Characterization of Stormwater Runoff in Three Catchments

Final Report
Volume I of II

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PROLOGUE

The GVRD is committed to the principle of managing liquid waste in a manner which protects the receiving aquatic environment using cost-effective approaches. This commitment is detailed in the 1996 Liquid Waste Management Plan (LWMP) submission for the GVS&DD area and is the basis for development of the Stage 2 LWMP scheduled for completion in 1999. The LWMP process is mandated by the provincial government and is designed to facilitate an integrated and local approach to making liquid waste management decisions. A key component of this plan involves assessing the environmental impact of discharges within each of the major discharge categories, including WWTP effluents, CSOs, and stormwater. Using this information, discharges will be assessed in terms of their potential impacts on the environment. Additionally, environmental assessments will provide baseline information upon which to define the incremental benefits of implementing abatement programs. Work in this area is guided and reviewed by an LWMP Environmental Assessments Task Group comprised of representatives from member municipalities, the GVRD, senior governments, the academic community, and public. The observations and conclusions presented in this report have been reviewed by this committee.

For more information on this or any other LWMP environmental impact/assessment study, please contact:

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EXECUTIVE SUMMARY

This stormwater monitoring program was developed to assist the Greater Vancouver Regional District (GVRD) in the evaluation of both water quality and discharge rates in three Lower Mainland catchments: Wagg Creek in North Vancouver, Still Creek in Burnaby, and the Serpentine River in Surrey. These catchments were selected based on the broad range of commercial and residential use of the catchment land base and to build on information collected during past monitoring activities.

Stormwater samples were collected during five storm events from each catchment during this study which covered the period April to September 1996 and October to December 1997. There were four routine events during which flow-proportioned composite samples were collected over a six-hour period, and one extended event where discrete samples were collected every half hour over a ten-hour period. In addition, suspended sediment samples were collected at the Still Creek and Serpentine River locations.

The stormwater and suspended sediment samples were analyzed for a wide range of parameters including bacteriological parameters, inorganic and physical parameters, total and dissolved metals, organic compounds, and toxicity. A quality assurance/quality control (QA/QC) program was implemented to evaluate the quality of the analytical data.

Flow measuring devices were installed and maintained by GVRD personnel at each of the sampling locations to develop flow hydrographs for the study and for use during future monitoring efforts. The tabulated hydrographs show that all three catchments respond quite quickly to the onset of precipitation.

A number of the routine sampling events completed in 1996, along with the field replicate and field blank samples, were repeated in 1997 due to an identified one-hour discrepancy between the time reference used for flow data collection, and the time reference used for the sample collection.

Contaminant concentrations recorded in stormwater and suspended sediment were generally greater than those reported in the Fraser Glen (Surrey) stormwater study completed by the GVRD in 1994. However, the analytical results were found to be in a similar range to those obtained during a recent 1996 GVRD study in the Fraserview (Vancouver) and William Street (Vancouver) catchments. Measured stormwater concentrations of a small subset of detected contaminants at the three catchments ranged from 0.005 - 0.057 mg/L (copper),

0.012 - 0.17 mg/L (zinc), and <0.03 - 1.11 μg/L (pyrene). Measured suspended sediment concentrations of the same contaminants at two of the three catchments ranged from 199 - 422 mg/kg (copper), 904 - 1800 mg/kg (zinc), and 4.0 - 7.0 mg/kg (pyrene).

Higher trace metal concentrations were consistently observed in stormwater originating from the Still Creek catchment relative to the other sampling sites. A higher proportion of industrial land use in the Still Creek catchment relative to the others may be responsible or the higher metal levels. These elevated metals concentrations were identified in the William Street industrial catchment as well. The Serpentine River catchment contained the highest concentration of organic contaminants when compared to all of the above mentioned studies.

A series of toxicity tests were performed on stormwater samples collected from each catchment. All stormwater samples were found to be non-toxic to rainbow trout and the bioluminescent bacteria, *Photobacterium phosphoreum (Vibrio fischeri). Ceriodaphnia dubia* survival and reproduction were inhibited after exposure to stormwater collected from all three catchments with the Serpentine stormwater sample being the most toxic (LC_{50} = 19%). No effects were observed on algal growth using *Selenastrum capricornutum* on the Serpentine River and Wagg Creek stormwater samples, however, slight toxicity was observed with the Still Creek sample (NOEC = 30% and LOEC = 90.9%).

Suspended sediments from the Still Creek and Serpentine River catchments were also collected and subjected to the bioluminescent bacteria toxicity testing with similar results (IC_{50} of 546 and IC_{50} of 523 ppm).

Throughout one storm event at each site, contaminant concentrations were found to be the highest with the first significant increase in flow when accumulated contaminants are being washed away.

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ACKNOWLEDGEMENTS

City of Surrey for providing information on the Serpentine River catchment.

Environment Canada weather office for providing weather forecasting information.

Greater Vancouver Regional District for providing information on all these catchments.

Kerr Wood Leidal Associates Ltd. of North Vancouver for providing information on the Wagg Creek catchment.

The following laboratories participated in this project:

Analytical Services Laboratory Ltd. of Vancouver, BC completed the analyses of water and suspended sediment samples for organic parameters during the 1996 field program.

Axys Analytical Services Ltd. of Sydney, BC completed the analyses of suspended sediment samples for dioxins and furans.

Greater Vancouver Regional District of Burnaby, BC completed the bacteriological analysis of stormwater samples in their laboratory.

Integrated Resource Consultants Inc. of Richmond, BC completed the toxicity testing on the stormwater samples.

Quanta Trace Laboratories Ltd. of Burnaby, BC provided sample compositing services and completed the analyses of water and suspended sediment samples for general and inorganic parameters during the 1996 field program.

Philip Analytical Services Corp. completed analyses of water samples for general, inorganic, and organic parameters, during the 1997 field program.

1. BACKGROUND

As part of the Liquid Waste Management Plan, the Greater Vancouver Regional District (GVRD) has identified the need to characterize water quality and discharge rates in urban stormwater runoff. The data are required by the GVRD for regional stormwater management planning that includes the identification and prioritization of catchments and contaminants, and the evaluation of potential control measures. Limited data are available from previous studies of stormwater sewer discharges for small catchments and sub-catchments such as those studied here.

In order to meet the need for stormwater characterization data, the GVRD developed a stormwater monitoring program that included both water quality evaluation and discharge rate measurements in sub-catchments of three Lower Mainland catchments, namely, Wagg Creek in North Vancouver, Still Creek in Burnaby, and the Serpentine River in Surrey. They were selected based on the broad range of land uses across the catchment areas, and to build on information collected during past monitoring activities.

2. SCOPE OF WORK

2.1. Objective of the Study

The primary objective of the stormwater characterization study was to develop a data set of stormwater quality and discharge rates for three Lower Mainland catchments of known size and land use. The program was initiated to obtain samples during the late winter/early spring rainfall period (March through May), representative of the typical Lower Mainland spring wet period. During that period, storm events tend to be more predictable and precipitation evenly distributed. The later spring/summer months have a tendency to be drier with storm events of a more convective nature and the precipitation more localized.

The program included the collection of stormwater samples during four rainfall events and concurrent, continuous measurement of flow rates at the sample locations. Analytical costs were minimized by utilizing flow-proportioned composite samples prepared for each routine sampling event on the basis of the recorded flow data. The program was supplemented by analyses of individual (discrete) samples during an extended sampling event, the addition of toxicity analyses for one event, and suspended sediment sampling during one event.

To validate the data, the program also included a Quality Assurance and Quality Control (QA/QC) program consisting of field blanks and replicates, laboratory blanks and replicates, and the analyses of standard reference materials and surrogate standard recoveries.

In order to meet the study objective, certain modifications to the program described above were necessary due to climatic and other conditions. These modifications are discussed where applicable in appropriate sections of this report.

2.2. Description of Study Areas

Three catchment areas representative of typical urban development in the Lower Mainland were selected for this study. A regional map showing the location of the three catchments is provided in Figure 2.1.

2.2.1. Wagg Creek

The Wagg Creek watershed is located in North Vancouver with the headwaters in the central Lonsdale area near the Trans-Canada Highway. Wagg Creek discharges to the mouth of

Mosquito Creek and then into Burrard Inlet. The Wagg Creek sampling catchment (60 ha.) is located in the headwaters of the watershed and was selected to take advantage of information available from previous and ongoing studies defining the watershed characteristics.

The general location of the catchment is shown in Figure 2.1. A detailed drawing showing the catchment boundaries, catchment land use, and area is provided in Figure 2.2.

The estimated amount of impervious land cover for the catchment is 37%. This has been calculated by Kerr Wood Leidal Associates Ltd. (KWL) based on a detailed review of aerial photographs and land use in the area.

The sampling location for this catchment is the stormsewer maintenance hatch on the west side of Chesterfield Avenue at 20th Street within the Wagg Creek park (see Figure 2.2).

The stormsewer at this location is constructed of 0.9 m diameter concrete pipe with a standard 0.56 m diameter maintenance hatch providing access from the ground surface. The depth from ground surface to the invert was measured to be 2.1 m. The slope of the stormsewer upstream of the sample location is approximately 5%, increasing to 21% downstream. The sampling location was immediately upstream of the inflection point.

2.2.2. Still Creek

The Still Creek watershed is the major drainage system of central Burnaby with the headwaters located in the eastern portion of Vancouver. Still Creek discharges into Burnaby Lake which then discharges into the Fraser River via the Brunette River. The Still Creek sampling catchment (152 ha.) is located on the north side of Lougheed Highway in west central Burnaby. This catchment was selected to supplement information collected during several previous studies.

The general location of the catchment is shown in Figure 2.1. A detailed drawing showing the catchment boundaries, catchment land use, and area is provided in Figure 2.3.

The calculated average amount of impervious area for the catchment is 60%, based on an impervious land cover estimate of 90% for commercial/industrial, 50% for single-family, 0% for parks and green space, and 70% for multi-family residential land uses. These values for estimated percentage of impervious land cover for commercial/industrial and residential land uses are based on a recent land use analysis in the watershed (McCallum, 1995). The estimated impervious land cover value for multi-family residential was obtained from a recent City of Surrey report (I.D. Group/Duncan & Associates Engineering Inc., 1996).

The sampling location for this catchment is the stormsewer maintenance hatch on the north side of Lougheed Highway, approximately 0.3 km east from Boundary Road and adjacent to the BC Gas Utility Ltd. (BC Gas) site fence (see Figure 2.3).

The stormsewer is a concrete box culvert approximately 1.9 m by 2.0 m. Access is via a standard 0.56 m maintenance hatch installed at ground level. The depth from ground surface to the invert is 4 m. The slope of the culvert is 0.14%.

2.2.3. Serpentine River

The Serpentine River watershed is one of the major drainage systems in Surrey, with the headwaters in the Guildford area near the Port Mann Bridge. It discharges into Boundary Bay. The Serpentine River sampling catchment (141 ha.) is located at the headwaters within the northwestern sub-catchment of the Upper Serpentine basin in north central Surrey. This catchment was selected based on GVRD's recognition of water quality concerns in the Serpentine River.

The general location of the catchment is shown in Figure 2.1. A detailed drawing showing the catchment boundaries, catchment land use, and area is provided in Figure 2.4.

The calculated impervious ground cover for the Serpentine River catchment is 50% based on impervious land cover estimates for the developed lands of the catchment. This estimate was obtained by using the same percentage of impervious land cover estimates for land use as described in a report prepared for the City of Surrey (I.D. Group/Duncan & Associates Engineering Inc., 1996).

The sampling location for the catchment is the stormsewer maintenance hatch adjacent to a pedestrian walkway in a residential complex west of 153rd Street and 0.3 km north from 106th Avenue (see Figure 2.4).

The stormsewer consists of a 1.5 m by 1.8 m concrete box culvert with standard maintenance hatch access. The invert is 1.9 m below the ground surface. The slope of the stormsewer is 0.55%.

2.3. Sampling Event Criteria

During development of this study, it was estimated that the mean storm event during the January through March period would be approximately 10 hours in duration with a total accumulated precipitation of over 9.4 mm. This estimate was based on precipitation data collected between 1958 and 1975 at the Kitsilano gauging station located on 10th Avenue at Vine Street in Vancouver (McCallum, 1996).

For this study, the GVRD specified the sampling event criteria as follows:

- the antecedent dry period must be a minimum of six hours at each location;
- the sampling program must be initiated within one hour of the beginning of the storm;
- the minimum duration between sampling events was 24 hours;
- the sampling program would continue for six hours; and
- the total accumulated rainfall volume at the sample site during the routine sampling event six-hour period must be greater than 3 mm, and greater than 5 mm for the concurrent 10-hour extended sampling event.

To verify that the precipitation criteria during sampling events were met, an "Airguide" Model 609D, cone shaped, clear plastic, manually read, portable rain gauge with 1 mm gradations was installed upon arrival at the site for a sampling event. The sampling program required samples to be obtained at each of the three sampling sites during four separate precipitation events.

2.4. Targeted Analytical Parameters

A wide range of analytical parameters were required by the GVRD for characterization of both stormwater and suspended sediment samples. Broken down into five main groups, these include:

- Group 1 Bacteriology;
- Group 2 Inorganic and Physical Parameters;
- Group 3 Total and Dissolved Metals;
- Group 4 Organic Compounds; and
- Group 5 Toxicity.

Table 2.1 (in the Tables section following this report) summarizes the analytical requirements according to the above Groups for each of the sample sites. A detailed summary of the stormwater analytical parameters and the corresponding required (maximum) method detection limits (MDL) as specified by the GVRD is included in Table 2.2.

2.5. Suspended Sediment Sampling

The sampling program included composite sampling of suspended sediment in the stormsewer systems. Suspended sediment samples were obtained by GVRD staff using a flow-through centrifuge concurrent with one of the stormwater sampling events. A detailed summary of the suspended sediment analytical parameters and the corresponding required (maximum) method detection limits (MDL) as specified by the GVRD is included in Table 2.3.

