THE EFFECTIVENESS OF STORMWATER PONDS IN CONTAMINANT REMOVAL FROM URBAN STORMWATER RUNOFF IN THE LOWER FRASER VALLEY, B.C.

by

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Abstract

As urbanization progresses rapidly throughout the Lower Fraser Valley (LFV) and many other areas in Canada, contaminants associated with urban land uses are found in elevated concentrations in urban waterways. One of the most common mitigation methods is the construction of stormwater ponds, which provide detention for volume control and remediation for water quality improvement.

The aim of this research is to investigate the quality of the stormwater entering five ponds in urban areas in the LFV and the effectiveness of trace metal and phosphorus removal in these ponds during the wet and dry seasons. Both water and sediment from the inlets and outlets of the ponds are analysed. A new technique of Diffusive Gradient in Thin Films (DGT) was employed to capture available metals over time and determine the accumulation of bioavailable metals during different storm events.

The results show that an average of 26% (range 0 – 60%) of the samples of inlet water from the ponds exceeded the guideline for zinc of the Canadian Environmental Quality Guidelines for Freshwater Aquatic Life. Copper and zinc concentrations found in the sediment at the inlets of all ponds exceeded the Probable Effects Level. The concentration of these metals is correlated to traffic volumes and percent impervious cover in the catchments. Zinc concentrations are reduced through the ponds by up to 41% in the water, 65% in the sediments and 78% in bioavailability. Most ponds were not effective in retaining aluminum, iron or manganese in the water and sediments. However, the bioavailable form of these metals is reduced particularly during the wet period by an average of 29% (range -155% to 81%). The extent of vegetation in the ponds had the strongest overall correlation to contaminant reduction in water, sediment and bioavailability, while surface area and volume were correlated to only reductions in manganese.

In conclusion, the most effective designs incorporate a combination of vegetation in the pond, a sufficient flow of water throughout the wet season, and a design that aids consistent sedimentation of coarse particles through the pond, while impeding the flow of finer clay particles to allow for remediation.

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Chapter I Introduction

1.1 Background

The development trends in the Lower Fraser Valley, and elsewhere in Canada, suggest that urban sprawl is continuing at an increasing rate. The expansion of the urban boundary from Vancouver eastward has infilled many natural areas with housing, commercial developments and the transportation needed to support these changes. The demand for housing has driven development onto the hillslopes, removing forest cover and altering drainage patterns. As impervious surfaces replace natural cover, the changes in the hydrologic system increase stormwater runoff, as infiltration is impeded and water is channelled out of the city to receiving waters.

The effects of watershed development on stream conditions have been studied for over two decades. Due to the runoff changes that occur during and after urbanization, which cause flooding, erosion and habitat damage, many municipalities have required that some degree of stormwater management to reduce peak flows be implemented in new developments (Booth et al., 2002). It has, however, been found that certain stormwater management techniques can also be efficient at improving water quality. This is important because runoff from urban areas picks up suspended sediments, along with heavy metals, toxic organic compounds, oil and grease, bacteria and nutrients. Two basic strategies are used to address the problems associated with urban runoff. Firstly, source reduction is the best approach, as pollutants never get into receiving waters. The second is to provide some type of treatment (Stanley, 1996). A common on-site measure that is implemented as part of the landscape is stormwater detention. Stormwater ponds were originally constructed to control flooding and have been introduced into areas where runoff has become a problem. They are now often used as a tool to remove some of the pollutants that are created from urban uses before they are flushed into the natural watercourse (Bartone et al., 1999; Pettersson, 1998; Kennedy and Mayer, 2002).

A stormwater pond can improve water quality through adsorption of constituents to sediments, plant uptake and microbial processes (Pettersson, 1998). Despite this knowledge, there have been relatively few intensive investigations into the water and sediment quality improvement occurring in detention ponds in the Lower Fraser Valley. The effects that the stormwater ponds will have on the aquatic ecosystems of the receiving waters are largely affected by the bioavailability of contaminants, however extensive studies have not been carried out to address this issue in the region.

1.2 Study Goals and Objectives

As the development of various types of stormwater ponds become a major part of urban watershed management, it is important to better understand how they are affecting water quality and how they can be used most effectively. To help provide information on the effectiveness of stormwater ponds in the Lower Fraser Valley, this study will generate new data on heavy metals and phosphorus concentrations and relative amounts removed in the ponds. A comparison of the effectiveness of removing pollutants from urban stormwater runoff will be made, as well as suggestions on which features correspond to the most successful examples.

Given that stormwater ponds are becoming major tools used to mitigate the effects of development on natural water courses, it is important to know the value of these tools, and what makes some more useful than others. This involves comparing the effectiveness of various approaches that are being undertaken in the Lower Fraser Valley with regards to stormwater detention and the resultant effects on water quality.

Therefore, this study will address the following research question:

What is the quality of the water and the sediments in stormwater ponds in the Lower Fraser Valley and what factors are contributing to their performance?

In order to investigate this question, the research focused on four major objectives:

(1) To determine the quality of the water and sediments entering the ponds, collecting in the ponds, and being released into receiving waters

(2) To assess the performance of the ponds in terms of contaminant removal through wet and dry seasons

(3) To identify the most effective methods to quantify pollutants entering and leaving stormwater ponds

(4) To identify the characteristics of the catchment that may be influencing the quality of the stormwater

(5) To identify which designs are having the greatest effect on the quality of stormwater

1.3 General Methodology

Five stormwater ponds were selected throughout the Lower Fraser Valley as a sample of the efforts that have been made in site scale stormwater ponds since the early 1990s. The main objective in site selection was to identify several ponds that were receiving urban runoff from suburban areas and had differences in design characteristics. The ponds selected are similar in nature and scale, which reduces the variables at work in the systems, while still allowing for the comparison of different design and catchment parameters.

Heavy metals were the primary target contaminants in this study, due to their prevalence in urban stormwater runoff and the toxicity that some, such as copper and zinc, pose to aquatic organisms. Total phosphorus was also investigated as it is introduced into stormwater runoff through lawn fertilizers and household cleaners. High levels of phosphorus in receiving waters can lead to eutrophication and subsequent threats to aquatic life. Therefore, the removal of these contaminants will be an important role of stormwater ponds.

Three main routes of analysis were focused on throughout the study. First, grab water sampling from the inlet and outlet provided a consistent measure of the dissolved metal fraction in the water column. Levels of dissolved oxygen, pH and specific conductivity were also measured from the water at the inlet and outlet as indicators of water quality. Second, sediment samples were taken from the top layer of sediments at the inlet and outlet to monitor total metal and phosphorus concentrations that had accumulated in the sediments. The sediments were also analysed for particle size distributions, which is important in examining how sediments are settling through the pond. Lastly, Diffusive Gradient in Thin Films (DGT) units were deployed at the inlet and outlet to measure the accumulation of the bioavailable fraction of metals in the water column over a period of approximately three weeks. This water and sediment sampling took place every three weeks during the wet season and every six to eight weeks during the dry season. Over the monitoring period of one year, data collection allowed for the assessment of the effectiveness of the ponds in contaminant removal and provided information regarding the mechanisms that were dominant in the systems.

From the data collected, statistical analyses were conducted in order to gain information on the effectiveness of each pond and their performance throughout the year. Data were also examined for insights into the chemical and physical processes that were taking place in the pond. The characteristics of the catchments draining into the ponds were analysed for size, land use, percent imperviousness and traffic volumes. These variables were then related to the quality of the water and sediment of the corresponding pond. As the ponds all had different characteristics, the surface area, percent of vegetation in the pond and the volume were used to relate the design of the ponds to the contaminant removal shown over the monitoring period.

The study gained new information on the stormwater runoff that is being produced in suburban areas of the Lower Fraser Valley and the effectiveness of ponds in improving the water quality before it is released to receiving waters. This information will be useful to planners, engineers and watershed managers as it provides a baseline of knowledge regarding the performance of existing ponds in the region. The assessment of runoff being produced in these catchments also contributes to the knowledge of the impacts of urban land uses on water and sediment quality. By linking the characteristics of pond design to contaminant removal, the importance of proper construction is shown and can aid in future stormwater management efforts.

Chapter II Literature Review

2.1 Urbanization and the Impacts of Impervious Surfaces

As urbanization expands from the confines of downtown cores to suburbs, more impervious surfaces are created to house and transport residents. The landscape is altered, which places new stresses on the water system and aquatic life. This section will address the hydrologic changes that take place due the expansion of the built environment and increase in impervious surfaces. Effects of these changes with regards to aquatic life will also be discussed.

2.1.1 The Urban Environment and Measures of Imperviousness

The majority of developable land in British Columbia is located in the southwestern portion, and accounts for only about 5% of all land in the province. As populations grow, more pressure is put on the available land and suburban areas become denser. The Georgia Basin, which encompasses Greater Vancouver, the Lower Fraser Valley and east coast of Vancouver Island, has experienced an increase in population which is putting pressure on the urban and suburban environments to accommodate more residents and workers. The total population has reached 3 million, about 75% of the provincial total, and is expected to double within the next 50 years (Stephens et al., 2002). The population-driven changes to the urban environment will therefore continue to alter the landscape of B.C., and require a focused effort on stormwater management to protect aquatic ecosystems.

The general concept of current water management in urban areas is important to keep in mind when considering stormwater. Precipitation that falls on impervious surfaces in urban areas is channelled away from where it falls directly to a receiving waterbody. This is achieved through a series of storm sewer pipes that create a system for collecting the rainwater in catch basins on the road and transporting it through pipes to outfalls into natural waterbodies. This basic design is typical of the engineering in most Canadian cities and towns. The main idea is to rid the urban area of water on the ground so that flooding events are avoided. Therefore, the precipitation that falls on the city rarely reaches the pervious areas, such as grasses and parks, as it has been quickly channelled away to the natural waterbody. .

Impervious cover is often used as an indicator of aquatic system degradation in urban areas. While imperviousness is not the sole process responsible for pollutant loading and subsequent effects on watershed health, its importance in assessing the impacts of urbanization warrant its consideration. It has been found in numerous studies that stream degradation begins when 10% of the watershed is covered in impervious surfaces. This incorporates many factors of stream health, such as pollutant loads, habitat quality, aquatic species diversity and abundance. While degradation begins at 10% imperviousness, it becomes completely degraded above 30% (Bestbier et al., 2000; Arnold et al., 1996).

2.1.2 Dynamics of Stormwater Hydrology

In a natural system, soil and vegetation absorb rainwater through various environmental processes. Organic matter and soil pores allow for the suspension of water in the soil that makes it available to roots of plants. Solid particles are incorporated into the soil matrix and water storage in the soil provides a year-round moisture supply. Pollutants are decomposed by microorganisms to provide nutrients while groundwater discharges to streams steadily throughout the year. This forms the baseflow of streams, which is increased during rainy periods as the hydraulic gradient is increased and water from storage is released. Base flows and storm flows are dynamic systems, as biotic and physical systems interact and readjust. As waters rise, waves may flood their banks, but remain on the floodplains where they infiltrate the soil. Disruptions to the watershed system are managed by the system through aggradation, degradation and meandering. Mature stream systems are generally able to maintain themselves through small and long-term changes. As water is continually absorbed, stored and released in the system, the effects of flooding and drought are moderated, keeping larger systems in equilibrium (Ferguson, 1998). When the landscape, and consequently the related environmental processes, are altered, this equilibrium becomes increasingly more difficult to maintain.

During urban development, land is cleared of vegetation, soil is compacted and drained, and impervious roads and buildings are introduced. While pavement and rooftops reduce the infiltration capacity to zero, surrounding landscapes also have reduced infiltratability due to soil compaction. Thus, the soil reaches surface saturation quickly and results in overland flow (Booth et al., 1997; Dunne et al., 1978). When rainwater collects on impervious surfaces, pollutants are collected and transported directly to streams, omitting the steps of infiltration, storage, pollutant degradation and gradual release. Pavement and rooftops generate runoff while curbs and storm sewers accelerate it to receiving waters. This increase in velocity and volume of runoff results in more flooding, as the flows of the river are heightened and the time it takes precipitation to reach the stream is diminished. By paving over organic mulch and soil pores, the soil is deprived of water and air, which in turn deprives the plants of soil moisture. Aquifers are not replenished and therefore neither are streams and wetlands through dry periods when the system needs the water from groundwater storage. As rainwater and pollutants from the pavement are quickly transported to a stream, floods are larger and happen faster, increasing the erosion of banks and channels (Ferguson, 1998; Arnold et al., 1996). This in turn affects the habitat of organisms, which face dry conditions from a reduced and unreliable baseflow and quick, large floods during rainy periods. These large pulses of rainwater entering the receiving waters are a particular problem in urban areas and the term "stormwater" is used to refer to the volume and rates of flow in individual storm events. The heaviest pollution loads are seen in the initial periods of runoff during a storm, when concentrations are substantially higher than during later periods of the storm. This phenomenon is referred to as the first flush (Ferguson, 1998; Lee et al., 2002).

Due to the volume and velocity of stormwater, many pollutants that are concentrated on the pavement are carried to the receiving waters. While runoff would otherwise contain only constituents from the mineralogy of the watershed and precipitation, urban areas introduce oils, bacteria, litter, sediment, fertilizers, metals and foreign chemicals from the various activities that take place in the watershed. As they enter the receiving water rapidly, water quality is compromised and the organisms living in the aquatic system are threatened. Since water tables are lowered, the concentrations of any pollutants in the stream increase and pose a toxicity risk to aquatic organisms. As vegetation is removed in order to create impervious surfaces, the reduction in tree cover surrounding the stream results in water temperature fluctuations. This will further stress fish habitats and vegetation growth in the stream (Arnold et al., 1996).

