BRITISH COLUMBIA
The Best Place on Earth

Ministry of Environment

LOWER MAINLAND REGION

Little Campbell River Watershed
Water Quality Monitoring

2005 – 2007

ENVIRONMENTAL QUALITY

Little Campbell River Watershed Water Quality Monitoring:

2005 – 2007

Prepared by:
Christy Juteau
Ministry of Environment
Environmental Quality Section
2nd Floor, 10470 152 Street
Surrey, B.C.
V3R 0Y3
604-582-5200

June 2008

Preface

This report is one in a series of water, groundwater, and air quality reports that are being issued by the Lower Mainland Regional Office in fiscal year 2006/07. It is the intention of the Regional Office to publish air and water quality reports on our website (http://www.env.gov.bc.ca/epd/regions/lower_mainland/index.htm) in order to provide the information to industry and local government, other stakeholders and the public at large. By providing such information in a readily understood format, and on an ongoing basis, it is hoped that local environmental quality conditions can be better understood, and better decisions regarding air and water quality management can be made.

Acknowledgements

This project was initiated and supported by the Shared Waters Alliance. The Ministry of Environment led and designed the project, provided funding for sampling and sample analysis, and prepared the final report. Environment Canada aided in development of the sampling plan and report review. A Rocha Canada provided support to the project through a contribution of staff time, funded through Environment Canada's Science Horizons Youth Internship Program. Rachel Krause, A Rocha Canada's Science Horizons Intern, assisted with field sampling and the writing of Part 2 of this report. The City of White Rock, City of Surrey and Township of Langley provided data for the development of the sampling plan and interpretation of the results.

Executive Summary

The Little Campbell River (LCR) watershed has been identified as a significant contributor of fecal coliform contamination to the receiving waters of Semiahmoo Bay, which has been closed to shellfish harvesting since the 1960s due to bacteriological contamination. The purpose of this study was to better characterize the dynamics of bacteriological contamination in the LCR watershed, to assess potential relationships between fecal coliform concentrations and types of pollution sources and to initiate an automated sampling program for baseline information to support long-term planning and watershed management.

There were three main components to the study:

1a) a year-long longitudinal survey, to better characterize the baseline fecal coliform conditions of the LCR mainstem, including
b) attainment monitoring to assess compliance with select water quality objectives at long-term trend sites in the LCR mainstem,
2) sub-watershed scale seasonal monitoring to consider runoff from lands with different source characteristics (i.e. urban, agricultural, on-site septic systems), and
3) semi-continuous automated monitoring, through the installation of a water quality station in the LCR mainstem at 12th Avenue to measure dissolved oxygen, temperature, conductivity and turbidity and the installation of 15 temperature loggers throughout the watershed.

Longitudinal Survey and Attainment Monitoring
In Part I, the longitudinal survey showed that fecal coliform loadings were greatest near the mouth of the LCR throughout the year and that they largely originate from the lower 16% of the watershed (West Sub-watershed). Land use in this area near the mouth is mainly urban (30% impervious area) and is largely serviced by sanitary sewers with approximately 300 on-site sewage disposal systems, mostly in the Fergus Creek sub-watershed. High fecal coliform levels did not show a strong relationship with precipitation in this area, indicating that fecal sources may be entering the LCR via other routes in addition to overland runoff. Alternate pathways could include direct deposit of fecal material into tributaries or the mainstem (domestic pets, wildlife – including waterfowl), urban stormwater (dry-weather flows), resuspension of fecal coliform adsorbed to sediments, failing on-site sewage disposal systems, and/or sanitary sewer cross-connections.

Water quality objectives attainment monitoring re-affirmed that in addition to fecal coliform contamination, levels of dissolved oxygen continue to be of concern in the LCR watershed. The pH levels met water quality objectives during this sampling in the summer of 2006.

Seasonal Monitoring
The second component of the study used historic water quality data from the LCR watershed to identify potential seasonal trends. High concentrations of fecal coliform were found during summer (Jun–Aug), fall (Oct/Nov) and winter (Jan). <u>Three provisional statements</u> were developed in an attempt to characterize these peaks, and <u>the monitoring program was designed to test the statements</u> and assess any linkages between fecal coliform contamination and particular land use activities. The three provisional statements considered were:

1. Contaminated runoff originating from urban areas is a significant contributor to high fecal loadings at the mouth of the LCR, particularly during summer months (June – August).
2. Agricultural waste (manure) runoff in sub-watersheds with a high density of agricultural land use is a significant contributor to high fecal loadings of the LCR during October and November; loadings are strongly correlated with precipitation events.
3. Runoff from areas with a high density of on-site sewage disposal systems is contributing to high fecal loadings in the LCR during January when water tables may be elevated enough to cause septic field failures.

The first provisional statement was tested during the summer of 2006 (Part II). It was found that urban runoff sources do contribute significantly to elevated fecal coliform levels in the LCR mainstem during summer months and continue to contribute during the winter as well.

Agricultural runoff was monitored during the fall of 2006 to test the second provisional statement and assess the relative contribution of fecal contamination from sub-watersheds containing a high density of livestock versus a sub-watershed with little to no agricultural activity (Part III). Fecal coliform levels from the agricultural sub-watersheds consistently exceeded the B.C. approved water quality guideline of 200 CFU/100mL for the protection of recreational use, and general livestock use (MOE 2006), while water quality downstream of the non-agricultural site was in attainment of the guidelines throughout the study period. The relative contribution of fecal coliforms from these agricultural sub-watersheds to the overall fecal load at the LCR mouth appeared to be limited; effects remained fairly localized within the agricultural portion of the LCR watershed.

Monitoring to test the third provisional statement assessed runoff from a residential area with a high density of on-site sewage disposal systems (SDS) during winter 2006/2007 (Part IV). Geometric means of fecal coliform concentration remained below the 200 CFU/100mL guideline at both upstream and downstream sites throughout the study period, and there was no significant difference detected between the sites. This indicates that the incidence of on-site SDS failure was relatively low in this area of the LCR watershed during the time of sampling, and suggests that failing on-site SDS may not be a significant contributor to fecal contamination of the LCR watershed and the receiving waters of Semiahmoo and Boundary bays.

Automated Monitoring

A Hydrolab station was established near the middle of the LCR watershed in October 2005 and has been collecting semi-continuous automated data (every 15 minutes) for water quality parameters: temperature, dissolved oxygen, specific conductivity, turbidity and stage. From October 2005 to October 2007, dissolved oxygen and turbidity levels were found to be of greatest concern. Dissolved oxygen levels dropped below the instantaneous minimum objective level of 11.0 mg/L when salmonid eggs or alevin could have been present, during the fall/spring of 2005/2006 and 2006/2007. Dissolved oxygen levels dropped below 8.0 mg/L objective level between June and October in 2006 and 2007. Levels reached minimums below 6mg/L in the fall of 2005 and 2007. Turbidity levels were greatest during the wet season (fall and winter). Magnitude and duration analysis indicated that there have been a number of turbidity events generating a marked increase in water cloudiness that would be expected to be enough to reduce fish growth rate and habitat size, and are considered a “significant impairment” of the system.

Automated data collected from fifteen temperature loggers throughout the LCR watershed were also analyzed in this study. From July 2005 to June 2007, water temperatures in the LCR watershed did not exceed 24°C, levels of acute toxicity that could result in direct mortality. Elevated temperatures (>17°C) in the mainstem near the mouth and tributaries in the upper watershed could have chronic impacts on salmonid and other aquatic life.

Overall Conclusions and Recommendations

It is recommended that the results of this study be used for pollution prevention initiatives, such as those of the Shared Waters Alliance, and for planning purposes such as the Integrated Stormwater Management Plan (ISMP) that has been initiated for the Little Campbell River watershed as a joint venture between the City of Surrey and the Township of Langley. The results help to clarify the relative contribution of potential bacteriological contamination sources, as well as providing information on the status of dissolved oxygen, turbidity and temperature levels in the watershed, and should aid in prioritizing efforts to improve water quality.

The results of this study indicate that the lowermost portion of the LCR watershed, which is mainly urban (30% impervious area), contributes the greatest amount of fecal coliform bacteria to the river mouth and subsequently the receiving waters of Semiahmoo and Boundary bays. High fecal coliform levels did not appear to be precipitation-driven in this area, indicating that fecal sources may be entering the LCR via other routes in addition to overland runoff. Alternate pathways could include direct deposit of fecal material into tributaries or the mainstem (domestic pets, wildlife), urban stormwater (dry-weather flows), re-suspension of FC adsorbed to sediments, failing on-site sewage disposal systems, and/or sanitary sewer cross-connections.

The agricultural sub-watersheds studied were found to be a significant source of fecal contamination; however, their relative contribution to the total load near the river mouth appears to be limited. Fecal coliform levels generated from agricultural runoff in the upper LCR watershed may have more localized effects on water quality used for livestock watering and/or crop irrigation. Recent and historical attainment monitoring, as well as the automated monitoring underway in the watershed, have shown that dissolved oxygen levels are of concern. Continued efforts to improve manure management (i.e. proper storage, timing of application) are recommended to improve water quality in the LCR watershed.

The automated monitoring has indicated that, in addition to dissolved oxygen, turbidity and temperature are parameters of concern and should be an on-going focus for water quality improvement efforts. It is recommended that both the Hydrolab station and the temperature loggers continue to collect automated data for long-term trend assessment.

A portion of the LCR mainstem (~1.5 km) was found to be completely de-watered during the summer, and potentially remains this way for 5 months of the year. This restricts the movement of contaminants from the upper watershed to the mouth, but also poses a risk to aquatic life. Groundwater and surface water extraction rates could be contributing to this condition. It is recommended that extraction rates in this watershed be investigated and managed to prevent over-extraction and de-watering of the mainstem.

TABLE OF CONTENTS

TABLES AND FIGURES

APPENDICES

1.0 INTRODUCTION

Water quality in Boundary Bay has long been recognized as impacted by the variety of activities and land uses within the watershed. Of particular concern is the presence of fecal contamination, which caused the closure of productive bi-valve shellfish harvesting in Boundary Bay's Mud Bay in 1962, followed by a full closure of the Canadian side of Boundary Bay in 1972 (Cheung 2003). Fecal coliform levels have relevance to several other water uses in the watershed, including: recreational swimming and boating, livestock watering, and irrigation of crops (Swain 1988). Fecal contamination in Boundary Bay's smaller basin of Semiahmoo Bay has been attributed to cumulative impacts from a number of potential pollution sources: animal manures, failing on-site septic fields, cross-connections between storm and sanitary sewer systems, domestic pets, and/or wildlife.

In 2002, the Shared Waters Alliance (SWA), an international working group focusing on water quality in the Canada-US shared waters of Boundary Bay, commissioned a circulation study of Semiahmoo Bay in response to rising concerns regarding fecal contamination of the bay. The study assessed six sources of fecal coliform around the bay and concluded that "the greatest benefit to water quality in Semiahmoo Bay would be achieved by concentrating on reducing fecal coliform levels in the Little Campbell River" (Hay & Co. 2003).

The Little Campbell River (LCR) is one of the tributaries entering Boundary Bay via Semiahmoo Bay (Figure 1). Historical grab sampling in the LCR watershed has identified relatively high fecal coliform levels, elevated nutrients, suspended solids and metals in certain locations, as well as low dissolved oxygen, particularly in the upper watershed (Bull 2003; Fleming and Quilty 2006). Previous assessments of the LCR have identified dominant agricultural land use (40.4%), significant urban development pressure and high rates of surface and ground water extraction. These factors likely are contributors to degraded water quality in the watershed (Swain 1988; Drever and Brown 1999; Bull 2003; Fleming and Quilty 2006; Zevit, Page and Goble 2008, In Review).

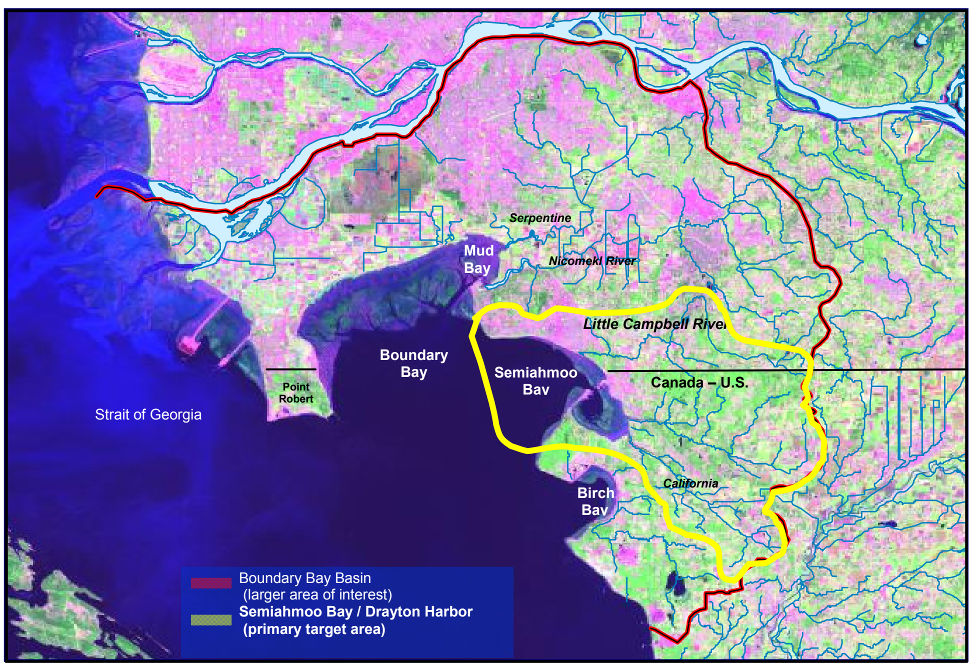

Figure 1. Study area – Little Campbell River, Semiahmoo Bay and Boundary Bay watersheds

From fall 2005 to spring 2007, the Ministry of Environment (MoE), in cooperation with the SWA has focused its efforts on a strategic water quality monitoring program in the LCR. The purpose of this program was to:

1. better characterize the dynamics of bacteriological contamination in the mainstem and consider levels relative to tributary and mainstem sub-watershed areas,
2. gain a better understanding of how fecal coliform concentrations could be related to types of pollution sources in the watershed, and to
3. initiate an automated sampling program for baseline information to support long-term development planning and watershed management.

1.1 Project Description and Report Structure

There were three main components to the program:

1a) a year-long longitudinal survey, to better characterize the baseline fecal coliform conditions of the LCR mainstem,
b) attainment monitoring to assess compliance with water quality objectives at long-term trend sites in the LCR mainstem,
2) sub-watershed scale seasonal monitoring to consider runoff from lands with different source characteristics (i.e. urban, agricultural, on-site septic systems), and
3) semi-continuous automated monitoring, through the installation of a water quality station in the LCR mainstem at 12th Avenue to measure dissolved oxygen, temperature, conductivity and turbidity and the installation of 15 temperature loggers throughout the watershed.

This report has been prepared so that its sections fit together to provide a full accounting of the monitoring program while results can be used separately to support pollution prevention initiatives by stakeholders with different roles related to non-point source pollution. The results of components 1a, 1b and 2 are summarized and discussed in Parts I-IV of this report. The results of the automated data are summarized and discussed in Part V of this report.

1.1.1 Part I: Longitudinal Survey and Attainment Monitoring

Four sample sites were established along the LCR mainstem for the longitudinal survey. These sites were located near the downstream end of four distinct sub-watersheds, based on their differing soil characteristics, aquifer vulnerability and susceptibility to septic contamination (Figure 2). The sub-watersheds were delineated through a watershed characterization study of the LCR (Zevit *et al*. 2008), which was initiated in January 2006 and provided baseline information for the development of the monitoring program.

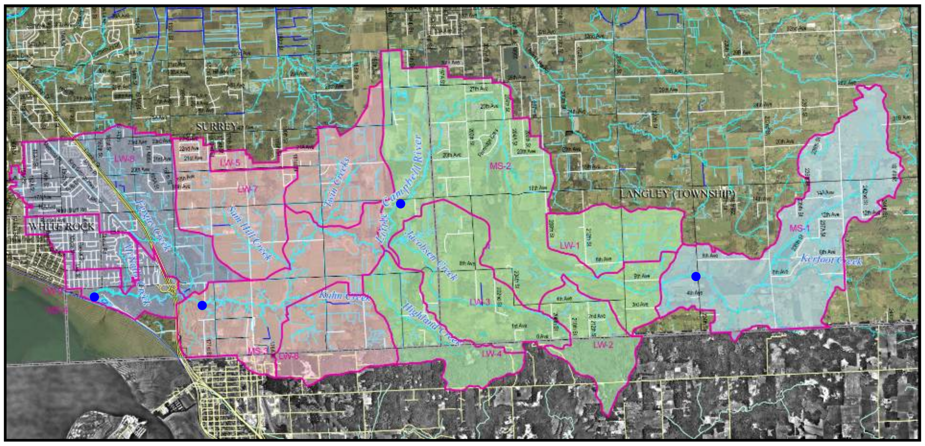

Figure 2. Sub-watersheds and longitudinal survey sample sites in the Little Campbell River watershed.

Water quality objectives were established for the LCR in 1988 (Swain 1988). Subsequent attainment monitoring occurred in 1992 and 2002 in the LCR mainstem at 216th Street (upstream site) and 176th Street (downstream site) (Bull 2003). Attainment monitoring was also conducted at these sites in 2006/07 during May, August and December (5 times in 30 days). Grab samples were analyzed for fecal coliforms, metals, nutrients, suspended solids, dissolved oxygen, pH and temperature. Results were compared with past attainment monitoring results to determine any trends in LCR water quality over time.

<u>1.1.2 Parts II, III and IV: Seasonal Monitoring</u>

Preliminary analysis of historical fecal coliform data (collected from 1973 to 2003) identified seasonally high counts (peaks) in the LCR watershed during summer (Jun-Aug), fall (Oct-Nov) and winter (Jan) (Figure 3).

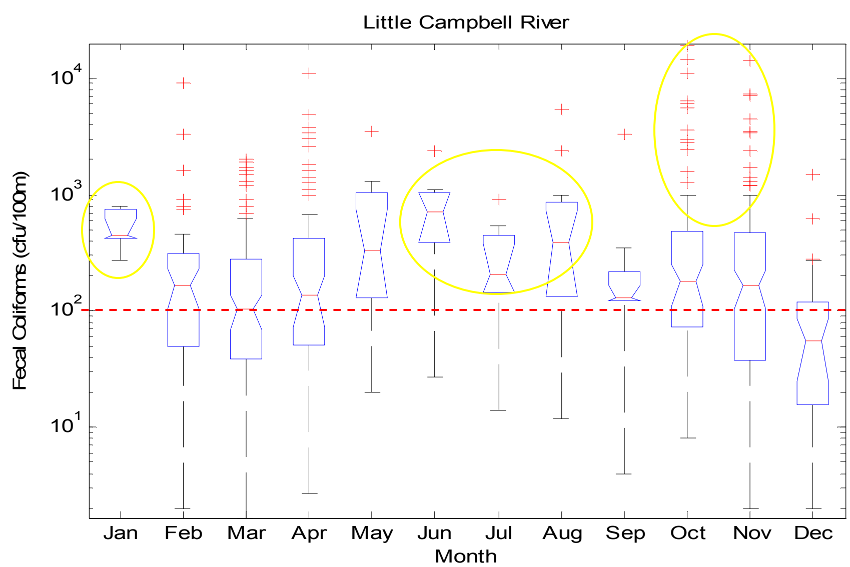

Figure 3. Boxplots of monthly fecal coliform concentrations found in the Little Campbell River through historical monitoring (1973 to 2003).

In order to better understand the water quality dynamics of the LCR, three provisional statements were developed in an attempt to characterize these peaks. The validity of these statements were tested during the 2006/07 water quality monitoring program, strategically targeting the issues of concern that had been identified through previous sampling activities. The intent of this approach was to obtain data that would be linked to specific locations, times of the year and activities, thus providing site specific information that would be more useful for local decision making than ambient water quality data.

The three provisional statements considered were:

1. Contaminated runoff originating from urban areas is a significant contributor to high fecal loadings at the mouth of the LCR, particularly during summer months (June – August).
2. Agricultural waste (manure) runoff in sub-watersheds with a high density of agricultural land use is a significant contributor to high fecal loadings of the LCR during October and November; loadings are strongly correlated with precipitation events.
3. Runoff from areas with a high density of on-site sewage disposal systems is contributing to high fecal loadings in the LCR during January when water tables may be elevated enough to cause septic field failures.

Further details regarding the reasoning behind the development of these statements is included in Parts II – IV of the report.

1.1.3 Part V: Automated Water Quality Data

An automated water quality monitoring station (Hydrolab) was established in October 2005 near the centre of the watershed, upstream of any tidal influence. In July 2005, fifteen temperature loggers were placed throughout the watershed in the mainstem and key tributaries, targeting areas of major current or planned urban development projects. In 2007, two new temperature logger stations were established in a portion of the LCR mainstem that de-waters during summer months. This area was identified during the 2006/07 sampling program and it is hoped that these new stations will provide data to determine the timing of channel de-watering.

The purpose for setting up the Hydrolab station and distributing automated temperature loggers throughout the watershed was to establish a baseline of continuous data from which to identify and assess long-term trends. Automated water quality data collection was initiated in the LCR in 2005 and will continue to be monitored (every 15 minutes) as long as resources allow.

1.2 Fecal Coliform as an Indicator

The grab sampling components of this study focused primarily on bacteriological contamination in the LCR watershed, using fecal coliform bacteria as an indicator. Fecal coliform bacteria are present in the feces of warm-blooded organisms, including humans, cattle, and wildlife. The presence of fecal coliform bacteria in watercourses indicates the presence of feces, as well as the potential for additional pathogenic (disease-causing) micro-organisms. The reason for using fecal coliform bacteria as an indicator, rather than *E.coli* or *Enterococci*, was to:

- enable comparison with historic data[1] ,
- enable comparison with water quality guidelines, relating to existing water uses in the watershed; such as shellfish harvesting, drinking, recreation (swimming, boating, etc.), livestock watering, and irrigation of ready-to-eat produce.

The water quality guidelines used in this report are based on approved B.C. MoE Water Quality Criteria and are listed in Appendix A.

The B.C. MoE criteria for fecal coliform bacteria (recreation and irrigation water uses) are based on a geometric mean, rather than a standard mean. Since microbes tend to be associated with particulate material, it is possible to have clumps of bacteria collected, which can lead to higher variability in the data. The geometric mean is used because it dampens the influence of individual high or low values. It is calculated using the following equation: GM = $\sqrt[n]{n1*n2*n3*n4*n5}$, using a minimum of 5 individual bacterial sample results collected over a 30 day period.

1.3 Limitations of the Data

There are a number of limitations to the data collected in this report which should be considered when analysing the results.

- With the exception of the automated data collection, the sampling program consisted of "grab sample" data; samples were collected at one moment in time rather than continuously. As a result, there may have been times when these watercourses had bacterial counts outside of the ranges reported, but those levels were undetected because a sample was not collected at that specific time.

- Sample sites and times were not selected randomly. For the longitudinal survey, sites were selected based on sub-watershed delineations, in order to characterize the water quality of each portion of the LCR watershed as a whole. For the seasonal monitoring, sample sites were selected based on indications of water quality from previous sampling, proximity to urban land use, agricultural land use or on-site sewage disposal systems, and accessibility. For this reason, analyses of the seasonal monitoring results focused on site character rather than the entire LCR watershed. Sample timing was determined based on tides to allow for sampling at the river mouth during the lowest tide possible each week.

- As with many studies resources can be limited. The data set for a number of sites in this study may be considered small from a statistical perspective for trend analysis or for comparing geometric means between sites. Caution has therefore been exercised in making such comparisons. Parameters in addition to fecal coliform bacteria, such as nutrients or heavy metals, were only analyzed in the attainment monitoring portion of this report due to the limited budget of this study.

[1]Water quality records dating back to 1973 use fecal coliform bacteria as an indicator. Records of *E.coli* are sparse and *Enterococci* has not yet been used as an indicator in this watershed.

- Discharge measurements were calculated based on field measurements at each site at the time of sampling, representing only a "snap shot" in time. During extreme low and extreme high flow conditions it was not always possible to take accurate measurements, either due to insufficient equipment or safety concerns. Estimates of discharge were made in these situations and are noted in the data records.

- One of the stormwater outfall monitoring sites that entered the LCR near the mouth was unique in that it functioned on a pump system with two outfalls pipes to the mainstem. A holding tank would be emptied periodically as a "pulse event" into the LCR from either the lower or upper outfall (alternately). To estimate discharge, it was assumed, based on communications with Kevin Pollard at the City of White Rock, that the entire holding tank was discharged with each "pulse event".

  During the summer sampling period, pulse event frequency was estimated by installing automated temperature data loggers in both outfalls and measuring temperature semi-continuously at 15 second intervals. Each pulse event was indicated by a peak in temperature. From these data, estimates of discharge under dry conditions (little to no precipitation) and wet conditions were determined. Discharge estimates during heavy precipitation conditions were likely under-estimated because the outfalls would often pulse continuously, indicating little to no change in temperature. During the winter sampling period, discharge values were estimated based on the number of pulse events observed while on-site.

- Fecal coliform data at the mouth of the LCR were analyzed using MPN methodology, while the remainder of the sites were analyzed using MF methodology (See Section 2.2 for reasoning and a description of methodologies). MPN results have a wider confidence interval than MF (less precise) and a positive statistical bias (Sargeant 2004). MPN may result in higher fecal coliform values than MF because of the positive bias and the ability to recognize stressed or injured bacteria (Borrego and Figueras 1997, in Sargeant 2004).

  To determine the variability between MF and MPN methodologies, four samples taken at the mouth of the LCR were analyzed using both methods of analysis and results were compared. Three out of four comparisons found the MPN results to be 0.2 to 2.2% greater than the MF value, well within the respective 95% confidence intervals; however, the remaining sample showed the MPN result as 72% greater than the MF result. This shows that there is an element of uncertainty when comparing MPN and MF results.

- When calculating FC decay rates, sedimentation relationships were not considered. This was due to the lack of data regarding the fraction of pathogens attached to suspended sediment, the combined particle settling velocity and resuspension rates. Studies have shown that sedimentation can remove up to 30% of bacteria through adhesion to particles; however, die-off rates are very slow in sediment (McCorquodale *et al*. 2004) and the unknown rate of resuspension poses a relationship that is very difficult to quantify.

- Correlation coefficients were used to assess potential relationships between FC data and additional water quality parameters. Correlation is limited because it only determines the strength of linear relationships. In reality, relationships in the natural environment are very complex and are difficult to measure without over-simplification. Fecal coliform data are extremely variable, as a grab sample only collects results for a moment in time and fecal coliform levels can be affected by a myriad of factors.

2.0 METHODS

2.1 Field Collection Methods

Water samples were collected weekly for fecal coliform (FC) analysis during the following periods:

	Sampling Period	Number of Sites	Number of Samples per Site
Longitudinal Survey	April 27, 2006 to March 19, 2007	4	n=48
Attainment Monitoring	May 4 to 30, 2006, August 3 to 28, 2006, and December 11, 2006 to January 9, 2007	2	n=15
Seasonal Monitoring	July 5 to August 28, 2006	9	n=9
	October 10 to November 29, 2006	4	n=9
	October 24 to December 7, 2006 and January 24 to March 19, 2007	3	n=15

Maps with site descriptions and UTM coordinates are included in Parts I through V of the report for each component of the study. Photos for each sample site are included in Appendix B.

Sampling procedures were conducted according to the Resources Information Standards Committee: Freshwater Biological Sampling Manual (Resources Inventory Committee 1997). Water samples were collected in sterilized 500 mL polyethylene bottles supplied by the laboratory. Samples were taken just below the water surface and were kept on ice in coolers for transport to the laboratory. Coolers were transported to the laboratory via courier or by Ministry staff to allow initiation of laboratory analysis within 48 hours of sampling.

Water chemistry parameters were recorded during weekly sampling, using a hydrolab. These parameters were water temperature, pH, specific conductivity, dissolved oxygen and turbidity. Where possible, flow and depth were also recorded, to allow for conversion of FC concentrations to loadings. Appendix C contains an example showing how loading was calculated. Samples near the river mouth were collected at the lowest tide possible to minimize the effects of salinity within the LCR mainstem.

A Hydrolab deployment tube containing a Hydrolab DataSonde 4 was set up in the LCR mainstem at 12th Avenue on October 5, 2005 to collect semi-continuous water quality data at 15 minute intervals. From October 2005 to April 2006, the hydrolab was serviced and calibrated every 5-6 weeks, using U.S. Geological Survey techniques and methodology for continuous water quality monitoring (Wagner, R.J. *et al*. 2006), and from April 2006 to present, the stations were serviced and calibrated every 4 weeks according to the B.C. Resource Information Standards Committee procedures (RISC 2006).

The temperature loggers (StowAway Tidbit Data Loggers) were secured to re-bar posts and placed underwater, within a relatively deep and stable portion of the channel at 6 mainstem sites and 9 tributary sites. The loggers were set to collect automated semi-continuous temperature data at 15 minute intervals. They were serviced two times per year, in May and October, to assess their working condition, download the data and re-launch them for the next sampling period.

