
14-Sep-03 5:45	5.75	13.6	80.75	9.60	8.00	6.20	5.70	3.87	2.28	Intermediate
15-Sep-03 22:15	1.75	2.2	34.75	3.60	3.60	2.40	1.90	0.73	0.38	Minor
16-Sep-03 7:45	4.75	1.4	7.75	2.40	1.60	1.20	0.60	0.27	0.25	Minor
18-Sep-03 5:15	19.75	14.9	40.75	6.00	4.00	2.80	2.10	1.17	0.98	Minor
10-Nov-03 9:30	10.75	15.2	512.5	3.60	2.80	2.60	2.40	1.93	1.62	Minor

Table B.7 (cont.) Precipitation Summaries for Storm Events (2001-2003) based on Marble Hill Rain Gauge Data

Event	Duration (hrs)	Total Precip (mm)	Ant. Dry Period (hrs)	Peak Intensity (mm/hr)						Storm Class
				5 min	15 min	30 min	1 hour	3 hour	6 hour	
16-Nov-03 10:30	12.00	11.7	134.25	3.60	3.20	2.80	2.40	1.57	1.03	Minor
17-Nov-03 18:15	36.75	78.2	19.75	6.00	5.20	5.00	4.60	3.77	3.50	Intermediate
19-Nov-03 20:00	1.00	0.7	13	1.20	1.20	1.00	0.70	0.23	0.12	Minor
23-Nov-03 18:00	4.75	5	93	3.60	2.80	2.40	1.80	1.20	0.85	Minor
25-Nov-03 13:15	3.25	3.7	38.5	4.80	4.00	3.00	2.10	1.23	0.62	Minor
26-Nov-03 3:00	0.75	0.5	10.5	1.20	0.80	0.80	0.50	0.17	0.08	Minor
28-Nov-03 2:00	22.75	41.6	46.25	6.00	5.20	4.80	4.40	3.13	2.82	Intermediate
2-Dec-03 20:30	3.00	8.6	91.75	6.00	5.60	5.40	4.80	2.87	1.43	Minor
4-Dec-03 18:45	6.00	3	43.25	1.20	1.20	1.20	1.00	0.53	0.50	Minor
5-Dec-03 10:30	2.50	1.5	9.75	1.20	1.20	0.80	0.80	0.50	0.40	Minor
5-Dec-03 23:00	6.25	8.7	10	7.20	6.00	5.60	4.00	2.47	1.43	Minor
7-Dec-03 19:15	1.00	0.6	38	1.20	1.20	0.80	0.60	0.27	0.22	Minor
8-Dec-03 8:30	2.00	1.1	12.25	1.20	1.20	0.80	0.80	0.40	0.20	Minor

Figure B.8 Cumulative Frequency Distribution of Storm Variables (2001-2003) at Two Sites (Promontory and Marble Hill): a) Total Rainfall (mm); b) Antecedent Dry Period (hrs); c) Peak 60-minute Intensity (mm/hr); d) Peak 5-minute Intensity (mm/hr); e) Duration (hrs); f) Peak 15-minute Intensity (mm/hr)

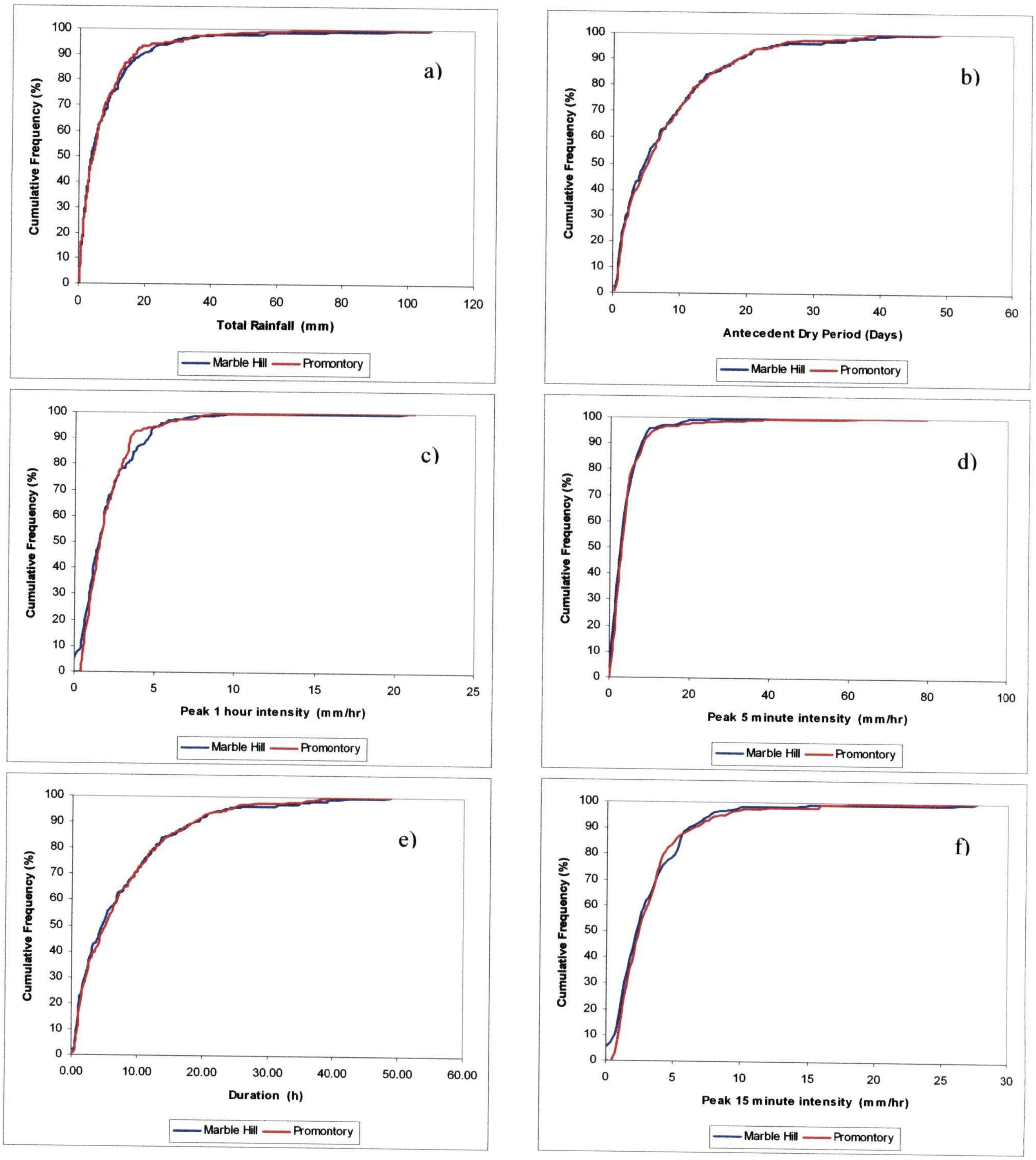


Table B.9 Total Daily Rainfall Recorded at Chilliwack for the Missing Record Periods of Promontory and Marble Hill

	Year	N[α]	Number of Days at Chilliwack with a Total Daily Rainfall of: 0 mm (No rainfall)	0 to 10 mm	10 to 30 mm	30 to 60 mm	60 to 100 mm	≥ 100 mm	No data
PROMONTORY	2001	81	46 (56.8%)	29 (35.8%)	6 (7.4%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
	2002	93	53 (57.0%)	24 (25.8%)	2 (2.2%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	14 (15.1%)
	2003	172	92 (53.5%)	39 (22.7%)	15 (8.7%)	3 (1.7%)	1 (0.6%)	1 (0.6%)	21 (12.2%)
	Overall	346	191 (55.2%)	92 (26.6%)	23 (6.6%)	3 (0.9%)	1 (0.3%)	1 (0.3%)	35 (10.1%)
MARBLE HILL	2001	75	42 (56.0%)	26 (34.7%)	6 (8.0%)	1 (1.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
	2002	135	54 (40.0%)	50 (37.0%)	16 (11.9%)	2 (1.5%)	0 (0.0%)	0 (0.0%)	13 (9.6%)
	2003	206	96 (46.6%)	58 (28.2%)	22 (10.7%)	4 (1.9%)	1 (0.5%)	1 (0.5%)	24 (11.7%)
	Overall	416	192 (46.2%)	134 (32.2%)	44 (10.6%)	7 (1.7%)	1 (0.2%)	1 (0.2%)	37 (8.9%)

[α] N =

Table B.10 Statistical Summary of Storm Characteristics for the Three Storm Classes (based on rainfall data from the Promontory tipping bucket).

Class	Year	Statistic	Total Precip. (mm)	Peak Intensity (mm/hr) 5 min	15 min	60 min	Duration (hrs)	Ant. Dry Period (hrs)	N
MINOR	2001	*Mean*	6.0	4.07	2.85	1.77	6.94	74.74	79
		Median	4.0	3.60	2.00	2.00	4.50	33.75	
		Range	0.4-40.6	1.2-40.8	1.0-14.0	1.7-1.5	0.3-34.5	6.3-554.8	
		Std. Dev	7.2	4.66	1.95	0.83	6.97	105.90	
	2002	*Mean*	4.7	3.77	2.74	1.73	5.72	88.81	62
		Median	3.0	3.60	2.00	1.50	4.38	26.13	
		Range	0.5-16.6	1.2-14.4	1.0-8.0	3.0-1.0	0.5-19.5	6.3-653.0	
		Std. Dev	4.4	2.60	1.65	0.83	5.06	137.80	
	2003	*Mean*	5.6	3.81	2.56	3.00	6.74	70.95	46
		Median	3.4	2.40	2.00	1.00	4.00	35.75	
		Range	0.5-33.3	1.2-31.2	1.0-10.0	5.0-5.0	0.8-25.8	7.0-556.0	
		Std. Dev	6.6	4.46	1.59	0.81	6.99	97.13	
	Overall	*Mean*	5.4	3.91	2.74	1.72	6.48	78.51	187
		Median	3.3	3.60	2.00	2.00	4.38	31.88	
		Range	0.4-40.6	1.2-40.8	1.0-14.0	1.0-4.0	0.3-34.5	6.3-653.0	
		Std. Dev	6.2	4.02	1.76	0.82	6.39	115.28	
INTERMEDIATE	2001	*Mean*	20.6	15.51	9.31	5.00	16.62	69.87	13
		Median	17.4	8.40	7.00	5.00	14.25	52.00	
		Range	10.8-55.6	6.0-79.2	5.0-27.0	4.3-4.0	3.8-37.5	9.5-215.3	
		Std. Dev	12.3	19.49	6.01	1.91	8.85	65.06	
	2002	*Mean*	34.6	8.40	6.33	4.33	25.17	38.17	3
		Median	12.1	8.40	5.00	4.00	20.25	47.50	
		Range	11.4-80.2	6.0-10.8	5.0-9.0	5.0-5.0	8.8-46.5	8.5-58.5	
		Std. Dev	39.5	2.40	2.31	1.53	19.35	26.27	
	2003	*Mean*	26.1	9.00	7.17	5.00	16.83	26.21	6
		Median	16.0	7.80	6.00	5.00	16.13	13.25	
		Range	11.7-72.7	6.0-13.2	6.0-10.0	0.0-0.0	2.8-36.3	9.8-91.3	
		Std. Dev	23.7	2.91	1.83	2.00	11.06	32.06	
	Overall	*Mean*	24.0	12.76	8.32	4.91	17.84	53.64	22
		Median	17.3	8.40	7.00	4.50	15.00	47.75	
		Range	10.8-80.2	6.0-79.2	5.0-27.0	3.0-8.0	2.8-46.5	8.5-215.3	
		Std. Dev	19.8	15.20	4.84	1.82	10.88	56.05	
MAJOR	2001	*Mean*[1]	44.6	20.40	16.00	9.00	38.75	11.7	1
		Median	n/a	n/a	n/a	n/a	n/a	n/a	
		Range	n/a	n/a	n/a	n/a	n/a	n/a	
		Std. Dev	n/a	n/a	n/a	n/a	n/a	n/a	
	2002	*Mean*[2]	53.7	37.20	24.00	19.00	6.25	229.00	1
		Median	n/a	n/a	n/a	n/a	n/a	n/a	
		Range	n/a	n/a	n/a	n/a	n/a	n/a	
		Std. Dev	n/a	n/a	n/a	n/a	n/a	n/a	
	2003	*Mean*	n.d	n.d	n.d	n.d	n.d	n.d	0
		Median	n.d	n.d	n.d	n.d	n.d	n.d	
		Range	n.d	n.d	n.d	n.d	n.d	n.d	
		Std. Dev	n.d	n.d	n.d	n.d	n.d	n.d	
	Overall	*Mean*	49.2	28.80	20.00	14.00	22.50	173.00	2
		Median	49.2	28.80	20.00	14.00	22.50	173.00	
		Range	44.6-53.7	20.4-37.2	16.0-24.0	9.0-19.0	6.3-38.8	117.0-229.0	
		Std. Dev	6.4	11.88	5.66	7.07	22.98	79.20	

n/a = not applicable, n.d = no data

[1]value based on 1 storm event (21-Aug-2001)

[2] value based on 1 storm event (17-Jun-2002)

Table B.11 Storm Response Variables for Individual Events >10 mm (2001 to 2003) at the Bailey Ditch Station

Bailey Ditch (Storm Event)	Total Rainfall (mm)	Peak Discharge (m^3/s)	Peak Runoff Rate (mm/hr)	Lag Time (hrs)
4-Jan-01 10:00	34.8		No data	
21-Jan-01 3:00	17.2	0.348	0.287	7.50
8-Mar-01 2:45	11.3	0.091	0.075	23.00
18-Mar-01 6:45	18.1	0.459	0.378	3.75
25-Mar-01 21:45	10	0.155	0.128	1.00
14-May-01 1:45	17.8	0.200	0.165	6.00
15-May-01 21:15	10.7	0.323	0.266	4.25
28-May-01 12:00	10.9	0.031	0.025	3.75
1-Jun-01 8:30	21.7	0.122	0.100	2.00
8-Jun-01 19:15	10.8	0.080	0.066	11.75
9-Jun-01 20:30	10.8	0.202	0.167	11.30
10-Jun-01 19:15	16.4	0.408	0.336	16.00
21-Aug-01 9:00	44.6	0.122	0.100	3.00
23-Aug-01 10:15	17.4	0.143	0.118	3.50
1-Sep-01 4:30	12		No data	
10-Oct-01 8:45	13.7	0.038	0.031	7.75
21-Oct-01 8:00	12.8	0.067	0.055	6.50
22-Oct-01 3:15	19	0.153	0.126	16.75
26-Oct-01 8:15	32.5	0.441	0.363	38.25
30-Oct-01 14:15	15.6	0.366	0.302	11.25
4-Nov-01 7:15	17.6	0.400	0.329	9.25
13-Nov-01 15:15	40.6	0.611	0.503	10.75
19-Nov-01 8:00	13.3	0.409	0.337	6.25
1-Dec-01 12:15	12.4	0.593	0.489	2.25
8-Dec-01 7:15	22.1	0.711	0.586	6.25
12-Dec-01 15:30	55.6	1.058	0.872	5.25
15-Dec-01 14:45	31.2	0.794	0.654	3.25
19-Jan-02 14:30	12.6	0.407	0.335	12.25
23-Jan-02 11:30	15.6	0.483	0.398	6.75
24-Jan-02 17:45	15.2	0.892	0.735	5.50
31-Jan-02 13:30	10.8		Minimal response	
21-Feb-02 3:45	80.2	0.984	0.811	6.50
11-Mar-02 1:15	16.3		Minimal response	
9-Apr-02 9:15	12.1	0.385	0.317	3.75
13-Apr-02 18:15	11.4	0.494	0.407	1.00
17-Jun-02 22:45	53.7	0.866	0.713	9.75
28-Jun-02 14:30	16.6	0.367	0.302	1.50
2-Sep-02 6:30	14.1	0.032	0.026	10.00
22-Jan-03 22:00	11.7		Minimal response	
25-Jan-03 15:45	28.5		No data	
30-Jan-03 16:45	12.6		No data	
10-Mar-03 23:45	18.9		No data	
12-Mar-03 6:45	26		No data	
21-Mar-03 18:00	13.1		No data	
16-Apr-03 14:30	13.8		No data	
24-Apr-03 3:00	12.1		No data	
4-May-03 0:00	10.4		No data	
16-Nov-03 10:00	12.1		No data	
17-Nov-03 18:00	72.7		No data	
28-Nov-03 2:00	33.3		No data	
2-Dec-03 20:15	11.7		No data	

Table B.12 Storm Response Variables for Individual Events >10 mm (2001 to 2003) at the Lefferson Creek Station

Lefferson Creek (Storm Event)	Total Rainfall (mm)	Peak Discharge (m^3/s)	Peak Runoff Rate (mm/hr)	Lag Time (hrs)
4-Jan-01 10:00	34.8	0.093	0.584	0.00
21-Jan-01 3:00	17.2	0.028	0.177	5.75
8-Mar-01 2:45	11.3	0.20	0.124	0.25
18-Mar-01 6:45	18.1	0.054	0.336	0.75
25-Mar-01 21:45	10	0.031	0.195	0.00
14-May-01 1:45	17.8	0.019	0.121	7.25
15-May-01 21:15	10.7	0.035	0.221	3.25
28-May-01 12:00	10.9	0.010	0.065	2.50
1-Jun-01 8:30	21.7	0.048	0.302	1.00
8-Jun-01 19:15	10.8	0.032	0.197	1.00
9-Jun-01 20:30	10.8	0.021	0.129	1.25
10-Jun-01 19:15	16.4	0.019	0.120	2.25
21-Aug-01 9:00	44.6	0.064	0.403	0.75
23-Aug-01 10:15	17.4	0.016	0.102	2.00
1-Sep-01 4:30	12	0.009	0.059	3.50
10-Oct-01 8:45	13.7	0.024	0.150	1.75
21-Oct-01 8:00	12.8	0.018	0.115	1.00
22-Oct-01 3:15	19	0.023	0.14	1.00
26-Oct-01 8:15	32.5	0.034	0.2154	6.75
30-Oct-01 14:15	15.6	0.013	0.080	1.00
4-Nov-01 7:15	17.6		Minimal response	
13-Nov-01 15:15	40.6	0.050	0.315	10
19-Nov-01 8:00	13.3	0.022	0.142	6.25
1-Dec-01 12:15	12.4	0.049	0.309	0.25
8-Dec-01 7:15	22.1	0.065	0.406	0
12-Dec-01 15:30	55.6	0.096	0.600	2.25
15-Dec-01 14:45	31.2		Minimal response	
19-Jan-02 14:30	12.6		Minimal response	
23-Jan-02 11:30	15.6		Minimal response	
24-Jan-02 17:45	15.2	0.102	0.636	2.00
31-Jan-02 13:30	10.8		Minimal response	
21-Feb-02 3:45	80.2		Minimal response	
11-Mar-02 1:15	16.3		No data	
9-Apr-02 9:15	12.1	0.024	0.148	0.00
13-Apr-02 18:15	11.4	0.024	0.152	0.50
17-Jun-02 22:45	53.7	0.288	1.803	1.00
28-Jun-02 14:30	16.6	0.019	0.121	2.00
2-Sep-02 6:30	14.1	0.024	0.152	12.25
22-Jan-03 22:00	11.7		No data	
25-Jan-03 15:45	28.5		No data	
30-Jan-03 16:45	12.6		No data	
10-Mar-03 23:45	18.9		No data	
12-Mar-03 6:45	26		No data	
21-Mar-03 18:00	13.1		No data	
16-Apr-03 14:30	13.8		No data	
24-Apr-03 3:00	12.1		No data	
4-May-03 0:00	10.4		No data	
16-Nov-03 10:00	12.1		No data	
17-Nov-03 18:00	72.7		No data	
28-Nov-03 2:00	33.3		No data	
2-Dec-03 20:15	11.7		No data	

Table B.13 Storm Response Variables for Individual Events >10 mm (2001 to 2003) at the Luckakuck Creek Station

Luckakuck Creek (Storm Event)	Total Rainfall (mm)	Peak Discharge (m^3/s)	Peak Runoff Rate (mm/hr)	Lag Time (hrs)
4-Jan-01 10:00	34.8		No data	
21-Jan-01 3:00	17.2		No data	
8-Mar-01 2:45	11.3		No data	
18-Mar-01 6:45	18.1		No data	
25-Mar-01 21:45	10		No data	
14-May-01 1:45	17.8	0.141	0.171	4.00
15-May-01 21:15	10.7	0.142	0.172	4.50
28-May-01 12:00	10.9	0.151	0.183	3.75
1-Jun-01 8:30	21.7	0.166	0.201	1.75
8-Jun-01 19:15	10.8	0.201	0.244	2.00
9-Jun-01 20:30	10.8	0.198	0.240	2.50
10-Jun-01 19:15	16.4	0.219	0.266	5.50
21-Aug-01 9:00	44.6	0.261	0.317	2.00
23-Aug-01 10:15	17.4	0.214	0.259	3.50
1-Sep-01 4:30	12	0.200	0.243	4.50
10-Oct-01 8:45	13.7	0.129	0.156	7.25
21-Oct-01 8:00	12.8	0.146	0.178	5.75
22-Oct-01 3:15	19	0.201	0.244	13.00
26-Oct-01 8:15	32.5	0.206	0.250	13.00
30-Oct-01 14:15	15.6	0.220	0.267	2.75
4-Nov-01 7:15	17.6		No data	
13-Nov-01 15:15	40.6	0.318	0.386	0.25
19-Nov-01 8:00	13.3	0.266	0.323	1.75
1-Dec-01 12:15	12.4	0.376	0.456	2.75
8-Dec-01 7:15	22.1	0.417	0.507	0.25
12-Dec-01 15:30	55.6	0.506	0.614	1.75
15-Dec-01 14:45	31.2	0.411	0.499	0.75
19-Jan-02 14:30	12.6	0.367	0.445	9.00
23-Jan-02 11:30	15.6	0.374	0.454	0.25
24-Jan-02 17:45	15.2	0.450	0.546	0.25
31-Jan-02 13:30	10.8		Minimal Response	
21-Feb-02 3:45	80.2	0.681	0.827	2.50
11-Mar-02 1:15	16.3		Inconsistent Data	
9-Apr-02 9:15	12.1	0.237	0.287	1.50
13-Apr-02 18:15	11.4	0.350	0.425	0.50
17-Jun-02 22:45	53.7	0.585	0.710	2.75
28-Jun-02 14:30	16.6		No data	
2-Sep-02 6:30	14.1	0.160	0.195	3.75
22-Jan-03 22:00	11.7	0.149	0.181	1.50
25-Jan-03 15:45	28.5	0.187	0.227	3.25
30-Jan-03 16:45	12.6		No data	
10-Mar-03 23:45	18.9	0.317	0.385	3.25
12-Mar-03 6:45	26		No data	
21-Mar-03 18:00	13.1		No data	
16-Apr-03 14:30	13.8	0.363	0.440	2.00
24-Apr-03 3:00	12.1		No data	
4-May-03 0:00	10.4		No data	
16-Nov-03 10:00	12.1		No data	
17-Nov-03 18:00	72.7		No data	
28-Nov-03 2:00	33.3		No data	
2-Dec-03 20:15	11.7			

Table B.14 Storm Response Variables for Individual Events >10 mm (2001 to 2003) at the Parsons Brook Station

Parsons Brook (Storm Event)	Total Rainfall (mm)	Peak Discharge (m^3/s)	Peak Runoff Rate (mm/hr)	Lag Time (hrs)
4-Jan-01 10:00	34.8		No data	
21-Jan-01 3:00	17.2	0.117	0.206	19.5
8-Mar-01 2:45	11.3	0.196	0.344	
18-Mar-01 6:45	18.1	0.102	0.179	14.00
25-Mar-01 21:45	10	0.111	0.195	13.50
14-May-01 1:45	17.8	0.122	0.215	18.50
15-May-01 21:15	10.7	0.033	0.057	15.00
28-May-01 12:00	10.9	0.110	0.194	16.50
1-Jun-01 8:30	21.7	0.110	0.194	13.75
8-Jun-01 19:15	10.8	0.110	0.194	8.75
9-Jun-01 20:30	10.8	0.135	0.236	21.50
10-Jun-01 19:15	16.4	0.241	0.423	28.00
21-Aug-01 9:00	44.6	0.096	0.168	13.00
23-Aug-01 10:15	17.4	0.047	0.083	12.75
1-Sep-01 4:30	12	0.034	0.059	17.0
10-Oct-01 8:45	13.7		No data	
21-Oct-01 8:00	12.8		No data	
22-Oct-01 3:15	19		No data	
26-Oct-01 8:15	32.5		No data	
30-Oct-01 14:15	15.6		No data	
4-Nov-01 7:15	17.6		No data	
13-Nov-01 15:15	40.6		Minor response	
19-Nov-01 8:00	13.3		Minor response	
1-Dec-01 12:15	12.4		No data	
8-Dec-01 7:15	22.1		No data	
12-Dec-01 15:30	55.6		No data	
15-Dec-01 14:45	31.2		No data	
19-Jan-02 14:30	12.6		No data	
23-Jan-02 11:30	15.6		No data	
24-Jan-02 17:45	15.2		No data	
31-Jan-02 13:30	10.8		No data	
21-Feb-02 3:45	80.2		No data	
11-Mar-02 1:15	16.3		No data	
9-Apr-02 9:15	12.1	0.029	0.052	9.75
13-Apr-02 18:15	11.4		No data	
17-Jun-02 22:45	53.7	0.137	0.241	12.75
28-Jun-02 14:30	16.6		No data	
2-Sep-02 6:30	14.1		No data	
22-Jan-03 22:00	11.7		No data	
25-Jan-03 15:45	28.5		No data	
30-Jan-03 16:45	12.6		No data	
10-Mar-03 23:45	18.9		No data	
12-Mar-03 6:45	26		No data	
21-Mar-03 18:00	13.1		No data	
16-Apr-03 14:30	13.8		No data	
24-Apr-03 3:00	12.1		No data	
4-May-03 0:00	10.4		No data	
16-Nov-03 10:00	12.1		No data	
17-Nov-03 18:00	72.7		No data	
28-Nov-03 2:00	33.3		No data	
2-Dec-03 20:15	11.7		No data	

Table B.15 Storm Response Variables for Individual Events >10 mm (2001 to 2003) at the Elkview Creek Station

Elkview Creek (Storm Event)	Total Rainfall (mm)	Peak Discharge (m^3/s)	Peak Runoff Rate (mm/hr)	Lag Time (hrs)
4-Jan-01 10:00	34.8		No data	
21-Jan-01 3:00	17.2	0.156	0.259	17.25
8-Mar-01 2:45	11.3	0.41	0.067	31.25
18-Mar-01 6:45	18.1	0.119	0.198	16.00
25-Mar-01 21:45	10	0.051	0.084	13.50
14-May-01 1:45	17.8	0.135	0.224	19.25
15-May-01 21:15	10.7	0.150	0.249	15.50
28-May-01 12:00	10.9	0.074	0.123	15.75
1-Jun-01 8:30	21.7	0.133	0.221	14.00
8-Jun-01 19:15	10.8	0.441	0.733	8.00
9-Jun-01 20:30	10.8	0.173	0.287	21.25
10-Jun-01 19:15	16.4	0.345	0.573	25.5
21-Aug-01 9:00	44.6	0.117	0.195	12.75
23-Aug-01 10:15	17.4	0.180	0.300	14.00
1-Sep-01 4:30	12	0.042	0.070	17.00
10-Oct-01 8:45	13.7	0.067	0.112	19.25
21-Oct-01 8:00	12.8	0.088	0.145	13.75
22-Oct-01 3:15	19	0.111	0.185	24.00
26-Oct-01 8:15	32.5	0.346	0.576	19.25
30-Oct-01 14:15	15.6		No data	
4-Nov-01 7:15	17.6	0.216	0.360	1.00
13-Nov-01 15:15	40.6	0.732	1.217	10.75
19-Nov-01 8:00	13.3	0.480	0.798	3.75
1-Dec-01 12:15	12.4	0.375	0.624	0.25
8-Dec-01 7:15	22.1	0.443	0.737	3.00
12-Dec-01 15:30	55.6		No data	
15-Dec-01 14:45	31.2		No data	
19-Jan-02 14:30	12.6		No data	
23-Jan-02 11:30	15.6		No data	
24-Jan-02 17:45	15.2		No data	
31-Jan-02 13:30	10.8		No data	
21-Feb-02 3:45	80.2		No data	
11-Mar-02 1:15	16.3		No data	
9-Apr-02 9:15	12.1		No data	
13-Apr-02 18:15	11.4		No data	
17-Jun-02 22:45	53.7	0.124	0.207	2.00
28-Jun-02 14:30	16.6		Minimal response	
2-Sep-02 6:30	14.1		No data	
22-Jan-03 22:00	11.7		No data	
25-Jan-03 15:45	28.5	0.118	0.197	2.25
30-Jan-03 16:45	12.6		Minimal response	
10-Mar-03 23:45	18.9	0.112	0.187	2.75
12-Mar-03 6:45	26		No data	
21-Mar-03 18:00	13.1		Minimal response	
16-Apr-03 14:30	13.8		Minimal response	
24-Apr-03 3:00	12.1		Minimal response	
4-May-03 0:00	10.4		Minimal response	
16-Nov-03 10:00	12.1		No data	
17-Nov-03 18:00	72.7		Minimal response	
28-Nov-03 2:00	33.3		No data	
2-Dec-03 20:15	11.7		No data	

Table B.16 Storm Response Variables for Individual Events >10 mm (2001 to 2003) at the Teskey Creek Station

Teskey Creek (Storm Event)	Total Rainfall (mm)	Peak Discharge (m^3/s)	Peak Runoff Rate (mm/hr)	Lag Time (hrs)
4-Jan-01 10:00	34.8		No data	
21-Jan-01 3:00	17.2	0.287	0.615	0.00
8-Mar-01 2:45	11.3	0.185	0.400	0.00
18-Mar-01 6:45	18.1	0.423	0.916	0.25
25-Mar-01 21:45	10	0.181	0.392	0.00
14-May-01 1:45	17.8	0.258	0.558	1.50
15-May-01 21:15	10.7	0.328	0.710	0.25
28-May-01 12:00	10.9	0.104	0.225	1.25
1-Jun-01 8:30	21.7	1.359	2.940	0.75
8-Jun-01 19:15	10.8	0.219	0.474	0.25
9-Jun-01 20:30	10.8	0.116	0.250	0.25
10-Jun-01 19:15	16.4		No data	
21-Aug-01 9:00	44.6		Inconsistent data	
23-Aug-01 10:15	17.4		No data	
1-Sep-01 4:30	12		No data	
10-Oct-01 8:45	13.7	0.484	1.047	1.25
21-Oct-01 8:00	12.8	1.165	1.047	0.75
22-Oct-01 3:15	19	1.186	2.565	0.25
26-Oct-01 8:15	32.5	1.724	3.731	6.75
30-Oct-01 14:15	15.6	0.419	1.047	7.00
4-Nov-01 7:15	17.6	0.605	1.308	0.50
13-Nov-01 15:15	40.6	0.867	1.876	0.00
19-Nov-01 8:00	13.3	0.375	0.812	1.50
1-Dec-01 12:15	12.4	0.608	1.315	0.25
8-Dec-01 7:15	22.1	0.666	1.440	1.50
12-Dec-01 15:30	55.6	1.221	2.642	1.50
15-Dec-01 14:45	31.2	0.900	1.947	0.00
19-Jan-02 14:30	12.6		No data	
23-Jan-02 11:30	15.6		No data	
24-Jan-02 17:45	15.2		No data	
31-Jan-02 13:30	10.8		Minimal response	
21-Feb-02 3:45	80.2	0.428	0.925	0.25
11-Mar-02 1:15	16.3		Inconsistent data	
9-Apr-02 9:15	12.1	0.109	0.237	0
13-Apr-02 18:15	11.4		No data	
17-Jun-02 22:45	53.7	0.177	0.384	0.5
28-Jun-02 14:30	16.6		No data	
2-Sep-02 6:30	14.1	0.076	0.165	1.75
22-Jan-03 22:00	11.7	0.991	1.047	0.25
25-Jan-03 15:45	28.5		Inconsistent data	
30-Jan-03 16:45	12.6		Inconsistent data	
10-Mar-03 23:45	18.9	0.346	0.748	1.25
12-Mar-03 6:45	26	0.420	0.909	0.25
21-Mar-03 18:00	13.1		No data	
16-Apr-03 14:30	13.8		No data	
24-Apr-03 3:00	12.1		Inconsistent data	
4-May-03 0:00	10.4		Inconsistent data	
16-Nov-03 10:00	12.1		No data	
17-Nov-03 18:00	72.7		No data	
28-Nov-03 2:00	33.3		No data	
2-Dec-03 20:15	11.7		No data	

Table B.17 Storm Response Variables for Individual Events >10 mm (2001 to 2003) at the Semiault Creek Station

Semiault Creek (Storm Event)	Total Rainfall (mm)	Peak Discharge (m^3/s)	Peak Runoff Rate (mm/hr)	Lag Time (hrs)
4-Jan-01 10:00	34.8		No data	
21-Jan-01 3:00	17.2		No data	
8-Mar-01 2:45	11.3		No data	
18-Mar-01 6:45	18.1		No data	
25-Mar-01 21:45	10		No data	
14-May-01 1:45	17.8		No data	
15-May-01 21:15	10.7		No data	
28-May-01 12:00	10.9		No data	
1-Jun-01 8:30	21.7		No data	
8-Jun-01 19:15	10.8		No data	
9-Jun-01 20:30	10.8		No data	
10-Jun-01 19:15	16.4		No data	
21-Aug-01 9:00	44.6		No data	
23-Aug-01 10:15	17.4		No data	
1-Sep-01 4:30	12		No data	
10-Oct-01 8:45	13.7		No data	
21-Oct-01 8:00	12.8		No data	
22-Oct-01 3:15	19		No data	
26-Oct-01 8:15	32.5		No data	
30-Oct-01 14:15	15.6		No data	
4-Nov-01 7:15	17.6		No data	
13-Nov-01 15:15	40.6		No data	
19-Nov-01 8:00	13.3		No data	
1-Dec-01 12:15	12.4		No data	
8-Dec-01 7:15	22.1		No data	
12-Dec-01 15:30	55.6		No data	
15-Dec-01 14:45	31.2		No data	
19-Jan-02 14:30	12.6		No data	
23-Jan-02 11:30	15.6		No data	
24-Jan-02 17:45	15.2		No data	
31-Jan-02 13:30	10.8		No data	
21-Feb-02 3:45	80.2		No data	
11-Mar-02 1:15	16.3		No data	
9-Apr-02 9:15	12.1		No data	
13-Apr-02 18:15	11.4		No data	
17-Jun-02 22:45	53.7		No data	
28-Jun-02 14:30	16.6		No data	
2-Sep-02 6:30	14.1		No data	
22-Jan-03 22:00	11.7		No data	
25-Jan-03 15:45	28.5		No data	
30-Jan-03 16:45	12.6	2.731	0.633	8.50
10-Mar-03 23:45	18.9	3.230	0.749	17.25
12-Mar-03 6:45	26	3.213	1.138	5.25
21-Mar-03 18:00	13.1	2.892	0.670	5.75
16-Apr-03 14:30	13.8	2.189	0.509	9.25
24-Apr-03 3:00	12.1		No data	
4-May-03 0:00	10.4	0.808	0.187	7.50
16-Nov-03 10:00	12.1		No data	
17-Nov-03 18:00	72.7	5.001	1.159	47.50
28-Nov-03 2:00	33.3	5.162	1.196	12.00
2-Dec-03 20:15	11.7			

Table B. 18 Storm Response Variables for Individual Events >10 mm (2001 to 2003) at the Chilliwack Creek Station

Chilliwack Creek (Storm Event)	Total Rainfall (mm)	Peak Discharge (m^3/s)	Peak Runoff Rate (mm/hr)	Lag Time (hrs)
4-Jan-01 10:00	34.8		No data	
21-Jan-01 3:00	17.2		No data	
8-Mar-01 2:45	11.3		No data	
18-Mar-01 6:45	18.1		No data	
25-Mar-01 21:45	10		No data	
14-May-01 1:45	17.8		No data	
15-May-01 21:15	10.7		No data	
28-May-01 12:00	10.9		No data	
1-Jun-01 8:30	21.7		No data	
8-Jun-01 19:15	10.8		No data	
9-Jun-01 20:30	10.8		No data	
10-Jun-01 19:15	16.4		No data	
21-Aug-01 9:00	44.6		No data	
23-Aug-01 10:15	17.4		No data	
1-Sep-01 4:30	12		No data	
10-Oct-01 8:45	13.7		No data	
21-Oct-01 8:00	12.8		No data	
22-Oct-01 3:15	19		No data	
26-Oct-01 8:15	32.5		No data	
30-Oct-01 14:15	15.6		No data	
4-Nov-01 7:15	17.6		No data	
13-Nov-01 15:15	40.6		No data	
19-Nov-01 8:00	13.3		No data	
1-Dec-01 12:15	12.4		No data	
8-Dec-01 7:15	22.1		No data	
12-Dec-01 15:30	55.6		No data	
15-Dec-01 14:45	31.2		No data	
19-Jan-02 14:30	12.6		No data	
23-Jan-02 11:30	15.6		No data	
24-Jan-02 17:45	15.2		No data	
31-Jan-02 13:30	10.8		No data	
21-Feb-02 3:45	80.2		No data	
11-Mar-02 1:15	16.3		No data	
9-Apr-02 9:15	12.1		No data	
13-Apr-02 18:15	11.4		No data	
17-Jun-02 22:45	53.7		No data	
28-Jun-02 14:30	16.6		No data	
2-Sep-02 6:30	14.1		No data	
22-Jan-03 22:00	11.7	1.210	0.280	9.00
25-Jan-03 15:45	28.5	3.479	0.806	6.00
30-Jan-03 16:45	12.6		No data	
10-Mar-03 23:45	18.9	4.563	1.617	15.25
12-Mar-03 6:45	26	4.816	1.116	4.00
21-Mar-03 18:00	13.1	4.497	1.593	4.00
16-Apr-03 14:30	13.8	4.1	1.453	12.00
24-Apr-03 3:00	12.1		No data	
4-May-03 0:00	10.4	2.242	0.795	8.25
16-Nov-03 10:00	12.1	1.285	0.455	9.00
17-Nov-03 18:00	72.7		No data	
28-Nov-03 2:00	33.3		No data	
2-Dec-03 20:15	11.7	0.905	0.321	17.75

Table B.19 Summary of Storm Response Variables at each Hydrometric Station within the Chilliwack Creek Watershed, for Three Storm Classes

			Parsons	Elkview	Lefferson	Teskey	Luckakuck	Bailey	Semiault	Chilliwack
N	Minor		6	13	16	14	17	19	5	4
	Inter.		8	11	13	13	14	12	3	5
	Major		2	2	2	1	2	2	0	0
	Total		16	26	31	28	33	33	8	9
Peak Discharge (m^3/s)	Minor	*Median*	0.12	0.17	0.02	0.43	0.27	0.41	2.73	3.17
		Range	0.03 -0.24	0.04 -0.73	0.02 -0.10	0.08 -1.72	0.13 -0.45	0.04 -0.89	0.81 -5.16	1.29 -4.82
	Inter.	*Median*	0.11	0.12	0.03	0.42	0.21	0.36	3.23	3.48
		Range	0.03 -0.12	0.04 -0.44	0.01 -0.10	0.10 -1.36	0.15 -0.68	0.03 -1.06	2.89 -5.00	0.91 -4.56
	Major	*Median*	0.12	0.12	0.18	n/a	0.42	0.49	n/a	n/a
		Range	0.10 -0.14	0.12 -0.12	0.06 -0.29	n/a	0.26 -0.59	0.12 -0.87	n/a	n/a
	Total	*Median*	0.11	0.13	0.02	0.42	0.22	0.39	3.05	3.48
		Range	0.03-0.24	0.04-0.73	0.01-0.29	0.08-1.72	0.13-0.68	0.03-1.06	0.81-5.16	0.91-4.82
Peak Runoff Rate (mm/hr)	Minor	*Median*	0.20	0.29	0.15	0.93	0.32	0.34	0.63	0.96
		Range	0.06 -0.42	0.07 -1.22	0.12 -0.64	0.17 -3.73	0.16 -0.55	0.03 -0.74	0.19 -1.20	0.46 -1.45
	Inter.	*Median*	0.19	0.20	0.18	0.93	0.25	0.29	0.75	0.81
		Range	0.05 -0.21	0.07 -0.73	0.06 -0.60	0.23 -2.94	0.18 -0.83	0.03 -0.87	0.67 -1.16	0.28 -1.62
	Major	*Median*	0.20	0.20	1.10	n/a	0.51	0.41	n/a	n/a
		Range	0.17 -0.24	0.20 -0.21	0.40 -1.80	n/a	0.32 -0.71	0.10 -0.71	n/a	n/a
	Total	*Median*	0.19	0.22	0.15	0.92	0.27	0.32	0.71	0.81
		Range	0.05-0.42	0.07-1.22	0.06-1.80	0.17-3.73	0.16-0.83	0.03-0.87	0.19-1.197	0.18-1.62
Lag Time (hrs)	Minor	*Median*	20.00	15.50	2.00	0.63	2.50	6.50	8.50	8.63
		Range	13.50 -31.75	1.00 -31.25	0.00 -12.25	0.00 -6.75	0.25 -13.00	1.00 -38.25	5.25 -12.00	4.00 -12.00
	Inter.	*Median*	13.87	14.00	1.00	0.25	2.75	4.50	17.25	9.00
		Range	8.75 -19.50	0.25 -24.00	0.00 -5.75	0.00 -7.00	1.50 -13.00	2.00 -16.75	5.75 -47.25	4.00 -17.75
	Major	*Median*	12.88	7.38	0.88	n/a	2.38	6.38	n/a	n/a
		Range	12.75 -13.00	2.00 -12.75	0.75 -1.00	n/a	2.00 -2.75	3.00 -9.75	n/a	n/a
	Total	*Median*	14	14	1.25	0.38	2.75	6.25	8.88	9
		Range	2.28-31.75	0.25-31.25	0.00-12.25	0.00-7.00	0.25-13.00	1.00-38.25	5.25-47.25	4.00-17.75