There is also a relationship between imperviousness levels and biological integrity. When channel stability is reduced due to increased erosion rates and runoff, riparian and in-stream habitat quality is degraded. The varied natural stream bed of pebbles, rock ledges and deep pools is covered by a uniform blanket of eroded sand and silt from the sediment loaded runoff, and population shifts within some species of fish are measurable beyond the 10% imperviousness threshold (Arnold et al., 1996).

2.1.3 Effects of Stormwater Runoff on Receiving Waters

These alterations to the landscape reflect the impact that urbanization can have on watershed hydrology. In discussing water quality, it is important to identify the effects that each pollutant has on an aquatic ecosystem once it has been carried with the stormwater runoff from the pavement to the receiving water body.

Table 2.1, excerpted from Ferguson (1998) summarizes the major contaminants found in urban stormwater and their effect on aquatic systems. It can be seen that the contaminants introduced into aquatic systems through urban stormwater runoff can pose serious threats to habitat and the physiology of aquatic organisms. This study focuses on the trace metals and phosphorus found in stormwater ponds, therefore a detailed discussion of these contaminants follows.

2.2 Metals in Aquatic Systems

2.2.1 Sources in Urban Areas

As indicated in Table 2.1, trace metals are introduced into the urban environment mainly through automobile use, construction materials and chemicals such as de-icing agents. While the specific sources of each metal will vary depending on the catchments and land use activities, some general sources have been identified in the literature. Parking and storage areas have been linked to high concentrations of nickel in the stormwater, and vehicle service areas and street runoff have shown to be a source of cadmium and lead. Industrial sources have been linked to copper concentrations, in addition to copper wires and pipes. Roof runoff has been linked to zinc in stormwater, primarily from galvanized roof drainage components as well as automobile use. Lead based paints are thought to contribute to lead concentrations and chromium is also associated with automobile use (Field et al., 2000; Ward, 2003).

Table 2.1 Stormwater contaminants and effects on aquatic systems

Constituent	Source in Nature	Role in Natural Ecosystem	Source of Urban Excess	Role of Excess
Sediment	Banks of meandering channels	Maintain stream profile and energy gradient; store nutrients	Construction sites; eroding stream banks	Abrade fish gills; carry excess nutrients and chemicals in adsorption; block sunlight; cover gravel bottom habitats
Organic Compounds	Decomposing organic matter	Store nutrients	Car oil; herbicides; pesticides; fertilizers	Deprive water of oxygen by decomposition
Nutrients	Decomposing organic matter	Support ecosystems	Organic compounds; organic litter; fertilizers; food waste; sewage	Unbalance ecosystem; produce algae blooms; deprive water of oxygen by decomposition
Trace Metals	Mineral weathering	Support ecosystems	Cars; construction materials; foreign chemicals	Reduce resistance to disease; reduce reproductive capacity; alter behaviour
Chloride	Mineral weathering	Support ecosystems	Pavement de-icing salts	Sterilize soil and reduce biotic growth
Bacteria	Native animals	Participate in ecosystems	Pet animals; dumpsters; trash handling areas	Cause risk of disease
Oil	Decomposing organic matter	Store nutrients	Cars	Deoxygenate water

2.2.2 Important Physical and Chemical Processes

In discussing metals in aquatic systems, it is important to define key terms and processes that will be useful in addressing the functions of stormwater ponds. Metals can be trapped in sediments by a variety of processes. The combination of these processes is referred to as sorption. An important component of sorption is cation exchange, where one positively charged ion attached to the sediment is replaced with another. Humic substances contain large amounts of hydroxyl and carboxylic functional groups, which are hydrophilic and act as cation binding sites. Other portions of humic substances are hydrophobic and polar. This results in the formation of micelles which are groups of humic molecules with their nonpolar sections combined in the center and their negatively charged polar portions exposed on the surface of the micelle. Positively charged ions can then associate with these negatively charged sites. Micelles are one form of ligand that can bind metal ions. The cation exchange capacity (CEC) of a material is the number of ligands per gram of dry solid, determined from the number of metal ions that can be sorbed by a fully protonated sample (Kadlec, 1994). Clay minerals, which are hydrous aluminium silicates with a sheet-silicate structure, are important to the CEC. Most clay minerals have a negative electrical charge on their flat surfaces, which will allow for adsorption with cations. In addition, the outer sheath of hydroxyl groups of the clays absorbs metal ions. Since clay minerals are very common due to being one of the main products of weathering, they will play a large role in the CEC of sediments (McGeary, 1994, Fergusson, 1990).

Chemical transformations are often dependent on the oxidation states of the sediments. A range of oxidation states is usually present in flooded soils, as free oxygen decreases rapidly with depth. This is due to the metabolism of microbes, which consume organic matter in the sediment, and through chemical oxidation of reduced substances. This results in an increasingly negative electric potential between a standard platinum electrode and the concentration of oxygen in the sediment. This measure of electric potential is referred to as the redox potential (Eh) and provides an estimate of the sediment's oxidation or reduction potential. When the redox potential is above 300 mV, dissolved oxygen is available and the condition is referred to as aerobic and a redox potential below this level indicates that no dissolved oxygen is available and the condition is termed anaerobic. Conditions which have near-zero dissolved oxygen are often referred to as anoxic. Oxidation and reduction involve the movement of protons and electrons between molecules. A generalized oxidation-reduction reaction can be described as two half reactions where one half reaction accepts electrons by an oxidized molecule to become a reduced molecule (reduction) and the second half reaction where a reduced molecule is oxidized by the loss of one or more electrons (oxidation). It should be noted that half reactions do not generally occur alone because free electrons are reactive in aqueous environments (Bunce, 1993; Kadlec, 1994; Yen, 1999).

Since the only source of free oxygen is from atmospheric diffusion at the top of the sediment layer, the redox potential of many flooded soils decreases with vertical depth. Typically, a thin oxidized layer is at the sediment-water interface is followed by increasingly reduced conditions with depth. As well, the vertical redox gradients are not as steep away from the inlet, so that each horizon of underlying sediment has a higher redox potential near the outlet than the inlet (Kadlec, 1994).

The pH of flooded soils is typically neutral, even though it may become acidic just after initial flooding due to aerobic decomposition releasing carbon dioxide into the interstitial water. However, over time the soil will return to the neutral range of pH 6.7 to 7.2 units (Kadlec, 1994).

2.2.3 Effects of Metals on Aquatic Biota and Habitat

Toxicity of Metals to Aquatic Life

Aquatic ecosystems can be seen as one of the regulating systems essential for the maintenance of life. In order to fulfil this role, the aquatic medium must ensure a sufficient supply of vital elements and prevent excessive increases in toxic elements. Group I cations (e.g. Na^+, K^+, Mg^{2+}, Ca^{2+}) can be directly assimilated in their dissolved ionic form and play an important role by regulating the formation and maintenance of vital structures. They are released by the weathering of rocks and hence found at high concentrations in aquatic systems. They are usually highly soluble and do not need a particular complexing reaction. For example, sodium and potassium are highly mobile due to their weak complexing ability and facilitate electrical flow through membranes and regulate osmotic pressure. Calcium and magnesium are mainly involved in stabilizing or modifying the formation of biological structures with their weak electrostatic interactions with dissociated oxygen-donor sites on macromolecules and membranes. Group II cations (e.g. Cr^{2+}, Mn^{2+}, Fe^{2+}, Ni^{2+}, Cu^{2+}) are often found as complexes with oxygen-donor sites of suspended particles. They dissociate from their inorganic support to diffuse towards the cell. These processes are accelerated by the formation of aggregates between organisms and inorganic particles. Cohesion is facilitated by polysaccharide fibril macromolecules present in the bulk water phase and around unicellular algae and bacteria. Group II cations have an affinity for three groups of ligands: major anions, carboxylic and phenolic sites, as well as nitrogen and sulfur containing sites. Copper, iron and manganese can also have several stable oxidation sites, which results in complicated reactivity. Despite this complexity, their bivalent forms can be expected to compete for carboxylic and phenolic sites from group I cations and for nitrogen and sulfur containing sites from Group III cations. Therefore, Group II cations provide the majority of metal co-enzymes primarily due to their redox properties. Group III metals (e.g. Cu^+, Zn^{2+}, Cd^{2+}, Pb^{2+}) are the most toxic, as their complexes are more stable than those formed with Group II metals and can consequently replace these metals and inhibit their vital ecological role. They have an affinity for mostly nitrogen and sulfur containing sites, which are often found on proteins and aquagenic fulvic acids in the water column. By reacting with sulphur sites on organic matter, the Group III metals become tightly bound to sediments. (Buffle et al., 1994).

Different metal fractions are important to identify, as they affect the toxic threat to aquatic life. The total fraction is generally defined as that which does not filter through a 0.45μm membrane, while the bioavailable fraction does pass through the membrane and is considered to be the most available for uptake. The free metal ion is thought to be the most toxic to aquatic life, as its activity reflects the chemical reactivity of the metal, which influences the metal's reaction at the cell surface and hence its bioavailability.

Several environmental factors play a role in the toxicity of metals. Research has shown that the Cu^{2+} and Cu-hydroxy complexes are the chemical species most toxic to fish (EVS, 1997). Since alkalinity is thought to be important in controlling Cu^{2+} concentration, the bicarbonate system, which controls alkalinity, is a key factor in the toxicity of metals. The pH of the water also plays a role, as it controls the solubility and concentrations of major metal species. As acidity increases, so does the concentrations of free metal ions. Therefore, metals are more likely to be toxic in acidic than neutral waters. Dissolved organic compounds such, as humic acids, also influence the bioavailability of metals. In general, suspended inorganic and organic matter will bind metals and make them less bioavailable to organisms. In certain cases, however, higher concentrations of dissolved organic carbon (DOC) increase the toxicity of metals such as copper and cadmium to aquatic biota. Therefore, dissolved organic matter may not be a simple hydrophilic ligand that will bind metals and decrease their bioavailability (Wood et al., 1999; EVS, 1997; Reichman, 2002).

The complex nature of the toxicity of metals to aquatic biota is important to consider, as there are no simple answers as to why one species will be affected by metals in one situation rather than another. Also, the entire nature of the aquatic system needs to be considered, rather than one simple aspect. The bioavailability of metals is important to investigate in stormwater, as it will help in determining the actual threat that is posed to aquatic life in the receiving waters.

Measuring Bioavailability using Diffusive Gradient in Thin Films (DGT)

Diffusive Gradients in Thin Films (DGT) consist of a binding agent that accumulates solutes quantitatively after their passage through a well-defined diffusion layer. A polyacrylamide hydrogel is commonly used as the diffusive layer, while Chelex 100 resin, incorporated into a second gel layer, serves as the binding agent. The two gels are enclosed in a small plastic device that is immersed in solution and can be deployed in-situ (Zhang et al., 1998; Peters et al., 2003; Gimpel et al., 2001). A diagram of the DGT unit is provided in Figure 2.1.

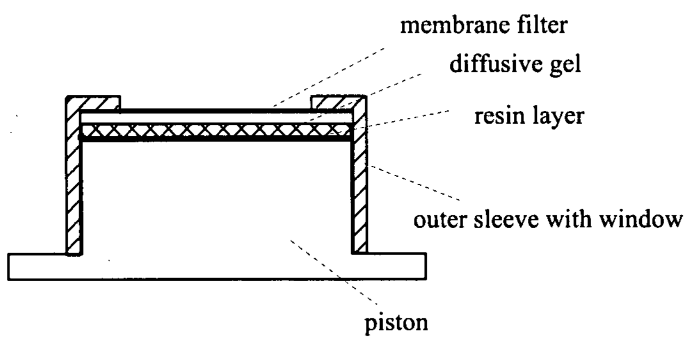

Figure 2.1 A schematic representation of a section through the DGT unit (DGT Research Limited, 2002)

The Chelex 100 resin is an ion exchange resin that is more selective for multivalent metals than standard cation exchange resins and does not alter the concentration of non-metallic ions. Chelex 100 resin is composed of styrene divinylbenzene copolymers containing paired iminodiacetate ions that act as chelating groups for binding polyvalent metal ions. The resin is classed with the weakly acidic cation exchange resins by virtue of its carboxylic acid groups, but it differs from ordinary exchangers because of its high selectivity for polyvalent metal ions and its higher bond strength. It has an unusually high preference for copper, iron and other heavy metals over cations such as sodium and potassium (Bio-Rad, 2003). Since ion exchange resins accumulate ions through exchange mechanisms, they model the action of cell walls on plant roots, fish gills, and aquatic invertebrates (Reichman, 2002).

DGT preconcentrates metal solutes, which alleviates the problems of contamination and poor detection at trace levels. The pore size of the diffusive gel generally permits free metal ions and inorganic and small organic metal complexes to diffuse through to the resin while excluding particles and large colloids. For metal complexes to be measured they must dissociate during their transport through the diffusive layer. Therefore, only labile complexes that can dissociate are measured. This includes metal–fulvic complexes but excludes complexes with very strongly binding ligands, such as EDTA. Since DGT measures dissolved labile species of molecular sizes smaller than the hydrogel pore size, discrimination of species is possible by using gels with different pore sizes. DGT units have proven to be useful due to their ability to operate in-situ and eliminate the need for sample collection and storage. It has been used for measuring labile metal species *in situ* in natural waters and for assessing metal re-supply fluxes and concentrations in sediments at high spatial resolution (Gimpel et al., 2001).