2.2 Laboratory Methods

Laboratory analyses were performed by CANTEST Ltd. and procedures followed the B.C. Environmental Laboratory Manual for the Analysis of Water, Wastewater, Sediment, Biological Materials and Discrete Ambient Air Samples (2005).

Water samples were analyzed for FC bacteria using the Membrane Filtration Method (MF), except for samples collected at the site near the mouth (29.20), which were analyzed using the Most Probable Number Method (MPN). The MF method gives direct counts of FC concentration, whereas the MPN method provides estimates based on a multiple tube fermentation technique. The MF method provides a statistically more precise result for freshwater samples; however, the presence of high suspended solids, heavy ions, algae, or other interfering substances in marine water may limit the application of the MF test in shellfish growing water (Menon 2000). The MPN method is used for the bacteriological examination of marine waters for shellfish harvesting (Canadian Shellfish Sanitation Program) and recreational use (B.C. water quality guidelines). MPN methodology was used for the mainstem site near the mouth (29.20) due to its tidal influence, relatively high salinity, and for more accurate comparison between values at the mouth and marine sample results.

2.3 Statistical Analysis

Statistical analysis was completed using Microsoft Excel and the statistical software, JMP IN® (Version 5.1, © SAS Institute, Inc.).

2.3.1 Running geometric means of fecal coliform data

The geometric mean, an average of FC concentrations from five consecutive samples collected within 30 days, was calculated for each site. Running geometric means were graphed for the year-long sampling period, where each point on the graph represents the geometric mean of the previous 5 sampling days. Concentrations were then compared to the provincially approved water quality guideline for primary contact recreational use (MoE 2006). Using catchment data provided through the watershed characterization study (Zevit *et al*. 2008), and depth-flow profiles measured on-site, FC loading was calculated for each site and each sampling day.

2.3.2 Comparison of fecal coliform data between sites

FC concentrations were compared between sampling sites to determine significant ($\alpha = 0.05$) difference. T-tests were used when comparing two sites and ANOVA tests were used when comparing multiple sites. Paired tests were used when comparing sites that were sampled on the same day. Due to the lognormal distribution of environmental quality data, the FC concentration data were converted to log format before analysis. For Part I, the longitudinal study, FC concentrations were compared between each of the four mainstem sites. For Parts II, III and IV, FC concentrations were compared in order to test each provisional statement.

2.3.3 Relationship of fecal coliform data with precipitation

For the longitudinal study, FC concentrations from each of the four sampling sites were graphed with precipitation data to determine the potential strength of each relationship (correlation). Antecedent precipitation records (24hr, 48hr and 96hr) were used for this analysis.

2.3.4 Missing data

For data sets with missing discharge data due to insufficient flow to detect velocity measurements with available equipment or due to high flow events resulting in unsafe conditions to measure depth or velocity profiles, discharge was estimated based on the best fit relationship between cross-sectional area and discharge (rating curve).

2.4 Quality Assurance/Quality Control

Quality assurance/quality control procedures followed guidelines in the Resources Information Standards Committee: Freshwater Biological Sampling Manual (Resources Inventory Committee 1997). Fifteen percent of the samples collected were for the purpose of QA/QC. These samples included duplicates, field blanks and trip blanks. QA/QC data are displayed in Appendix D.

3.0 STRATEGIC MONITORING PROGRAM COMPONENTS

The sampling design, results, discussion and conclusions for each component of the strategic monitoring program were written separately and are found in the following parts:

Part I: Longitudinal Survey of the LCR (pp 10 – 24),
Part II: Urban Runoff (pp 25 – 40),
Part III: Agricultural Runoff (pp 41 – 48),
Part IV: On-site Sewage Disposal Systems (pp 49 – 55), and
Part V: Automated Water Quality Monitoring (pp 56 – 70).

Little Campbell River Watershed Water Quality Monitoring:

Part 1: Longitudinal Survey and Attainment Monitoring

April 2006 to March 2007

Prepared by:
Christy Juteau
Ministry of Environment
Environmental Quality Section
2nd Floor, 10470 152 Street
Surrey, B.C.
V3R 0Y3
604-582-5200

June 2008

I.A SAMPLING DESIGN

Table 1 and Figure 4 show the locations of the four sample sites for the longitudinal survey and the two sites for the water quality objectives attainment monitoring. At the longitudinal survey sites, water samples were collected weekly from April 27, 2006 to March 19, 2007 for fecal coliform (FC), as well as pH, temperature, dissolved oxygen, specific conductivity and turbidity. At the water quality objectives attainment monitoring sites, water samples were collected for FC analysis 5 times in 30 days during May-06, Aug-06 and Dec-06/Jan-07. Additional water quality parameters were analyzed, including dissolved oxygen, pH and turbidity.

Table 1. Longitudinal survey and attainment monitoring - sample site IDs, UTM coordinates and site descriptions.

	Site ID[1]	UTM Zone 10 Easting	UTM Zone 10 Northing	Site Description
Longitudinal Survey	1006-1 East S-W	529001	5429055	LCR mainstem crossing at 224th Street and 600 block, d/s of bridge
	722-2 Langley S-W	522846	5430949	LCR mainstem upstream of hatchery at 16th Avenue, d/s of bridge
	146-1-A Surrey S-W	518544	5428911	LCR mainstem at 172nd Street, downstream of feedlot, d/s of bridge
	29.20 West S-W	515888.8	5429181	LCR mainstem at bend near the mouth, downstream of Habgood outfall
Attainment Monitoring	701-1 LCR@216	527415	5428874	LCR mainstem crossing 216th Street and 600 block, d/s of bridge
	143-1-B LCR@176	519387	5428818	LCR mainstem at 176th Street truck crossing bridge near border, u/s of bridge

[1] Site identification codes follow those used in Fleming and Quilty 2006, listed in order from upstream to downstream.

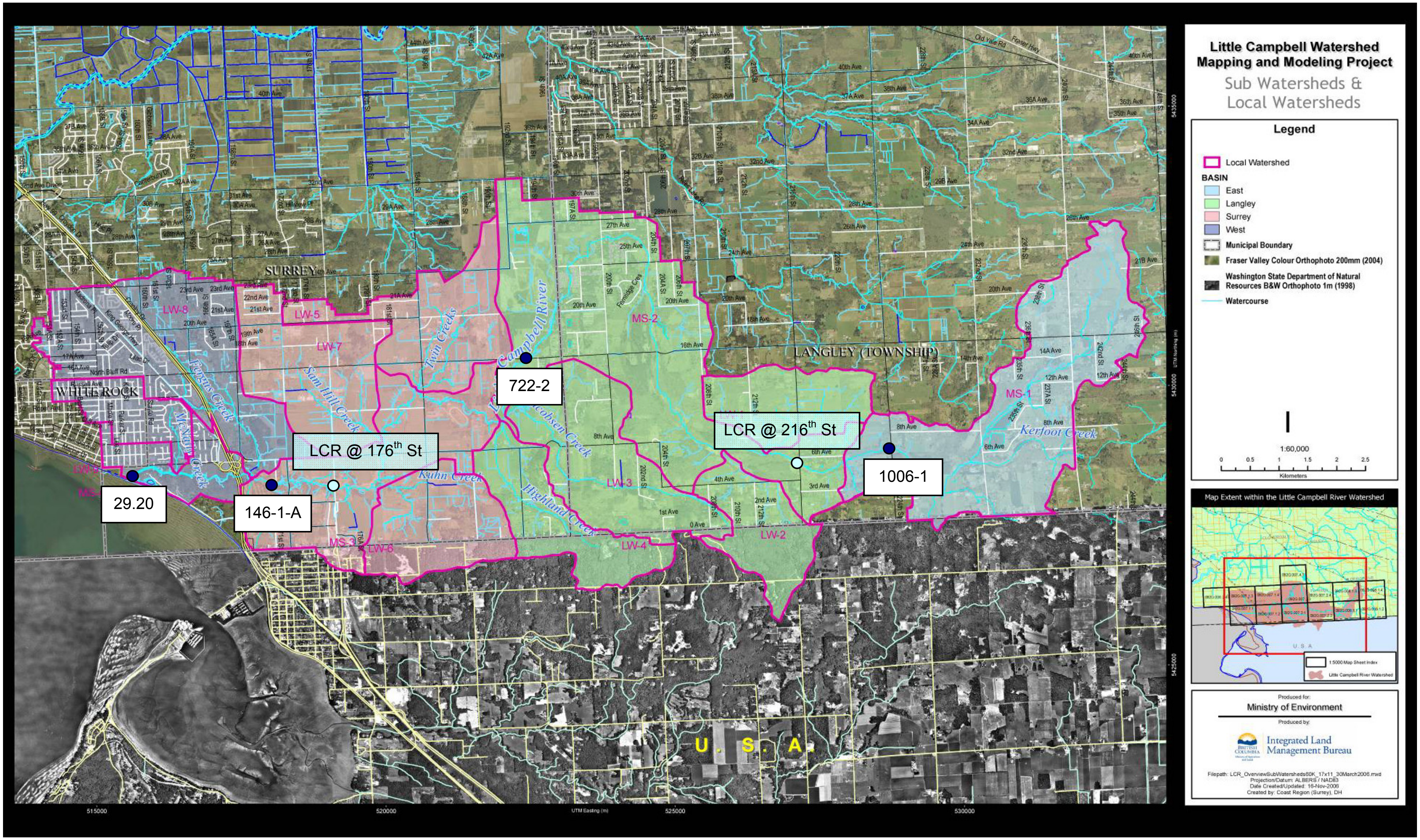

Figure 4. Map of sample sites for longitudinal survey and attainment monitoring. Dark blue circles indicate longitudinal survey sample sites and light blue circles indicate attainment monitoring sample sites.

I.B RESULTS AND DISCUSSION

Appendix E contains the raw water quality data collected for this study.

I.B1 Comparison of fecal coliform data with water quality standards

Running geometric means of fecal coliform (FC) concentrations were calculated for each sampling site, and are displayed on a logarithmic scale in Figure 5. Each color corresponds with the sub-watershed it was sampled from; map inset is shown in Figure 5. Also shown is the provincially approved water quality guideline for fecal coliform in waters used for primary contact recreation (200 CFU/100mL). Appendix F shows the running geometric means of FC concentrations for each site including 95% confidence intervals.

Overall, FC levels appeared to increase towards the downstream end of the watershed, with highest concentrations occurring near the mouth, particularly during the wet season. This is consistent with earlier findings that also indicate poorer water quality in the lower half of the watershed (Swain 1988, Bull 2002, Fleming and Quilty 2006), and is likely due to the cumulative impact of multiple sources of fecal contamination entering the river throughout the watershed, but also due to the input of fecal contamination sources near the river mouth (See Part II for more details). FC concentrations were particularly high near the mouth from October to February, consistently exceeding the 200 CFU/100mL guideline and reaching a maximum concentration of 17 million CFU/100mL during wet conditions.

During the late summer, FC concentrations were greatest at the most upstream sample site (LCR at 224 St), reaching a maximum of 2,100 CFU/100mL and geometric means up to 674, well above the 200 CFU/100mL guideline for recreational use. Turbidity was relatively high (14-200 NTU) during this time, which may have resulted in higher FC readings due to the adsorption of bacteria to suspended sediment particles. FC bacteria have been found to survive and reproduce in stream sediments and have frequently been recorded at levels 3 to 4 orders of magnitude greater than the overlying water column (Schueler and Holland 2000). These high FC levels did not appear to degrade water quality downstream however, due to almost nil precipitation and very low discharge in the upper watershed at this time.

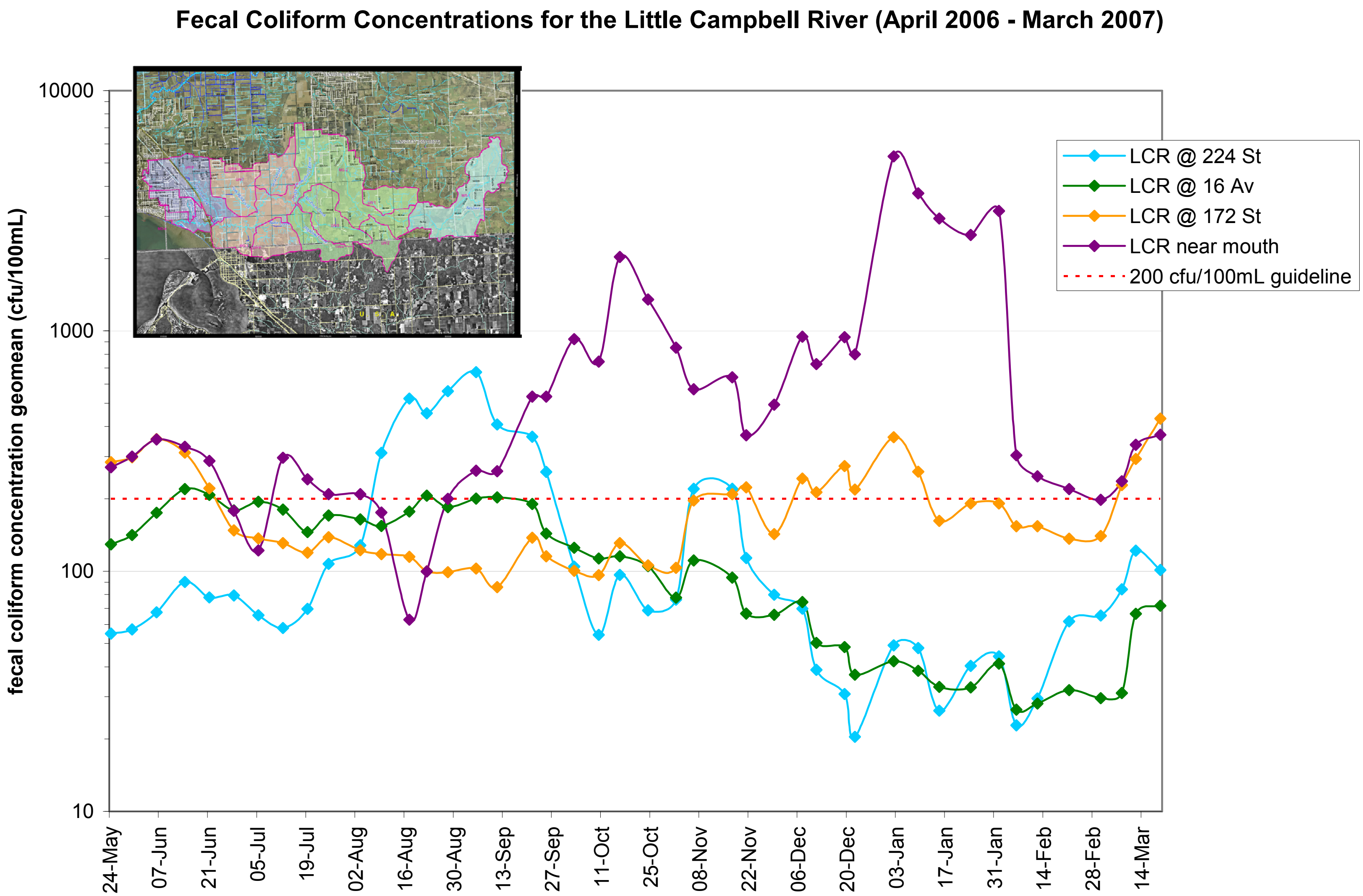

Figure 5. Running geometric mean of fecal coliform concentrations sampled from four mainstem sites in the Little Campbell River watershed, April 2006 – March 2007

I.B2 Analysis of fecal coliform data by season

Seasonally, there appeared to be a distinct shift in FC concentration response during the spring and summer (dry) season as compared to the fall and winter (wet) season (Figure 5). FC concentrations were analyzed by wet and dry seasons to determine the frequency of exceedence of the 200 CFU/100mL water quality guideline (Figure 6 and Table 2). Seasons were defined as follows: wet season – fall (Sep 21 – Dec 20) and winter (Dec 21 – Mar 20); dry season – spring (Mar 21 – Jun 20) and summer (Jun 21 – Sep 20).

During the dry season, FC geometric means appeared to hover around the 200 CFU/100mL guideline, with exceedences occurring at all four sites approximately 30% of the time (Figure 6). During the wet season, the two upper watershed sites showed a substantial decrease in FC levels with a strong linkage to precipitation (Figure 9, Table 5), and the two downstream sites showed an increase in FC, particularly near the river mouth. The majority of exceedences occurred during the wet season in the lower half of the watershed.

Analysis of variance only showed a significant difference between the sites during the wet season ($F_{0.05,3}=23.67$, $p<0.0001$). Tukey multiple comparison analyses showed that LCR near the mouth had the greatest FC concentrations during the wet season, followed by LCR at 172nd Street, and both were found to be significantly different from each other. The two upper watershed sites were grouped together, and although not different from each other, were significantly different from the two lower watershed sites. A summary of these statistical analysis results are included in Appendix F.

FC loading analysis showed a similar seasonal trend. Tukey multiple comparison analyses grouped the two lower watershed sites as having significantly greater FC loads than the two upper watershed sites during the wet season; however, during the dry season, all three lower watershed sites were grouped together, while the most upstream site (LCR at 224th Street) was found to have significantly lower loadings (Appendix F). FC loadings at each sampling site are displayed as boxplots in Figure 7.

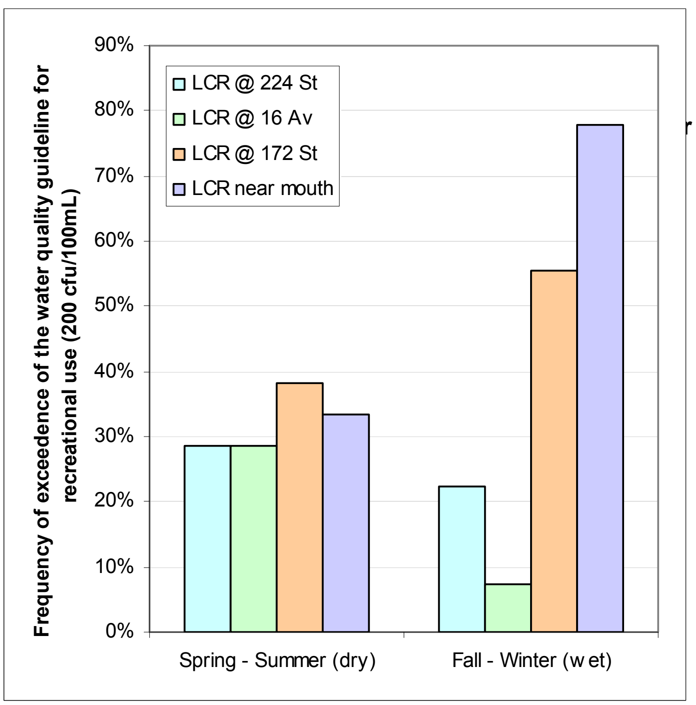

Figure 6. Seasonal frequency of exceedence of the provincially approved recreational water quality guideline (200 CFU/100mL) at four mainstem sites in the Little Campbell River.

Table 2. Seasonal frequency of exceedence of the provincially approved recreational water quality guideline (200 CFU/100mL)

	Spring	Summer	Fall	Winter
Dates	Mar 21 – Jun 20	Jun 21 – Sep 20	Sep 21 – Dec 20	Dec 21 – Mar 20
Total Precipitation	170.5 mm	82.6 mm	386.2 mm	601.4 mm
Sample Size	8	13	14	13
Number of exceedences per number of samples				
LCR at 224 St	*0/8*	*6/13*	*3/14*	*3/13*
LCR at 16 Av	*2/8*	*4/13*	*1/14*	*1/13*
LCR at 172 St	*7/8*	*1/13*	*8/14*	*7/13*
LCR near mouth	*3/8*	*4/13*	*12/14*	*9/13*
Total	*12/32*	*15/52*	*24/56*	*20/52*

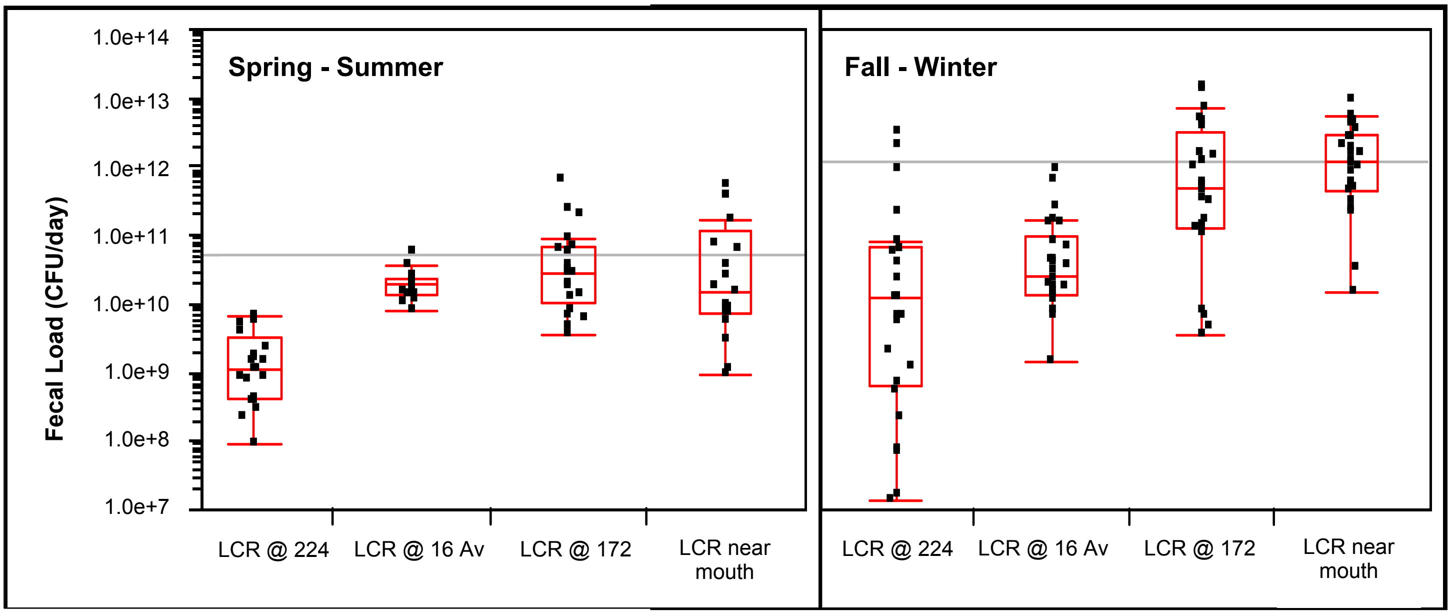

Figure 7. Boxplots of seasonal fecal coliform loadings from four mainstem sites in the Little Campbell River watershed, April 2006 – March 2007. Red boxes show the median, 25% and 75%. Red bars represent 10% and 90%. Black points show individual data points. Grey lines show the grand mean.

I.B3 Analysis of fecal coliform data by sub-watershed area

Relative Contributions of Fecal Contamination

The FC concentration and loading results represent the water quality at the site when the grab sample was taken, which could result from an accumulation of upstream sources. By analyzing the longitudinal survey, it is possible to estimate the relative contribution of each sub-watershed to the total FC grab sample result at each site, through the consideration of pathogen transport time and removal rates.

As pathogens are transported downstream, they can be removed from the water column due to decay or deposition. Removal rates are mainly driven by salinity, temperature, light exposure, turbidity and sedimentation (McCorquodale *et al*. 2004; Thomann and Mueller 1987; Mills *et al*. 1985). Figure 8 shows the relative fecal contribution of each sub-watershed based on rates of transport and decay due to salinity, temperature and light intensity. Sedimentation rates were not accounted for due to a lack of data: the fraction of pathogens attached to suspended sediment, the combined particle settling velocity, the pathogen decay rate in sediment and the possibility of resuspension were unknown. Appendix F contains the literature-derived equations that were used to calculate seasonal pathogen decay rates.

During the spring 2006, the Langley, Surrey and West sub-watersheds each contributed an estimated 14%, 31%, and 55% of the total FC load, respectively, to the mouth (Figure 8). During the summer 2006, an estimated contribution approaching 100% of the FC load at the LCR mouth originated from the West Sub-watershed. Low discharge and extended travel times appear to have restricted FC sources from reaching downstream sub-watersheds, thereby keeping contamination localized. Another barrier to FC transport during summer months is that a portion of the LCR mainstem (~1.5 km) within the Langley Sub-watershed routinely becomes de-watered. It is unknown how long the channel is typically dry; however, a landowner who has lived adjacent to the river for 18 years estimated that this portion of the river becomes dry from about mid-June to November every year. In 2006, re-connection of surface flows did not occur until a heavy, sustained rain event (113 mm) from November 2 – 6. This could have a profound effect on watershed hydrology and contaminant transport. Temperature loggers have been installed in this area to determine the exact times of de-watering for future records (See Part V for more information).

During the fall 2006 and winter 2006/07, FC load contributions to the LCR mouth largely originated from the West Sub-watershed (estimated 83% in fall and 96% in winter) in addition to minor contributions from the Langley and Surrey sub-watersheds. It appears that the East Sub-watershed only contributed FC loading to downstream sub-watersheds during winter, accounting for approximately 0.4% of the total load at the mouth.

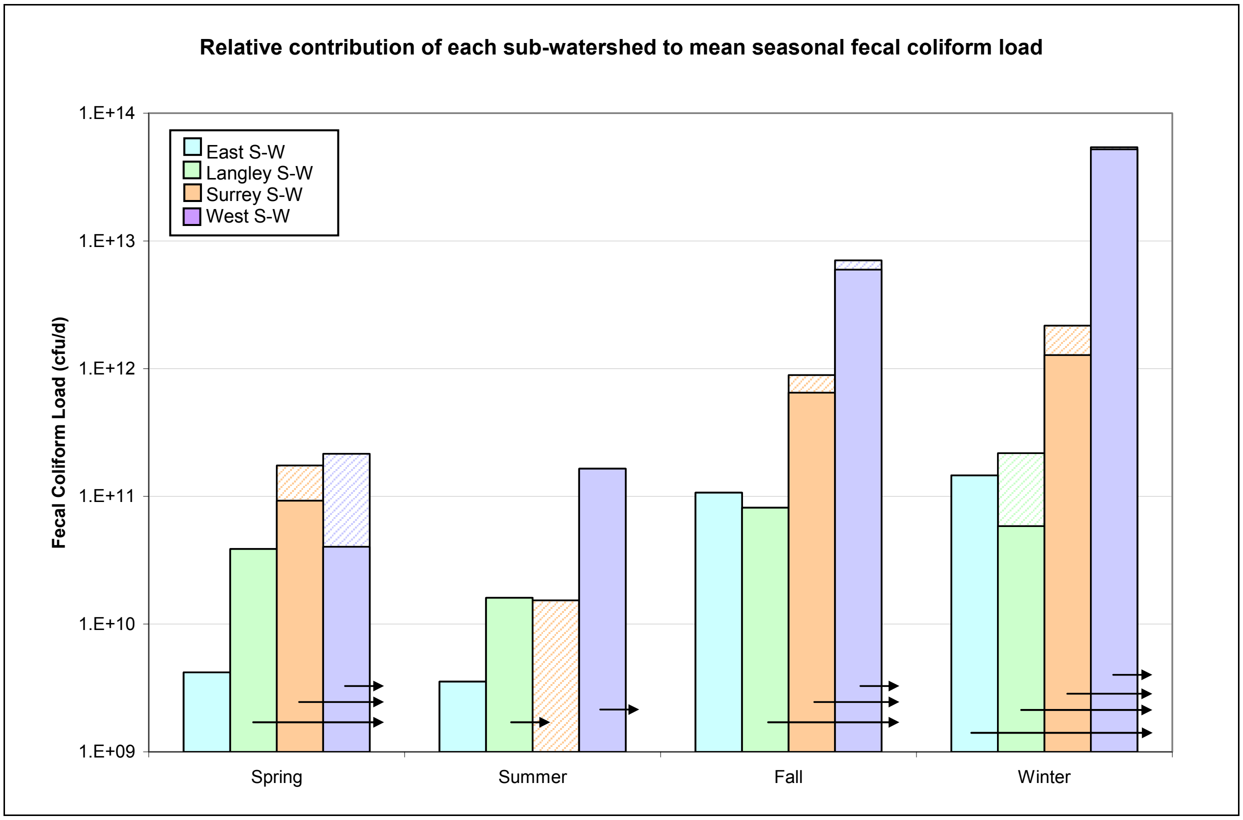

Figure 8. Mean seasonal fecal coliform load contribution from each sub-watershed. Solid-coloured bars indicate the estimated relative contribution of fecal coliform load (CFU/day) from each sub-watershed based on pathogen decay rates. Hatched areas indicate the estimated total load measured at each sampling site, but contributed by upstream sub-watersheds. The arrows indicate which sub-watersheds contribute contaminants to downstream areas. Arrows extending to the right of the West-SW indicate contributions to the mouth of the Little Campbell River and Semiahmoo Bay.