2.6. Flow Measurement

Flow measuring devices were installed and maintained by GVRD personnel at each of the sampling locations (details provided in Section 3.4). The flow data will permit the GVRD to develop a unit hydrograph for each sample location for use during future monitoring efforts. For this program, the flow data for each routine sampling event were utilized in the preparation of a flow-proportioned composite sample.

3. FIELD SAMPLING METHODOLOGY

3.1. Sample Site Preparation

Prior to initiating the project, each of the sampling locations was evaluated to determine the optimum configuration and placement of the sampling equipment. For each site, it was determined that the sampling equipment would be situated on the ground surface with the suction tube placed into the flowing stormwater through the maintenance hatch.

In order to keep the suction tube in the optimum position, each site was fitted with a 50 mm diameter PVC plastic pipe with a threaded fitting connected to a 50 mm diameter stainless steel well screen approximately 0.9 m in length. The stainless steel well screen was open at the lower end to facilitate the flow-through of water and suspended sediment. At Still Creek and Wagg Creek, this sampling conduit passed through 150 mm diameter PVC plastic sleeves which were permanently anchored to the wall of the maintenance hatch. At the Serpentine River site, the conduit was attached to the maintenance hatch ladder. The configuration of the sampling conduit at each stormsewer sampling location is illustrated in Figures 3.1 through 3.3.

3.2. Sampling Equipment

Careful consideration went into the selection of the sampling equipment to ensure sufficient capacity and operational flexibility for this project. The sampling pumps had to be capable of providing sufficient sample volume within a 10-minute sampling period for the various combinations of analyses required by the routine event as described in Section 3.6. Other constraints to the selection of the sampling equipment included the absence of 120 volt AC power at each of the sites, the unpredictable frequency and timing of the sampling events, and the relatively high suction head at Wagg Creek and Still Creek. In addition, it would be difficult to access the stormsewer from inside the maintenance hatch as it is considered a confined space.

To obtain the stormwater samples, Morrow Environmental Consultants Inc. (MECI) staff utilized 12 volt, reversible and variable speed peristaltic pumps. One pump, with associated sample collection tubes, was configured and dedicated to each site. The pumps were powered by the field personnel's vehicle batteries.

Samples were collected through 6 mm internal diameter Teflon® tubing which had been lowered into the stormsewer via a sampling conduit to a point approximately 5 cm above the invert. The Teflon® tubing was connected via stainless steel compression fittings to approximately 0.5 m of peroxide cured silicon peristaltic pump tubing. This tubing was necessary for the pump to function optimally. On the pressure side of the pump, the silicon tube was connected to a stainless steel compression "T" fitting with one stem discharging into a tygon discharge tube. The other stem of the "T" was fitted into Teflon® tubing for sample collection. A hose clamp was used at the appropriate time to divert the water from the discharge tube into the sampling tube. The tubing configuration was specific for each sampling location and was dedicated to the location for the duration of the program. The sample tubing was removed from the sampling conduit between each sampling event.

There was a significant variation in sample pumping rate at each site due to variations in the depth of water. At Still Creek, the peristaltic pump was fitted with a Masterflex Standard Pump Head with a larger (#18) silicon tube in order to produce sufficient sample volume within the predetermined 10-minute sampling period (see Section 3.6 for details of sample collection and compositing during routine events). With this configuration, the pump produced approximately 600 mL per minute. The Wagg Creek pump was configured with an Easy Load Pump Head and #16 tubing, producing approximately 300 mL per minute. The Serpentine River pump was configured with an Easy Load Pump Head and #16 tubing, producing approximately 800 mL per minute.

In addition to the site specific set-up, a field kit was assembled for each sample location. A complete kit of equipment, documentation, bottles and coolers was stocked, ready and available for immediate use. All bottles were labelled in advance. The kit also consisted of a maintenance hatch cover puller, a plywood maintenance hatch safety cover, rain gauge, latex gloves, marking pens, sample collection field log, extra sample collection bottles for the various parameters, hazard warning cones, extra tubing, and tools for minor repairs.

3.3. Sample Collection and Handling

At the commencement of each event, stormwater was pumped for a minimum of five minutes to purge the tube. The peristaltic pump was run continuously to eliminate the need for purging between samples.

The requisite samples were collected according to the predetermined schedule as specified on the Sampling Field Record. Verification of sample collection was also recorded on the Sampling Field Record. Samples were collected by diverting the water into the appropriate sample bottle through the Teflon® sampling tube, filling the bottle to exclude all air, then sealing the bottle with a Teflon® lined lid.

Samples for volatile organics were obtained using the appropriate bottles containing preservatives supplied by the laboratory. As volatile organic samples cannot be reliably composited, these were collected as discrete samples (at the midpoint of each routine event). In order to minimize the loss of volatiles to the atmosphere, the samples were carefully poured down the side of the vial, and the vial was sealed with the Teflon® lined lid. Sampling equipment and tubing were not allowed to contact the sample container in order to avoid potential introduction of contaminants.

Following collection, the samples were placed into ice-chilled coolers. With the exception of volatile organic samples as noted above, the samples were not chemically preserved or filtered in the field. The samples were returned to MECI's Burnaby office until delivery to the laboratories for compositing and preparation for analysis as required. All samples were composited within 48 hours of the sampling event. (See Section 3.6 for a discussion of the compositing protocol used.)

3.4. Flow Measurement

Flow in the stormsewer at each of the sampling locations was measured continuously during the study period. The GVRD installed, calibrated and maintained depth-velocity meters at each of the sample locations. The velocity was measured by an ultrasonic velocity transducer (using the Doppler effect) or by an electromagnetic transducer. Depth was measured by a pressure transducer. The in-stream sensors were held in place by a clamping ring or anchor bar fitted to each location.

The flow measuring sensors were connected to data loggers mounted inside the maintenance hatch. Data were recorded at five minute intervals. GVRD staff downloaded the data on a weekly basis and immediately after completion of each sampling event. The flow data were then evaluated by GVRD using a program developed for each catchment relating depth to cross-sectional area for the culvert and utilizing the velocity measurements. The data were then validated by GVRD by means of a visual check and provided digitally to MECI.

All flow data are recorded by the GVRD in pacific standard time (PST) and are not adjusted during the time change period of daylight savings time (DST). However, all field data collected by MECI personnel were recorded in the current time period (i.e., DST in late spring and summer). This led to confusion with respect to the use of the correct flow data time interval for flow proportioned composite sample preparation. Only three of the routine event samples collected in 1996 were corrected for PST. These included the Still Creek sample collected 1996 05 12, and Serpentine River samples collected 1996 08 30 and 1996 09 04. This error was discovered once the field work was completed and the initial draft report issued. The Serpentine River sample, collected on 1996 08 30, was improperly composited due to limited flow data provided at the time.

Once the error related to PST/DST was discovered, it was determined that the routine event samples which were not properly corrected for PST in 1996 and the 1996 08 30 Serpentine River sample would be repeated. This required the flow sensors and data loggers to be re-installed in October 1997 by the GVRD in a similar manner as previously done in the 1996 program.

3.5. Sampling Event Initiation

MECI used the services of the Environment Canada Weather Office to provide forecasts for precipitation. In order to minimize false starts (i.e., mobilization to a site and initiation of sampling), the teams were placed on-call if the forecast called for greater than 3 mm to 5 mm of rainfall in a six-hour period. During the 1996 winter/spring events in April and May, the typical forecast was for in excess of 10 mm to 15 mm in a six-hour period; therefore, mobilization could be forecasted relatively easily. During the summer sampling events of July to September 1996, the degree of certainty that the necessary accumulation of rainfall would be achieved was significantly reduced by the convective nature of the typical summer rainfall events.

The second phase of the program was conducted in late 1997 and these events would be considered fall/winter events. The fall/winter events had similar weather patterns as those in the 1996 winter/spring events.

Once a storm event was forecasted, MECI would be in regular contact with Environment Canada to determine the anticipated arrival time of the system and the start of precipitation. Environment Canada tracked the systems and developed forecasts through the use of satellite imagery, Doppler radar, and computer modelling. In addition, they have weather stations operated by either Environment Canada or the GVRD on-line throughout the Greater Vancouver area and could determine when precipitation had been recorded. Once precipitation was observed by Doppler radar and/or recorded by the weather stations in the sampling areas or was anticipated to start within an hour, MECI personnel were mobilized. The sampling teams successfully mobilized to the site(s) within approximately one hour from the start of a precipitation event.

The required six hour antecedent dry period was verified by Environment Canada to determine if any recorded precipitation had occurred within six hours at the various weather stations located nearest to the sampling sites. In addition, a maximum recorded precipitation of 0.2 mm was used as a cut-off point for determining if precipitation had occurred and/or the start of precipitation for an event. This was agreed to by the GVRD and MECI to account for heavy dew which can occur in the late evening and/or early morning hours. This is also the lowest reading the weather station rain gauges can record in order to determine the start of precipitation.

3.6. Routine Event

By definition, a routine event consisted of a series of individual samples obtained every 10 minutes over a period of six hours (for a total of 37 samples), during which time a total accumulated rainfall of 3 mm (minimum) was required. The routine event samples were then composited on a flow-proportioned basis, homogenized, and decanted into the appropriate laboratory-supplied bottles. All samples were then shipped to the appropriate laboratories for analyses. Analytical parameters for the routine event included general and inorganic parameters, metals total and dissolved, organics and toxicity (see Table 2.2 for a summary). Separate discrete samples for bacteriological and volatile organics were collected at the midpoint of the routine event.

The flow data set, provided to MECI by the GVRD for the sampling location and period, was imported into an Excel© spreadsheet to calculate the appropriate individual sample volume to make up a flow-proportioned composite sample. The calculation of the proportion is based on the ratio of flow at any given sample time increment versus the maximum flow during the sampling period. For the sample obtained at the time increment with the highest flow, 100% of the sample was utilized. For each other time increment, the relative percentage was utilized. All sample volumes were normalized, where necessary, such that the total composite sample would fit into the 20 L glass carboy used for compositing. An example of a flow-proportioned composite calculation sheet is included as Table 3.1. The calculation sheets for each event have been provided in the appropriate Appendices in Volume II of this report.

The selection of sample bottle size for the routine event was critical to the success of the sampling program. It was apparent from the composite calculation methodology described above that a minimum sample volume of 13 L would have to be collected to permit the full complement of analytical parameters. Where flow rates had the potential to vary widely, it was possible that insufficient routine event composite sample volume would be available if the individual samples were too small. Without advance flow discharge rate data, MECI estimated that a minimum sample volume of one litre would have to be collected in order to ensure that a sufficient sample would be available for each time increment so that the minimum composite sample volume of 13 L was obtained. Therefore, MECI used one-litre amber glass bottles with Teflon® lids for individual sample collection. The jars were solvent rinsed and heat treated by the laboratory prior to packaging and delivery to MECI's Burnaby office.

3.7. Extended Event

For an extended event, a series of samples were collected every 30 minutes for a 10-hour duration (for a total of 21 samples), during which time a minimum rainfall accumulation of 5 mm was required. The Still Creek extended event was successfully completed concurrently with a routine event. The extended events at Wagg Creek and Serpentine River were completed with routine events in 1996; however, the routine events had to be repeated in 1997 due to flow compositing problems previously discussed.

The extended event samples were analyzed on an individual basis for general parameters and metals only. MECI utilized laboratory prepared one-litre rectangular polyethylene bottles to collect these samples.

3.8. Toxicity Event

During one routine event in each study area, samples were obtained for toxicity analysis at the same frequency as routine event samples with a total of 37 samples collected concurrently over a six-hour period at 10-minute intervals. Individual 1.75 L samples were collected and field composited in three 22 L collapsible polyethylene jugs for a total sample volume of 66 L required to conduct the toxicity tests. The sample containers were further composited and decanted into the appropriate sample size by the laboratory prior to toxicity testing.

Composited samples underwent several toxicity tests. These tests included liquid phase Microtox© *(Vibro fischeri)*, 96-hour rainbow trout survival, *Selenastrum capricornutum* growth and survival, and a *Ceriodaphnia dubia* survival and reproduction. The toxicity tests are described in detail in section 4.2.

3.9. Field Replicate Sample

The field replicate samples were obtained concurrently with the routine samples during one of the routine sampling events. The field replicate samples were collected in bottles of the same size and type in which the routine samples were collected and were composited using the same flow-proportioned composite ratios determined for the routine event samples. The same analyses as the routine event were conducted. The use of the field replicate samples in the QA/QC program is described in greater detail in Section 5.

3.10. Field Blank

Two sets of field blank samples were collected from each catchment. One set was collected during the 1996 phase of the field program and the other during the 1997 phase, as different sample collection tubing was used. Field blank samples were collected according to the field sampling protocol at each of the sampling sites using the dedicated site sampling equipment. The 1996 samples were collected by running distilled water provided by Quanta Trace Laboratories Inc. (QTL) through the sampling equipment. The 1997 field blanks were collected by running distilled water provided by Philip Analytical Services Corp. (Philip) through the sampling equipment which had been replaced since the initial (1996) phase of the program. These field blanks were collected in one-litre amber glass bottles and composited on an equal proportion (time composite) basis.

At both Still Creek and Serpentine River, both sets of field blank samples were collected during dry weather prior to the use of the equipment during a rainfall sampling event. These samples, therefore, represent equipment as well as field blanks for these two sites. At Wagg Creek, the field blank samples were collected after two of the routine events were completed. This allowed a comparison of the potential effect that the used sampling equipment may have had on the analytical results. The use of field blanks in the QA/QC program is discussed in Section 5.