The DGT technique relies on establishing a linear diffusion gradient through the gel while it is deployed. The accumulated mass of metal, M, is measured after deployment by eluting the metal with acid so that the concentration can then be calculated (see Appendix V).

It has been found that the concentrations of metals measured by DGT in solutions with pH values between 5 and 8.3 agree well with those obtained by direct measurement. Gel swelling may occur if the units are deployed in water with a pH over 12, which causes the gels to burst from the plastic holder. Otherwise, the DGT units have been shown to function satisfactorily in waters with a pH below 11 (Gimpel et al., 2001; DGT Research Ltd., 2002).

It has been found that varying the angle of the unit with respect to the flow has a small effect on the measured concentrations. Reducing the flow to zero resulted in a 50% decline in metal accumulation. However, when DGT is deployed in rivers or streams with reasonable flow rates, the measurement should be independent of flow to within 5% (Gimpel et al., 2001; DGT Research Ltd., 2002). Therefore, DGT can be expected to work reliably as both a device for measuring concentrations of labile metal ions and as a speciation tool in natural waters such as the LFV.

2.3 Phosphorus in Aquatic Systems

2.3.1 Sources in Urban Areas

As identified in table 2.1, nutrients can be introduced into stormwater through organic litter, fertilizers, food waste and sewage. In urban areas, fertilizers applied to lawns are a major source of phosphorus, as application before rainfall events often results in stormwater transporting the phosphorus to receiving waters. As well, many household cleaners often contain phosphates.

2.3.2 Important Physical and Chemical Processes

The retention of soluble anions, such as phosphorus, depends on the charge of ions and colloids. Since the aluminnosilicate layer-lattice minerals that dominate the clay fraction are typically negatively charged, the physical adsorption of cations is far more common than the adsorption of anions. However, anions such as phosphorus are weakly soluble as they form strong chemical bonds with the cations in soil clays. Since these bonds can overcome the electrostatic repulsion of the negative charge, strong soil retention can be achieved. The layer silicates develop negative charges, which will repel the anions, however the positive charges on clay edges and hydrous oxides, will attract the anions (Bohn et al., 1985). In order to understand the processes affecting phosphorus adsorption onto sediments, the process of ligand exchange is important to discuss.

An amphoteric system, such as a hydrous oxide system, has either a negative or positive charge and has capacities for both cation and anion exchange depending on the pH. Iron or aluminum oxide-dominated soils have a much greater capacity to adsorb anions and can scavenge phosphate and similar anions from solutions. This strong adsorption is often explained by ligand exchange. This process involves the oxygen ions on a hydrous oxide surface being replaced by anions, such as phosphate, which can enter into sixfold coordination with Al^{3+} and

Fe^{3+} ions. It takes place within the crystal and results in the surfaces of the oxides being more negative. This negative charge arises when a part of the liberated hydroxyl ions are liberated by the formation of water. The ligand exchange process can occur on surfaces with a net negative, positive or neutral charge (Bohn et al, 1985).

Phosphate is fixed by soils in large quantities by converting readily soluble phosphorus to forms less available to plants. In terms of ligand exchange, as discussed above, phosphate adsorption on oxide surfaces is characterized by the process of phosphate replacing singly coordinated OH groups and then reorganizing into a stable binuclear bridge between cations. The adsorption of phosphorus by layer two silicates is divided into two steps. First, a rapid reaction occurs which is a combination of nonspecific adsorption and ligand exchange on mineral edges. The second step consists of a complex combination of mineral dissolution and precipitation of added phosphorus with exchangeable cations. It is important to note that phosphorus should precipitate in basic soils as one of several Ca^{2+} phosphate compounds (Bohn et al., 1985; Lorion, 2001; Jing et al., 2001).

While the mineral chemistry is generally complex, three trends are apparent. In acid soils, phosphorus may be fixed by aluminum and iron. In alkaline soils, calcium and magnesium can fix phosphorus. Finally, reducing conditions lead to the solubilization of iron minerals and the release of phosphorus coprecipitates (Kadlec and Knight, 1996).

2.3.3 Effects of Phosphorus on Aquatic Biota and Habitat

The primary effect of phosphorus entering aquatic systems is eutrophication. Eutrophication is nutrient enrichment that removes the limitation of a component that is required for growth, thereby accelerating the growth of phytoplankton and aquatic plants. Freshwater bodies usually have phosphorus as a limiting nutrient, while seawater is usually limited by nitrogen. In freshwater, excess nutrients can change the dominant form of algae. As plant matter and algae growth increases, oxygen is produced, however the subsequent decomposition will deplete the aquatic system of oxygen, threatening the survival of organisms (Bunce, 1993; Comings, 1998; Sakadevan et al., 1999).

2.4 Urban Stormwater Ponds

As the problems of stormwater runoff become more problematic for expanding cities, efforts have been made to mitigate the impacts on the surrounding environment. Methods of detaining water have been used in order to reduce peak flows in receiving waters in order to mitigate downstream flooding, erosion and deleterious effects on aquatic habitat. However, these measures can also be useful in contaminant removal, which is discussed in this section.. In addition to detention in ponds, several other small-scale methods have been developed to handle stormwater runoff, which are also described.

2.4.1 Important Physical and Chemical Processes in Stormwater Ponds

Detention ponds are usually constructed so that discharge to streams after development should not be any greater than before development. Therefore, in theory, receiving waters should not experience an impact from the development, at least in terms of volume of water. This is accomplished by restricting the pond's outflow with the use of a constructed outlet, which is made small enough to reduce the flow and the pond is large enough to hold excess water. A secondary overflow is usually incorporated at the outlet for large volumes of water that exceed the pond's capacity. The detention storage refers to the volume of the pond above the outlet's invert elevation. Stormwater runoff accumulates in this storage area and is released gradually through the constricted outlet. An infiltration basin works in a similar manner, as stormwater runoff fills the empty pond, however the outlet only releases water which exceeds the capacity of the pond. Therefore, the runoff from average storms fills the pond but is not released through the outlet. Instead, it remains in the pond and infiltrates the soil (Field et al., 2000).

In a wet pond or constructed wetland, where there is a permanent pool of water, the detention time is increased from a simple detention pond that only handles individual storm events. Therefore, runoff is contained in the pond for a longer period of time before being released from the outlet. If the capacity of the wetland is exceeded by a very large storm, the water would move faster through the pond and be less effective than during average storm events.

In most ponds, processes involving sediments, organic material and microbes are largely responsible for the removal of metals from wastewater. The settling of particulates is a process common to both dry and wet detention ponds. Sedimentation and trapping are the two main mechanisms that remove solids from the water. Sedimentation results when slow moving waters allow time for the physical settling of total suspended solids. Solids sink in water due to the density difference between the particle and water. Suspendable material can be generated from within wetlands due primarily to the death of microflora and fauna. In this case, a fine detritus is created, which is rich in nutrients and decomposes rapidly. This results in the slow, lateral transport of solids in the direction of water flow. Physical resuspension is not a dominant process, as water velocities are usually too low to dislodge a settled particle from the bottom or submerged vegetation. However, resuspension can occur through wind-driven turbulence, bioturbation and gas lift. In open water areas, wind-driven currents can cause surface flow in the wind direction and return flows along the bottom in the opposite direction. These velocities can be higher than the net velocity from inlet to outlet. Animals can resuspend particles from looking for food and nesting. Gas lift occurs when bubbles of gas become trapped in or attached to particulate matter. Wetland sediments are usually near-neutral buoyancy, so a small amount of gas can cause resuspension. Gases are generated primarily through the photosynthetic production of oxygen by algae and production of methane in anaerobic zones. Resuspension can be limited by fully vegetated wetlands, where litter and roots stabilize soils and sediments (Kadlec, 1994).

Adsorption and precipitation also play important roles in contaminant removal from the water column. Trace metals can readily form complexes with the organic matter contained in sediments, as organic soils have been shown to have a high cation exchange capacity. Heavy metals may be sorbed to the soil or chelated with organic matter. It should be noted that once a system has reached its capacity for metal sorption, metal sulfide formation becomes the main method of metal removal. Bacteria oxidize organic matter and reduce sulfate to form hydrogen sulfide. This reacts with metals to form metal sulfides, which precipitate (Lorion, 2001:2). Precipitated and adsorbed materials settle in the wetland or are filtered out through. The metals can get taken up by plants, but more often are precipitated out as sulfides or carbonates (Simeral, 2002; Walker et al., 2002). The behaviour of iron and manganese in ponds is regulated by a complex exchange at the water-sediment interface. The two metals can be oxidized from Fe^{2+} and Mn^{2+} to Fe^{3+} and Mn^{4+} oxides, which precipitate on the surface of sediments. However, under anoxic conditions, often caused by decreased respiration in the winter season, iron and manganese are released into the water column in the dissolved form (Goulet et al., 2001).

The phosphorus compounds dissolved phosphorus, solid mineral phosphorus and solid organic phosphorus, are frequently found in the stormwater pond environment. Plant uptake is reported to be the principal mechanism for organic phosphorus removal in wetlands, whereas the principal mechanism for inorganic phosphorus removal is adsorption and precipitation in the root bed media. (Lorion, 2001; Kadlec and Knight, 1996; Jing et al., 2001).

Phosphorus is also incorporated in pond biota and corresponding detritus. Because phosphorus is a nutrient, the addition of this element stimulates growth and causes an increase in biomass. Since the increase in the pool of biomass phosphorus is a short-term process and presumably reversible, it should not be considered a long-term removal capacity of stormwater ponds. A more important process is the overall cycle of growth, death and decomposition of biomass. The accretion of biomass residuals and minerals is considered to be the only sustainable storage mechanism for phosphorus removal (Kadlec and Knight, 1996).

Flooded soils such as those in stormwater ponds have a variable capacity to sorb phosphorus. This storage capacity is soon saturated under increased phosphorus loading. Soil water can store phosphorus in its porewater, in the solid as part of its chemical structure and on the surface of the solid as sorbed phosphorus compounds. Soils often have steep vertical gradients in total phosphorus content, with a large reduction occurring in the first 30 cm. This corresponds roughly to the root zone for emergent macrophytes such as cattail. Most of the phosphorus in the soil column is structural, both organic and inorganic (Kadlec and Knight, 1996).

Microbial soil processes are also very important in the removal of metals and phosphorus in stormwater ponds. They influence the chemistry of the sediments and result in transformations of nitrogen, iron, sulfur and carbon. The processes are typically affected by the concentrations of reactants, the redox potential of the soil and the pH of the soil. For example, after denitrification has produced nitrogen gas, bacterial nitrogen fixation can transform the gas to organic nitrogen (Kadlec and Knight, 1996). The vegetation in stormwater ponds enhances microbial activity by maintaining an extensive root and leaf substrate for bacterial biofilms and by providing an additional source of dissolved oxygen. Some aquatic plants are adapted to anaerobic soil conditions and transport oxygen to the root zone through special structures called aerenchyma. Oxygen is produced as a by-product of wetland plant growth, resulting in higher dissolved oxygen concentrations in the water and in the soil immediately surrounding the plant roots. The presence of these microsites enhances the system's capacity for aerobic bacterial decomposition of pollutants (Kennedy and Mayer, 2002).

2.4.2 Types of Best Management Practices

In order to mitigate some of the effects of stormwater runoff, several best management practices (BMPs) have been developed which can be implemented on a site or community scale. While prevention of the amount and runoff and pollutants are the most desirable, stormwater can also be treated through conveyance, collection and cleansing. These four steps represent the pathway that stormwater takes from when it enters a watershed to when it reaches the receiving watercourse. At each stage of the process, BMPs can be introduced to reduce the volume and improve the quality of the stormwater before it is released. The options described below represent structural techniques that can be implemented on a small scale in order to improve stormwater quality.

In order to prevent precipitation from running over the surface of the landscape, measures can be taken to improve the permeability of surfaces. The most obvious choice would be to preserve as much of the original soil cover and vegetation as possible, thereby reducing soil compaction. When land use activities dictate the need for some alteration to be made, there are alternatives to the common soil stripping and paving process. Porous pavement, which consists of a layer of porous asphalt overlying an underground reservoir of stone aggregate, allows runoff to infiltrate the asphalt and collect in reservoirs where it can then infiltrate into the subsoil. Porous pavement requires extensive maintenance to prevent clogging, which can result in poor performance (Shammaa et al., 2001; Ward et al., 2003). Stormwater runoff can also be avoided by harvesting the rainwater for on-site uses. This involves collecting the water to maintain a permanent pool in order to keep it functioning in dry periods. Rainwater can also be harvested in barrels or cisterns and used for lawn care and to irrigate gardens, thereby reducing runoff as well as municipal water consumption (Ferguson, 1998). Source control techniques can be used to help remove pollutants before they enter stormwater systems. Oil and grit separators can be used in highly impervious areas such as parking lots, industrial sites and petroleum stations. They are usually large underground structures and separate grit and other floatables by skimming and containment. Thus oil, grit and some fine particles can be trapped at the source. Street sweeping is a technique used to remove contaminants from roads in order to prevent them from being carried away by stormwater. Mechanical sweepers, and vacuums are the basic technologies employed to remove particles from the pavement, which can include de-icing agents, leaf litter and sediments (Shammaa et al., 2001).