Potential Pollution Sources and Sinks

Each sub-watershed area has different land use characteristics, some of which may contribute pathogens to the LCR. Potential pollution sources and sinks have been identified for the LCR watershed and assessed on a sub-watershed scale (Zevit *et al.* 2008). In this report, these characteristics were assessed for any indications of linkages between land use and sub-watershed water quality. Table 3 shows the relative densities of livestock, on-site sewage disposal systems, roads and percent impervious area as potential fecal pollution sources or conduits. Table 4 shows the percent area of wetlands, floodplains, hydric soils, and forests as potential pollution sinks.

Of the potential pathogen sources analysed in this report, manure production and livestock density were greatest in the upper watershed and decreased further downstream, on-site sewage disposal system density was fairly consistent throughout the watershed (0.2 – 0.36 per hectare), and urban land use was greatest at the downstream end of the watershed, decreasing further upstream. It is difficult to draw direct linkages between these pollution sources and LCR water quality data because of their non-point source nature. Parts II-IV attempt to characterize the relationships between FC levels and land use more specifically.

Table 3. Land use characteristics of each sub-watershed in the Little Campbell River watershed – potential pollution sources and/or conduits. (Source: Agricultural Land Use Inventory data (MAFF 2001, MAL 2005), On-site sewage disposal systems inventory mapping layers (GVRD 2002), impervious area estimates and road network information (Zevit *et al*. 2008).

	Agricultural Land Use			**On-site Sewage Disposal Systems (SDS)**	**Urban Land Use**		
Sub-watershed	Estimated Livestock Operations per hectare	Estimated daily manure production[2] (kg/ha)	Dominant Livestock Types	Estimated On-site SDS per hectare	Total Impervious Area (%)	Effective Impervious Area (%)	Road Density (m/ha)
East	0.12	36.2 – 112.1	Horse, Poultry, Beef	0.20	4.6	1.1	17
Langley	0.08	18.7 – 108.8	Poultry, Horse, Dairy	0.36	4.2	1.3	21
Surrey	0.02	10.5 – 36.7	Poultry, Beef, Dairy	0.21	9.6	5.2	25
West	0.001	0.2 – 0.8	Beef (1 operation)	0.31	30.1	22.1	100

Table 4. Land use characteristics of each sub-watershed in the Little Campbell River watershed – potential pollution sinks.

	Wetland/Floodplain Area (%)	Hydric Soils Area (%)	Forested Area (%)
East	42.55	8.77	29.8
Langley	9.76	3.72	44.0
Surrey	3.17	27.93	26.0
West	7.47	8.70	16.3

I.B4 Relationship of fecal coliform data with precipitation

FC concentration data were analyzed to determine the strength of relationship with antecedent precipitation (24hr, 48hr, and 96hr) by site. Fecal coliform concentrations were expected to have a positive relationship with antecedent precipitation, perhaps with a lag effect, as increased surface runoff would cause fecal contamination sources to be washed into nearby watercourses and eventually into the river mainstem. Relationship strength was quantified using correlation coefficients. A perfect linear relationship has a correlation coefficient of positive or negative 1, depending on the nature of the relationship. Table 5 shows the correlation coefficients for each of the four LCR mainstem sampling sites. Scatterplot matrices are shown in Appendix F.

Correlation with antecedent precipitation was very weak near the mouth (r^2 = 0.04-0.09), and weakly negative through the mid-watershed, but showed a relatively strong positive relationship in the upper watershed (r^2 = 0.41-0.50) (Table 5). This may be due to a greater amount of above-ground fecal contamination sources in the upper watershed that could be affected by precipitation and transported via overland run-off.

Another way to characterize the relationship between precipitation and FC concentration is to determine which FC peaks line up with peaks in precipitation (Figure 9). Table 6 shows the number of water quality guideline exceedences (Table 2) that can be linked with precipitation events in each sub-watershed.

[2] Based on animal unit equivalent (AUE) calculations. AUEs represent the amount of manure generated per livestock type, based on a literature-derived baseline. This is primarily based on work done by the American Society of Agricultural Engineers that calculated mean manure production and associated fecal coliform production per day depending on livestock type (ASAE 2003). Data values represent fresh (as voiced) feces and urine combined, using 1000 kg of live animal mass as the unit equivalent.

Results from this analysis are similar to those seen in the correlation analysis (Table 6 and Figure 9), particularly for the wet season. In the upper watershed (LCR at 224th St. and LCR at 16 Av.), 100% of FC guideline exceedences were linked with precipitation events during the wet season. Although there were a greater number of guideline exceedences in the lower watershed during this time, only a few of these could be linked with precipitation events. Similarly, during the dry season, very few FC guideline exceedences were linked with precipitation events. This suggests that FC bacteria enter the LCR watershed via pathways in addition to overland runoff, particularly in the lower watershed. Alternative pathways could include direct deposit of fecal material into tributaries or the mainstem (improper manure storage adjacent to streams, domestic pets, wildlife – including waterfowl), urban stormwater (dry-weather flows), resuspension of FC adsorbed to sediments, failing on-site sewage disposal systems, and/or sanitary sewer cross-connections.

Table 5. Correlation coefficients indicating strength of linear relationships between fecal coliform concentration and antecedent precipitation. Strongest relationships highlighted in bold.

Parameter	**LCR @ 224 St** FC Concentration	**LCR @ 16 Av** FC Concentration	**LCR @ 172 St** FC Concentration	**LCR near mouth** FC Concentration
24 hr Precip	**0.4960**	-0.0211	-0.1494	0.0858
48 hr Precip	**0.4241**	-0.0431	-0.1883	0.0663
96 hr Precip	**0.4125**	-0.0340	-0.1586	0.0395

Table 6. Seasonal frequency of exceedence of the provincially approved recreational water quality guideline (200 CFU/100mL) that can be linked with precipitation events.

	Spring – Summer (Dry)		**Fall – Winter (Wet)**	
Dates	Mar 21 – Sep 20		Sep 21 – Mar 20	
Sample Size	21		27	
	Number of exceedences	*Exceedences linked with precipitation events*	*Number of exceedences*	*Exceedences linked with precipitation events*
LCR @ 224 St	*6*	*1 (17%)*	*6*	*6 (100%)*
LCR @ 16 Av	*6*	*1 (17%)*	*2*	*2 (100%)*
LCR @ 172 St	*8*	*1 (13%)*	*15*	*5 (33%)*
LCR near mouth	*7*	*2 (29%)*	*21*	*4 (19%)*

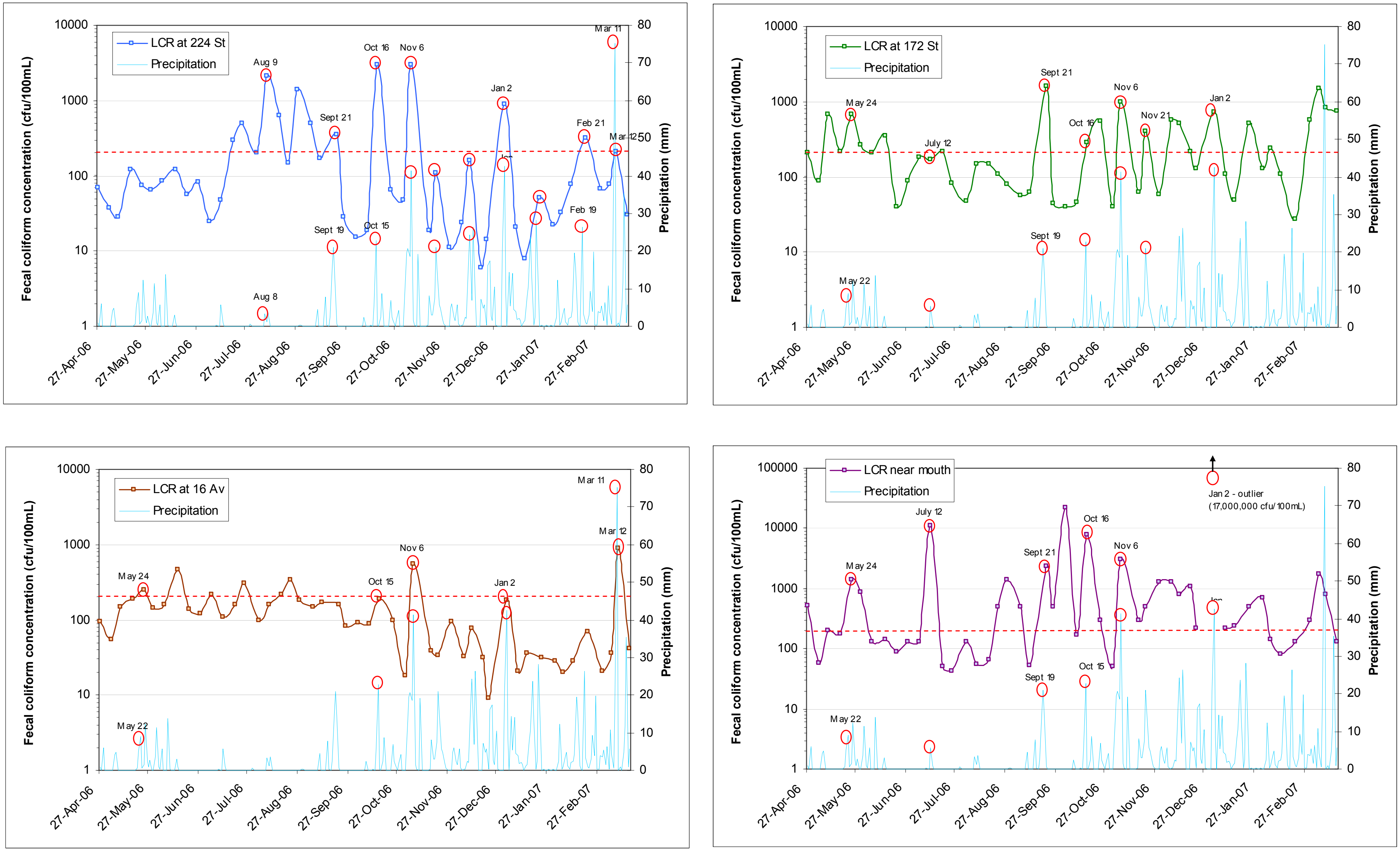

Figure 9. Precipitation events linked with peaks in fecal coliform concentrations sampled at four sites within the Little Campbell River mainstem. Red circles indicate observed linkages between precipitation events and the corresponding peaks in fecal coliform concentration. Red dashed line shows the water quality guideline for recreational use (200 CFU/100mL).

I.B5 Water quality objectives attainment monitoring

Tables 7-9 show the WQO attainment monitoring results for 2006/2007. Comparison of the 2006/2007 results with previous attainment monitoring (1971 – 2002) is included in Appendix F.

In 2006/07, during the summer sampling period, water quality objectives for the LCR were met for pH, but objectives were not met for dissolved oxygen at both upstream and downstream sites, or FC bacteria at the upstream site. During the winter sampling period, water quality objectives were not met for dissolved oxygen, turbidity, pH or FC bacteria.

When compared with past attainment monitoring results in 1988, 1989, 1990, 1991, 1992 and 2002 (MOE 1989, MOE 1990, MOE 1991, MOELP 1993a, MOELP 1993b, Bull 2003), the 2006/07 results show conditions to be adequate and stable for pH. Dissolved oxygen levels continue to be poor and unstable, particularly at the upstream site. Despite general improvement in FC bacteria from 1983 to 2002, the 2006/07 results showed a decline in water quality for this indicator.

Table 7. Bacteriological objectives attainment in the Little Campbell River – 2006/2007

Variable & Objective	Site	Date	Sample Size	Range, Geometric Mean (gm) & 90th percentile (np)	Conclusion
Fecal coliform (CFU/100mL) ≤200/100mL geometric mean ≤400/100mL 90th percentile (np)	LCR (0300066) Upstream	Apr 27, May 4, 10, 17, 24, 30	6	9 – 45 gm = 24 np = 41	Objectives met
	LCR (0300065) Downstream	Apr 27, May 4, 10, 17, 24, 30	6	65 – 1390 gm = **257** np = **1258**	**Objectives not met**
	LCR (0300066) Upstream	Aug 3, 9, 17, 22, 28	5	87 – 330 gm = **202** np = 330	**Objectives not met**
	LCR (0300065) Downstream	Aug 3, 9, 17, 22, 28	5	70 – 290 gm = 128 np = 225	Objectives met
	LCR (0300066) Upstream	Dec 11, 19, 22 Jan 2, 9	5	6 – 540 gm = 40 np = 288	Objectives met
	LCR (0300065) Downstream	Dec 11, 19, 22 Jan 2, 9	5	68 – 750 gm = **252** np = **690**	**Objectives not met**

Table 8. Water quality objectives attainment in the Little Campbell River – Summer 2006

Variable & Objective	Site	Date	Sample Size	Result or Range	Conclusion
Turbidity (NTU) 5 NTU increase when upstream ≤ 50 NTU (10% maximum increase when upstream >50 NTU)	LCR (0300066) Upstream	Aug 3, 9, 17, 22, 28	5	22.2 – 31.0	Upstream site
	LCR (0300065) Downstream	Aug 3, 9, 17, 22, 28	5	3.1 – **118.9** (Max increase 95.5 mg/L, Aug 9)	**Provincial criterion not met** (only Aug 9)
Dissolved Oxygen (mg/L) 6 mg/L (Jun – Oct) 8 mg/L (long term) 11 mg/L minimum (when salmonids present)	LCR (0300066) Upstream	Aug 3, 9, 17, 22, 28	5	**0.26 – 2.9**	**Objective not met**
	LCR (0300065) Downstream	Aug 3, 9, 17, 22, 28	5	**2.54** – 9.26	**Objective not met**
pH 6.5 to 8.5	LCR (0300066) Upstream	Aug 3, 9, 17, 22, 28	5	6.71 – 7.93	Objective met
	LCR (0300065) Downstream	Aug 3, 9, 17, 22, 28	5	7.4 - 7.74	Objective met[3]

[3] Aug 3 measurement of 7.4 was a laboratory result

Table 9. Water quality objectives attainment in the Little Campbell River (LCR) – Winter 2006-2007

Variable & Objective	Site	Date	Sample Size	Result or Range	Conclusion
Turbidity (NTU) 5 NTU increase when upstream ≤ 50 NTU (10% maximum increase when upstream >50 NTU)	LCR (0300066) Upstream	Dec 11, 19, 22 Jan 2, 9	5	1 – 18	Upstream site
	LCR (0300065) Downstream	Dec 11, 19, 22 Jan 2, 9	5	17.8 – 88.7 (max increase 80.4 on Jan 2)	**Provincial criterion not met**
Dissolved Oxygen (mg/L) 11 mg/L minimum (when salmonids present)	LCR (0300066) Upstream	Dec 11, 19, 22 Jan 2, 9	5	**6.86 – 8.77**	**Objective not met**
	LCR (0300065) Downstream	Dec 11, 19, 22 Jan 2, 9	5	**9.91** – 11.71	**Objective not met**
pH 6.5 to 8.5	LCR (0300066) Upstream	Dec 11, 19, 22 Jan 2, 9	5	**6.3** – 7.62	**Objective not met**
	LCR (0300065) Downstream	Dec 11, 19, 22 Jan 2, 9	5	7.01 – 7.97	Objective met

I.C CONCLUSIONS

Fecal coliform (FC) loadings were greatest near the mouth of the Little Campbell River (LCR) throughout the sampling period (April 2006 to March 2007). FC concentrations near the mouth were particularly high during the wet season, with geometric means ranging from 200 to 5300 CFU/100 mL, consistently exceeding the B.C. approved water quality guideline for recreational use (200 CFU/100 mL, MOE 2006).

The West Sub-watershed was found to be the greatest contributor of fecal contamination to the river mouth and subsequently the receiving waters of Semiahmoo and Boundary bays (estimated contribution approaching 100% - summer, 83% - fall, 96% - winter, 55% - spring). Land use in this area is mainly urban (30% impervious area) and is largely serviced by sanitary sewers with approximately 300 on-site sewage disposal systems, mostly in the Fergus Creek sub-watershed. High FC levels were not strongly linked to precipitation suggesting that fecal sources may be entering the LCR via other routes in addition to overland runoff. Alternate pathways could include direct deposit of fecal material into tributaries or the mainstem (domestic pets, wildlife – including waterfowl), urban stormwater (dry-weather flows), resuspension of FC adsorbed to sediments, failing on-site sewage disposal systems, and/or sanitary sewer cross-connections.

During the summer, FC concentrations were high in the upper watershed (LCR at 224th Street), exceeding the B.C. MoE 200 CFU/100 mL guideline for recreational use and general livestock use, for all of August and September. It appears that this contamination may have remained localized, however; due to very little precipitation and low flows.

A portion of the LCR mainstem (~1.5 km) becomes completely de-watered during the summer, potentially up to 5 months of the year. This restricts the movement of contaminants from the upper watershed to the mouth, but also poses a risk to aquatic life. Groundwater and surface water extraction rates could be contributing to this condition.

The Water Quality Objectives attainment monitoring found that pH levels were adequate, while fecal coliform, turbidity and dissolved oxygen continue to indicate water quality concerns in the LCR watershed.

Little Campbell River Watershed Water Quality Monitoring:

Part 2: Urban Runoff – Summer 2006

Prepared by:
Rachel Krause
(A Rocha Canada)
and
Christy Juteau

Prepared for:
Ministry of Environment
Environmental Quality Section
2nd Floor, 10470 152 Street
Surrey, B.C.
V3R 0Y3
604-582-5200

June 2008

II.A SAMPLING DESIGN

One of the seasonal trends identified through the analysis of historical monitoring data from the Little Campbell River (LCR) watershed, was high levels of fecal coliform (FC) bacteria at the river mouth during summer months. These high fecal loadings are especially of concern because Semiahmoo Bay is most frequently used by recreational swimmers and boaters during the summer. Due to high levels of fecal coliform bacteria previously found in urban stormwater near the mouth (Cheung 2003) and summer low flows contributing relatively low volumes of potential contaminants from upper reaches, it was suspected that **contaminated runoff originating from urban areas near the river mouth was significantly contributing to these seasonally high fecal loadings**.

The main purpose of this component of the Little Campbell River (LCR) monitoring study was to characterize the water quality of urban runoff entering the LCR watershed near the mouth during the summer in order to test the validity of the above provisional statement. The lower LCR watershed (West Sub-watershed) is largely urban with medium-density residential and commercial development. Urban runoff mainly enters the LCR mainstem through three outlets in the West Sub-watershed: Fergus Creek, McNalley Creek and the stormwater outfalls at Habgood Street. This portion of the study examined the relative contributions of McNalley Creek and the Habgood outfalls to LCR water quality as examples of runoff from urban land use areas. Fergus Creek was not examined in this study because its watershed is large with a greater complexity of land uses.

An additional purpose of this component of the report was to compare the 2006 summer sampling results with water quality data collected from the same area in 1999-2001 (Cheung 2003) and to determine whether there had been any significant improvements. Results of the 1999-2001 study showed high levels of FC at many of the sample sites. Since 2001, storm and sanitary sewer infrastructure in White Rock has been upgraded. Most notably, a siphon was added to the sanitary sewer system at Finlay Street to pump sewage eastward more effectively to the pump station located at Oxford Street, which pumps the City of White Rock's sewage north to the GVRD sewage treatment plant at Annacis Island (T. Haight, personal communication, 2006). Further upgrades to the storm sewer system are anticipated in the next few years, including a proposed outfall into the LCR at Stayte Road. Marine stormwater outfalls at Oxford Street and Finlay Street and the Habgood outfall were examined in this portion of the study.

Table 10 and Figure 10 show the ten sample sites at stormwater outfalls and in-stream locations within the lower LCR watershed. Water samples were collected weekly from July 5 to August 28, 2006 for fecal coliform (FC), as well as pH, temperature, dissolved oxygen, specific conductivity and turbidity. Two of the sites were also sampled weekly from January 24 to March 12, 2007: McNalley Creek at the mouth (31.30) and the stormwater outfall at Habgood Street (30/31), to assess their relative contributions of fecal contamination to the LCR mouth during the wet season.

Table 10. Seasonal monitoring of urban runoff - sample site IDs, UTM coordinates and site descriptions.

Site ID[1]	UTM Zone 10 Easting	UTM Zone 10 Northing	Site Description
31.60	516542	5430117	McNalley Creek at 12th Ave
31.30-W	516682	5429729	Outfall into McNalley Creek at 10th Ave, from west
31.30-E1	516682	5429727	Outfall into McNalley Creek at 10th Ave, from east, upstream outfall
31.30-E2	516683	5429720	Outfall into McNalley Creek at 10th Ave, from east, downstream outfall
31.10	516629	5429172	McNalley Creek at mouth, upstream of footbridge

[1] Site identification codes follow those used in Cheung 2003, listed in order from upstream to downstream.

Table 10. cont.

Site ID[2]	UTM Zone 10 Easting	UTM Zone 10 Northing	Site Description
29.30	516117	5429271	LCR at Stayte Rd, downstream of footbridge
30/31	515935	5429216	Upper/lower Habgood outfalls into LCR
29.20	515888.8	5429182.3	LCR at the bend south of Habgood outfalls
28/28.1	515316	5429266	Marine outfall at Finlay St, west outfall
23	513710	5430001	Marine outfall at Oxford St

Figure 10. Map of sample sites for seasonal monitoring of urban runoff.

[2] Site identification codes follow those used in Cheung 2003, listed in order from upstream to downstream.

II.B RESULTS AND DISCUSSION

II.B1 Comparison of fecal coliform data with water quality standards

Appendix E contains the raw water quality data collected for this study. Running geometric means of fecal coliform concentrations were calculated for each site sampled in the summer of 2006, and are displayed in Figures 11-12 (LCR mainstem and Habgood outfalls) and 15-16 (McNalley Creek and marine outfalls), along with the provincially approved water quality guideline for fecal coliform in waters used for primary contact recreation (200 cfu/100mL). FC loadings were also calculated for each site sampled in summer of 2006, and are displayed on a logarithmic scale in Figures 13-14 and 17-18. Appendix C contains example depth-flow profiles for the in-stream sample sites as well as discharge calculations for stormwater outfall sample sites; these were used to calculate loading.

The highest FC concentrations recorded during the 2006/07 urban runoff monitoring program were from the two Habgood outfalls (30 and 31). Throughout the study period, all of the FC geometric means at the Habgood outfalls, the marine outfall at Finlay Street (28/28.10) and McNalley Creek at the mouth (31.10) exceeded the 200 cfu/100mL primary contact recreational use guideline, ranging from 216 to 3068 CFU/100mL. The lowest FC concentrations and loadings were in the upstream eastern outfall into McNalley Creek at 10th Avenue (31.30-E1) and the Little Campbell River near Stayte Road (29.30).

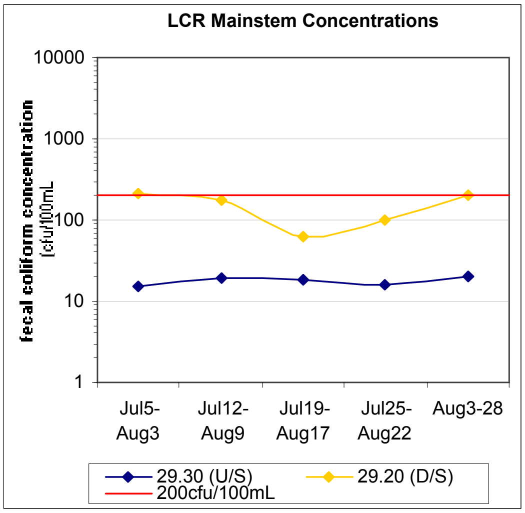

Figure 11. Geometric means of fecal coliform concentrations from July 5 to August 28, 2006, in the Little Campbell River mainstem, at Stayte Road (29.30) and downstream of the Habgood outfalls (29.20).

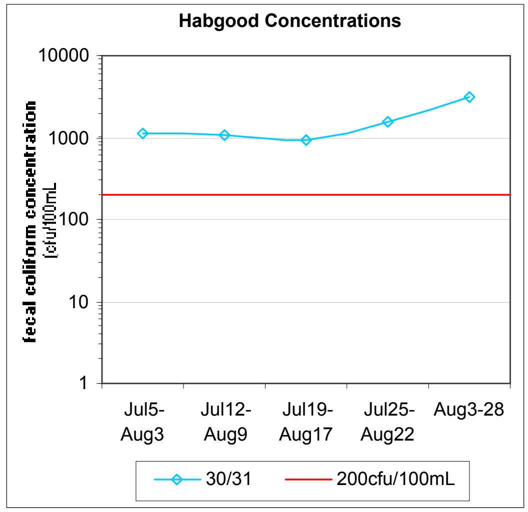

Figure 12. Geometric means of fecal coliform concentrations from July 5 to August 28, 2006, from the upper and lower Habgood outfalls (30/31).

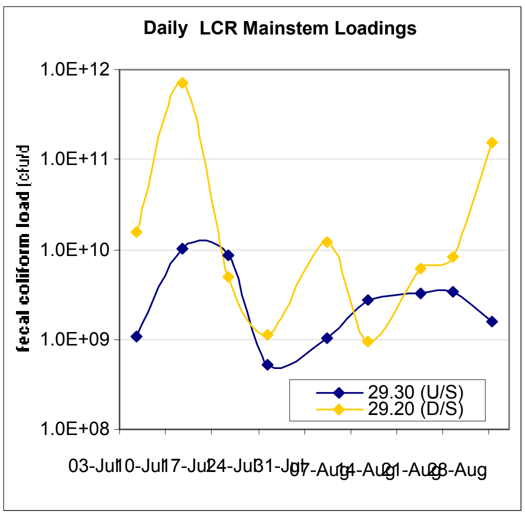

Figure 13. Daily fecal coliform loading from July 5 to August 28, 2006, in the Little Campbell River mainstem, at Stayte Road (29.30) and downstream of the Habgood outfalls (29.20).

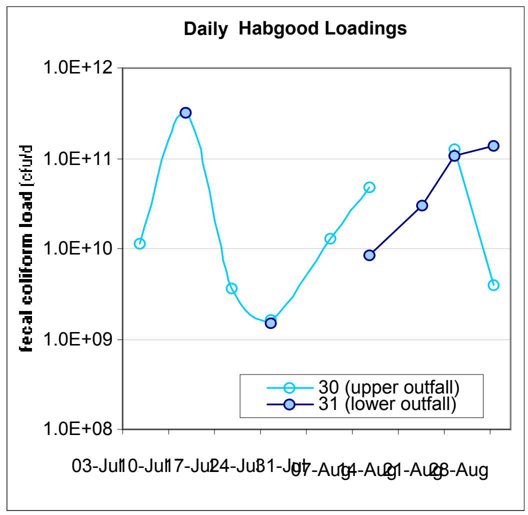

Figure 14. Daily fecal coliform loading from July 5 to August 28, 2006, from the upper and lower Habgood outfalls (30/31).

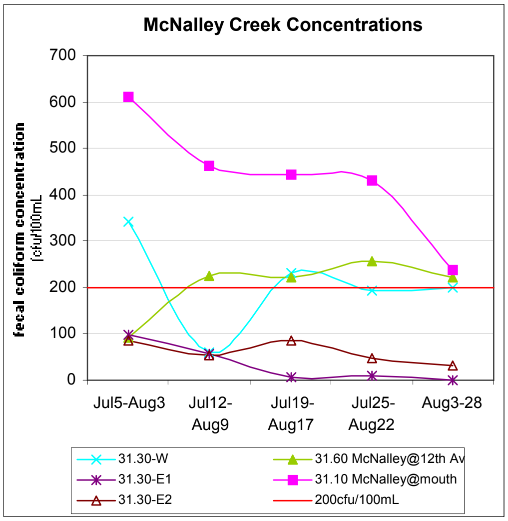

Figure 15. Geometric means of fecal coliform concentrations from July 5 to August 28, 2006, in McNalley Creek at 12th Avenue (31.60), at the mouth (31.10), and from three outfalls emptying into McNalley Creek at 10th Avenue (31.30-W, 31.30-E1, 31.30-E2).

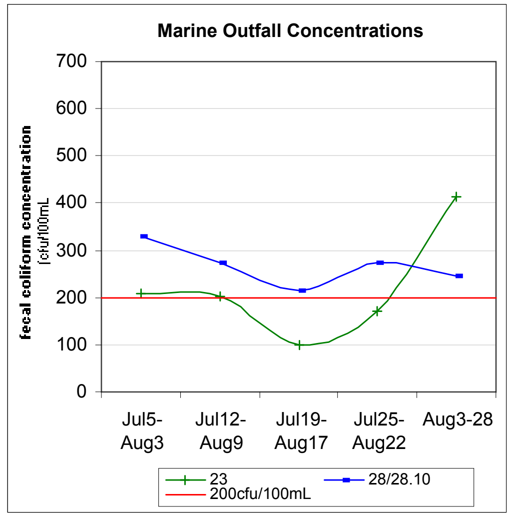

Figure 16. Geometric means of fecal coliform concentrations from July 5 to August 28, 2006, from marine outfalls at Oxford Street (23) and Finlay Street (28/28.1).