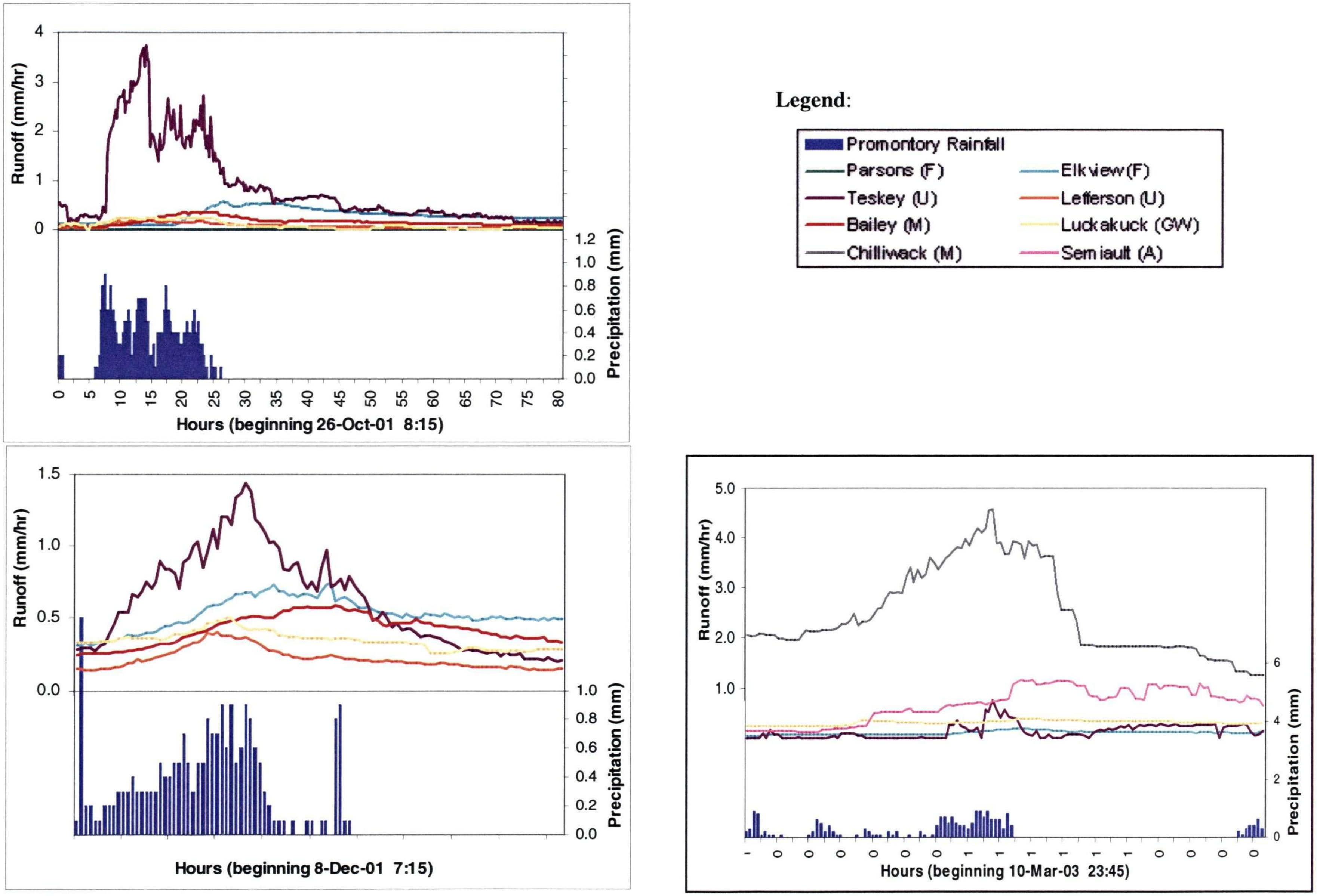


Figure B.1 Hydrographs for Three of the Selected Storm Events (8-Dec-01, 26-Oct-01 and 10-Mar-03)

Appendix C: Water Quality Data

Table C.1 Selection of ater quality variables in relation to different land uses. Highlighted variables included in this study (Adapted from Chapman 1993)

	Indicator	Sewage/ municipal waste water	Urban Runoff	Agricultural Activities	Waste Disposal to land		Industrial Activities				Forestry Activities
					Solid Waste	Hazardous Chemicals	Oil extraction/ refining	Mining	Metallurgy	Textiles	
General Variables	Temperature	X	X	X			X	X	X	X	XXX
	Conductivity	XX	XX	XX	XXX	XXX	XXX	XXX	XXX	XXX	X
	pH	X	X	X	XX	XXX	X	XXX	XXX	X	X
	Dissolved Oxygen	XXX	XXX	XXX	XXX	XXX	XXX	XXX	X	XXX	XXX
	Suspended Solids	XXX	XX	XXX	XX	XX		XXX	XXX	XXX	XXX
Nutrients	Ammonia	XXX	XX	XXX	XX		XX	X	X	X	X
	Nitrate	XXX	XX	XXX	XX			X	X	X	X
	Phosphorus	XXX	XX	XXX	X					X	X
Organic Matter	TOC	X	X	X			X	X	X	X	XX
	COD	XX	XX	X	XXX	XXX	X	X	X	X	XX
	BOD	XXX	XX	XXX	XXX	XX	XXX	X	X	XXX	XX
Major Ions	Sodium	XX	XX	XX			X	X		X	
	Potassium	X	X	X			X	X		X	
	Calcium	X	X	X			X	X	XX	X	
	Magnesium	X	X	X			X	X	X	X	
	Chloride	XXX	XX	XXX	XX	XX	XX	XXX	X	XXX	
	Sulphate	X	X	X			XX	X	X	X	
Heavy Metals	Aluminium						XX	XXX	XXX	XX	
	Cadmium		X		XXX	XXX	XX	XXX	XXX	XX	
	Chromium		X		XXX	XX	XX	XXX	XXX	XX	
	Copper	X	X	XX[1]	XXX	XX	XX	XXX	XXX	XX	
	Iron	XX	XX		XXX	XX	XX	XXX	XXX	XX	
	Mercury	X	X	XXX[1]	XXX	XXX	XX	XXX	XXX	XX	
	Lead	XX	XXX		XXX	XX	XX	XXX	XXX	XX	
	Zinc		X	XX[1]	XXX	XX	XX	XXX	XXX	XX	
	Arsenic		X	XXX[1]	XXX	XXX		X	X	X	
	Selenium		X	XXX[1]	X	X		X	X	X	
Organics	Oil and Petroleum products	XX	XXX		XX	X	XXX		XXX	X	
	Pesticides		X	XXX[2]		X					XXX
Microbial indicators	Faecal coliforms	XXX	XX	XX	XXX					XX	XX

X-XXX Low to high likelihood that the concentration of the variable will be affected

[1]Only needs to be measure when used locally or occurs naturally at high concentrations

Table C.2 Detection Limits for Water Samples (Nutrients and Dissolved Elements)

Parameter	Detection Limit (mg/L)
Nitrate-N	0.1
Ammonia-N	0.1
Orthophosphate-P	0.02
Al	0.05
As	0.2
B	0.01
Ba	0.01
Ca	0.1
Cd	0.025
Co	0.055
Cr	0.025
Cu	0.05
Fe	0.05
K	0.5
Mg	0.01
Mn	0.005
Mo	0.05
Na	0.25
Ni	0.1
P	0.2
Pb	0.2
Se	0.2
Si	0.15
Sr	0.002
Zn	0.01

Table C.3 Wet and Dry Season Means for Water Quality Parameters

Sampling Station	pH		Dissolved Oxygen (mg/L)		Specific Conductivity (µS/cm)		Temperature (°C)		Nitrate + Nitrite -N (mg/L)		Ammonia-N (mg/L)		Orthophosphate-P (mg/L)	
	Wet	*Dry*	*Wet*	*Dry*	*Wet*	*Dry*	*Wet*	*Dry*	*Wet*	*Dry*	*Wet*	*Dry*	*Wet*	*Dry*
A15	7.0	7.5	10.6	7.6	188	234	8.2	16.0	0.798	0.128	0.179	0.122	0.049	0.042
A16	7.2	7.4	11.2	9.9	286	235	9.6	17.9	0.942	0.208	1.083	0.131	0.060	0.060
A18	7.0	6.9	8.5	7.8	261	275	10.8	17.3	0.682	0.263	0.874	0.281	0.138	0.070
A17	7.4	7.6	11	9.2	304	307	9.8	15.9	0.830	0.622	1.396	0.145	0.071	0.089
A2	7.1	7.2	8.6	9.6	402	370	10.7	15.3	2.718	0.163	0.334	0.196	0.086	0.087
A11	7.2	6.9	10.8	8.5	224	184	9.0	13.4	1.145	0.243	0.170	0.158	0.043	<0.020
F12	7.6	7.6	12.2	8.7	216	250	10.7	15.1	0.855	0.436	<0.1	0.125	0.034	0.038
F14	7.7	7.3	12.6	8.9	249	280	7.4	14.8	0.840	0.515	0.243	<0.1	0.032	0.039
F13	7.5	7.1	11.9	8.5	155	153	8.2	14.2	0.833	0.331	0.236	0.176	0.039	0.042
U3	7.4	7.3	7.7	7.9	214	261	8.0	15.8	0.672	0.673	0.235	0.173	0.054	0.051
U5	7.6	7.3	8.2	9.0	185	273	7.5	14.0	0.598	0.417	<0.1	0.122	0.045	0.052
U7	7.8	7.6	11.9	8.9	206	230	8.0	14.0	0.453	0.108	0.124	<0.1	0.046	0.060
U4	7.6	7.3	7.9	9.8	214	247	7.6	14.3	0.872	0.679	<0.1	0.115	0.045	0.053
U6	7.8	7.6	12.6	10.3	169	191	7.9	13.8	0.510	0.272	0.148	<0.1	0.045	0.064
U8	7.8	7.3	12.5	9.6	166	187	7.5	12.3	0.417	0.402	<0.1	<0.1	0.056	0.062
M9	7.2	7.1	11.1	9.4	257	242	9.4	16.1	0.298	0.143	0.189	0.139	0.100	0.049
M10	7.2	7.1	9	8.4	347	329	9.2	15.1	0.960	0.592	2.151	0.203	0.074	0.061
M19	7.0	6.8	11	8.1	246	306	10.0	13.8	2.284	3.061	0.178	0.116	0.040	0.056
M20	7.1	7.4	5.9	6.9	286	307	10.9	15.4	1.481	0.389	0.433	0.204	0.101	0.079
G1	6.7	6.7	8.6	9.8	151	165	9.8	11.6	0.869	0.974	0.139	0.123	0.036	0.046

Table C.4 (Nitrate+Nitrite)-N Results (in mg/L)

Watercourse	Site	13-May-02	27-May-02	21-Aug-02	10-Oct-02	12-Nov-02	12-Dec-02	3-Mar-03	1-May-03	9-Jul-03
Interception Ditch	A15	-	0.245	<0.1	<0.1	0.516	1.359	0.785*	0.532	0.166
	A16	-	0.211	<0.1	0.520	0.522	1.434	0.957	0.854	<0.1
	A18	-	0.298	0.283	0.175	0.430	0.744	0.937	0.615	0.294
Teskey Way Ditch	A17	-	0.453	0.573	0.561	0.519	1.740	0.591	0.470	0.902
Semiault Creek	A2	-	0.134	<0.1	0.252	4.133	5.678	0.787	0.275	0.215
Armstrong Ditch	A11	-	0.153	Stream dry	Stream dry	0.738	2.153	1.169	0.521	0.333
Elkview Creek	F12	-	0.355	0.473	0.383	0.831	0.630	1.105	0.855	0.531
	F14	-	0.360	0.616	0.541	0.815	0.644	1.070	0.831	0.542
Parsons Brook	F13	-	0.411	0.293	0.234	0.700	0.995	0.941	0.694	0.386
Teskey Creek	U3	-	0.795	0.484	0.509	0.389	0.503	1.022	0.775	0.905
	U5	-	0.319	0.362	0.208	0.343	0.505	0.949	0.593	0.778
Lefferson Creek	U7	-	0.110	<0.1	<0.1	0.936	0.373	0.376	0.126	0.220
	U4	-	0.732	0.662	0.391	0.494	0.589	1.351*	1.052	0.929
Benchley Creek	U6	-	0.283	0.291	0.315	0.599	0.541	0.599	0.300	0.197
Walker Creek	U8	-	0.308	0.410	0.415	0.372	0.401	0.522	0.372	0.474
Teskey Way Ditch	M9	-	0.127	0.114	0.130	0.215	0.342	0.419	0.214*	0.199
Bailey Ditch	M10	-	0.355	0.516	0.650	1.084	2.011	0.502	0.243	0.846
Chilliwack Creek	M19	-	4.241	2.967	2.053	1.189	1.591	3.223	3.134	2.982
	M20	-	0.464	0.246	0.300	1.147	3.352	0.764	0.660	0.546
Luckakuck Creek	G1	-	1.015	0.936	0.883	0.790	0.826	0.926	0.934	1.061

* average of triplicate samples

Table C.5 Ammonia-N Results (in mg/L)

Watercourse	Site	13-May-02	27-May-02	21-Aug-02	10-Oct-02	12-Nov-02	12-Dec-02	3-Mar-03	1-May-03	9-Jul-03
Interception Ditch	A15	-	0.150	0.122	<0.1	<0.1	0.129	0.143*	0.266	0.166
	A16	-	0.220	<0.1	0.138	0.213	3.405	0.354	0.358	0.118
	A18	-	0.281	0.131	0.480	0.714	1.770	0.711	0.300	0.233
Teskey Way Ditch	A17	-	0.268	0.160	<0.1	0.106	4.228	0.725	0.526	0.100
Semiault Creek	A2	-	0.308	0.304	<0.1	0.426	0.273	0.303	<0.1	0.121
Armstrong Ditch	A11	-	0.170	Stream dry	Stream dry	0.178	0.165	0.115	0.221	0.147
Elkview Creek	F12	-	0.118	<0.1	0.207	<0.1	<0.1	0.101	0.175	<0.1
	F14	-	0.129	<0.1	0.110	<0.1	<0.1	0.601	0.272	<0.1
Parsons Brook	F13	-	0.120	<0.1	0.357	<0.1	<0.1	0.577	0.265	<0.1
Teskey Creek	U5	-	0.140	0.377	0.126	0.135	<0.1	0.706	<0.1	<0.1
	U3	-	0.138	0.252	<0.1	<0.1	<0.1	0.147	<0.1	<0.1
Lefferson Creek	U7	-	0.114	0.135	<0.1	<0.1	<0.1	0.345	<0.1	<0.1
	U4	-	0.138	0.223	<0.1	<0.1	<0.1	0.185*	<0.1	<0.1
Benchley Creek	U6	-	0.110	0.188	<0.1	<0.1	<0.1	0.440	<0.1	<0.1
Walker Creek	U8	-	0.126	<0.1	0.154	<0.1	<0.1	0.117	<0.1	<0.1
Teskey Way Ditch	M9	-	0.161	<0.1	0.217	0.212	0.127	0.118	0.298*	0.129
Bailey Ditch	M10	-	0.332	<0.1	0.147	<0.1	5.233	0.409	0.811	0.283
Chilliwack Creek	M19	-	0.159	<0.1	<0.1	<0.1	0.122	0.234	<0.1	0.139
	M20	-	0.423	<0.1	0.146	0.517	0.556	0.456	0.202	0.199
Luckakuck Creek	G1	-	0.139	0.252	<0.1	0.131	<0.1	0.325	<0.1	<0.1

* average of triplicate samples

Table C.6 Orthophosphate-P Results (in mg/L)

Watercourse	Site	13-May-02	27-May-02	21-Aug-02	10-Oct-02	12-Nov-02	12-Dec-02	3-Mar-03	1-May-03	9-Jul-03
Interception Ditch	A15	-	<0.02	0.038	0.111	0.049	~~0.172~~	~~0.126~~	~~0.185~~	<0.02
	A16	-	<0.02	0.078	0.143	0.060	~~0.198~~	~~0.176~~	~~0.206~~	<0.02
	A18	-	<0.02	0.134	0.126	0.138	~~0.220~~	~~0.180~~	~~0.243~~	<0.02
Teskey Way Ditch	A17	-	<0.02	0.163	0.144	0.071	~~0.207~~	~~0.185~~	~~0.201~~	0.038
Semiault Creek	A2	-	0.022	0.156	0.158	0.086	~~0.304~~	~~0.237~~	~~0.339~~	<0.02
Armstrong Ditch	A11	-	<0.02	Stream dry	Stream dry	0.043	~~0.293~~	~~0.150~~	~~0.234~~	<0.02
Elkview Creek	F12	-	<0.02	0.073	0.059	0.034	~~0.123~~	~~0.110~~	~~0.161~~	<0.02
	F14	-	<0.02	0.075	0.060	0.032	~~0.120~~	~~0.113~~	~~0.176~~	<0.02
Parsons Brook	F13	-	<0.02	0.077	0.071	0.039	~~0.132~~	~~0.112~~	~~0.188~~	<0.02
Teskey Creek	U5	-	0.021	0.105	0.069	0.054	~~0.123~~	~~0.124~~	~~0.222~~	<0.02
	U3	-	<0.02	0.097	0.079	0.045	~~0.132~~	~~0.118~~	~~0.193~~	0.022
Lefferson Creek	U7	-	<0.02	0.121	0.101	0.046	~~0.201~~	~~0.141~~	~~0.223~~	<0.02
	U4	-	<0.02	0.100	0.093	0.045	~~0.165~~	~~0.141~~	~~0.247~~	<0.02
Benchley Creek	U6	-	<0.02	0.129	0.107	0.045	~~0.202~~	~~0.152~~	~~0.303~~	<0.02
Walker Creek	U8	-	0.023	0.111	0.094	0.056	~~0.193~~	~~0.154~~	~~0.215~~	0.020
Teskey Way Ditch	M9	-	<0.02	0.088	0.088	0.100	~~0.172~~	~~0.154~~	~~0.226~~	<0.02
Bailey Ditch	M10	-	<0.02	0.117	0.106	0.074	~~0.192~~	~~0.175~~	~~0.206~~	<0.02
Chilliwack Creek	M19	-	0.028	0.091	0.094	0.040	~~0.173~~	~~0.156~~	~~0.182~~	<0.02
	M20	-	<0.02	0.146	0.150	0.101	~~0.307~~	~~0.289~~	~~0.765~~	<0.02
Luckakuck Creek	G1	-	<0.02	0.085	0.077	0.036	~~0.128~~	~~0.095~~	~~0.199~~	<0.02

Table C.7 pH Results

Watercourse	Site	13-May-02	27-May-02	21-Aug-02	10-Oct-02	12-Nov-02	12-Dec-02	3-Mar-03	1-May-03	9-Jul-03
Interception Ditch	A15	-	7.3	7.1	8.1	7.3	6.6	7.0	7.2	7.3
	A16	6.4	7.0	7.3	7.6	7.4	7.3	7.1	7.1	8.8
	A18	6.4	6.9	7.2	7.1	7.1	6.9	6.8	7.1	6.9
Teskey Way Ditch	A17	-	7.3	7.5	7.9	7.5	7.3	7.2	7.4	7.8
Semiault Creek	A2	6.5	7.3	6.9	7.5	7.1	6.6	7.2	7.4	7.7
Armstrong Ditch	A11	6.4	7.0	Stream dry	Stream dry	7.8	6.6	7.1	7.2	7.4
Elkview Creek	F12	-	7.7	6.6	8.0	7.6	7.6	7.5	7.8	8.1
	F14	6.0	7.6	7.4	7.8	7.7	7.6	7.6	7.8	7.9
Parsons Brook	F13	6.3	7.4	6.5	7.7	7.5	7.3	7.4	7.6	7.7
Teskey Creek	U5	-	7.5	7.0	7.1	7.3	7.0	7.6	7.5	7.6
	U3	6.7	6.9	7.6	7.5	7.6	7.2	7.7	7.8	7.7
Lefferson Creek	U7	-	7.5	6.9	7.9	7.7	7.6	7.8	8.0	8.0
	U4	6.4	7.0	7.5	7.8	7.7	7.2	7.6	7.7	7.9
Benchley Creek	U6	6.5	7.8	7.6	8.0	7.7	7.6	7.8	7.9	7.9
Walker Creek	U8	6.4	7.5	6.7	8.0	7.7	7.6	7.9	8.0	8.0
Teskey Way Ditch	M9	6.3	7.2	6.8	7.6	7.2	6.9	7.2	7.4	7.4
Bailey Ditch	M10	6.4	7.1	6.9	7.8	7.4	7.0	7.1	7.2	7.5
Chilliwack Creek	M19	6.1	7.2	6.9	7.1	7.0	6.8	7.0	7.1	6.9
	M20	-	7.8	6.7	7.6	7.3	7.0	7.0	7.2	7.3
Luckakuck Creek	G1	6.4	6.3	7.3	6.9	6.9	6.3	6.9	6.8	6.7

Table C.8 Specific Conductivity Results (in μS/cm)

Watercourse	Site	13-May-02	27-May-02	21-Aug-02	10-Oct-02	12-Nov-02	12-Dec-02	3-Mar-03	1-May-03	9-Jul-03
Interception Ditch	A15	-	183	247	329	194	277	149	130	175
	A16	234	247	240	268	221	533	228	160	185
	A18	282	273	298	247	232	379	227	206	277
Teskey Way Ditch	A17	-	335	321	268	200	481	266	268	305
Semiault Creek	A2	382	407	385	319	408	550	352	299	358
Armstrong Ditch	A11	168	183	Stream dry	Stream dry	262	320	169	144	201
Elkview Creek	F12	-	283	261	257	199	304	199	160	197
	F14	253	295	322	309	240	316	272	168	221
Parsons Brook	F13	138	155	156	175	181	204	124	110	143
Teskey Creek	U5	-	207	318	216	103	193	295	265	301
	U3	373	258	258	226	97	186	235	221	248
Lefferson Creek	U7	-	253	243	206	165	252	210	196	217
	U4	282	257	252	196	145	235	239	237	247
Benchley Creek	U6	198	190	204	175	150	196	171	160	190
Walker Creek	U8	207	196	191	165	135	194	178	155	176
Teskey Way Ditch	M9	238	297	236	216	184	353	273	216	225
Bailey Ditch	M10	339	346	343	288	276	538	286	289	329
Chilliwack Creek	M19	349	344	316	237	193	258	282	252	286
	M20	-	331	316	268	222	350	300	271	311
Luckakuck Creek	G1	172	172	172	154	127	167	158	150	154

Table C.9 Temperature Results (in °C)

Watercourse	Site	13-May-02	27-May-02	21-Aug-02	10-Oct-02	12-Nov-02	12-Dec-02	3-Mar-03	1-May-03	9-Jul-03
Interception Ditch	A15	-	15.0	-	-	-	7.0	6.1	11.5	16.9
	A16	12.0	19.0	-	-	-	8.0	8.5	12.3	22.6
	A18	14.0	17.0	-	-	-	8.1	10.2	14.0	20.8
Teskey Way Ditch	A17	-	16.3	-	-	-	7.4	8.2	13.7	15.4
Semiault Creek	A2	12.9	16.0	-	-	-	9.8	9.9	12.3	17.0
Armstrong Ditch	A11	12.4	13.0	-	-	-	8.1	8.2	10.6	14.9
Elkview Creek	F12	-	14.0	16.7	-	-	16.9	5.2	10.1	14.6
	F14	12.0	14.5	18.7	-	-	6.9	5.0	10.3	14.1
Parsons Brook	F13	14.0	13.3	-	-	-	7.3	6.6	10.7	15.2
Teskey Creek	U5	-	15.7	16.6	-	-	6.8	5.5	11.7	15.2
	U3	13.0	13.8	15.3	-	-	7.0	4.6	11.0	13.9
Lefferson Creek	U7	-	13.0	15.3	-	-	7.8	5.6	10.6	13.8
	U4	13.0	14.4	15.8	-	-	7.2	5.0	10.5	14.1
Benchley Creek	U6	13.0	12.8	15.8	-	-	7.7	5.4	10.5	13.7
Walker Creek	U8	11.3	12.0	13.7	-	-	7.5	4.7	10.4	12.3
Teskey Way Ditch	M9	13.0	16.0	18.6	-	-	8.1	8.1	11.9	16.9
Bailey Ditch	M10	14.0	15.5	-	-	-	8.0	7.2	12.3	15.7
Chilliwack Creek	M19	13.0	15.0	-	-	-	7.8	9.5	12.8	13.4
	M20	-	18.0	13.2	-	-	10.4	9.9	12.4	14.9
Luckakuck Creek	G1	11.5	11.4	12.5	-	-	10.1	9.3	10.1	10.8

Table C.10 Dissolved Oxygen Sampling Results (in mg/L)

Watercourse	Site	13-May-02	27-May-02	21-Aug-02	10-Oct-02	12-Nov-02	12-Dec-02	3-Mar-03	1-May-03	9-Jul-03
Interception Ditch	A15	-	9.2	-	-	-	-	10.6	-	6.0
	A16	8.3	8.9	-	-	-	-	11.2	-	12.6
	A18	6.2	8	-	-	-	-	8.5	-	9.1
Teskey Way Ditch	A17	-	9.1	-	-	-	-	11	-	9.3
Semiault Creek	A2	8.2	8.6	-	-	-	-	8.6	-	11.9
Armstrong Ditch	A11	8.5	7.8	-	-	-	-	10.8	-	9.3
Elkview Creek	F12	-	7.7	8.7	-	-	-	12.2	-	9.8
	F14	-	11.5	4.5	-	-	-	12.6	-	10.6
Parsons Brook	F13	-	7.8	-	-	-	-	11.9	-	9.2
Teskey Creek	U5	-	10.8	3.9	-	-	-	7.7	-	9.1
	U3	8.9	8.2	9.3	-	-	-	8.2	-	9.6
Lefferson Creek	U7	-	7.4	9.4	-	-	-	11.9	-	10.0
	U4	9.3	11.4	8.5	-	-	-	7.9	-	9.9
Benchley Creek	U6	9.3	12.8	8.9	-	-	-	12.6	-	10.2
Walker Creek	U8	9.0	8.8	9.3	-	-	-	12.5	-	11.2
Teskey Way Ditch	M9	9.2	6	15.2	-	-	-	11.1	-	7.2
Bailey Ditch	M10	7.6	8.7	8.0	-	-	-	9	-	9.3
Chilliwack Creek	M19	8.3	7	-	-	-	-	11	-	9.0
	M20	-	9.3	5.2	-	-	-	5.9	-	6.2
Luckakuck Creek	G1	7.1	13.7	9.2	-	-	-	8.6	-	9.3

Table C.11 Dissolved Major Ion (Ca, K, Mg and Na) Results (in ppm)

Watercourse	Site	Ca			K			Mg			Na		
		27-May-02	3-May-03	9-Jul-03	27-May-02	3-May-03	9-Jul-03	27-May-02	3-May-03	9-Jul-03	27-May-02	3-May-03	9-Jul-03
Interception Ditch	A15	18.656	16.204	20.779	0.554	<0.5	0.692	3.199	2.601	3.295	-	5.120	7.246
	A16	23.873	21.183	19.297	0.893	0.965	1.569	3.722	3.313	4.677	-	6.306	8.174
	A18	30.405	27.358	36.118	1.376	1.404	1.671	5.563	4.907	7.042	-	6.596	6.175
Teskey Way Ditch	A17	34.608	35.128	40.200	1.817	2.420	1.763	7.208	7.222	7.898	-	8.998	7.256
Semiault Creek	A2	50.790	48.071	53.117	1.427	1.257	1.143	6.826	6.464	7.487	-	6.353	7.064
Armstrong Ditch	A11	22.222	20.510	27.185	0.557	0.669	0.631	3.152	2.693	3.758	-	3.635	5.811
Elkview Creek	F12	23.794	19.787	23.569	0.832	0.664	0.839	3.208	2.422	2.829	-	8.281	9.344
	F14	25.913	20.554	27.091	0.831	0.685	0.872	3.224	2.502	3.062	-	8.362	9.983
Parsons Brook	F13	15.033	13.740	18.037	0.532	<0.5	0.570	2.293	1.901	2.664	-	4.200	5.932
Teskey Creek	U5	15.567	25.767	27.649	1.201	1.469	2.129	5.526	8.594	9.648	-	13.901	12.800
	U3	21.500	24.182	27.354	1.281	1.280	1.601	6.177	6.927	7.463	-	9.988	8.356
Lefferson Creek	U7	26.477	26.715	29.473	1.109	1.213	1.647	6.996	7.155	7.449	-	3.931	3.715
	U4	22.225	24.680	27.091	1.297	1.235	2.232	6.323	6.769	7.480	-	11.924	8.212
Benchley Creek	U6	21.080	21.621	25.649	0.782	0.794	0.814	5.341	5.404	6.167	-	3.591	3.533
Walker Creek	U8	20.819	23.506	24.553	1.149	1.031	1.094	6.286	5.388	5.536	-	3.048	2.926
Teskey Way Ditch	M9	30.083	30.428*	30.890	0.610	0.696*	0.795	4.965	5.383*	4.941	-	7.379*	5.760
Bailey Ditch	M10	35.627	38.984	43.906	1.783	2.477	1.828	7.428	8.092	8.838	-	9.172	7.177
Chilliwack Creek	M19	39.449	37.355	39.438	2.675	2.205	2.712	5.957	5.269	6.191	-	6.325	6.836
	M20	37.726	40.021	43.244	2.462	1.800	1.768	6.992	7.016	7.739	-	5.777	5.999
Luckakuck Creek	G1	20.848	22.156	21.924	0.944	0.967	0.939	2.253	2.272	2.275	-	3.325	3.172

* average of triplicate samples

Table C.12 Dissolved Metals (Fe and Mn) Results (in ppm)

Watercourse	Site	Fe			Mn		
		27-May-02	3-May-03	9-Jul-03	27-May-02	3-May-03	9-Jul-03
Interception Ditch	A15	0.666	0.546	0.588	0.086	0.076	0.138
	A16	1.359	1.038	0.794	0.163	0.133	0.007
	A18	1.583	1.685	0.805	0.187	0.204	0.218
Teskey Way Ditch	A17	0.732	0.804	0.567	0.062	0.247	0.008
Semiault Creek	A2	0.478	0.377	0.210	0.252	0.220	0.172
Armstrong Ditch	A11	0.937	0.578	0.584	0.099	0.082	0.055
Elkview Creek	F12	<0.05	<0.05	<0.05	<0.005	<0.005	<0.005
	F14	<0.05	<0.05	<0.05	<0.005	<0.005	<0.005
Parsons Brook	F13	0.185	0.110	0.184	0.042	0.023	0.038
Teskey Creek	U5	0.330	0.157	0.166	0.008	0.058	0.046
	U3	0.091	<0.05	<0.05	<0.005	<0.005	<0.005
Lefferson Creek	U7	<0.05	<0.05	<0.05	0.009	<0.005	<0.005
	U4	0.155	0.160	0.085	0.035	0.035	<0.005
Benchley Creek	U6	<0.05	<0.05	<0.05	0.010	<0.005	<0.005
Walker Creek	U8	0.074	<0.05	<0.05	0.006	<0.005	<0.005
Teskey Way Ditch	M9	0.637	0.313	0.424	0.096	0.083	0.043
Bailey Ditch	M10	0.861	1.079	0.600	0.119	0.380	0.124
Chilliwack Creek	M19	0.070	0.086	<0.05	0.026	0.018	0.012
	M20	0.472	0.399	0.157	0.240	0.257	0.066
Luckakuck Creek	G1	<0.05	<0.05	<0.05	<0.005	<0.005	<0.005

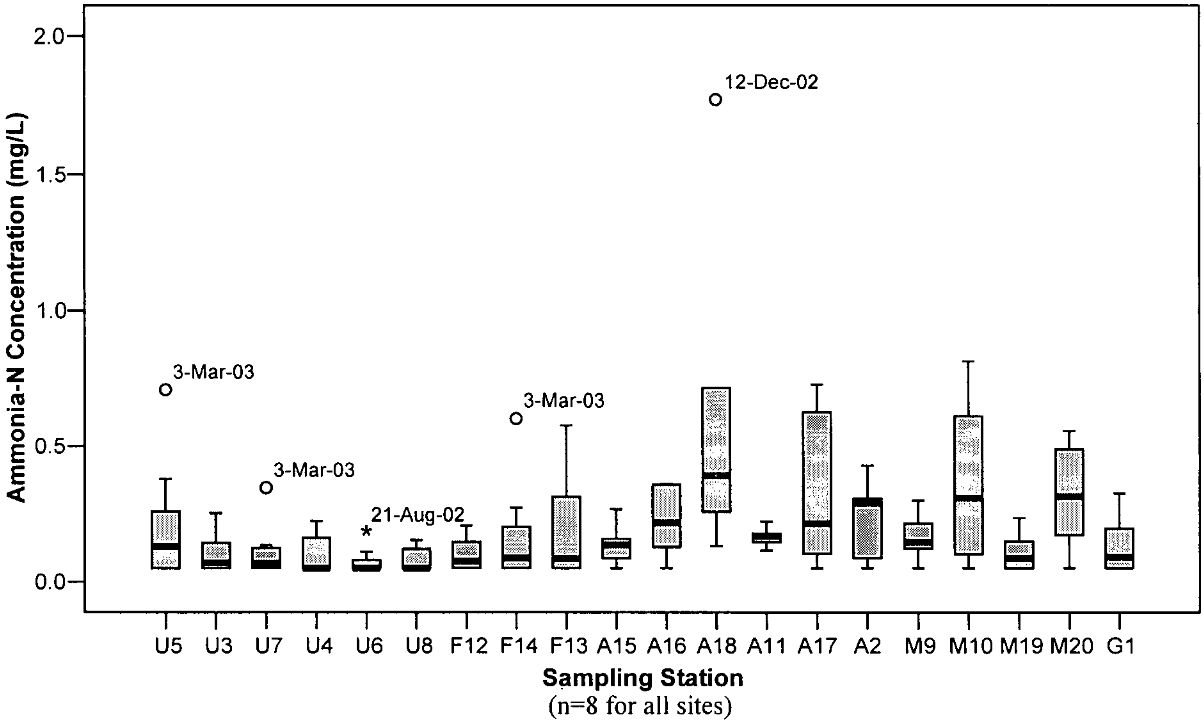
* average of triplicate samples

Table C.13 16-October-2003 Storm Sampling Results for Nitrate-N and Dissolved Elements

Watercourse (Site)	Time	Nitrate-N (mg/L)	Al (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Ca (ppm)	K (ppm)	Mg (ppm)	Na (ppm)
Teskey Creek (U3)	1:19	0.292	0.562	0.524	0.011	<0.010	3.315	1.525	0.779	2.763
	3:24	1.123	0.529	0.533	0.010	<0.010	7.216	1.989	2.084	2.753
	4:51	1.401	0.775	0.752	0.015	<0.010	8.135	2.171	2.414	3.153
	6:20	1.501	0.543	0.552	0.013	<0.010	9.009	2.186	2.607	3.486
Elkview Creek (F14)	1:33	1.391	0.250	0.284	0.008	<0.010	22.975	1.418	2.715	8.842
	3:37	1.656	0.265	0.312	0.008	<0.010	18.589	1.598	2.283	7.695
	5:06	1.914	0.284	0.329	0.010	<0.010	19.554	1.596	2.373	7.861
	6:32	2.141	0.220	0.269	0.008	<0.010	19.722	1.575	2.389	7.821
Semiault Creek (A2)	1:38	2.104	0.091	0.248	0.113	0.014	62.453	5.958	8.472	7.795
	3:45	3.025	0.103	0.256	0.136	0.015	60.983	7.015	8.369	8.497
	5:10	4.411	0.188	0.327	0.182	0.026	66.647	6.771	8.650	7.885
	6:36	7.617	0.427	0.415	0.348	0.050	74.740	6.871	9.061	7.069
Interception Ditch (A18)	1:44	1.228	0.194	0.431	0.092	<0.010	26.138	4.595	5.767	7.847
	3:50	2.416	0.397	0.473	0.159	<0.010	25.400	4.536	5.441	8.130
	5:26	3.149	1.121	1.237	0.159	<0.010	24.896	5.009	5.431	7.986
	6:42	3.903	0.179	0.311	0.182	<0.010	26.155	4.804	5.654	9.192
Chilliwack Creek (M20)	5:19	1.274	0.066	0.361	0.082	<0.010	15.772	2.225	3.213	3.504

Extreme Outliers:

A16 (12-Dec-02): 3.41;
A17 (12-Dec-02): 4.23;
M10 (12-Dec-02): 5.23



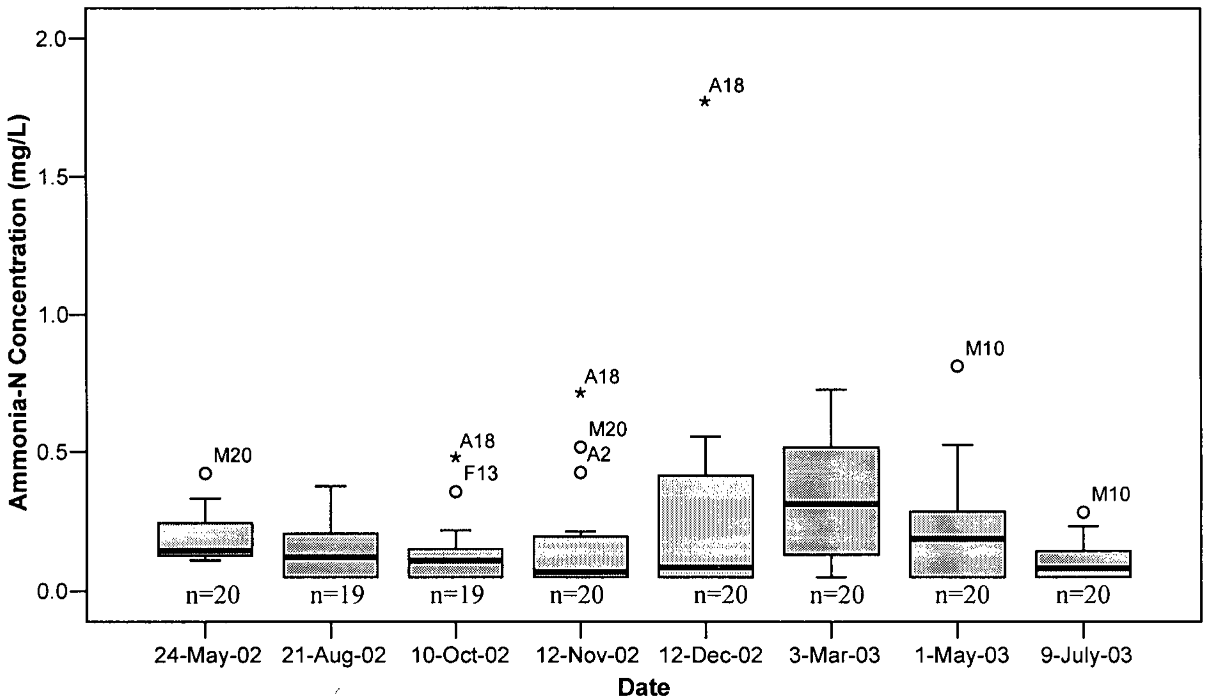
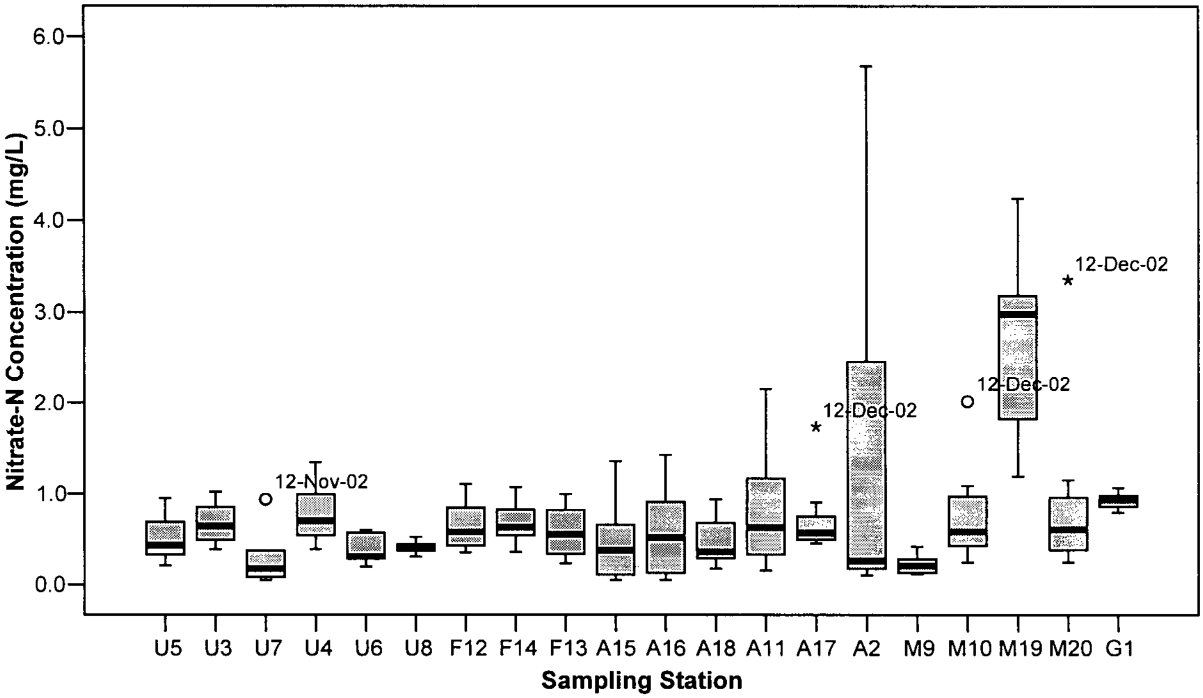


Figure C.1 Boxplots of Ammonia-N Results (mg/L) by Sampling Station and Sampling Date



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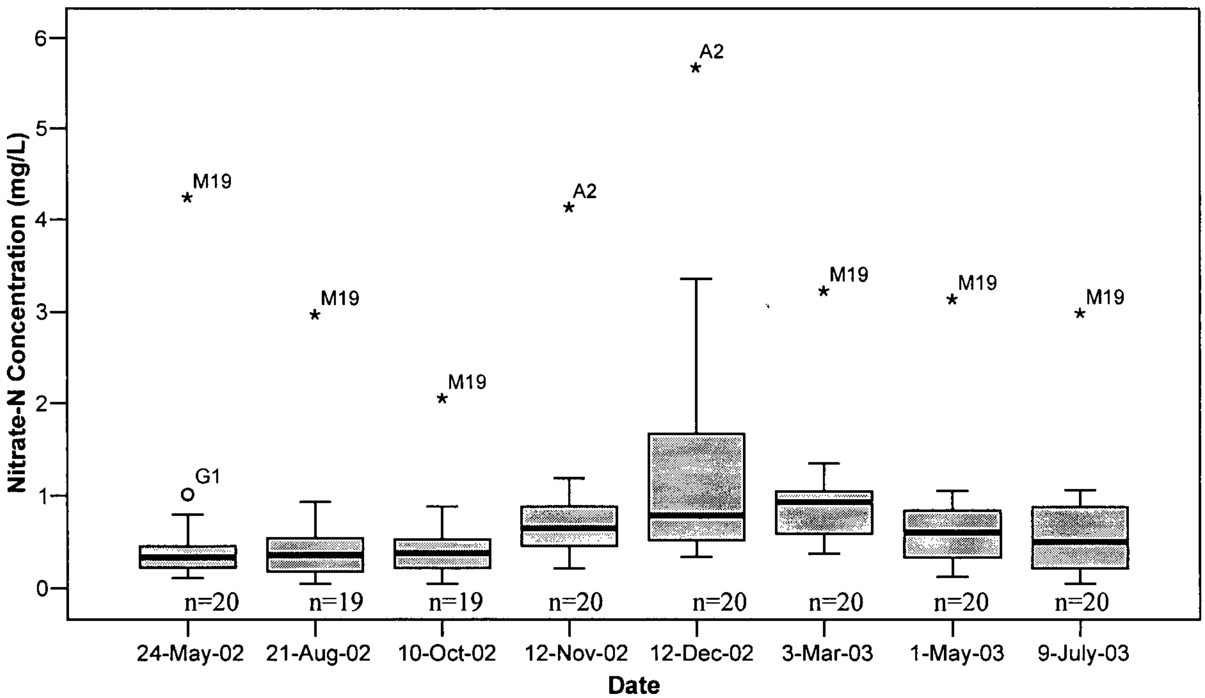
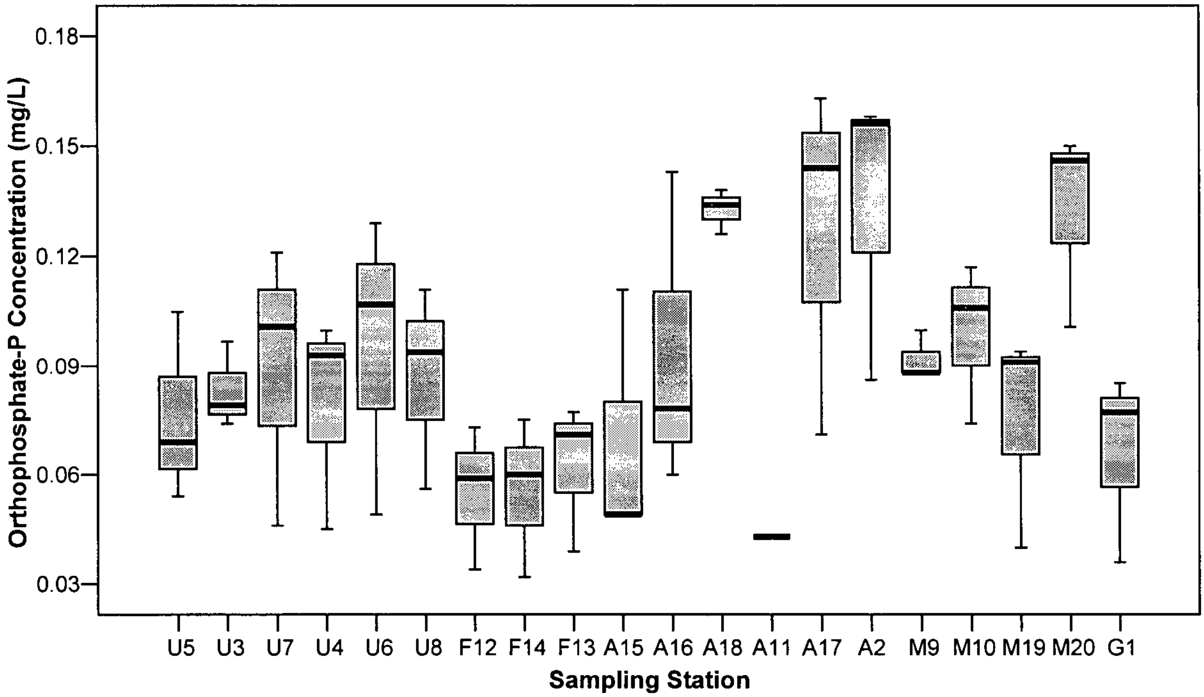


Figure C.2 Boxplots of Nitrate-N Results (mg/L) by Sampling Station and Sampling Date



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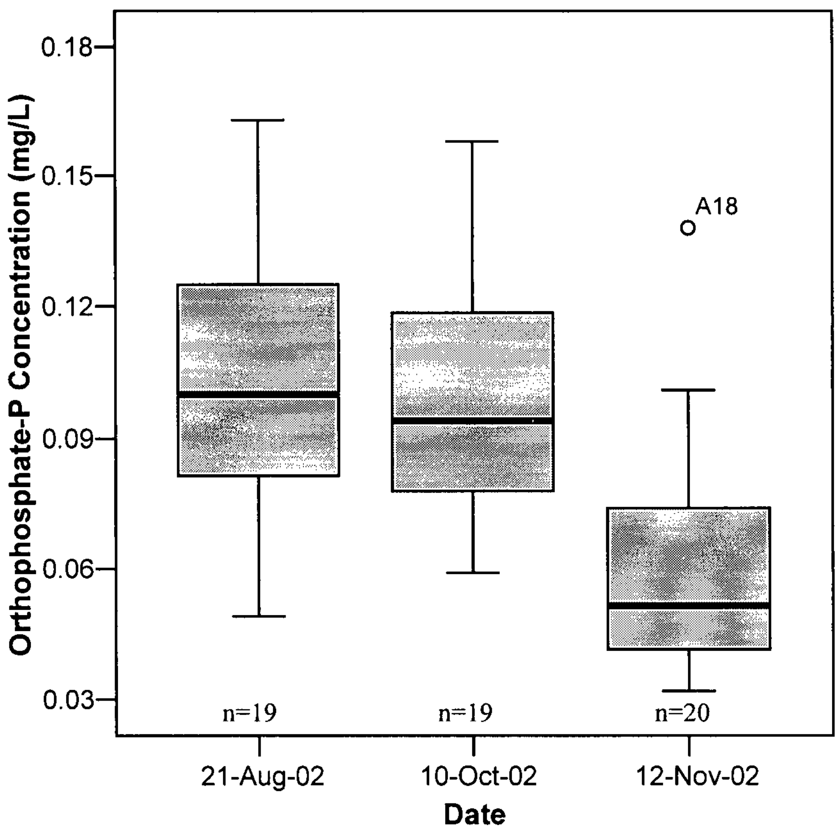
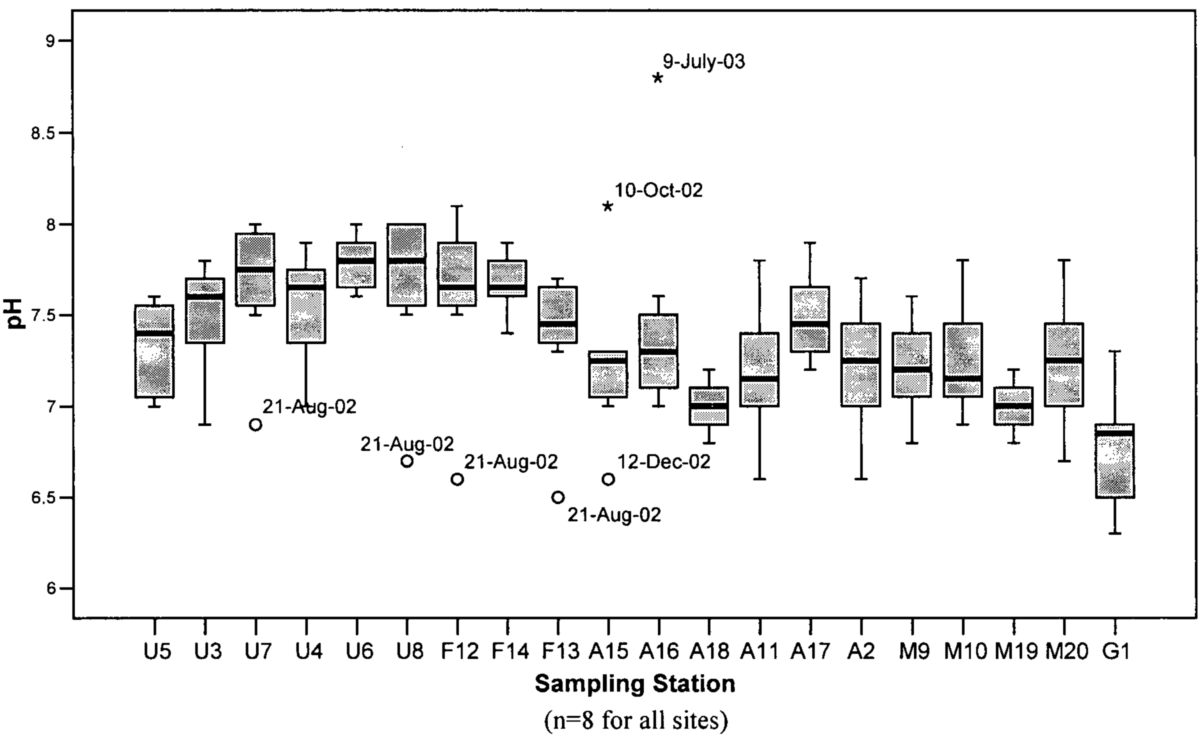


Figure C.3 Boxplots of Orthophosphate-P Results (mg/L) by Sampling Station and Sampling Date



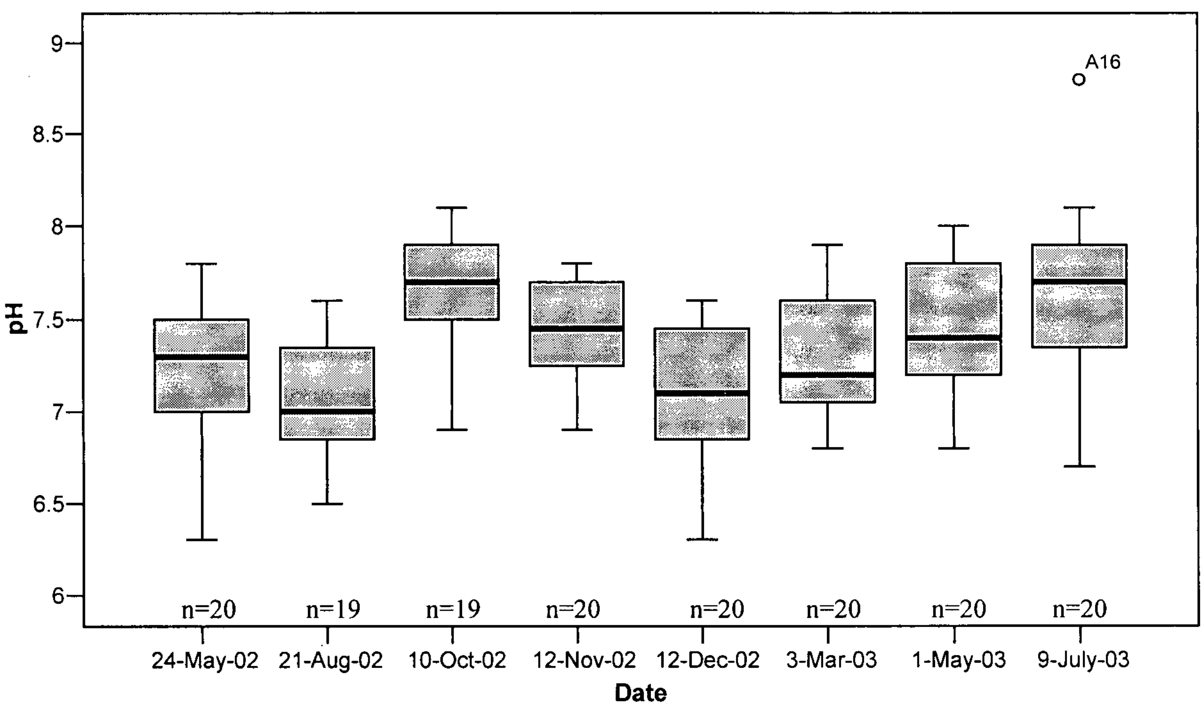
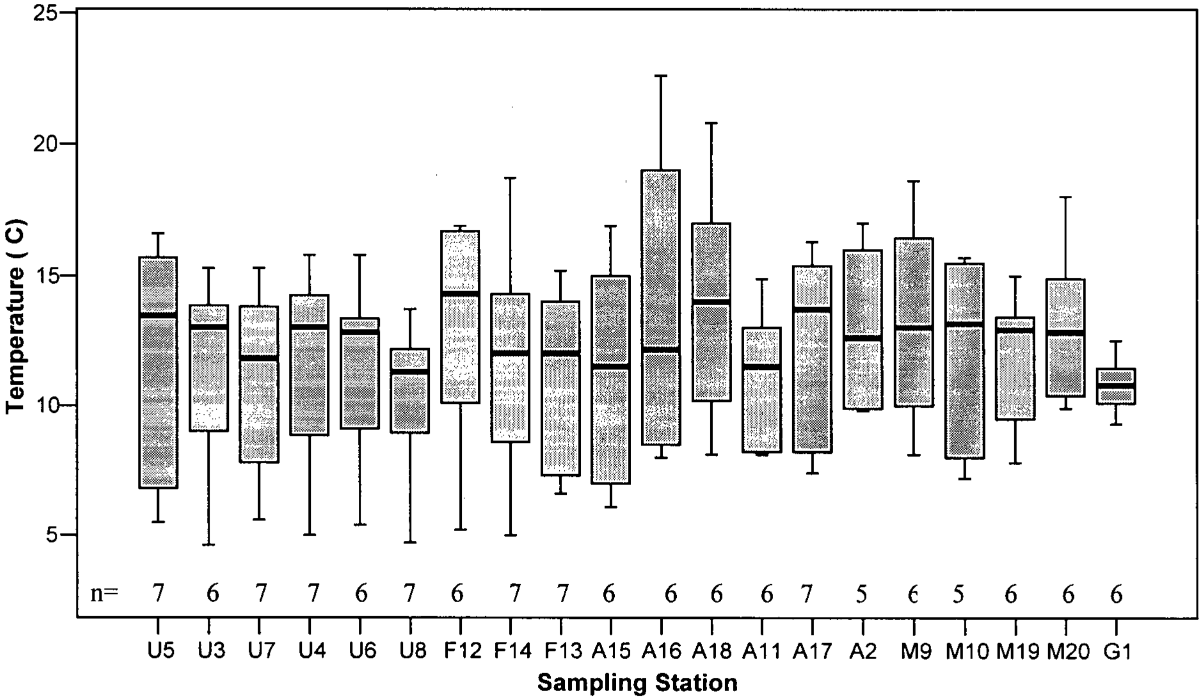


Figure C.4 Boxplots of pH Results by Sampling Station and Sampling Date



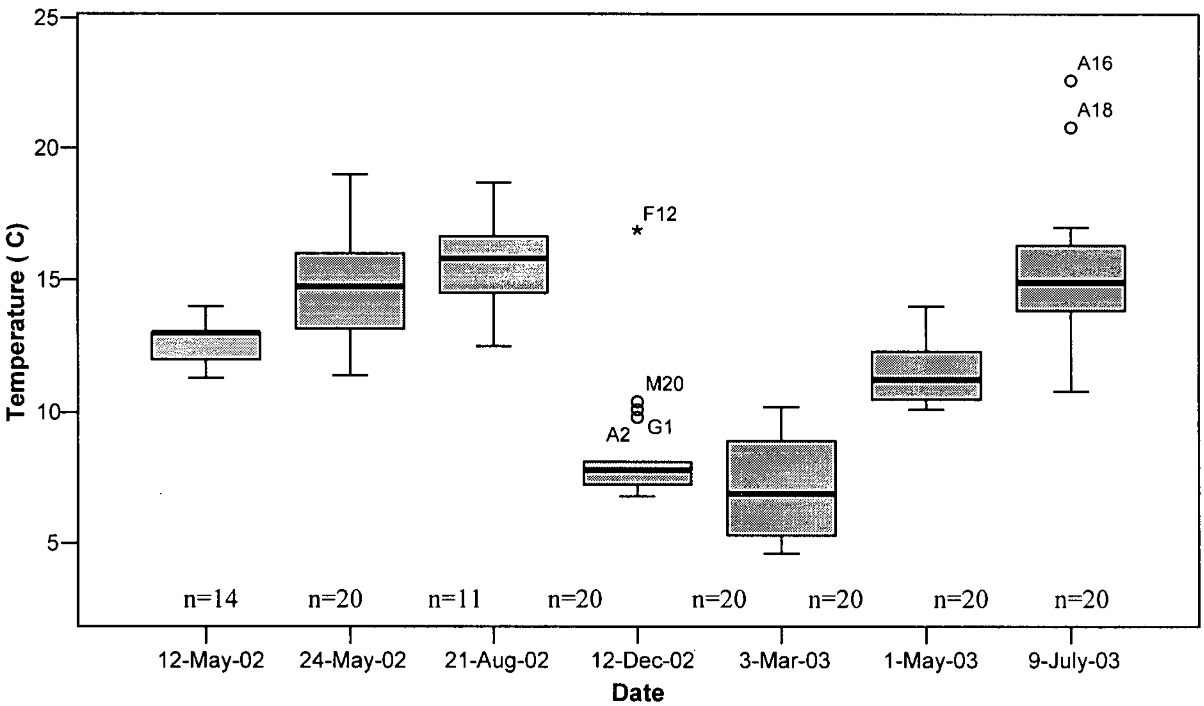
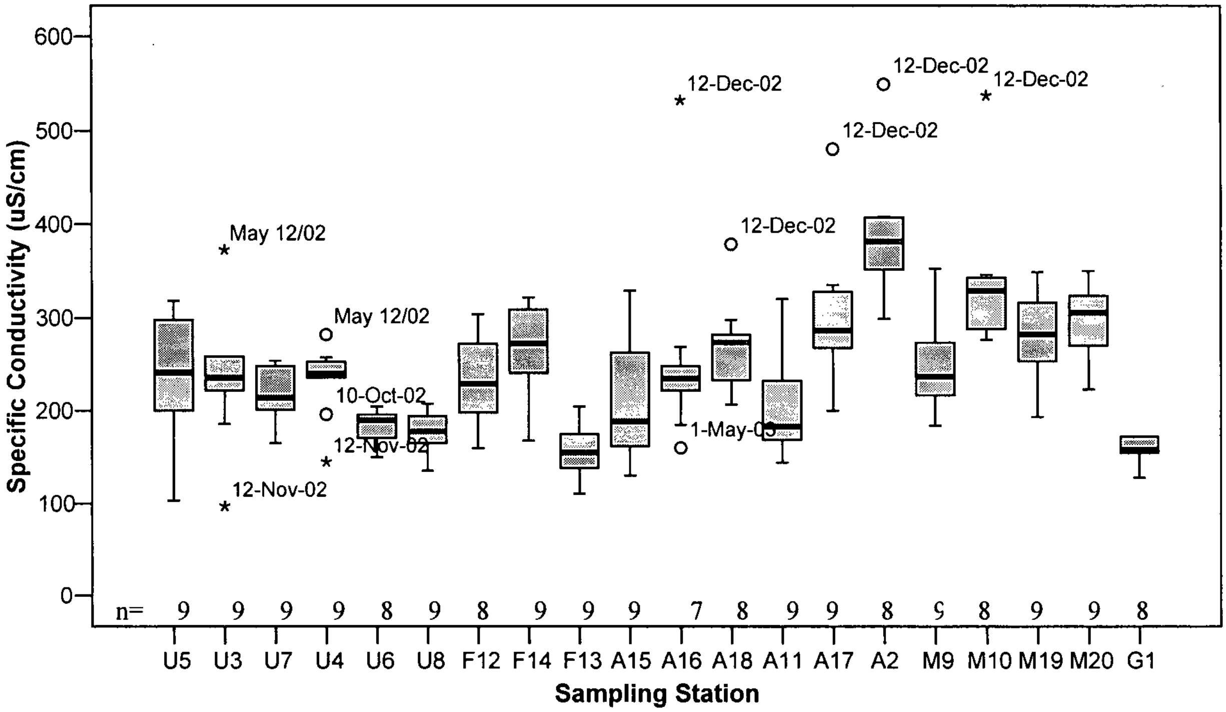


Figure C.5 Boxplots of Temperature Results (°C) by Sampling Station and Sampling Date



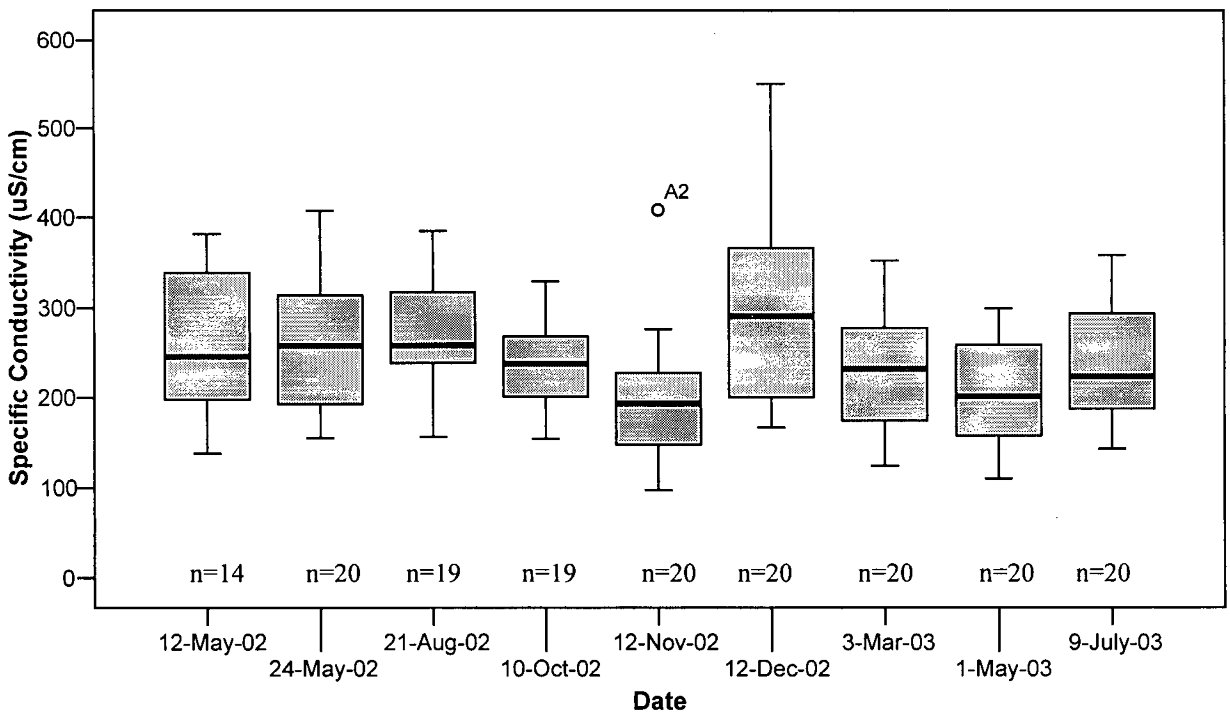
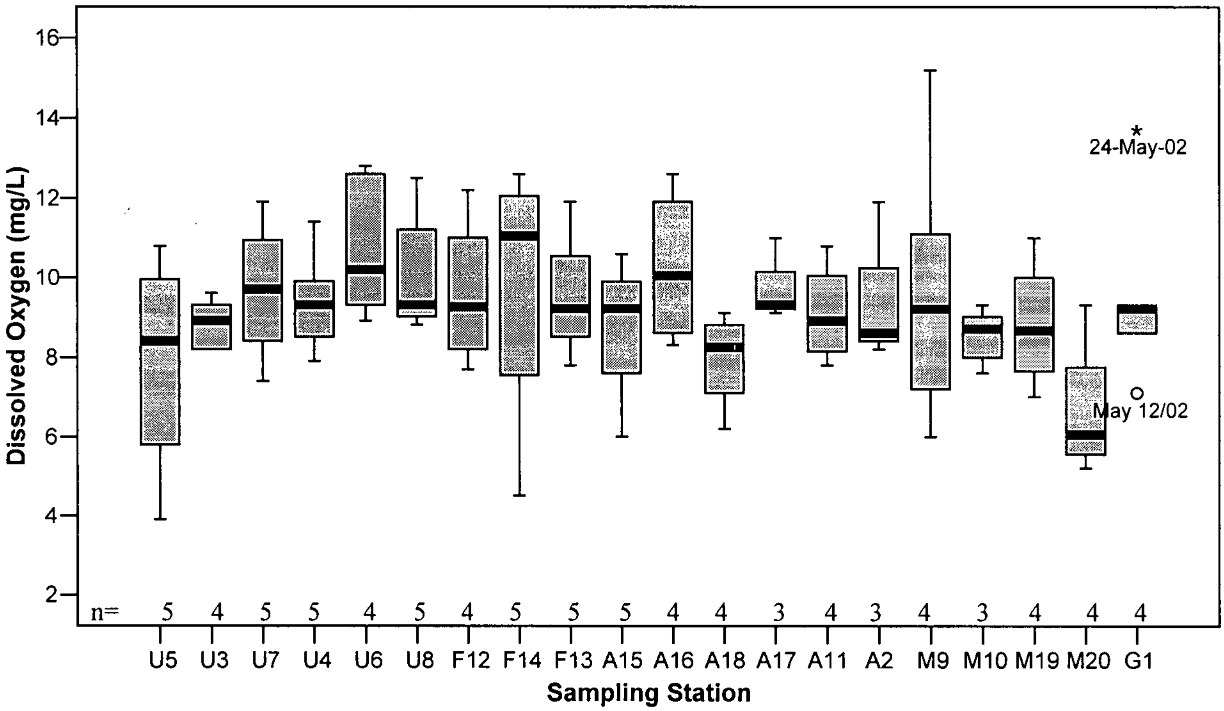


Figure C.6 Boxplots of Specific Conductivity Results (μS/cm) by Sampling Station and Sampling Date



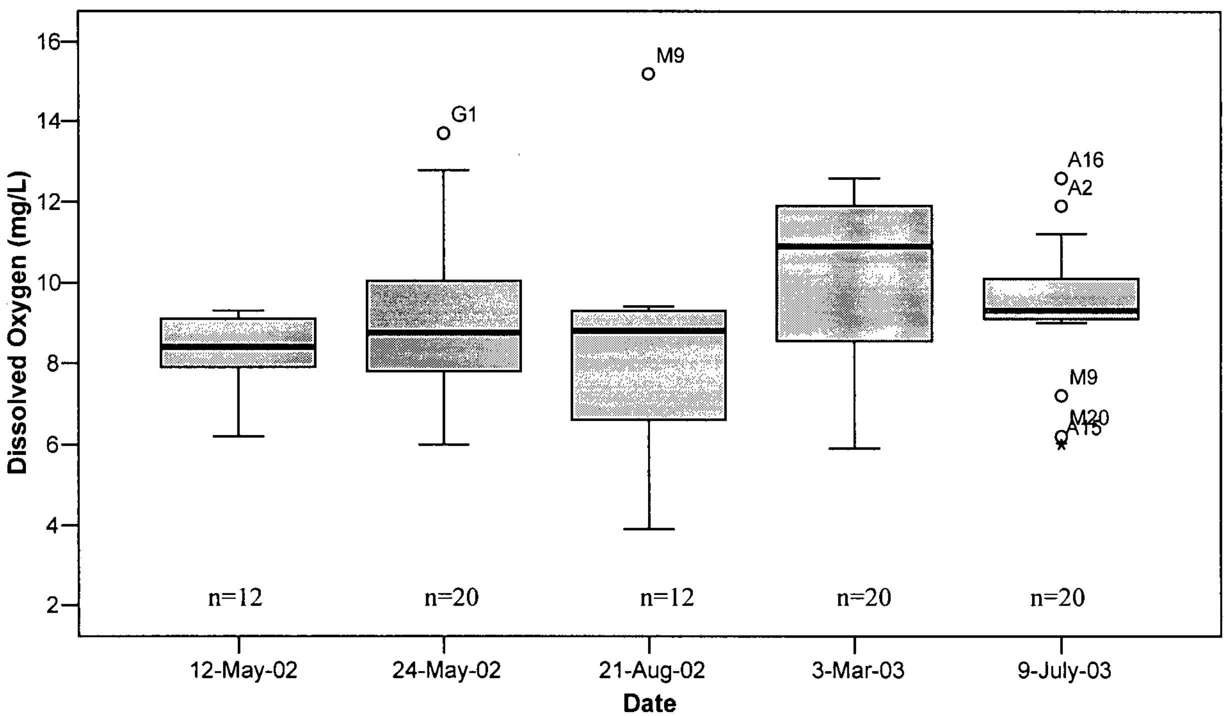
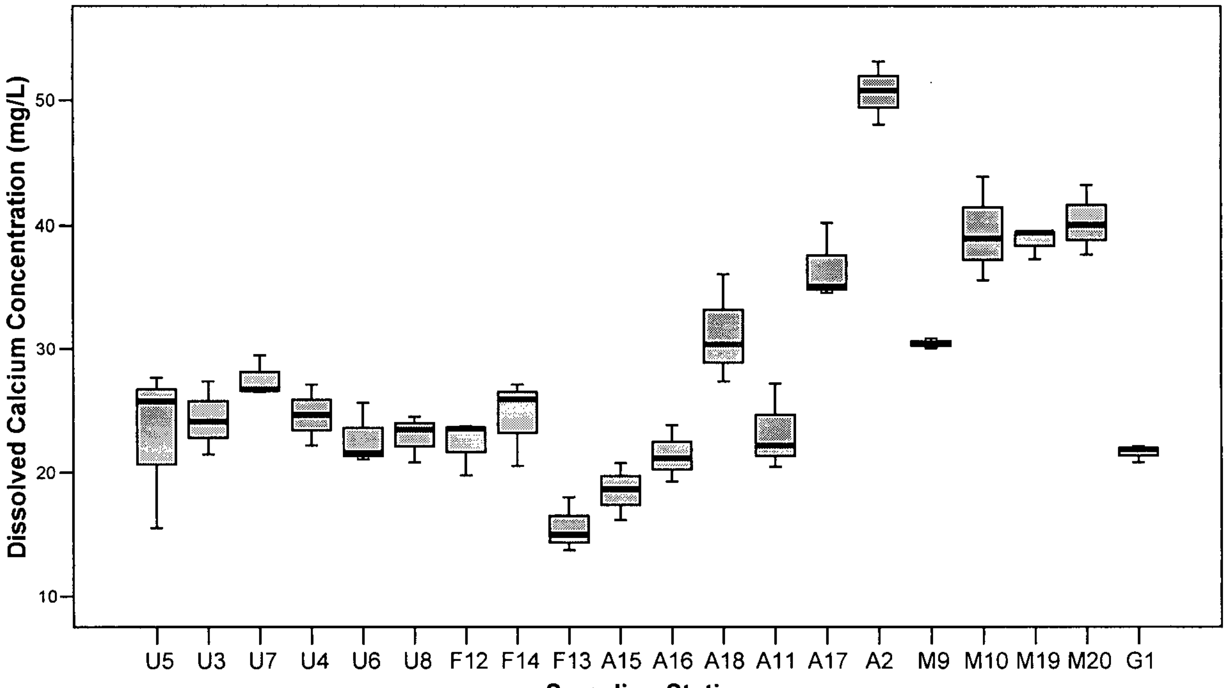


Figure C.7 Boxplots of Dissolved Oxygen Results (mg/L) by Sampling Station and Sampling Date



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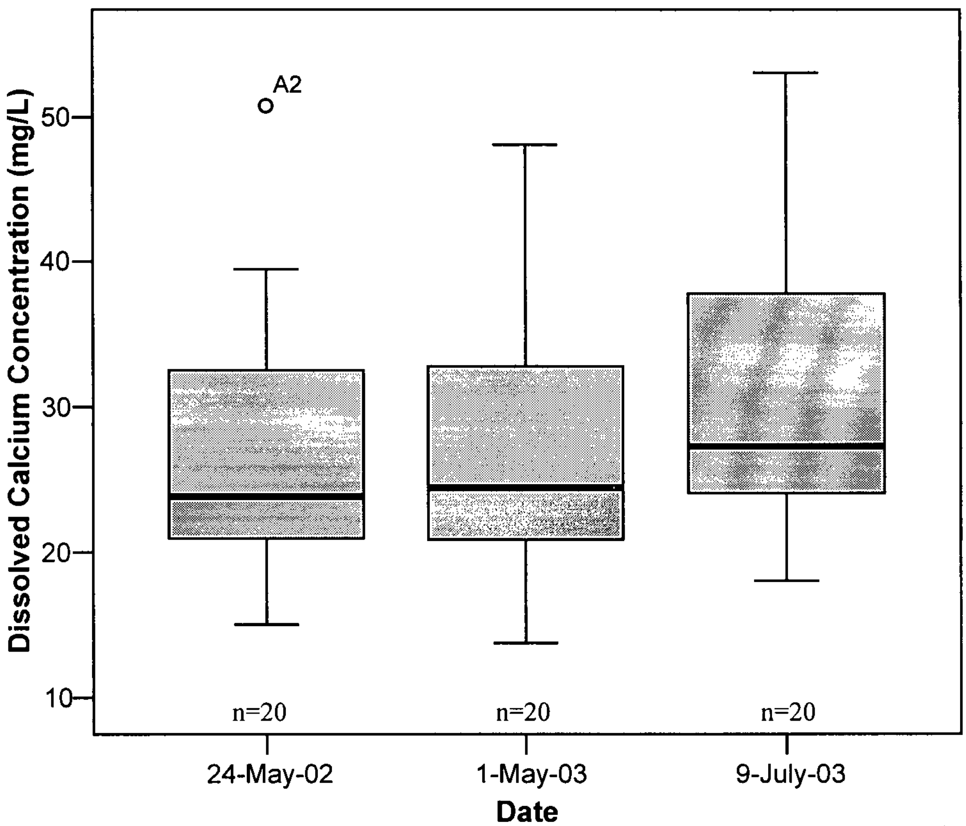
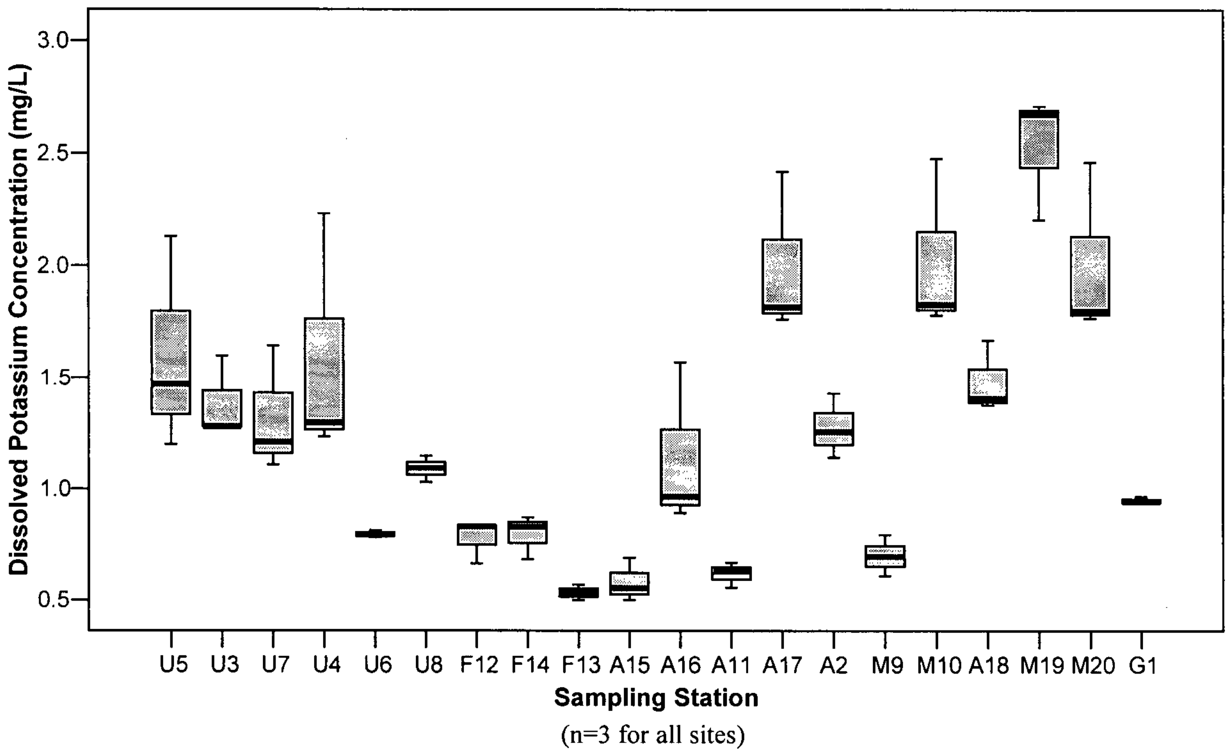