During conveyance, several opportunities exist for BMP implementation. Grassed swales are vegetated channels that transport stormwater while removing pollutants by filtration through grass and infiltration through soil. They are generally sufficient in residential subdivisions as a replacement for curb and gutter systems and can slow or reduce runoff. However, they have a limited ability to control large storms and function best when soils have very high infiltration rates. Grass buffer strips can also be an integral part of the conveyance system, as they can intercept the flow path of stormwater runoff and remove large particles while promoting infiltration. They are most effective when flow is slow and shallow. Infiltration trenches collect surface runoff and promote infiltration while conveying water to subsequent infiltration sites. They are designed to retain the first flush and are effective at removing particles from stormwater. Maintenance is important to avoid clogging and groundwater contamination can be a concern if proper studies are not undertaken prior to implementation (Shammaa et al., 2001; Field et al., 2000).

Collection facilities are useful for the trapping and infiltration of stormwater to groundwater storage and detention of stormwater before it is released to receiving waters. Infiltration basins usually have dry bottoms covered with native grasses with the potential to handle 1 to 3 year storms and become completely dry between storms. Highly permeable soils are required and regular maintenance is needed to ensure proper functioning. Soil and groundwater contamination is a concern, and therefore extensive design guidance is essential (Shammaa et al., 2001; Field et al., 2000). Dry ponds, also known as extended detention basins, consist of an inlet and an outlet, which allows stormwater to pass through the pond, leaving the pond dry between storms. The ponds generally hold water during the wet season but stay completely dry during the dry season. Maintenance of the inlets and outlets, as well as sediment removal and litter collection, has been identified as important to the performance of dry ponds (Shammaa et al., 2001).

Wet ponds, also known as retention ponds, have a permanent pool of water and can also include a formal surcharge detention volume above this pool. Marsh plants often grow around the perimeter of the pond, providing biological media for trapping small sediment and removing nutrients and other dissolved constituents. Sediment removal and erosion control are important maintenance measures, and regular inspections are required to monitor any eutrophication or structural problems. Constructed wetlands are essentially wet ponds planted with emergent and submergent rooted vegetation or colonized naturally by volunteer plant communities. Efforts are usually made to mimic natural situations as much as possible to take advantage of the treatment potential of a wetland system. Areas with shallow groundwater help to ensure that sufficient water is available in dry seasons. They are generally designed to handle 2 year and smaller storms and require similar maintenance as wet ponds (Shammaa et al., 2001; Field et al., 2000).

The wide variety of small scale stormwater detention and remediation options can be implemented in series, which maximizes the opportunities for water quality improvement. In addition, non-structural BMPs are important for ensuring effective stormwater management. These measures include reducing the use of products known to cause problems in aquatic habitats (e.g. detergents containing phosphorus, de-icing agents), using landscaped areas for the discharge of stormwater and providing operation and maintenance for publicly owned BMPs (Field et al., 2000).

2.4.3 Performance of Urban Stormwater Ponds

An extensive 1992 study in the United States assembled the average removal efficiencies of various types of stormwater management techniques for several parameters. The results of the study are presented in Table 2.2, which has been adapted from Urbonas (2000). Total Suspended Solids (TSS) are reported as the particulate matter contributes to turbidity levels and contaminants are adsorbed to the particles.

Table 2.2 Typical contaminant removal ranges in percent for several BMPs

Type of BMP	TSS	Phosphorus	Zinc	Lead
Porous Pavement	80 - 95	65	98	80
Grass Lined Swale	20 -40	0 - 15	0 - 20	n/a
Wet Pond	91	0 - 79	0 - 71	9 - 95
Dry Detention Pond	50 - 70	10 - 20	30 - 60	75 - 90
Wetland Basin	40 - 94	(-4) - 90	(-29) - 82	27 - 94

It can be seen from Table 2.2 that large ranges of removal efficiencies exist in different ponds. This is due to the wide variety of site conditions, such as detention time, incoming pollutant loads and internal geometry and nature of the systems. They should therefore be considered as general ranges (Mallin et al., 2002). Inlet concentrations affect the percent removals, whether measured as a reduction in concentration or loadings from inlet to outlet. The "percent removal" increases as the inlet concentrations increases, producing higher results for more contaminated runoff in spite of the actual remediation occurring in the systems. Therefore, the raw data needs to be examined to determine which systems are releasing the most contaminated water, instead of relying solely on the percent removal for the assessment of a technique (Urbonas, 2000).

The variability of the effectiveness of contaminant removal is investigated in this study by comparing several stormwater pond systems. Removal efficiencies are explored in the Lower Fraser Valley of British Columbia and possible factors affecting positive and negative results are explored. This study is expected to contribute to the knowledge of the performance of stormwater ponds in the region and identify land use and design characteristics which have common effects on the systems. This will provide background information for stormwater management in the region and aid in predicting the success of future projects.

Chapter III Methodology

3.1 Study Sites

In order to select a sample of the stormwater detention efforts in the Lower Fraser Valley (LFV), a set of selection criteria were outlined. The aim was to find examples of typical techniques that had been employed by municipalities in the LFV that would represent a cross section of what had been happening in the region in terms of stormwater management. The selection process began with contacting municipal government officials responsible for stormwater management who had been involved with the efforts in their communities in recent years. Field tours with the officials were arranged to view the best examples of stormwater management techniques in urbanizing areas. Sites in North Vancouver, Chilliwack, Langley, Burnaby and Surrey were visited and from there, a selection of ten sites was chosen as an initial subset of the most representative sites in the LFV. These ten sites, located in North Vancouver, Chilliwack, Langley and Burnaby, were monitored for sediment and water quality in July 2003. Initial monitoring results and subsequent sampling in the fall of 2003 led to the reduction of the sample size to five of the most comparable stormwater detention sites. These fulfilled the selection criteria that had been formulated and were accessible for monitoring efforts.

The selection criteria was defined by several parameters were outlined as important for comparison of the sites:

Catchment land use: The study aimed to look at the effect of stormwater management techniques in urbanizing areas, therefore sites with primarily suburban residential or transportation uses typical of those in areas undergoing urban expansion were required.

Age: In order to minimize the effects of the age of the ponds in their performance, sites no more than ten to thirteen years old were monitored. This ensured that the most recent efforts made by municipalities during urbanization were considered.

Size: Sites with similar surface areas were chosen. The sites were all small enough to be integrated into a site plan of a subdivision, while being large enough to perform water quality improvement functions.

Pond to catchment ratio: An attempt was made to select sites that had similar sizes in terms of surface area and volume, with some differences in catchment size. This allowed sites to be included in the study despite accepting the runoff from a slightly larger subdivision. The pond to catchment ratio was important to consider, as this parameter would affect the quality of the stormwater that was released into the pond. Therefore, only sites of a comparable size accepting runoff from a typical suburban use were chosen, keeping the pond to catchment ratios as similar as possible.

Shape: Some attempt was made to choose sites with differing shapes, as it became evident that those with meandering characteristics appeared to have more movement of water, which was suspected to affect sediment deposition and contaminant removal.

Extent of vegetation: From inspecting several stormwater detention sites in the LFV, it was clear that a major difference would be the presence of emergent and submergent vegetation in the ponds. This is the primary difference between a constructed wetland and a detention pond. As this is thought to be a factor in contaminant removal, sites with differing extents of vegetation were chosen. Initial water and sediment sampling at nine ponds in Chilliwack, Burnaby, Langley and North Vancouver was undertaken between July and December 2003. This allowed for a period of time to determine which ponds would provide reliable sampling access, which would hold water throughout the wet season and be most comparable in terms of how they function. As well, the proximity of the sites to one another was taken into consideration in order to increase the feasibility of the sampling program and minimize climatic differences. In January 2004, the scope of the study was refined to include five sites in Langley, Burnaby and North Vancouver.

Parameters for the sites were collected in order to compare characteristics that affect the quality of the runoff that enters the pond and the performance of the pond itself. A brief description of the parameters and how they were measured follows:

Date of completion: Number of years since the date of completion of construction activities. The information was gathered from municipal engineering reports or reports from the company responsible for construction.

Reason for construction: A brief account of the original purpose of the detention system, as reported from municipal records.

Catchment: The size of each catchment was delineated in ArcGIS 9 using storm sewer information from the municipalities. The catchment area is defined as the area whose stormwater drains into catchment basins and is transported through the storm sewer system to the inlet of the pond. Land use was interpreted from aerial photographs and site visits. Percent imperviousness was determined using land use as an indicator (Bestbier et al, 2000) and aerial photographs, where medium density residential subdivisions in this study were estimated to be between 50 and 65% percent impervious, and the highway catchment was 100% impervious.

Size: The size of each pond was determined from plans provided by the municipality or measured on-site by either surveying with a total station survey instrument or manual measurements.

Shape: Each site was described by the shape of the primary pond if there were more than one settling area. Shapes were defined as either oval, meandering or rectangular. These were determined by field visits, plans and aerial photographs.

Volume: The volume of the pond was obtained from the engineering designs when available. Otherwise, the volume was estimated from the dimensions of the pond, either reported in municipal records or measured on site.

Extent and types of vegetation: The extent of vegetation was determined by examining aerial photographs and field inspection in cases where aerial photography was out of date or did not exist. The extent was estimated as the percentage of the pond that was vegetated versus non-vegetated. The primary types of vegetation present were identified in municipal reports on the sites or through field inspection.

Traffic volumes: An estimate of the average daily weekday traffic volume in the catchment was obtained from municipal studies. Where traffic information did not exist for a specific catchment, the closest intersection which had been monitored was used as an estimate of the amount of cars driving through the catchment on a typical day.

A summary of the parameters describing each site can be found in Table 3.1. Photos of each pond are provided in Appendix I and aerial photographs of each catchment are provided in Appendix II. Drawings of the 52Ave/221A Street Detention Facility and Oakalla Biofiltration System are provided in Appendix III and a map of the locations of all the ponds are provided in Appendix IV.

3.2 Field Sampling

3.2.1 Overview of Sampling Methodology

The sampling program focused on obtaining water, sediment and Diffusive Gradient in Thin Film Technique (DGT) samples during the wet and dry seasons over a one-year period. Samples of all three types were taken at the inlet and outlet of the ponds to compare the concentrations of contaminants as the stormwater enters and leaves the pond. Samples were taken as consistently as possible throughout the year in order to gather sufficient information for an assessment of the contaminant levels in the ponds throughout different seasons. Sampling was more intensive during the wet season as increased rain led to higher rates of precipitation and therefore more stormwater that transports contaminants to the ponds. Efforts to capture specific rainstorms and their effect on the function of the pond were beyond the scope of this project. Since stormwater ponds of this size generally serve the purpose of managing average rainstorms, the focus of the sampling program was on sampling at regular intervals to measure the consistent levels of contaminants entering and leaving the ponds and not extreme events. Effects of increased precipitation were taken into account by collecting climatic data corresponding to the sampling period.

3.2.2 Water Sampling Techniques

Water sampling was done at the inlet and outlet of each pond. Grab samples were taken as close as possible to the inlet pipe with a 250 mL Nalgene bottle. Outlet samples were taken in the same manner from water that was about to exit the pond. In the case of the 52nd Ave/221A Street detention facility, water was also sampled halfway through the pond and from a small inlet ditch due to the more complex design of the pond. It should be noted that there was no

Table 3.1 Characteristics of study ponds

Site name / Parameter	Westview Interchange Detention Pond	52Ave/221A Street Detention Facility	Tempe Heights Pond	Griffin Park Biofiltration Pond	Oakalla Biofiltration System
Location	City of North Vancouver	Langley	City of North Vancouver	District of North Vancouver	Burnaby
Date of completion	1996	1999	1993	1998	1990
Reason for Construction	Detention of stormwater runoff to reduce volume entering Mosquito Creek	Detention of stormwater runoff to reduce volume entering Nicomeckl River	Detention of stormwater runoff to reduce volume; improve water quality entering Keith Creek; and provide an aesthetic amenity	Detention of stormwater runoff to reduce volume; improve water quality entering Mosquito Creek Salmon Habitat Area; and provide an aesthetic amenity to Griffin Park	Detention of stormwater runoff to reduce volume; improve water quality entering Deer Lake; and provide an aesthetic amenity to Deer Lake Park
Catchment Size	2 km^2	0.28 km^2	0.0014 km^2	0.0036 km^2	0.3 km^2
Catchment land use	Major highway	Primarily residential subdivisions and some commercial	Primarily reseidentail subdivision and park	Primarily residential subdivisions and park	Primarily residential subdivision
Percent impervious cover	100%	50%	65%	60%	55%
Size	300 m^2	4000 m^2	608 m^2	90.3 m^2	966 m^2
Shape	Oval with curve after inlet	2 square cells divided by bridge with culvert passing underneath	Oval with curve near middle of pond	Meandering channel	Two ponds and one large marsh
Volume	300 m^3	4900 m^3	668.8 m^3	72.24 m^3	1615 m^3
Percent vegetation	0%	50%	20%	60%	70%
Types of vegetation	None	Primarily cattails	Cattails	Cattails; native plants and grasses	Cattails; grasses
Average Annual Daily Traffic (Year Collected)	72000 (2000)	900 (2000)	960 (2004)	7108 (2000-2002)	640 (2001)

attempt to take grab water samples at a specific point in a storm, which resulted in an inherent variability in the results. Water and temperature was measured at the inlet and outlet for conductivity using a YSI model #30M/50 F1 meter and dissolved oxygen using a YSI model #58 meter. Samples were transported in a cooler to the lab and analysed for pH using a Beckman 44 pH meter. Analysis for a range of trace metals was carried out on the water samples.

Initial water sampling took place in July and September 2003. Samples were taken every three to four weeks from October to June 2004 to monitor the concentration of contaminants in the stormwater from the catchments and the water that is being released to the receiving waters. These sampling times also coincided with the deployment of DGT units.