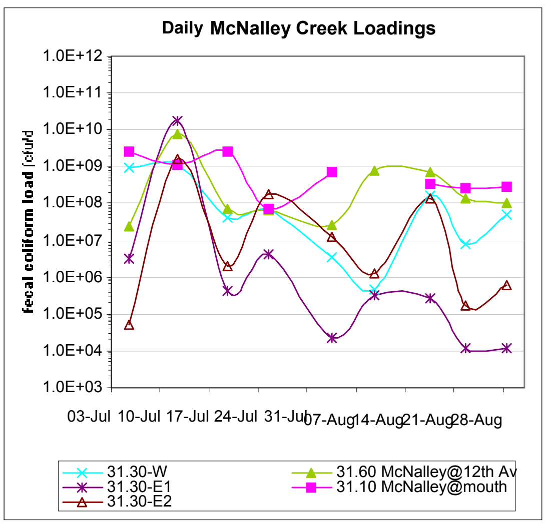

Figure 17. Daily fecal coliform loadings from July 5 to August 28, 2006, in McNalley Creek at 12th Avenue (31.60), at the mouth (31.10), and from three outfalls emptying into McNalley Creek at 10th Avenue (31.30-W, 31.30-E1, 31.30-E2).

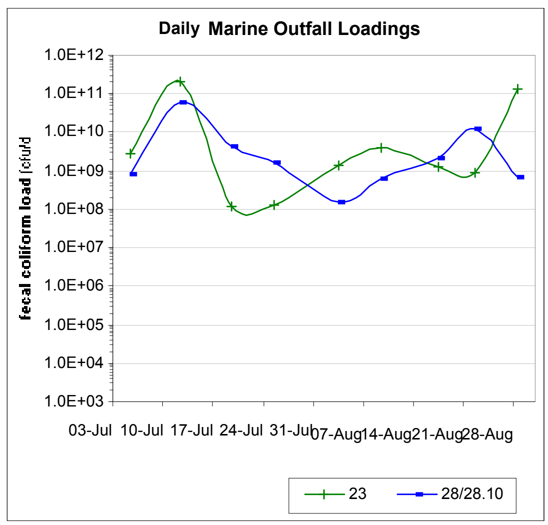

Figure 18. Daily fecal coliform loadings from July 5 to August 28, 2006, from marine outfalls at Oxford Street (23) and Finlay Street (28/28.1).

II.B2 Analysis of fecal coliform data from urban runoff sources by season

Two urban runoff sources were examined in this study to determine their relative contribution of FC contamination to the LCR mainstem during summer and winter seasons: McNalley Creek and the stormwater outfalls at Habgood Street. The Habgood outfalls drain approximately 1.4 ha of urban area within the City of White Rock and McNalley Creek drains approximately 20.5 ha of urban area within the City of White Rock and the City of Surrey. Although the Habgood outfalls drain a relatively small area, the mean seasonal discharge was estimated to be four times that of McNalley Creek in summer and twice the discharge in winter (See Section 1.3 Limitations of Data, for details on Habgood outfall discharge estimations).

Figure 19 shows the estimated relative contribution of discharge and FC loading for the Habgood outfalls and McNalley Creek as they compare with the LCR mainstem near the mouth, during summer and winter sampling periods. The Habgood outfalls' mean FC loading in summer contributed ~60% of the mean FC loading calculated in the LCR mainstem near the mouth and only about 12% of the discharge. The FC load contribution of McNalley Creek was much less at an estimated 1% of the total FC load in the LCR mainstem and about 3% of the discharge.

During the winter, the relative contribution of the Habgood outfalls was less (~20%) than the summer, whereas McNalley Creek contributed approximately the same in both seasons (~1%). This indicates that although these urban runoff sources continue to release high levels of FC contamination year-round, there are additional FC sources that are contributing to the overall FC load in the LCR mainstem under wet conditions. Higher flow conditions allow pathogens and other pollutants to be transported quickly downstream, so that contamination sources in the upstream portions of the watershed have greater potential to reach the river mouth and the receiving waters of Semiahmoo and Boundary bays.

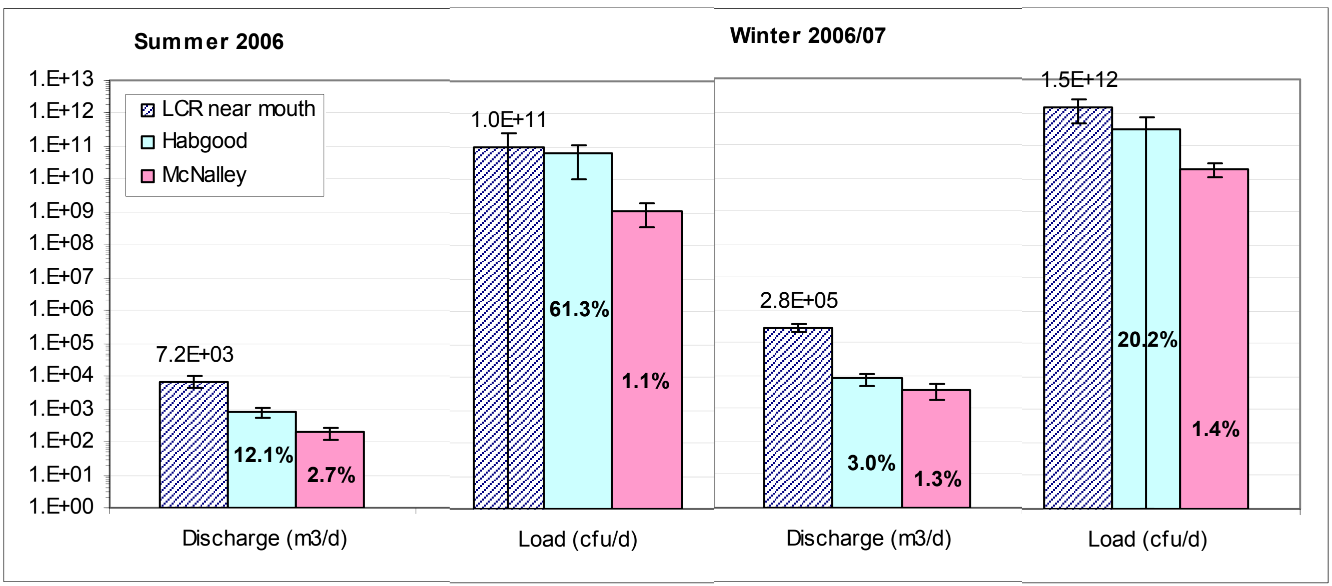

Figure 19. Estimated relative seasonal mean discharge and fecal coliform load data from the Habgood outfalls and McNalley Cr. compared with the Little Campbell River mainstem near the mouth, during summer and winter sampling periods. Error bars indicate 95% confidence interval (2 standard errors) about the mean.

FC concentrations and loadings at both McNalley Creek and the Habgood outfalls were compared to determine if there were significant differences between summer and winter data. Winter FC concentrations at both sites were not found to be significantly different from summer concentrations and continued to exceed the 200 CFU/100mL guideline for recreational use throughout the winter (Figure 20 and 22). Statistical analyses are included in Appendix F. Geometric means ranged from 202 to 695

CFU/100mL at McNalley and 805 to 3068 CFU/100mL at Habgood. This indicates that urban runoff sources are contributing bacterial contamination to the LCR watershed throughout the year, not only during the summer months.

For the Habgood outfall, there appeared to be a general decrease in FC concentration during the winter sampling period (Figure 22), despite no significant difference, with the exception of one outlier in January, which was linked with a large rain event (63mm of 48hr antecedent precipitation). This decrease in concentration was likely due to dilution effects from increased discharge during the winter; loading remained fairly consistent between seasons (Figure 23).

For McNalley Creek, FC loading was found to be significantly greater during the winter sampling period (Figure 21, Table 12). This indicates the increased precipitation and corresponding discharge in the creek during winter months.

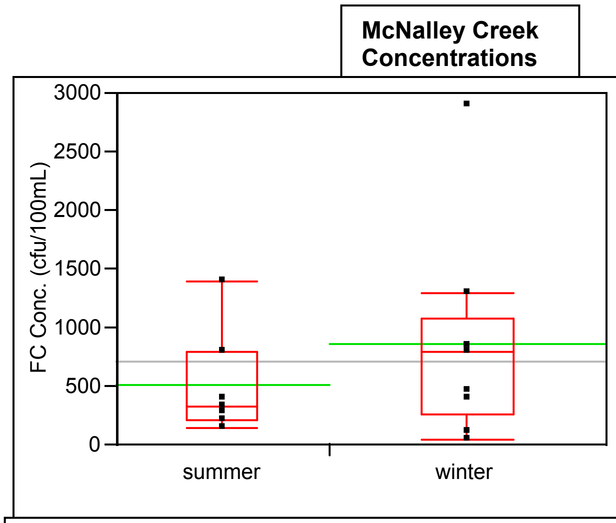

Figure 20. Boxplot showing fecal coliform concentrations from McNalley Creek at the mouth (31.10), sampled during summer 2006 and winter 2006/07. Concentrations during summer and winter do not differ significantly ($t_{0.05,14}$=-0.516, p=0.6136). Red boxes show the median, 25% and 75%. Red lines represent 10% and 90%. Green lines show means. Black dots show individual data points.

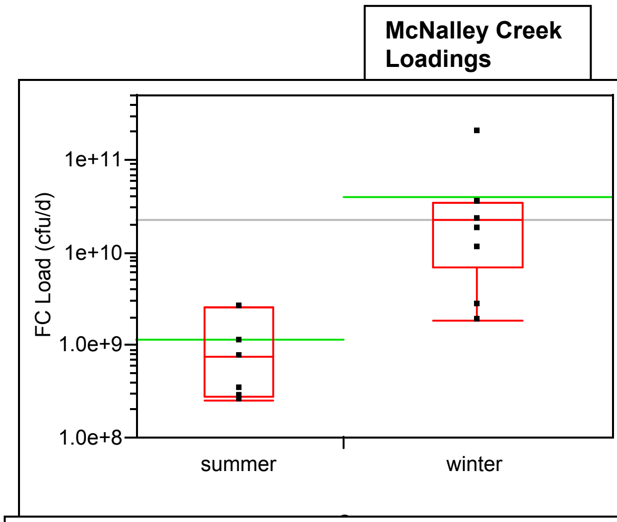

Figure 21. Boxplot showing fecal coliform loadings from McNalley Creek at the mouth (31.10), sampled during summer 2006 and winter 2006/07. Loading during winter was found to be significantly greater than loading during summer ($t_{0.05,14}$=-4.99, p=0.0002). Red boxes show the median, 25% and 75%. Red lines represent 10% and 90%. Green lines show means. Black dots show individual data points.

Table 11. Descriptive statistics for fecal coliform concentration data sampled at the mouth of McNalley Creek during summer 2006 and winter 2006/07.

Season	Summer 2006	Winter 2006/07
n	7	9
Mean	505.71	856.44
Std. Dev.	448.40	862.67
Std. Error	169.48	287.56
Lower 95%	91.01	193.34
Upper 95%	920.4	1519.6
Range	140 – 1400	48 – 2900

Table 12. Descriptive statistics for fecal coliform loading data sampled at the mouth of McNalley Creek during summer 2006 and winter 2006/07.

Season	Summer 2006	Winter 2006/07
n	7	9
Mean	1.13e+9	4.01e+10
Std. Dev.	1.05e+9	6.14e+10
Std. Error	3.97e+8	2.05e+10
Lower 95%	1.58e+8	-7.13e+9
Upper 95%	2.10e+9	8.72e+10
Range	2.5e+8 – 2.6e+9	1.8e+9 – 2e+11

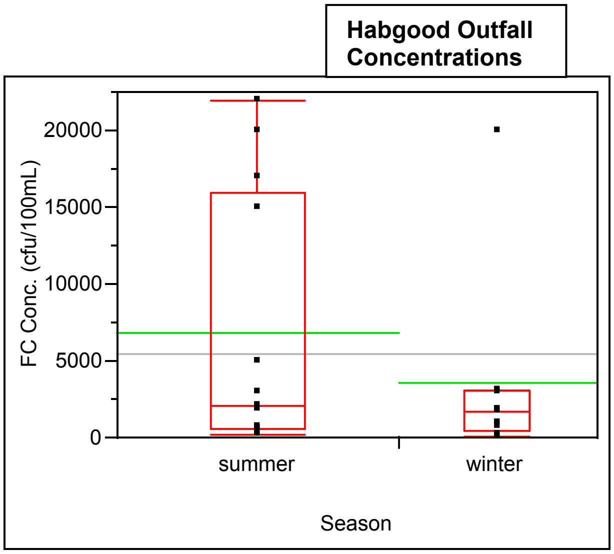

Figure 22. Boxplot showing fecal coliform concentrations from Habgood stormwater outfall (30/31), sampled during summer 2006 and winter 2006/07. Concentrations during summer and winter do not differ significantly ($t_{0.05,20}$=1.031, p=0.3149). Red boxes show the median, 25% and 75%. Red lines represent 10% and 90%. Green lines show means. Black dots show individual data points.

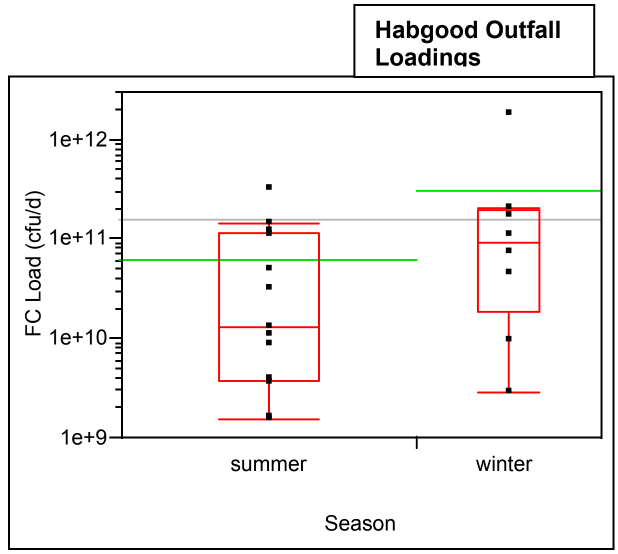

Figure 23. Boxplot showing fecal coliform loadings from Habgood stormwater outfall (30/31), sampled during summer 2006 and winter 2006/07. Loadings during summer and winter do not differ significantly ($t_{0.05,19}$=-1.583, p=0.1298). Red boxes show the median, 25% and 75%. Red lines represent 10% and 90%. Green lines show means. Black dots show individual data points.

Table 13. Descriptive statistics for fecal coliform concentration data sampled at Habgood stormwater outfall during summer 2006 and winter 2006/07.

Season	Summer 2006	Winter 2006/07
n	13	9
Mean	6,773.08	3,500.67
Std. Dev.	8,383.7	6,284.3
Std. Error	2,325.2	2,094.8
Lower 95%	1707	-1330
Upper 95%	11839	8331
Range	240 – 22,000	26 – 20,000

Table 14. Descriptive statistics for fecal coliform loading data sampled at Habgood stormwater outfall during summer 2006 and winter 2006/07.

Season	Summer 2006	Winter 2006/07
n	13	8
Mean	6.25e+10	3.01e+11
Std. Dev.	9.19e+10	6.10e+11
Std. Error	2.55e+10	2.16e+11
Lower 95%	6.92e+9	-2.08e+11
Upper 95%	1.18e+11	8.11e+11
Range	1.5e+9 – 3.2e+11	2.9e+9 – 1.8e+12

To further examine the contribution of the Habgood outfalls on LCR mainstem water quality, FC concentrations were compared between the two sample sites on the Little Campbell River mainstem, one at Stayte Road, upstream of the Habgood outfalls (29.30) and one near the mouth, downstream of the Habgood outfalls (29.20). The sampling site in the LCR downstream of the Habgood outfalls (29.20) had significantly higher FC concentrations than the sampling site in the LCR at Stayte Road (Figure 24; Table 15, Appendix F). Since these two sampling sites are in close proximity to each other (within 250 meters), and the only consistent discharge of urban stormwater between them is the Habgood outfalls, this confirms that the contribution of fecal contamination to the LCR from Habgood is significant.

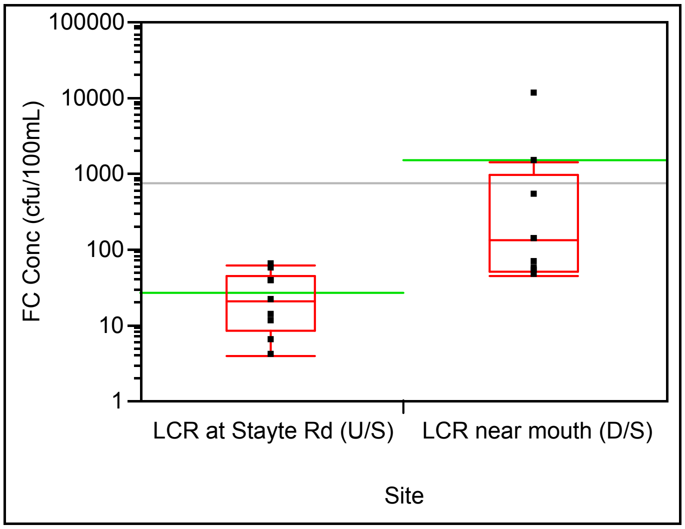

Figure 24. Boxplot of fecal coliform concentrations at sampling sites in the LCR downstream of the Habgood outfalls (29.20) and at Stayte Road (29.30), upstream of the Habgood outfalls. Concentrations were significantly greater in the LCR mainstem downstream of the Habgood outfalls, ($t_{0.05,8}$=-4.025, p=0.0038); Red boxes show the median, 25% and 75%. Red lines represent 10% and 90%. Green lines show means. Black dots show individual data points.

Table 15. Descriptive statistics for fecal coliform concentration data sampled from two LCR mainstem sites.

Site	LCR d/s of Habgood 29.20	LCR at Stayte Rd 29.30
n	9	9
Mean	1485.78	27.00
Median	130	20
Std. Dev.	3594.92	21.23
Std. Err.	1198.3	7.1
Lower 95%	-1278	11
Upper 95%	4249.1	43.3
Range	43 - 11000	4 - 62

II.B3 Comparison between stormwater outfall sources entering McNalley Creek

FC concentrations from the three outfalls into McNalley Creek at 10th Avenue (31.30-W, 31.30-E1 and 31.30-E2) were also compared. The comparison between the mean FC concentrations of the three outfalls in McNalley Creek at 10th Avenue showed a significant difference between the sites (Figure 25; Table 16). Tukey multiple comparison analyses found that the western outfall (31.30-W) was significantly greater than 31.30-E1. A summary of the statistical analysis results is included in Appendix F. The western outfall showed very high variability (Table 16), indicating the occurrence of episodic events with very high FC concentrations entering McNalley Creek from the west.

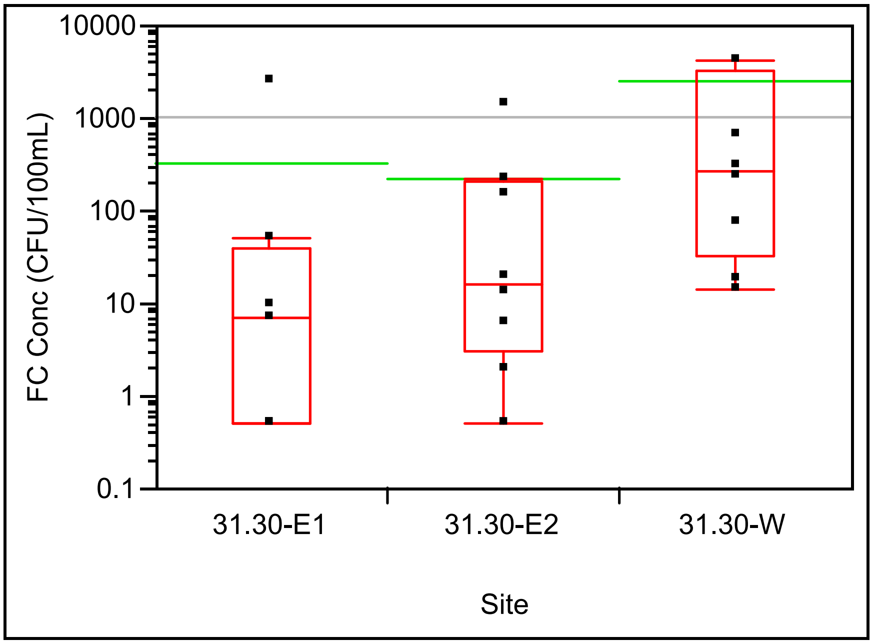

Figure 25. Boxplot showing fecal coliform concentrations from three storm sewer outfalls entering McNalley Creek at 10th Avenue (31.30-E1, 31.30-E2 and 31.30-W), during July and August of 2006. Concentrations at the western outfall (31.30-W) were significantly greater than those at the eastern upstream outfall (31.30-E1) ($F_{0.05,2}$=3.846, p=0.047). Red boxes show the median, 25% and 75%. Red lines represent 10% and 90%. Green lines show means. Black dots show individual data points.

Table 16. Descriptive statistics for fecal coliform concentration data sampled at three outfalls entering McNalley Creek at 10th Avenue.

Site	31.30-E1	31.30-E2	31.30-W
n	8	8	8
Mean	334.44	226.44	2551.00
Median	7	16.5	270
Std. Dev.	915.57	481.27	5214.54
Std. Err.	323.7	170.2	1843.6
Lower 95%	-431	-176	-1808
Upper 95%	1099.9	628.8	6910.5
Range	<1 - 2600	<1 - 1400	14 - 15000

II.B4 Comparison of urban runoff sources between 1999 and 2006

Two comparisons were made between FC concentration data collected in the summer of 1999, recorded in Cheung 2003, and data collected in the summer of 2006: (1) Habgood outfall data, and (2) Marine outfall data at Finlay Street and Oxford Street (Figures 26-28 and Tables 17-19). For the marine outfalls, samples were collected once every two weeks in July and August in 1999, and once every week in 2006. The two years were compared, even though sampling in 1999 took place at high tide, while sampling in 2006 took place at low tide; thereby creating inherent uncertainty in the results.

Both upper and lower Habgood outfalls were sampled separately as two different sample sites; however, it was determined during the study period that both outfalls originated from the same source (pump station) and drained the same catchment area (K. Pollard, personal communication, 2006). FC concentration data from both upper and lower outfalls were compared using 1999 and 2006 data, and the data were not significantly different (1999: $t_{0.05,69}$=0.074, p=0.941; 2006: $t_{0.05,19}$=0.601, p=0.555). Based on these comparison results, data from the two outfalls were pooled as though from one sample site for statistical analysis.

The mean FC concentration from the Habgood outfalls and the marine outfalls were not significantly different between 1999 and 2006, even though mean FC concentration was higher in 2006. This is despite infrastructure improvements to the storm sewer outfall system around Habgood. In her report for Environment Canada in 2003, Cheung noted that "fecal coliform counts at outfall stations #30 and #31 clearly far surpass those recorded at other freshwater sites in this project." This continues to be true in 2006.

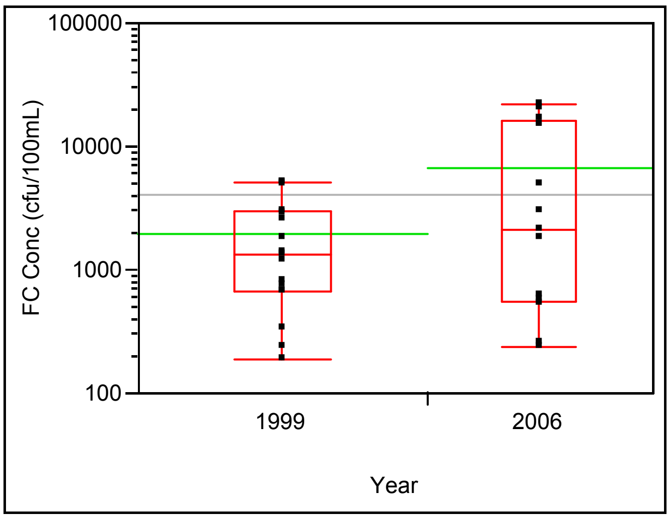

Figure 26. Boxplot of mean of fecal coliform concentration from Habgood outfalls in July and August of 1999 and 2006. Mean fecal coliform concentrations were not significantly different between the two years ($t_{0.05,28}$=-1.280, p=0.211). Red boxes show the median, 25% and 75%. Red lines represent 10% and 90%. Green lines show means. Black points show individual data points.

Table 17. Descriptive statistics for fecal coliform concentration data sampled at Habgood outfalls during the summers of 1999 and 2006.

Year	1999	2006
n	17	13
Mean	1948.24	6773.08
Median	1355	2100
Std. Dev.	1723.16	8383.72
Std. Err.	417.9	2325.2
Lower 95%	1062.3	1062.3
Upper 95%	2834	11839
Range	190 - 5200	240 - 22000

There was no significant difference in FC concentrations at either of the marine outfalls between the summers of 1999 and 2006; however, there does appear to be a trend towards a decrease in contamination from 1999 to 2006 at the Finlay Street sampling site. This may be due to the installation of the siphon in 2001, which aids in transporting sewage from the east side of White Rock at Finlay Street to the sanitary pump station at Oxford Street, and ultimately to the GVRD sewage treatment plant on Annacis Island. Drainage system upgrades at that time also split the previous Finlay outfall into two outfalls, and in 2006, samples were only collected at the western outfall. Essentially, this means that the samples collected in 2006 were from half the catchment area drained by the outfall sampled in 1999. Therefore, the trend seen in the Finlay Street outfall data may simply be an artifact of infrastructure changes between sampling dates. Also, in 1999 both marine outfalls were sampled at high tide, while sampling in 2006 took place at low tide. Consequently, the samples collected in 1999 would have been more diluted than the 2006 samples. The 1999 samples would also have been more saline, and salinity is typically found to be inversely correlated with fecal coliform density (Mallin *et al*. 2000). This suggests that the concentrations of fecal coliforms in the 1999 samples may have been under-reported as compared to the 2006 samples.

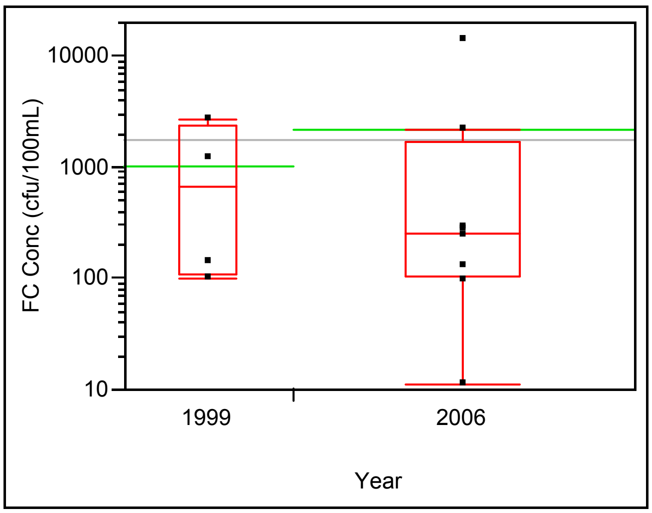

Figure 27. Boxplot of fecal coliform concentration from Oxford Street marine outfall (23) in July and August of 1999 and 2006. Mean fecal coliform concentrations were not significantly different between the two years ($t_{0.05,10}$=0.333, p=0.7459). Red boxes show the median, 25% and 75%. Red lines represent 10% and 90%. Green lines show means. Black points show individual data points.

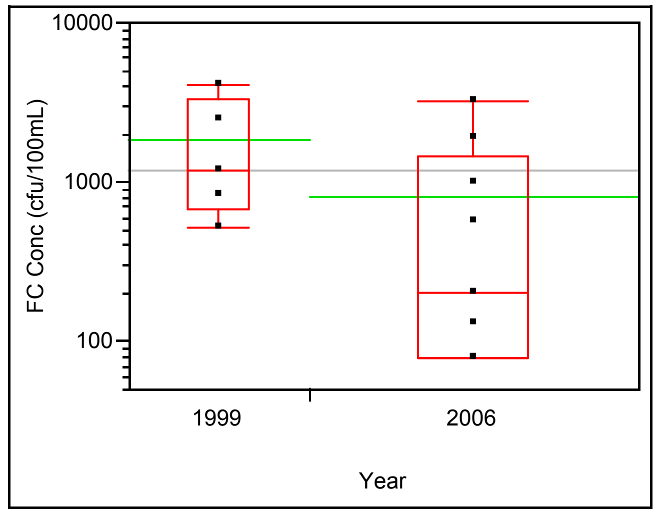

Figure 28. Boxplot of fecal coliform concentration from Finlay Street marine outfall (28/28.10) in July and August of 1999 and 2006. Mean fecal coliform concentrations were not significantly different between the two years ($t_{0.05,12}$=2.013, p=0.0671). Red boxes show the median, 25% and 75%. Red lines represent 10% and 90%. Green lines show means. Black points show individual data points.

Table 18. Descriptive statistics for fecal coliform concentration data sampled from the marine outfall at Oxford Street during the summers of 1999 and 2006.