3.11. Suspended Sediment Sample

Concurrent with a routine sampling event at each catchment sampling location, GVRD staff attempted to obtain a suspended sediment sample using an Alfa-Laval MAB103 centrifuge sampler (supplied by Environment Canada). A Marsh 5CMD submersible pump delivered stormwater to the continuous centrifuge at a rate of 4 L/min. The suspended sediment sampling period lasted longer than the routine event so that sufficient sample could be collected for the full suspended sediment analytical program.

The desired mass of suspended sediment sample was approximately 200 grams (wet basis) for chemical and toxicity (solid-phase Microtox©) analyses and 100 grams for particle size analyses. After nine hours of sampling, the Serpentine River sample weighed 136 grams (wet basis) and the Still Creek sample weighed 106 grams (wet basis). Because of this shortfall in sample mass, the mass of sample allocated to each of the laboratories had to be reduced and the particle size distribution had to be determined using a wet sieve technique.

A suspended sediment sample was not collected at Wagg Creek for this program because of the low suspended sediment content of the stormwater during sampling attempts.

3.12. Sample Collection Dates

The field program began on 1996 04 11 with the collection of the field blank at the Still Creek sampling site, and the initial field program was completed on 1996 09 04. Once the discrepancy was discovered, with respect to the flow data time reference which resulted in the improper preparation of flow-proportioned composite samples, the GVRD decided that 10 of the routine events had to be repeated. The initial field replicates were collected and prepared with routine events which were improperly prepared and, as such, required resampling as well. The field blanks were also repeated to verify the integrity of the new sample collection tubing.

The second phase of the field sampling program began on 1997 10 16 with the collection of the field blank at the Still Creek sampling site, and the second phase of the field program was completed on 1997 12 07. The date on which each sample was collected is summarized in Table 3.2.

4. DATA ANALYSIS METHODOLOGY

4.1. Comparison of Analytical Results

The analytical results obtained for the stormwater and suspended sediment samples were compared to:

- results from previous work performed by the GVRD;
- ranges of typical provincial urban runoff quality, as outlined in the BC Ministry of Environment, Lands and Parks (BC ELP) document entitled, *Urban Runoff Quality Control Guidelines for British Columbia - June 1992*; and
- the provincial working criteria (water/sediment) for freshwater aquatic life (Nagpal et al, 1995).

Based on discussions with the GVRD and the BC ELP, the aquatic life criteria for water and/or sediment are not applicable to stormwaters and suspended sediments contained within a stormsewer as these criteria apply to ambient waters outside of the dilution zone of 100 m downstream (and 100 m upstream in tidal areas) or ¼ the width of the stream from the discharge point (Swain, 1998), (McCallum, 1998). However, comparison was done for information purposes as stormwater from the sewer systems targeted for this study discharges to water bodies which support aquatic life.

Two previous stormwater studies commissioned by the GVRD were reviewed for comparison to the current work. The GVRD (1994) study examined contaminant levels in the Fraser Glen wet pond (Surrey) influent, effluent, and deposited sediments. The Norecol, Dames and Moore Inc. (1996) study examined stormwater discharges from both an industrial catchment (William Street, Vancouver) and a residential catchment (Fraserview, Vancouver).

4.2. Urban Runoff and Suspended Sediment Analyses

With respect to analytical methodologies, the laboratories followed the protocols outlined by the American Public Health Association, US Environmental Protection Agency, BC ELP, and Environment Canada. Table 4.1 summarizes the analytical methods used for various parameter groups.

4.2.1. Stormwater

The bacteriological samples were analyzed for both enterococci and fecal coliform counts. The enterococci levels were determined by the membrane filtration method (MF) and fecal coliform counts were determined by the multiple tube filtration method (MTFT) with both results expressed as the most probable number (MPN). Due to bacteriological analytical method limitations, data precision is limited for both analytical methods. The MF method is more accurate with an approximate accuracy of $c \pm 2\sqrt{c}$, where c is the MPN detected. The MTFT method has an approximate accuracy for the lower 95% confidence limit of approximately one-third of the MPN and an upper 95% confidence limit of three times the MPN. The relative accuracy of both tests should be considered when reviewing the bacteriological data.

Four different bioassays were conducted on stormwater samples: a 96-hour rainbow trout LC_{50} test; the Microtox© bacterial bioluminescence basic test using *Vibrio fischeri*; a chronic (growth and survival) test using the freshwater alga *Selenastrum capricornutum*; and a chronic (reproduction and survival) test using *Ceriodaphnia dubia*. These tests are further described below with a full description provided in the detailed analytical reports.

The rainbow trout bioassay is a 96-hour exposure test in which death is the endpoint. The concentration at which 50% of the test population dies (LC_{50} where LC is lethal concentration) is determined. A five concentration dilution series of 100%, 56%, 32%, 18% and 10% (volume effluent/volume dilution water) was used for each test effluent. The bioassay was conducted according to the methods described in Environment Canada's EPS 1/RM/9 (1990).

The Microtox© test utilizes a bioluminescent bacteria (*Vibrio fischeri*) to measure the inhibiting concentration of a toxic effluent that will cause a 50% (IC_{50}) and 20% (IC_{20}) decrease in light output by the organisms. The IC_{50} is the typical endpoint of the Microtox© basic test with 5, 15, and 30 minute exposure. The 15 minute IC_{50} is being reported in this study with readings taken at 5 and 15 minutes. The Microtox© basic test was conducted according to the method described in Environment Canada's EPS 1/RM/24 (1992) and the Microtox© manual (Microbics Corporation, 1992).

The *Ceriodaphnia dubia* test is an exposure test where the test endpoints are based on survival and reproduction. Test endpoints that were determined included the concentration at which 50% of the test population dies (LC_{50}), the concentration at which 25% and 50% less young are produced (IC_{25} and IC_{50}, respectively), the no observed effects concentration (NOEC), and the lowest observed effects concentration (LOEC). The *Ceriodaphnia dubia* test was conducted according to the protocol outlined in Environment Canada's EPS 1/RMS/21 (1992).

Selenastrum capricornutum was utilized to determine the concentration at which algal growth was inhibited by 50% (the IC_{50}). NOEC and LOEC were also determined. The test was conducted according to Environment Canada's EPS 1/RM/25 (1992) protocol.

4.2.2. Suspended Sediment

Suspended sediment samples were also subjected to the Microtox© test for *Photobacterium phosphoreum* bacteria. These tests were in accordance with the Solid Phase Large Sample Procedure described in Microtox© *Update Manual* dated December 1992 and the updated procedure summary issued by Microbics in May 1995.

4.3. Precipitation and Discharge Data

Two sources of precipitation data were available: MECI supplied on-site rain gauges and GVRD monitoring stations. The MECI on-site rain gauges provided data only for the sampling period and not for the time period before and after sample collection. Therefore, rain gauge data were only used to verify that precipitation requirements for sampling events were met. The GVRD monitoring station data provided hourly precipitation readings which included the time period before and after sampling. GVRD monitoring stations used in this program included:

- Wagg Creek - Site: DN53 - Firehall on Lynn Valley Road;
- Still Creek - Site: VA04 - Renfrew Elementary School; and
- Serpentine River - Bear Creek Park (1996 data), Site: SU56 - Whalley Reservoir (1997 data).

Precipitation data were supplied to MECI by the GVRD after completion of the sampling programs. Data from these weather stations were not accessible to Environment Canada for determining the start of precipitation for sampling crew call out purposes. Both MECI on-site rain gauge and GVRD monitoring station precipitation data are presented in the appropriate sections of Appendix II.

The GVRD provided MECI with flow data directly after the completion of a sampling event to allow for immediate preparation of the routine event samples. In many cases, the data only covered the time MECI personnel were on site sampling and not the time period before and/or after, which would show the full duration of the storm event. In addition, in many cases, the data set initially provided to MECI comprised raw data or single point flow measurements collected at five minute intervals. GVRD personnel made corrections to any obvious outlier data and compensated for instrument errors discovered in the downloading process. In these cases, the raw flow data retrieved by GVRD personnel were presented along with the corrected data and MECI was advised which data set was to be used for flow-proportioned composite sample preparation.

For each event, a second set of flow data was provided to MECI after completion of the field program which covered the time period of the entire field program. These data sets were based on the average or mean flow over the five minute reporting interval. These data sets were reviewed more thoroughly by GVRD flow monitoring personnel and corrections/adjustments were made to compensate for errors as described above. MECI has used these mean flow data sets for flow calculations and graphical presentation purposes in this report. These data are more representative of actual flows and provide more consistency between data sets for comparison of different storm events.

MECI reviewed both flow data sets provided by the GVRD and visually inspected them for outlier data, extreme changes in flow rate between recording intervals, and for overall data acceptability. Where outlier data or a large increase or decrease in flow rate were identified, the value was replaced with an average of the flow rates before and after the extreme value.

These corrections/adjustments were required for the flow-proportioned composite sample calculations, as an extreme increase in flow would skew the calculations resulting in inadequate sample volume being available for analysis. The full sample volume for the peak measured flow and flow-proportioned amounts of other samples are used for the composite sample preparation. If the flow-proportioned amounts are reduced due to low levels, then the total composite sample volume is also reduced, resulting in inadequate sample volume available to meet the analytical requirements.

All applicable original flow data sets provided by the GVRD are presented in Appendix II along with data sets containing adjustments/corrections made by MECI. Any changes made to the flow data sets by GVRD and MECI personnel are identified.

The applicable flow data set and GVRD monitoring station precipitation data were plotted together to assess the responsiveness of the catchment during each storm event and to illustrate the characteristics of the storm such as start time, intensity and duration. The antecedent dry period for each event was determined by reviewing hourly precipitation data recorded at the GVRD weather station nearest the sampling locations.

MECI notes that all manipulations and adjustments of data completed by MECI were done in accordance with general procedures which were accepted and authorized by the GVRD for this project.

5. QUALITY ASSURANCE AND QUALITY CONTROL

5.1. Field QA/QC

During sampling, field quality control was provided by using only laboratory-supplied sample containers, handling all samples according to the procedures specified in Section 3.3, and collecting all samples according to the schedule specified on the Field Sampling Records.

The integrity of the analytical data set was evaluated through the use of field blanks and field replicate samples. A field blank consists of de-ionized or distilled water that is transferred to the appropriate sample container after passing through the decontaminated field sampling equipment. Field blanks were used to assess the potential for contaminants to be introduced to subsequent samples from decontaminated sampling equipment. Field replicates consisted of two samples collected at the same time but labelled as different samples (i.e., blind). To collect sample replicates, both the sample and replicate containers were alternately filled 1/3 at a time until they were both full to maintain similar effluent quality. Field replicate samples were handled and analyzed in a manner identical to the routine samples. The analytical data for the field blanks and field replicates are summarized in Tables 5.1 to 5.7.

The United States Environmental Protection Agency (USEPA) sets data quality objectives for field blanks at five times the method detection limit (MDL) for a given analyte. Five times the MDL is commonly defined as the Practical Quantitation Limit (PQL); this represents the concentration above which values can be reliably quantified.

Two sets of field blank samples were collected from each catchment. One set was collected during the 1996 phase of the field program and the other during the 1997 phase as different sample collection tubing was used. Field blank samples were collected according to the field sampling protocol at each of the sampling sites. The field blanks consisted of laboratory prepared de-ionized and/or distilled water that was pumped to sample containers from plastic carboys rather than pumping stormwater from the sewer.

In both 1996 and 1997, the field blank samples were collected at the Still Creek and Serpentine River sampling locations during dry periods prior to pumping stormwater through the new collection tubing. These samples provided information on which contaminants (if any) were introduced to the stormwater samples from the new sampling equipment.

The field blank sample collected at the Wagg Creek sampling location on 1996 04 29 was collected after the extended and toxicity sampling events, while the sample collected on 1997 11 06 was collected between the second and third storm sampling events. During the 1997 phase of the field work, the Wagg Creek blank sample collected for volatile organic compound (VOC) analysis was prepared by using laboratory-supplied de-ionized water stored in one litre glass containers which was pumped through the collection tubing. This method was chosen after discussions with the laboratory (Philip Analytical Services Corp.) revealed that distilled water can contain chloroform which is not removed in the distilling process. All other blank samples submitted for VOC analysis were prepared with distilled water.

As shown in Table 5.1, up to seven inorganic and physical parameters, ten metals, and six organics were detected in the blank water samples. However, most detected parameter concentrations measured were below the PQL.

Three inorganic and physical parameters (bicarbonate, total alkalinity, and turbidity) were detected at concentrations above the PQL. All three parameter concentrations were above the PQL in the 1997 Wagg Creek field blank sample. Both bicarbonate and total alkalinity were detected in the Still Creek and Serpentine River 1997 field blank samples.

Three total metals (calcium, iron, and magnesium) were detected at concentrations greater than the PQL. Measured calcium concentrations were greater than the PQL in all three 1997 field blank samples. Iron was also detected at concentrations greater than the PQL in the Wagg Creek and Still Creek 1996 field blanks. Magnesium was detected at concentrations greater than the PQL in the 1997 Still Creek field blank sample.

Toluene was the only organic contaminant detected at concentrations greater than the PQL and this was in the field blank sample collected at Still Creek in 1997.

Chloroform was detected in five of the six blank samples. All five samples with detectable chloroform concentrations were prepared with distilled water. The only sample with no detectable chloroform concentration was prepared with de-ionized water. This appears to confirm Philip Analytical's concerns regarding the use of distilled water for preparation of blanks for VOC analysis as mentioned above.

The parameters detected at concentrations greater than the PQL in the field blanks collected at Wagg Creek suggest a small amount of certain analytes may have been carried over into a second water sample collected with the same tubing. However, the concentrations detected were significantly lower than those in the stormwater samples collected before and after the blank sample and do not influence the interpretation of the results. As such, carry over between samples due to sampling equipment is considered insignificant for the sampling protocol used during the project.