3.2.3 Sediment Sampling Techniques

Sediment samples were taken manually using a plastic scoop and stored in a plastic bag. When water levels were very high and access was prohibited, a stainless steel scoop was attached to a 4 metre pole and lowered into the pond where the top layer of sediments were scooped and placed in a plastic bag. The top layer of sediment was removed in order to obtain the newest sediments that had been deposited. Sample points were located at the inlet pipe, where the first sediment is deposited as the stormwater moves through the system, and at the outlet of the pond, where the final sediment is deposited. Sediment was also collected in a similar manner from the middle of the pond at the beginning and the end of the sampling period in order to obtain more information about how the contaminants were settling out in the pond. Samples were analysed for a range of trace metals. Particle size analysis was carried out 3 times throughout the sampling period in order to observe general trends without being logistically prohibitive.

Sediment was sampled at approximately six to ten week intervals during the dry season, and three to seven week intervals once the wet season had began. Intervals between sampling times was adjusted depending on the intensity of rainfall, as it was expected that more sediment was being transported to the ponds during periods of high rainfall and therefore warranted more frequent sampling. Initial sampling took place in July 2003 and again in September 2003. Heavy rains began in October 2003 and sediment sampling was increased to every three to four weeks from November 2003 to January 2004. As precipitation began to diminish, sediment sampling was reduced to six to seven week intervals from January to June 2004.

3.2.4 The Use of Diffusive Gradient in Thin Films (DGT) Units

As described in Chapter 2, Diffusive Gradients in Thin Films (DGT) consist of a binding agent that accumulates solutes quantitatively after their passage through a well-defined diffusion layer. The DGT units were installed at the inlet and outlet of the ponds using fishing line to attach the DGT to either grates at the pipes or surrounding trees which would keep the device in place during deployment. Weights were sometimes attached to the DGT as well in order to ensure that it did not rise too close to the surface of the water and some slack was left in the fishing line to ensure that it did not break if water levels fluctuated. The DGT was placed in the middle of the water column with the diffusion layer facing the incoming water from the inlet or the outgoing water at the outlet. This ensured that the water flowed towards the DGT and the resin could therefore accumulate metal ions. The placement of DGT units were kept consistent at each site once a successful procedure was found in order to obtain data which could be compared from one deployment period to the next. The devices were retrieved by cutting the fishing line and rinsing the face of the DGT with distilled water to prevent excess stormwater to pass through the diffusion layer after retrieval. DGT units were kept hydrated with distilled water in plastic Ziploc bags and transported back to the laboratory in a cooler.

DGT units were deployed in the ponds from September 2003 to June 2004. Most of the ponds tended to experience great drops in water levels during the summer months, therefore DGT units were not deployed as dehydration of the devices would have become common and very few storm events would be captured. Calibration of the devices in the field took place in September and October the full sampling program begun in November 2003. The DGT units were deployed for periods of three to four weeks. This was found to be a sufficient period of time to accumulate metal ions from the stormwater while minimizing algae growth and general bio fouling of the device. This helped to avoid skewed results resulting from water being blocked by algae or organic matter on the face of the DGT. As well, the three to four week period allowed for the accumulation of metal ions resulting from enough storm events that allowed levels to be detected by the Varian Simultaneous ICP-AES which was not always possible with grab samples and therefore enhanced the information on the nature and extent of the trace metals in the stormwater ponds.

3.3 Laboratory Analysis

3.3.1 Water Sample Analysis

Water samples were brought back to the laboratory and filtered using Whatman #42 filter paper (diameter 110 mm) into 25 mL plastic Nalgene bottles to eliminate any sediment or plant particles. Each sample was then acidified with 0.250 mL of Trace Metal Grade nitric acid using an Eppendorf Pipette. The bottles were then capped and shaken about eight times to thoroughly mix the contents. Samples were stored in the fridge at 4°C until analysis for metal and phosphorus concentrations was performed on the Varian Simultaneous ICP-AES. The detection limits of the instrument calculated during analysis are provided in Appendix VI.

3.3.2 Sediment Sample Analysis

Metals

The U.S. Environmental Protection Agency method 200.2 for the determination of metals in environmental samples (EPA, 1992) was used to analyse the metals in the sediment fraction. This is also referred to as aqua regia. Sediment samples were first wet sieved with distilled water to obtain the fraction less than 63 μm. This fraction was then dried at 55°C in an oven until a constant weight was reached. The fraction represents the clay/silt particles where metals tend to accumulate. One gram of the dried sediment was weighed and transferred to a 150 mL or 250 mL beaker. A graduated cylinder was used to measure 4 mL of 1:1 nitric acid and 10 mL of 1:4 hydrochloric acid and was then added to the beaker. Each beaker was covered with a watch glass and heated in an oven at 85°C for thirty minutes. The samples were then removed from the oven and cooled for one hour. Contents of the beakers were filtered with a #42 Whatman filter (110mm) into 100 mL volumetric flasks. The flasks were then diluted to volume with deionized water and mixed. The contents of the flasks were transferred to a 60 mL plastic Nalgene bottle and kept in the fridge until analysis on the Varian Simultaneous ICP-AES. Analysis took place within a week of the aqua regia digestion.

Particle Size Analysis

Sediment samples were analysed for soil texture, or the relative size distribution of the primary particles. Soil textural composition is described in terms of the percentage of sand, silt and clay. Particle size analysis was performed on sediment samples by following the Rapid Method as outlined by Kettler et al (2001). Sediment samples were wet sieved through a 2 mm stainless steel sieve with distilled water. Samples were then dried at 55°C in an oven and 15 grams were placed in a 100 mL Beckman Centrifuge tube. Detergent grade sodium hexametaphosphate (HMP) was used to make a 3% by weight aqueous concentration solution. 45 mL of the HMP solution was then added to the dried sediment in the tube and placed on a shaker for 2 hours. The contents were then wet sieved through a 0.053 mm stainless steel standard mesh and the particles that did not pass through the sieve were dried at 55°C until a constant weight was reached. The samples were then transferred to pre- weighed crucibles and placed in a muffle furnace at 450°C for at least 4 hours to oxidize the organic matter in the sand fraction. The samples were then weighed to obtain a final mass of the sand fraction. The sediment particles that did pass through the 0.053 mm sieve were transferred to a beaker and stirred thoroughly to suspend the particles. The beakers were allowed to settle at room temperature for a sedimentation period of 3 hours. Silt particles settle during this period while clay particles remain in suspension. The suspended particles were discarded and the settled silt particles were transferred to a pre-weighed drying pan and dried at 55°C until they reached a constant weight. The samples were then transferred to pre-weighed crucibles and placed in a muffle furnace at 450°C for at least 4 hours and then weighed again to obtain the final silt fraction mass. The final mass measurements for the sand and silt fractions was subtracted from the original 15 grams of sediment used in the analysis to obtain the mass of the clay fraction. Values for each fraction were then calculated as a percent.

3.3.3 DGT Unit Analysis

After the DGT units were brought back to the laboratory in the small plastic bags, they were analysed according to directions provided by DGT Research Limited (2003). The resin gel was retrieved by inserting a screwdriver into the groove in the cap and twisting it off. The filter paper and diffusive gel layer was peeled off with the use of tweezers. The resin gel layer was then removed with the tweezers and placed in a 30 mL plastic Nalgene containing 20 mL of 1 M nitric acid. The bottle was shaken to ensure the resin gel was fully immersed in the nitric acid. The resin gel was left in the acid for at least 72 hours to ensure that sufficient elution time was provided. The gel was then removed from the bottle and discarded. The bottle of nitric acid, which had eluted the metals from the resin gel, was kept in the fridge until analysis was preformed within one week on the Varian Simultaneous ICP-AES.

3.4 Statistical Analysis

Descriptive statistics of the results of the monitoring program were calculated using *SPSS for windows (Release 12.0)*. The Shapiro-Wilks test was applied to the inlet and outlet data to determine if the data was normally distributed. Results indicated that the data was non-normal at both the inlet and outlet for the data set comprising the five ponds. Non-parametric statistics for analysis of the results were therefore used.

A Mann-Whitney test was performed on the data set to determine if there was a significant difference between the wet and dry season and if the analysis should proceed by separating the data set in this manner.

The statistical analysis was carried out in three stages. First, the same statistical tests were performed on the results of all five ponds, treating them as separate systems and garnering information on how they function. Second, comparisons were made between ponds to identify any significant differences and note any similarities through all five ponds. Lastly, the relationship between characteristics of the catchments and ponds themselves were analysed with the monitoring results to identify if any trends of effects that design or catchments use were having on the quality of the water and sediment in the ponds as well as their performance in terms of catchment area. Predictive merits of this study were also explored using the results of all five ponds together.

In each pond, the results of the monitoring program were used to calculate the percent difference of measured parameters between the inlet and outlet using Equation 3.1.

$$\text{Percent Difference} = ((\text{Inlet Concentration} - \text{Outlet Concentration})/\text{Inlet Concentration})*100$$

Equation 3.1 Calculation of Percent Difference

Significant differences between the inlet and outlet were tested for using the Wilcoxin Signed Ranks Test, as the two data sets were related since the inlet concentrations will affect the outlet concentrations. Spearman Rank Test correlations were conducted in order to determine if correlations existed between the precipitation that had fallen on the catchment in various periods preceding sampling and the sample results.

The results of the ponds were also compared against each other in terms of inlet and outlet quality as well as percent difference. The Mann Whitney test for significance was used for this purpose, as the five ponds were not related to each other.

Spearman Rank Test correlations were conducted on the results of the monitoring program and the catchment characteristics in an attempt to draw conclusions about the land use activities and their effects on the quality of the water and sediments seen in the ponds. Correlations were also conducted on the pond characteristics and the monitoring results to identify if the design of the ponds could be correlated to the contaminant removal through the pond.

A simple regression line was fit to selected data to investigate whether a predictive relationship could be identified between catchment characteristics and the quality of the water and sediments in the ponds. A full regression was not performed due to the non-normal distribution of the data set.

Chapter IV Results

4.1 Data Considerations

The water, sediment and DGT results were analysed in order to determine if the difference between wet and dry season was significant enough to warrant analysing the data in separate seasons. The wet season was defined as the months of October through March and the dry season as the months of April through September, based on precipitation data for the sampling period (see Appendix VII). It was determined that several water quality parameters at the outlets were significantly different between seasons as well as the temperature at the inlets. The sediment quality differed significantly between seasons at the inlets for several parameters and for phosphorus at the outlets. Certain metals measured by the DGT units at the inlets and outlets also differed significantly between seasons. Therefore, the entire data set was separated into wet and dry seasons for further analyses. A summary of the tests for significance between wet and dry seasons is displayed in Table 4.1. It should be noted that both seasons were amalgamated in order to examine the effects of precipitation.

Table 4.1 Significantly different parameters between wet and dry seasons (Mann Whitney test, $p<0.1$)

	Inlets	**Outlets**
Water	Temperature	Al, Fe, Mn, Temperature
Sediment	Ca, Fe, K, Na, Ni, P, Si	P
DGT	Fe, Zn	Al, Mn, Zn

Water, sediment and DGT results that were below the detection limit of the ICP instrument were assigned a value of half the detection limit before statistical tests were performed. Any parameters that were consistently detected less than half of the time were not included in statistical tests. This resulted in a reduced set of variables that were used for statistical tests. It should be noted that a detailed discussion of aluminum in water is only included for the three ponds where it was detected over half of the time and excluded in the other two ponds. Otherwise, the parameters used for statistical purposes were the same for all five ponds. A summary of the reduced set of variables is presented in Table 4.2.

Table 4.2 Parameters used for statistical analyses

Water	Al, Ca, Fe, K, Mg, Mn, Na, Si, Zn, Temperature, Specific Conductivity, DO, pH
Sediment	Al, Ca, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, Si, Zn
DGT	Al, Fe, Mn, Zn

4.2 Accuracy and Precision

4.2.1 Method Precision for Metal Analysis in Water

The precision of metal analysis was determined by assessing the precision of field and laboratory procedures. Duplicate water samples were taken in the field at several sampling points throughout the field season. They were analyzed at each sampling time and the percent difference between them was calculated. The average of the percent differences was used as a measure of method precision. The results are summarized in Table 4.3.

Table 4.3 Method precision for field sampling of dissolved metals

Parameter	Average % Difference	Average% Difference Standard Deviation
Aluminum	16.97	16.56
Calcium	4.3	5.9
Iron	17.5	14.0
Potassium	3.8	4.0
Magnesium	4.1	7.0
Manganese	12.0	12.5
Sodium	2.1	2.1
Silicon	3.0	5.7
Zinc	24.6	31.7

The variability of the dissolved metal data at all sites was determined by calculating the coefficient of variation for each set of duplicates and averaging them for each dissolved metal. Results are given in Table 4.4.

Table 4.4 Average site variability for dissolved metals.

Parameter	Average Coefficient of Variance (%)	Average Coefficient of Variance Standard Deviation (%)
Aluminum	13.71	18.20
Calcium	3.07	4.34
Iron	13.52	12.62
Potassium	2.76	3.01
Magnesium	2.95	5.35
Manganese	8.73	9.78
Sodium	1.44	1.45
Silicon	2.13	4.26
Zinc	21.78	62.81

The precision of laboratory procedures was determined by splitting a field sample into two samples once they had been returned to the laboratory. Each of the samples underwent the same analysis and the percent difference between them was used to determine method precision. Results are presented in Table 4.5.