Figure C.8 Boxplots of Dissolved Calcium Results (mg/L) by Sampling Station and Sampling Date



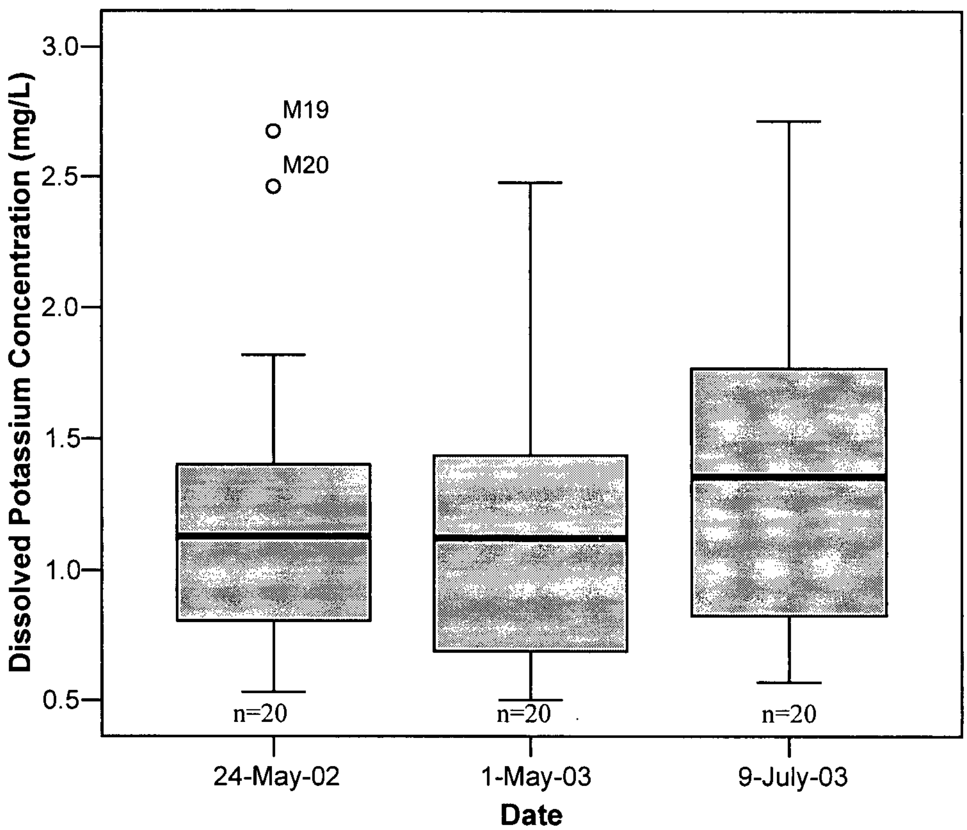
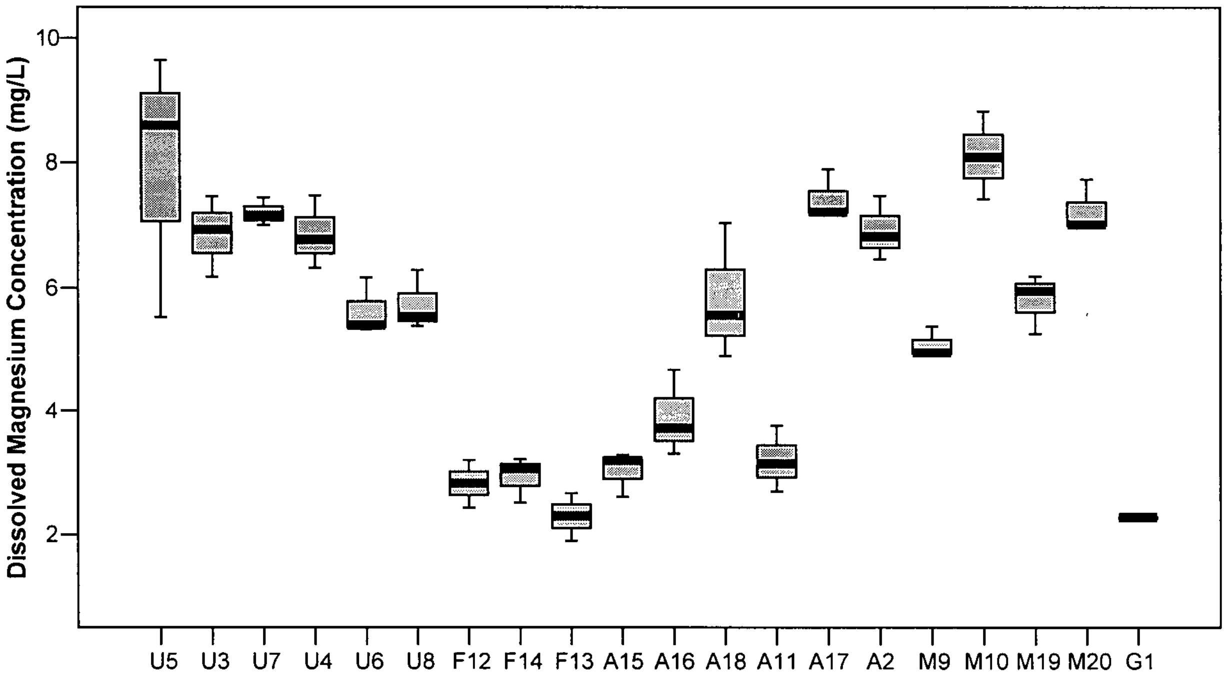


Figure C.9 Boxplots of Dissolved Potassium Results (mg/L) by Sampling Station and Sampling Date



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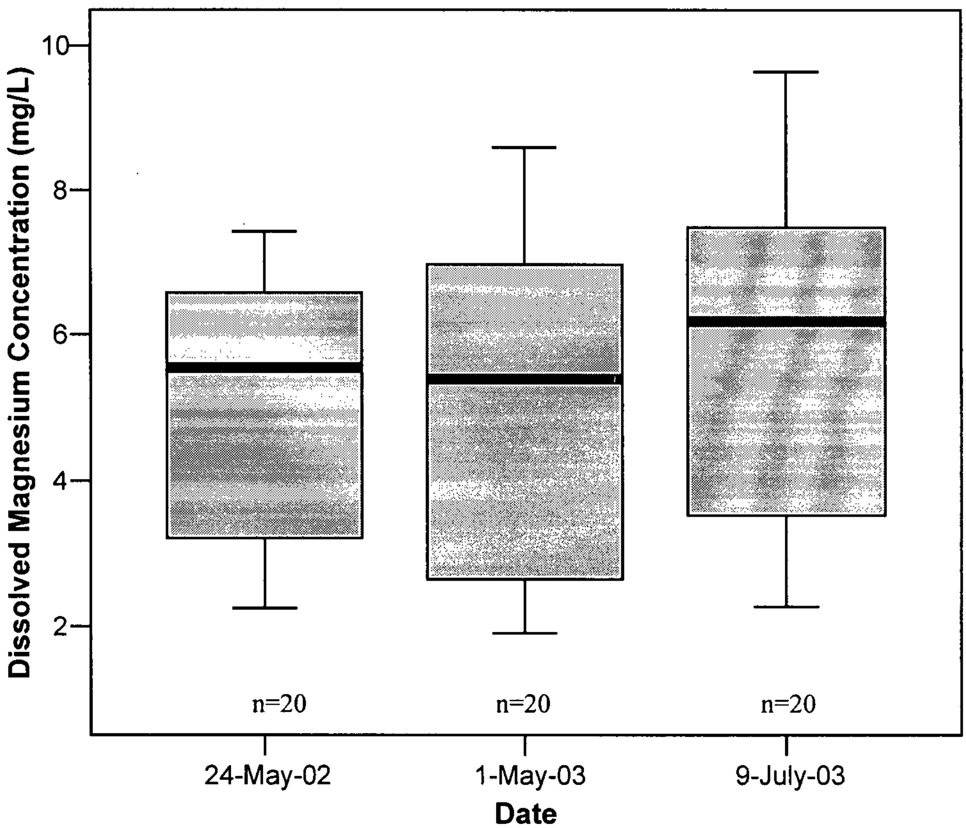
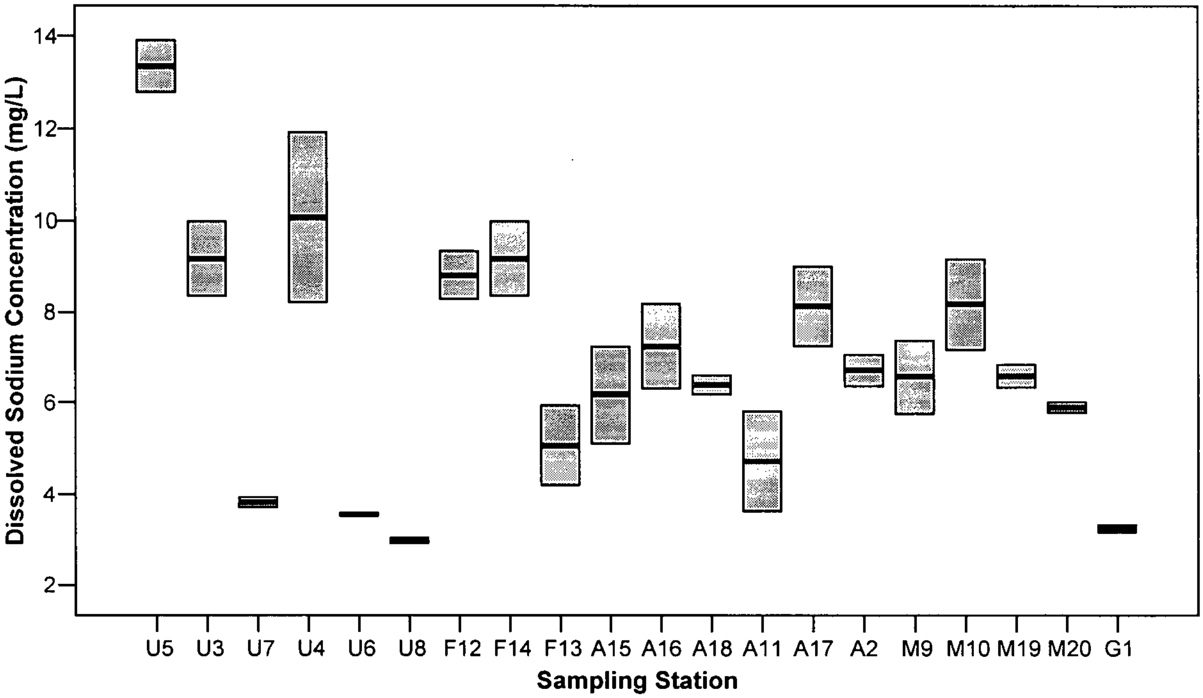


Figure C.10 Boxplots of Dissolved Magnesium Results (mg/L) by Sampling Station and Sampling Date



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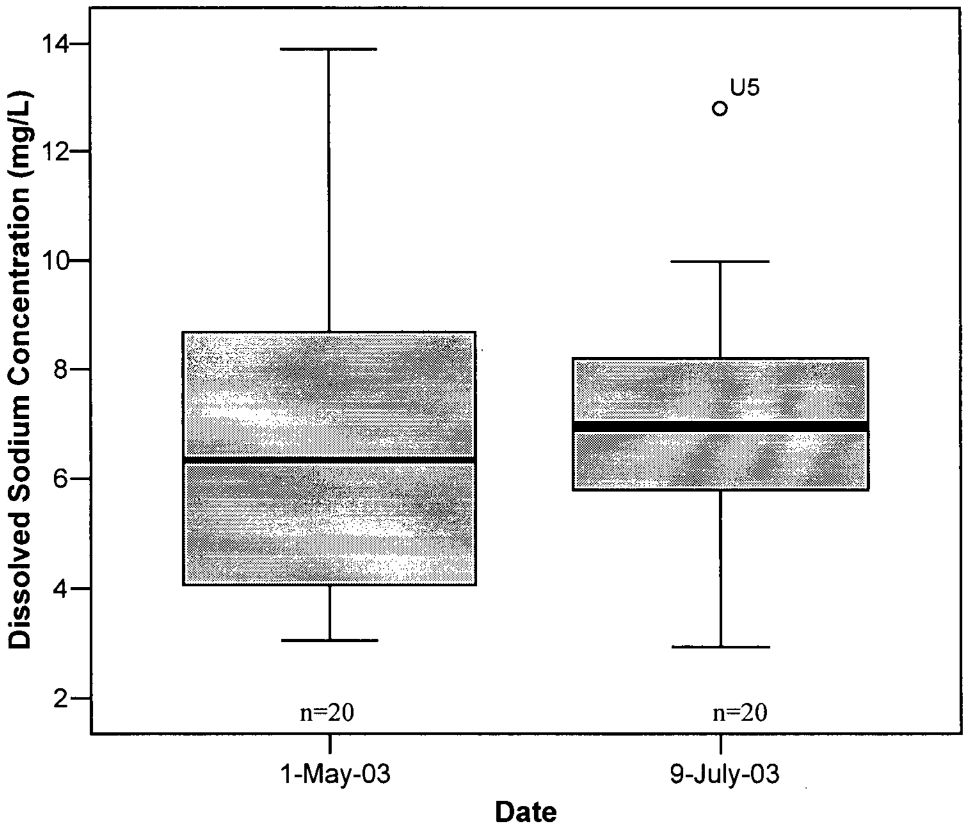
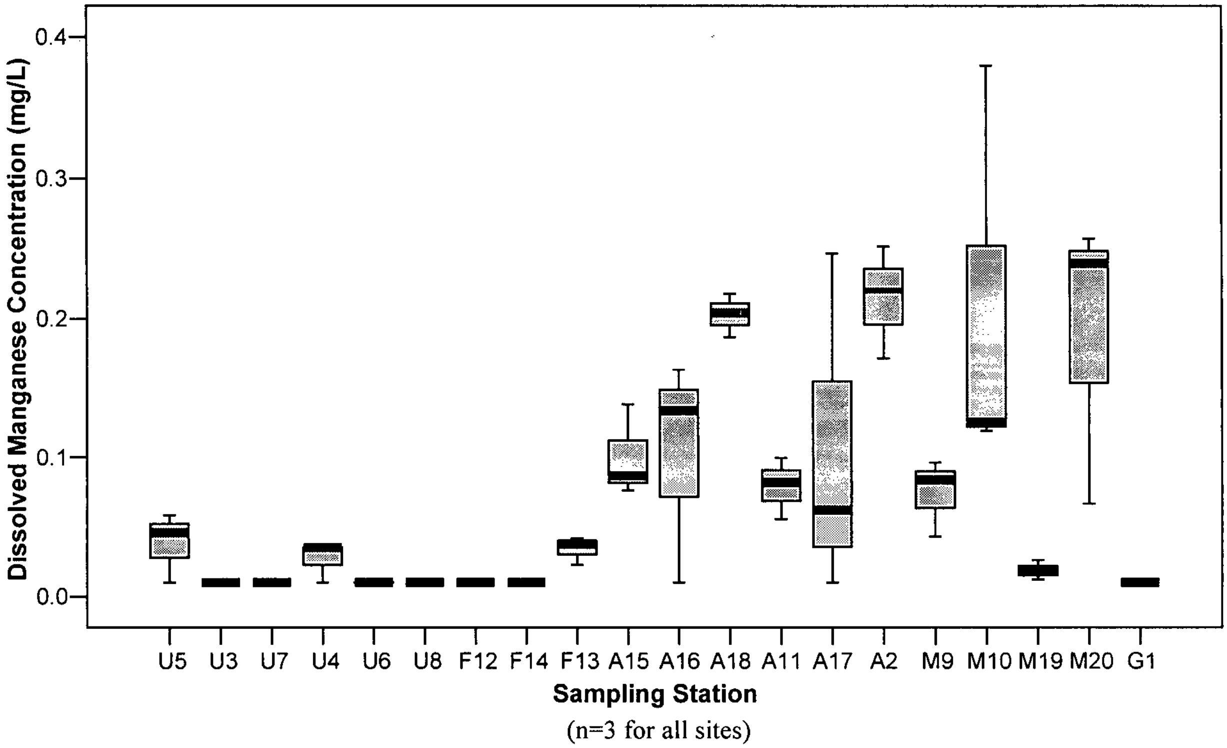


Figure C.11 Boxplots of Dissolved Sodium Results (mg/L) by Sampling Station and Sampling Date



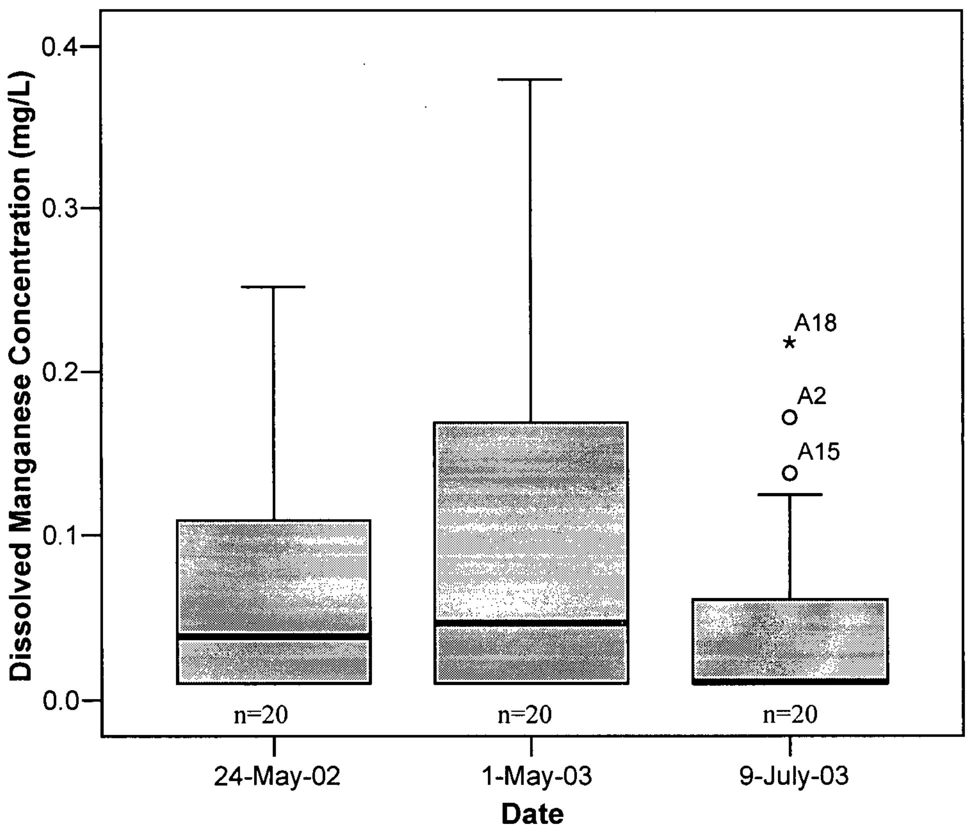
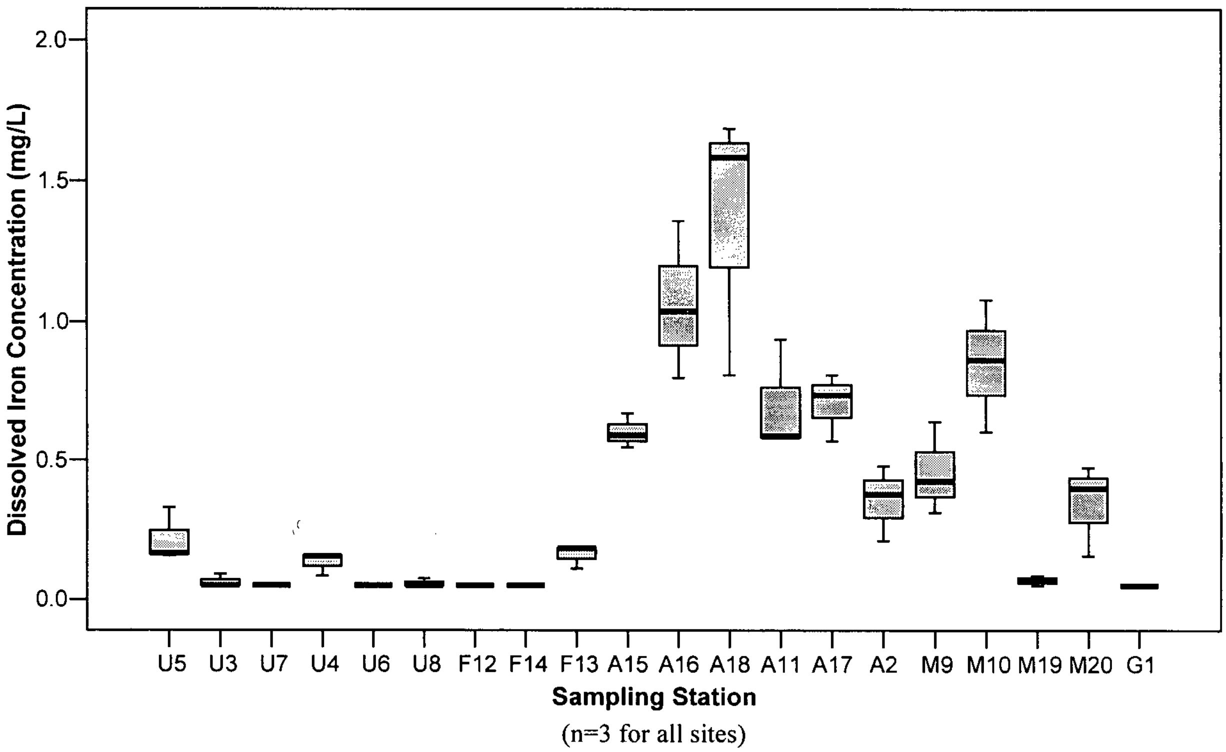


Figure C.12 Boxplots of Dissolved Manganese Results (mg/L) by Sampling Station and Sampling Date



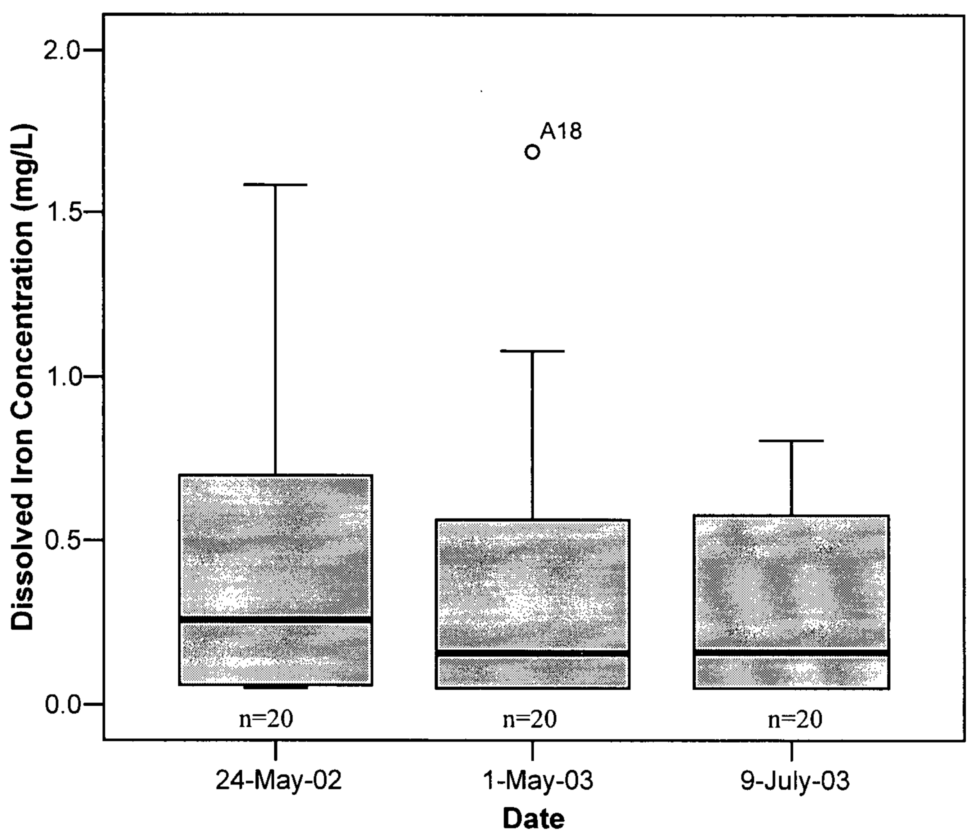


Figure C.13 Boxplots of Dissolved Iron Results (mg/L) by Sampling Station and Sampling Date

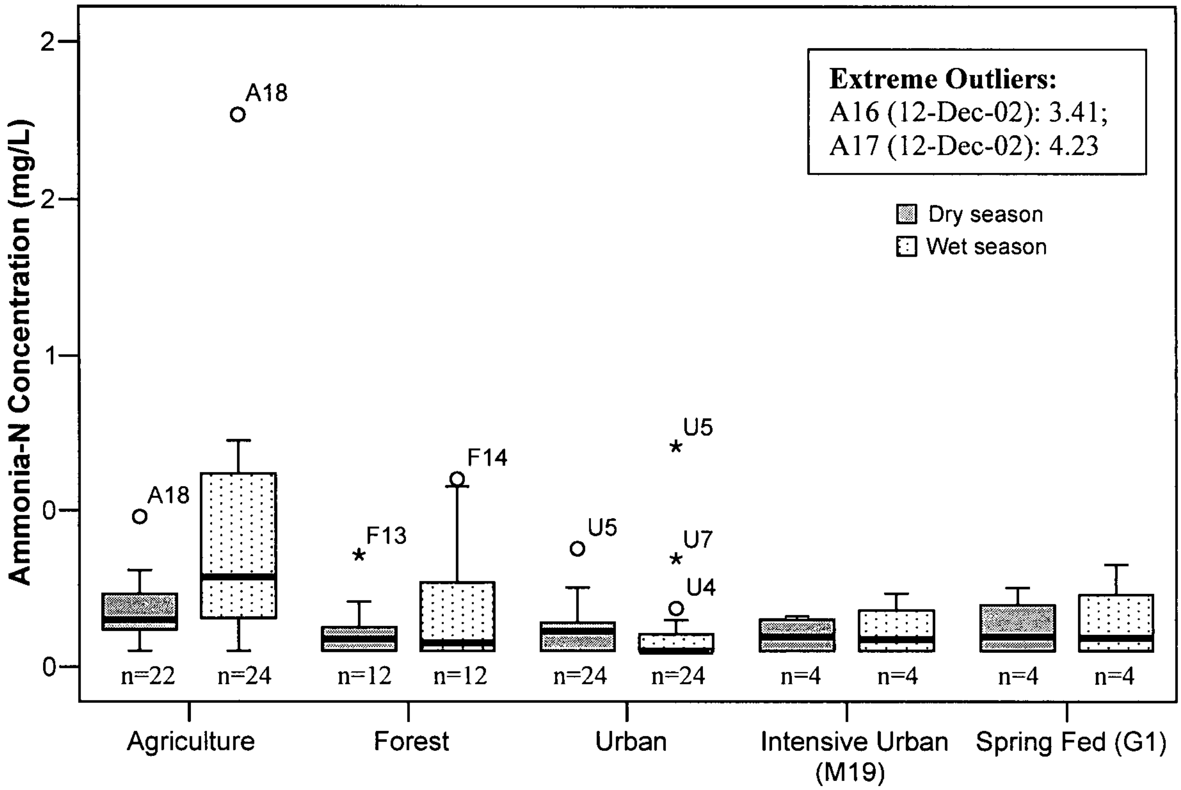


Figure C.14 Boxplots of Ammonia-N Results (mg/L) by Land Use Category

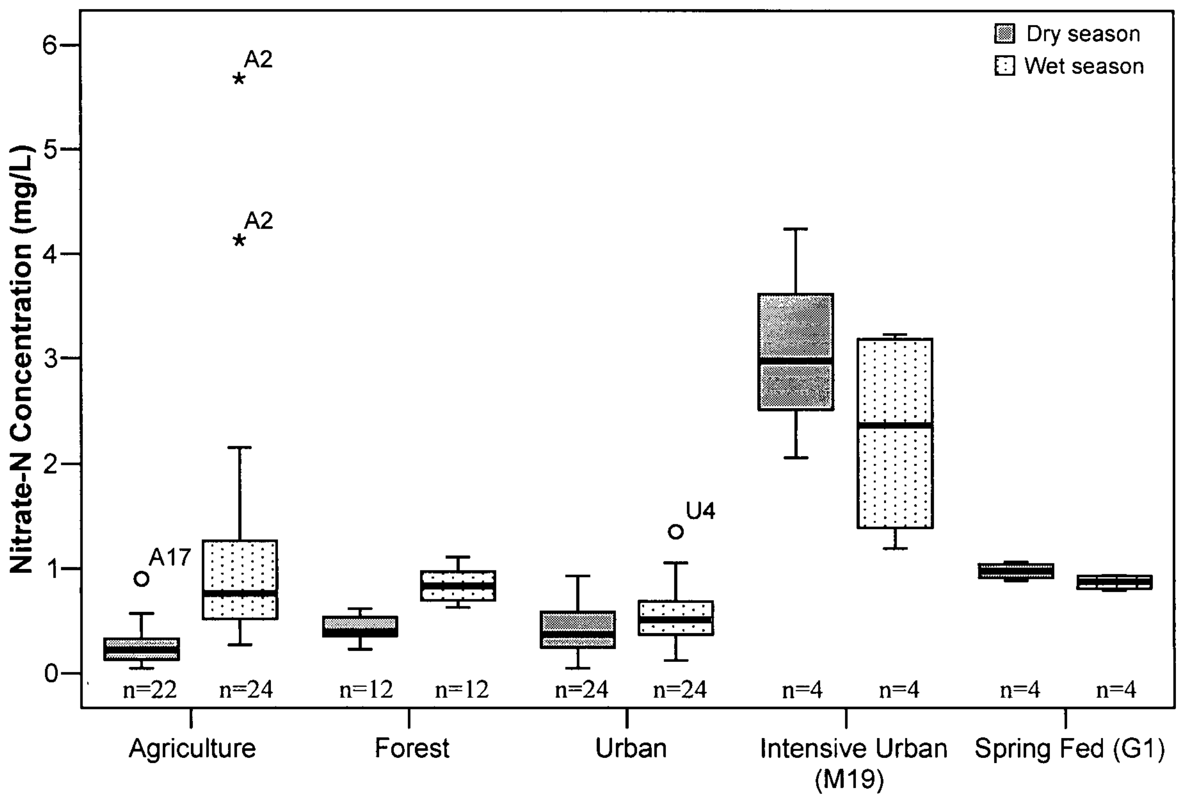


Figure C.15 Boxplots of Nitrate-N Results (mg/L) by Land Use Category

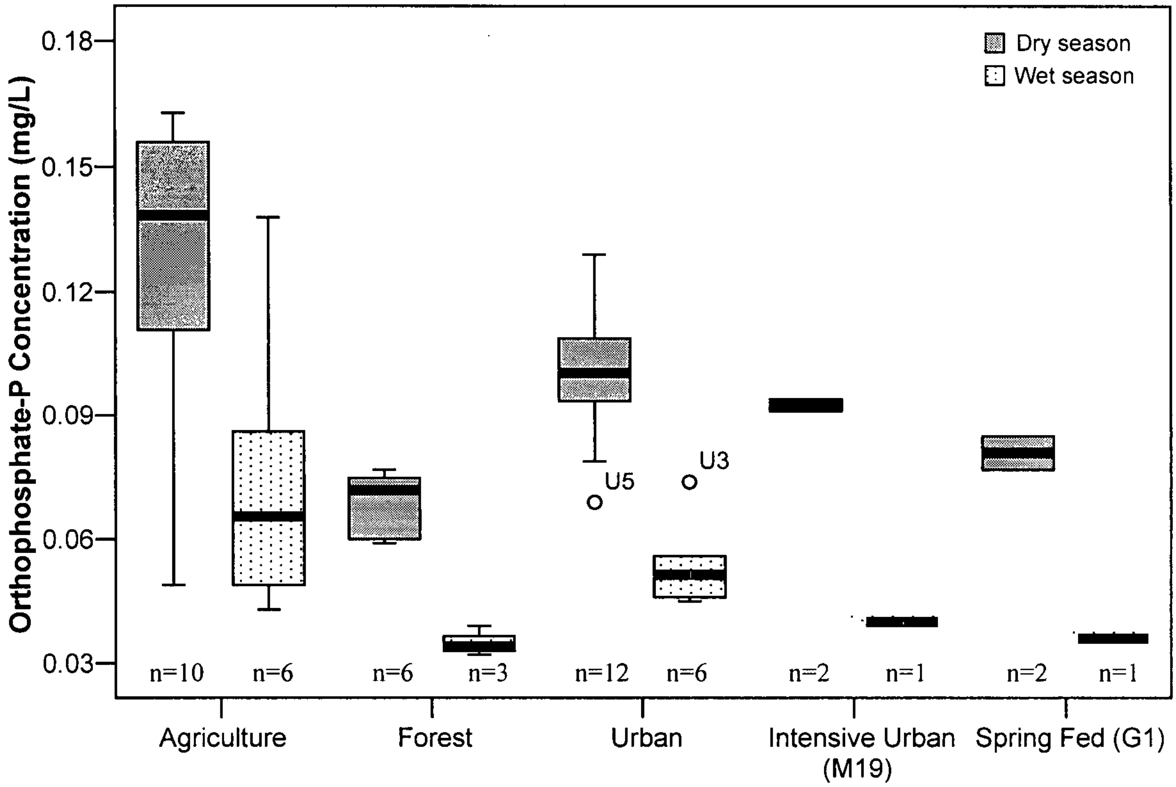


Figure C.16 Boxplots of Orthophosphate-P Results (mg/L) by Land Use Category

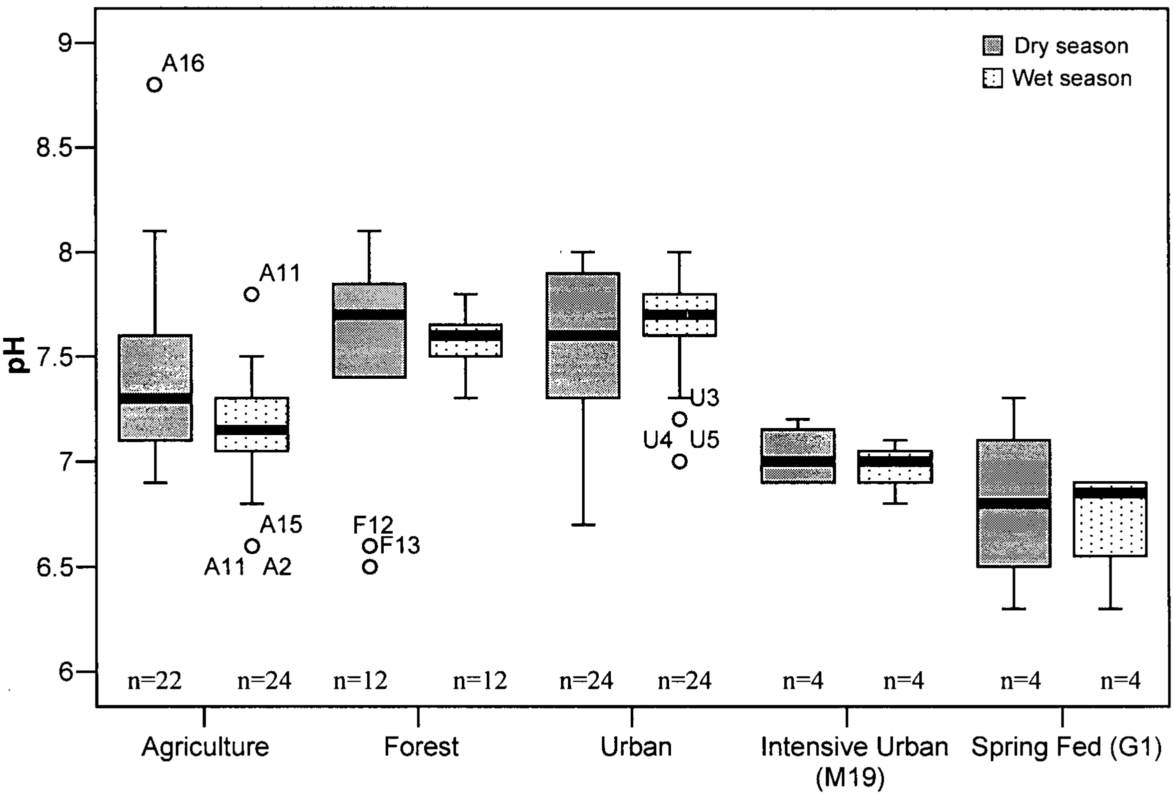


Figure C.17 Boxplots of pH Results by Land Use Category

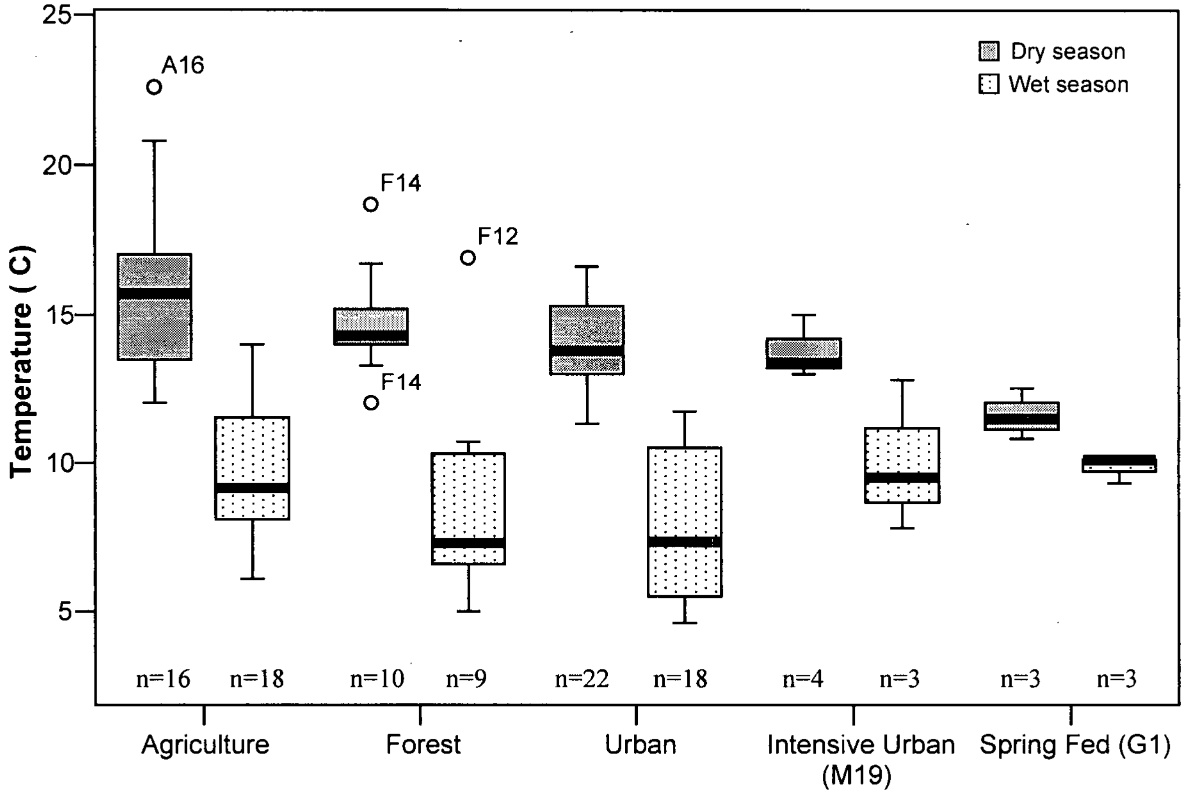


Figure C.18 Boxplots of Temperature Results (°C) by Land Use Category

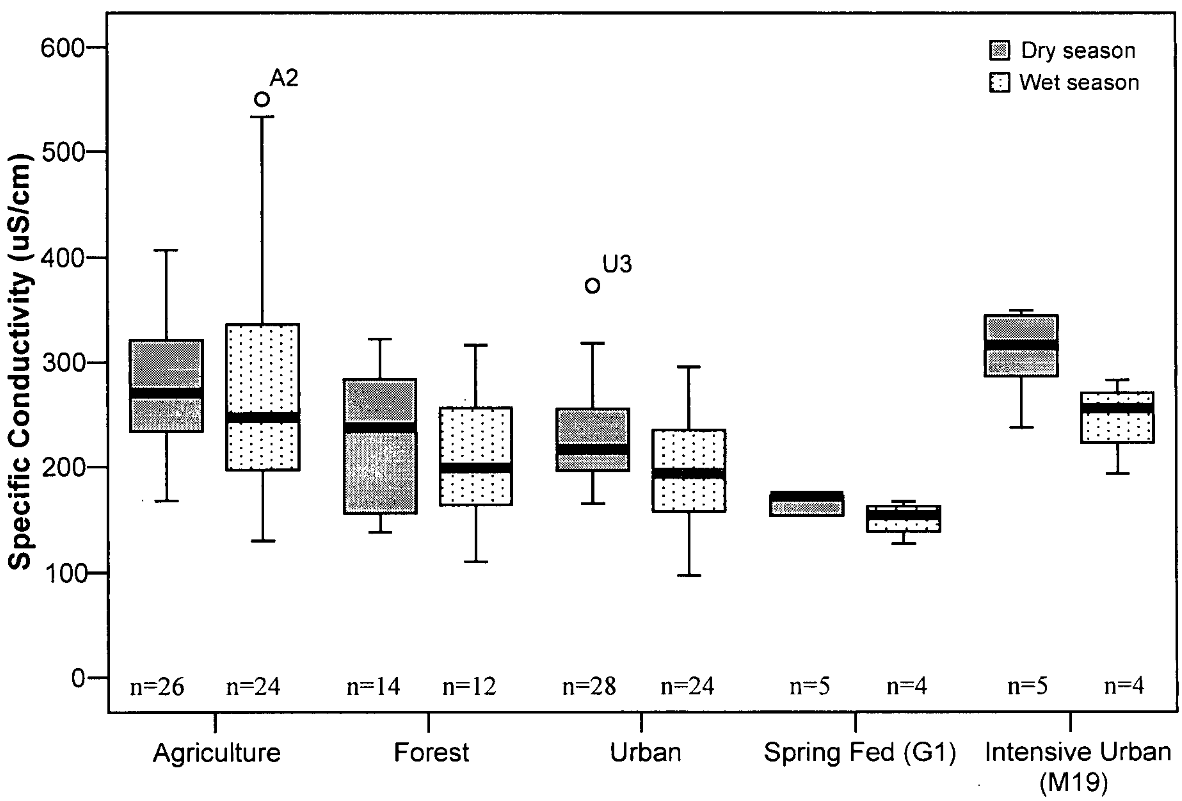


Figure C.19 Boxplots of Specific Conductivity Results (μS/cm) by Land Use Category