As mentioned above, the blank samples collected at Still Creek and Serpentine River were collected with new sampling equipment prior to collection of the routine samples. Potential sources of the parameters detected at concentrations greater than the respective PQLs include sampling or storage equipment and/or laboratory equipment. The concentrations of inorganic and physical parameters detected were significantly lower than the concentrations detected in the actual stormwater samples and, therefore, do not influence the interpretation of the results. The source of the anomalous concentration of toluene detected in the blank collected at Still Creek is unknown. Toluene was not detected in the samples collected after the blank nor was it detected in Philip's method blank. However, the concentration detected was much lower than the referenced aquatic life criteria (Nagpal et al, 1995) and, therefore, does not influence the interpretation of the results.

The second method for evaluating the integrity of the analytical data was the use of field replicate samples at each of the sampling locations. During one storm event at each study area, a second (or replicate) sample was collected at the same time as the routine event sample. Three field replicate samples were collected during the extended events (one per area). For the field replicates, the relative percent difference between the field replicates (RPD_{REP}) was calculated for parameters where the concentration measured in both samples was greater than the PQL. The RPD_{REP} is defined as the absolute value of the difference between the two samples divided by the average of the two samples.

There are no accepted standards for use in measuring the variability of field replicate samples. *Standard Methods for the Analysis of Water and Wastewater* (American Public Health Association, 1995) specifies acceptable RPD_{REP} for various parameters; however, these values are for laboratory replicates and are not considered applicable to field replicates. Field replicates exhibit higher RPD_{REP} due to sampling variability because parameters, such as metals, are strongly affected by the suspended sediment load in a given sample. Quality assurance limits for RPD_{REP} values are determined from statistical distributions of historical data sets and generally represent a point on the distribution beyond which the replicates do not agree at the 95% confidence interval. For the purposes of this project, an arbitrary limit of RPD_{REP} = 50% has been used to evaluate the data.

The results of the analyses conducted on replicates and the calculated RPD_{REP} values are presented in Tables 5.2 to 5.7. Of the RPD_{REP} values calculated, 90% of the data met the data quality objective for the project. Based on this fact, the data collected during this investigation are considered reliable. The remaining 10% of the RPD_{REP} values that were greater than the QA limit were associated primarily with a replicate pair collected from Still Creek (Event #3). Potential causes for the disagreement between this replicate pair include sample switching or sample heterogeneity.

For a QA/QC program to be considered an external review of laboratory performance, all field replicate samples and field blanks must be submitted to the laboratories labelled as regular samples (i.e., "blind"). MECI's experience indicates that sample switching in the laboratory is by far the biggest source of error in water and soil sampling programs. The submission of blind QA samples is an effective way to identify this error. For this study, the 1996 field replicates and field blanks were not submitted in this way; therefore, this external QA/QC program was equivalent to the laboratories' internal QA/QC programs and, as such, these QA/QC sample results do not offer significant insight into the potential for laboratory errors associated with sample switching. However, the reproducibility of the concentrations measured in the field replicates appears to indicate that the sampling procedure has a relatively high degree of precision.

The 1997 field blanks and replicates were submitted blind to the laboratory as they were only identified with an abbreviation of the catchment and a sample number (i.e., the Wagg Creek field blank sample was identified as WC-3). However, the laboratory prepared the flow-proportioned composite sample and all of the field blank aliquots were of the same volume. This could have indicated to the laboratory personnel that these samples may be blanks or spiked samples. The 1997 field replicates were submitted at the same time as the routine event samples (with the dissolved metals analysis conducted on the routine event sample). A different total composite sample volume with different aliquot volumes was used for the routine event sample (with dissolved metals) when compared to the replicate sample volumes. This limits the possibility that laboratory personnel could identify the samples as replicates.

5.2. Laboratory Internal QA/QC Program

The accuracy of the analytical results was measured using the laboratories' internal QA/QC programs. All QA documentation provided by the analytical laboratories are included in their reports in Volume II. The following lists the methods utilized by the laboratories to ensure analytical integrity:

1) laboratory replicate samples were prepared and analyzed;

2) surrogate standards were used for organic analyses to evaluate contaminant recoveries;

3) instrument calibrations were checked in the middle of analytical runs; and,

4) reference samples were analyzed and compared to the known values.

In addition to the above methods, Quanta Trace Laboratories also verified selected parameters by analyzing samples by alternative (acceptable) protocols.

The three primary laboratories used for this study were Analytical Service Laboratories, Philip Analytical Services, and Quanta-Trace Labs. All are accredited for specific analyses by the Canadian Association of Environmental Analytical Laboratories (CAEAL) under the authority of the Standards Council of Canada. CAEAL accreditation means that the labs are required to meet accepted standards for data management, sample tracking, instrument calibration, QA/QC procedures, etc. Summaries of ASL's, Philip's and Quanta-Trace's internal QA programs (as provided by the laboratories) are included in Appendix IV.

In summary, the ASL report indicated that none of the analyzed parameters were detected in any of the internal method blanks. Matrix spike recoveries were generally within acceptable ranges with the exception of several dibenzo-pyrenes, phthalates, naphthalene and 2-chlorophenol. Dibenzo-pyrenes have very high boiling points and, therefore, are more susceptible to chromatographic variability with low recoveries. Phthalates are common laboratory contaminants found in plastics resulting in elevated spike recoveries. Naphthalene and 2-chlorophenol could not be chromatographically resolved.

The Philip report indicated that all recommended holding times were met. Method blanks for chloroform and alkalinity concentrations exceeded Philip's criteria. Chloroform is a disinfection by-product that is concentrated during distillation of city water. Alkalinity was measured due to a pH difference between de-ionized water (pH = 5.5) and the titration end point (pH = 4.5) and was not a result of hydroxide or carbonate in the blanks. All duplicate samples met QA standards with an average absolute relative percent difference of 3.5%. Blank spike, matrix spike and surrogate standard recoveries for the overall project were generally considered acceptable.

The QA/QC data provided by Quanta Trace Laboratories presented the results of analyses conducted on a de-ionized water sample that was stored in an ASL sample bottle overnight. None of the parameters analyzed in the blank rinse water were detected at concentrations greater than their respective PQLs. Certified reference material (CRM) recoveries conducted concurrently with the project samples were within acceptable ranges for the analyzed parameters. In addition, all Quanta Trace internal laboratory replicate sample analysis were within acceptable limits.

For toxicity testing, control groups placed in dilution water were used in conjunction with the individual tests, and toxicity testing with reference toxicants was used to verify the accuracy of the various testing procedures. The reference toxicant testing results are presented in Table 5.8 and indicate they are within acceptable limits verifying the accuracy of the toxicity tests. Further details of the QA/QC program conducted with the toxicity testing are presented in the detailed analytical reports attached in Volume II.

The internal laboratory QA/QC programs described above have verified the accuracy of the analytical methods based on the accuracy and/or repeatability of the internal QA/QC samples.

6. RESULTS FOR WAGG CREEK CATCHMENT AREA

6.1. Precipitation and Discharge Data

The GVRD provided hourly precipitation data recorded at the weather station located at the firehall on Lynn Valley Road in the District North Vancouver and flow discharge data recorded by the stormsewer sample location data logger. The data for each sampling event are graphically presented in Figures 6.1 to 6.6. Detailed data sets, including the recorded depth and velocity measurements with calculated flow rates, are included in Appendix II. The flow rates used for the compositing of routine event samples are also identified in Appendix II. Table 6.1 summarizes the event dates, minimum flows, maximum flows, average (or mean) flows, and total recorded volume discharged. The total event precipitation recorded by MECI field personnel using portable rain gauges is also presented in Table 6.1.

The initial flow data sets for routine events #1 and #3 provided by the GVRD were identical to the second data set provided by the GVRD after the completion of the field program. MECI did not make any adjustments to these data sets for composite sample volume calculation or for graphical presentation of flow. However, GVRD flow personnel noticed instrument error in depth readings when downloading the flow data for routine event #3 and adjusted the depth and flow readings accordingly.

The flow data sets for routine events #2 and #4 provided by the GVRD were slightly different than the second data sets (used for graphical presentation only). The initial or raw flow data were used to calculate the composite sample volumes and no adjustments were made by MECI to these data. The second or mean flow data sets were used for graphical presentation of flow data. No adjustments were made to the second data set with the exception of one routine event #2 data point at 9:13 which appeared to represent an extreme change in flow rate. MECI adjusted the flow rate for this data point to the average of the data points prior to and after this time period. In addition, this data set contained a gap in the 5-minute data point intervals with one data point on 1997 11 03 at 8:25 and the next at 8:38. This appears to have been caused by the data logger being off-line during data download for the raw data file.

The extended and toxicity event flow data provided by the GVRD are those for the mean or average flow, and were used for graphical presentation of flow data. No adjustments were made to these data with the exception of extended event obvious outlier data between 11:35

and 12:10 based on depth readings of 8,191 mm. MECI adjusted the flow to the average of the data points before and after this time period as the corresponding recorded velocity readings appeared to be in line with this adjustment.

Suspended sediment sampling attempts were not successful at Wagg Creek. Therefore, no flow data have been presented.

All four routine events were conducted from October to December in 1997 and the extended and toxicity events were both conducted in April 1996. All sampling events for this catchment were conducted during storm events of similar climatic conditions as they occurred during the wetter months from October to early May. The storms are predictable during this time with precipitation more evenly dispersed throughout the Greater Vancouver area.

The antecedent dry periods for the first three routine events and the extended and toxicity events were of similar duration with a range of 36 to 53 hours. Routine event #4 was the only sampling event that occurred after a long antecedent dry period (seven days).

The toxicity event had the highest recorded event precipitation (18.5 mm) based on MECI rain gauge measurements by field personnel for the six hour duration. The recorded precipitation levels were similar for all four routine events, ranging from 8.7 mm (routine event #1) to 12 mm (routine event #4).

By comparing the precipitation and flow curves in Figures 6.1 to 6.6, the Wagg Creek catchment response rate appears to be quite well defined in all cases, particularly in Figures 6.4 and 6.5. There is a distinct increase in flow immediately after a recorded precipitation of 2 mm or more. However, when reviewing the data, note that precipitation is presented on an hourly basis and could have occurred at any time and at varying rates during this one hour period.

6.2. Bacteriology

The bacteriological data are summarized in Table 6.2 and the detailed analytical reports are included in Appendix II.

All four bacteriology samples collected from the Wagg Creek stormwater catchment (one per routine event) were analyzed for the presence of *enterococci and fecal coliforms*. With the exception of routine event #1, the results for both parameters were all within a similar range for all four events, given the accuracy of the analytical methods (as discussed in Section 4.2).

There are no aquatic life criteria (Nagpal et al, 1995) or guidelines for urban runoff quality (BC Research Corp., 1992) which are applicable for comparison of these results.

6.3. Inorganic and Physical Parameters

The analytical results for inorganic and physical parameters for the four routine events and the extended event are summarized in Table 6.2. Also provided in the table are the provincial working criteria for freshwater aquatic life (Nagpal et al, 1995) and ranges of typical provincial urban stormwater runoff quality (BC Research Corp., 1992), for comparison purposes. Any references to criteria or runoff quality in this section apply to these two references. The tabulated analytical results for the extended event and the detailed analytical reports are included in Appendix II.

All inorganic and physical parameters were detectable in all four routine events with the exception of 5 day biochemical oxygen demand (BOD_5) and ortho-phosphate. The concentrations of inorganic and physical parameters measured in the Wagg Creek samples were less than the provincial aquatic life criteria (where criteria exist) and all were within the range of typical urban runoff values, where data were available.

The measured conductivity and chloride concentration were higher during Event #4 when compared to the other three events. This may indicate a higher ionic content in the stormwater, although dissolved metal data are not available for these two events to confirm this interpretation.

6.4. Total and Dissolved Metals

The analytical results for metals parameters for the four routine events and the extended event are summarized in Table 6.3. The provincial working criteria for freshwater aquatic life (Nagpal et al, 1995) and ranges of typical urban stormwater runoff quality (BC Research Corp., 1992) have also been provided for comparison purposes. Any references to criteria or runoff quality in this section apply to these two references. These metals parameters are specified for total metals with the exception of aluminum where the criterion specified is for dissolved metals. The tabulated analytical results for the extended event and the detailed analytical reports are included in Appendix II.

The concentrations of seven total metals (cadmium, chromium, copper, iron, lead, mercury, and zinc) exceeded the provincial aquatic life criteria in one or more samples, but the concentration of dissolved aluminum did not exceed the aquatic life criteria. Specific concentrations which exceeded the aquatic life criteria are summarized as follows:

- total copper concentrations in all four routine event samples and in twenty of the twenty-one extended event samples;
- total iron concentrations in all four routine event samples and in all but five of the extended event samples;
- total zinc concentrations in two of the routine event samples and in five of the extended event samples;
- total chromium concentrations in one of the routine event samples and three extended event samples;
- total cadmium concentration during routine event #4; and
- total mercury concentrations in routine event #1.

Data for typical urban runoff quality were only available for seven total metals: arsenic, cadmium, chromium, copper, lead, nickel, and zinc. The concentrations of these metals detected in the Wagg Creek samples were within the range of typical urban runoff quality as shown in Table 6.3.

6.5. Organic Parameters

Analytical results for detected organic parameters in the Wagg Creek stormwater samples are summarized in Table 6.4. The provincial working criteria for freshwater aquatic life (Nagpal et al, 1995) and ranges of typical urban stormwater runoff quality (BC Research Corp., 1992) have also been provided for comparison purposes. Any references to criteria or runoff quality in this section apply to these two references. The detailed analytical reports are included Appendix II.

Most organic parameter concentrations were less than the laboratory detection limits. A total of 20 parameters were detected altogether, with a maximum of 13 parameters detected in one sample (routine event #4) and a minimum of three parameters in another (routine event #3). With the exception of pyrene, all measured concentrations were less than the aquatic life criteria. Total measured polycyclic aromatic hydrocarbons (PAH), and oil and grease concentrations were within the ranges found in typical urban stormwater runoff. No other data were available for organic parameters in typical urban stormwater runoff.