Table 4.5 Method precision for laboratory procedures in dissolved metal analyses

Parameter	Average % Difference	Average% Difference Standard Deviation
Aluminum	10.00	6.79
Calcium	1.33	0.79
Iron	5.72	5.38
Potassium	2.95	6.61
Magnesium	1.07	0.79
Manganese	3.54	4.78
Sodium	1.66	2.19
Silicon	0.58	0.61
Zinc	32.90	34.23

Calculating the coefficient of variation and taking the average of each dissolved metal determined the variability of the samples duplicated in the laboratory. Results are summarized in Table 4.6.

Table 4.6 Variability of laboratory procedure for determining dissolved metals

Parameter	Average Coefficient of Variance (%)	Average Coefficient of Variance Standard Deviation (%)
Aluminum	7.61	5.46
Calcium	0.94	0.56
Iron	3.89	3.52
Potassium	2.27	5.26
Magnesium	0.76	0.56
Manganese	2.60	3.69
Sodium	1.12	1.61
Silicon	0.41	0.44
Zinc	32.02	64.22

4.2.2 Method Precision and Accuracy for Metal Analysis in Sediment

Sediment samples were duplicated at random sites throughout the field season and analysed at the same time to assess the precision of the metal analysis. The percent difference between the duplicates was calculated and the average percent difference was then taken for each metal. Results are presented in Table 4.7.

Table 4.7 Precision of analysis for metals in sediment

Parameter	Average % Difference	Average% Difference Standard Deviation
Al	8.1	5.9
Ca	5.7	6.6
Cr	7.2	5.1
Cu	6.1	4.9
Fe	8.0	5.6
K	5.8	4.3
Mg	8.6	4.5
Mn	6.8	5.5
Na	8.1	8.0
Ni	8.1	3.9
P	4.6	5.5
Pb	7.5	10.1
Si	7.7	8.5
Zn	4.2	5.2

Calculating the coefficient of variation for each duplicate set and taking the average for each metal determined the variability of the duplicate sediment samples. The variability of the sediment samples was calculated as the average coefficient of variation for each duplicate set. The results are summarized in Table 4.8.

Table 4.8 Variability of metals in sediment

Parameter	Average Coefficient of Variance (%)	Average Coefficient of Variance Standard Deviation (%)
Al	6.0	4.5
Ca	4.3	5.2
Cr	5.3	4.0
Cu	4.5	3.8
Fe	5.9	4.3
K	4.3	3.2
Mg	6.3	3.4
Mn	5.1	4.3
Na	6.6	5.8
Ni	6.0	3.1
P	3.4	4.3
Pb	6.0	8.2
Si	5.7	6.8
Zn	3.1	4.1

The accuracy of metal results in sediment were determined using a certified standard reference material from Priority PollutnT^{TM}/CLP (Lot No. DO35-540). The results are summarized in Table 4.9.

Table 4.9 Results for Priority PollutnT™/CLP Lot No. DO35-540 reference sediment material

Element	Certified Value	Acceptable Range	Analysed on 25-Aug-03	Analysed on 25-Aug-03	Analysed on 14-Jun-04	Analysed on 14-Jun-04
Al	6340	2760-9920	3322	2614	4378	3443
Ca	3370	2550-4190	3334	3036	3131	2970
Cr	133	103-163	130	117	123	122
Cu	93.9	74.4-113	93.9	84.7	86.7	88.0
Fe	11600	5500-17700	6378	5069	8647	6700
K	1890	1200-2580	1387	1074	1631	1397
Mg	2000	1410-2590	1501	1260	1726	1530
Mn	320	242-398	315	283	297	288
Na	241	122-360	282	259	421	376
Ni	174	136-211	184	168	169	170
Pb	160	124-196	170	173	153	152
Zn	246	189-303	246	224	234	229

4.2.3 Method Precision for Particle Size Analysis

Duplicate sediment samples were also taken when performing particle size analysis. They were analysed as separate samples in order to determine the precision of the method. The average percent difference between duplicates for each particle fraction is presented in Table 4.10.

Table 4.10 Precision of particle size analysis

Parameter	Average % Difference	Average % Difference Standard Deviation
% Sand	1.3	1.4
% Silt	9.7	12.9
% Clay	46.2	32.0

The high percent difference for clay particles is due to low values used in the averages. For instance, the duplicates done in June 2004 were measured as one gram and four grams, which resulted in a high 76% difference.

4.2.4 Calibration of DGT in Laboratory

The performance of the DGT units was tested in the laboratory prior to initial deployment. The procedure was provided by DGT Research Ltd. (2002). The first trial was undertaken by suspending three DGT units in a beaker of 2.11 mg/L cadmium solution for 4 hours. The DGT units were then retrieved and eluted in 1M HNO_3 solution for 24 hours. The eluents were then measured on the ICP-AES and compared to the concentration of the cadmium solution. The results of the first trial are provided in Table 4.11.

Table 4.11 Results of first trial of DGT laboratory calibration

Solution Label	C_{DGT} (mg/L)	Solution Concentration (mg/L)	% Error	Elution Efficiency
DGT_1_eluent	1.27	2.11	39.81	60.19
DGT_2_eluent	1.68	2.11	20.38	79.62
DGT_3_eluent	1.37	2.11	35.08	64.92

C_{DGT} = concentration of metal measured by the DGT

A second trial was performed in an attempt to better mimic conditions in a natural water body. A stirring bar was used at medium speed in the beaker of cadmium solution while the DGTs were measuring the solution, to provide flow in the water column. The results of this trial were slightly improved and are provided in Table 4.12. Overall, the DGT units were found to be between 78 and 84.5% efficient.

Table 4.12 Results of second trial of DGT laboratory calibration

Solution Label	C_{DGT} (mg/L)	Solution Concentration (mg/L)	% Error	Elution Efficiency
DGT_1_eluent	1.62	2.00	19.00	81.00
DGT_2_eluent	1.56	2.00	22.00	78.00
DGT_3_eluent	1.69	2.00	15.50	84.50

C_{DGT} = concentration of metal measured by the DGT

4.2.5 Method Precision for Metal Analysis in DGT

DGT units were deployed in duplicates throughout the field season in order to determine the precision of the method. The units were analysed in the same manner and the percent difference of the metals that had accumulated on the resins were calculated once analysis and calculation of the metal concentrations was complete. A summary of the average percent differences for each metal is presented in Table 4.13.

Table 4.13 Method precision for bioavailable metals measured by DGT units

Parameter	Average % Difference	Average% Difference Standard Deviation
Al	18.6	25.4
Fe	17.6	25.7
Mn	27.5	22.8
Zn	22.4	30.0

The variability of the DGT duplicates was calculated as the average of the coefficients of variation for each metal of the duplicate set. The results are summarized in Table 4.14.

Table 4.14 Variability of bioavailable metals as measured by DGT units

Parameter	Average Coefficient of Variance (%)	Average Coefficient of Variance Standard Deviation (%)
Al	16.3	23.0
Fe	20.0	30.1
Mn	21.0	23.9
Zn	17.9	25.7

4.3 Overview of Urban Stormwater Runoff Quality at Study Sites

The quality of the runoff from the catchment areas was assessed by sampling the water and sediments at the inlets of each pond. Samples were compared to the Canadian Environmental Quality Guidelines to provide an indication of the level of contamination resulting from the urban uses. A summary of the exceedences of the guidelines for detected metals in the water and sediment are provided in Tables 4.15 and 4.16 respectively.

Table 4.15 Summary of water samples at inlet that exceed the Canadian Environmental Quality Guidelines. Results given in percent. *n* = 12.

Parameter	Guideline Concentration (mg/L)	Percentage of Samples at Inlet Exceeding Guideline				
		D	E	F	G	I
Al	0.005-0.10 (0.10 was used)	18	0	50	0	0
Fe	0.30	0	8	40	18	0
Zn	0.03	0	8	60	9	0

D = 52Ave/221A Street Detention Facility, Langley, E = Griffin Park Biofiltration Pond,
F = Westview Interchange Detention Pond, G = Tempe Heights Pond, I = Oakalla Biofiltration System

Table 4.16 Summary of sediment samples at inlet that exceed the Canadian Environmental Quality Guidelines. Results given in percent. *n* = 8.

Parameter	Guideline	Guideline Concentration (mg/kg)	Percentage of Samples at Inlet Exceeding Guideline				
			D	E	F	G	I
Cr	ISQG	37.30	43	25	87.5	43	29
	PEL	90.0	0	0	12.5	0	0
Cu	ISQG	35.70	71	100	100	100	100
	PEL	197.0	0	100	100	100	0
Pb	ISQG	35.0	27	100	100	14	86
	PEL	91.3	0	100	100	86	0
Zn	ISQG	123.0	18	100	100	100	43
	PEL	315.0	36	100	100	100	57

D = 52Ave/221A Street Detention Facility, Langley, E = Griffin Park Biofiltration Pond, F = Westview Interchange Detention Pond, G = Tempe Heights Pond, I = Oakalla Biofiltration System; ISQG = Interim Sediment Quality Guideline, PEL = Probable Effect Level

The highest levels of metals at the inlets were generally seen in the Westview Interchange Detention Pond. The median value for zinc in the water was 0.026 mg/L in the wet season and 0.044 mg/L in the dry season. Sediment concentrations of zinc had a median value of 1030.2 mg/kg in the wet season and 1072.6 in the dry season. The levels of copper and chromium in the sediments were also highest at this pond. Median values for copper were 392.7 mg/kg in the wet season and 642.1 mg/kg in the dry season; chromium values were 57.5 mg/kg in the wet season and 81.3 mg/kg in the dry season. Many of these levels were significantly higher than in the other ponds, which are discussed in further detail in section 4.4.

The sources of the heavy metals found in urban areas are believed to be automobile by-products, atmospheric fallout and road surface materials. Exhaust emissions, lubrication losses, degradation of tires, brake linings and road surfaces have all been identified as sources of metals in areas affected by traffic. Therefore, characteristics of the catchments, such as traffic volume and percent impervious cover, have a major influence on the chemical composition of urban runoff (Karouna-Renier et al, 2001; Hares et al., 1999). The concentrations of heavy metals found at the inlets of the ponds varied widely, suggesting that the characteristics of the catchments were playing a role in the quality of runoff. The general land use was suburban for four of the ponds, although even within this designation there are differences in the concentrations of metals and possible threats to aquatic life, as can be seen in Tables 4.12 and 4.13. Residential uses such as lawn fertilizers and detergents have been identified as non-point sources of phosphorus, which was also present in the ponds (Comings et al., 1998). The roles of traffic and percent impervious cover, as well as the size of the catchment, in the quality of urban runoff entering the study sites are explored further in section 4.5.

The high percentages of samples exceeding water and sediment quality guidelines at the inlets of the ponds indicate that urban runoff in these areas poses a threat to aquatic life and that the attempts at remediation through facilities such as stormwater ponds are necessary. A detailed reporting of the results of each pond is provided in section 4.4 Further examination of the violations of the Canadian Environmental Quality Guidelines for Freshwater Aquatic Life is provided in section 4.4.5.

4.4 Individual Pond Results

4.4.1 52Ave/221A Street Detention Facility, Langley

Water Quality Results

Water sampling done during the wet season at the detention facility in Langley revealed that the concentration of salts was significantly less at the outlet of the pond than at the inlet. Dissolved metals generally displayed small removal rates between the inlet and outlet, and iron was found to be significantly higher at the outlet of the pond than at the inlet. Specific conductivity was generally high at the inlet of the pond and was significantly reduced through the pond and lower specific conductivity was seen at the outlet. A summary of the water quality results for the wet season is presented in Table 4.17. It should be noted that dissolved aluminum was only detected four out of eleven samples at the inlet and seven out of eleven at the outlet. Dissolved zinc was only detected in two samples at the inlet and five at the outlet. The tests of significance are more meaningful for iron and manganese where close to all the samples were above the detection limit of the ICP.

Table 4.17 Water quality results for the wet season at 52Ave/221A Street Detention Facility. Results are given as median. $n = 6$.

Parameter	Inlet	Outlet	% Difference
Aluminum, mg/L	0.025	0.162	-316.00
Calcium, mg/L	31.738	19.878**	38.80
Iron, mg/L	0.038	0.135**	-260.00
Potassium, mg/L	1.57	1.276**	16.71
Magnesium, mg/L	15.297	8.921**	42.90
Manganese, mg/L	0.025	0.016	20.31
Sodium, mg/L	13.440	13.256	2.71
Silicon, mg/L	9.144	5.675**	30.65
Zinc, mg/L	0.005	0.005	0
Temperature, C	9.8	5.6	43.86
Specific Conductivity, uS/cm	307.8	168.4**	43.18
Dissolved Oxygen, mg/L	9.48	8.63	-1.85
pH	7.51	7.25	3.16

**Significant at the 0.05 probability level (Wilcoxin Signed Ranks Test).

The general trends in water quality were similar during the dry season. However, dissolved manganese concentrations tended to increase between the inlet and outlet, although the difference was not found to be significant. Temperatures also tended to be higher at the outlet than the inlet, which was the reverse during the wet season. A summary of the results for the dry season are presented in Table 4.18.

Table 4.18 Water quality results for the dry season at 52Ave/221A Street Detention Facility. Results are given as median. $n = 5$.

Parameter	Inlet	Outlet	% Difference
Aluminum, mg/L	0.025	0.025	0
Calcium, mg/L	39.720	28.105*	28.06
Iron, mg/L	0.050	0.193*	-488.00
Potassium, mg/L	1.818	1.339*	29.07
Magnesium, mg/L	16.895	11.858*	35.41
Manganese, mg/L	0.025	0.067	-191.30
Sodium, mg/L	14.836	12.749	6.50
Silicon, mg/L	9.853	5.428	44.91
Zinc, mg/L	0.005	0.010	0
Temperature, C	14.6	17.8	-11.11
Specific Conductivity, uS/cm	404.2	285.6*	10.23
Dissolved Oxygen, mg/L	10.05	5.75	0.00
pH	7.42	7.50	0.26

*Significant at the 0.1 probability level (Wilcoxin Signed Ranks Test).