Year	1999	2006
n	4	8
Mean	1035.00	2154.75
Median	670	255
Std. Dev.	1221.30	4839.38
Std. Err.	610.6	1711.0
Lower 95%	-908	-1891
Upper 95%	2978.4	6200.6
Range	100 - 2700	11 - 14000

Table 19. Descriptive statistics for fecal coliform concentration data sampled from the marine outfall at Finlay Street during the summers of 1999 and 2006.

Year	1999	2006
n	5	9
Mean	1825.00	804.22
Median	1200	200
Std. Dev.	1475.01	1085.69
Std. Err.	659.64	361.90
Lower 95%	-6.46	-30.31
Upper 95%	3656.5	1638.8
Range	515 - 4090	79 - 3200

II.B5 Relationship of fecal coliform data with precipitation

During the summer sampling period (July 5 – August 28, 2006) there was very little precipitation. Two small events (<10 mm) were captured the samples: July 11-12 and August 8-10. Figures 29-33 show FC concentrations for each sample site, along with precipitation data collected at the Semiahmoo Fish and Game Club (12th Ave and 184th St) near the centre of the LCR watershed.

During the summer, FC data reached high levels despite very low precipitation, indicating that not all urban FC sources are precipitation-driven. Figure 31 shows the precipitation data and FC concentrations from McNalley Creek and the stormwater outfalls at Habgood Street during the winter sampling period. It appears that FC levels from the Habgood outfall increased with increased precipitation, while those from McNalley Creek did not. This may indicate that FC sources from the Habgood outfall are more consistent and not as readily diluted as those from McNalley Creek.

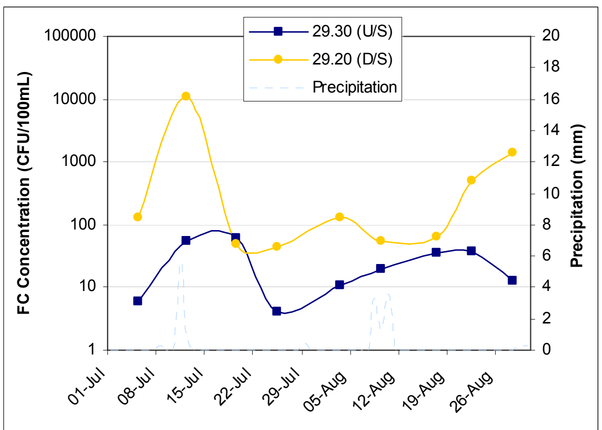

Figure 29. Precipitation data and daily fecal coliform concentrations from July 5 to August 28, 2006, in the Little Campbell River mainstem, at Stayte Road (29.30) and downstream of the Habgood outfalls (29.20).

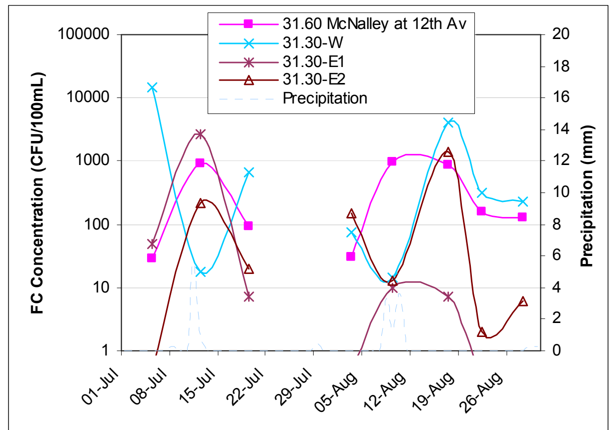

Figure 30. Precipitation data and daily fecal coliform concentrations from July 5 to August 28, 2006, in McNalley Creek at 12th Avenue (31.60), and from three outfalls emptying into McNalley Creek at 10th Avenue (31.30-W, 31.30-E1, 31.30-E2).

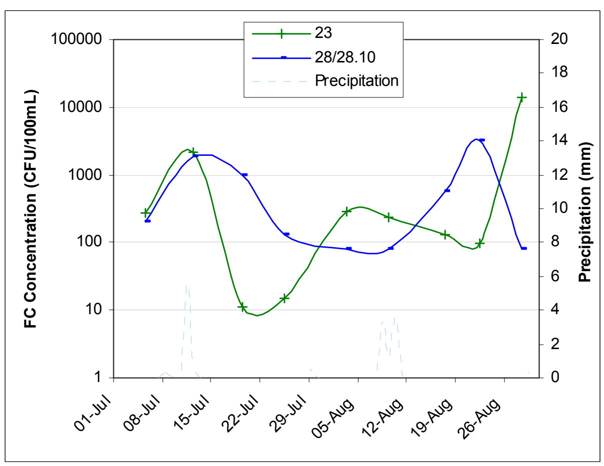

Figure 31. Precipitation data and daily fecal coliform concentrations from July 5 to August 28, 2006, from marine outfalls at Oxford Street (23) and Finlay Street (28/28.1).

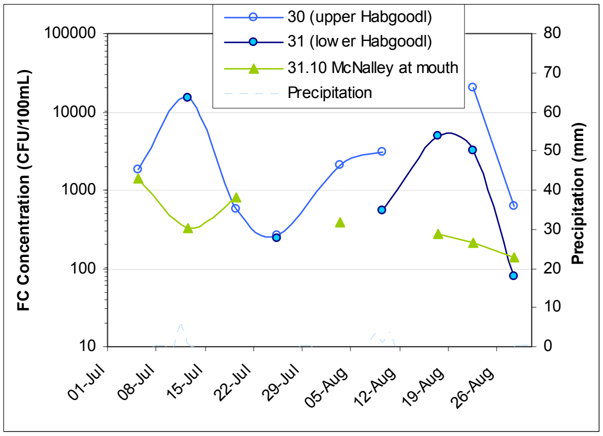

Figure 32. Precipitation data and daily fecal coliform concentrations from July 5 to August 28, 2006, from McNalley Creek at the mouth (31.10) and the Habgood outfalls (30/31).

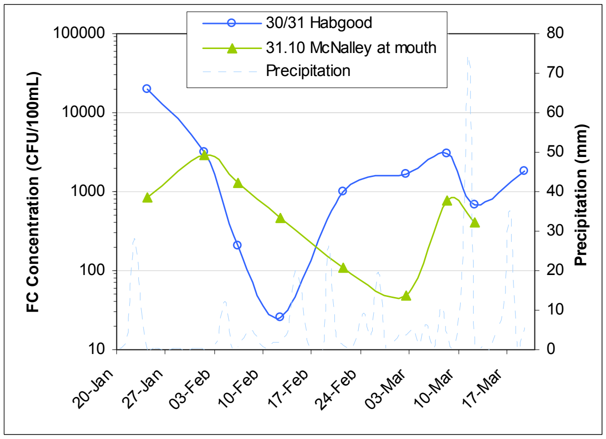

Figure 33. Precipitation data and daily fecal coliform concentrations from January 24 to March 19, 2007, from McNalley Creek at the mouth (31.10) and the Habgood outfalls (30/31).

II.C CONCLUSIONS

From the results of this component of the study, it was found that urban runoff sources do contribute significantly to elevated fecal coliform (FC) levels in the Little Campbell River (LCR) mainstem during summer months and continue to contribute during the winter as well.

Of particular concern is the stormwater outfall at Habgood Street where the highest FC concentrations and loadings were recorded, reaching a maximum of 22,000 CFU/100mL and contributing approximately 60% of the total FC load in the LCR mainstem near the mouth during the summer. FC concentrations exceeded the B.C. approved water quality guideline for recreational use (200 CFU/100mL) throughout the summer and winter sampling periods, with geometric means ranging from 805 to 3068 CFU/100mL.

During the winter, the relative contribution of Habgood to the total FC load in the LCR mainstem was less than the summer (~20%), but still significant, considering that it only contributes approximately 3% of the total discharge. The decrease in FC load contribution during winter indicates that additional sources that are contributing to the overall FC load in the LCR mainstem under wet conditions.

McNalley Creek also consistently exceeded the B.C. water quality guideline for recreational use throughout the summer and winter sampling periods, with geometric means ranging from 202 to 695 CFU/100mL. The relative contribution of McNalley Creek to the total FC load in the LCR mainstem was less than the Habgood outfall and more reasonable considering relative discharge (~1% of FC load and ~1-3% of discharge).

Stormwater input into McNalley Creek from the outfalls at 10th Avenue showed variable FC results. The western outfall (31.30-W) showed the highest FC concentrations, reaching 15,000 CFU/100mL. These events were episodic but not linked with precipitation, indicating that these FC sources were not necessarily transported via overland runoff, but may have originated from alternate sources, such as direct deposition of fecal matter (domestic pets/wildlife), or contaminated sediments within the storm sewer system.

Despite recent sanitary sewer and storm sewer infrastructure upgrades, there has been no significant improvement in FC levels from the marine outfalls at Oxford and Finlay Streets or from the stormwater outfall at Habgood Street since previous sampling in 1999. Both marine outfalls released high concentrations of FC into Semiahmoo Bay during the summer of 2006, ranging from 11 to 14,000 CFU/100mL. The marine outfall at Finlay Street was in exceedence of the B.C. water quality guideline for recreational use throughout the summer study period, with geometric means ranging from 216 to 330 CFU/100mL.

Little Campbell River Watershed Water Quality Monitoring:

Part 3: Agricultural Runoff – Fall 2006

Prepared by:
Christy Juteau
Ministry of Environment
Environmental Quality Section
2nd Floor, 10470 152 Street
Surrey, B.C.
V3R 0Y3
604-582-5200

June 2008

III.A SAMPLING DESIGN

Historic fecal coliform (FC) monitoring data from the Little Campbell River (LCR) watershed indicated a high frequency of outliers during October/November as well as March/April. It was suspected that these outliers were due to episodic events of contaminated runoff entering the LCR, likely corresponding with precipitation events. Agricultural runoff was thought to be a potential source of this contaminated runoff. It was suspected that contaminated runoff from agricultural sources would mainly be due to livestock density and manure handling practices (application and storage). It was expected that as livestock density increased past a threshold, the amount of manure production would result in increased probability of fecal pollution release from those operations.

Based on this background information, the monitoring program for fall 2006 was designed to test the following provisional statement: **Agricultural waste (manure) runoff in sub-watersheds with a high density of agricultural land use is a significant contributor to high fecal loadings of the LCR during October/November and loading are strongly correlated with precipitation events.**

To assess the validity of this statement, FC levels from two local watersheds (delineated during the watershed characterization study of the LCR; Zevit *et al* 2008) within the LCR watershed were compared; one containing the greatest density of livestock in the watershed, particularly horses (LW-1), and the other containing little to no agricultural activity (LW-6). Additionally, FC levels were assessed in a tributary draining a feedlot operation (greatest density of bovines in the watershed). All three of these tributaries were assessed to determine their relative contributions to fecal loading in the LCR mainstem near the mouth.

Table 20 and Figure 34 show the four sample sites selected to test the validity of the above provisional statement. Water samples were collected weekly from October 10 to December 7, 2006 for FC bacteria, as well as pH, temperature, dissolved oxygen, specific conductivity and turbidity.

Table 20. Seasonal monitoring of agricultural runoff - sample site IDs, UTM coordinates and site descriptions.

Site ID[1]	UTM Zone 10 Easting	UTM Zone 10 Northing	Site Description
701-2 (LW-1)	526804	5429166	Tributary to LCR – Unnamed north @ 214th Street near mouth
147-1 (LW-6)	520162	5428861	Kuhn Creek near mouth, in golf course
146-2	518634	5428937	Tributary to LCR – draining feedlot
29.20	515888.8	5429181	LCR mainstem at bend near the mouth, downstream of Habgood outfall

[1] Site identification codes follow those used in Fleming and Quilty 2006, listed in order from upstream to downstream.

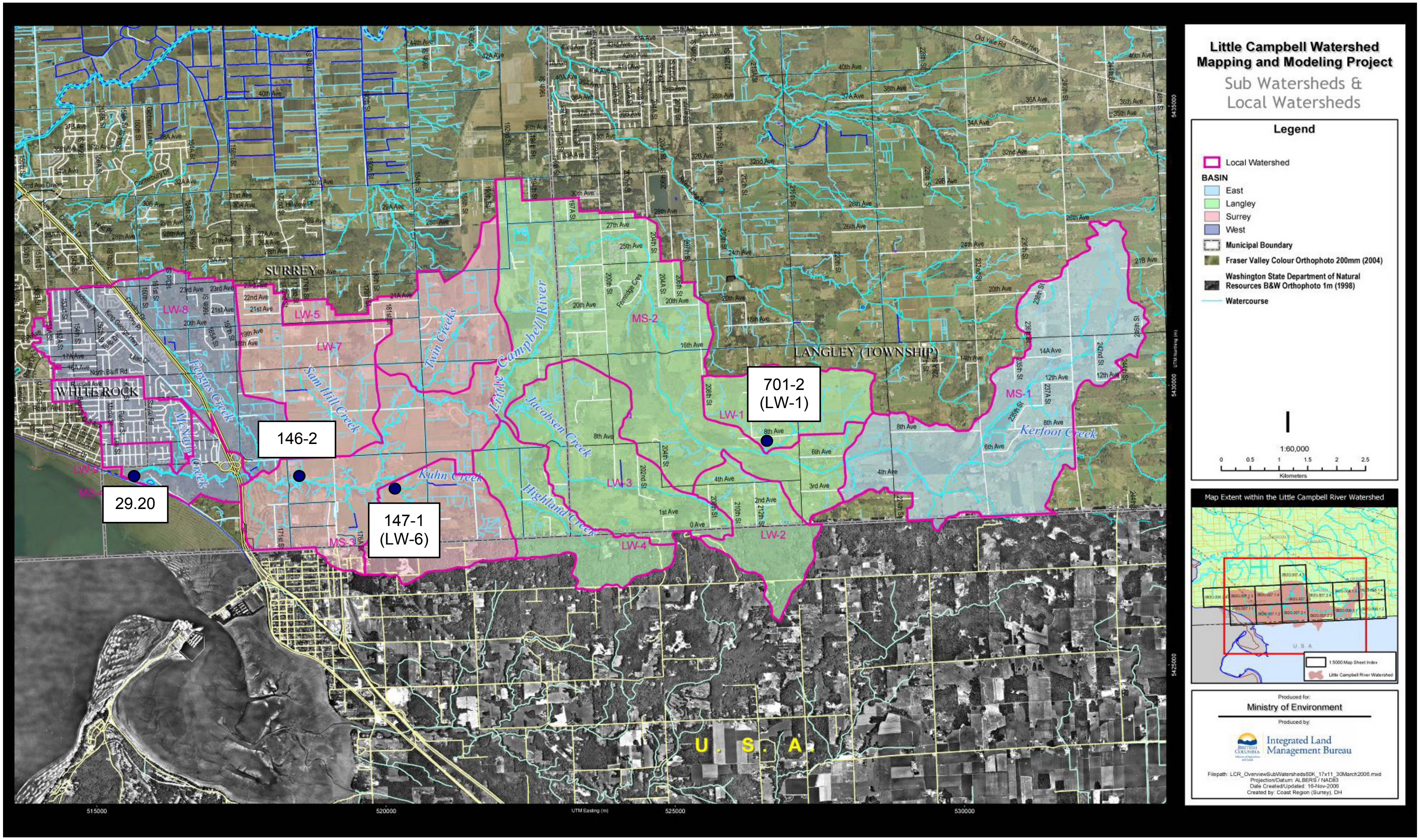

Figure 34. Map of sample sites for seasonal monitoring of agricultural runoff.

III.B RESULTS AND DISCUSSION

III.B1 Comparison of fecal coliform data with water quality standards

Appendix E contains all of the raw water quality data collected for this study. Running geometric means of FC concentrations were calculated for each of the three tributary sites sampled in the fall of 2006, and are displayed on a logarithmic scale in Figure 35. Also shown is the provincially approved water quality guideline for FC in waters used for primary contact recreation (200 CFU/100mL). The same guideline value is approved for general livestock use and for irrigation of produce that is typically eaten raw (MOE 2006).

It was found that during the fall study period, LW-1 (701-2), the sub-watershed with the greatest livestock density, consistently produced higher concentrations of FC bacteria than a similarly sized, non-agricultural sub-watershed (LW-6/147-1). Also, geometric means from LW-1 consistently exceeded the 200 CFU/100mL water quality guideline (ranging from 465 to 950 CFU/100mL), whereas the geometric means from LW-6 remained in attainment of the guideline throughout the study period.

Site 146-2, a tributary that drains a feedlot operation containing a very high density of bovines was found to have the greatest FC concentrations, with results up to 14,000 CFU/100mL and geometric means consistently exceeding the 200 CFU/100mL water quality guideline. Geometric means ranged from 1102 to 7972 CFU/100mL throughout the study period. Dissolved oxygen levels at this site were also found to be very low (minimum: 1.45 mg/L, mean: 5.69 mg/L), well below the B.C. water quality guidelines for aquatic life: 5.0 mg/L instantaneous minimum, and 8.0 mg/L 30-day average. Fish are unlikely to be present in this tributary; however, the impact of this contamination may reach the LCR mainstem.

Non-agricultural sources of FC (i.e. failing on-site sewage disposal systems, wildlife) could also contribute to the contamination found in these agricultural sub-watersheds; further sampling would be required to address the site-specific sources of FC contamination in this study area.

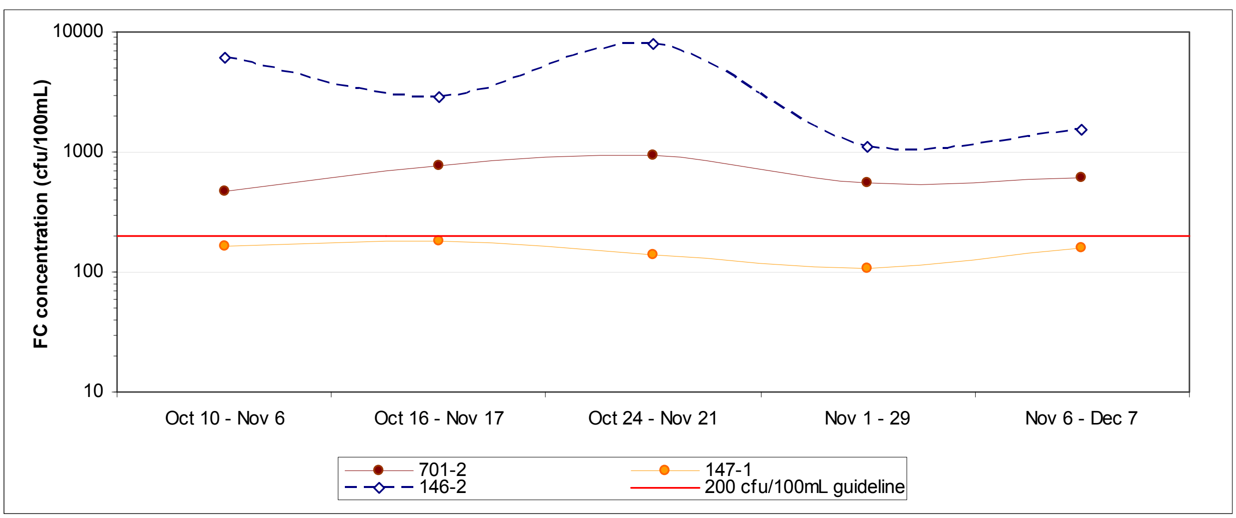

Figure 35. Geometric means of fecal coliform concentration from two tributaries draining areas with high-densities of livestock (701-2/LW-1 and 146-2) and one tributary draining a non-agricultural area (147-1/LW6).

III.B2 Analysis of fecal coliform data by livestock density

FC concentrations were compared between each of the three tributary sample sites (Figure 36, Table 21). It was found that there was evidence to detect a difference between the FC concentration means ($F_{0.05,2}$ = 4.3080, p = 0.0319). The Tukey multiple comparison test showed that there was no difference between the two agricultural sites (146-2 and LW-1), nor between LW-1 and LW-6, even though FC concentrations were consistently higher at LW-1. There was a significant difference found between 146-2, the feedlot tributary and LW-6, the non-agricultural sub-watershed. A summary of the statistical analysis results are found in Appendix F.

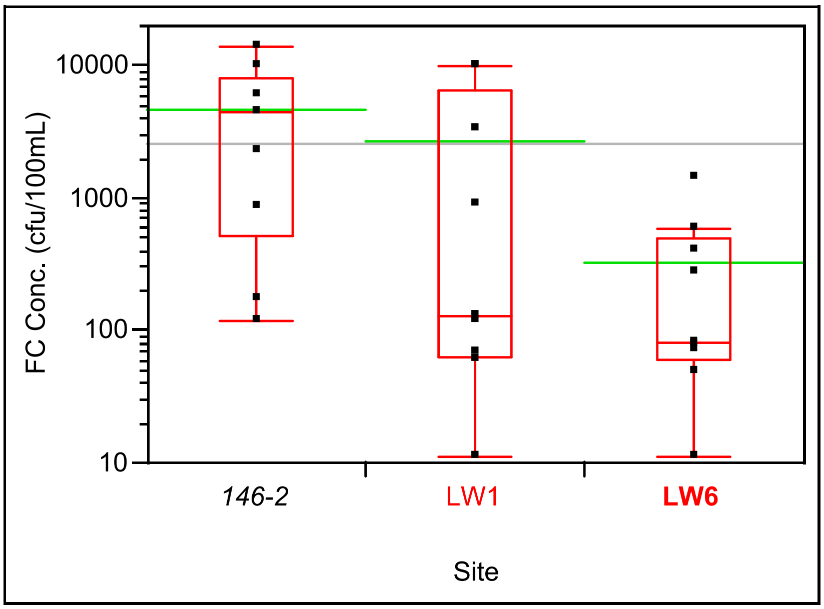

Figure 36. One-way analysis of fecal coliform concentration by site. Results from three tributaries within the Little Campbell River watershed (LW-1: dense agriculture, LW-6: very little agriculture, 146-2: feedlot), sampled October to December 2006. Red boxes show the median, 25% and 75%. Red lines represent 10% and 90%. Green lines show means. Black dots show individual data points.

Table 21. Descriptive statistics for fecal coliform concentration data sampled from three tributaries in the Little Campbell River watershed (LW-1: dense agriculture, LW-6: very little agriculture, 146-2: feedlot), sampled October to December 2006.

Site	LW-1	LW-6	146-2
n	9	9	9
Mean	2730.78	328.89	4716.67
Std. Dev.	4251.58	445.76	4721.63
Std. Error	1417.2	148.6	1573.9
Lower 95%	-537	-14	1087
Upper 95%	5998.8	671.5	8346.0
Range	11 – 10,000	11 – 1,400	120 – 14,000

Figure 37 shows the estimated relative contribution of each of the three tributary sample sites to discharge and FC load at site 29.20 (LCR mainstem near the mouth) during the fall sampling program. As pathogens are transported downstream, they can be removed from the water column due to decay or deposition. Pathogen decay rates are mainly driven by salinity, temperature, light exposure, turbidity and sedimentation (McCorquodale et al. 2004; Thomann and Mueller 1987; Mills et al. 1985). Appendix F contains the literature-derived equations that were used for this analysis.

Although LW-1 releases a greater concentration of FC to the LCR mainstem than LW-6 (non-agricultural), it appears that its location in the upper part of the watershed prevents it from contributing fecal load to the LCR mainstem near the mouth. The tributary draining the feedlot operation appeared to contribute the greatest amount of fecal load to the LCR near the mouth (an estimated 1.5% of total fecal load near the mouth). This was likely due to its close proximity to the mouth in addition to its high levels of FC. LW-6, the non-agricultural local watershed, contributed FC to the river mouth (an estimated 0.7% of the total fecal load), despite its compliance with the water quality guidelines for recreational use. This indicates the cumulative nature of pathogens as non-point source pollutants.

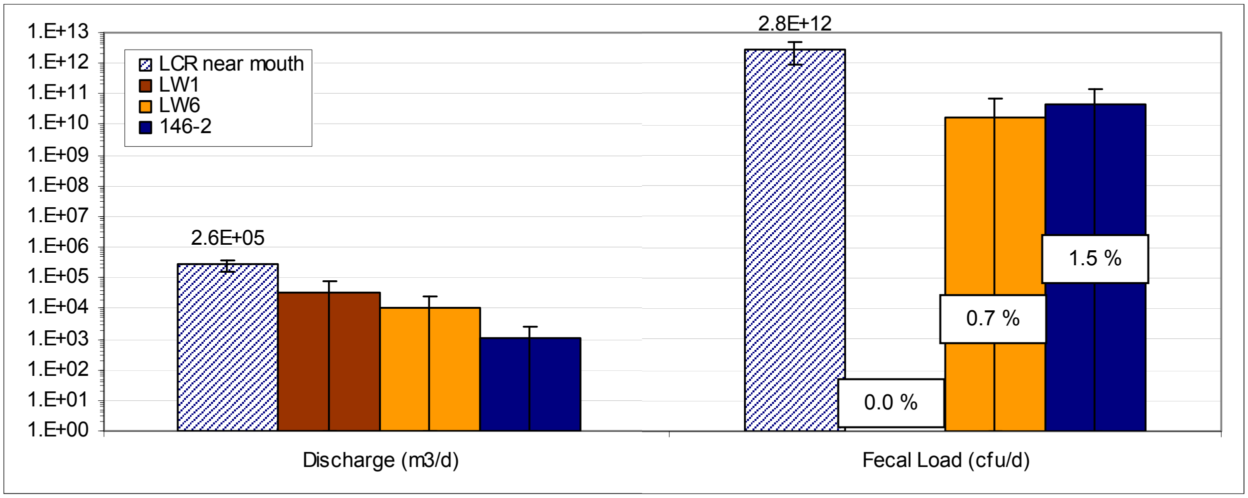

Figure 37. Estimated relative contributions of discharge and fecal coliform load from LW-1, LW-6 and 146-2 to the Little Campbell River mainstem near the mouth.

III.B3 Relationship of fecal coliform data with precipitation

It was expected that increased FC levels in agricultural runoff would be strongly linked with increased precipitation. Figure 38 shows the FC loadings at each sample site with daily precipitation. The relationships between FC concentrations and loadings with antecedent precipitation (24, 48, and 96 hours previous to sampling) were analysed for correlation using a scatterplot matrix (Figure 39). Correlation coefficients are indicated in bold to quantify the strength of these relationships. Correlation coefficients range between -1 and 1; a value of 1 or -1 represents a perfect linear (positive or negative) relationship, whereas a value of 0 represents no relationship.

FC concentrations at LW-1 showed a very strong positive relationship with antecedent precipitation (24, 48 and 96 hrs previous to sampling). This was expected in an agricultural area, indicating that precipitation washes exposed manures into nearby watercourses, thereby increasing FC with increased precipitation. Similar to LW-1, LW-6 showed a moderately strong positive relationship between FC concentration and antecedent precipitation. This indicates that the major sources of FC contamination in both sub-watersheds are likely mobilized via overland flow, which is driven by increased precipitation.

The feedlot tributary (146-2) showed a very different relationship (weakly negative) between FC concentration and precipitation. Examination of the scatterplot diagram shows very high FC concentrations with very little antecedent precipitation. This indicates that the source of FC may be directly entering the tributary, either continually or intermittently, without the assistance of increased precipitation and runoff. FC levels show a slight decrease corresponding with large precipitation events, indicating a dilution effect of precipitation, rather than a mobilization of nearby FC sources.

There was not a particular time-frame (24 hr, 48 hr or 96 hr) of antecedent precipitation that resulted in greater FC increase to the watercourse.

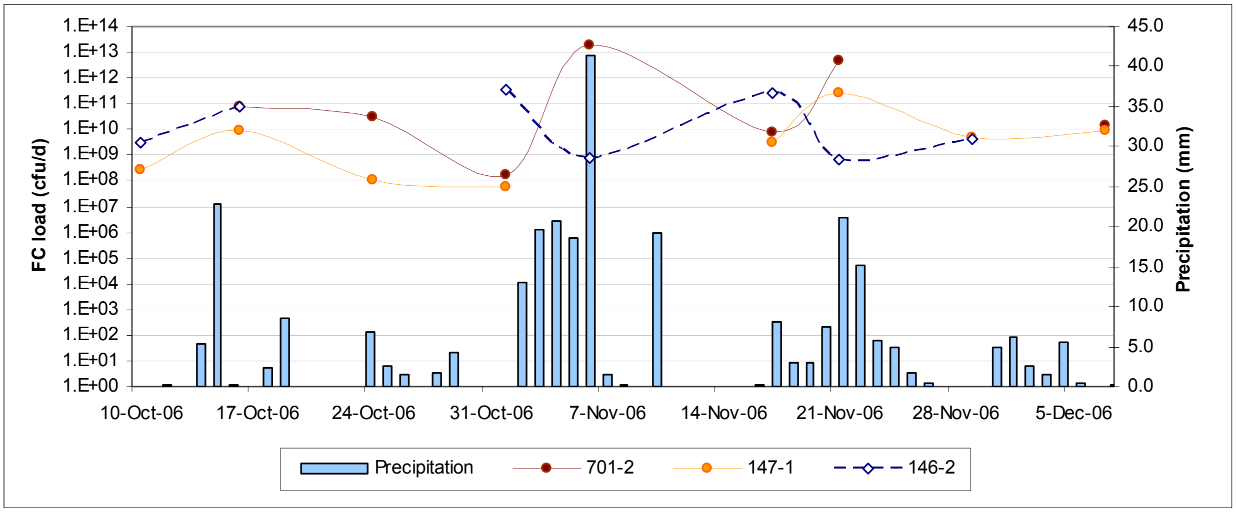

Figure 38. Daily fecal coliform loadings from two tributaries draining areas with high densities of livestock (701-2 and 146-2) and one tributary draining a non-agricultural area (147-1), showing daily precipitation.