Methylphenanthrene was the only organic compound (a PAH) detected in all four routine event samples. Fluoranthene, methylnaphthalenes, pyrene, nonylphenol, and oil and grease were detected in three of the four routine event samples. All other detected organic compounds were present in only one or two of the samples.

6.6. Toxicity

The toxicity results for the Wagg Creek stormwater sample, dated 1996 04 25, are presented in Table 6.5. The detailed analytical report is included in Appendix II.

The Wagg Creek stormwater sample did not have a toxic effect on *Vibrio fischeri* (Microtox© basic test), rainbow trout or *Selenastrum capricornutum* algae. However, the stormwater was found to have inhibiting and lethal effects on *Ceriodaphnia dubia* reproduction with an LC_{50} concentration of 71%, and an IC_{50} concentration of 53% as shown in Table 6.5. No effect on the growth of *Selenastrum capricornutum* algae was noted with the Wagg Creek stormwater sample at the maximum concentration of 90.9%.

6.7. Suspended Sediment

No suspended sediment sample was collected from the Wagg Creek catchment during this sampling program.

7. RESULTS FOR STILL CREEK CATCHMENT AREA

7.1. Precipitation and Discharge Data

The GVRD provided hourly precipitation data recorded at the weather station located at the Renfrew Elementary School on 22nd Avenue in Vancouver and flow discharge data recorded by the stormsewer sample location data logger. The data for each sampling event are graphically presented in Figures 7.1 to 7.6. Detailed data sets including the recorded depth and velocity measurements with calculated flow rates are included in Appendix III. The flow rates used for the compositing of routine event samples are also summarized in Appendix III. Table 7.1 summarizes the event dates, minimum flows, maximum flows, average (i.e., mean) flows, and total recorded volume discharged. The total event precipitation recorded by MECI field personnel using portable rain gauges is also presented in Table 7.1.

The initial combined routine event #1/extended event raw flow data set provided by the GVRD after sampling was different than the second set of mean flow data provided after the completion of the field program. MECI used the raw flow data to prepare the flow-proportioned composite sample. Routine event sample number 29 was supposed to be collected at 1:48 and was apparently missed and was collected at 1:58 instead. MECI adjusted the flow-proportioned composite calculation sheet to account for this error.

The time reference for routine event #1 mean flow data provided by the GVRD was adjusted forward by two minutes for graphical presentation purposes only. In addition, this data set contained obvious outlier flow data recorded at 19:03 and 20:23 with 0 L/s flow recorded. MECI adjusted these two data points to the average of the flow rates prior to and after. Both of these data points were outside the routine event sample collection time period. No other adjustments were made and the adjusted mean flow data set was used for graphical presentation purposes.

The initial flow data provided by the GVRD for the remaining three routine events were identical to the second data set and MECI did not make any adjustments to these data for composite sample volume calculation. However, the second flow data set for routine event #2 had been corrected by GVRD personnel to compensate for obvious velocity errors based on depth readings.

The flow data for routine event #3 contained obvious outlier flow data based on depth readings recorded between 6:00 and 6:15, and at 9:05 with 0 L/s flow recorded at a significant depth reading. An additional flow data point recorded at 9:10 also showed an unusually low flow rate based on the depth reading. MECI adjusted these data points to the average of the flow rates prior to and/or after for graphical presentation purposes only.

The routine event #4 flow data had been adjusted by GVRD personnel to compensate for errors in depth readings discovered during data download. The adjustments were made by GVRD personnel until the 10:00 data point but did not cover the full five hour time period after the end of sampling required for graphical presentation of the storm. Therefore, MECI used the non-corrected raw data from 10:00 to 12:30 for graphical presentation purposes only as the raw data are similar to the adjusted data and would provide the general flow characteristics of the storm.

The toxicity event and suspended sediment sampling event flow data provided by the GVRD represent the mean or average flow and no adjustments were made to either data sets by MECI.

Routine event #1, the extended event, and the toxicity event were all conducted in May 1996 and the last three routine events were conducted during the period of October to December in 1997. All of these events were conducted during storm events of similar climatic conditions as they occurred during the wetter months of October to early May. These storms are predictable during this time with precipitation more evenly dispersed throughout the area.

The suspended sediment sampling event was completed in July 1996 during the drier summer period when storms were more convective in nature and less predictable. These storms tend to be more concentrated and occur as heavy showers. Tracking them and estimating the anticipated precipitation is more difficult than for storms which occur during the wetter seasons.

The antecedent dry periods for the last three routine events and the toxicity event were similar in duration with a range of 24 to 45 hours. Routine event #1 and the suspended sediment sampling event both occurred after a long antecedent dry period of 5 days and 14 days, respectively.

The total recorded precipitation was similar for all four routine events based on MECI rain gauge measurements made by field personnel. Routine event #4 had the highest recorded routine event precipitation of 9.1 mm and routine event #2 had the lowest recorded routine event precipitation of 8.0 mm. The toxicity event experienced the lowest recorded precipitation with an accumulation of 4.2 mm. The extended event sampling was completed at the same time as routine event #1 and a total accumulated precipitation of 10.8 mm was recorded over a ten-hour period. No MECI rain gauge data are available for the suspended sediment event as MECI personnel were not on site at the time of suspended sediment sampling.

By comparing the precipitation and flow curves in Figures 7.1 to 7.6, the Still Creek catchment response rate appears to be quite well defined for all routine and extended events, particularly routine events #1, #3, and #4 (i.e., Figures 7.1, 7.3 and 7.4). There is a distinct increase in flow immediately after a recorded precipitation of 1 mm or more. However, when reviewing the data, one must remember that precipitation is presented on an hourly basis and could have occurred at any time and at varying rates during this one hour period. This could explain the varying flow rates indicated in Figure 7.2

7.2. Bacteriology

The bacteriological data are summarized in Table 7.2 and the detailed analytical reports are included in Appendix III.

All four bacteriology samples collected from the Still Creek stormwater catchment (one per routine event) were analyzed for the presence of *enterococci and fecal coliforms.* The results for both parameters were all within a similar range for all four events, given the accuracy of the analytical methods (as discussed in Section 4.2). There are no aquatic life criteria (Nagpal et al, 1995) or guidelines for urban runoff quality (BC Research Corp., 1992) which are applicable for comparison of these results.

7.3. Inorganic and Physical Parameters

The analytical results for inorganic and physical parameters for the four routine events and the extended event are summarized in Table 7.2. They are presented with the provincial working criteria for freshwater aquatic life (Nagpal et al, 1995) and ranges of typical urban stormwater runoff quality (BC Research Corp., 1992) which have been used for comparison purposes only. Any references to criteria or runoff quality in this section apply to these two references. The tabulated analytical results for the extended event and the detailed analytical reports are included in Appendix III.

All inorganic and physical parameters were detectable in all four routine event and extended event samples with the exception of total suspended volatile solids (TVSS), ammonia, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and ortho-phosphorus. BOD was only detected in one routine event sample. Ortho-phosphorus was detected in two routine event samples and ammonia, COD, and TVSS were non-detectable in only one sample. The concentrations of inorganic and physical parameters measured on the Still Creek samples were less than the provincial aquatic life criteria (where criteria exist) and all were within the range of typical urban runoff values, where data were available.

The measured bicarbonate, total alkalinity concentration, and conductivity reading were higher during routine event #3 when compared to the other three events. This would suggest a slightly higher ionic content in the stormwater. Although dissolved metals data are available for these two events, it is difficult to confirm this interpretation based on the limited parameters.

7.4. Total and Dissolved Metals

The analytical results for metals parameters for the four routine events and the extended event are summarized in Table 7.3. Also provided in the table are the provincial working criteria for freshwater aquatic life (Nagpal et al, 1995) and ranges of typical urban stormwater runoff quality (BC Research Corp., 1992), for comparison purposes. Any references to criteria or runoff quality in this section apply to these two references. These metals parameters are specified for total metals with the exception of aluminum where the criterion specified is for dissolved metals. The tabulated analytical results for the extended event and the detailed analytical reports are included in Appendix III.

The total concentrations of eight metals (cadmium, chromium, copper, iron, lead, manganese, silver, and zinc) exceeded the provincial aquatic life criteria in one or more samples. Specific results in which concentrations exceeded the aquatic life criteria are summarized as follows:

- Total concentrations of copper and zinc in all four routine event samples and in all twenty-one extended event samples;
- Total iron concentrations in all four routine event samples and in twenty of the extended event samples;
- Total cadmium and chromium concentrations in three of the routine event samples and in one (cadmium) and three (chromium) extended event samples;

- Total manganese concentrations in two routine event samples and in one of the extended event samples;
- Total silver concentrations in 13 of the extended event samples; and
- Total lead concentrations in one routine event sample.

Data for typical urban runoff quality were only available for seven total metals: arsenic, cadmium, chromium, copper, lead, nickel, and zinc. The concentrations of these metals detected in the Still Creek samples were within the range of typical urban runoff quality as shown in Table 7.3.

7.5. Organic Parameters

Analytical results for detected organic parameters in the Still Creek stormwater samples are summarized in Table 7.4. The provincial working criteria for freshwater aquatic life (Nagpal et al, 1995) and ranges of typical urban stormwater runoff quality (BC Research Corp., 1992) are also provided for comparison purposes. Any references to criteria or runoff quality in this section apply to these two references. The detailed analytical reports are included Appendix III.

Most organic parameter concentrations were less than the laboratory detection limits. Twenty-five parameters were detected altogether with a maximum of 22 parameters detected in one sample (routine event #2) and a minimum of one parameter (routine event #1). With the exception of benzo(a)pyrene and pyrene, all measured concentrations were less than the aquatic life criteria. Total measured PAH, and oil and grease concentrations were within the ranges found in typical urban stormwater runoff. The pentachlorophenol concentrations in the routine event #2 sample exceeded the aquatic life criterion. No other data were available for organic parameters in typical urban stormwater runoff.

Pyrene was the only organic parameter detected in all four routine event samples. Dimethylnaphthalenes, fluoranthene, methylnaphthalenes, methylphenanthrenes, nonylphenol, pyrene, and toluene were detected in three of the four routine event samples. All other detected organic parameters were present in only one or two of the samples.

7.6. Toxicity

The toxicity results for the Still Creek stormwater sample, dated 1996 05 21, are presented in Table 6.5. The detailed analytical report is included in Appendix II.

The Still Creek stormwater sample did not have a toxic effect on *Vibrio fischeri* (Microtox© basic test), rainbow trout or *Selenastrum capricornutum*. However, stress was reported on the rainbow trout test subjects at 48 hours in a 100% solution and at 96 hours in a 56% solution. The LC_{50} and IC_{50} concentrations were found to be >100% for *Ceriodaphnia dubia,* with the IC_{25} concentration determined at 73% and the NOEC and LOEC determined at 50% and 100%, respectively. The Still Creek stormwater sample had a lowest observable effect concentration of 90.91% on the growth of *Selenastrum capricornutum* algae with no observable effect at a concentration of 30.3%.

7.7. Suspended Sediment

A suspended sediment sample was collected from Still Creek on 1996 07 17. The suspended sediment was analyzed for various inorganic and organic parameters as listed in Table 2.3. The laboratory results for the suspended sediment samples are summarized in Tables 7.5 to 7.7 and the detailed analytical reports are included in Appendix III. Also provided in the tables are the provincial working criteria for freshwater aquatic life (Nagpal et al, 1995) and the concentrations detected in the Fraser Glen stormwater study (GVRD, 1994), for comparison purposes. Any references to criteria or the Fraser Glen Study in this section apply to these two references.

Particle size analysis performed on the Still Creek suspended sediment indicates that the majority of the suspended sediment is composed of silt and clay material (95.9%), <0.053 mm in size. The remaining material is comprised of sand which is <2.0 mm and >0.053 mm in size.

There are eleven metals for which provincial aquatic life sediment quality criteria are available, and all eleven of the detected metals concentrations exceeded these criteria as shown in Table 7.5. All of the metals detected at concentrations exceeding the aquatic life sediment quality criteria were at higher concentrations than those found in the Fraser Glen stormwater study.

As shown in Table 7.6, a range of organic parameters was detected in the Still Creek suspended sediment sample, including mono- and polycyclic aromatic hydrocarbons (PAH), phthalate esters, chlorinated and non-chlorinated phenols, and extractable hydrocarbons. The freshwater aquatic life criteria were exceeded for hexachlorobenzene, polychlorinated biphenyls (PCB 1260), and four PAH parameters for which specified criteria are provided (i.e., benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, and pyrene). Sediment quality criteria are specified for phthalate esters in marine water (as opposed to freshwater) environments and two of the five phthalate ester concentrations exceeded these criteria.

Other organic parameters detected were oil and grease and total petroleum hydrocarbons. Oil and grease (total) was measured at 27,200 mg/kg (dry weight basis) according to the standard gravimetric method analysis and total petroleum hydrocarbons were measured at 14,000 mg/kg.

A review of Table 7.7 shows the presence of dioxins and furans in the suspended sediment sample at a concentration of 165.7 pg/g when expressed as 2,3,7,8-TCDD equivalents. There are no freshwater aquatic life sediment criteria for dioxins or furans.

The results of the solid-phase Microtox© bioassay indicated that the Still Creek suspended sediment sample had a 10-minute inhibiting concentration (IC_{50}) of 546 mg/L on *Vibrio fischeri*.

8. RESULTS FOR SERPENTINE RIVER CATCHMENT AREA

8.1. Precipitation and Discharge Data

The GVRD provided hourly precipitation data recorded at the weather station located in Bear Creek Park (central Surrey) for the 1996 portion of the field program, and Site: SU56 located at the Whalley Reservoir (North Surrey) for the 1997 field program. The flow discharge data were recorded by the stormsewer sample location data logger. Detailed data sets including the data for each sampling event are graphically presented in Figures 8.1 to 8.6. The recorded depth and velocity measurements with calculated flow rates are included in Appendix IV. The flow rates used for the compositing of routine event samples are also summarized in Appendix IV. Table 8.1 summarizes the event dates, minimum flows, maximum flows, average flows and total recorded volume discharged. The total event precipitation recorded by MECI field personnel using portable rain gauges is also presented in Table 8.1.