The highly negative median percent difference of dissolved aluminum during the wet season is primarily due to several high concentrations at the outlet during the wet season. The dry season produced very few values over the detection limit of the ICP, which resulted in the low median values reported for the dry season.

The significantly higher dissolved iron concentrations in the outlet of the detention facility compared to the inlet in both the wet and dry seasons can be seen in Figure 4.1. For all sampling dates except July 9, 2003, the outlet water had a higher concentration than the inlet water.

As it became evident that dissolved iron was higher at the outlet of the pond than the inlet, additional locations of the pond were sampled in an attempt to determine if other sources could be introducing iron close to the outlet sampling point. Two main possibilities were identified. A small inlet brings runoff from 52nd Avenue into the pond, just after the bridge over the middle of the pond. The amount of runoff entering the pond from this inlet tended to be minimal compared to the main inlet. Also, a ditch along 221A Street brings runoff from a small parking lot to the end of the pond adjacent to the outlet. The flow at this inlet is also not high compared to the main inlet but at times there was enough water to sample from the ditch. The portion of the pond between the main inlet and the bridge has no extra inlets. Therefore, additional sampling took place in the pond just before the water left the first pond and went under the bridge towards the second pond. In November and December 2003, water was sampled from the pond before the bridge and at the small inlet after the bridge. The flow at the side inlet then became very low and sampling was not feasible. In March 2004, samples were taken from the pond before the bridge and, when flow was sufficient, from the ditch along 221A Street. This sampling continued until June 2004 when flow was sufficient. It was found that the water entering the pond from the ditch did generally contain fairly high concentrations of dissolved iron relative to what was found in the inlet of the pond. However, there was also usually an increase in dissolved iron concentration from the inlet to the sampling point before the bridge.

Detailed results from the water sampling undertaken at the detention facility are provided in Appendix VIII.

Sediment Results

Sediments sampled from the detention facility in Langley during the wet season generally had higher concentrations of metals at the inlet than the outlet although the differences were not statistically significant. Potassium and magnesium were often found in slightly higher concentrations at the outlet. The results of the wet season sediment sampling are found in Table 4.19.

Table 4.19 Sediment quality results for the wet season at 52Ave/221A Street Detention Facility. Results given as median in mg/kg. $n = 4$.

Parameter	Inlet	Outlet	% Difference
Aluminum	13522.0	11948.9	11.86
Calcium	8346.5	4570.0	44.99
Chromium	40.4	30.2	29.40
Copper	80.9	43.9	52.34
Iron	20127.8	18385.5	12.99
Potassium	983.4	930.2	-8.17
Magnesium	5486.7	5324.3	-9.05
Manganese	1333.7	476.7	60.02
Sodium	420.4	288.2	35.37
Nickel	34.7	27.0	29.77
Phosphorus	1191.7	915.4	24.16
Lead	38.1	13.7	66.63
Silicon	1818.6	1160.7	43.86
Zinc	342.3	188.1	50.66

The results of sediment sampling in the dry season were similar to the wet season, as can be seen in Table 4.20. The concentrations of metals and salts in the sediments did not vary greatly between seasons and the differences between inlet and outlet were still not significant, suggesting that the settling of sediments followed a similar pattern throughout the year.

Table 4.20 Sediment quality results for the dry season at 52Ave/221A Street Detention Facility. Results given as median in mg/kg. $n = 3$.

Parameter	Inlet	Outlet	% Difference
Aluminum	15414.2	12413.4	18.83
Calcium	8740.4	4055.1	53.61
Chromium	33.8	30.0	21.00
Copper	83.9	37.1	62.26
Iron	23607.5	19779.7	16.21
Potassium	942.2	1090.9	-11.43
Magnesium	6358.4	6511.3	-2.40
Manganese	1191.6	425.0	72.86
Sodium	463.7	239.6	48.34
Nickel	31.2	26.7	23.18
Phosphorus	1095.4	785.8	32.70
Lead	45.2	12.0	72.34
Silicon	1712.1	781.1	57.49
Zinc	457.3	166.9	63.51

In an attempt to gain more information about the behaviour of iron in the pond, the sediments were also sampled from the pond just before the bridge, at the small inlet off 52nd Avenue and from the ditch off 221A Street. The concentrations of iron at the sampling point before the bridge were generally similar or less than those at the inlet, while the sediments from the ditch were generally higher than those at the outlet. The small inlet from 52nd Avenue was sampled in

December 2003 for sediments and the concentration of iron was similar to the results from the sampling point before the bridge. Results from the 221A Street ditch showed higher iron concentrations than the main inlet and the outlet.

Particle size analysis was performed on the July 2003, January 2004 and June 2004 samples to gain information on how the different particles were settling through the pond. It can be seen from the summary of results in Table 4.21 that the percentage of sand particles generally decrease from inlet to outlet, as seen by the positive median percent difference. However, the median inlet and outlet values for percent sand did not follow the same trend through the three sampling periods, therefore the median inlet and outlet values do not reflect this decrease. The variability in percent difference of sand particles suggest that they were not settling through the pond in the same manner at all times of the year. The decrease in silt particles and increase in clay particles from inlet to outlet was also variable.

Table 4.21 Particle size results for 52Ave/221A Street Detention Facility. Results are given as median percent. *n* = 3.

Parameter	Inlet	Outlet	Percent Difference
% Sand	27.81	49.29	46.12
% Silt	56.33	38.48	89.47
% Clay	15.13	9.86	-9.06

Complete results of the sediment sampling program at 52Ave/221A Street Detention Facility are provided in Appendix IX.

DGT Results

During the wet season, four DGT units were successfully deployed over the three to four week period. The concentration of metal accumulated on the resin is calculated as an instantaneous concentration and results are presented in Table 4.22. Aluminum was found to be significantly higher at the outlet, while manganese was significantly higher at the inlet. It is interesting to note that manganese was the only metal which showed a positive percent difference between the inlet and outlet.

Table 4.22 DGT Results for the wet season at 52Ave/221A Street Detention Facility, Langley. Results given as median in mg/L. $n = 4$.

Parameter	Inlet	Outlet	% Difference
Aluminum	0.004	0.016*	-155.11
Iron	0.003	0.007	-8.17
Manganese	0.028	0.007*	73.60
Zinc	0.005	0.007	-38.10

*Significant at the 0.1 probability level (Wilcoxin Signed Ranks Test).

The dry season results did not show any significant differences between the inlet and outlet for any of the detected metals. However, the percent difference between manganese is negative, indicating the seasonal variation in the accumulation of the metal. The positive median percent difference for zinc is also a reversal from the wet season, however the values are quite low. Results are summarized in Table 4.23.

Table 4.23 DGT Results for the dry season at 52 Ave/221A Street Detention Facility. Results given as median in mg/L. $n = 3$.

Parameter	Inlet	Outlet	% Difference
Aluminum	0.003	0.002	-16.93
Iron	0.002	0.008	-277.14
Manganese	0.045	0.152	-116.92
Zinc	0.003	0.001	58.30

The temporal results of manganese for the DGT units can be seen in Figure 4.2. The negative percent difference in the dry season is primarily due to a sharp increase in the outlet concentration in May 2004.

The concentrations of zinc measured by the DGT units over the sampling period are also interesting as the outlet decreases through the wet season to produce a positive percent difference during April, May and June 2004. The results for zinc as measured by the DGT can be seen in Figure 4.3.

Detailed results of the DGT measurements are provided in Appendix X.

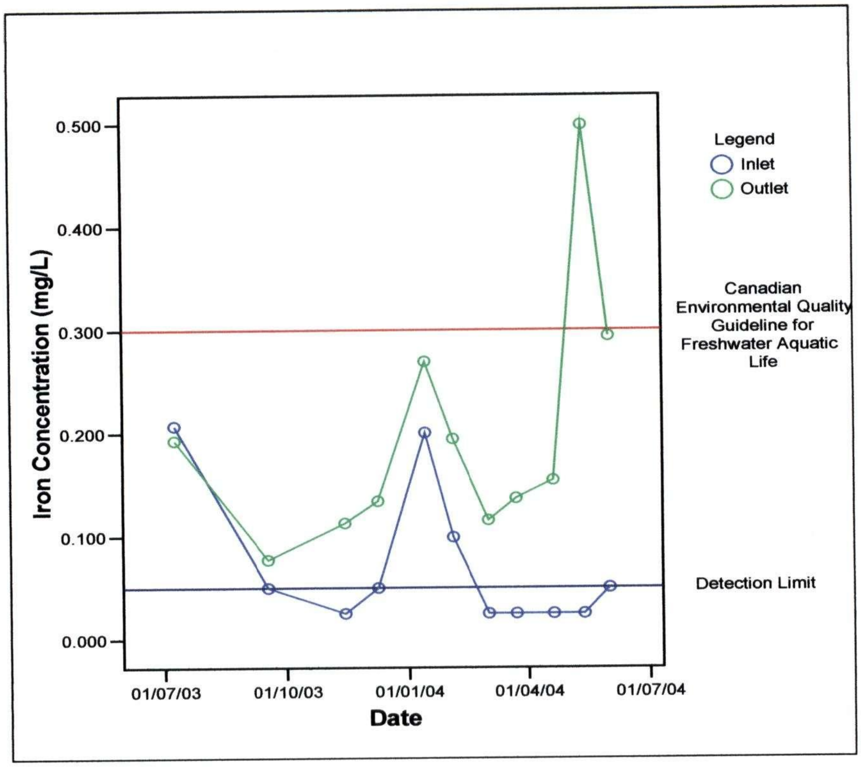

Figure 4.1 Dissolved iron concentrations at the inlet and outlet of 52Ave/221A Street Detention Facility, Langley

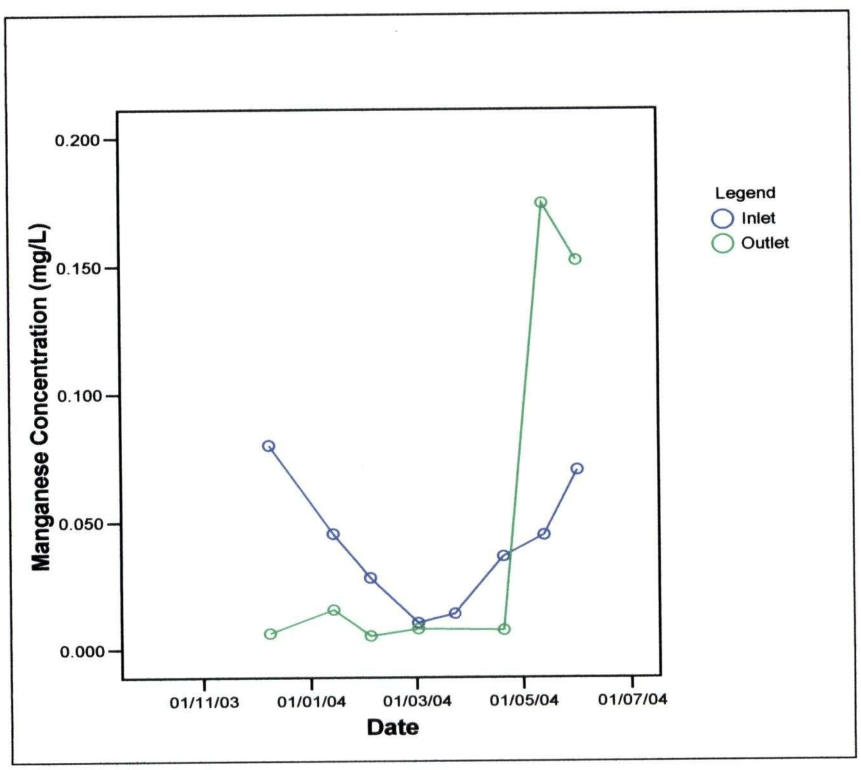

Figure 4.2 Bioavailable manganese concentrations at inlet and outlet of 52Ave/221A Street Detention Facility, Langley

Effect of Precipitation

A negative correlation exists between the salts calcium, potassium and sodium in the inlet water and the rainfall that fell on the catchment in the previous 48 and 72 hours. Temperature, specific conductivity and pH also decreased when rainfall increased. The only significant positive correlation observed between a metal and precipitation at the inlet was aluminum, which was positively correlated with the amount of precipitation in the 24, 48 and 72 hours prior to sampling.

The outlet concentration of dissolved salts, specific conductivity and pH showed similar correlations as the inlets. The concentration of dissolved manganese was negatively correlated with the precipitation of the previous 72 hours and aluminum did not show any significant correlations.

The inlet sediment concentrations showed a significantly negative correlation between aluminum and iron and the precipitation that had fallen on the catchment in the previous 72 hours. Outlet sediments showed a significantly positive correlation between sodium and the precipitation of the previous 24 hours.

The concentrations of aluminum, iron and zinc measured by the DGT units at the inlet of the detention facility were positively correlated with the amount of rainfall that fell on the catchment during the deployment period. At the outlets, concentrations of aluminum and zinc from the DGT were positively correlated with the rainfall of the deployment period.

The results of the correlation between precipitation and water, sediment and DGT results are presented in Appendix XI.