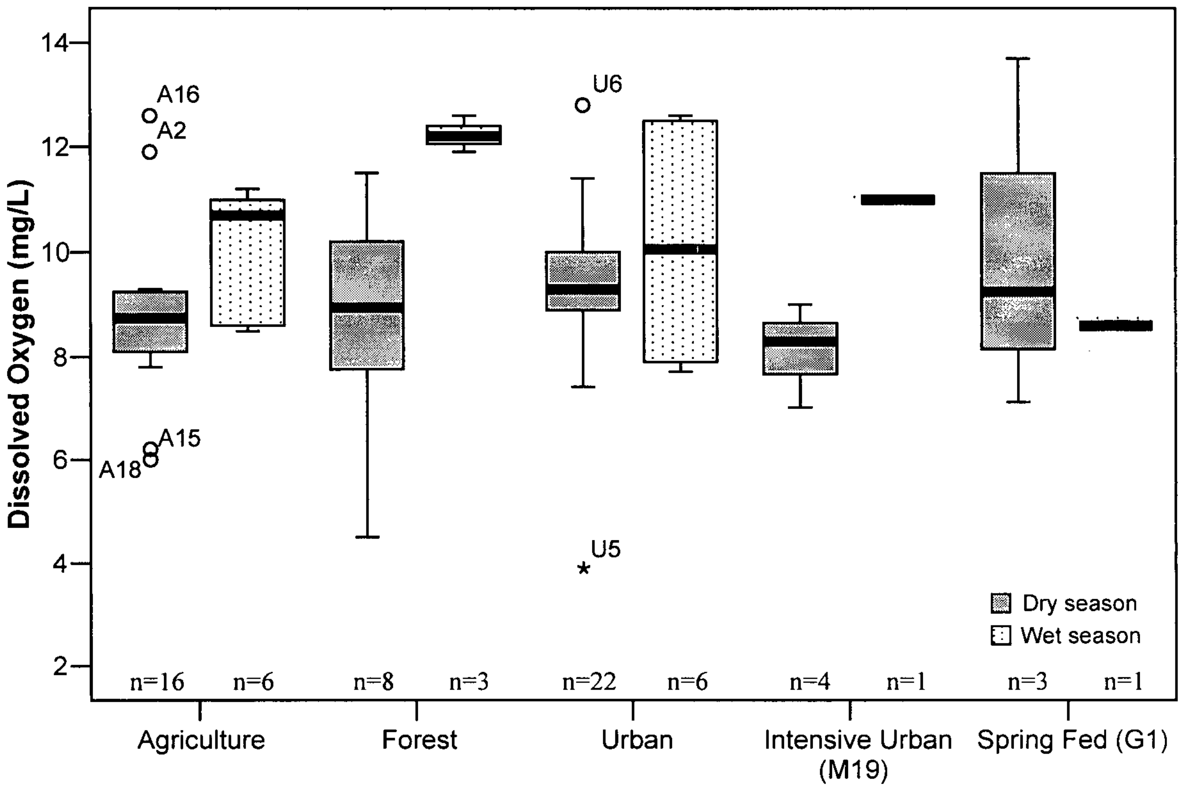


Figure C.20 Boxplots of Dissolved Oxygen Results (mg/L) by Land Use Category

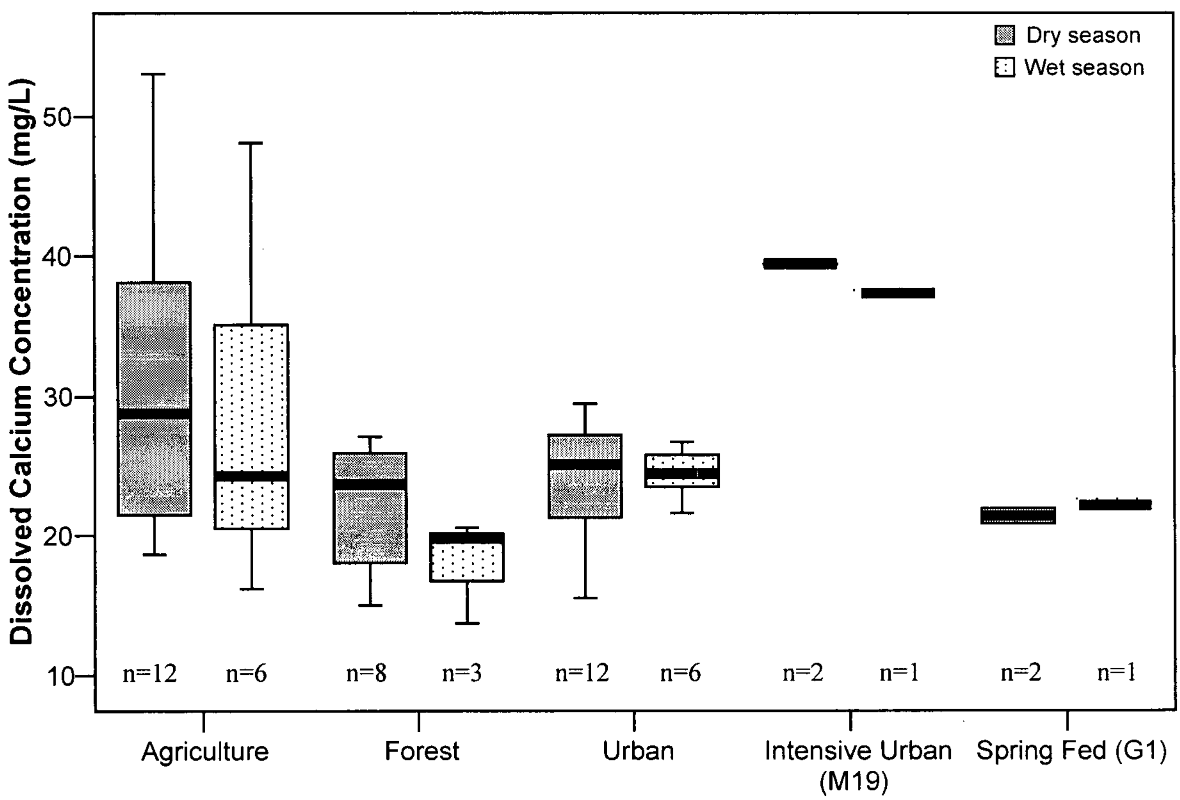


Figure C.21 Boxplots of Dissolved Calciun Results (mg/L) by Land Use Category

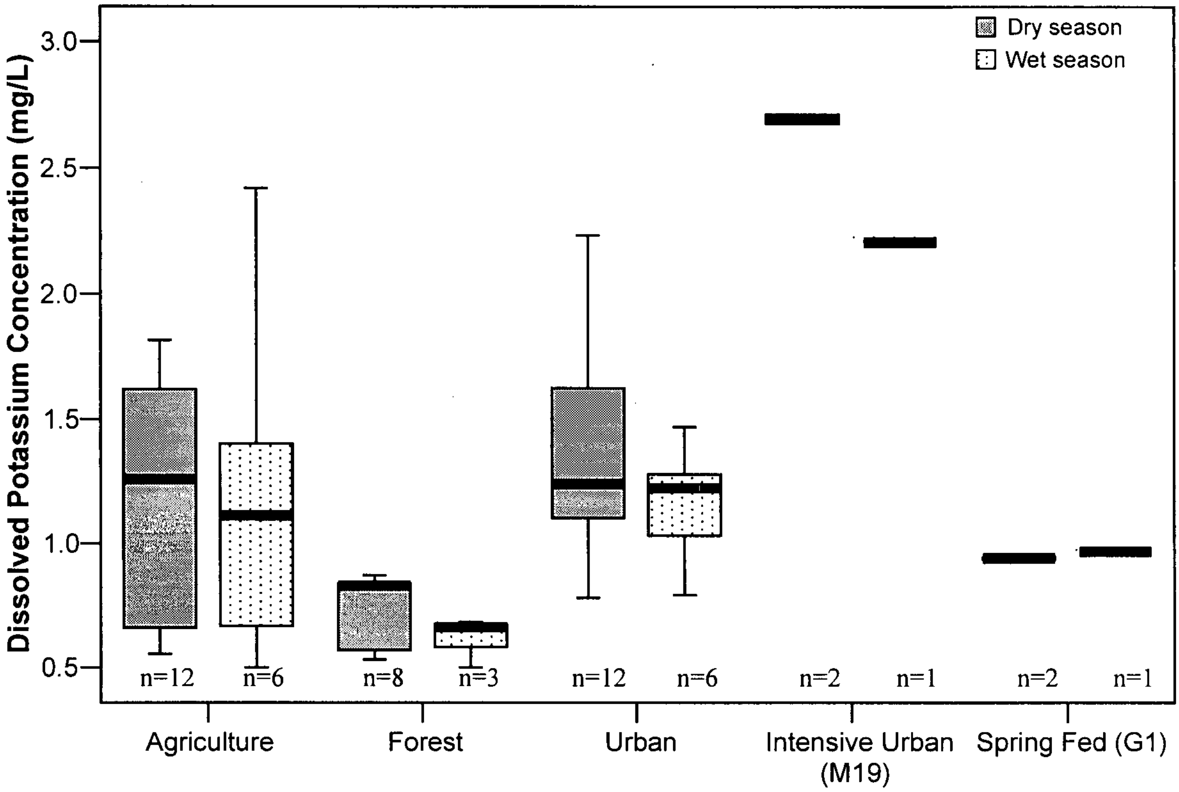


Figure C.22 Boxplots of Dissolved Potassium Results (mg/L) by Land Use Category

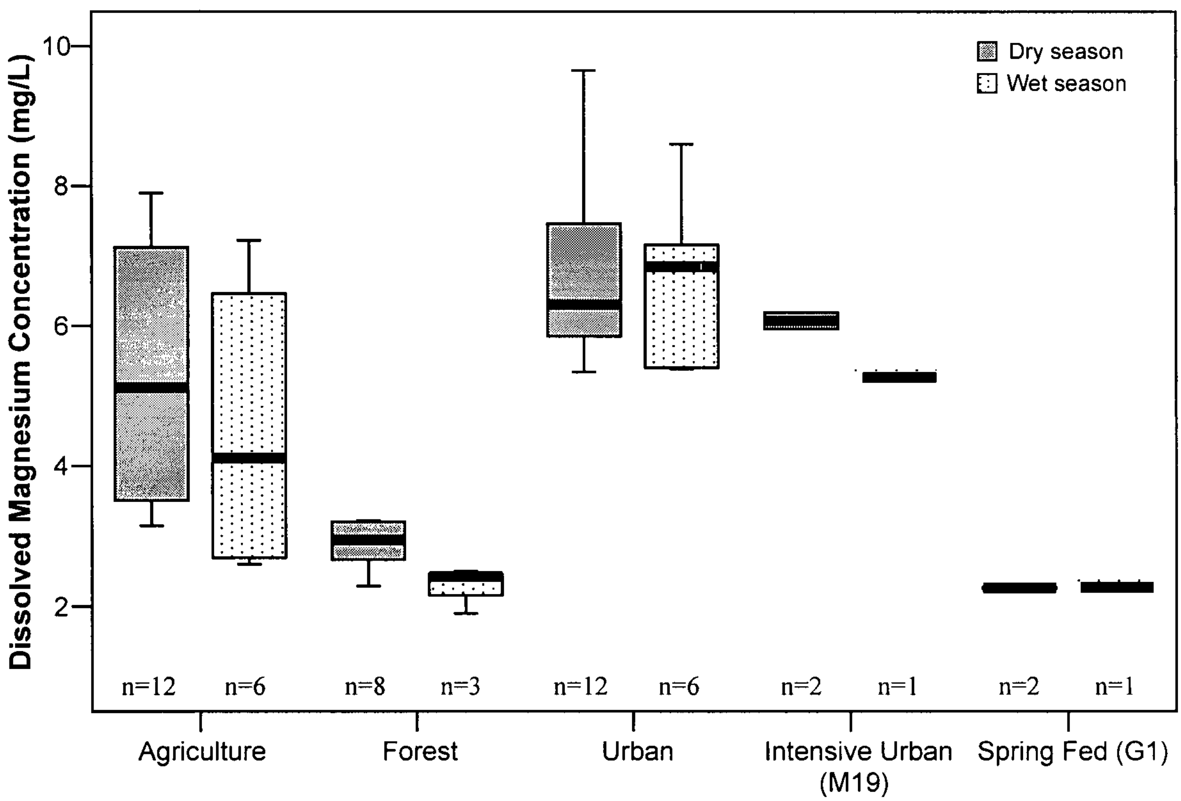


Figure C.23 Boxplots of Dissolved Magnesium Results (mg/L) by Land Use Category

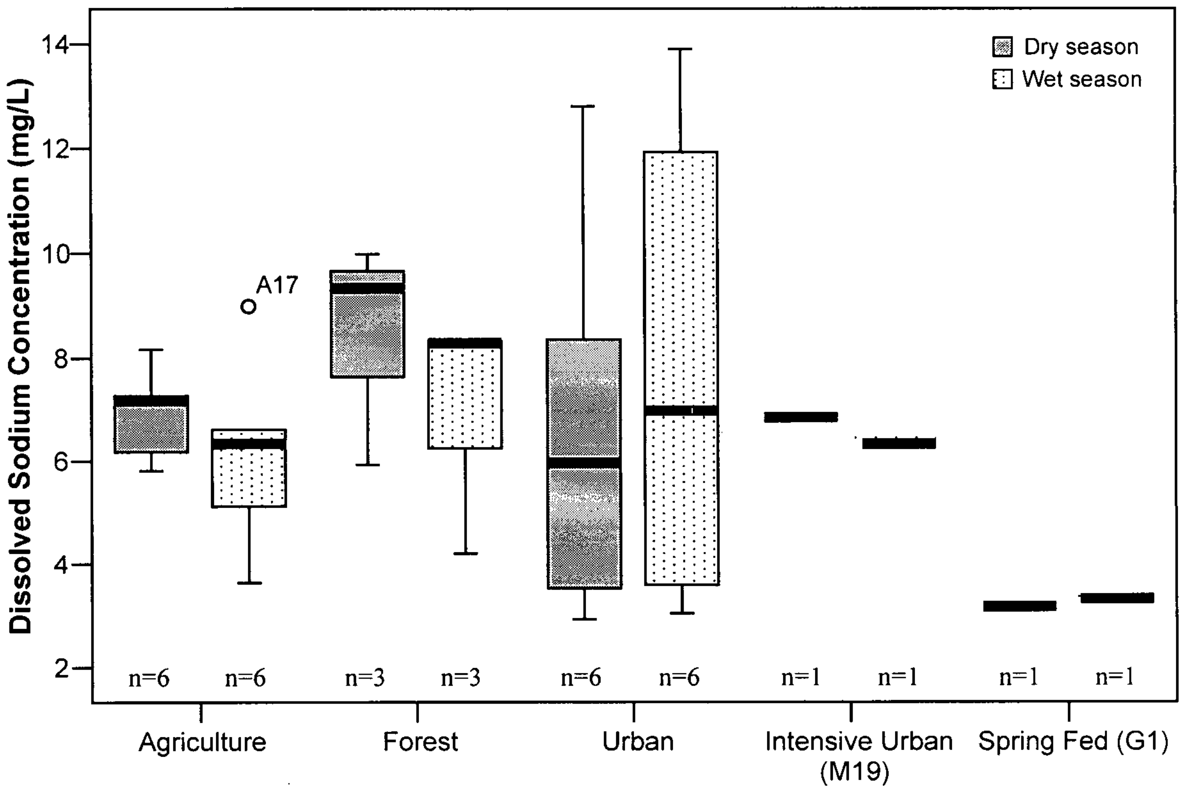


Figure C.24 Boxplots of Dissolved Sodium Results (mg/L) by Land Use Category

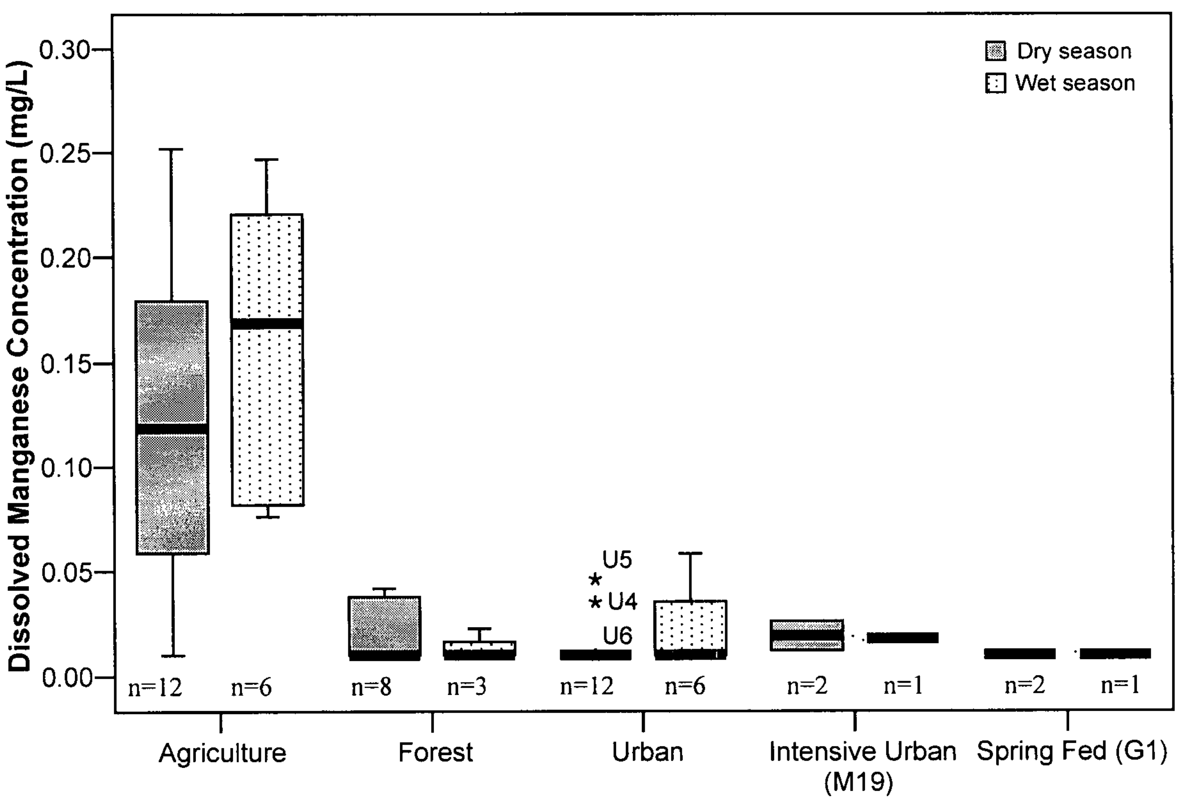


Figure C.25 Boxplots of Dissolved Manganese Results (mg/L) by Land Use Category

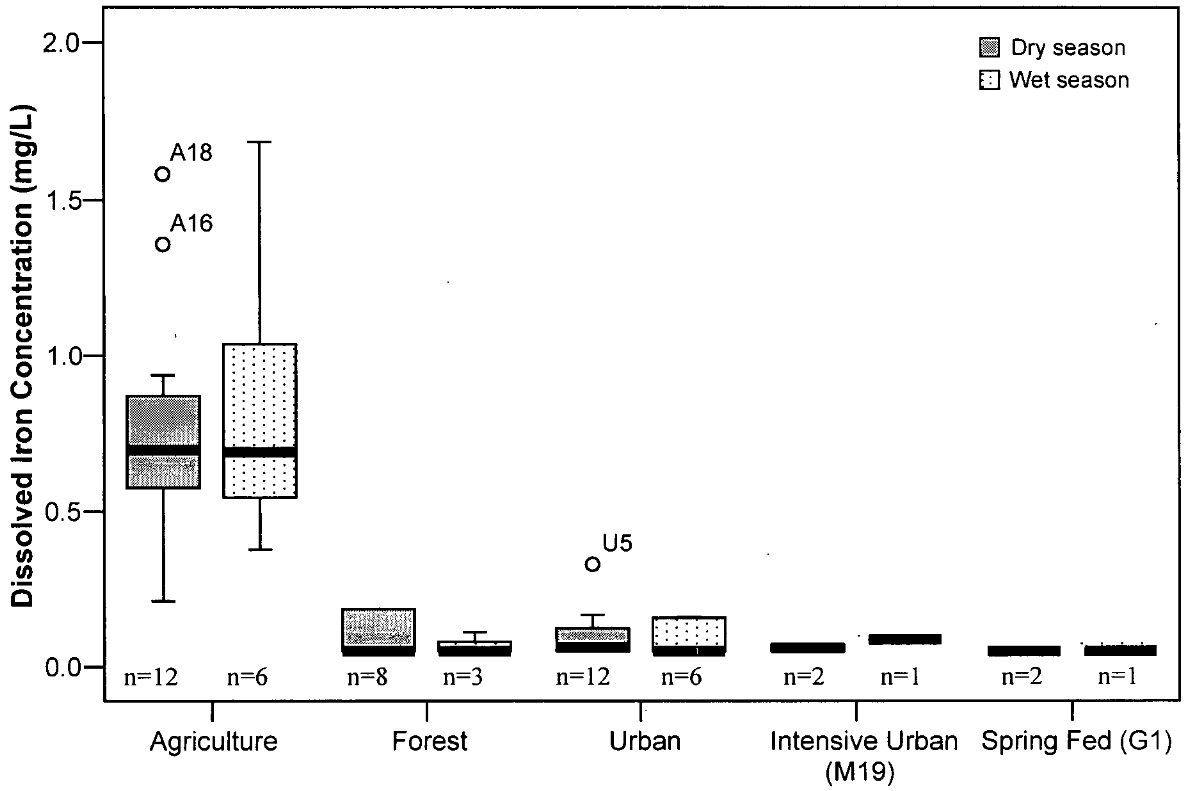


Figure C.26 Boxplots of Dissolved Iron Results (mg/L) by Land Use Category

Analysis Methods for Nutrients

Nitrate+Nitrite – N:

Method: QuickChem Method #12-107-04-1-B.

Description: In this method the nitrate in the sample is reduced to nitrite by passing the sample through a column containing cadmium that has been treated with copper sulfate ($CuSO_4$). The nitrite that is produced and the original nitrite reacts in an acidic medium with sulfanilamide to form an intermediate diazonium salt which couples with N-(1-naphthyl)-ethylenediamine dihydrochloride to form a highly colored azo dye. This dye is then measured colorimetrically (at 520 nm) wityh a spectrophotometer spectrometer to determine the concentration of nitrate+nitrite - N. In aerobic conditions typical of most aquatic systems, nitrite is rapidly oxidized to nitrate (Heathwaite, 1993). It will therefore be assumed that the concentrations from this analysis consist of only nitrate-N, and will be referred to throughout this thesis as nitrate-N.

Ammonia-N:

Method: QuickChem Method #10-107-06-2-A (Prokopy 1992).

Description: The samples are heated with salicylate and hypochlorite in an alkaline phosphate buffer. The free ammonia reacts in the presence of sodium nitroprusside to produce an emerald green color which absorbs light at 660 nm, allowing measurement with a spectrophotometer.

Orthophosphate-P:

Method: QuickChem Method #10-115-01-1-A (Diamond 1995)

Description: In this method, sulfuric acid (H_2SO_4), potassium antimonyl tatrate, ammonium molybdate, and ascorbic acid are added to the sample. The potassium antimonyl tatrate and ammonium molybdate react in the acid with the orthophosphate to form phosphomolybdic acid. The phosphomolybdic acid is then reduced to a blue color by the ascorbic acid, which is then measured with a spectrophotometer.

Appendix D: Sediment Data

Table D.1 Detection Limits for Sediment Samples

Parameter	Detection Limit (mg/L)
Al	0.2
As	0.25
B	0.1
Ba	0.1
Ca	0.1
Cd	0.025
Co	0.1
Cr	0.05
Cu	0.1
Fe	0.1
K	0.5
Mg	0.05
Mn	0.01
Mo	0.05
Na	1
Ni	0.1
P	0.25
Pb	0.25
Se	0.5
Si	0.075
Sr	0.0025
Zn	0.025

Table D.2 Metal Concentrations in Sediments (in ppm)

Watercourse	Site	Al		Cd		Co		Cr		Cu		Fe	
		2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
Interception Ditch	A15	14617	12247	3.62	3.50	13.3	11.9	35.9	33.7	37.9	29.5	34680	32483
	A16	14614	9718	5.30	6.73	12.7	11.4	32.1	24.1	43.6	42.9	55945	53274
	A18	14367*	11540	5.78*	3.84	12.1*	10.8	30.6*	26.4	47.2*	42.3	61227*	33158
Teskey Way Ditch	A17	15245	10531	4.39	3.78	16.1	12.8	35.0	25.1	56.6	48.3	43490	29862
Semiault Creek	A2	-	8188	-	11.24	-	27.7	-	24.8	-	38.9	-	89488
Armstrong Ditch	A11	12368	8657	3.06	2.87	10.6	<10.0	27.2	20.1	34.2	29.0	26444	22027
Elkview Creek	F12	17014	14008	4.93	5.14	22.0	24.0	34.0	27.6	63.1	62.9	44339	39972
	F14	12837	9517	3.44	3.75	14.7	12.9	26.6	20.7	43.4	43.9	30089	24409
Parsons Brook	F13	12890	9587	2.53	2.78	<10.0	<10.0	34.6	21.2	27.1	24.9	22934	22283
Teskey Creek	U5	15964*	7596	3.25*	<2.46	14.4*	<10.0	34.7*	19.2	29.5*	20.8	30322*	15328
	U3	13729	10393	2.99	3.00	13.2	11.1	31.7	25.7	30.1	32.7	28172	23964
Lefferson Creek	U7	13073	9670	2.48	<2.46	10.6	<10.0	33.2	22.8	25.3	20.7	23596	15556
	U4	13081	6927	2.76	<2.46	11.8	<10.0	31.7	18.4	29.0	17.9	26590	17237
Benchley Creek	U6	12949	7473	2.94	<2.46	13.7	<10.0	35.7	23.4	33.5	29.8	27781	16791
Walker Creek	U8	10960	8496	<2.50	<2.46	10.7	<10.0	32.1	26.2	27.3	25.3	22443	18055
Teskey Way Ditch	M9	14263	9173*	4.47	4.64*	13.0	11.0*	36.5	25.8*	40.4	37.7*	46433	40233*
Bailey Ditch	M10	-	9195	-	4.39	-	11.0	-	24.4	-	39.3	-	40572
Chilliwack Creek	M19	-	7871	-	5.17	-	13.3	-	64.9	-	79.0	-	39110
	M20	-	8571*	-	10.45*	-	12.0*	-	26.7*	-	80.8*	-	82449*
Luckakuck Creek	G1	10430	7237	3.34	2.78	<10.0	<10.0	36.4	21.9	45.6	39.5	22565	17023

*average of duplicate samples

Table D.2 (cont.) Metal Concentrations in Sediments (in ppm)

Watercourse	Site	Ca		K		Mg		Na		Sr		Si	
		2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
Interception Ditch	A15	3362	3607	462	354	5685	4997	130	153	33.9	36.1	1051	1037
	A16	4073	3765	682	501	6999	4409	248	169	26.0	30.0	1079	1858
	A18	4258*	3853	741*	598	7067*	5687	242*	168	27.5*	23.9	1225*	1402
Teskey Way Ditch	A17	6525	5476	1006	738	8387	5551	303	195	43.4	33.3	1372	1598
Semiault Creek	A2	-	4319	-	232	-	2854	-	165	-	29.0	-	2082
Armstrong Ditch	A11	4280	3450	446	292	5494	3500	293	226	36.8	33.1	1045	1276
Elkview Creek	F12	5222	4946	460	359	8106	6750	156	141	47.8	50.5	1645	1900
	F14	4173	3993	371	246	5657	3846	<100	122	40.3	39.3	1187	1613
Parsons Brook	F13	3470	2861	301	249	4283	3090	113	108	36.3	28.7	936	1427
Teskey Creek	U5	3388*	2568	496*	354	5116*	2824	149*	<89	26.6*	20.2	1153*	1079
	U3	4579	4468	540	442	5306	3755	168	189	36.2	41.3	1290	1836
Lefferson Creek	U7	4648	3717	490	347	4662	2204	153	<89	26.8	21.3	1192	1484
	U4	4175	3131	561	347	5062	2650	164	97	31.6	22.9	1212	1325
Benchley Creek	U6	5356	4220	655	488	6207	3679	209	<89	37.7	30.0	1143	1362
Walker Creek	U8	3885	3757	427	363	4536	2996	126	<89	22.7	22.8	1097	1424
Teskey Way Ditch	M9	5405	3883*	595	590*	7518	4574*	275	157*	40.1	28.1*	1311	1717*
Bailey Ditch	M10	-	3300	-	747	-	4670	-	148	-	21.8	-	1837
Chilliwack Creek	M19	-	9900	-	694	-	4697	-	273	-	51.8	-	1454
	M20	-	4263*	-	423*	-	4017*	-	180*	-	26.4*	-	1238*
Luckakuck Creek	G1	6596	4542	1176	565	22565	3925	309	166	36.4	23.9	904	970

*average of duplicate samples

Table D.2 (cont.) Metal Concentrations in Sediments (in ppm)

Watercourse	Site	Ba		Mn		Ni		P		Pb		Zn	
		2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
Interception Ditch	A15	139.7	108.9	380	324	32.5	29.2	958	971			152.5	84.1
	A16	184.3	176.3	523	508	31.7	22.9	1750	2053			151.5	150.6
	A18	184.2*	166.2	415*	247	31.2*	27.2	1395*	980			148.8*	111.9
Teskey Way Ditch	A17	172.4	154.5	1318	1265	34.5	26.2	1415	1013			205.7	161.4
Semiault Creek	A2	-	293.5	-	907	-	31.3		2884	-		-	157.3
Armstrong Ditch	A11	127.7	116.8	382	226	25.5	17.9	1194	1071			218.4	94.7
Elkview Creek	F12	184.9	134.7	1446	1037	45.1	41.9	839	862		26.2	149.7	154.1
	F14	115.9	108.7	809	725	31.1	26.6	684	702		26.8	110.9	130.5
Parsons Brook	F13	79.5	101.1	359	654	25.1	20.2	500	625			64.6	71.5
Teskey Creek	U5	136.8*	90.9	1073*	446	35.8*	20.3	849*	635			97.7*	64.6
	U3	144.4	123.7	1656	742	31.1	23.3	770	689		25.8	91.3	118.7
Lefferson Creek	U7	121.7	107.6	668	500	30.4	18.5	777	753			70.0	54.1
	U4	145.1	97.4	1483	981	30.9	16.2	824	674			98.2	75.4
Benchley Creek	U6	130.8	105.5	1237	1040	37.2	33.4	714	620			94.7	67.5
Walker Creek	U8	98.9	99.9	653	947	27.9	23.1	650	638			68.9	76.1
Teskey Way Ditch	M9	133.7	119.0*	757	452*	30.2	22.9*	1209	1242*		29.2	135.6	116.9*
Bailey Ditch	M10	-	128.0	-	343	-	23.9	-	1190	-		-	105.1
Chilliwack Creek	M19	-	219.1	-	1805	-	34.3	-	1897	-	56.5	-	221.8
	M20	-	246.5*	-	714*	-	27.8*	-	5110*	-	50.2	-	264.9*
Luckakuck Creek	G1	76.1	59.0	313	142	20.2	16.4	1580	670	76.2	70.0	100.1	83.6

*average of duplicate samples

Table D.3 Total % Carbon, Total % Nitrogen Results

Watercourse	Site	% Total Carbon		% Total Nitrogen		C:N Ratio	
		2002	2003	2002	2003	2002	2003
Interception Ditch	A15	3.51	2.1	0.27	0.14	13.1	14.5
	A16	3.45	1.29	0.27	0.1	12.9	13.4
	A18	3.5	1.45	0.28	0.11	12.4	12.9
Teskey Way Ditch	A17	4.19	0.38	0.37	0.15	11.5	2.5
Semiault Creek	A2	-	3.89	-	0.32	-	12.0
Armstrong Ditch	A11	3.71	3.17	0.28	0.22	13.4	14.3
Elkview Creek	F12	2.44	0.82	0.18	0.08	13.9	10.1
	F14	2.06	1.33	0.15	0.09	14.1	14.2
Parsons Brook	F13	2.03	2.29	0.16	0.14	13.0	16.9
Teskey Creek	U5	2.13	2.51	0.16	0.15	13.4	16.5
	U3	2.63	0.35	0.18	0.03	14.6	10.0
Lefferson Creek	U7	3.41	1.38	0.25	0.11	13.4	12.5
	U4	2.7	1.62	0.19	0.11	14.2	14.5
Benchley Creek	U6	2.19	0.44	0.16	0.03	13.6	13.0
Walker Creek	U8	1.55	0.83	0.12	0.06	13.3	13.3
Teskey Way Ditch	M9	2.33	0.97	0.16	0.07	14.5	13.7
Bailey Ditch	M10	-	3.48	-	0.24	-	14.4
Chilliwack Creek	M19	-	0.61	-	0.06	-	10.3
	M20	-	4.74	-	0.35	-	13.4
Luckakuck Creek	G1	9.33	7.04	0.91	0.51	10.3	13.7

Table D.4 Phosphorus in Sediment Results

Watercourse	Site	Orthophosphate[α] (ppm in soil)	DPS[β] (%)	P[ω] (ppm in soil)
Interception Ditch	A15	<2.98*	5.32	971
	A16	5.40	6.72	2053
	A18	<2.98*	5.87	980
Teskey Way Ditch	A17	28.51	4.46	1013
Semiault Creek	A2	<3.54	7.39	2884
Armstrong Ditch	A11	12.59	8.46	1071
Elkview Creek	F12	14.00*	4.81	862
	F14	24.33	4.85	702
Parsons Brook	F13	7.23	5.46	625
Teskey Creek	U5	9.12	6.65	635
	U3	17.61*	4.03	689
Lefferson Creek	U7	53.97	8.45	753
	U4	19.56*	6.77	674
Benchley Creek	U6	11.51*	4.47	620
Walker Creek	U8	17.61*	4.55	638
Teskey Way Ditch	M9	<2.98	4.53*	1242*
Bailey Ditch	M10	<.76	5.84	1190
Chilliwack Creek	M19	27.15	6.25	1897
	M20	10.00	14.58	5110*
Luckakuck Creek	G1	29.90	8.47	670

[α]Orthophospahte concentration measured from Bray 1 extracts
[β]Degree of Phosphorus Sorption (DPS) measured from AAO (acidified ammonium oxalate) extractable Fe, Al and adsorbed P
[ω]ICP analyses of sediments
* average of duplicate samples

Table D.5 Particle-Size Results

Watercourse	Site	% sand	% silt	% clay
Interception Ditch	A15	49.3	41.9	8.9
	A16	78.7	13.6	7.7
	A18	67.0	24.7	8.3
Teskey Way Ditch	A17	94.9	2.8	2.3
Semiault Creek	A2	50.3	35.9	13.9
Armstrong Ditch	A11	57.5	33.5	9.1
Elkview Creek	F12	89.7	6.9	3.4
	F14	86.1	10.3	3.7
Parsons Brook	F13	65.9	26.5	7.7
Teskey Creek	U5	41.8	49.7	8.5
	U3	92.7	4.8	2.5
Lefferson Creek	U7	76.7	19.3	4.0
	U4	74.3	20.9	4.8
Benchley Creek	U6	92.3	5.7	2.0
Walker Creek	U8	81.4	14.3	4.3
Teskey Way Ditch	M9	81.0	14.1	4.9
Bailey Ditch	M10	19.3	66.1	14.6
Chilliwack Creek	M19	97.7	0.9	1.3
	M20	49.9	32.8	17.3
Luckakuck Creek	G1	65.7	28.3	6.1