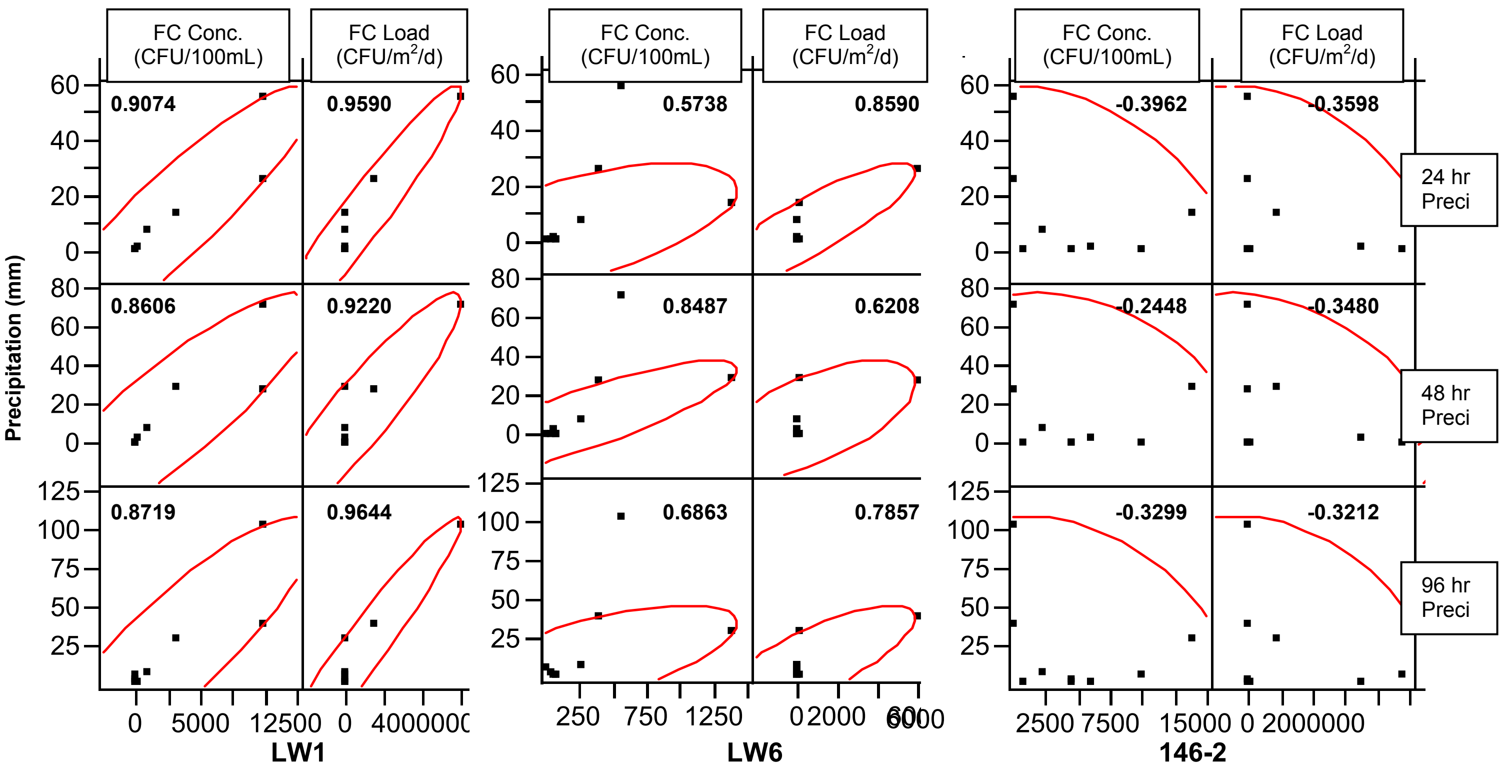

Figure 39. Scatterplot diagrams showing correlation between precipitation and fecal coliform concentration and loading. Results from three tributaries within the Little Campbell River watershed (LW1: high density agricultural, LW6: non-agricultural, 146-2: feedlot operation), sampled October – December 2006. Correlation coefficients are shown in bold for each scatterplot.

III.C CONCLUSIONS

As was expected, the analysis results showed an increased release of FC concentrations from two agricultural sub-watersheds containing a high density of livestock when compared with a non-agricultural sub-watershed. FC levels at the agricultural sites (LW-1 and 146-2) consistently exceeded the B.C. approved water quality guideline of 200 CFU/100mL for the protection of recreational use, general livestock use and irrigation of produce typically eaten raw (MOE 2006), while the non-agricultural site was in attainment of the guideline throughout the study period.

Despite high levels of FC originating from agricultural sub-watersheds, their relative contribution to the total FC load in the LCR mainstem near the mouth appears to be limited. FC released from LW-1 in the upper LCR watershed, did not reach the mouth of the river and the feedlot tributary contributed an estimated 1.5% of the total FC load. This indicates that FC contamination generated from agricultural runoff in the upper LCR watershed may have more localized effects. Although the upper watershed is not typically used for swimming and boating (primary contact recreation), it may be used for livestock watering and/or crop irrigation, which could be impacted by elevated FC levels.

FC concentrations at LW-1 showed a very strong positive relationship with antecedent precipitation (24, 48 and 96 hrs previous to sampling). This was expected in an agricultural area, indicating that precipitation washes exposed manures into nearby watercourses, thereby increasing FC with increased precipitation. The feedlot tributary (146-2) did not exhibit the same relationship; correlation of FC with antecedent precipitation was weakly negative. This indicates that the source of FC may be directly entering the tributary, either continually or intermittently, without the assistance of increased precipitation and runoff.

Non-agricultural sources of FC (i.e. failing on-site sewage disposal systems, wildlife) could also contribute to the contamination found in these agricultural sub-watersheds; further sampling would be required to address the site-specific sources of FC contamination in this study area.

Little Campbell River Watershed Water Quality Monitoring:

Part 4: On-site Sewage Disposal Systems – Winter 2006/07

Prepared by:
Christy Juteau
Ministry of Environment
Environmental Quality Section
2nd Floor, 10470 152 Street
Surrey, B.C.
V3R 0Y3
604-582-5200

June 2008

IV.A SAMPLING DESIGN

Historic monitoring data from the Little Campbell River (LCR) watershed indicated high fecal coliform (FC) loadings during the month of January. It was suspected that failing on-site sewage disposal systems (SDS) were releasing fecal pollution to the LCR, especially during the winter season when precipitation increases and water tables rise.

The purpose of this component of the LCR monitoring program was to test the validity of the following provisional statement: **Runoff from areas with a high density of on-site SDS is contributing to high fecal loadings in the LCR during January when water tables may be elevated enough to cause septic field failures.**

Since rural/agricultural areas are often serviced by on-site SDS, it is difficult to separate the relative contributions of fecal pollution from each potential source. A residential area in the central watershed, just downstream of Campbell Valley Regional Park, was identified where there is a high density of on-site SDS and no perceived agricultural activity. This area overlays well draining soils typically considered suitable for on-site sewage disposal systems (Zevit, et al., 2008), and the Brookswood aquifer. It was expected that, during the wet season, high water tables or rapid drainage rates, could result in fecal contamination, being transported to nearby surface waters of the LCR from failing on-site SDS.

Table 22 and Figure 40 show the three sample sites used to test the validity of the above provisional statement. Water samples were collected weekly during two sampling periods: **A)** October 24 to December 7, 2006 and **B)** January 24 to March 19, 2007, upstream and downstream of the identified residential area that was serviced by a high density of on-site SDS. During sampling period A, a portion of the LCR mainstem was found to be completely de-watered and therefore the upstream sample site was located further downstream (722-1). Surface flows resumed in the de-watered portion of the LCR mainstem after a heavy, sustained rain event from November 2 – 6 (113mm). During sampling period B, the upstream sample site was moved upstream (722-5) to capture a larger portion of the target sample area. The water samples were analyzed for FC bacteria, as well as pH, temperature, dissolved oxygen, specific conductivity and turbidity.

Table 22. Seasonal monitoring of runoff from an area with a high density of on-site sewage disposal systems - sample site IDs, UTM coordinates and site descriptions.

Site ID[1]	UTM Zone 10 Easting	UTM Zone 10 Northing	Site Description
722-5	524943	5432598	LCR mainstem at 24th Avenue and 204th Street, upstream crossing, downstream of bridge
722-1	523543	5432570	LCR mainstem at 24th Avenue and 19600 block, downstream crossing, downstream of bridge
722-2 (LCR at 16th Ave)	522849	5430957	LCR mainstem, upstream of hatchery at 16th Avenue, downstream of bridge

[1] Site identification codes follow those used in Fleming and Quilty 2006, listed in order from upstream to downstream.

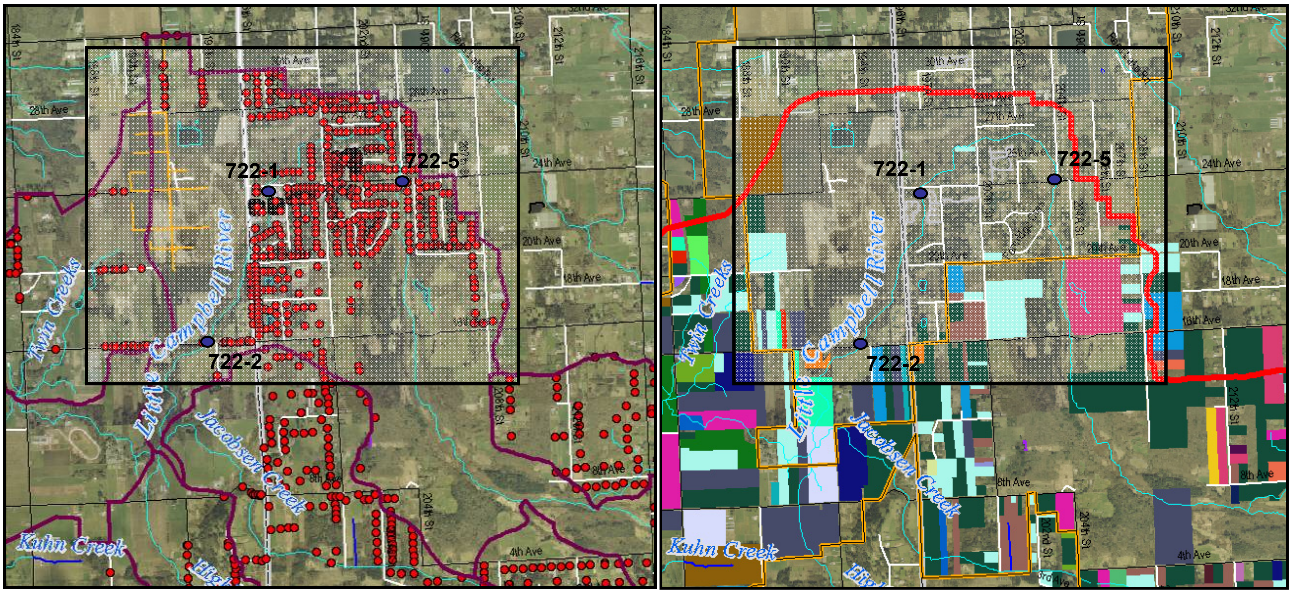

Figure 40. Sample site locations for seasonal monitoring, upstream and downstream of a residential area (non-agricultural) serviced by on-site sewage disposal systems. Locations of on-site sewage disposal systems are shown on the left and agricultural land use is shown on the right.

IV.B RESULTS AND DISCUSSION

IV.B1 Comparison of fecal coliform data with water quality standards

Appendix E contains all of the raw water quality data collected for this study. Running geometric means of fecal coliform concentrations were calculated and are displayed on a logarithmic scale in Figure 41. Also shown is the provincially approved water quality guideline for fecal coliform in waters used for primary contact recreation (200 cfu/100mL). The geometric means from both sites did not exceed the guideline during the sampling period.

FC loadings were also calculated, and are displayed on a logarithmic scale in Figure 42. Appendix C contains example depth-flow profiles, which were used to calculate loading.

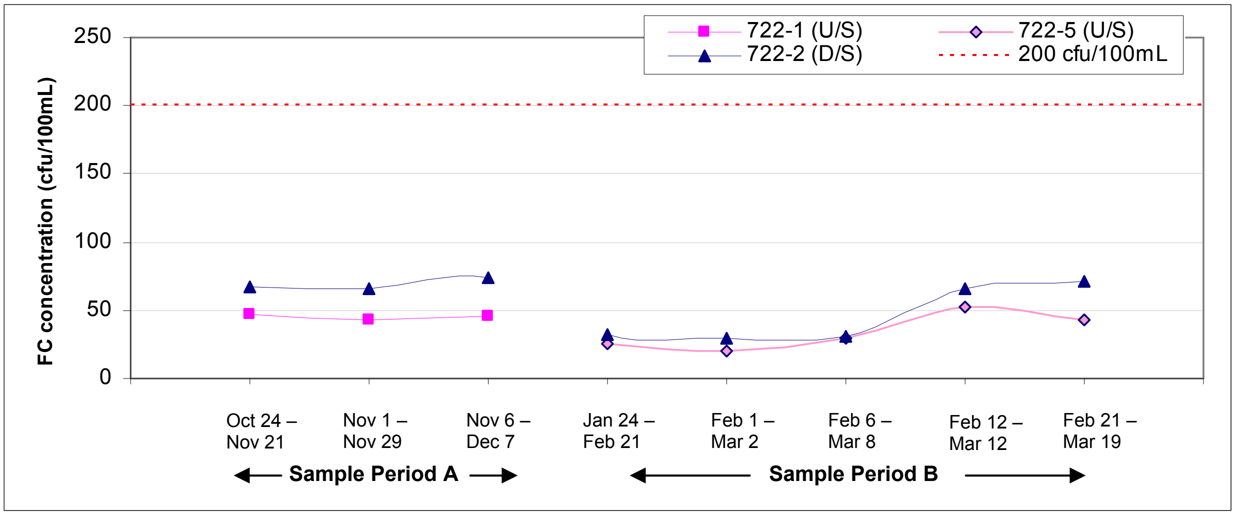

Figure 41. Geometric means of fecal coliform concentration - upstream (722-1 during sample period A, and 722-5 during sample period B) vs. downstream (722-2) of residential area serviced by on-site sewage disposal systems.

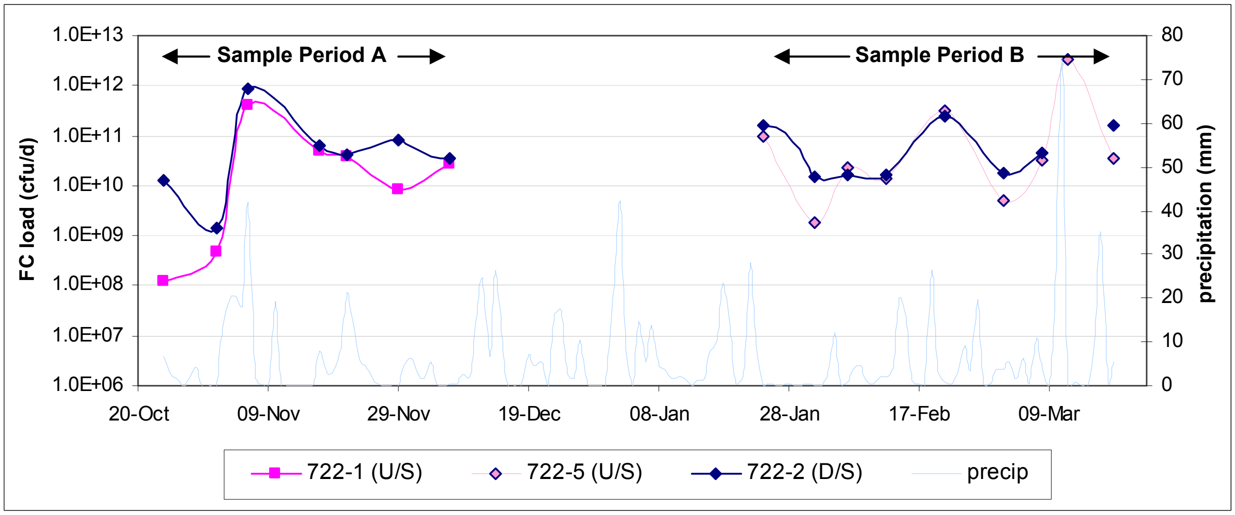

Figure 42. Daily fecal coliform loadings - upstream (722-1 during sample period A, and 722-5 during sample period B) vs. downstream (722-2) of residential area serviced by on-site sewage disposal systems.

IV.B2 Analysis of fecal coliform data and on-site sewage disposal systems

The study area for this part of the project contained very porous, well-draining soils, which overlay the unconfined Brookswood aquifer. There are a large number of on-site sewage disposal systems (SDS) within this area (approx. 600). Estimates of failure rates for SDS in this watershed are not readily available, but near Puget Sound shorelines SDS failure rates have been estimated to be as high as 25% (PSWQAT 2001). In the Brookswood area, if on-site SDS were failing, fecal contamination from failing on-site SDS could be transported to nearby surface waters of the LCR. The study area is residential, rather than agricultural, so as to isolate the effects of FC from on-site SDS sources, without the contribution of agricultural runoff.

The upstream (722-1 and 722-5) and downstream (722-2) sites were compared to determine if there was evidence to detect a difference in FC concentration during sample periods A and B. Statistical results are included in Appendix F. Contrary to what was expected, there was not a significant increase in FC concentration downstream of this residential area serviced by on-site SDS (Figures 43 and 44, Table 23). There was a slight increase in FC concentration seen at the downstream site (722-2); however, geometric means at both sites remained below the 200 cfu/100mL B.C. water quality guideline for recreational water use throughout the study period.

It is possible that the effects of on-site SDS failure are more distinguishable at a smaller scale, and that FC concentrations were diluted by the large volume of water in the LCR mainstem from heavy precipitation during the winter study period. In addition, there is a lower density of on-site SDS in the downstream portion of the study area, which may have resulted in a diluted result at the downstream site (Figure 40). Alternately, the failure rate of on-site SDS may be low and/or the soil characteristics in this area may limit the release of fecal contamination to surface waters. Further monitoring would be required to verify the results of this study and to determine the overall effects of on-site SDS on downstream water quality in the LCR watershed. From this study it appears as though failing on-site SDS in this portion of the watershed in this soil group may not be the greatest contributor of FC contamination to the watershed and the receiving waters of Boundary Bay.

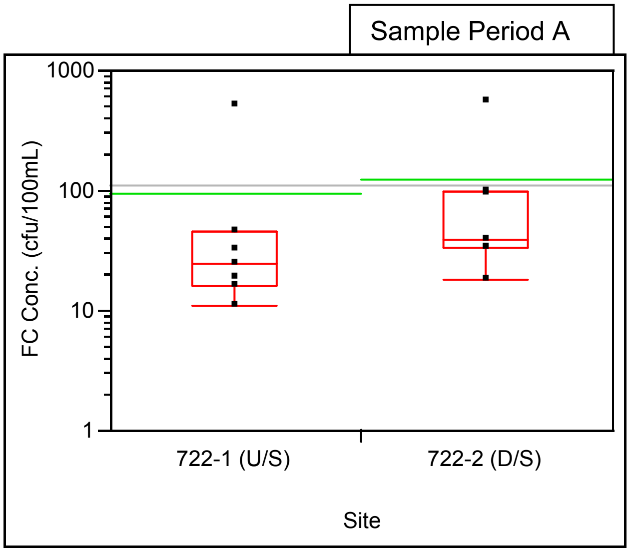

Figure 43. One-way analysis of fecal coliform concentration by site. Results from two sites in the Little Campbell River mainstem, upstream (722-1) and downstream (722-2) of a residential area serviced by on-site sewage disposal systems), sampled October to December 2006. Concentrations do not differ significantly between upstream and downstream sites ($t_{0.05,6} = -1.634$, $p = 0.1534$). Red boxes show the median, 25% and 75%. Red lines represent 10% and 90%. Green lines show means. Black dots show individual data points.

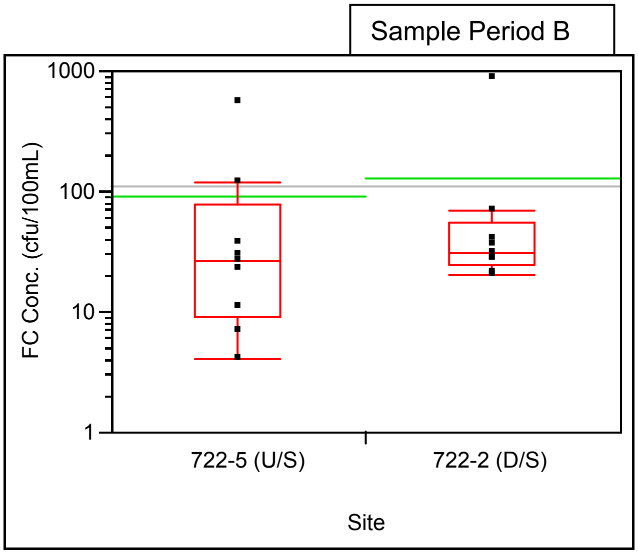

Figure 44. One-way analysis of fecal coliform concentration by site. Results from two sites in the Little Campbell River mainstem, upstream (722-5) and downstream (722-2) of a residential area serviced by on-site sewage disposal systems), sampled January to March 2007. Concentrations do not differ significantly between upstream and downstream sites ($t_{0.05,8} = -1.631$, $p = 0.1415$). Red boxes show the median, 25% and 75%. Red lines represent 10% and 90%. Green lines show means. Black dots show individual data points.

Table 23. Descriptive statistics for fecal coliform concentration data sampled from the Little Campbell River mainstem, upstream and downstream of a residential area serviced by on-site sewage disposal systems.

Sample Period A *(October 24 – December 7, 2006)*

Site	Upstream 722-1	Downstream 722-2
n	7	7
Mean	94.14	124.0
Std. Dev.	183.74	190.52
Std. Error	69.45	72.01
Lower 95%	-75.79	-52.20
Upper 95%	264.07	300.20
Range	11 – 510	18 – 550

Sample Period B *(January 24 – March 19, 2007)*

Site	Upstream 722-5	Downstream 722-2
n	9	9
Mean	91.00	129.33
Std. Dev.	179.30	285.63
Std. Error	59.77	95.21
Lower 95%	-46.82	-90.22
Upper 95%	228.82	348.89
Range	4 – 560	20 – 890

IV.C CONCLUSIONS

It was expected that there would be an increase in FC downstream of a residential area serviced by a high density of on-site SDS. The results of the study show however, that there was not a significant increase in FC concentration downstream of this area. Geometric means of FC concentration remained below the 200 CFU/100mL guideline at both upstream and downstream sites throughout the study period. This suggests that the incidence of on-site SDS failure in the area studied, may be relatively low, and fecal contamination from SDS in this section of the watershed in this soil group does not appear to be a significant contributor to FC contamination of the LCR surface waters and the receiving waters of Semiahmoo and Boundary bays at this time. Further monitoring would be required to verify the results of this study and to confirm the overall effects of on-site SDS on downstream water quality in the LCR watershed.

Little Campbell River Watershed Water Quality Monitoring:

Part 5: Automated Monitoring of the Little Campbell River Mainstem

July 2005 to October 2007

Prepared by:
Christy Juteau
Ministry of Environment
Environmental Quality Section
2nd Floor, 10470 152 Street
Surrey, B.C.
V3R 0Y3
604-582-5200

June 2008

V.A SAMPLING DESIGN

Table 24 and Figure 45 show the locations of the hydrolab station at 12th Avenue, established in October 2005, and the 15 temperature logger sites throughout the Little Campbell River (LCR) watershed, which were initiated in July 2005. Automated water quality data continues to be collected at each of these sites in 15-minute intervals at the Hydrolab station and at 30 minute intervals at the temperature logger sites. The hydrolab collects data for the following parameters: water temperature, pH, specific conductivity, dissolved oxygen, turbidity and stage; and the temperature loggers collect water temperature data.

Table 24. Automated monitoring site IDs, UTM coordinates and descriptions.

	Site ID[1]	UTM Zone 10 Easting	UTM Zone 10 Northing	Site Description
Little Campbell River mainstem	Hydrolab Site			
	137-1-B	520512	5430142	LCR mainstem at 12th Avenue
	Temperature Logger Sites			
	701-1	527412	5428883	LCR mainstem at 216th Street
	711-1	525012	5431022	LCR mainstem at Boy Scout Camp, north of 16th Avenue, east side of loop
	722-5	524943	5432598	LCR mainstem at 24th Avenue and 204th Street, east side of loop
	722-4	524151	5433028	LCR mainstem at 200th Street, upstream of bridge
	722-1	523543	5432570	LCR mainstem at 24th Avenue and 19600 block, west side of loop
	722-2	522849	5430957	LCR mainstem at 16th Avenue, south of bridge, west side of loop
	723-1	521379	5430262	LCR mainstem at Semiahmoo Fish and Game Club hatchery
	146-1	518581	5428958	LCR mainstem at 172nd Street
Tributaries in the Little Campbell River watershed	139-1-D	523157	5429653	Jacobsen Creek, upstream of road to Puesta de Sol housing development
	138-1	522474	5429363	Jenkins Creek, north of 8th Avenue
	136-1-A	520966	5430830	West Twin Creek, east side of 184th Street
	136-2-A	520964	5430538	East Twin Creek, east side of 184th Street
	137-2-C	519542	5430150	Watercourse between Thompson Creek and 176th Street at 12th Avenue
	137-2-B	519365	5430080	Sam Hill Creek at 176th Street
	147-1	520178	5428854	Kuhn Creek in Hazelmere Golf Course
	146-2-C	517732	5430027	Fergus Creek at 168th Street
	145-3	516620	5429371	McNalley Creek, north of 8th Avenue

[1] Site identification codes follow those used in Fleming and Quilty 2006, listed in order from upstream to downstream.

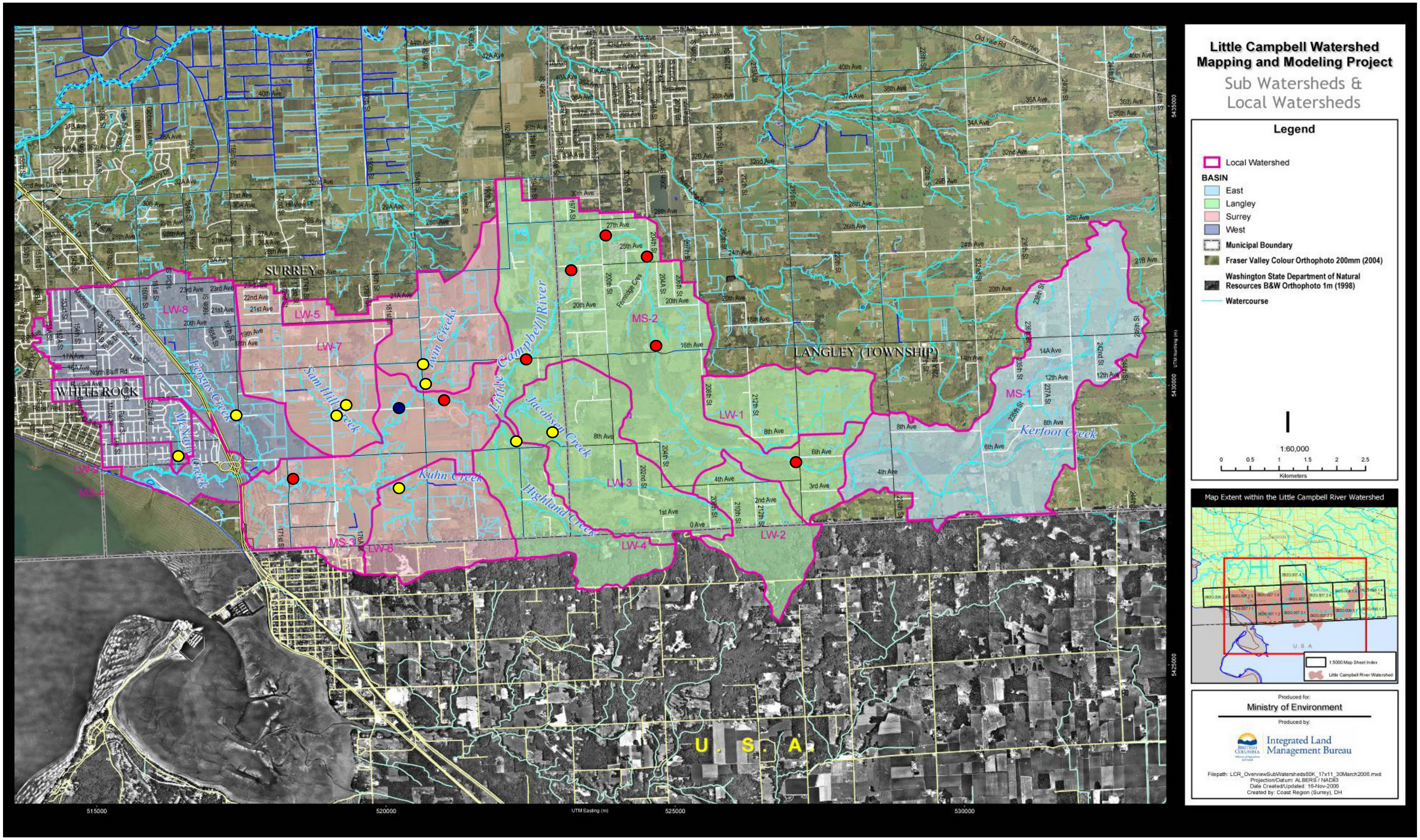

Figure 45. Map of automated monitoring sites – hydrolab station and temperature loggers. Blue circle indicates hydrolab station, red circles indicate temperature loggers in mainstem, yellow circles indicate temperature loggers in tributaries.