The initial routine event #1 raw flow data set provided by the GVRD after sampling was different than the second set of mean flow data provided after the completion of the field program. MECI used the raw flow data to prepare the flow-proportioned composite sample. Due to the short duration of recorded flow during the sampling event, inadequate sample volume would be generated by using the raw flow data as provided. MECI adjusted the flow-proportioned composite calculation sheet by reducing peak flows and assigning flows to other data points based on depth readings in order to generate adequate sample volume. No adjustments were made to the mean flow data set and it was used for graphical presentation purposes.

Both flow data sets provided by the GVRD for routine events #2, #3, and #4 were the same and did not require any adjustments by MECI for either composite sample volume calculation or for graphical presentation purposes. No flow data set was provided for routine event #3 for the time between 12:15 to 12:35 as this is when the initial data set was being downloaded after the sampling event. The flow data set provided for routine event #4 was adjusted by GVRD personnel to compensate for errors in depth readings.

The mean flow data provided after the completion of the sampling program were used for graphing the extended event and suspended sediment sampling event (1996 04 22) and the toxicity event (1996 08 30). These flow data are only used for graphical presentation as no routine event samples were collected during these events. The flow data provided for the

1996 04 22 events contained obvious outlier data based on velocity readings which were >5 m/s and others with velocity readings of 0 m/s located between data points with significant flows and similar depths. These data points were adjusted by MECI to the average of the data points prior to and after for graphical presentation purposes.

The Serpentine catchment is drier than the other two catchments covered in this study and, consequently, the completion of the program in this area was more difficult. The initial phase of the sampling program was not completed until 1996 09 04 due to climatic conditions. The second phase of the sampling program was completed with less difficulty but this catchment was still the most difficult to sample of the three catchments.

Routine event #1 and the toxicity event were completed during the drier part of the year in late summer when storms were more convective in nature and less predictable. These storms tend to be more concentrated over a small area and occur as heavy showers as indicated in routine event #1 where the collection of over 5 mm of rain was recorded in a 30 minute period. Tracking these storms and estimating the anticipated precipitation was also more difficult.

The other three routine events were conducted during October to December in 1997 and the extended and suspended sediment sampling events were conducted in late April of 1996. All of these events were conducted during storm events of similar climatic conditions as they occurred during the wetter months of October to early May. These storms are more predictable during this time with precipitation more evenly dispersed throughout the area.

The antecedent dry periods for the first three routine events were of similar duration with a range of 29 to 42 hours. The extended and suspended sediment sampling event was completed after an antecedent dry period of four and a half days. Routine event #4 and the toxicity event both were completed after long antecedent dry periods of seven days and ten days, respectively.

The amount of recorded precipitation was similar for all four routine events based on MECI rain gauge measurements made by field personnel. Routine event #1 had the highest recorded routine event precipitation of 12.0 mm and routine event #4 had the lowest recorded routine event precipitation of 8.8 mm. The lowest recorded precipitation of 4.0 mm was during the toxicity event. The extended event sampling was completed at the same time as suspended sediment sampling, with a total accumulated precipitation of 14.5 mm over a 10-hour period.

However, no MECI rain gauge data are available for the suspended sediment event as MECI personnel were not on site for the full duration of suspended sediment sampling.

Although the routine events had very similar total recorded precipitation, the flow rate for event #3 was five times that of event #1. Routine event #1 occurred late in the afternoon during the drier summer months when the permeable land cover would be drier, so that a significant amount of the precipitation could have been absorbed. Routine event #3 occurred during the wet season when the ground would be expected to be more saturated. This same characteristic is also indicated for the toxicity event which occurred five days before event #1, received half the precipitation of routine event #3, but only one-tenth the total flow volume was recorded. The majority of the flow for routine event #1 occurred during a very brief period and this event had the highest recorded flow rate of all of the events.

When reviewing the precipitation/flow graphs, one must consider the fact that the 1996 precipitation data recorded by the GVRD was collected at the Bear Creek Park weather station which is located approximately 4.0 km to the south of the catchment. This could affect the accuracy of the recorded precipitation data with respect to the actual precipitation which occurred within the sampling catchment. The 1997 precipitation data were recorded at the Whalley Reservoir which is closer to the catchment. Therefore, it is expected that the 1997 precipitation data would be more representative of the actual catchment.

For the Serpentine River catchment, an increase in precipitation was followed by a corresponding increase in flow rate. This is particularly evident in the last three routine events where the flow curves closely paralleled the precipitation curves (Figures 8.2 to 8.4). The precipitation and flow curves for routine events #3 and #4 (Figures 8.3 and 8.4) show that the flow response is similar and almost immediate when compared to the increase in precipitation.

8.2. Bacteriology

The bacteriological data are summarized in Table 8.2 and the detailed analytical reports are included in Appendix IV.

All four bacteriology samples collected from the Serpentine River stormwater catchment (one per routine event) were analyzed for the presence of *enterococci and fecal coliforms*. The results for both parameters were all within a similar range for all four events, given the accuracy of the analytical methods (as discussed in Section 4.2). There are no aquatic life criteria

(Nagpal et al, 1995) or guidelines for urban runoff quality (BC Research Corp., 1992) which are applicable for comparison of these results.

8.3. Inorganic and Physical Parameters

The analytical results for inorganic and physical parameters for the four routine events and the extended event are summarized in Table 8.2. Also provided in the table are the provincial working criteria for freshwater aquatic life (Nagpal et al, 1995) and ranges of typical urban stormwater runoff quality (BC Research Corp., 1992), for comparison purposes. Any references to criteria or runoff quality in this section apply to these two references. The tabulated analytical results for the extended event and the detailed analytical reports are included in Appendix II.

All inorganic and physical parameters were detectable in all four routine events with the exception of nitrate+nitrite, 5 day biochemical oxygen demand (BOD_5), and ortho-phosphate which were non-detectable in one or more samples. The concentrations of inorganic and physical parameters measured on the Serpentine River samples were less than the provincial aquatic life criteria (where criteria exist) and all were within the range of typical urban runoff values, where data were available.

The total suspended solids (TSS) concentration was more than three times higher in routine event #1 when compared to the other routine event samples and all of the extended event samples. The measured conductivity and chloride concentration were higher during event #4 when compared to the other three events. This would suggest a slightly higher ionic content in the stormwater, however, dissolved metal data are not available for these two events to confirm this interpretation.

8.4. Total and Dissolved Metals

The analytical results for metals parameters for the four routine events and the extended event are summarized in Table 8.3, along with the provincial working criteria for freshwater aquatic life (Nagpal et al, 1995), and ranges of typical urban stormwater runoff quality (BC Research Corp., 1992) which are provided for comparison purposes. Any references to criteria or runoff quality in this section apply to these two references. These metals parameters are specified for total metals with the exception of aluminum where the criterion specified is for dissolved metals. The tabulated analytical results for the extended event and the detailed analytical reports are included in Appendix IV.

The total concentrations of six metals (cadmium, chromium, copper, iron, manganese, and zinc) exceeded the provincial aquatic life criteria in one or more samples. Specific concentrations which exceeded the aquatic life criteria are summarized as follows:

- Total copper concentrations in all four routine event samples and in all twenty-one extended event samples;
- Total zinc concentrations in all routine event samples and in thirteen of the extended event samples;
- Total iron concentrations in three of the routine event samples and in all but one of the extended event samples;
- Total chromium concentrations in three of the routine event samples and eight extended event samples;
- Total cadmium concentrations in three routine event samples; and
- Total manganese concentrations in six extended event samples.

Data for typical urban runoff quality were only available for seven total metals: arsenic, cadmium, chromium, copper, lead, nickel, and zinc. The concentrations of these metals detected in the Serpentine River samples were within the range of typical urban runoff quality as shown in Table 8.3.

8.5. Organic Parameters

Analytical results for detected organic parameters in the Serpentine River stormwater samples are summarized in Table 8.4, along with the provincial working criteria for freshwater aquatic life (Nagpal et al, 1995), and ranges of typical urban stormwater runoff quality (BC Research Corp., 1992), which are provided for comparison purposes. Any references to criteria or runoff quality in this section apply to these two references. The detailed analytical reports are included Appendix IV.

Most organic parameter concentrations were less than the laboratory detection limits. A total of 28 parameters were detected altogether with a maximum of 22 parameters detected in one sample (routine event #1) and a minimum of nine parameters (routine event #4). Total measured concentrations of pyrene exceeded the aquatic life criteria in all four routine event samples.

Benzo(a)anthracene, benzo(a)pyrene, fluoranthene, phenanthrene, pyrene and total oil and grease measured concentrations each exceeded the aquatic life criteria in one event (routine event #1). All other measured concentrations were less than the aquatic life criteria. The concentrations of pentachlorophenol exceeded the aquatic life criteria in the sample from routine event #2.

Total measured PAH concentrations in routine event #1 were greater than those found in typical stormwater runoff. No other data were available for organic parameters in typical stormwater runoff other than oil and grease and all measured oil and grease concentrations were within the recorded typical range.

Benzo(a)anthracene, fluoranthene, nonylphenol, and pyrene were detected in all four routine event samples. Benzo(b)fluoranthene, benzo(g,h,i)perylene, chrysene, methylnaphthalenes, dimethylnaphthalenes, phenanthrene, and methylphenanthrene were detected in three of the four routine event samples. All other detected organic contaminants were present in only one or two of the samples.

8.6. Toxicity

The toxicity results for the Serpentine River stormwater sample dated 1996 08 30 are presented in Table 6.5. The detailed analytical report is included in Appendix IV.

The Serpentine River stormwater sample did not have a toxic effect on *Vibrio fischeri* (Microtox© basic test) or rainbow trout and did not have an observed reduction in the growth of *Selenastrum capricornutum* algae. However, *Ceriodaphnia dubia* was affected by the stormwater at the following concentrations: LC_{50} = 19%, the IC_{50} = 25%, the IC_{25} = 19%, LOEC = 25%, and the NOEC = 12.5%.

Both the *Ceriodaphnia dubia* LC_{50} and IC_{50} are calculated values based on the test concentration series of 100%, 50%, 25%, 12.5% and 6.25%. The 12.5% solution had a 100%

survival rate of the test subjects and the 25% solution experienced a survival rate of only 10%. The 12.5% solution experienced the highest reproduction rate of the test concentrations and the 25% solution had several test subjects producing a high number of offspring. These factors resulted in a calculated LC_{50} concentration lower than the IC_{50} concentration.

8.7. Suspended Sediment

A suspended sediment sample was collected from the Serpentine River study area on 1996 04 22. The suspended sediment sample was analyzed for various inorganic and organic parameters as listed in Table 2.3. The laboratory results for the suspended sediment samples are summarized in Tables 7.5 to 7.7 and the detailed analytical reports are included in Appendix IV. Also provided in the tables are the provincial working criteria for freshwater aquatic life (Nagpal et al, 1995), and the concentrations detected in the Fraser Glen stormwater study (GVRD, 1994), for comparison purposes. Any references to criteria or Fraser Glen in this section apply to these two references.

The analytical results for metals are presented in Table 7.5. There are eleven metals for which provincial aquatic life sediment quality criteria are available, and nine of the detected metals were at levels exceeding the criteria.

As shown in Table 7.6, a range of organic parameters was detected in the suspended sediment sample monocyclic aromatic hydrocarbons, PAH, phthalate esters, chlorinated and non-chlorinated phenols, and extractable hydrocarbons. For the PAH parameters for which individual freshwater aquatic life criteria are available, four parameters exceeded the specified criteria: benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, and pyrene. Sediment quality criteria are specified for phthalate esters in marine water environments (as opposed to freshwater) and one of the five phthalate ester concentrations exceeded this criterion.

Other organic parameters detected were total oil and grease and total petroleum hydrocarbons. Total oil and grease was measured at 47,000 mg/kg (dry weight basis) according to the standard gravimetric and total petroleum hydrocarbons were measured at 13,200 mg/kg.

A review of Table 7.7 indicates the presence of dioxins and furans in the suspended sediment sample at a concentration of 55.8 pg/g when expressed as 2,3,7,8-TCDD equivalents. There are no freshwater aquatic life criteria for dioxins or furans.

The results of the solid phase Microtox© bioassay indicated that the Serpentine River suspended sediment sample had a 10-minute inhibiting concentration (IC_{50}) of 523 mg/L on *Vibrio fischeri*.

9. DISCUSSION

The results for stormwater and suspended sediment analyses were compared to the provincial approved and working quality criteria for aquatic life (Nagpal et al, 1995), as well as published ranges of typical provincial urban stormwater quality (BC Research Corp., 1992). These results have been summarized in Sections 6.0, 7.0 and 8.0 of this report. The discussion of results presented here identifies overall trends evident from specific results in this study, and compares these with other GVRD stormwater and suspended sediment sampling studies, including Fraser Glen (GVRD, 1994), Fraserview (Norecol, Dames and Moore Inc., 1996), and William Street (Norecol, Dames and Moore Inc., 1996).

The table below identifies the size of the various catchments, the primary and secondary land uses, and the studies for the previous study catchments (where known) and the three catchments included in the current study. The discussion of trends which follows has been developed on this basis. Details of the data collected for the three catchments have been provided in previous sections and will not be repeated.