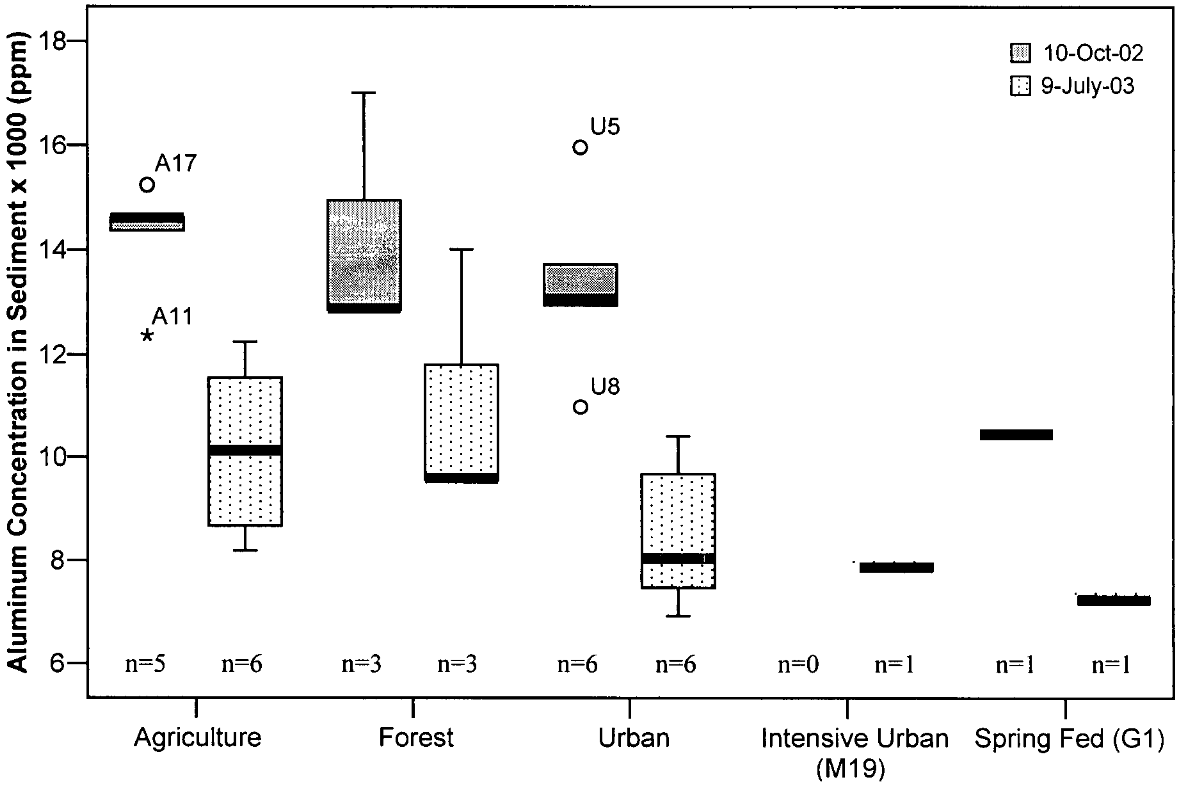


Figure D.1 Boxplots of Aluminum Sediment Results by Land Use Category

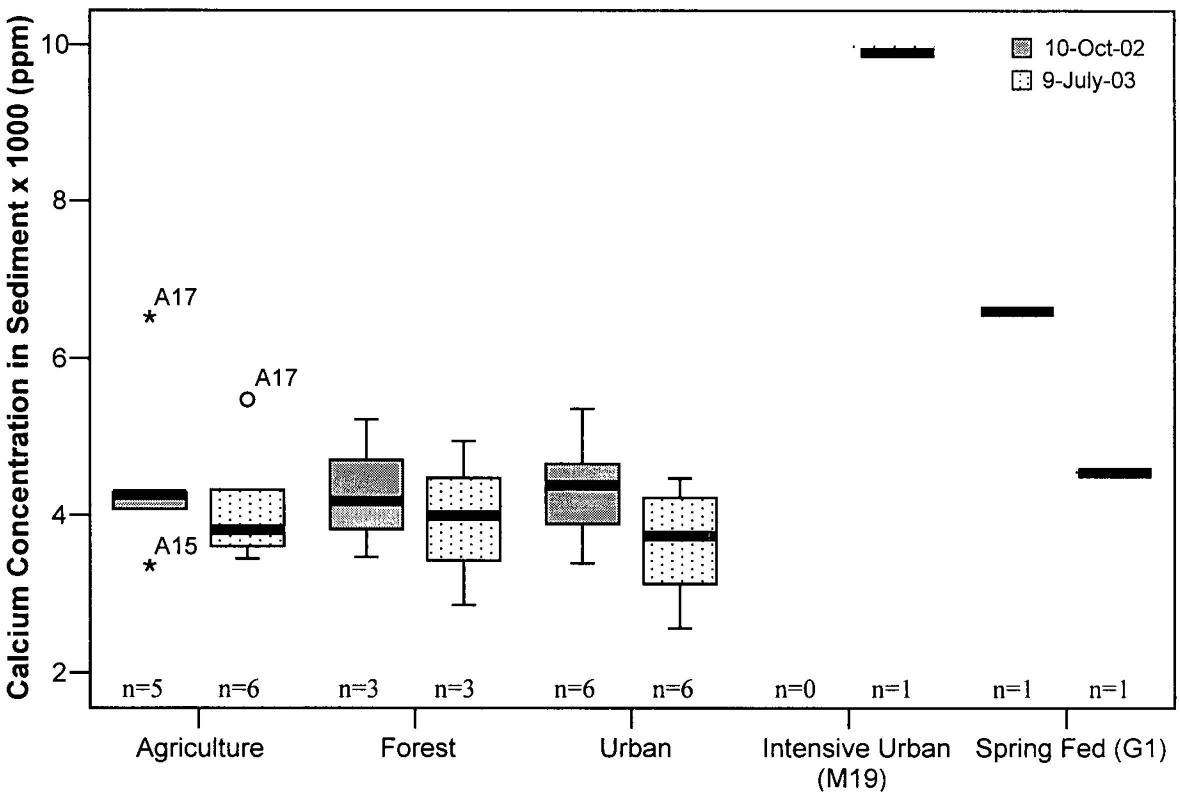


Figure D.2 Boxplots of Calcium Sediment Results by Land Use Category

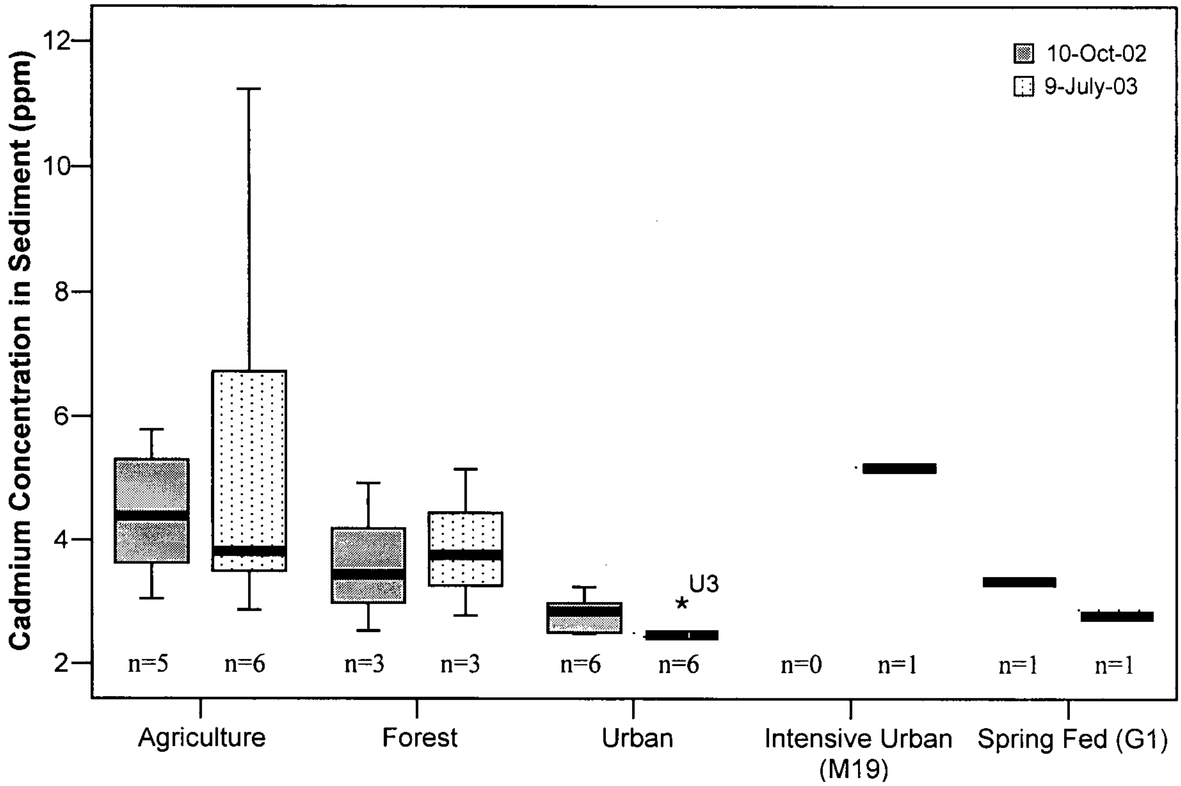


Figure D.3 Boxplots of Cadmium Sediment Results by Land Use Category

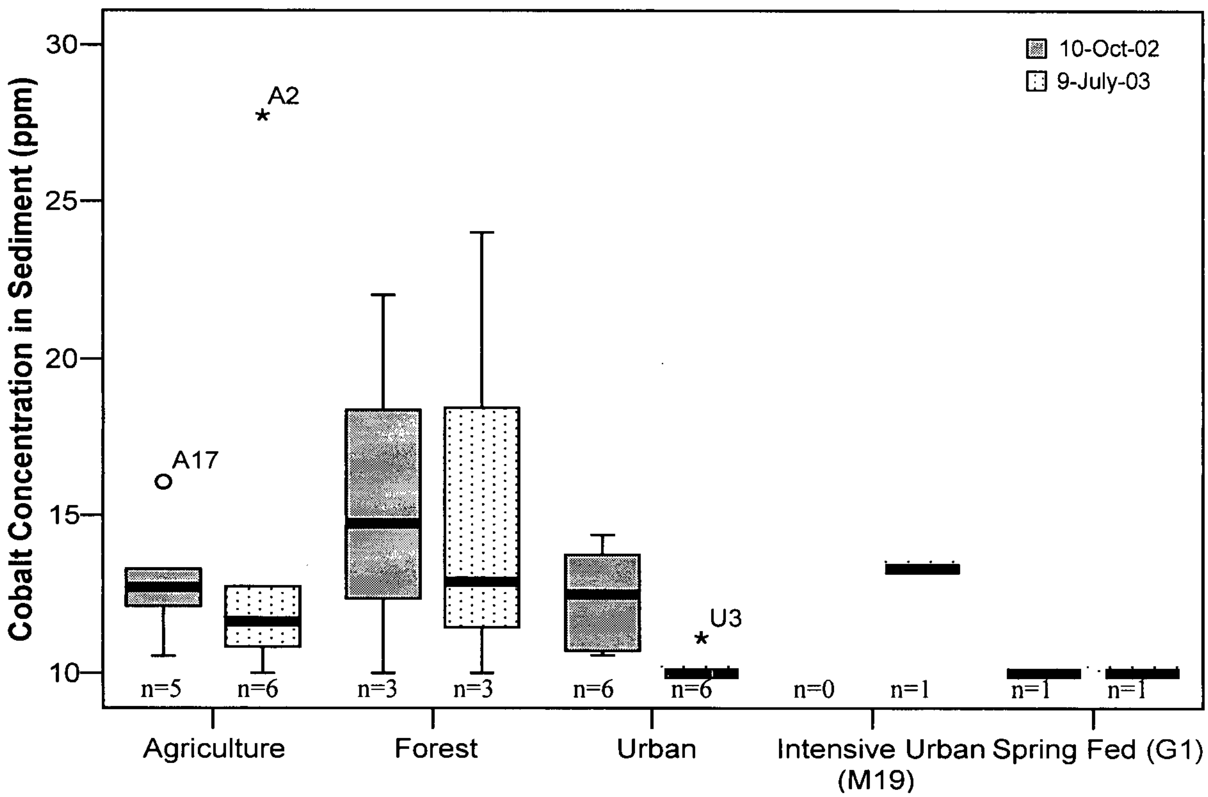


Figure D.4 Boxplots of Calcium Sediment Results by Land Use Category

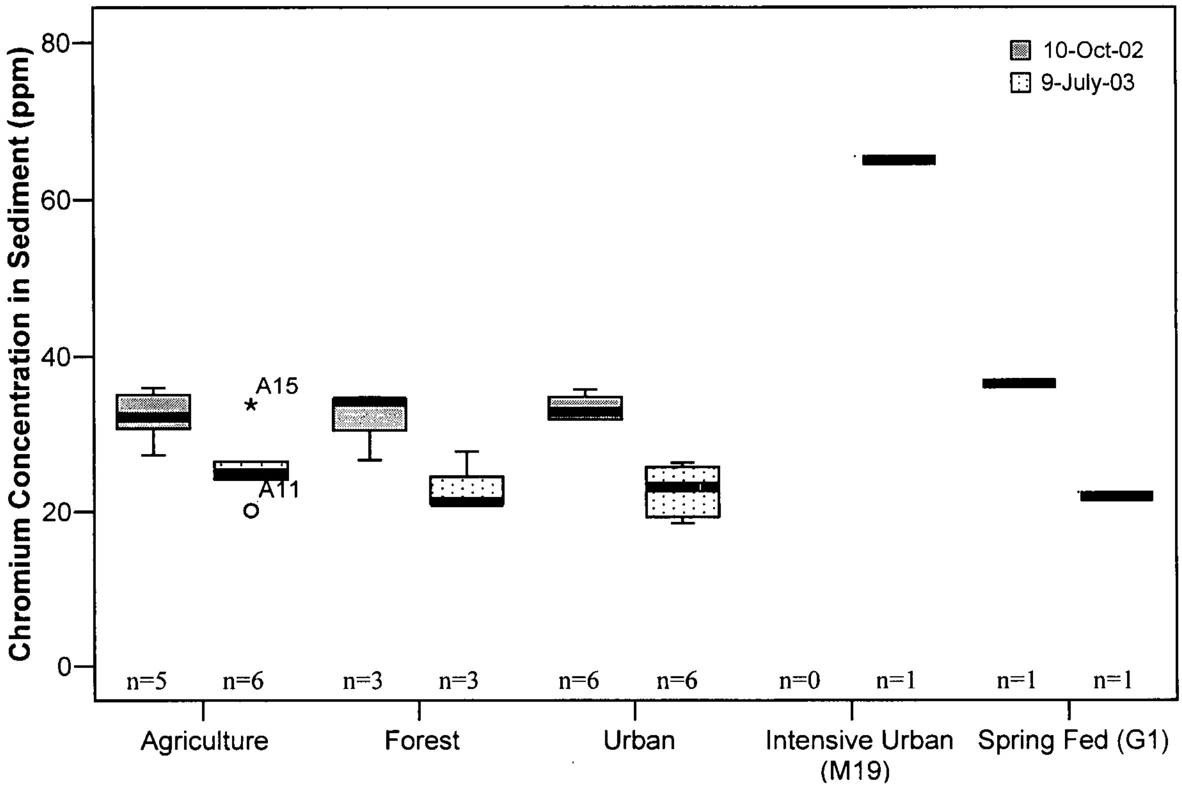


Figure D.5 Boxplots of Chromium Sediment Results by Land Use Category

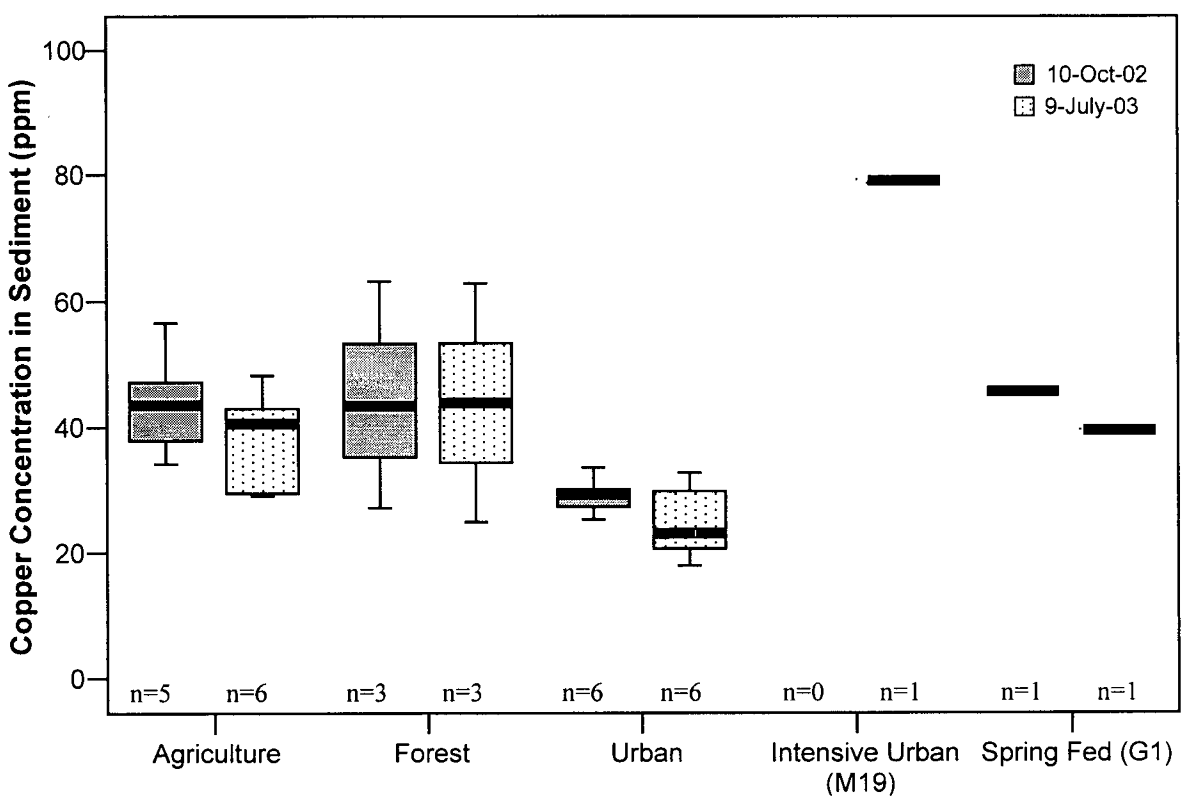


Figure D.6 Boxplots of Copper Sediment Results by Land Use Category

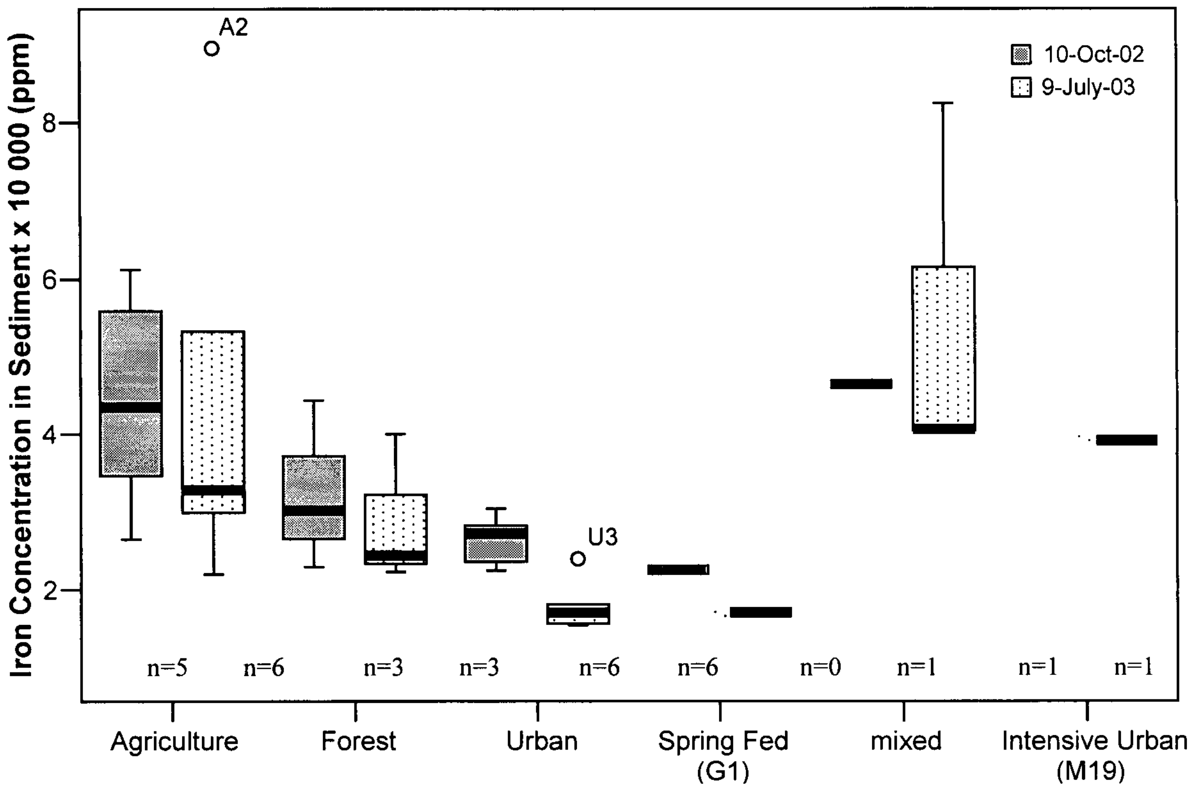


Figure D.7 Boxplots of Iron Sediment Results by Land Use Category

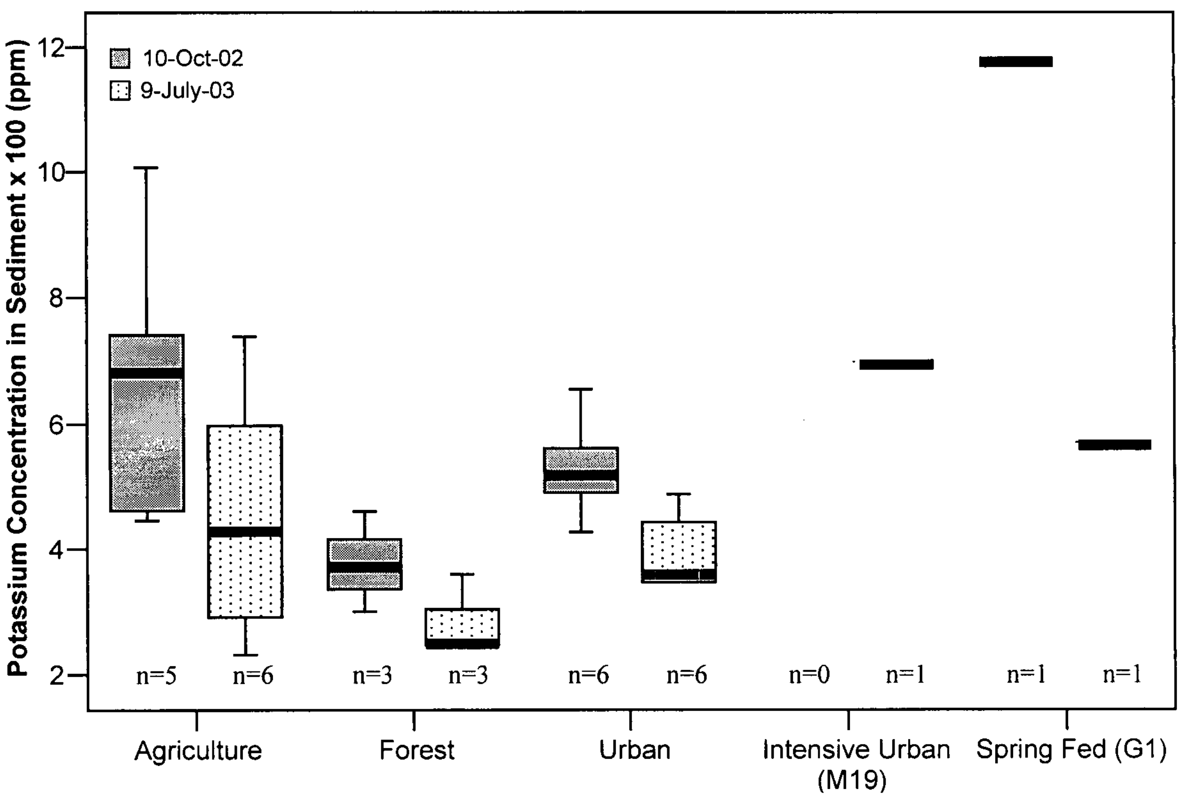


Figure D.8 Boxplots of Potassium Sediment Results by Land Use Category

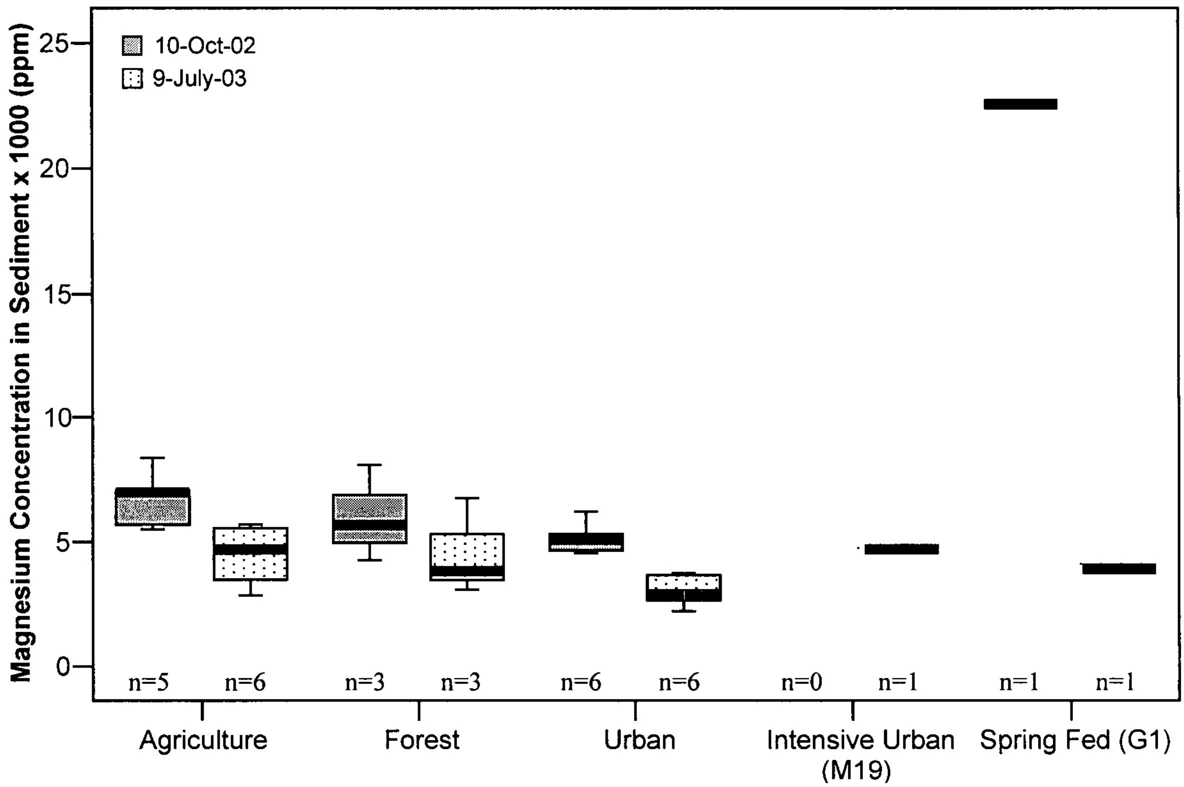


Figure D.9 Boxplots of Magnesium Sediment Results by Land Use Category

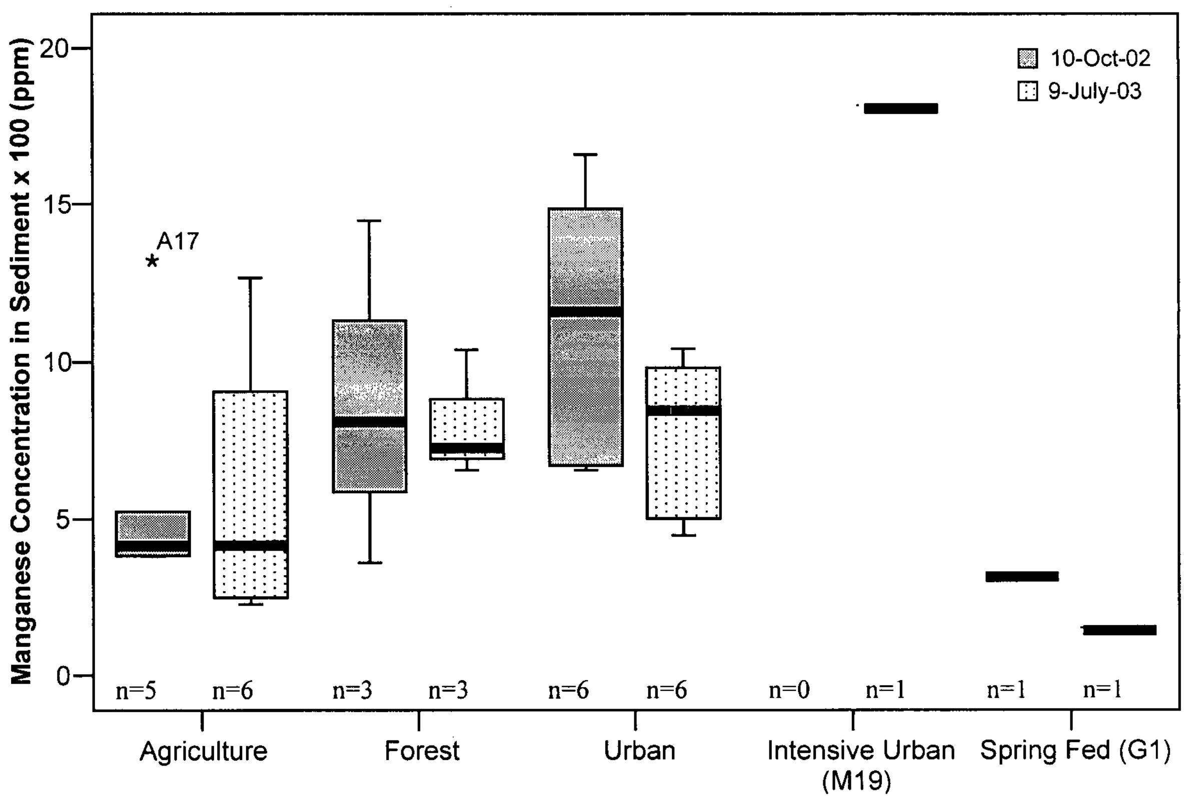


Figure D.10 Boxplots of Manganese Sediment Results by Land Use Category

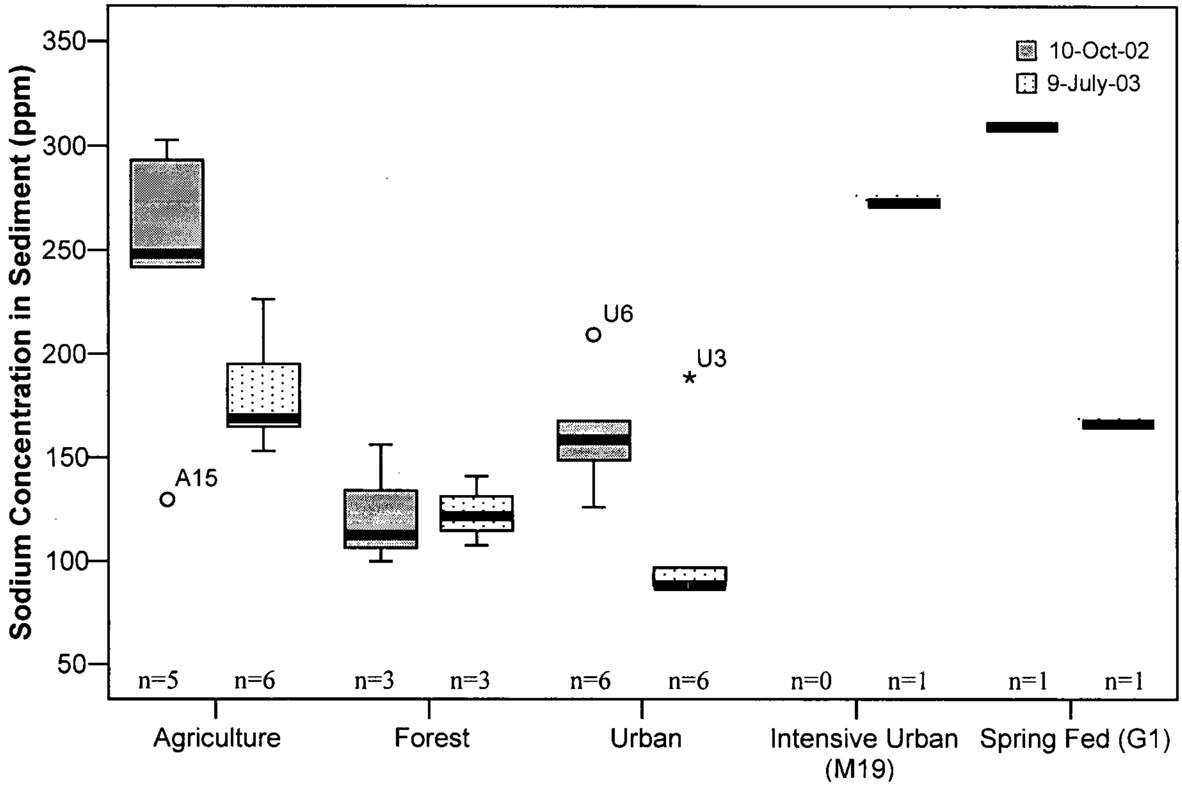


Figure D.11 Boxplots of Sodium Sediment Results by Land Use Category

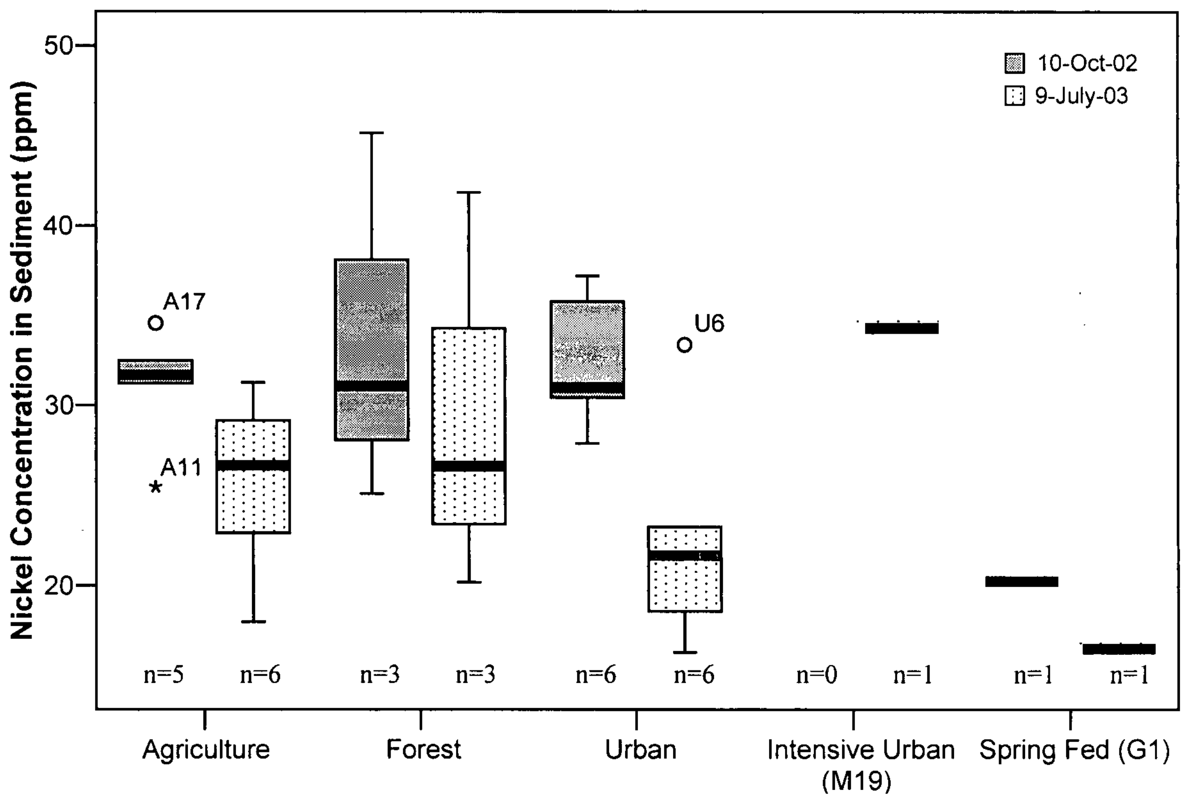


Figure D.12 Boxplots of Nickel Sediment Results by Land Use Category

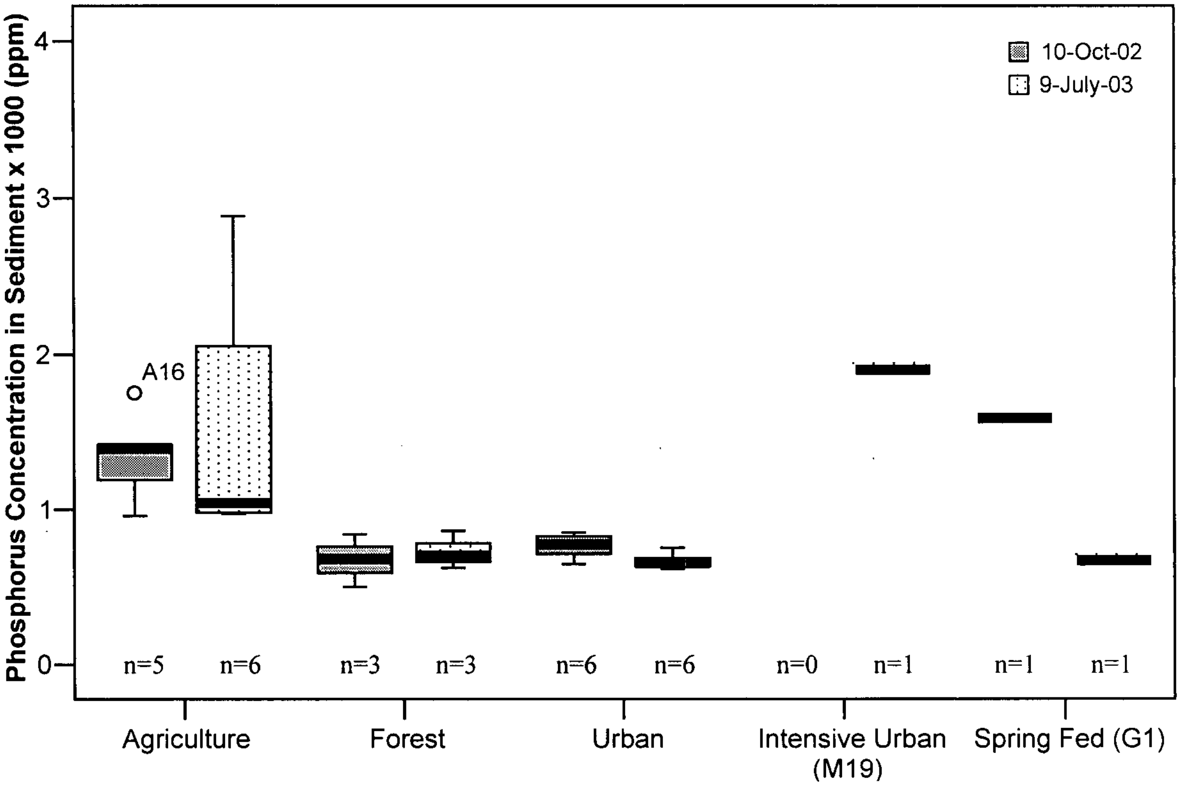


Figure D.13 Boxplots of Phosphorus Sediment Results by Land Use Category

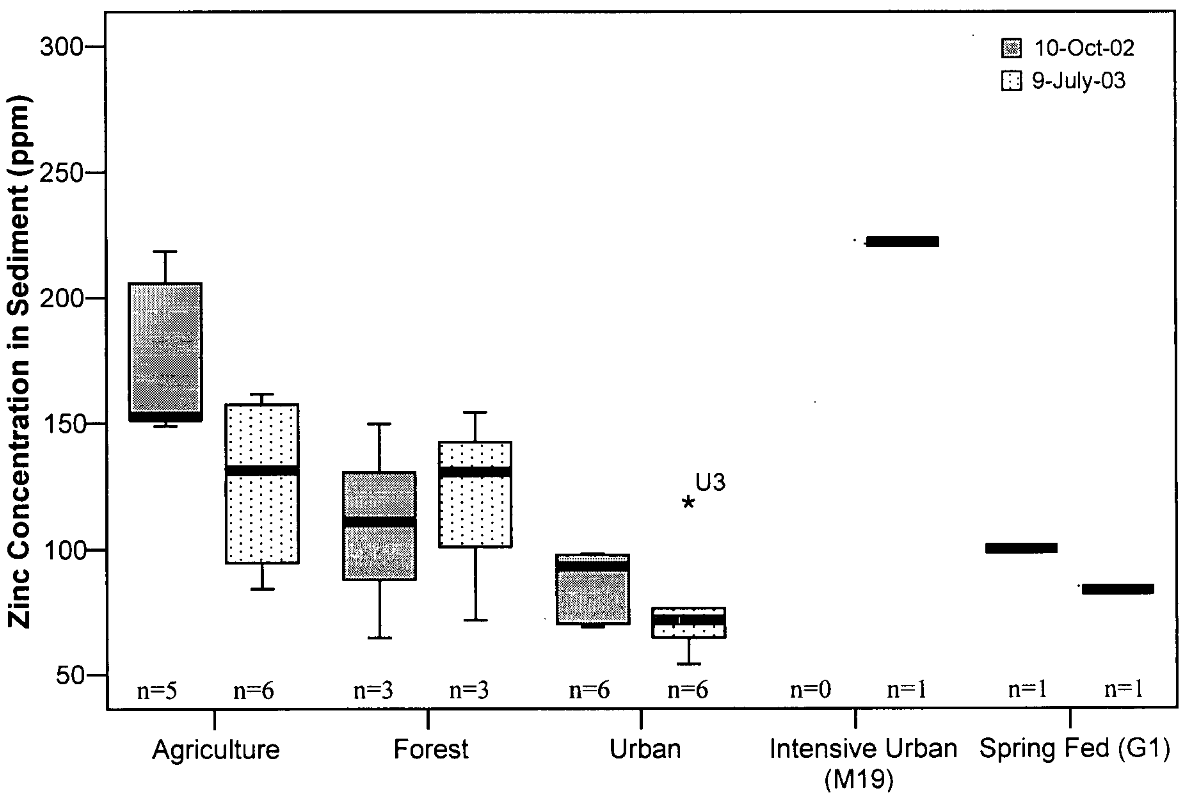


Figure D.14 Boxplots of Zinc Sediment Results by Land Use Category

Appendix E: Quality Analysis and Quality Control Data

Table E.1 Site Variability for Water Quality Parameters

	Date	Sampling Station	NO_3^-N (mg/L)	NH_4-N (mg/L)	Sp. Cond (μS/cm)	pH	Ca (mg/L)	Fe (mg/L)	K (mg/L)	Mg (mg/L)	Mn (mg/L)	Na (mg/L)
	03-Mar-2003	U4	1.301	0.131	228	7.64	-	-	-	-	-	-
			1.295	0.082	227	7.61	-	-	-	-	-	-
			1.458	0.341	225	7.6	-	-	-	-	-	-
Average			1.352	0.185	226.7	7.6	-	-	-	-	-	-
Std. Dev.			0.092	0.137	1.5	0.0	-	-	-	-	-	-
CV(%)			6.81	74.24	0.7	0.3	-	-	-	-	-	-
	03-Mar-2003	A15	0.751	0.091	139	6.98	-	-	-	-	-	-
			0.777	0.095	140	6.97	-	-	-	-	-	-
			0.826	0.244	140	6.95	-	-	-	-	-	-
Average			0.784	0.143	139.7	7.0	-	-	-	-	-	-
Std. Dev.			0.038	0.087	0.6	0.0	-	-	-	-	-	-
CV(%)			4.84	60.85	0.4	0.2	-	-	-	-	-	-
	01-May-2003	M9	0.211	0.271	209	7.5	30.537	0.306	0.760	5.404	0.084	7.383
			0.221	0.337	211	7.38	30.260	0.329	0.662	5.349	0.083	7.332
			0.228	0.286	210	7.38	30.486	0.304	0.666	5.395	0.083	7.423
Average			0.220	0.298	210.0	7.4	30.428	0.313	0.696	5.383	0.083	7.379
Std. Dev.			0.009	0.035	1.0	0.1	0.147	0.014	0.055	0.029	0.000	0.046
CV(%)			3.92	11.62	0.5	0.9	0.48	4.38	7.96	0.55	0.43	0.62
Average CV (%)			**5.19**	**48.90**	**0.5**	**0.5**	**0.48**	**4.38**	**7.96**	**0.55**	**0.43**	**0.62**
Std. Dev for Average CV (%)			**1.47**	**32.97**	**0.1**	**0.4**	*	*	*	*	*	*