V.B RESULTS AND DISCUSSION

V.B1 Hydrolab Data Analysis

Data Validation and Correction

The hydrolab data were validated and corrected using AQUARIUS Time Series Software, developed by Aquatic Informatics. Data corrections were performed on the automated water quality parameters of temperature, pH, specific conductivity, dissolved oxygen, and turbidity collected during the time period of October 2005 to October 2007 before generating descriptive statistics. Typical errors included sensor calibration drift and fouling, data outliers, and technical issues with the sensor (e.g. power failure, disturbance during site visits). Calibration drift and fouling of the sensor were corrected using the methods described by B.C. Ministry of Environment. A statistical filter, consisting of an hourly (4-point) moving average, was used to correct the noise on the turbidity data, which is typical of data from these types of sensors. Table 25 summarizes the data corrections applied to each parameter sensor.

Table 25. Summary of data corrections applied to data from the Little Campbell River hydrolab, October 2005 to October 2007.

Parameter	No. of Corrections	Common Reason
Water Temperature	20	Sensor fouling
pH	37	Sensor warm-up
Dissolved Oxygen	36	Sensor fouling and calibration
Specific Conductivity	10	Non-physical values below zero
Turbidity	38	Erratic readings due to low battery

A number of technical difficulties have arisen since the installation of the hydrolab station in October 2005, resulting in periods of missing data (Table 26). Due to these substantial data gaps, it is difficult to thoroughly assess seasonal trends without a longer term data set.

Table 26. Hydrolab sampling periods and currently available data records.

Start of Sampling Period	End of Sampling Period	Missing Data	Reason for Data Loss
5-Oct-05	24-Nov-05	-	-
25-Nov-05	17-Jan-06	*Nov 25-Dec 19, 2005* *Jan 1-17, 2006*	*Power failure*
18-Jan-06	7-Mar-06	-	-
8-Mar-06	29-Mar-06	-	-
30-Mar-06	24-Apr-06	*Mar 30-Apr 24, 2006*	*Log file setup error*
25-Apr-06	2-Jun-06	-	-
2-Jun-06	3-Aug-06	*Jun 2-Aug 3, 2006*	*Download error*
3-Aug-06	26-Sep-06	*Sep 10-26, 2006*	*Unknown*
		Sep 27-Oct 27, 2006	*Repair/maintenance*
27-Oct-06	23-Nov-06	-	-
24-Nov-06	28-Dec-06	*Nov 24-Dec 28, 2006*	*Log file setup error*
23-Jan-07	17-Feb-07	-	-
20-Feb-07	29-Mar-07	*Mar 15-29, 2007*	*Power failure*
30-Mar-07	24-Apr-07	-	-
25-Apr-07	28-May 07	*Apr 25-May22,2007*	*Power failure*
25-Apr-07	24-Oct 07	-	-

Water Temperature

Stream temperature varied from 1-2°C in the winter to approximately 21°C in the summer (Table 27, Figure 46). It should be noted that the majority of the summer season data for 2006 (June 2 – August 3, 2006) were missing and therefore the upper temperatures for 2006 are under-reported. The temperature logger data provide a more complete data set of seasonal water temperatures and are found in Section V.B2.

The provincially recommended guidelines for water temperature are + or – 1 degree Celsius beyond the optimum temperature range for the most sensitive fish species present (MOE 2006). Coho, cutthroat and steelhead are present in the LCR year-round, and coho has the most sensitive temperature range for rearing (9.0 – 16.0°C), therefore these guidelines were used for this assessment. Appendix A contains the Tables of Recommended Guidelines. Table 27 shows the number of days per season that LCR water temperature exceeded these guidelines.

Table 27. Summary of seasonal water temperature data from the Little Campbell River Hydrolab station, October 2005 to October 2007.

		Temperature (°C)			Exceedence of Guideline			
Season	**n**	**Min**	**Max**	**Mean**	**No. days above 17°C**	**% of time sampled**	**No. days below 8°C**	**% of time sampled**
Fall 2005	4926	2.03	12.92	9.08			20.7	40.3
Winter 2005/06	6995	1.45	8.65	5.66			71.1	97.5
Spring 2006	4445	6.92	18.39	12.16	0.92	2.0	3.3	7.2
Summer 2006	3669	12.64	18.30	15.29	3.07	8.0		
Fall 2006	2579	3.31	11.93	7.96			16.7	62.3
Winter 2006/07	4541	1.93	9.80	5.41			43.8	92.7
Spring 2007	5074	5.42	18.46	12.02	1.65	3.1	3.2	6.0
Summer 2007	8063	10.60	21.14	15.61	15.22	18.1		
Fall 2007	3263	8.38	13.13	10.77				

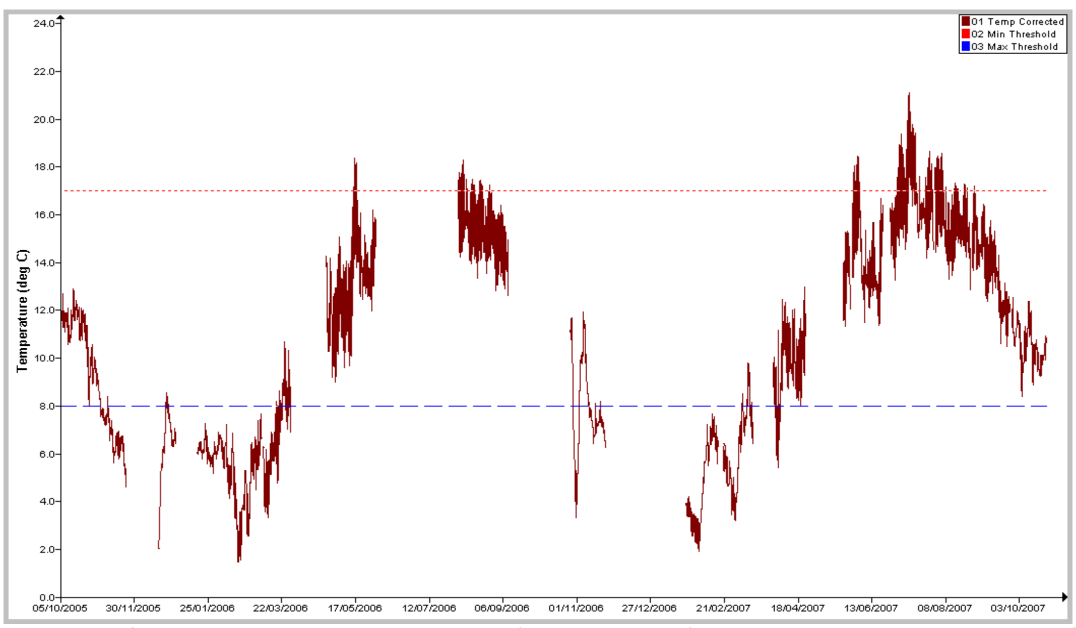

Figure 46. Corrected water temperature data from the Little Campbell River Hydrolab station, October 2005 to October 2007. Red line shows maximum criteria and blue line shows minimum criteria.

pH

The pH data ranged from 6.6 to 9.0 during the study period. These values fall within the provincially approved pH guidelines for freshwater aquatic life (6.5 – 9.0, MOE 2006); however the water quality objectives for the LCR use slightly more stringent guidelines, based on the criteria for drinking water (6.5 – 8.5, Swain 1988). When compared to these guidelines, the LCR pH exceeded 8.5 for a short period of time during spring 2006 (Table 28); pH levels did not drop below 6.5 throughout the study period. During warmer months, the pH data exhibited large diurnal fluctuations, indicating very high productivity within the LCR mainstem (Figure 47).

Table 28. Summary of seasonal pH data from the Little Campbell River Hydrolab station, October 2005 to October 2007.

		pH			Exceedence of Guideline	
Season	**n**	**Min**	**Max**	**Mean**	**No. days above 8.5**	**% of time sampled**
Fall 2005	4923	7.18	7.70	7.44		
Winter 2005/06	6980	6.96	7.60	7.28		
Spring 2006	4445	7.46	9.01	7.91	3.2	7.0
Summer 2006	3668	7.37	8.42	7.60		
Fall 2006	2573	6.63	7.86	7.12		
Winter 2006/07	4532	6.79	7.47	7.29		
Spring 2007	2698	7.46	8.06	7.73		
Summer 2007	8059	7.28	8.42	7.76		
Fall 2007	3261	7.38	8.43	7.99		

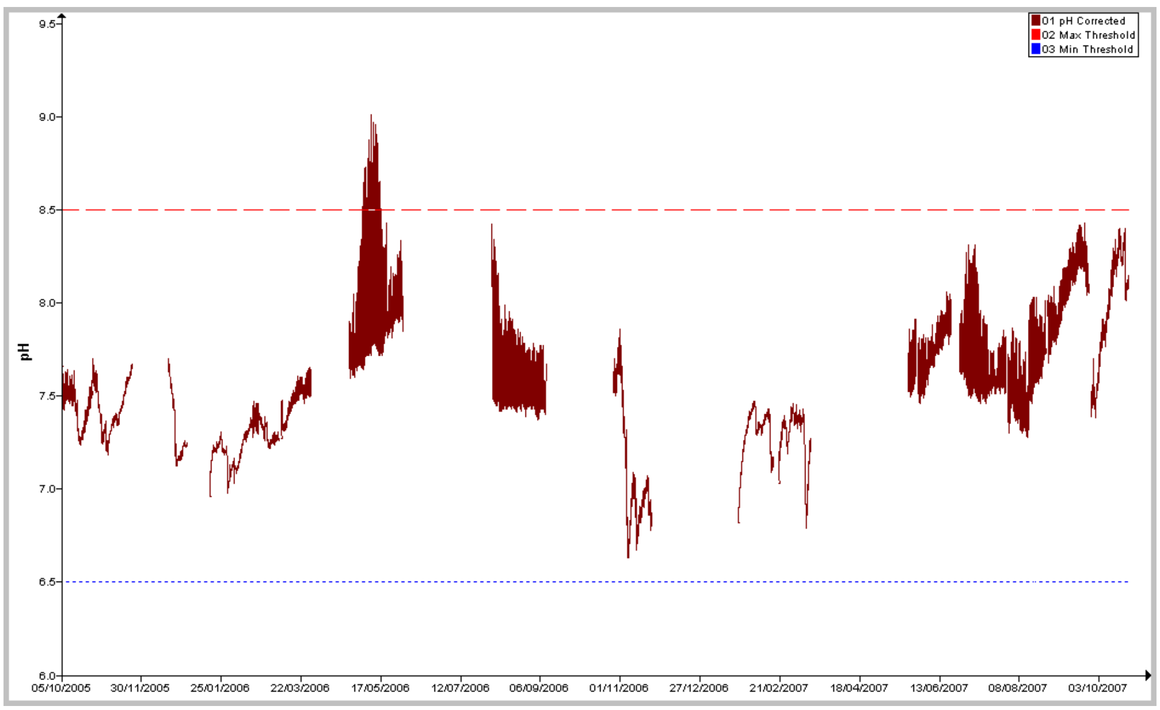

Figure 47. Corrected pH data from the Little Campbell River Hydrolab station, October 2005 to October 2007. Red line shows maximum criteria and blue line shows minimum criteria.

Specific Conductivity

Specific conductivity data ranged from minimums of 63-87 µS/cm in winter to >400 during the summer (Table 29 and Figure 48). Higher readings during the summer are indicative of groundwater infiltration during low-flow periods.

Table 29. Summary of seasonal specific conductivity data from the Little Campbell River Hydrolab station, October 2005 to October 2007.

	Specific Conductivity (uS/cm)			
Season	**n**	**Minimum**	**Maximum**	**Mean**
Fall 2005	4926	144	381	217.1
Winter 2005/06	7001	87	219	147.1
Spring 2006	4448	169	313	230.2
Summer 2006	3669	285	429	338.5
Fall 2006	2581	101	379	176.8
Winter 2006/07	4541	63	176	126.7
Spring 2007	5075	128	293	195.2
Summer 2007	8069	226	367	284.8
Fall 2007	3272	161	384	276.9

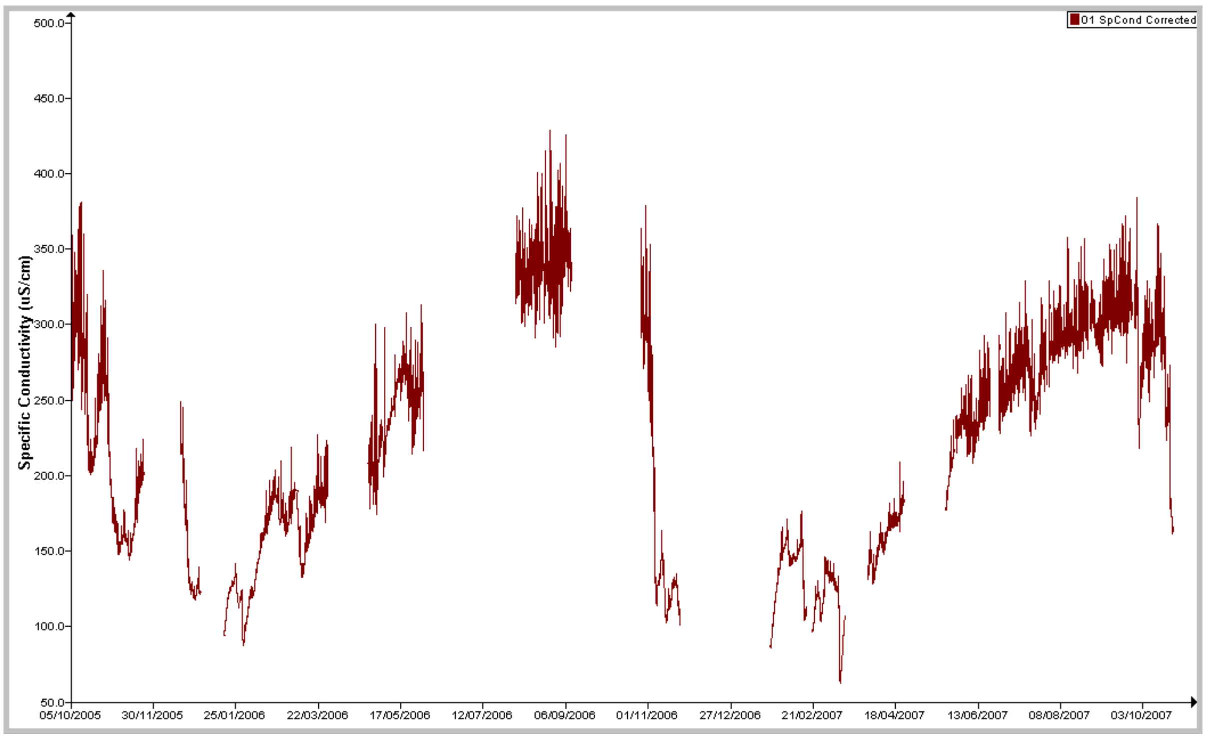

Figure 48. Corrected specific conductivity data from the Little Campbell River Hydrolab station, October 2005 to October 2007.

Dissolved Oxygen

Dissolved oxygen levels ranged from approximately 5.7 mg/L to 15 mg/L (Table 30 and Figure 49). The provincially approved water quality guidelines for dissolved oxygen for aquatic life are minima of 5.0 mg/L (instantaneous) for all salmonid life stages other than buried embryos/alevins and 9.0 mg/L (instantaneous) when buried embryo/alevin life stages are present (MOE 2006). The Little Campbell River water quality objectives set a long-term minimum objective of 8.0 mg/L from June to October and an 11.0 mg/L minimum when salmonid eggs, larvae or alevin are present. Table 30 shows the frequency of exceedence of the long-term minimum objective (8.0 mg/L) and the instantaneous minimum which applies when salmonid eggs, larvae or alevin are present (11.0 mg/L).

Table 30. Summary of seasonal dissolved oxygen data from the Little Campbell River Hydrolab station, October 2005 to October 2007.

		Dissolved Oxygen (mg/L)			Exceedence of Guideline			
Season	n	Min	Max	Mean	No. days below 8	% of time sampled	No. days below 11	% of time sampled
Fall 2005	4926	5.74	15.22	7.34	43.72	85.20	49.71	96.89
Winter 2005/06	6995	9.46	13.17	11.42			22.14	30.38
Spring 2006	4444	7.81	13.27	9.92	0.17	0.36	38.11	82.36
Summer 2006	3670	6.02	11.14	7.85	23.11	60.46	38.06	99.59
Fall 2006	2579	6.59	12.01	8.25	16.10	59.95	25.84	96.24
Winter 2006/07	4539	9.60	13.39	11.34			18.68	39.50
Spring 2007	5069	7.06	12.70	9.24	4.02	7.61	49.46	93.67
Summer 2007	8066	6.48	11.78	8.77	17.73	21.10	82.42	98.10
Fall 2007	3268	5.86	10.17	8.70	3.59	10.86	32.12	100.00

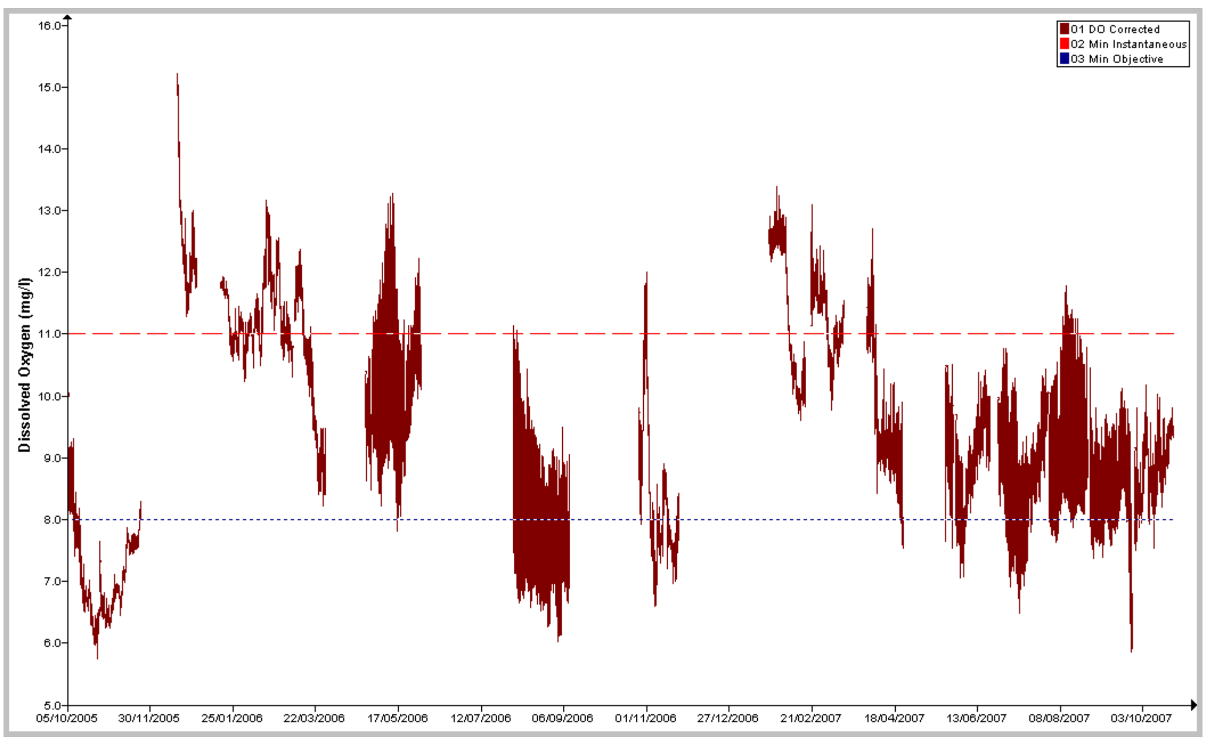

Figure 49. Corrected dissolved oxygen data from the Little Campbell River Hydrolab station, October 2005 to October 2007. Blue lines show minimum criteria – the dotted line shows the instantaneous minimum when salmonid eggs, larvae or alevin are present and the solid line shows the long-term objective.

Turbidity

Turbidity levels ranged from 0 to 1253 NTU, with the highest levels occurring during fall and winter months (Table 31, Figure 50). Turbidity means were substantially greater during the wet season (fall/winter) than the dry season (spring/summer). Table 31 and Figure 50 provide a summary of the turbidity data collected.

Table 31. Summary of seasonal turbidity data from the Little Campbell River Hydrolab station, October 2005 to October 2007.

		Turbidity (NTU)		
Season	**n**	**Min**	**Max**	**Mean**
Fall 2005	4923	0.0	209	16.92
Winter 2005/06	6905	0.0	161	15.37
Spring 2006	4454	0.0	41	1.80
Summer 2006	3670	0.8	59	3.40
Fall 2006	2581	0.0	1253	45.02
Winter 2006/07	4474	0.0	375	20.48
Spring 2007	5104	0.0	53	2.74
Summer 2007	8072	0.0	139	7.48
Fall 2007	3289	0.2	311	9.82

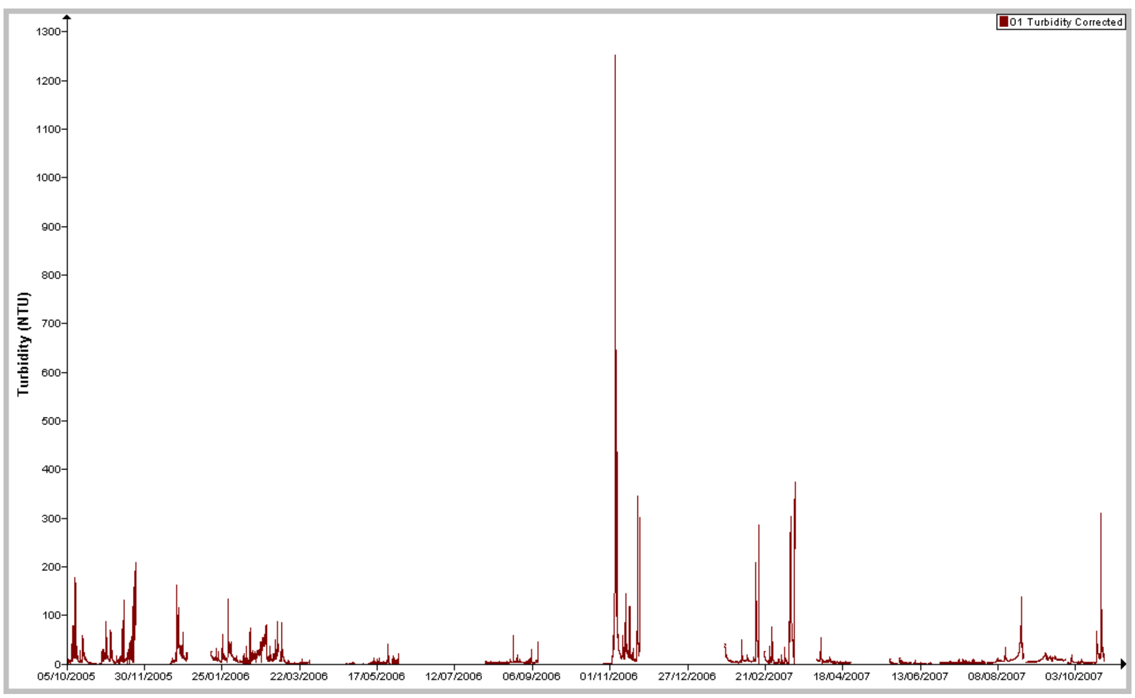

Figure 50. Corrected turbidity data from the Little Campbell River Hydrolab station, October 2005 to April 2007. Red line shows maximum criteria.

The turbidity data were assessed for magnitude and duration of events to determine the severity-of-ill-effect (SEV) index ratings, based on the model developed by Charles Newcombe (Newcombe 2000). The model is meant to assess **the impacts of reduced water clarity** for clear water fishes as a function of **both the magnitude and duration** of turbidity events.

The Newcombe severity-of-ill-effect scale is as follows:

SEV	Effect	Conditions	Details
0 ≤ SEV < 0.5	nil	**"ideal"**	Best for adult fishes that must live in a clear water environment most of the time.
0.5 ≤ SEV < 3.5	minor	**"slightly impaired"**	Feeding and other behaviours begin to change: severity of effect increases with duration
3.5 ≤ SEV < 8.5	moderate	**"significantly impaired"**	Marked increase in water cloudiness could reduce fish growth rate, habitat size, or both.
SEV ≥ 8.5	severe	**"severely impaired"**	Profound increases in water cloudiness could cause poor 'condition' or habitat alienation.

The location of the hydrolab downstream of land use activities means that it is not possible to establish a natural "background" (baseline) for turbidity using this data. The data from the hydrolab provides information on the cumulative water quality condition in the watershed. Since there is no background information to refer to, the Newcombe model was run at three different thresholds (for defining the start of an "event") - 8 NTU, 16 NTU and 25 NTU. Results from these three scenarios are provided in Appendix F Part V. There is only minor variation in the results generated using the different thresholds and the general conclusions from the results are the same. Table 32 and Figure 51 show the SEV ratings for the turbidity events for the middle threshold (16NTU). For this scenario a turbidity event was defined as any continuous period of time over which 16 NTU was exceeded. The magnitude of each event was calculated as the mean NTU over the course of the event.

The majority of turbidity events were rated as having "nil effect", representing ideal conditions; however, there were also a number of "minor" and "moderate" events during the study period. Most of the "moderate" and "minor" events occurred during the wet season (fall/winter).

Table 32. Summary of severity-of-effect (SEV) ratings for turbidity events from Oct 2005 to Oct 2007.

Magnitude – Duration Analysis					
Season	**No. of Events (>16 NTU)**	***SEV Rating***			
		Nil "Ideal"	**Minor "Slightly Impaired**	**Moderate "Significantly Impaired"**	**Severe "Severely Impaired"**
Fall 2005	44	17	23	4	0
Winter 2005/06	52	35	13	4	0
Spring 2006	3	2	1	0	0
Summer 2006	3	1	2	0	0
Fall 2006	6	1	2	3	0
Winter 2006/07	12	6	4	2	0
Spring 2007	1	0	1	0	0
Summer 2007	7	3	3	1	0
Fall 2007	12	8	2	2	0

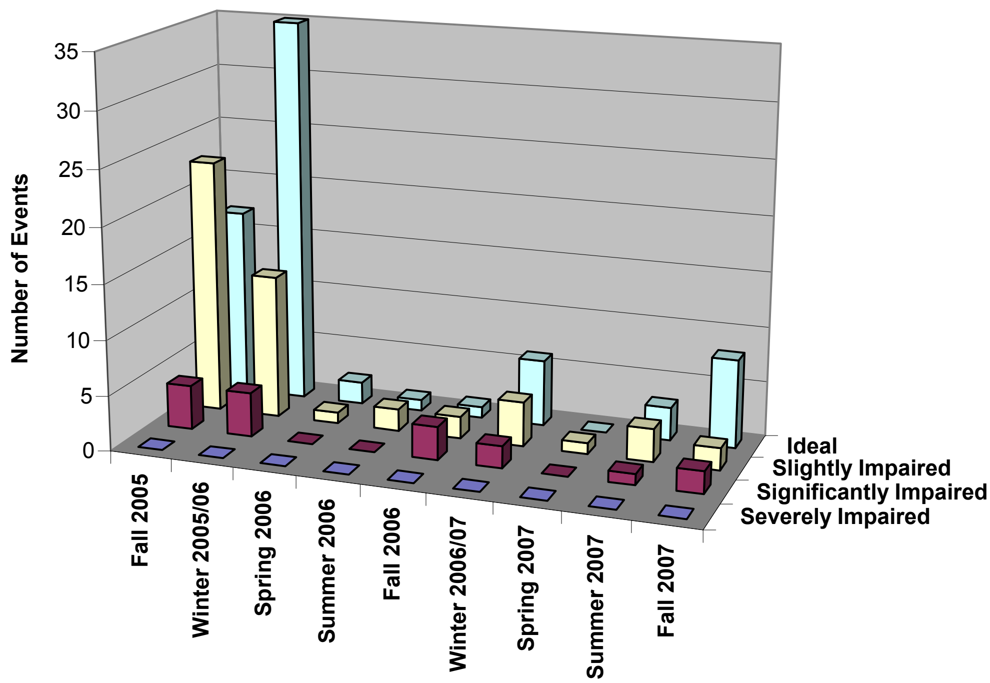

Figure 51: Severity-of-ill-effect scale results for the Little Campbell River by season from October 2005 to October 2007

It is important to note with this dataset, that there are significant gaps in the data, some of which may correspond to periods of reported high turbidity due to land use changes in the watershed. This means that all turbidity events have not been captured between October 2005 and October 2007. It should also be noted that the results presented, represent the mainstem condition at the hydrolab station, and may not necessarily reflect the condition in the tributaries.