Summary of Catchment Size and Land Use

Catchment (Size)	Land Use [1]		Study
	Primary	Secondary	
Fraser Glen (30 ha.)	Single-family Residential		GVRD, 1994
Fraserview (13 ha.)	Single-family Residential	Multi-Family Residential	Norecol, Dames and Moore Inc., 1996
William Street (not available))	Commercial/Industrial		Norecol, Dames and Moore Inc., 1996
Wagg Creek (60 ha.)	Single-Family Residential	Multi-Family Residential	
Still Creek (152 ha.)	Single Family Residential	Commercial/Industrial	
Serpentine River (141 ha.)	Multi-Family Residential	Single Family Residential	

[1] Determined by MECI's knowledge of areas and information provided by the GVRD.

9.1. Bacteriology

The range of fecal coliform bacteriological results for the three catchments are illustrated in Figure 9.1 along with results from previous GVRD stormwater studies. Samples from the Wagg Creek catchment exhibited the lowest range (110 MPN/100 mL - 1,300 MPN/100 mL) and lowest mean concentration of the three catchments, and the mean value of 533 MPN/100 mL was similar to the mean value of 92 MPN/100 mL found in the Fraser Glen (GVRD, 1994) study. Samples from the Serpentine River catchment exhibited the highest range and mean concentration of the three catchments. The range and mean concentration of the samples collected in the Still Creek catchment were similar to those found in the William Street (Norecol, Dames and Moore Inc., 1996) study.

The source(s) of bacteria in the stormsewer systems include animal feces being washed into the stormsewer system, and domestic sewage from sanitary systems (cross connected or leaking sanitary sewers, and/or infiltration from septic fields). The higher measured bacteria concentrations in the Serpentine River catchment could have resulted from either of these sources. The lands in this catchment are primarily zoned for commercial and multi-family residential land use which indicates that the presence of septic systems would be unlikely. However, discussions with the City of Surrey indicate that septic systems were present in this catchment prior to the installation of the sanitary sewer system and some of these may still be in use or abandoned in place.

The concentration of bacteria found in stormsewers could also be related to land use and impervious land cover. Catchments with a high population density and a high percentage of impervious land surfaces could tend to have higher bacterial concentrations present and these would be washed into the sewers.

9.2. Inorganic, Physical and Metal Parameters

9.2.1. Stormwater

The range of inorganic, physical, and metal parameter concentrations for the three catchments and typical urban stormwater runoff quality (BC Research Corp., 1992) are illustrated in Figures 9.2 to 9.6. Also presented are concentrations found in previous GVRD stormwater studies: Fraser Glen (GVRD, 1994), Fraserview (Norecol, Dames and Moore Inc., 1996) and William

Street (Norecol, Dames and Moore Inc., 1996). Any references to these studies or runoff quality in this section apply to these four references.

The range of TSS concentrations illustrated in Figure 9.2 indicates that the Wagg Creek catchment exhibited the lowest range and the lowest mean concentration of the three catchments with levels similar to those found in the Fraser Glen and Fraserview studies. The Serpentine River catchment exhibited the highest range and mean TSS concentration of the three catchments, with similar trends to those found in the William Street study. The range and mean TSS concentration of the Still Creek catchment were twice those in the Wagg Creek catchment. The mean TSS concentrations for all three catchments were below the range for typical urban stormwater runoff quality.

Concentrations of total copper, iron and zinc were detected at concentrations which exceed the provincial aquatic life criteria (Nagpal et al, 1995) in three or more routine event samples in all three catchments as shown in Tables 6.3, 7.3, and 8.3. Cadmium, chromium, lead, manganese, mercury, and silver were detected at concentrations greater than the aquatic life criteria in one or more routine and extended event samples.

The ranges for total copper, iron, and zinc concentrations illustrated in Figure 9.3, 9.4, and 9.6, respectively, indicate that the Wagg Creek catchment had the lowest range and mean metals concentration of the three. The Still Creek catchment exhibited the highest range and mean concentration for lead (see Figure 9.5) of the three catchments; values were about twice those detected in Wagg Creek. The mean concentrations for all three catchments were below those of typical urban stormwater runoff quality.

As shown in Figure 9.3, the ranges of mean copper concentrations detected in the three catchments were similar to those found in the Fraserview and the Fraser Glen studies, and were below those identified in the William Street study.

Figures 9.4 to 9.6 indicate that overall iron, and zinc mean concentrations and ranges detected in the Wagg Creek and Serpentine River catchments were within a similar range to those detected in the Fraser Glen study sites, which are also primarily single-family residential land based catchments. These figures also indicate that the detected metals concentrations and ranges in the Still Creek and William catchments, both with significant industrial use land bases, were detected in elevated concentrations and were similar in nature.

The source(s) of the metals (total and/or dissolved) detected in the stormwater cannot be confirmed based on the information available to date; however, there are several likely sources. Many of these metals are likely contained in the suspended sediment carried into the stormsewer. The high concentrations of copper may be attributable to the use of copper in metallic brake pads, corrosion of copper pipes by acidic water (such as Vancouver area drinking water), or the use of copper in fungicides and pesticides applied to soils and vegetation. Another potential source of metals in the stormwater would be runoff from industrial sites. A detailed review of each catchment would be required to determine if any potential industrial sources of metals are present. Groundwater infiltrating into the stormsewer system is another potential source of aluminum, iron, and manganese, as groundwater in a reducing environment could carry these metals in the dissolved form.

Field filtering was not done due to the large number of samples (37) and the total volume required for each sample in order to prepare a flow-proportioned composite sample. Dissolved metal samples were prepared from the routine event composite sample and filtered in the laboratory. Given that the stormwater was already exposed to air (as indicated by the measured dissolved oxygen content as well as the exposed nature of the stormsewer environment), it is unlikely that a significant precipitation of metals resulted after sample collection.

9.2.2. Suspended Sediment

The Still Creek suspended sediment sample contained metals concentrations which exceeded the aquatic life criteria (Nagpal et al, 1995) for all eleven metals for which provincial aquatic life sediment quality criteria are available. The Serpentine River suspended sediment sample contained nine metals that exceeded these criteria. Iron was found in the highest measured concentrations in both suspended sediment samples (up to 77,000 mg/kg) followed by manganese, zinc, copper, lead, and chromium.

As illustrated in Figure 9.7, the Still Creek suspended sediment sample exhibited the highest overall metals concentrations compared to all of the previous GVRD study sites referenced in this report, followed by the Serpentine River suspended sediment sample. The William Street (Norecol, Dames and Moore Inc., 1996) deposited sediment sample contained the highest detected lead concentrations when compared to all above mentioned study sites. As noted in Section 9.2.1, the Still Creek and William Street catchments both are characterized by a significant industrial land base. The majority of other detected metals concentrations in the William Street, Fraserview (Norecol, Dames and Moore Inc., 1996), and Fraser Glen (GVRD, 1994) studies were slightly below those detected in the Serpentine River sample.

9.3. Organic Parameters

9.3.1. Stormwater

A range of organic parameters was detected in the stormwater samples including mono-aromatic hydrocarbons (e.g., benzene, ethylbenzene, toluene, and xylenes) and polycyclic aromatic hydrocarbons, chlorinated and non-chlorinated phenols, and extractable hydrocarbons. The concentrations of organics in the water were generally near the detection limits for the various parameters and quantification at these concentrations would generally be considered unreliable given the potential for false positive readings at these levels.

Table 9.1 presents a comparison of the detected organics in the stormwater samples for the three catchments, showing the range and frequency detected. Also presented is the total number of parameters detected at each catchment and the total number of detections for all organic parameters. The Serpentine River catchment exhibited the highest total number of individual organic parameters detected (28) and the highest number of total detections (59). Wagg Creek exhibited the lowest total number of organic parameters detected (19) and the lowest number of total detections (36). These results compare with 32 detected organics in the William Street (Norecol, Dames and Moore Inc., 1996) study and 25 detected organics in the Fraserview (Norecol, Dames and Moore Inc., 1996) study. No organic parameters were detected in the inflow stormwater in the Fraser Glen (GVRD, 1994) study.

The highest range of total PAHs components was 0.92 μg/L to 20.18 μg/L, detected at the Serpentine River catchment in which the land base is primarily residential. Ranges of total PAHs were lower in the Wagg Creek (0.06μg/L to 3.88 μg/L, primarily residential land base), and Still Creek (0.11 μg/L to 3.26 μg/L, residential and industrial land base) studies.

Oil and grease were detected in the stormwater samples. The maximum concentration measured in stormwater was 6 mg/L (Still Creek). The concentrations measured would be expected in stormwater from urban areas which include runoff from roads and parking lots. Note that the provincial standard for total extractable hydrocarbons (TEH) in stormwater discharging from petroleum storage and distribution facilities is 15 mg/L (BC ELP, 1994).

Further discussion of possible sources of PAHs and other organic parameters in water and suspended sediment is provided in the next section.

9.3.2. Suspended Sediment

A range of organic parameters was detected in the two suspended sediment samples including mono- and polycyclic aromatic hydrocarbons, phthalate esters, chlorinated and non-chlorinated phenols, surfactants and extractable hydrocarbons. Polychlorinated biphenyls (PCBs) were also detected in the suspended sediment sample from Still Creek.

The phthalate ester concentrations detected in the two suspended sediment samples may be an artifact of the sampling or analysis methodology. Phthalate esters are used to keep plastics flexible, and consequently are now ubiquitous in the environment. Phthalate esters were detected in stormwater and suspended sediment samples in the Fraserview (Norecol, Dames and Moore Inc., 1996) and William Street (Norecol, Dames and Moore Inc., 1996) study areas. However, stormwaters in this study were not analyzed for phthalate esters.

Most detected organic parameters in the Still Creek and Serpentine River suspended sediment samples were at concentrations greater than those detected in the deposited suspended sediment samples of the William Street (Norecol, Dames and Moore Inc., 1996) and Fraserview (Norecol, Dames and Moore Inc., 1996) studies and all were at concentrations greater than those detected in the deposited sediment sample of the Fraser Glen (GVRD, 1994) study.

The most commonly detected organic parameters in this study were PAHs which are generally derived from the incomplete combustion of fossil fuels. PAHs are more recalcitrant (i.e., persistent, slower to biodegrade) than the lighter mono-aromatic.

PAHs are relatively insoluble in water (hydrophobic) and would be expected to strongly sorb to the organic matter that is associated with soils, such as silts and clays (Schwarzenbach, 1993). This is reflected in the relatively high concentration of PAHs and other hydrophobic contaminants, such as PCBs and total oil and grease which were identified in the two suspended sediment samples analyzed (when compared to the concentrations in stormwater samples). The association of these hydrophobic organic contaminants with the suspended sediment may result in a relationship between increases in observed organic concentrations in water, and increases in total suspended sediments (measured as TSS). There are, however, many variables involved which would require further evaluation to verify the use of this type of broad correlation, as one of the main factors regulating the adsorption of hydrophobic substances to solids is the organic content of the solids.

The surfactant nonylphenol was detected in stormwater samples from all three catchments and in both suspended sediment samples. Surfactants are used in soaps, detergents, etc., therefore, the presence of such compounds in the stormwater sewer system of an urban community is not unusual. Nonylphenol is known to bio-degrade slowly, although other types of surfactants currently in use bio-degrade relatively quickly.

Total petroleum hydrocarbons and oil and grease were detected at more significant levels in the suspended sediment samples than in the stormwater samples, which is to be expected given that oil and grease and petroleum hydrocarbons are hydrophobic and, therefore, would preferentially sorb to organic materials in the sediments, as previously discussed for PAHs.

9.4. Toxicity

9.4.1. Stormwater

None of the stormwater samples were found to be toxic to rainbow trout when subjected to the 96-hour LC_{50} test. However, the undiluted Still Creek stormwater sample was found to result in stress on the fish during the period from 48 to 96 hours. None of the stormwater samples were found to have an effect on the light output of the luminescent bacteria (*Vibrio fischeri*) at the maximum concentration of 90% during the Microtox® basic test. All stormwater samples did have an effect on *Ceriodaphnia dubia,* as shown in Table 6.5, with the Serpentine River sample having the greatest effect with a lethal effect on 50% of the population at a concentration of 19%. Toxicity testing on *Selenastrum capricornutum* (algae) indicated an inhibition to algal growth in the stormwater sample from Still Creek.

There are no detailed stormwater analytical data available for the toxicity samples. The toxicity samples were collected during the 1996 routine storm events, which had to be repeated due to the identification of errors in sample preparation (PST and limited flow data issues discussed in Section 3.4). Therefore, it is not possible to relate the toxicity results to actual chemical data. However, general trends in the stormwater quality at each of the catchments can be used to evaluate the possible source(s) of the toxic effects measured.

A review of the general chemistry of the stormwater at the three catchments indicates that the Still Creek samples had the highest overall total metal concentrations, three of which (copper, iron, and zinc) exceeded the freshwater aquatic life criteria (Nagpal et al, 1995) in all four routine event samples. The Serpentine River samples also contained elevated total metals concentrations, two of which (i.e., copper and zinc) exceeded the aquatic life criteria in all routine event samples. The Wagg Creek samples had the lowest metals concentrations. It should be noted that mixtures of metals such as copper and zinc can increase their toxicity and that their effects can be cumulative. The Serpentine River catchment had the highest total number of organic parameters detected and the highest total number of detections of all parameters, followed by Still Creek and Wagg Creek.

It is not possible in this study to confirm which parameter(s) have the most toxic effect based on the available information. Additional toxicity testing would be required to determine if the results are typical for each catchment and which contaminants are having the greatest effect on the test subjects.

9.4.2. Suspended Sediment

Both the Still Creek and Serpentine River suspended sediment samples had similar toxic effects on *Vibrio fischeri* (Microtox©) with a 10-minute inhibiting concentration (IC_{50}) of 546 mg/L and 523 mg/L, respectively. No further discussion can be given at this time due to the limited data set. As with the stormwater results, further (more detailed) testing would be necessary to determine which specific contaminant(s) have contributed to the toxicity measured.