* based on a single replicate set, no overall standard deviation calculated

Table E.2 Method Precision for Analyzed Trace Elements in Sediments in October 2002 and July 2003

Date	Sampling Station	Al	Ba	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	P	Si	Sr	Zn
October 2002	U5 (mg/kg)	15562	135.9	3305	3.2	14.3	33.5	29.3	29681	478.6	4983	1075	142.9	34.2	848	1192	26.2	96.4
		16366	137.6	3471	3.3	14.5	35.8	29.7	30962	513.4	5249	1072	154.6	37.3	851	1113	27.0	99.0
	% difference	5.04	1.27	4.89	0.63	1.44	6.69	1.65	4.23	7.01	5.20	0.32	7.86	8.69	0.40	6.81	3.09	2.64
	A18 (mg/kg)	14713	187.5	44.0	6.0	12.5	31.3	48.0	62659	759.1	7249	425	253.0	31.9	1425	1264	28.2	152.1
		14021	180.9	41.4	5.6	11.8	29.8	46.4	59794	722.4	6886	405	230.4	30.5	1365	1187	26.8	145.4
	% difference	4.81	3.59	5.96	6.38	5.58	5.03	3.55	4.68	4.96	5.14	4.67	9.36	4.31	4.29	6.30	4.89	4.55
	Avg. diff. std. dev.	**0.16**	**1.64**	**0.76**	**4.07**	**2.93**	**1.18**	**1.35**	**0.32**	**1.45**	**0.04**	**3.07**	**1.06**	**3.10**	**2.75**	**0.36**	**1.27**	**1.35**
	Avg. % difference	**4.92**	**2.43**	**5.42**	**3.50**	**3.51**	**5.86**	**2.60**	**4.45**	**5.99**	**5.17**	**2.50**	**8.61**	**6.50**	**2.35**	**6.56**	**3.99**	**3.59**
July 2003	M9 (mg/kg)	9150	118.7	4571	4.9	10.8	27.3	50.7	31292	439.4	4638	579	178.1	22.1	1297	1728	35.1	127.9
		9195.3	119.4	4467	4.9	11.1	27.1	36.2	39894	433.2	4477	561	165.2	22.0	1294	1707	34.4	128.7
	% difference	0.49	0.63	2.30	0.48	2.22	0.84	33.40	24.17	1.41	3.55	3.23	7.50	0.87	0.23	1.18	2.03	0.59
	M20 (mg/kg)	8741.3	250.1	4335	10.5	12.1	27.2	81.2	82570	429.6	4099	716	183.4	28.3	5065	1231	26.9	265.7
		8401	242.9	4190	10.4	11.9	26.3	80.3	82329	416.9	3935	713	175.7	27.4	5155	1244	25.9	264.0
	% difference	3.97	2.92	3.39	1.67	1.66	3.53	1.17	0.29	2.99	4.09	0.42	4.32	3.33	1.76	1.04	3.71	0.67
	Avg. diff. std. dev.	**2.46**	**1.62**	**0.77**	**0.84**	**0.39**	**1.90**	**22.79**	**16.88**	**1.12**	**0.39**	**1.99**	**2.25**	**1.74**	**1.08**	**0.10**	**1.19**	**0.06**
	Avg. % difference	**2.23**	**1.77**	**2.85**	**1.08**	**1.94**	**2.19**	**17.28**	**12.23**	**2.20**	**3.82**	**1.82**	**5.91**	**2.10**	**1.00**	**1.11**	**2.87**	**0.63**

Table E.3 Measurement of Method Accuracy for October 2002 Sediment Sampling Using MESS-1 Marine Reference Sediment

	Al	As	B	Ba	Ca	Cd	Co	Cr	Cu	Fe	K
Replicate Concentrations (mg/kg)	9275	8.1	21.3	31.3	1789	2.3	8.8	19.5	20.79	18942	1336
	9534	7.8	21.1	32.3	1809	2.3	9.0	19.9	20.35	19269	1358
Average Concentration (mg/kg)	9405	7.95	21.2	31.8	1799	2.3	8.9	19.7	20.57	19106	1347
Certified Concentration (mg/kg)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	71 +/- 11	25.1 +/- 2.7	N/A	N/A
% Error outside range	N/A	N/A	N/A	N/A	N/A	N/A	N/A	67.2	8.2	N/A	N/A

Table E.3 (cont.) Measurement of Method Accuracy for October 2002 Sediment Sampling Using MESS-1 Marine Reference Sediment

	Mg	Mn	Mo	Na	Ni	P	Pb	Se	Si	Sr	Zn
Replicate Concentrations (mg/kg)	5211	256.9	1.70	6156	17.33	497.06	25.44	0	1040.6	24.57	152.16
	5328	262.7	1.74	6280	17.67	501.39	24.59	0	1027.5	25.02	151.28
Average Concentration (mg/kg)	5270	259.8	1.72	6218	17.50	499.23	25.02	0	1034.1	24.80	151.72
Certified Concentration (mg/kg)	N/A	N/A	N/A	N/A	29.5 +/- 2.7	N/A	N/A	N/A	N/A	N/A	191+/- 17
% Error outside range	N/A	N/A	N/A	N/A	34.7	N/A	N/A	N/A	N/A	N/A	12.8

Table E.4 Measurement of Method Accuracy for July 2003 Sediment Sampling Using Priority PollutnT™/CLP (Lot No. DO35-540) Reference Sediment

	Al	As	B	Ba	Ca	Cd	Co	Cr	Cu	Fe	K
Sample Concentrations	3593	167.3	128.2	371.1	2986	119.8	52.46	118.2	85.18	7292	1469
Certified Concentration	6340	192.0	131.0	417.0	3370	125.0	56.80	133.0	93.90	11600	1890
Performance Limits	2760-9920	152-232	98.6-164	332-502	2550-4190	101-149	45.0-68.7	103-163	74.4-113	5500-17700	1200-2580
% Error outside range	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Table E.4 (cont.) Measurement of Method Accuracy for July 2003 Sediment Sampling Using Priority PollutnT™/CLP (Lot No. DO35-540) Reference Sediment

	Mg	Mn	Mo	Na	Ni	P	Pb	Se	Si	Sr	Zn
Sample Concentration	1509	287.3	57.89	296.0	161.3	411.1	153.9	89.33	884.8	144.7	220.1
Certified Concentration	2000	320.0	62.90	241.0	174.0	N/A	160.0	97.00	N/A	178.0	246.0
Performance Limits	1410-2500	242-398	47.6-78.1	122-360	136-211	N/A	124-196	69.6-124	N/A	132-224	189-303
% Error outside range	**0**	**0**	**0**	**0**	**0**	N/A	**0**	**0**	N/A	**0**	**0**

Table E.5 Measurement of Method Precision for Bray Extraction

Sampling Station	P (ppm)
U3	17.11
	18.11
% difference	5.66
U4	19.82
	19.30
% difference	2.68
U6	11.41
	11.60
% difference	1.64
U8	17.53
	17.70
% difference	1.00
F12	15.30
	12.69
% difference	18.66
Avg. % diff. std. dev	**2.08**
Avg. % difference	**3.33**

Table E.7 Measurement of Method Precision for Particle-Size Analysis

Sampling Station	% Sand	% Silt	% Clay
U6	93.27	5.13	1.60
	91.40	6.20	2.40
% difference	2.02	18.82	40.00
F12	90.60	6.20	3.20
	88.73	7.67	3.60
% difference	2.08	21.15	11.76
A15	48.80	41.27	9.93
	49.73	42.47	7.80
% difference	1.89	2.87	24.06
Avg. % diff. std. dev	**0.10**	**9.95**	**14.16**
Avg. % difference	**2.00**	**14.28**	**25.27**

Appendix F: Land Use Correlations

Table F.1 Summary of Contributing Areas by Sampling Station

Sampling Station	Tributary	Contributing Area		Total Upstream Contributing Area	
		Area (m^2)	% of watershed area	Area (m^2)	% of watershed area
M19	Chilliwack Creek	3,189,297	5.75	3,189,297	5.75
M20	Chilliwack Creek	26,694,003	48.17	55,419,314	100.00
A15	Interception Ditch	2,356,052	4.25	4,521,567	8.16
A16	Interception Ditch	1,587,335	2.86	9,344,005	16.86
A18	Interception Ditch	2,291,580	4.13	17,578,034	31.72
F13	Elkview Creek	2,165,515	3.91	2,165,515	3.91
F14	Parson's Brook	88,264	0.16	2,047,655	3.69
F12	Parson's Brook	1,959,390	3.54	1,959,390	3.54
A11	Armstrong Ditch	1,187,449	2.14	1,187,449	2.14
M9	Teskey Way Ditch	412,216	0.74	412,216	0.74
A17	Teskey Way Ditch	1,161,594	2.10	5,942,448	10.72
M10	Bailey Ditch	1,643,149	2.96	4,368,638	7.88
U7	Lefferson Creek	448,453	0.81	448,453	0.81
U4	Lefferson Creek	126,568	0.23	575,021	1.04
U5	Teskey/Thorton Creek	645,284	1.16	645,284	1.16
U3	Teskey/Thorton Creek	1,018,659	1.84	1,663,944	3.00
U8	Walker Creek	118,955	0.21	118,955	0.21
U6	Benchley Creek	367,570	0.66	367,570	0.66
A2	Semmihault Creek	7,957,980	14.36	7,957,980	14.36
G1	Luckakuck Creek	*Spring Fed Station (no contributing area delineated)*			

Table F.2 Spearman's Rank Correlation Coefficient for Nutrients vs Agricultural Land Use Indices

	type	NH_4 (Dry)	NO_3^- (Dry)	NH_4 (Wet)	NO_3^- (Wet)	PO_4 (Wet)
% total agriculture	ca	**0.50**	-0.25	**0.69**	**0.55**	**0.54**
	caup	0.37	-0.23	**0.55**	**0.57**	**0.45**
	50m	**0.71**	-0.20	**0.72**	**0.46**	**0.56**
	50mup	**0.56**	-0.37	**0.53**	**0.54**	0.35
	100m	**0.68**	-0.15	**0.71**	**0.50**	**0.54**
	100mup	**0.54**	-0.32	**0.51**	**0.58**	0.33
	200m	**0.65**	-0.16	**0.65**	**0.47**	**0.55**
	200mup	**0.51**	-0.26	**0.51**	**0.60**	**0.40**
% arable	ca	**0.50**	-0.17	**0.56**	0.33	**0.61**
	caup	0.28	-0.16	**0.42**	**0.45**	**0.43**
	50m	**0.63**	-0.23	**0.64**	**0.39**	**0.57**
	50mup	**0.45**	-0.34	**0.43**	**0.48**	0.30
	100m	**0.61**	-0.21	**0.63**	**0.39**	**0.59**
	100mup	**0.48**	-0.29	**0.42**	**0.49**	**0.39**
	200m	**0.55**	-0.17	**0.58**	0.36	**0.53**
	200mup	**0.40**	-0.29	0.38	**0.49**	0.34
% cattle	ca	**0.39**	-0.26	**0.47**	**0.54**	0.19
	caup	**0.56**	-0.24	**0.53**	**0.56**	0.36
	50m	0.35	-0.02	**0.45**	**0.64**	0.16
	50mup	**0.61**	-0.20	**0.54**	**0.64**	0.36
	100m	0.35	-0.02	**0.45**	**0.60**	0.16
	100mup	**0.57**	-0.19	**0.54**	**0.66**	0.36
	200m	0.37	-0.05	**0.48**	**0.60**	0.16
	200mup	**0.61**	-0.23	**0.58**	**0.61**	**0.39**
% poultry	ca	**0.42**	-0.22	**0.48**	0.20	**0.55**
	caup	**0.45**	-0.22	**0.48**	0.18	**0.57**
	50m	**0.42**	-0.22	**0.48**	0.20	**0.55**
	50mup	**0.42**	-0.22	**0.48**	0.20	**0.55**
	100m	**0.42**	-0.22	**0.48**	0.20	**0.55**
	100mup	**0.42**	-0.22	**0.48**	0.20	**0.55**
	200m	**0.42**	-0.22	**0.48**	0.20	**0.55**
	200mup	**0.42**	-0.22	**0.48**	0.20	**0.55**
% horticulture	ca	**0.40**	-0.28	**0.50**	0.21	0.15
	caup	**0.43**	-0.35	**0.46**	0.19	0.17
	50m	0.12	**-0.41**	0.18	0.20	-0.24
	50mup	**0.39**	**-0.44**	0.34	0.20	0.08
	100m	0.12	**-0.41**	0.18	0.20	-0.24
	100mup	**0.39**	**-0.44**	0.34	0.20	0.08
	200m	0.25	**-0.39**	0.25	0.31	-0.08
	200mup	**0.40**	**-0.43**	0.36	0.20	0.11
	200m	0.34	0.00	0.22	0.30	0.37
	200mup	0.34	0.00	0.22	0.30	0.37
% hobby farms	ca	-0.17	0.21	-0.15	0.10	**-0.55**
	caup	0.10	0.07	0.22	0.11	-0.14
	50m	-0.05	0.13	-0.37	-0.10	**-0.49**
	50mup	0.08	0.08	0.18	0.10	-0.16
	100m	0.01	0.21	-0.27	-0.03	**-0.42**
	100mup	0.05	0.10	0.18	0.13	-0.15
	200m	0.02	0.16	-0.19	0.02	**-0.38**
	200mup	0.10	0.04	0.24	0.10	-0.08
% unused agricultural land	ca	**0.58**	-0.20	**0.42**	**0.42**	**0.55**
	caup	**0.74**	-0.12	**0.78**	0.32	**0.82**
	50m	**0.56**	-0.23	**0.38**	**0.41**	**0.46**
	50mup	**0.72**	-0.15	**0.75**	0.32	**0.74**
	100m	**0.56**	-0.23	**0.38**	**0.41**	**0.46**
	100mup	**0.73**	-0.13	**0.76**	0.35	**0.74**

*Values in bold significant at the $\alpha=0.05$ level

Table F.3 Spearman's Rank Correlation Coefficient for Nutrients vs Greenspace Land Cover Indices

		NH_4 (Dry)	NO_3^- (Dry)	NH_4 (Wet)	NO_3^- (Wet)	PO_4 (Wet)
% total natural	ca	**-0.59**	-0.02	**-0.51**	**-0.49**	**-0.53**
	caup	**-0.52**	-0.22	**-0.46**	**-0.48**	**-0.45**
	50m	**-0.71**	-0.12	**-0.54**	**-0.42**	**-0.51**
	50mup	**-0.64**	-0.22	**-0.41**	**-0.49**	-0.36
	100m	**-0.71**	-0.13	**-0.59**	**-0.44**	**-0.54**
	100mup	**-0.66**	-0.22	**-0.44**	**-0.52**	**-0.40**
	200m	**-0.72**	-0.09	**-0.58**	**-0.42**	**-0.58**
	200mup	**-0.64**	-0.19	**-0.47**	**-0.52**	**-0.46**
% forest	ca	**-0.46**	-0.27	-0.26	**-0.43**	**-0.45**
	caup	**-0.42**	-0.37	-0.29	**-0.41**	**-0.45**
	50m	**-0.64**	-0.14	**-0.40**	-0.30	**-0.59**
	50mup	**-0.59**	-0.14	-0.27	-0.35	**-0.39**
	100m	**-0.62**	-0.17	**-0.39**	-0.32	**-0.56**
	100mup	**-0.59**	-0.18	-0.28	-0.35	**-0.41**
	200m	**-0.59**	-0.19	**-0.41**	-0.33	**-0.57**
	200mup	**-0.57**	-0.19	-0.29	-0.35	**-0.47**
% open space	ca	-0.08	0.24	-0.31	-0.35	-0.05
	caup	-0.22	0.34	-0.24	**-0.41**	-0.10
	50m	-0.24	-0.21	**-0.46**	**-0.39**	-0.37
	50mup	-0.11	-0.14	-0.12	**-0.46**	-0.12
	100m	-0.21	-0.15	**-0.42**	-0.35	-0.37
	100mup	-0.01	-0.03	-0.02	**-0.39**	-0.14
	200m	-0.18	-0.01	**-0.44**	-0.33	-0.35
	200mup	-0.05	0.09	-0.09	**-0.46**	-0.11
% parks/ playing fields	ca	0.33	**0.45**	0.15	0.07	0.25
	caup	**0.39**	**0.55**	0.20	0.18	0.28
	50m	0.15	**0.43**	-0.16	0.17	-0.01
	50mup	0.37	**0.56**	0.18	0.17	0.25
	100m	0.15	**0.43**	-0.16	0.17	-0.01
	100mup	0.37	**0.56**	0.18	0.17	0.25
	200m	0.15	**0.43**	-0.16	0.17	-0.01
	200mup	**0.44**	**0.43**	**0.40**	0.27	**0.41**
% rural residential	ca	**-0.46**	-0.15	**-0.55**	**-0.44**	**-0.50**
	caup	**-0.59**	-0.09	-0.31	-0.27	**-0.41**
	50m	**-0.48**	-0.21	**-0.44**	-0.26	**-0.60**
	50mup	**-0.42**	-0.22	-0.26	-0.21	**-0.53**
	100m	**-0.46**	-0.20	**-0.44**	-0.28	**-0.64**
	100mup	**-0.41**	-0.24	-0.21	-0.21	**-0.52**
	200m	**-0.38**	-0.19	**-0.44**	**-0.41**	**-0.54**
	200mup	-0.38	-0.25	-0.20	-0.23	**-0.46**

*Values in bold significant at the α=0.05 level

Table F.4 Spearman's Rank Correlation Coefficient for Nutrients vs Urban Land Use Indices

		NH_4 (Dry)	NO_3^- (Dry)	NH_4 (Wet)	NO_3^- (Wet)	PO_4 (Wet)
% total urban	ca	0.09	**0.55**	-0.07	-0.16	0.05
	caup	0.13	**0.63**	0.09	-0.09	0.11
	50m	-0.12	0.37	**-0.39**	-0.14	-0.21
	50mup	0.11	**0.56**	0.11	-0.13	0.11
	100m	-0.11	0.37	**-0.38**	-0.15	-0.20
	100mup	0.12	**0.58**	0.10	-0.11	0.11
	200m	-0.09	**0.44**	**-0.41**	-0.11	-0.21
	200mup	0.13	**0.62**	0.11	-0.08	0.12
% industrial/ commercial	ca	**0.43**	0.33	**0.38**	0.27	0.35
	caup	**0.49**	**0.48**	**0.51**	0.23	**0.43**
	50m	**0.45**	0.32	0.17	0.19	0.22
	50mup	**0.63**	**0.41**	**0.44**	0.07	**0.49**
	100m	**0.46**	0.31	0.20	0.20	0.24
	100mup	**0.63**	**0.41**	**0.44**	0.07	**0.49**
	200m	**0.46**	0.31	0.20	0.20	0.24
	200mup	**0.61**	**0.42**	**0.43**	0.08	**0.47**
% residential	ca	0.10	**0.52**	-0.21	-0.30	0.01
	caup	0.08	**0.65**	0.05	-0.17	0.06
	50m	-0.28	**0.39**	**-0.52**	-0.35	-0.35
	50mup	0.06	**0.59**	0.08	-0.21	0.07
	100m	-0.28	**0.39**	**-0.52**	-0.35	-0.35
	100mup	0.07	**0.61**	0.07	-0.19	0.07
	200m	-0.23	**0.47**	**-0.52**	-0.28	-0.33
	200mup	0.08	**0.65**	0.06	-0.17	0.07
% high density urban	ca	0.35	-0.07	0.27	-0.22	0.32
	caup	0.20	**0.42**	0.01	-0.19	0.06
	50m	0.10	-0.02	0.14	-0.16	0.05
	50mup	0.19	**0.43**	0.03	-0.19	0.06
	100m	0.11	-0.01	0.14	-0.17	0.06
	100mup	0.14	**0.40**	-0.03	-0.20	0.02
	200m	0.11	-0.01	0.14	-0.17	0.06
	200mup	0.14	**0.40**	-0.03	-0.20	0.02
% low density urban	ca	0.11	**0.61**	-0.17	-0.25	0.01
	caup	0.08	**0.64**	0.07	-0.19	0.07
	50m	-0.18	**0.49**	**-0.44**	-0.26	-0.27
	50mup	0.08	**0.64**	0.07	-0.19	0.07
	100m	-0.18	**0.49**	**-0.44**	-0.26	-0.27
	100mup	0.08	**0.64**	0.07	-0.19	0.07
	200m	-0.17	**0.51**	**-0.45**	-0.24	-0.28
	200mup	0.08	**0.64**	0.07	-0.19	0.07

*Values in bold significant at the α=0.05 level

Table F.5 Spearman's Rank Correlation Coefficient for Physical Water Quality Parameters vs Agricultural Land Use Indices

	type	pH (Dry)	Temp. (Dry)	Cond. (Dry)	DO (Dry)	pH (Wet)	Temp. (Wet)	Cond. (Wet)	DO (Wet)
% total agriculture	ca	-0.04	**0.61**	**0.46**	-0.20	**-0.69**	**0.83**	**0.74**	-0.18
	caup	-0.07	**0.53**	**0.49**	-0.22	**-0.69**	**0.81**	**0.70**	-0.12
	50m	-0.23	**0.60**	0.35	-0.21	**-0.71**	**0.75**	**0.61**	-0.31
	50mup	-0.29	**0.46**	0.17	-0.32	**-0.73**	**0.67**	**0.44**	-0.19
	100m	-0.23	**0.57**	**0.38**	-0.23	**-0.73**	**0.77**	**0.61**	-0.31
	100mup	-0.30	**0.44**	0.21	-0.34	**-0.75**	**0.68**	**0.44**	-0.19
	200m	-0.29	**0.57**	**0.42**	-0.26	**-0.79**	**0.82**	**0.62**	-0.33
	200mup	-0.34	**0.46**	0.34	-0.34	**-0.82**	**0.76**	**0.55**	-0.22
% arable	ca	-0.22	**0.46**	**0.46**	-0.18	**-0.66**	**0.87**	**0.67**	-0.19
	caup	-0.18	0.34	**0.46**	-0.10	**-0.64**	**0.78**	**0.65**	-0.04
	50m	-0.29	**0.52**	0.32	-0.18	**-0.72**	**0.78**	**0.57**	-0.21
	50mup	-0.35	0.30	0.15	-0.26	**-0.72**	**0.63**	0.35	-0.10
	100m	-0.29	**0.52**	0.33	-0.16	**-0.74**	**0.80**	**0.61**	-0.21
	100mup	**-0.45**	0.26	0.22	-0.24	**-0.77**	**0.70**	**0.45**	-0.12
	200m	-0.33	**0.42**	0.31	-0.18	**-0.72**	**0.80**	**0.57**	-0.18
	200mup	**-0.40**	0.26	0.22	-0.20	**-0.75**	**0.72**	**0.48**	-0.09
% cattle	ca	-0.03	0.25	0.24	-0.18	**-0.51**	**0.42**	**0.40**	-0.25
	caup	-0.16	0.36	0.32	-0.24	**-0.62**	**0.54**	**0.49**	**-0.43**
	50m	0.03	0.17	**0.38**	-0.11	**-0.48**	0.33	**0.49**	-0.25
	50mup	-0.22	0.30	0.36	-0.30	**-0.69**	**0.51**	**0.55**	**-0.43**
	100m	0.04	0.20	0.36	-0.13	**-0.48**	0.34	**0.45**	-0.26
	100mup	-0.22	0.31	0.37	-0.30	**-0.72**	**0.55**	**0.56**	**-0.41**
	200m	0.04	0.21	0.32	-0.13	**-0.46**	0.34	**0.43**	-0.23
	200mup	-0.23	0.38	0.33	-0.32	**-0.71**	**0.57**	**0.52**	**-0.38**
% poultry	ca	-0.03	**0.54**	0.13	-0.16	-0.36	**0.51**	**0.39**	-0.26
	caup	-0.07	**0.54**	0.15	-0.20	-0.38	**0.52**	**0.39**	-0.28
	50m	-0.03	**0.54**	0.13	-0.16	-0.36	**0.51**	**0.39**	-0.26
	50mup	-0.03	**0.54**	0.13	-0.16	-0.36	**0.51**	**0.39**	-0.26
	100m	-0.03	**0.54**	0.13	-0.16	-0.36	**0.51**	**0.39**	-0.26
	100mup	-0.03	**0.54**	0.13	-0.16	-0.36	**0.51**	**0.39**	-0.26
	200m	-0.03	**0.54**	0.13	-0.16	-0.36	**0.51**	**0.39**	-0.26
	200mup	-0.03	**0.54**	0.13	-0.16	-0.36	**0.51**	**0.39**	-0.26
% horticulture	ca	-0.03	0.37	-0.24	0.20	-0.36	0.34	0.12	-0.06
	caup	-0.11	**0.41**	-0.25	-0.34	**-0.42**	0.36	0.05	-0.12
	50m	-0.02	0.11	**-0.56**	0.06	-0.20	0.01	-0.18	0.13
	50mup	-0.20	0.32	-0.37	-0.36	**-0.42**	0.28	-0.05	-0.10
	100m	-0.02	0.11	**-0.56**	0.06	-0.20	0.01	-0.18	0.13
	100mup	-0.20	0.32	-0.37	-0.36	**-0.42**	0.28	-0.05	-0.10
	200m	-0.04	0.16	**-0.44**	0.21	-0.28	0.16	-0.08	-0.03
	200mup	-0.19	0.35	-0.34	-0.38	**-0.42**	0.30	-0.04	-0.12
% hobby farms	ca	0.15	0.04	-0.16	-0.21	0.17	**-0.39**	-0.30	-0.02
	caup	0.15	**0.47**	0.02	**-0.40**	-0.07	0.01	-0.03	-0.10
	50m	-0.01	0.06	-0.28	-0.23	0.11	-0.23	**-0.54**	-0.18
	50mup	0.15	**0.46**	-0.04	-0.36	-0.03	0.01	-0.11	-0.08
	100m	-0.03	0.07	-0.16	-0.28	0.09	-0.20	**-0.42**	-0.22
	100mup	0.20	**0.46**	0.01	-0.36	-0.03	0.03	-0.06	-0.07
	200m	0.06	0.17	-0.19	-0.19	0.08	-0.17	-0.36	-0.19
	200mup	0.20	**0.53**	0.02	-0.36	-0.06	0.06	-0.03	-0.09
% unused agricultural land	ca	-0.38	0.11	0.37	-0.17	**-0.43**	**0.41**	**0.60**	-0.36
	caup	-0.28	**0.49**	**0.53**	-0.14	**-0.54**	**0.64**	**0.83**	-0.37
	50m	**-0.42**	0.04	0.27	-0.12	**-0.42**	0.35	**0.56**	-0.30
	50mup	-0.31	**0.42**	**0.45**	-0.10	**-0.53**	**0.59**	**0.80**	-0.32
	100m	**-0.42**	0.04	0.27	-0.12	**-0.42**	0.35	**0.56**	-0.30
	100mup	-0.30	**0.42**	**0.46**	-0.12	**-0.54**	**0.60**	**0.80**	-0.34
	200m	**-0.40**	0.07	0.29	-0.20	**-0.42**	**0.38**	**0.56**	-0.34
	200mup	-0.30	**0.45**	**0.46**	-0.17	**-0.53**	**0.62**	**0.80**	-0.35

*Values in bold significant at the $\alpha=0.05$ level

Table F.6 Spearman's Rank Correlation Coefficient for Physical Water Quality Parameters vs Greenspace Land Cover Indices

	type	pH (Dry)	Temp. (Dry)	Cond. (Dry)	DO (Dry)	pH (Wet)	Temp. (Wet)	Cond. (Wet)	DO (Wet)
% total natural	ca	0.21	**-0.50**	**-0.62**	0.28	**0.67**	**-0.72**	**-0.62**	**0.52**
	caup	0.23	-0.37	**-0.81**	**0.39**	**0.61**	**-0.58**	**-0.62**	**0.53**
	50m	**0.39**	**-0.42**	**-0.56**	**0.40**	**0.70**	**-0.65**	**-0.52**	**0.60**
	50mup	**0.51**	-0.23	**-0.63**	**0.47**	**0.69**	**-0.49**	**-0.45**	**0.62**
	100m	**0.38**	**-0.47**	**-0.60**	**0.38**	**0.72**	**-0.69**	**-0.59**	**0.57**
	100mup	**0.52**	-0.28	**-0.67**	**0.50**	**0.74**	**-0.57**	**-0.51**	**0.61**
	200m	**0.41**	**-0.51**	**-0.61**	**0.42**	**0.76**	**-0.71**	**-0.60**	**0.60**
	200mup	**0.45**	-0.36	**-0.69**	**0.45**	**0.75**	**-0.61**	**-0.57**	**0.59**
% forest	ca	0.26	**-0.43**	**-0.60**	0.17	**0.59**	**-0.57**	**-0.53**	**0.71**
	caup	0.31	-0.32	**-0.86**	0.20	**0.51**	**-0.46**	**-0.64**	**0.63**
	50m	**0.47**	**-0.48**	**-0.55**	0.21	**0.68**	**-0.61**	**-0.55**	**0.67**
	50mup	**0.62**	-0.28	**-0.55**	0.37	**0.67**	**-0.45**	**-0.41**	**0.64**
	100m	**0.43**	**-0.48**	**-0.53**	0.19	**0.67**	**-0.60**	**-0.54**	**0.67**
	100mup	**0.60**	-0.28	**-0.58**	0.34	**0.66**	**-0.45**	**-0.44**	**0.66**
	200m	0.37	**-0.50**	**-0.57**	0.17	**0.64**	**-0.60**	**-0.57**	**0.67**
	200mup	**0.56**	-0.32	**-0.65**	0.29	**0.65**	**-0.47**	**-0.51**	**0.69**
% open space	ca	-0.33	-0.01	0.03	-0.04	0.06	-0.09	-0.10	-0.21
	caup	-0.12	0.03	0.10	0.06	0.22	-0.29	-0.06	-0.11
	50m	-0.08	-0.29	**-0.65**	0.28	**0.42**	**-0.46**	**-0.52**	0.16
	50mup	-0.04	0.00	**-0.49**	0.18	**0.39**	-0.30	-0.26	0.17
	100m	-0.11	-0.24	**-0.54**	0.14	**0.39**	**-0.48**	**-0.47**	0.06
	100mup	-0.09	0.12	-0.26	0.08	0.30	-0.30	-0.15	-0.02
	200m	-0.14	-0.27	-0.37	0.15	0.37	**-0.43**	**-0.40**	-0.01
	200mup	-0.06	0.10	-0.13	0.12	0.33	-0.34	-0.14	-0.09
% parks/ playing fields	ca	**-0.38**	0.15	**0.49**	**-0.46**	**-0.38**	0.31	0.21	**-0.50**
	caup	**-0.40**	0.07	**0.60**	**-0.52**	-0.37	0.26	0.27	**-0.58**
	50m	-0.36	-0.12	0.33	**-0.44**	-0.25	0.08	-0.02	**-0.50**
	50mup	**-0.42**	0.05	**0.59**	**-0.51**	-0.36	0.22	0.25	**-0.59**
	100m	-0.36	-0.12	0.33	**-0.44**	-0.25	0.08	-0.02	**-0.50**
	100mup	**-0.42**	0.05	**0.59**	**-0.51**	-0.36	0.22	0.25	**-0.59**
	200m	-0.36	-0.12	0.33	**-0.44**	-0.25	0.08	-0.02	**-0.50**
	200mup	**-0.43**	0.18	**0.60**	**-0.59**	**-0.47**	**0.43**	**0.43**	**-0.49**
% rural residential	ca	0.28	-0.24	**-0.61**	0.19	**0.53**	**-0.46**	**-0.57**	0.26
	caup	**0.58**	-0.08	**-0.43**	0.34	**0.58**	**-0.42**	-0.28	**0.45**
	50m	0.33	-0.31	**-0.74**	0.30	**0.55**	**-0.46**	**-0.59**	**0.44**
	50mup	0.34	-0.14	**-0.69**	0.21	**0.48**	-0.36	**-0.48**	**0.45**
	100m	0.27	-0.30	**-0.71**	0.24	**0.54**	**-0.49**	**-0.60**	**0.39**
	100mup	0.33	-0.08	**-0.65**	0.20	**0.45**	-0.35	**-0.43**	**0.44**
	200m	0.19	-0.23	**-0.71**	0.15	**0.51**	**-0.45**	**-0.62**	0.32
	200mup	0.27	-0.01	**-0.62**	0.15	**0.41**	-0.32	**-0.40**	**0.40**

*Values in bold significant at the $\alpha=0.05$ level

Table F.7 Spearman's Rank Correlation Coefficient for Physical Water Quality Parameters vs Urban Land Use Indices

	type	pH (Dry)	Temp. (Dry)	Cond. (Dry)	DO (Dry)	pH (Wet)	Temp. (Wet)	Cond. (Wet)	DO (Wet)
% total urban	ca	-0.01	-0.05	**0.47**	-0.09	0.22	-0.18	0.02	**-0.48**
	caup	0.07	0.05	**0.56**	-0.07	0.18	-0.12	0.16	**-0.46**
	50m	0.08	-0.38	0.19	0.09	**0.43**	-0.36	-0.23	-0.31
	50mup	0.08	0.04	**0.54**	-0.09	0.21	-0.11	0.14	**-0.40**
	100m	0.06	-0.36	0.19	0.08	**0.42**	-0.36	-0.23	-0.32
	100mup	0.07	0.04	**0.55**	-0.10	0.20	-0.11	0.15	**-0.44**
	200m	0.04	-0.35	0.21	0.09	**0.40**	-0.38	-0.22	**-0.39**
	200mup	0.07	0.06	**0.57**	-0.08	0.18	-0.10	0.17	**-0.46**
% industrial/ commercial	ca	-0.25	0.28	**0.67**	**-0.39**	-0.21	0.15	**0.43**	**-0.42**
	caup	-0.13	0.37	**0.82**	-0.31	-0.21	0.24	**0.55**	**-0.46**
	50m	-0.32	0.00	**0.55**	-0.23	-0.14	-0.08	0.23	**-0.59**
	50mup	-0.34	0.27	**0.71**	-0.35	-0.30	0.19	**0.42**	**-0.65**
	100m	-0.32	0.02	**0.56**	-0.24	-0.15	-0.06	0.25	**-0.59**
	100mup	-0.34	0.27	**0.71**	-0.35	-0.30	0.19	**0.42**	**-0.65**
	200m	-0.32	0.02	**0.56**	-0.24	-0.15	-0.06	0.25	**-0.59**
	200mup	-0.33	0.25	**0.71**	-0.33	-0.28	0.17	**0.41**	**-0.64**
% residential	ca	-0.11	-0.11	0.27	-0.13	0.22	-0.21	-0.15	**-0.51**
	caup	0.07	0.02	**0.47**	-0.10	0.23	-0.17	0.08	**-0.42**
	50m	0.15	**-0.41**	-0.02	0.09	**0.57**	**-0.49**	**-0.43**	-0.22
	50mup	0.09	0.02	**0.46**	-0.12	0.25	-0.15	0.08	-0.36
	100m	0.15	**-0.41**	-0.02	0.09	**0.57**	**-0.49**	**-0.43**	-0.22
	100mup	0.08	0.03	**0.47**	-0.12	0.24	-0.15	0.09	**-0.39**
	200m	0.09	**-0.39**	0.04	0.07	**0.52**	**-0.49**	**-0.38**	-0.32
	200mup	0.08	0.03	**0.48**	-0.11	0.23	-0.16	0.09	**-0.41**
% high density urban	ca	**-0.41**	0.21	0.22	**-0.54**	-0.12	0.12	0.14	**-0.39**
	caup	-0.19	0.02	0.37	-0.24	0.10	-0.19	0.03	**-0.62**
	50m	-0.16	-0.01	0.15	-0.35	0.14	-0.12	0.04	-0.25
	50mup	-0.16	0.02	0.38	-0.23	0.11	-0.19	0.05	**-0.60**
	100m	-0.17	0.00	0.15	-0.35	0.14	-0.13	0.04	-0.26
	100mup	-0.15	0.01	0.32	-0.20	0.14	-0.21	0.01	**-0.60**
	200m	-0.17	0.00	0.15	-0.35	0.14	-0.13	0.04	-0.26
	200mup	-0.15	0.01	0.32	-0.20	0.14	-0.21	0.01	**-0.60**
% low density urban	ca	-0.07	-0.13	0.32	-0.09	0.23	-0.23	-0.12	**-0.50**
	caup	0.10	0.02	**0.46**	-0.09	0.24	-0.16	0.07	-0.37
	50m	0.10	**-0.39**	0.07	0.06	**0.49**	**-0.46**	-0.35	-0.27
	50mup	0.10	0.02	**0.46**	-0.09	0.24	-0.16	0.07	-0.37
	100m	0.10	**-0.39**	0.07	0.06	**0.49**	**-0.46**	-0.35	-0.27
	100mup	0.10	0.02	**0.46**	-0.09	0.24	-0.16	0.07	-0.37
	200m	0.08	**-0.38**	0.09	0.06	**0.48**	**-0.47**	-0.34	-0.31
	200mup	0.10	0.02	**0.46**	-0.09	0.24	-0.16	0.07	-0.37