V.B2 Temperature Logger Data Analysis

The temperature guidelines for streams and rivers in B.C. are based on temperature tolerance data for bull trout, Dolly Varden and salmonids. Bull trout and Dolly Varden are not present in the LCR and therefore, the temperature guidelines used in this analysis were based on the optimum temperature range for the most sensitive salmonid species present. Coho, cutthroat and steelhead are present in the LCR year-round, and coho has the most sensitive temperature range for rearing (9.0 – 16.0°C). B.C. guidelines recommend a maximum of + or – 1 degree Celsius beyond the optimum temperature range (MOE 2006), therefore these guidelines were used (8.0 – 17.0°C).

Exceedences above the maximum temperature guideline are of greatest concern due to salmonid sensitivity to elevated temperatures. Acute impacts (i.e. mortality) from high temperatures begin at approximately 24°C; however, chronic impacts can compromise feeding, growth, disease resistance, competitive ability, predator avoidance, and migration and spawning success (Fleming *et al*. 2004)

Graphs showing the temperature data for each site over time are found in Appendix F. The raw data records are too extensive to contain within this report and therefore are available by request from the Ministry of Environment, Lower Mainland Region, Environmental Quality Section. The sampling periods for each of the temperature logger sites are listed in Table 33.

Table 33. Sampling periods and currently available data records for temperature logger sites.

Location	Installation Date	Latest Download Date	Data Gaps
LCR at 216th St	Jul 28, 2005	May 7, 2007	Sep 8-27, 2005
LCR at 16th Ave (Boy Scout Camp)	Jul 28, 2005	May 7, 2007	-
LCR at 24th Ave (west of loop)	May 26, 2006	Oct 12, 2006	Oct 12, 2006 - May 2007
LCR at 16th Ave (west of loop)	Jul 6, 2005	May 7, 2007	-
LCR at Semiahmoo Fish & Game Club Hatchery	Jun 30, 2005	May 7, 2007	-
LCR at 172nd St	Jun 30, 2005	May 7, 2007	-
Jacobsen Cr at road to Puesta de Sol	Jul 6, 2005	May 17, 2007	-
Jenkins Cr north of 8th Ave	Jul 6, 2005	May 7, 2007	-
East Twin Cr at 184th St	Jun 30, 2005	May 7, 2007	-
West Twin Cr at 184th St	Jun 30, 2005	Oct 12, 2006	Sep 27, 2005 – May 26, 2006 Oct 12, 2006 – May 17, 2007
Creek between Thompson Cr and 176th St	Jun 30, 2005	May 7, 2007	-
Sam Hill Cr at 176th St	Jul 6, 2005	May 11, 2007	-
Kuhn Cr in Hazelmere Golf Course	Jul 6, 2005	May 7, 2007	-
Fergus Cr at 168th St	Jun 30, 2005	Oct 12, 2006	Oct 12, 2006 – May 17, 2007
McNalley Cr north of 8th Ave	Jun 30, 2005	May 7, 2007	-

Little Campbell River Mainstem Sites

Boxplots of the automated temperature data collected at LCR mainstem sites from July 2005 to June 2007 are displayed in Figure 52. Sites are compared from upstream to downstream (left to right). Summary statistics for LCR mainstem and tributary sites are shown in Tables 34 and 35, including the seasonal frequency of exceedence of the provincially recommended water temperature guidelines.

Sites 722-5 (LCR at 24th Avenue and 204th Street) and 722-4 (LCR at 200th Street) were established in March 2007, and data were not yet downloaded at the time of this report. Site 722-1 (LCR at 24th Avenue) only collected wet season data from Sep. 21 – Oct. 12, 2006 and therefore is not comparable to the other sample sites during the wet season.

Water temperature in the LCR mainstem varied from 0°C in the winter to approximately 22°C in the summer (Tables 34 and 35). Temperatures generally increased from upstream to downstream, with the warmest temperatures recorded at 172nd Street, approximately 3km from the mouth. The temperatures at this site exceeded the 17°C guideline 28% of the time during the dry season and showed the greatest risk of resulting chronic impacts to aquatic life. During the wet season, there were no exceedences of the 17°C guideline.

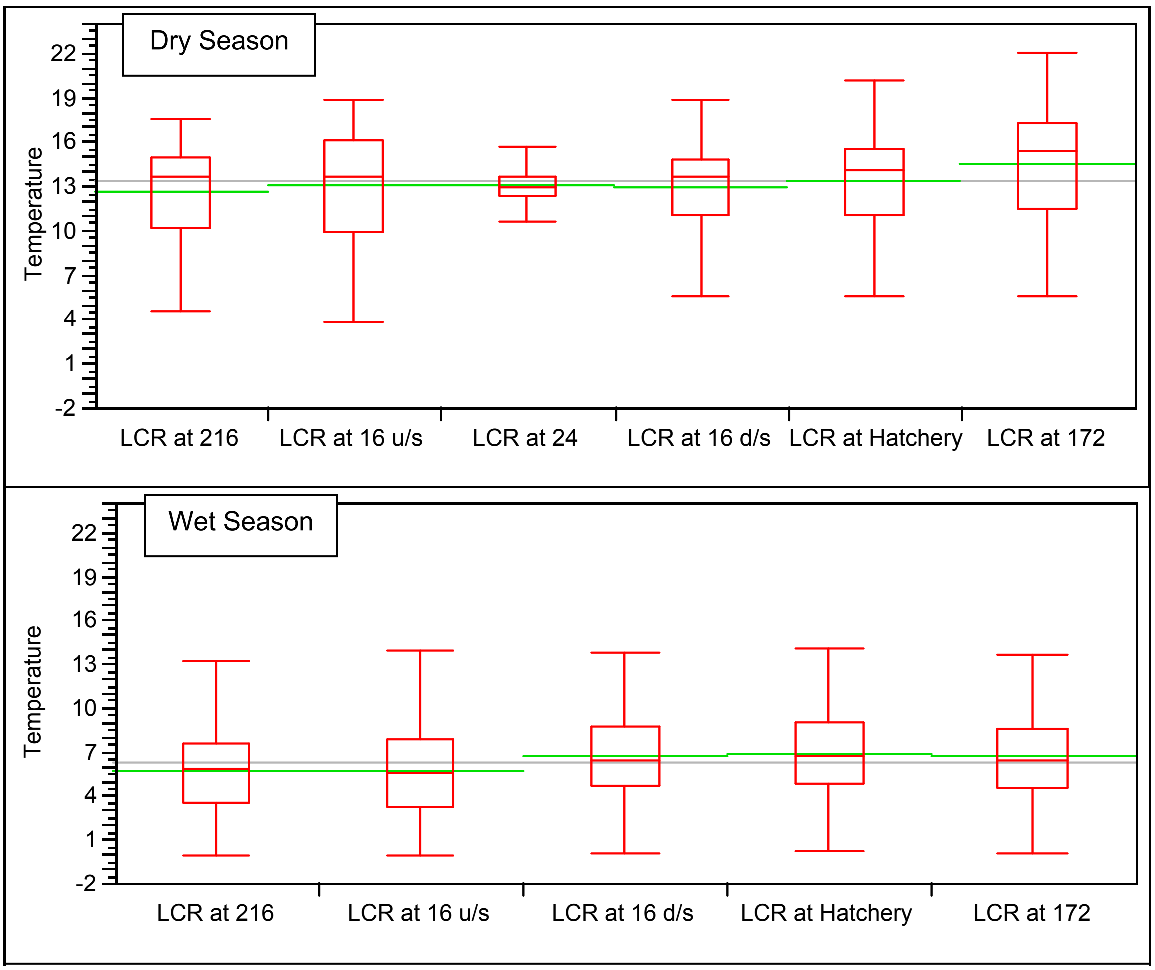

Figure 52. Temperature data for Little Campbell River mainstem sites during the dry season (spring and summer) and the wet season (fall and winter), sampled July 2005 to May 2007. Red boxes show the median, 25% and 75%. Red bars represent 10% and 90%. Green lines show the mean.

Table 34. Summary statistics for water quality parameters monitored during dry season (spring and summer).

		Temperature (°C)			Exceedence of Guideline			
	Temperature Logger Location	Min	Max	Mean	Days above 17°C	% of time	Days below 8°C	% of time
LCR Mainstem Sites	LCR at 216th St.	5.96	17.52	13.34	1.5	0.7%	9.2	4.2%
	LCR at boy scout camp, N of 16th Ave., east side of loop	3.91	18.89	13.10	15.5	5.5%	26.6	9.4%
	LCR at 24th Ave. and 19600 block, west side of loop	10.62	17.47	13.09	0.09	0.1%	0	0
	LCR at 16th Ave., west side of loop	7.01	17.97	13.02	3.00	1.3%	4.00	2.6%
	LCR at Semiahmoo Fish and Game Club hatchery	5.57	20.24	13.41	19.38	6.4%	11.41	3.7%
	LCR at 172nd St.	5.57	21.98	14.50	85.89	27.7%	11.14	3.6%
LCR Tributary sites	Jacobsen Creek	5.84	22.74	13.48	18.19	7.3%	13.32	5.2%
	Jenkins Creek	5.13	23.01	13.91	56.69	19.0%	18.76	6.2%
	West Twin Creek	10.29	20.73	15.15	17.36	9.0%	0	0
	East Twin Creek	6.27	20.91	14.02	41.45	13.5%	9.78	3.2%
	Watercourse between Thompson Creek and 176th St. at 12th Ave.	6.08	20.75	13.69	17.33	6.9%	7.89	3.1%
	Sam Hill Creek	5.32	17.78	12.33	0.28	0.1%	13.53	4.5%
	Kuhn Creek	4.22	19.74	13.09	15.91	5.4%	20.63	6.9%
	Fergus Creek	6.27	19.83	14.04	20.65	8.1%	6.05	2.4%
	McNalley Creek	5.02	19.80	13.39	15.57	5.1%	7.29	2.4%

Table 35. Summary statistics for water quality parameters monitored during wet season (fall and winter).

		Temperature (°C)			Exceedence of Guideline			
	Temperature Logger Location	Min	Max	Mean	Days above 17°C	% of time	Days below 8°C	% of time
LCR Mainstem Sites	LCR at 216th St.	-0.04	12.17	6.24	0	0	142.7	71.5%
	LCR at boy scout camp, N of 16th Ave., east side of loop	-0.04	13.82	5.75	0	0	270.1	75.1%
	LCR at 16th Ave., west side of loop	0.21	13.53	6.71	0	0	81.0	23.1%
	LCR at Semiahmoo Fish and Game Club hatchery	0.18	14.13	6.90	0	0	256.2	71.3%
	LCR at 172nd St.	0.04	13.64	6.72	0	0	253.0	70.4%
LCR Tributary sites	Jacobsen Creek	0.48	15.14	7.29	0	0	128.0	63.7%
	Jenkins Creek	0.87	15.38	6.98	0	0	246.6	68.6%
	West Twin Creek	7.82	14.48	11.14	0	0	0.33	1.3%
	East Twin Creek	0.12	14.34	6.83	0	0	246.8	68.7%
	Watercourse between Thompson Creek and 176th St. at 12th Ave.	0.87	14.01	7.57	0	0	184.4	60.4%
	Sam Hill Creek	1.36	15.73	7.47	0	0	227.1	63.3%
	Kuhn Creek	0.09	14.16	6.48	0	0	255.6	71.2%
	Fergus Creek	2.02	15.96	8.52	0	0	103.7	51.6%
	McNalley Creek	1.86	16.89	8.75	0	0	157.0	43.9%

Little Campbell River Tributary Sites

Boxplots of the automated temperature data collected at LCR mainstem sites from July 2005 to June 2007 are displayed in Figure 53. Sites are compared from upstream to downstream (left to right). Summary statistics for LCR mainstem and tributary sites are shown in Tables 33 and 34, including the seasonal frequency of exceedence of the provincially recommended water temperature guidelines.

West Twin Creek data contains large data gaps (Table 33) because the temperature loggers at this site were lost twice due to high flows during the wet season. A larger data set will need to be collected in order to include West Twin Creek in the temperature analysis.

Water temperature in the LCR mainstem varied from a minimum of 0-2°C in the winter to approximately 23°C in the summer (Tables 33 and 34). During the dry season, creeks in the upper watershed appeared to reach the highest temperatures (particularly Jenkins, East Twin and West Twin creeks) and exceeded the 17°C guideline approximately 10-20% of the time. This is the opposite trend of the LCR mainstem sites, where temperatures were highest at the downstream end of the watershed. During the wet season, there were no exceedences of the 17°C guideline; however, spawning generally occurs during the fall and the optimum temperature range maximum for spawning is 12.8°C for most salmonids. All of the tributaries exceeded 13.8°C during the fall/winter sampling period.

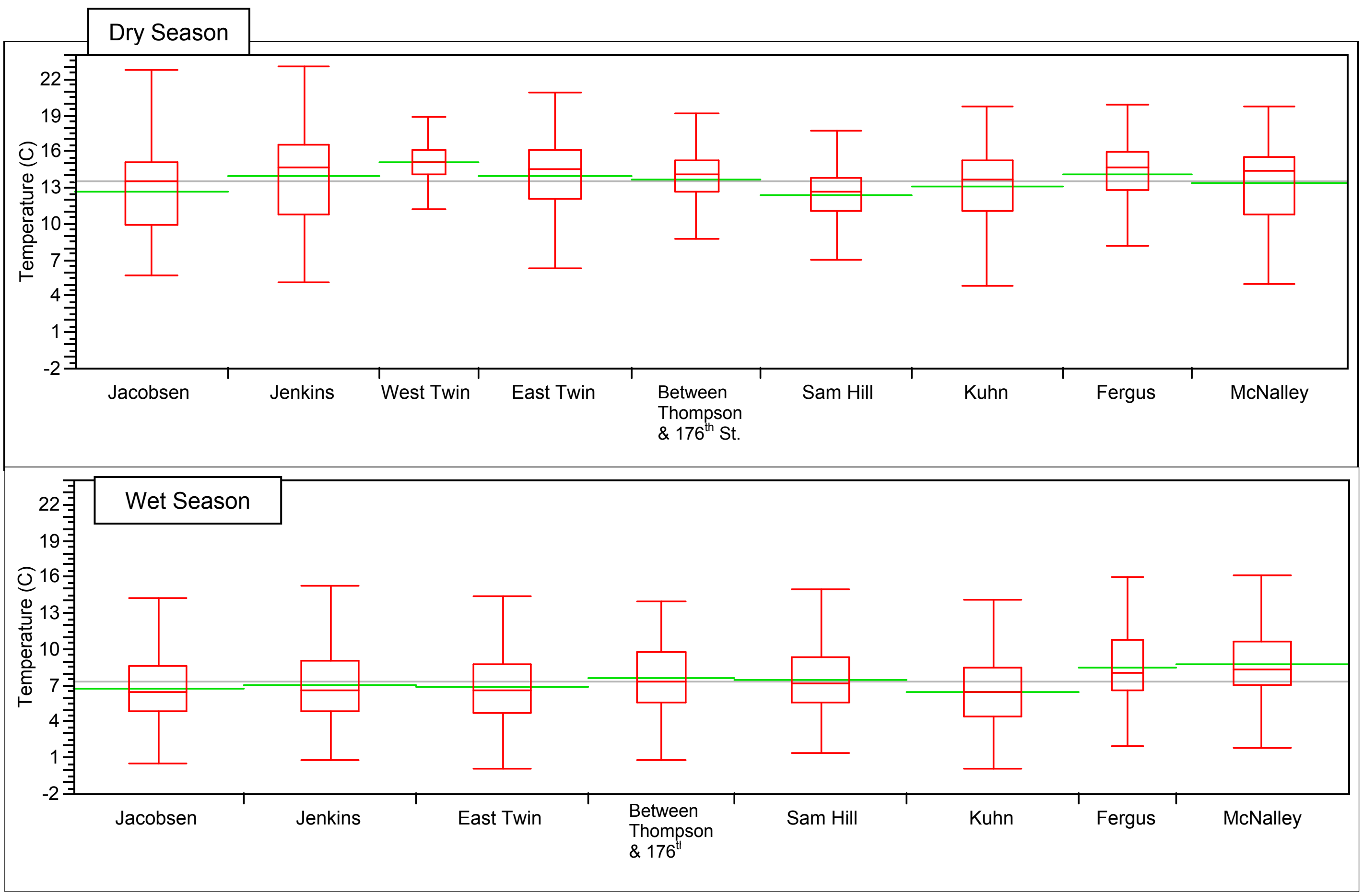

Figure 53. Temperature data for Little Campbell River tributary sites during the dry season (spring and summer) and the wet season (fall and winter), sampled July 2005 to May 2007. Red boxes show the median, 25% and 75%. Red bars represent 10% and 90%. Green lines show the mean.

V.C CONCLUSIONS

Of the parameters analysed at the Hydrolab station, dissolved oxygen and turbidity levels were of greatest concern.

Dissolved oxygen levels dropped below the instantaneous minimum of 11.0 mg/L when salmonid eggs or alevin could have been present during the fall/spring of 2005/2006 and 2006/2007. Dissolved oxygen levels dropped below the 8.0 mg/L objective level between June and October in 2006 and 2007. Levels reached minimums below 6 mg/L in the fall of 2005 and 2007.

Turbidity levels were greatest during the wet season (fall and winter). Magnitude and duration analysis indicated that there have been a number of turbidity events generating a marked increase in water cloudiness that would be expected to be enough to reduce fish growth rate, and habitat size, and are considered a “significant impairment” of the system.

From July 2005 to June 2007, water temperatures in the LCR watershed did not exceed 24°C, levels of acute toxicity that could result in direct mortality. Elevated temperatures (>17°C) in the mainstem near the mouth as well as tributaries in the upper watershed could have chronic impacts on salmonid and other aquatic life. These continuous temperature data loggers provide a valuable baseline to monitor long-term temperature trends over time.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The results of this study are relevant to planning processes and pollution prevention initiatives for the Little Campbell Watershed. These include the recently initiated Integrated Stormwater Management Plan by the City of Surrey and the Township of Langley, as well as work carried out through partnerships of the Shared Waters Alliance, an international water quality working group for Boundary Bay. This report is provided to support pro-active actions to help address current pollution issues, encourage consideration of how to reduce future impacts, and reduce cumulative effects to the watershed from land use activities.

Fecal Coliforms, Urban Impacts and Outfalls of Special Concern

Fecal coliform (FC) loadings were greatest near the mouth of the Little Campbell River (LCR) throughout the sampling period (April 2006 to March 2007), regularly exceeding the B.C. approved water quality guideline for recreational use (200 CFU/100 mL, MOE 2006).

Of the four sub-watersheds analysed, the West Sub-watershed, with land use that is primarily urban (30% impervious area), was found to be the greatest contributor of fecal contamination to the river mouth and subsequently the receiving waters of Semiahmoo and Boundary bays. High FC levels did not show a strong relationship with precipitation, indicating that fecal sources may be entering the LCR via other routes in addition to overland runoff. Alternate pathways could include direct deposit of fecal material into tributaries or the mainstem (domestic pets, wildlife), urban stormwater (dry-weather flows), re-suspension of FC adsorbed to sediments, failing on-site sewage disposal systems, and/or sanitary sewer cross-connections.

The highest fecal coliform concentrations among the sites sampled in this study came from the two Habgood outfalls into the LCR, which ranged from 240 to 22,000 cfu/100mL. The results suggest that fecal coliform loadings from these culverts are a significant source of fecal contamination to the river, and more widely, Semiahmoo Bay. McNalley Creek and the western marine outfall at Finlay Street also had high fecal coliform concentrations.

It is recommended that options be assessed and actions taken to mitigate the impact of urban sources on water quality, with Habgood being the highest priority to address followed by McNalley Creek and the Finlay Street outfall.

It is recommended that water quality continue to be monitored, particularly in the LCR at Stayte Road and at the Habgood outfalls. Sampling results from the LCR mainstem may serve as a baseline against which to compare water quality relative to future changes in storm sewers and outfalls.

It is recommended that, in recognition of the urban impact already seen to water quality near the mouth of the LCR, that planning processes for future development give consideration to how to prevent land use changes from further degrading water quality, particularly for recreation and aquatic life water uses at the river mouth.

Dissolved Oxygen, Turbidity and Temperature

Of the parameters analysed at the Hydrolab station, dissolved oxygen and turbidity levels were of greatest concern. Dissolved oxygen levels dropped below the objective minimum level of 11.0 mg/L when salmonid eggs or alevin could have been present during the fall/spring of 2005/2006 and 2006/2007. Dissolved oxygen levels dropped below the 8.0 mg/L objective level between June and October in 2006 and 2007. Levels reached minimums below 6 mg/L in the fall of 2005 and 2007. Turbidity levels were greatest during the wet season (fall and winter). Magnitude and duration analysis indicated that there have been a number of turbidity events generating a marked increase in water cloudiness that would be expected to be enough to reduce fish growth rate and habitat size, and are considered a "significant impairment" of the system.

Elevated temperatures (>17°C) in the mainstem near the mouth as well as tributaries in the upper watershed could have chronic impacts on salmonid and other aquatic life. Continuous temperature data provide a valuable baseline to monitor long-term temperature trends over time. **It is recommended that both the Hydrolab station and the temperature loggers continue to collect automated data for long-term trend assessment.**

It is recommended that the Shared Waters Alliance partners continue to work towards reducing pollutant inputs that contribute to low dissolved oxygen and elevated turbidity in the river.

Manure Management

FC levels at the agricultural sites (LW-1 and 146-2) consistently exceeded the B.C. approved water quality guideline of 200 CFU/100mL for the protection of recreational use and general livestock use (MOE 2006), while the non-agricultural site was in attainment of these guidelines throughout the study period. Despite high levels of FC originating from agricultural sub-watersheds, their relative contribution to the total FC load in the LCR mainstem, near the mouth, appears to be limited at this time. FC released from LW-1 in the upper LCR watershed, may not reach the mouth of the river. This suggests that FC contamination generated from agricultural runoff in the upper LCR watershed may have more localized effects. Although the upper watershed is not typically used for swimming and boating (primary and secondary contact recreation), it may be used for livestock watering and/or crop irrigation, which could be impacted by elevated FC levels. From past water quality results as well as recent attainment and automated monitoring results, it is clear that dissolved oxygen levels are of concern in the LCR. Inputs of organic materials, such as manure in runoff can contribute to low dissolved oxygen levels.

Continued efforts to improve manure management (e.g. proper storage, timing of application) are recommended to improve water quality in the LCR watershed.

Water Levels

A portion of the LCR mainstem (~1.5 km) becomes completely de-watered during the summer, potentially up to 5 months of the year. This restricts the movement of contaminants from the upper watershed to the mouth, but also poses a risk to aquatic life. Groundwater and surface water extraction rates could be contributing to this condition.

It is recommended that extraction rates in this watershed be assessed to determine whether there is an adequate balance between protection of aquatic life values and supply for other water uses, especially in light of climatic changes that may be expected due to global warming.

5.0 REFERENCES

Bull, J. 2003. Status of water quality conditions in the Little Campbell, Serpentine, and Nicomekl Rivers from 1971 to 2002. Prepared for the Ministry of Water, Land and Air Protection, Environmental Quality Section, Surrey, B.C.

Cheung, A. 2003. Semiahmoo Bay Water Quality Project. Environment Canada, and the Georgia Basin Ecosystem Initiative.

Drever, R. and M. Brown, 1999. Little Campbell River Overview Assessment. Prepared for the Little Campbell Watershed Society.

Environmental Management Act [EMA], 1992. B.C. Reg. 131/92 s.3, on-line: Queen's Printer (Agricultural Waste Control Regulation) http://www.qp.gov.bc.ca/statreg/reg/E/EnvMgmt/131_92.htm

Fleming, S.W., Quilty, E.J., Farahmand, T., Hudson, P. 2004. Magnitude-Duration Based Ecological Risk Assessment for Turbidity and Chronic Temperature Impacts: Method Development and Application to Millionaire Creek. Prepared for the Ministry of Environment, Environmental Quality Section, Surrey, B.C. Prepared by Aquatic Informatics Inc., Vancouver, B.C.

Fleming, S.W. and E.J. Quilty, 2006. A Novel Approach: Reconnaissance Analysis of the Little Campbell River Watershed. Report prepared for the Ministry of Environment, Environmental Quality Section, Lower Mainland Region. Aquatic Informatics Inc., Vancouver.

Hay & Co. Consultants Inc., 2003. Semiahmoo Bay circulation study, technical report. Environment Canada.

Mallin, M.A., K.E. Williams, E.G. Esham, and R.P. Low, 2000. Effect of Human Development on Bacteriological Water Quality in Coastal Watersheds. *Ecological Applications* 10(4):1047-1056.

McCorquodale, J.A., I. Georgiou, S. Carnelos, and A.J. Englande, 2004. Modeling coliforms in storm water plumes. *Journal of Environmental Engineering and Science* 3: 419-431. NRC Research Press.

Menon, A. 2000. Bacterial Indicators of Shellfish Water Quality. Environment Canada. http://www.shellfishquality.ca/Safety/BacterialIndicators.htm

Mills, W.B., D.B. Porcella, M.J. Ungs, S.A. Gherini, K.V. Summers, Lingfung Mok, G.L. Rupp, G.L. Bowie, and D.A. Haith, 1985. Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Groundwater – Part 1 (Revised). Report prepared for the U.S. Environmental Protection Agency. http://www.epa.gov/waterscience/library/modeling/wqascreenpart1.pdf

Ministry of Agriculture and Lands [MAL], 2005. City of Surrey Agricultural Land Use Inventory, 2004.

Ministry of Environment [MOE]. 1989. The Attainment of Ambient Water Quality Objectives in 1988. Water Management Branch, Victoria, B.C.

Ministry of Environment [MOE]. 1990. The Attainment of Ambient Water Quality Objectives in 1989. Water Management Division, Victoria, B.C.

Ministry of Environment [MOE]. 1991. The Attainment of Ambient Water Quality Objectives in 1990. Water Quality Branch, Water Management Division, Victoria, B.C.

Ministry of Environment [MOE], 2005. B.C. Environmental Laboratory Manual for the Analysis of Water, Wastewater, Sediment, Biological Materials and Discrete Ambient Air Samples. http://www.env.gov.bc.ca/air/wamr/labsys/lab_man_05_pdfs/section_e.pdf

Ministry of Environment [MOE], 2006. B.C. Approved Water Quality Guidelines 2006 Edition. http://www.env.gov.bc.ca/wat/wq/BCguidelines/approv_wq_guide/approved.html

Ministry of Environment, Lands and Parks [MELP]. 1993a. The Attainment of Ambient Water Quality Objectives in 1991. Water Quality Branch, Water Management Branch, Victoria, B.C.

Ministry of Environment, Lands and Parks [MELP]. 1993b. The Attainment of Ambient Water Quality Objectives in 1992. Water Quality Branch, Water Management Branch, Victoria, B.C.

Puget Sound Water Quality Action Team [PSWQAT], 2001. Puget Sound Water Quality Management Plan – On-site Sewage Systems Program. Olympia, WA. http://www.psat.wa.gov/Publications/manplan00/16_on-sites.pdf

Resources Inventory Committee, 1997. Resources Information Standards Committee: Freshwater Biological Sampling Manual. Province of British Columbia.

Sargeant, D., 2004. Dungeness Bay Fecal Coliform Bacteria Total Maximum Daily Load Study. Prepared for the Washington State Department of Ecology, Olympia, WA.

Schueler, T. and H. Holland (Ed.) 2000. Microbes and Urban Watersheds – Feature Article II: Concentrations, Sources and Pathways. *Watershed Protection Techniques*, 3(1):1-12.

Swain L.G. 1988. Ambient water quality objectives for Boundary Bay and its tributaries, Fraser-Delta area. Prepared for B.C. Environment, Water Management Division.

Thomann, R.V. and Mueller, J.A., 1987. Principles of Surface Water Quality Modelling and Control. Harper & Row, New York.

Zevit P, Page N, Goble H. 2008. Characterization of potential pollution sources in the Little Campbell River Watershed. Prepared for the Ministry of Environment, Environmental Quality Section, Lower Mainland Region.