9.5. Contaminant Concentrations Versus Catchment Land Use

Comparing the impact which land use has on contaminant concentrations is of interest with respect to the development of future monitoring programs. The three catchments in this study represent a variety of land uses. The Wagg Creek catchment contains the most park land and single-family residential land and has the lowest impervious land cover estimated at 37%. The Still Creek catchment is an even mix of residential and industrial land with an estimated 60% impervious land cover. The Serpentine River catchment lands are a mix of commercial, multi-family residential, single-family residential, and undeveloped lands with an estimated impervious land cover of 51%.

As noted above, Figures 9.2 to 9.6 show the ranges of TSS and selected metals found in the three catchments and compare them to results of the Fraserview (Norecol, Dames and Moore Inc., 1996), William Street (Norecol, Dames and Moore Inc., 1996) and Fraser Glen (GVRD, 1994) studies. Any references to these catchments in this section apply to these three references. These figures indicate that the Still Creek catchment had the highest average concentration of metal contaminants of the three catchments in this study and only the William Street study exhibited higher overall metals concentrations. The Still Creek catchment has the highest percentage of both impervious land cover and commercial/industrial lands of the three catchments in this study.

As discussed earlier, Table 9.1 summarizes all of the detected organic contaminants in all three catchments and shows that the Serpentine River catchment recorded the highest number of detected organic contaminants for the three catchments in this study. This catchment has a high concentration of multi-family and single-family residential lands with some commercial/industrial lands. The Fraser Glen study catchment had the lowest number of detected organics of all the study sites referenced in this report. The Fraser Glen study site comprised primarily single-family residential land use with a low percentage of impervious ground cover and is situated near the Serpentine River catchment study site.

9.6. Within Event Contaminant Concentrations

The effect of flow rate on contaminant concentrations is best discussed by reviewing the changes in contaminant concentrations during the individual extended events for the three catchments. Figures 9.8 to 9.22 illustrate the effect of flow on selected contaminant concentrations in stormwater during the extended event at each catchment. Both the TSS and metals concentrations appear to peak with the first significant increase in flow or "first flush" and then drop dramatically even before the flow has peaked. This could be indicative of suspended sediment collected on the impervious ground cover being washed into the stormsewer with the first significant precipitation, or suspended and/or deposited sediment being scoured out of the stormsewer with the increase in flow.

The Wagg Creek and Still Creek extended event precipitation and flow data graphs (Figures 6.5 and 7.1) show that precipitation had occurred an hour prior to the start of sampling and a review of the corresponding contaminant concentration/flow graphs (Figures 9.8 to 9.17) shows that the first sample collected has a higher contaminant concentration than the next several samples. This would indicate that sampling started near the end of the initial increase in the base flow rate and that these contaminants could have been present at higher concentrations than those detected in the initial sample. The extended event precipitation and flow data graph for the Serpentine River catchment (Figure 8.5) and the contaminant concentration/flow graphs (Figures 9.18 to 9.22) show that sampling had been initiated prior to an increase in the base flow rate of the stormsewer.

10. SUMMARY AND CONCLUSIONS

Morrow Environmental Consultants Inc. (MECI) has completed a characterization study of three catchments on behalf of the Greater Vancouver Regional District (GVRD). The catchments studied were Wagg Creek in North Vancouver, Still Creek in Burnaby, and the Serpentine River in Surrey. Although the concentrations of certain parameters in stormwater and suspended sediment samples collected during this study exceeded the provincial freshwater aquatic life criteria (Nagpal et al, 1995), the concentrations were found to be within ranges similar to those of typical urban stormwater and suspended sediment found in other studies (BC Research Corp., 1992). The following is a summary of the findings based on the flow data and the analytical results for stormwater and suspended sediment samples collected during the months of April to September 1996 and October to December 1997 from the three catchment areas.

10.1. Bacteriology

The bacteriological results for the three catchments indicated that the number of targeted organisms (i.e., counts) were comparable to those identified in the previous GVRD stormwater studies: William Street (Norecol, Dames and Moore Inc., 1996), Fraserview (Norecol, Dames and Moore Inc., 1996), and Fraser Glen (GVRD, 1994). Elevated bacterial counts were identified in the Serpentine River catchment but they were lower than those found in the Fraserview study. These elevated counts could be attributed to the following factors:

- sanitary system bypasses such as leaking septic and sanitary systems;
- elevated population density; or
- high percentage of impervious land cover.

However, further study is required to determine the main contributing factors to cause elevated bacterial counts.

10.2. Metals

Stormwater samples for all three catchments in this study contained total copper, iron, lead, and zinc concentrations which exceeded the freshwater aquatic life criteria (Nagpal et al, 1995). The Wagg Creek catchment samples exhibited the lowest range and mean metals concentrations of the three, and the Still Creek catchment exhibited the highest range and mean concentrations.

The mean concentrations for all three catchments were below the values for typical urban stormwater runoff quality (BC Research Corp., 1992). The Still Creek and William Street (Norecol, Dames and Moore Inc., 1996) catchments both contain significant commercial/industrial use land bases, and both contained elevated detected metals concentrations relative to the other catchments monitored in GVRD studies.

The analytical results for the suspended sediment samples at the Still Creek and Serpentine River catchment sites indicate that several metals are present at concentrations which exceed the provincial sediment quality criteria for aquatic life (Nagpal et al, 1995). These metals were detected at higher levels than those found in the deposited sediment of the Fraser Glen (GVRD, 1994) wet pond study. The most common metals detected in the suspended sediment are the same as those detected in the stormwater samples.

10.3. Organic Contaminants

The total number of organic compounds detected in the stormwater samples for the Serpentine River catchment were the highest of the three catchments in this study and higher than those detected in the Fraserview (Norecol, Dames and Moore Inc., 1996) and William Street (Norecol, Dames and Moore Inc., 1996) studies. The total number of organic compounds detected in the stormwater samples for the Wagg Creek catchment were found to be the lowest when compared to the results of this study and the Fraserview and William Street studies. The Fraser Glen (GVRD, 1994) inflow stormwater samples recorded the lowest number of detected organic compounds of the GVRD studies referred to in this report. This appears to indicate that catchments with land bases containing significant undeveloped lands and/or permeable land cover have correspondingly lower detectable organic concentrations in the stormwater runoff.

Several detected organic compounds in the suspended sediment samples from the Still Creek and Serpentine River catchments were at levels exceeding those found in the deposited sediment analyzed in the Fraser Glen (GVRD, 1994) stormwater study with several polycyclic aromatic hydrocarbon (PAH) parameters exceeding the aquatic life criteria (Nagpal et al, 1995). Organic contaminant concentrations in the suspended sediment samples were significantly greater than those found in the stormwater samples and the presence of these relatively insoluble (i.e., hydrophobic) organic compounds (including petroleum hydrocarbons and oil and grease) in the suspended sediment samples indicates that the organic contaminants are primarily associated with the suspended sediment. In addition, the oil and grease and total petroleum hydrocarbon concentrations in the suspended sediment samples were found to be at high concentrations when compared to stormwater samples. Both suspended sediment samples contained detectable amounts of dioxins and furans.

10.4. Toxicity

None of the stormwater samples were found to be toxic to rainbow trout when subjected to the 96-hour LC_{50} test, and none were found to have an effect on the light output of the luminescent bacteria at the maximum concentration of 90%. All stormwater samples did have an effect on *Ceriodaphnia dubia* with the Serpentine River sample having the greatest effect (LC_{50}=19%, and IC_{50}=25%). Testing of the stormwater on *Selenastrum capricornutum* indicated that only the stormwater sample at Still Creek had an observed effect on algal growth with an LOEC of 90.9% and NOEC of 30.3%. The exact chemical parameter(s) resulting in toxicity have not been confirmed in this study. In addition, effects from the wide variety of detected parameters are expected to have some additive effects on toxicity.

The suspended sediment samples at the Still Creek and Serpentine River catchments were found to have an inhibiting effect on the solid-phase Microtox© test at similar concentrations with an IC_{50} of 546 mg/kg and 523 mg/kg, respectively.

10.5. Contaminant Concentrations

Contaminant concentrations in stormwater were found to have a relationship with flow as shown in the extended event data at all three catchments. Contaminant concentrations increased and/or decreased with flow, such as with an increase in the base flow of the stormsewer at the start of an event. The highest contaminant concentrations appeared to occur with the first significant increase in flow or “first flush” and prior to the peak flow. This is when the accumulated contaminants in the form of sediment are being washed into the storm sewer system.

All three catchments in this study were found to have very short response times with respect to an increase in flow after recorded precipitation. During very short, intense events, the first flush may be missed with the current one-hour mobilization requirement for the start of sampling. This occurred with the Serpentine River toxicity sample collected on 1996 08 30, where a significant increase in flow was recorded prior to the start of sampling.

The suspended sediment samples collected in the Still Creek and Serpentine River catchments contained significant concentrations of trace metal and organic contaminants relative to levels detected in stormwater samples. This indicates that these contaminants are primarily associated with the TSS in stormwater. The catchments with a higher percentage of developed lands and impervious land cover (Still Creek and Serpentine River) experienced higher stormwater contaminant concentrations than the less developed Wagg Creek catchment.

11. RECOMMENDATIONS FOR FUTURE PROGRAMS

This study helped to characterize the stormwater quality in the three study area catchments (Wagg Creek, Still Creek and Serpentine River). The routine event flow-proportioned composite sampling and extended event discrete sampling collection methods helped reduce the analytical costs while maximizing the information obtained. Potential improvements to future sampling programs are described below.

11.1. Flow Data

Problems were encountered during the initial field portion of the sampling program, resulting in the requirement to repeat a number of the routine events, replicate events and field blanks. These problems can be avoided in the future by considering the following:

- Ensure the time reference used for both the flow data recording and collection of field samples is identified and made known to all parties responsible for these tasks.

- If future programs are to be conducted in the summer months with storms being more intense and of a short duration, then the sampling program should be modified to allow better preparation of flow-proportioned composite samples and less manipulation of flow data. The discrete samples could be collected every five minutes or a two-litre sample volume should be collected every ten minutes.

- Minimize the number of flow data sets supplied to the party responsible for preparing the flow graphs and preparing the flow-proportioned composite samples. If numerous data sets are collected then the most appropriate one should be identified. This was done for the second phase of the field program and resulted in increased clarity for all parties.

11.2. Stormwater Analyses

Steps can be taken to improve the analytical data such as the following:

- Dissolved metals samples should be field filtered and acidified to prevent the precipitation of iron, manganese and other redox sensitive metals as noted in Section 9.2. This should be done by collecting a discrete sample and splitting it for total and dissolved metals analysis.

- Additional bacteriological samples could be collected during the event to determine if bacterial counts vary throughout the storm.

11.3. Quality Assurance/Quality Control

The following recommendations are for the QA/QC Program:

- All field blanks, field replicates, and stormwater samples should be numbered sequentially for submission to the laboratories. Blind submission of all samples is crucial for an effective external review of laboratory performance. Therefore, information such as sample location, and date/time sampled should be noted in the field notes but not on the sample containers. Ideally, the laboratories should have no indication as to the type of sample submitted.

- The use of reference materials and/or spiked samples prepared by an independent analytical laboratory should be considered. Reference materials, when submitted blind to the laboratory along with regular samples, provide useful independent information on the accuracy of analyses. Reference materials for dissolved metals are readily available. Spiked samples are used for organic analyses for which reference materials are not available.

11.4. Extended Event

The extended events were useful to determine the contaminant concentrations versus flow rate for each catchment and they reflected the variability in contaminant concentrations throughout the full storm event. However, due to problems encountered with routine event sample preparation in this study, only one extended event was conducted concurrently with a routine event. This did not allow for a meaningful comparison between routine and extended events. Extended event sampling should be repeated in future studies to compare the results.

11.5. Reporting

The reporting format and level of detail required in the report should be better defined in the Request for Proposal (RFP). This may best be accomplished by providing a standard reporting format or a defined scope of reporting requirements. Another option would be to provide a reference to other reports for studies previously conducted for the GVRD which have a preferred format.

11.6. Use of Auto Samplers

MECI found it difficult to mobilize to the site within one hour of the start of an event during this program as the start of an event was difficult to predict and given the time required to mobilize to the site and set-up the sampling equipment. The use of auto samplers equipped with a tipping rain gauge could be considered for future programs to assist in obtaining the initial increase in base flow and possible first flush if the storm is initially very intense and the peak in flow and contaminant concentrations could be missed. The auto sampler would ensure samples are taken once a minimum amount of precipitation was received and ensure that the first flush is captured.

An auto sampler with adequate sample bottle size (one-litre) would be required to ensure that an adequate composite sample volume is obtained. Another option would be to use the auto sampler to capture the start of the event and have the timer set to sample more frequently than the current ten minutes to allow adequate sample volume collection. Personnel could then be mobilized to the site once an event starts and begin to manually collect samples. The smaller volume samples from the auto sampler could be composited on a ten-minute basis allowing the use of a smaller unit.

Auto samplers could be used for dry weather monitoring and be equipped to obtain samples once a flow is detected and would be helpful in determining the source and frequency of these flows. The principal drawback with auto samplers is the relatively high cost for purchase or rental.

11.7. Suspended Sediment Sampling

During this sampling program it was difficult to obtain adequate suspended sediment sample weights. Additional suspended sediment samplers or a larger capacity unit should be considered for future programs.

11.8. Dry Weather Monitoring

A future monitoring program involving dry weather flow monitoring and sampling of these and/or other catchments of concern could be considered to determine the effect on the stormsewer system from non-precipitation related sources. Examples of such potential sources include but are not limited to cross-connected sanitary systems, groundwater infiltration and commercial/industrial discharges, including cooling and process waters. These potential sources would have been diluted with precipitation runoff waters during this study and their presence and potential impact on the stormwater quality could not be determined. A dry weather monitoring program would determine if these potential sources are present, and whether a source control program should be implemented to control the quality of effluent discharged into the stormsewer system.

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