*Values in bold significant at the $\alpha=0.05$ level

Table F.8 Spearman's Rank Correlation Coefficient for Dissolved Ions and Metals vs Agricultural Land Use Indices

	type	Ca	K	Mg	Na	Fe	Mn
% total agriculture	ca	0.35	0.16	0.06	-0.06	**0.64**	**0.73**
	caup	**0.39**	0.11	-0.07	-0.04	**0.44**	**0.59**
	50m	0.26	0.08	0.05	-0.06	**0.79**	**0.82**
	50mup	0.11	-0.23	-0.29	-0.17	**0.54**	**0.65**
	100m	0.28	0.14	0.07	-0.04	**0.76**	**0.81**
	100mup	0.13	-0.18	-0.28	-0.16	**0.52**	**0.63**
	200m	0.34	0.21	0.10	-0.06	**0.73**	**0.78**
	200mup	0.26	-0.01	-0.18	-0.10	**0.52**	**0.63**
% arable	ca	**0.50**	0.33	0.22	-0.18	**0.55**	**0.60**
	caup	**0.52**	0.18	0.00	-0.14	0.31	**0.43**
	50m	0.30	0.09	0.01	-0.18	**0.70**	**0.72**
	50mup	0.16	-0.17	-0.26	-0.31	**0.42**	**0.53**
	100m	0.33	0.13	0.02	-0.17	**0.72**	**0.71**
	100mup	0.32	-0.07	-0.19	-0.29	**0.44**	**0.54**
	200m	0.37	0.21	0.08	-0.21	**0.64**	**0.62**
	200mup	0.34	-0.04	-0.20	-0.28	**0.39**	**0.47**
% cattle	ca	0.19	0.04	0.04	-0.14	**0.46**	**0.56**
	caup	0.31	0.16	0.14	-0.12	**0.60**	**0.70**
	50m	0.25	0.10	0.06	0.04	**0.41**	**0.53**
	50mup	0.30	0.10	0.08	-0.08	**0.65**	**0.73**
	100m	0.22	0.10	0.06	0.03	**0.43**	**0.53**
	100mup	0.30	0.13	0.06	-0.08	**0.63**	**0.72**
	200m	0.18	0.04	0.03	0.00	**0.44**	**0.54**
	200mup	0.25	0.08	0.01	-0.11	**0.64**	**0.73**
% poultry	ca	0.09	0.21	0.05	-0.09	**0.49**	**0.44**
	caup	0.12	0.23	0.06	-0.10	**0.50**	**0.45**
	50m	0.09	0.21	0.05	-0.09	**0.49**	**0.44**
	50mup	0.09	0.21	0.05	-0.09	**0.49**	**0.44**
	100m	0.09	0.21	0.05	-0.09	**0.49**	**0.44**
	100mup	0.09	0.21	0.05	-0.09	**0.49**	**0.44**
	200m	0.09	0.21	0.05	-0.09	**0.49**	**0.44**
	200mup	0.09	0.21	0.05	-0.09	**0.49**	**0.44**
% horticulture	ca	-0.29	-0.24	-0.27	-0.25	**0.63**	**0.46**
	caup	-0.31	-0.27	-0.31	-0.30	**0.59**	**0.47**
	50m	**-0.61**	**-0.56**	**-0.56**	-0.26	**0.38**	0.19
	50mup	**-0.40**	**-0.38**	**-0.43**	-0.34	**0.52**	**0.39**
	100m	**-0.61**	**-0.56**	**-0.56**	-0.26	**0.38**	0.19
	100mup	**-0.40**	**-0.38**	**-0.43**	-0.34	**0.52**	**0.39**
	200m	**-0.46**	**-0.43**	**-0.44**	-0.32	**0.39**	0.29
	200mup	**-0.38**	-0.35	**-0.40**	-0.34	**0.51**	**0.40**
% hobby farms	ca	**-0.55**	-0.37	**-0.42**	**0.52**	-0.14	-0.19
	caup	**-0.46**	-0.24	**-0.38**	**0.44**	0.16	0.10
	50m	**-0.59**	-0.33	-0.31	0.31	-0.18	-0.20
	50mup	**-0.49**	-0.25	**-0.40**	**0.40**	0.11	0.08
	100m	**-0.49**	-0.21	-0.19	**0.39**	-0.10	-0.11
	100mup	**-0.45**	-0.23	**-0.39**	**0.41**	0.09	0.07
	200m	**-0.57**	-0.22	-0.23	**0.42**	-0.01	-0.06
	200mup	**-0.47**	-0.20	-0.36	**0.41**	0.16	0.12
% unused agricultural land	ca	**0.59**	0.14	0.32	-0.09	**0.39**	**0.60**
	caup	**0.63**	0.34	**0.44**	-0.01	**0.78**	**0.84**
	50m	**0.52**	0.05	0.25	-0.10	**0.42**	**0.58**
	50mup	**0.57**	0.26	0.37	-0.02	**0.80**	**0.82**
	100m	**0.52**	0.05	0.25	-0.10	**0.42**	**0.58**
	100mup	**0.58**	0.29	**0.39**	-0.02	**0.80**	**0.83**
	200m	**0.54**	0.11	0.28	-0.12	**0.41**	**0.57**
	200mup	**0.59**	0.32	**0.40**	-0.03	**0.79**	**0.82**

*Values in bold significant at the α=0.05 level

Table F.9 Spearman's Rank Correlation Coefficient for Dissolved Ions and Metals vs Greenspace Land Cover Indices

	type	Ca	K	Mg	Na	Fe	Mn
% total natural	ca	**-0.42**	**-0.51**	-0.38	-0.17	**-0.53**	**-0.63**
	caup	**-0.55**	**-0.57**	**-0.43**	-0.32	-0.36	**-0.53**
	50m	**-0.44**	**-0.51**	**-0.39**	-0.13	**-0.59**	**-0.65**
	50mup	**-0.47**	**-0.51**	**-0.42**	-0.24	**-0.42**	**-0.56**
	100m	**-0.46**	**-0.52**	**-0.40**	-0.17	**-0.66**	**-0.71**
	100mup	**-0.51**	**-0.49**	-0.36	-0.23	**-0.47**	**-0.61**
	200m	**-0.47**	**-0.52**	**-0.40**	-0.16	**-0.66**	**-0.72**
	200mup	**-0.52**	**-0.52**	-0.36	-0.24	**-0.51**	**-0.62**
% forest	ca	**-0.55**	**-0.73**	**-0.54**	-0.34	**-0.44**	**-0.51**
	caup	**-0.74**	**-0.74**	**-0.62**	**-0.52**	-0.25	**-0.44**
	50m	**-0.60**	**-0.55**	**-0.46**	-0.21	**-0.58**	**-0.64**
	50mup	**-0.54**	**-0.43**	**-0.39**	-0.25	-0.36	**-0.52**
	100m	**-0.57**	**-0.57**	**-0.46**	-0.23	**-0.59**	**-0.63**
	100mup	**-0.58**	**-0.47**	**-0.44**	-0.28	-0.36	**-0.52**
	200m	**-0.59**	**-0.62**	**-0.51**	-0.25	**-0.59**	**-0.64**
	200mup	**-0.66**	**-0.57**	**-0.53**	-0.33	-0.38	**-0.54**
% open space	ca	0.17	0.29	0.34	0.31	-0.04	-0.13
	caup	0.15	0.28	0.33	**0.48**	-0.11	-0.22
	50m	**-0.40**	**-0.42**	-0.18	-0.09	-0.25	-0.36
	50mup	-0.25	-0.33	-0.11	0.00	-0.03	-0.18
	100m	-0.34	-0.35	-0.11	0.05	-0.26	-0.33
	100mup	-0.14	-0.18	0.05	0.28	0.03	-0.09
	200m	-0.19	-0.20	0.04	0.14	-0.28	-0.31
	200mup	-0.05	-0.04	0.19	0.37	0.00	-0.12
% parks/ playing fields	ca	**0.39**	**0.68**	**0.49**	0.26	0.18	0.18
	caup	**0.48**	**0.80**	**0.62**	0.33	0.20	0.24
	50m	0.25	**0.56**	0.37	0.25	-0.14	-0.07
	50mup	**0.46**	**0.79**	**0.62**	0.35	0.19	0.22
	100m	0.25	**0.56**	0.37	0.25	-0.14	-0.07
	100mup	**0.46**	**0.79**	**0.62**	0.35	0.19	0.22
	200m	0.25	**0.56**	0.37	0.25	-0.14	-0.07
	200mup	**0.53**	**0.80**	**0.62**	0.22	0.32	**0.40**
% rural residential	ca	**-0.53**	**-0.46**	-0.26	-0.09	-0.36	**-0.47**
	caup	**-0.46**	**-0.38**	-0.33	0.06	-0.31	**-0.42**
	50m	**-0.62**	**-0.62**	**-0.47**	-0.20	-0.37	**-0.46**
	50mup	**-0.62**	**-0.61**	**-0.55**	-0.15	-0.24	-0.38
	100m	**-0.60**	**-0.62**	**-0.45**	-0.12	**-0.41**	**-0.49**
	100mup	**-0.59**	**-0.61**	**-0.56**	-0.09	-0.24	-0.37
	200m	**-0.58**	**-0.58**	**-0.39**	-0.14	-0.34	**-0.44**
	200mup	**-0.56**	**-0.61**	**-0.56**	-0.07	-0.19	-0.32

*Values in bold significant at the $\alpha=0.05$ level

Table F.10 Spearman's Rank Correlation Coefficient for Dissolved Ions and Metals vs Urban Land Use Indices

	type	Ca	K	Mg	Na	Fe	Mn
% total urban	ca	0.35	**0.79**	**0.68**	**0.49**	-0.15	-0.12
	caup	0.37	**0.86**	**0.73**	**0.57**	-0.03	-0.02
	50m	0.16	**0.53**	**0.57**	0.29	**-0.43**	-0.33
	50mup	0.36	**0.85**	**0.73**	**0.50**	-0.05	-0.04
	100m	0.15	**0.53**	**0.58**	0.30	**-0.43**	-0.33
	100mup	0.37	**0.86**	**0.74**	**0.54**	-0.04	-0.03
	200m	0.16	**0.55**	**0.58**	0.37	**-0.40**	-0.31
	200mup	**0.38**	**0.87**	**0.74**	**0.57**	-0.02	-0.01
% industrial/ commercial	ca	0.34	**0.52**	0.37	**0.60**	0.19	0.30
	caup	**0.45**	**0.70**	**0.58**	**0.67**	0.30	**0.40**
	50m	0.37	**0.56**	**0.63**	**0.48**	0.13	0.28
	50mup	**0.53**	**0.77**	**0.76**	**0.48**	**0.40**	**0.47**
	100m	**0.38**	**0.57**	**0.64**	**0.48**	0.14	0.30
	100mup	**0.53**	**0.77**	**0.76**	**0.48**	**0.40**	**0.47**
	200m	**0.38**	**0.57**	**0.64**	**0.48**	0.14	0.30
	200mup	**0.52**	**0.77**	**0.77**	**0.49**	**0.38**	**0.46**
% residential	ca	0.23	**0.73**	**0.65**	0.36	-0.13	-0.17
	caup	0.29	**0.83**	**0.69**	**0.53**	-0.04	-0.08
	50m	-0.04	**0.46**	**0.47**	0.23	**-0.52**	**-0.53**
	50mup	0.29	**0.82**	**0.69**	**0.47**	-0.05	-0.09
	100m	-0.04	**0.46**	**0.47**	0.23	**-0.52**	**-0.53**
	100mup	0.30	**0.83**	**0.70**	**0.50**	-0.04	-0.08
	200m	0.00	**0.50**	**0.50**	0.33	**-0.46**	**-0.46**
	200mup	0.30	**0.84**	**0.70**	**0.53**	-0.03	-0.07
% high density urban	ca	0.30	**0.56**	**0.59**	0.12	0.18	0.22
	caup	0.37	**0.80**	**0.80**	**0.45**	0.04	0.05
	50m	0.22	**0.51**	**0.63**	0.16	-0.04	0.05
	50mup	0.37	**0.80**	**0.81**	**0.45**	0.04	0.05
	100m	0.20	**0.51**	**0.63**	0.17	-0.04	0.05
	100mup	0.36	**0.79**	**0.80**	**0.44**	0.00	0.01
	200m	0.20	**0.51**	**0.63**	0.17	-0.04	0.05
	200mup	0.36	**0.79**	**0.80**	**0.44**	0.00	0.01
% low density urban	ca	0.23	**0.76**	**0.67**	**0.40**	-0.11	-0.15
	caup	0.27	**0.82**	**0.67**	**0.50**	-0.04	-0.09
	50m	0.00	**0.51**	**0.50**	0.30	**-0.43**	**-0.43**
	50mup	0.27	**0.82**	**0.67**	**0.50**	-0.04	-0.09
	100m	0.00	**0.51**	**0.50**	0.30	**-0.43**	**-0.43**
	100mup	0.27	**0.82**	**0.67**	**0.50**	-0.04	-0.09
	200m	0.01	**0.52**	**0.50**	0.34	**-0.41**	**-0.42**
	200mup	0.27	**0.82**	**0.67**	**0.50**	-0.04	-0.09

*Values in bold significant at the α=0.05 level

Table F.11 Spearman's Rank Correlation Coefficient for Sediment-bound Elements vs Agricultural Land Use Indices

	type	Cd	Co	Cr	Cu	Fe	Mn	Ni	Zn
% total agriculture	ca	**0.84**	**0.62**	**0.47**	**0.70**	**0.83**	-0.08	**0.49**	**0.68**
	caup	**0.84**	**0.73**	**0.48**	**0.75**	**0.78**	0.04	**0.60**	**0.75**
	50m	**0.63**	0.38	0.29	**0.46**	**0.66**	-0.15	0.26	**0.50**
	50mup	**0.70**	**0.47**	0.32	**0.44**	**0.70**	-0.21	0.31	**0.52**
	100m	**0.65**	**0.42**	0.33	**0.50**	**0.67**	-0.10	0.31	**0.53**
	100mup	**0.72**	**0.51**	0.36	**0.48**	**0.71**	-0.16	0.36	**0.55**
	200m	**0.70**	**0.47**	**0.43**	**0.55**	**0.69**	-0.07	0.37	**0.58**
	200mup	**0.82**	**0.60**	**0.45**	**0.61**	**0.78**	-0.10	**0.45**	**0.66**
% arable	ca	**0.71**	**0.46**	**0.51**	**0.67**	**0.65**	0.04	**0.49**	**0.61**
	caup	**0.76**	**0.61**	**0.47**	**0.72**	**0.67**	0.18	**0.59**	**0.69**
	50m	**0.68**	**0.41**	**0.41**	**0.53**	**0.67**	-0.07	0.33	**0.56**
	50mup	**0.66**	**0.43**	**0.40**	**0.43**	**0.66**	-0.08	**0.39**	**0.47**
	100m	**0.70**	**0.42**	**0.42**	**0.57**	**0.68**	-0.07	0.32	**0.60**
	100mup	**0.71**	**0.43**	**0.41**	**0.50**	**0.68**	-0.06	**0.39**	**0.54**
	200m	**0.65**	0.36	**0.41**	**0.58**	**0.60**	-0.03	0.33	**0.57**
	200mup	**0.72**	**0.46**	**0.41**	**0.55**	**0.66**	-0.03	**0.41**	**0.58**
% cattle	ca	**0.51**	**0.43**	0.16	0.32	**0.48**	-0.11	0.11	**0.49**
	caup	**0.53**	0.35	0.19	0.32	**0.52**	-0.19	0.11	**0.47**
	50m	**0.56**	**0.56**	0.15	**0.44**	**0.52**	0.05	0.20	**0.64**
	50mup	**0.60**	**0.43**	0.23	**0.42**	**0.60**	-0.28	0.21	**0.55**
	100m	**0.54**	**0.55**	0.18	**0.43**	**0.51**	0.06	0.20	**0.62**
	100mup	**0.64**	**0.47**	0.27	**0.46**	**0.63**	-0.22	0.25	**0.59**
	200m	**0.52**	**0.51**	0.14	**0.40**	**0.50**	0.03	0.17	**0.58**
	200mup	**0.62**	**0.44**	0.27	**0.44**	**0.62**	-0.24	0.25	**0.55**
% poultry	ca	**0.45**	0.10	0.21	**0.41**	**0.44**	-0.27	0.09	0.33
	caup	**0.43**	0.09	0.23	**0.40**	**0.43**	-0.28	0.10	0.32
	50m	**0.45**	0.10	0.21	**0.41**	**0.44**	-0.27	0.09	0.33
	50mup	**0.45**	0.10	0.21	**0.41**	**0.44**	-0.27	0.09	0.33
	100m	**0.45**	0.10	0.21	**0.41**	**0.44**	-0.27	0.09	0.33
	100mup	**0.45**	0.10	0.21	**0.41**	**0.44**	-0.27	0.09	0.33
	200m	**0.45**	0.10	0.21	**0.41**	**0.44**	-0.27	0.09	0.33
	200mup	**0.45**	0.10	0.21	**0.41**	**0.44**	-0.27	0.09	0.33
% horticulture	ca	0.17	-0.02	0.01	0.12	0.18	-0.32	-0.16	0.14
	caup	0.19	-0.04	0.10	0.11	0.22	-0.41	-0.10	0.09
	50m	0.00	-0.17	-0.17	-0.19	0.05	-0.42	-0.31	-0.14
	50mup	0.15	-0.13	0.06	0.00	0.20	-0.53	-0.14	-0.02
	100m	0.00	-0.17	-0.17	-0.19	0.05	-0.42	-0.31	-0.14
	100mup	0.15	-0.13	0.06	0.00	0.20	-0.53	-0.14	-0.02
	200m	0.14	-0.10	-0.07	-0.03	0.18	-0.40	-0.23	0.01
	200mup	0.17	-0.10	0.09	0.03	0.22	-0.51	-0.11	0.00
% hobby farms	ca	-0.21	0.02	-0.27	-0.21	-0.17	-0.19	-0.13	-0.21
	caup	0.11	0.22	0.02	0.18	0.13	-0.30	0.10	0.08
	50m	-0.30	-0.10	-0.04	-0.37	-0.26	-0.03	-0.09	-0.31
	50mup	0.06	0.16	0.01	0.09	0.10	-0.20	0.06	0.01
	100m	-0.24	-0.08	-0.03	-0.32	-0.17	-0.10	-0.07	-0.30
	100mup	0.11	0.23	0.05	0.16	0.15	-0.18	0.12	0.08
	200m	-0.16	-0.06	-0.06	-0.28	-0.09	-0.12	-0.11	-0.26
	200mup	0.16	0.23	0.07	0.19	0.19	-0.24	0.12	0.10
% unused agricultural land	ca	**0.49**	0.16	0.06	0.22	**0.57**	-0.32	0.01	0.30
	caup	**0.57**	0.23	0.15	**0.44**	**0.62**	-0.29	0.06	**0.46**
	50m	**0.42**	0.10	-0.03	0.13	**0.49**	-0.38	-0.07	0.23
	50mup	**0.50**	0.17	0.07	0.37	**0.54**	-0.35	-0.01	**0.39**
	100m	**0.42**	0.10	-0.03	0.13	**0.49**	-0.38	-0.07	0.23
	100mup	**0.51**	0.18	0.08	**0.38**	**0.55**	-0.34	0.01	**0.41**
	200m	**0.44**	0.10	0.02	0.20	**0.51**	-0.38	-0.05	0.27
	200mup	**0.52**	0.17	0.12	**0.42**	**0.56**	-0.34	0.01	**0.42**

*Values in bold significant at the $\alpha=0.05$ level

Table F.11 (cont.) Spearman's Rank Correlation Coefficient for Sediment-bound Elements vs Agricultural Land Use Indices

	type	Ca	K	Mg	Na	P	Al
% total agriculture	ca	**0.40**	0.37	**0.61**	**0.63**	**0.81**	0.34
	caup	**0.54**	0.18	**0.57**	**0.61**	**0.77**	0.26
	50m	0.19	0.30	**0.51**	**0.60**	**0.60**	0.32
	50mup	0.18	-0.06	0.38	**0.56**	**0.61**	0.24
	100m	0.23	0.33	**0.53**	**0.62**	**0.61**	0.30
	100mup	0.22	-0.04	**0.39**	**0.58**	**0.62**	0.22
	200m	0.32	**0.40**	**0.56**	**0.67**	**0.67**	0.30
	200mup	0.35	0.10	**0.46**	**0.66**	**0.74**	0.17
% arable	ca	**0.53**	**0.57**	**0.59**	**0.63**	**0.71**	0.19
	caup	**0.64**	0.32	**0.51**	**0.60**	**0.72**	0.02
	50m	0.34	0.36	**0.52**	**0.66**	**0.63**	0.29
	50mup	0.25	0.05	0.34	**0.52**	**0.58**	0.07
	100m	0.38	**0.42**	**0.55**	**0.71**	**0.68**	0.27
	100mup	0.34	0.14	0.36	**0.61**	**0.66**	-0.01
	200m	**0.42**	**0.50**	**0.54**	**0.72**	**0.66**	0.20
	200mup	**0.42**	0.16	**0.39**	**0.65**	**0.69**	0.00
% cattle	ca	0.23	-0.10	0.12	**0.64**	**0.59**	0.29
	caup	0.17	-0.01	0.17	**0.64**	**0.61**	0.29
	50m	0.34	-0.05	0.17	**0.71**	**0.61**	0.16
	50mup	0.20	0.02	0.27	**0.74**	**0.68**	0.24
	100m	0.33	-0.01	0.20	**0.70**	**0.58**	0.20
	100mup	0.24	0.05	0.29	**0.75**	**0.71**	0.22
	200m	0.28	-0.05	0.18	**0.66**	**0.55**	0.21
	200mup	0.20	0.02	0.29	**0.69**	**0.65**	0.27
% poultry	ca	0.06	0.30	0.29	0.31	**0.44**	0.23
	caup	0.07	0.30	0.31	0.31	**0.42**	0.24
	50m	0.06	0.30	0.29	0.31	**0.44**	0.23
	50mup	0.06	0.30	0.29	0.31	**0.44**	0.23
	100m	0.06	0.30	0.29	0.31	**0.44**	0.23
	100mup	0.06	0.30	0.29	0.31	**0.44**	0.23
	200m	0.06	0.30	0.29	0.31	**0.44**	0.23
	200mup	0.06	0.30	0.29	0.31	**0.44**	0.23
% horticulture	ca	-0.15	0.06	0.29	**0.42**	0.22	**0.44**
	caup	-0.21	0.02	0.29	0.35	0.21	**0.45**
	50m	-0.41	-0.24	0.01	0.19	0.06	0.27
	50mup	-0.34	-0.10	0.19	0.26	0.16	0.37
	100m	-0.41	-0.24	0.01	0.19	0.06	0.27
	100mup	-0.34	-0.10	0.19	0.26	0.16	0.37
	200m	-0.33	-0.21	0.02	0.27	0.21	0.21
	200mup	-0.32	-0.09	0.20	0.25	0.18	0.37
% hobby farms	ca	-0.40	-0.41	0.02	-0.22	-0.37	0.26
	caup	-0.18	-0.14	0.38	0.02	-0.12	**0.58**
	50m	-0.34	-0.33	-0.04	-0.27	-0.48	0.23
	50mup	-0.25	-0.17	0.31	-0.10	-0.19	**0.52**
	100m	-0.39	-0.20	0.04	-0.28	-0.42	0.24
	100mup	-0.18	-0.16	0.36	-0.07	-0.14	**0.53**
	200m	-0.40	-0.15	0.06	-0.24	-0.34	0.28
	200mup	-0.17	-0.09	0.38	-0.02	-0.09	**0.57**
% unused agricultural land	ca	-0.02	0.06	0.01	0.29	**0.64**	-0.23
	caup	0.14	**0.45**	**0.38**	**0.51**	**0.69**	0.15
	50m	-0.08	0.01	-0.02	0.31	**0.60**	-0.23
	50mup	0.08	**0.41**	0.36	**0.53**	**0.65**	0.15
	100m	-0.08	0.01	-0.02	0.31	**0.60**	-0.23
	100mup	0.09	**0.40**	0.35	**0.54**	**0.66**	0.15
	200m	-0.06	0.07	0.02	0.32	**0.61**	-0.22
	200mup	0.10	**0.46**	**0.39**	**0.53**	**0.67**	0.16

*Values in bold significant at the α=0.05 level

Table F.12 Spearman's Rank Correlation Coefficient for Sediment-bound Elements vs Greenspace Land Cover Indices

	type	Cd	Co	Cr	Cu	Fe	Mn	Ni	Zn
% total natural	ca	**-0.74**	**-0.55**	**-0.45**	**-0.63**	**-0.68**	-0.02	**-0.48**	**-0.65**
	caup	**-0.70**	**-0.68**	**-0.46**	**-0.69**	**-0.62**	-0.11	**-0.59**	**-0.72**
	50m	**-0.57**	**-0.39**	-0.35	**-0.51**	**-0.50**	0.01	-0.30	**-0.57**
	50mup	**-0.55**	**-0.44**	-0.31	**-0.43**	**-0.48**	0.01	-0.36	**-0.51**
	100m	**-0.61**	**-0.43**	-0.37	**-0.55**	**-0.55**	0.03	-0.31	**-0.60**
	100mup	**-0.62**	**-0.52**	**-0.40**	**-0.52**	**-0.56**	0.01	**-0.40**	**-0.61**
	200m	**-0.65**	**-0.44**	**-0.43**	**-0.56**	**-0.60**	0.07	-0.34	**-0.60**
	200mup	**-0.70**	**-0.56**	**-0.45**	**-0.60**	**-0.64**	0.01	**-0.41**	**-0.67**
% forest	ca	**-0.51**	-0.34	-0.30	**-0.40**	**-0.45**	-0.15	-0.18	**-0.51**
	caup	**-0.60**	**-0.57**	-0.30	**-0.52**	**-0.51**	-0.23	-0.32	**-0.64**
	50m	**-0.50**	-0.30	-0.29	-0.35	**-0.45**	-0.05	-0.08	**-0.51**
	50mup	**-0.52**	-0.37	-0.28	-0.27	**-0.47**	0.01	-0.12	**-0.45**
	100m	**-0.47**	-0.27	-0.25	-0.33	**-0.42**	-0.06	-0.04	**-0.49**
	100mup	**-0.51**	-0.37	-0.26	-0.28	**-0.46**	-0.03	-0.10	**-0.47**
	200m	**-0.48**	-0.28	-0.25	-0.35	**-0.44**	-0.08	-0.05	**-0.49**
	200mup	**-0.54**	**-0.39**	-0.26	-0.31	**-0.48**	-0.04	-0.11	**-0.49**
% open space	ca	-0.31	-0.29	-0.06	-0.35	-0.32	-0.05	-0.32	-0.34
	caup	-0.32	-0.19	-0.17	-0.27	-0.34	0.02	**-0.40**	-0.24
	50m	**-0.60**	**-0.67**	**-0.50**	**-0.80**	**-0.52**	-0.23	**-0.68**	**-0.73**
	50mup	**-0.53**	**-0.58**	**-0.53**	**-0.58**	**-0.50**	-0.26	**-0.76**	**-0.55**
	100m	**-0.56**	**-0.61**	**-0.50**	**-0.75**	**-0.49**	-0.30	**-0.67**	**-0.70**
	100mup	**-0.45**	**-0.46**	**-0.56**	**-0.53**	**-0.43**	-0.31	**-0.73**	**-0.49**
	200m	**-0.51**	**-0.51**	**-0.42**	**-0.70**	**-0.45**	-0.16	**-0.58**	**-0.62**
	200mup	**-0.45**	**-0.40**	**-0.45**	**-0.49**	**-0.41**	-0.22	**-0.65**	**-0.45**
% parks/ playing fields	ca	-0.08	0.00	0.06	0.12	-0.18	-0.03	0.03	0.10
	caup	-0.02	0.01	0.03	0.14	-0.06	-0.12	0.03	0.09
	50m	-0.27	-0.13	-0.17	-0.24	-0.35	-0.09	-0.16	-0.17
	50mup	-0.01	-0.01	0.03	0.12	-0.05	-0.16	0.02	0.07
	100m	-0.27	-0.13	-0.17	-0.24	-0.35	-0.09	-0.16	-0.17
	100mup	-0.01	-0.01	0.03	0.12	-0.05	-0.16	0.02	0.07
	200m	-0.27	-0.13	-0.17	-0.24	-0.35	-0.09	-0.16	-0.17
	200mup	0.04	-0.06	-0.04	0.17	0.01	-0.23	0.04	0.00
% rural residential	ca	**-0.51**	**-0.39**	-0.06	**-0.49**	**-0.48**	0.06	-0.24	**-0.52**
	caup	-0.23	-0.07	-0.11	-0.07	-0.23	0.16	-0.11	-0.16
	50m	**-0.47**	**-0.43**	-0.28	**-0.51**	**-0.43**	0.09	**-0.42**	**-0.51**
	50mup	-0.34	-0.32	-0.28	-0.31	-0.33	0.03	-0.37	-0.36
	100m	**-0.49**	**-0.44**	-0.35	**-0.54**	**-0.48**	0.05	**-0.41**	**-0.56**
	100mup	-0.27	-0.27	-0.31	-0.27	-0.27	-0.01	-0.33	-0.35
	200m	**-0.53**	**-0.47**	-0.24	**-0.58**	**-0.51**	0.03	**-0.44**	**-0.58**
	200mup	-0.22	-0.22	-0.22	-0.25	-0.21	-0.07	-0.36	-0.30

*Values in bold significant at the $\alpha=0.05$ level

Table G.12 (cont.) Spearman's Rank Correlation Coefficient for Sediment-bound Elements vs Greenspace Land Cover Indices

	type	Ca	K	Mg	Na	P
% total natural	ca	**-0.45**	**-0.46**	**-0.44**	**-0.65**	**-0.68**
	caup	**-0.57**	-0.38	**-0.44**	**-0.64**	**-0.59**
	50m	-0.36	**-0.41**	-0.38	**-0.70**	**-0.54**
	50mup	-0.30	-0.28	-0.25	**-0.61**	**-0.48**
	100m	-0.36	**-0.48**	**-0.46**	**-0.72**	**-0.58**
	100mup	-0.38	-0.30	-0.36	**-0.70**	**-0.54**
	200m	-0.36	**-0.49**	**-0.48**	**-0.71**	**-0.61**
	200mup	**-0.43**	**-0.39**	**-0.42**	**-0.74**	**-0.63**
% forest	ca	-0.30	**-0.46**	-0.25	**-0.53**	**-0.55**
	caup	**-0.50**	-0.37	-0.22	**-0.53**	**-0.57**
	50m	-0.30	**-0.42**	-0.28	**-0.62**	**-0.54**
	50mup	-0.23	-0.20	-0.11	**-0.53**	**-0.50**
	100m	-0.25	**-0.42**	-0.26	**-0.59**	**-0.52**
	100mup	-0.25	-0.22	-0.11	**-0.54**	**-0.51**
	200m	-0.26	**-0.45**	-0.26	**-0.58**	**-0.54**
	200mup	-0.28	-0.29	-0.12	**-0.54**	**-0.56**
% open space	ca	-0.23	0.26	-0.04	-0.22	-0.19
	caup	-0.15	0.22	-0.05	-0.19	-0.22
	50m	**-0.65**	-0.36	**-0.54**	**-0.57**	**-0.47**
	50mup	**-0.56**	-0.24	-0.32	**-0.42**	**-0.38**
	100m	**-0.68**	-0.36	**-0.52**	**-0.57**	**-0.43**
	100mup	**-0.52**	-0.16	-0.25	-0.32	-0.34
	200m	**-0.55**	-0.26	**-0.47**	**-0.51**	**-0.41**
	200mup	**-0.41**	-0.02	-0.20	-0.30	-0.34
% parks/ playing fields	ca	0.14	0.35	0.16	0.24	-0.13
	caup	0.03	**0.48**	0.19	0.23	-0.05
	50m	-0.11	-0.01	-0.24	-0.05	-0.34
	50mup	-0.01	**0.48**	0.19	0.21	-0.04
	100m	-0.11	-0.01	-0.24	-0.05	-0.34
	100mup	-0.01	**0.48**	0.19	0.21	-0.04
	200m	-0.11	-0.01	-0.24	-0.05	-0.34
	200mup	-0.18	**0.49**	0.24	0.06	0.08
% rural residential	ca	-0.33	-0.17	-0.20	**-0.51**	**-0.38**
	caup	-0.11	-0.14	-0.03	**-0.38**	-0.15
	50m	**-0.42**	**-0.40**	-0.32	**-0.46**	**-0.39**
	50mup	-0.34	**-0.40**	-0.17	-0.31	-0.31
	100m	**-0.44**	**-0.45**	-0.34	**-0.49**	**-0.44**
	100mup	-0.33	**-0.38**	-0.12	-0.31	-0.27
	200m	**-0.46**	-0.36	-0.30	**-0.50**	**-0.46**
	200mup	-0.35	-0.37	-0.08	-0.28	-0.21

*Values in bold significant at the α=0.05 level

Table G.13 Spearman's Rank Correlation Coefficient for Sediment-bound Elements vs Urban Land Use Indices

	type	Cd	Co	Cr	Cu	Fe	Mn	Ni	Zn
% total urban	ca	-0.24	-0.13	-0.14	-0.04	-0.28	0.13	0.04	-0.13
	caup	-0.14	-0.02	-0.13	0.10	-0.19	0.18	0.03	0.02
	50m	-0.34	-0.22	-0.18	-0.32	-0.33	0.21	-0.02	-0.34
	50mup	-0.15	-0.04	-0.12	0.11	-0.20	0.15	0.07	-0.02
	100m	-0.35	-0.23	-0.20	-0.33	-0.35	0.19	-0.03	-0.35
	100mup	-0.15	-0.04	-0.13	0.09	-0.20	0.15	0.04	-0.02
	200m	-0.34	-0.22	-0.21	-0.34	-0.34	0.21	-0.07	-0.32
	200mup	-0.14	-0.03	-0.14	0.10	-0.19	0.18	0.04	0.01
% industrial/ commercial	ca	0.37	0.30	0.03	**0.38**	0.33	-0.25	0.27	0.26
	caup	0.36	**0.40**	0.05	**0.49**	0.28	-0.01	0.27	**0.43**
	50m	0.11	0.07	-0.12	-0.04	0.12	-0.16	0.03	0.02
	50mup	0.14	0.12	0.03	0.20	0.11	-0.11	0.10	0.19
	100m	0.12	0.07	-0.13	-0.04	0.13	-0.17	0.03	0.01
	100mup	0.14	0.12	0.03	0.20	0.11	-0.11	0.10	0.19
	200m	0.12	0.07	-0.13	-0.04	0.13	-0.17	0.03	0.01
	200mup	0.14	0.13	0.01	0.19	0.11	-0.09	0.09	0.19
% residential	ca	**-0.39**	-0.31	-0.08	-0.20	**-0.41**	0.09	-0.09	-0.27
	caup	-0.22	-0.10	-0.12	0.07	-0.26	0.15	-0.02	-0.04
	50m	**-0.55**	**-0.39**	-0.23	**-0.42**	**-0.55**	0.21	-0.14	**-0.48**
	50mup	-0.22	-0.11	-0.10	0.09	-0.27	0.14	0.02	-0.07
	100m	**-0.55**	**-0.39**	-0.23	**-0.42**	**-0.55**	0.21	-0.14	**-0.48**
	100mup	-0.22	-0.11	-0.12	0.07	-0.27	0.13	-0.02	-0.06
	200m	**-0.51**	-0.37	-0.24	**-0.42**	**-0.51**	0.20	-0.19	**-0.43**
	200mup	-0.22	-0.11	-0.13	0.07	-0.26	0.15	-0.02	-0.05
% high density urban	ca	-0.19	-0.34	-0.15	-0.20	-0.23	**-0.51**	-0.17	**-0.42**
	caup	-0.34	-0.28	-0.27	-0.28	-0.37	-0.10	-0.34	-0.27
	50m	-0.29	-0.34	-0.34	-0.34	-0.30	-0.35	-0.30	**-0.49**
	50mup	-0.33	-0.26	-0.26	-0.25	-0.36	-0.08	-0.33	-0.25
	100m	-0.29	-0.34	-0.34	-0.35	-0.32	-0.35	-0.30	**-0.50**
	100mup	**-0.38**	-0.31	-0.31	-0.34	**-0.41**	-0.07	**-0.39**	-0.31
	200m	-0.29	-0.34	-0.34	-0.35	-0.32	-0.35	-0.30	**-0.50**
	200mup	**-0.38**	-0.31	-0.31	-0.34	**-0.41**	-0.07	**-0.39**	-0.31
% low density urban	ca	-0.37	-0.29	-0.10	-0.16	-0.37	0.14	-0.05	-0.24
	caup	-0.22	-0.11	-0.11	0.10	-0.26	0.17	0.04	-0.05
	50m	**-0.47**	-0.35	-0.20	-0.35	**-0.46**	0.19	-0.09	**-0.42**
	50mup	-0.22	-0.11	-0.11	0.10	-0.26	0.17	0.04	-0.05
	100m	**-0.47**	-0.35	-0.20	-0.35	**-0.46**	0.19	-0.09	**-0.42**
	100mup	-0.22	-0.11	-0.11	0.10	-0.26	0.17	0.04	-0.05
	200m	**-0.47**	-0.34	-0.21	-0.36	**-0.45**	0.19	-0.12	**-0.40**
	200mup	-0.22	-0.11	-0.11	0.10	-0.26	0.17	0.04	-0.05

*Values in bold significant at the α=0.05 level

Table G.13 (cont.) Spearman's Rank Correlation Coefficient for Sediment-bound Elements vs Urban Land Use Indices

	type	Ca	K	Mg	Na	P
% total urban	ca	0.09	0.28	-0.10	-0.14	-0.30
	caup	0.15	**0.42**	0.03	0.00	-0.19
	50m	-0.04	0.04	**-0.40**	**-0.39**	-0.36
	50mup	0.15	**0.42**	0.03	-0.04	-0.20
	100m	-0.06	0.03	**-0.41**	**-0.40**	-0.37
	100mup	0.13	**0.40**	0.01	-0.04	-0.19
	200m	-0.08	0.02	**-0.41**	-0.36	-0.36
	200mup	0.14	**0.42**	0.03	-0.02	-0.19
% industrial/ commercial	ca	0.04	0.19	0.21	0.11	0.18
	caup	0.25	0.34	0.29	0.29	0.21
	50m	-0.11	0.11	-0.17	0.04	0.08
	50mup	0.08	**0.42**	0.16	0.26	0.12
	100m	-0.13	0.11	-0.17	0.02	0.09
	100mup	0.08	**0.42**	0.16	0.26	0.12
	200m	-0.13	0.11	-0.17	0.02	0.09
	200mup	0.08	**0.41**	0.14	0.26	0.12
% residential	ca	-0.03	0.35	-0.10	-0.16	**-0.40**
	caup	0.10	**0.46**	0.06	-0.02	-0.26
	50m	-0.11	0.06	**-0.41**	**-0.47**	**-0.55**
	50mup	0.12	**0.48**	0.07	-0.05	-0.26
	100m	-0.11	0.06	**-0.41**	**-0.47**	**-0.55**
	100mup	0.09	**0.47**	0.06	-0.05	-0.25
	200m	-0.14	0.06	**-0.40**	**-0.42**	**-0.51**
	200mup	0.09	**0.47**	0.06	-0.04	-0.25
% high density urban	ca	**-0.41**	0.18	-0.10	-0.28	-0.07
	caup	-0.20	0.24	-0.22	-0.08	-0.20
	50m	**-0.47**	0.03	-0.33	**-0.43**	-0.11
	50mup	-0.17	0.26	-0.20	-0.06	-0.19
	100m	**-0.48**	0.02	-0.34	**-0.43**	-0.12
	100mup	-0.23	0.19	-0.28	-0.13	-0.22
	200m	**-0.48**	0.02	-0.34	**-0.43**	-0.12
	200mup	-0.23	0.19	-0.28	-0.13	-0.22
% low density urban	ca	-0.02	**0.40**	-0.07	-0.15	**-0.39**
	caup	0.12	**0.50**	0.09	-0.05	-0.28
	50m	-0.13	0.15	-0.33	**-0.42**	**-0.50**
	50mup	0.12	**0.50**	0.09	-0.05	-0.28
	100m	-0.13	0.15	-0.33	**-0.42**	**-0.50**
	100mup	0.12	**0.50**	0.09	-0.05	-0.28
	200m	-0.13	0.14	-0.33	**-0.39**	**-0.49**
	200mup	0.12	**0.50**	0.09	-0.05	-0.28

*Values in bold significant at the α=0.05 level