4.4.2 Griffin Park Biofiltration Pond, North Vancouver

Water Quality Results

Small differences were seen in dissolved metal concentrations between the inlet and outlet of Griffin Park Biofiltration Pond, except in the cases of iron and manganese, where there was a higher median concentration at the outlet than the inlet, with the difference being significant during the wet season. The specific conductivity was low at the inlet and outlet, with values often below 100 μS/cm. Results for the wet season are summarized in Table 4.24.

Table 4.24 Water quality results for the wet season at Griffin Park Biofiltration Pond. Results are given as median. *n* = 7.

Parameter	Inlet	Outlet	% Difference
Aluminum, mg/L	0.025	0.025	0.00
Calcium, mg/L	6.910	5.460	16.65
Iron, mg/L	0.067	0.153**	-128.36
Potassium, mg/L	1.021	0.853	-4.23
Magnesium, mg/L	0.815	0.596*	11.37
Manganese, mg/L	0.003	0.011**	-166.67
Sodium, mg/L	5.005	5.073	7.71
Silicon, mg/L	3.379	3.154	5.81
Zinc, mg/L	0.012	0.010	0
Temperature, C	9.1	8.0	11.43
Specific Conductivity, uS/cm	90.1	73.9	6.45
Dissolved Oxygen, mg/L	9.80	8.90	5.15
pH	7.20	6.80**	4.05

*Significant at the 0.1 probability level (Wilcoxin Signed Ranks Test).
**Significant at the 0.05 probability level (Wilcoxin Signed Ranks Test).

While the trends were similar in both the wet and dry seasons, only the pH in the dry season differed significantly between the inlet and outlet. Water quality results of the dry season are presented in Table 4.25.

Table 4.25 Water quality results for the dry season at Griffin Park Biofiltration Pond. Results are given as median. *n* = 5.

Parameter	Inlet	Outlet	% Difference
Aluminum, mg/L	0.025	0.025	0.00
Calcium, mg/L	5.79	4.55	-4.668
Iron, mg/L	0.07	0.10	-287.281
Potassium, mg/L	1.07	0.66	-5.348
Magnesium, mg/L	0.64	0.56	-0.887
Manganese, mg/L	0.00	0.01	-133.333
Sodium, mg/L	4.06	4.26	2.210
Silicon, mg/L	3.20	3.00	3.322
Zinc, mg/L	0.01	0.005	0.00
Temperature, C	14.2	14.9	5.15
Specific Conductivity, uS/cm	66.5	60.4	-3.08
Dissolved Oxygen, mg/L	10.50	10.40	2.70
pH	7.19	7.08**	3.03

**Significant at the 0.05 probability level (Wilcoxin Signed Ranks Test).

Dissolved iron concentrations in the Griffin Park biofiltration pond were consistently higher at the outlet than the inlet. A similar trend can be seen in the concentrations of dissolved manganese over the sampling period. It can be seen from Figure 4.4 that even though the water from the inlet of the pond was below detection limit from February to June 2004, the water at the outlet had manganese concentrations of up to 0.017mg/L.

Detailed results from water sampling at the Griffin Park Biofiltration Pond are provided in Appendix VIII.

Sediment Results

The results of the wet season sediment sampling at Griffin Park biofiltration pond showed significant differences between the inlet and outlet concentrations of all parameters except iron. Aluminum, manganese and silicon were significantly higher at the outlet than the inlet, but in all other significant cases, the percent differences were positive. The results are summarized in Table 4.26.

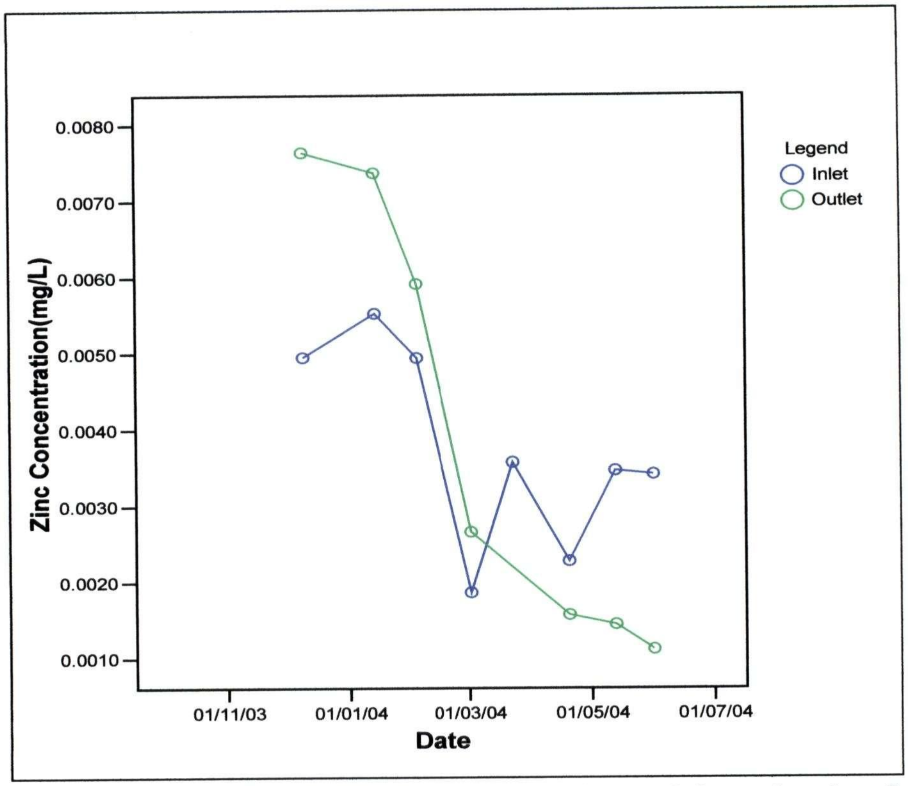

Figure 4.3 Bioavailable zinc concentrations at inlet and outlet of 52Ave/221A Street Detention Facility, Langley

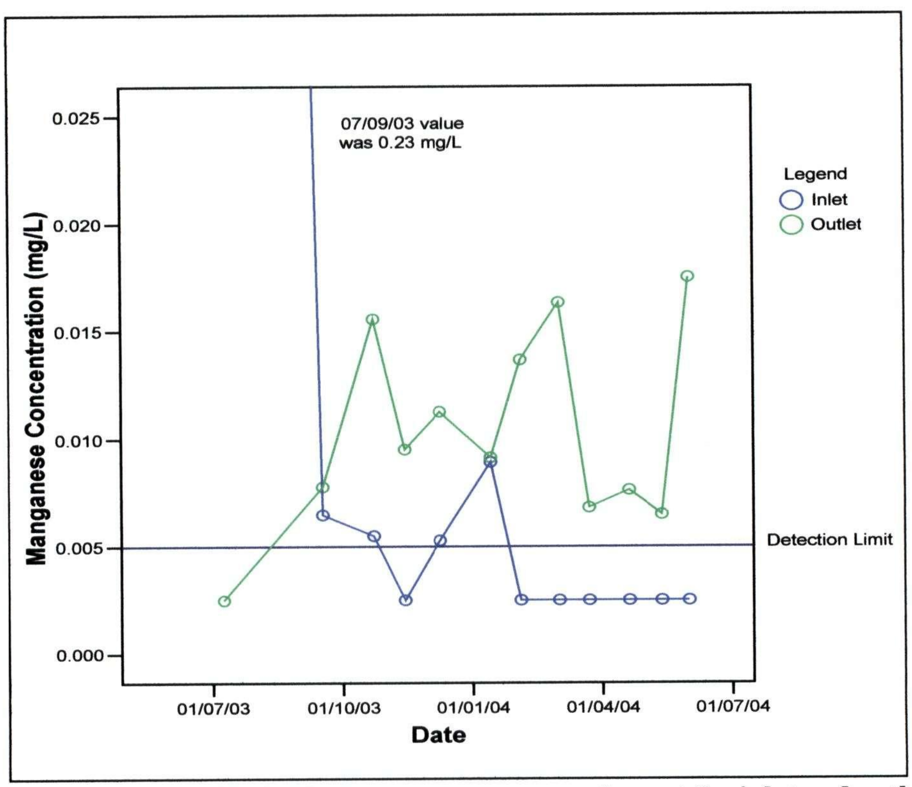

Figure 4.4 Dissolved manganese concentrations at the inlet and outlet of Griffin Biofiltration Pond, North Vancouver

Table 4.26 Sediment quality results for the wet season at Griffin Park Biofiltration Pond. Results given as median in mg/kg. *n* = 4.

Parameter	Inlet	Outlet	% Difference
Aluminum	9605.6	20225.9*	-73.58
Calcium	4944.0	3028.4*	33.52
Chromium	30.4	16.1*	44.58
Copper	258.1	84.5*	67.19
Iron	14133.3	22308.18	-34.30
Potassium	527.6	381.8*	24.06
Magnesium	2609.4	1515.3*	29.45
Manganese	194.3	299.5*	-38.04
Sodium	322.5	163.4*	43.66
Nickel	16.5	7.4*	66.69
Phosphorus	1301.9	699.7*	43.89
Lead	157.8	85.1*	49.11
Silicon	1878.9	3561.1*	-79.68
Zinc	669.0	230.1*	65.45

*Significant at the 0.1 probability level (Wilcoxin Signed Ranks Test).

The sediment sampling in the dry season produced statistically significant higher concentrations of most parameters at the inlet than the outlet. Although there were negative percent differences for aluminum, iron and silicon, the differences were not significant. Results of the dry season sediment sampling are presented in Table 4.27.

Table 4.27 Sediment quality results for the dry season at Griffin Park Biofiltration Pond. Results given as median in mg/kg. *n* = 4.

Parameter	Inlet	Outlet	% Difference
Aluminum	12485.4	14938.3	-24.91
Calcium	8657.0	3385.5*	58.73
Chromium	38.2	19.5*	53.99
Copper	278.6	108.1*	64.78
Iron	25482.9	24941.6	-2.93
Potassium	703.6	458.1*	29.93
Magnesium	2901.1	2024.8*	21.16
Manganese	578.3	566.4	5.06
Sodium	363.3	244.4*	39.05
Nickel	21.7	10.8*	53.59
Phosphorus	1663.4	917.6*	44.80
Lead	237.4	154.1	26.79
Silicon	2660.0	3351.0	-27.06
Zinc	666.8	297.4*	51.81

*Significant at the 0.1 probability level (Wilcoxin Signed Ranks Test).

It is interesting to note that manganese was significantly higher at the outlet than the inlet during the wet season and had a positive percent difference during the dry season. This pattern can be seen in Figure 4.5, where the concentration of manganese in the sediments is generally higher at the outlet, although samples from September and April are the reverse, suggesting seasonal effects.

Results of the particle size analysis performed in July, January and June showed that sand particles generally decrease from inlet to outlet and silt and clay particles generally increase. The results are summarized in Table 4.28. Note that no significant differences were found between the inlet and outlet.

Table 4.28. Results of particle size analysis for Griffin Park Biofiltration Pond. Results are given as median percent. *n*=3.

Parameter	Inlet	Outlet	Percent Difference
% Sand	87.13	74.98	7.51
% Silt	7.80	12.19	-6.84
% Clay	5.07	6.66	-21.05

Detailed sediment results are provided in Appendix IX.

DGT Results

The wet season showed positive median percent differences between inlet and outlet for all four detected metals. The differences in aluminum and manganese were significant although manganese concentrations were not particularly high. Results are summarized in Table 4.29.

Table 4.29 DGT results for the wet season at Griffin Park Biofiltration Pond. Results are given as median in mg/L. *n* = 5.

Parameter	Inlet	Outlet	% Difference
Aluminum	0.017	0.004**	77.53
Iron	0.014	0.003	73.12
Manganese	0.005	0.003**	35.13
Zinc	0.011	0.010	20.09

The dry season did not result in any significant differences between the inlet and outlet DGT concentrations. Although the median percent difference for manganese is highly negative, this is primarily due to a sharp increase in outlet concentrations in May and June 2004, which can be seen in Figure 4.6. Results of the dry season are presented in Table 4.30.

Figure 4.30 DGT results for the dry season at Griffin Park Biofiltration Pond. Results are given as median in mg/kg. *n* =3.

Parameter	Inlet	Outlet	% Difference
Aluminum	0.028	0.006	78.92
Iron	0.013	0.002	0.00
Manganese	0.003	0.011	-734.89
Zinc	0.007	0.004	42.11

Detailed DGT results at the Griffin Park biofiltration pond are provided in Appendix X.

Effects of Precipitation

The concentrations of most dissolved salts in the inlet water were negatively correlated with the precipitation of the 24 hours prior to water sampling. Dissolved zinc concentrations were positively correlated with the precipitation of 24, 48 and 72 hours prior to sampling. There was also a negative correlation between pH and the precipitation of the previous 24 and 72 hours. At the outlet, dissolved sodium, silicon and iron were negatively correlated with the precipitation of the previous 24 hours. The concentration of dissolved zinc was positively correlated with the previous 72 hours of precipitation. The pH was negatively correlated with the precipitation of the previous 24 and 72 hours, as it was at the outlet.

There was a negative correlation between aluminum concentration in the sediments at the inlet and the precipitation of the previous 72 hours. At the outlet, positive correlations existed between silicon concentrations in the sediment and the precipitation of the previous 24 and 48 hours.

The concentration of bioavailable manganese and zinc measured by the DGT units at the inlet was positively correlated with the precipitation that had fallen on the catchment during the deployment period. The outlet DGT concentration of zinc was also correlated with the deployment period precipitation and the concentration of aluminum was negatively correlated with the precipitation of the same period.

Correlation results between precipitation and water, sediment and DGT data for Griffin Biofiltration Pond are provided in Appendix XI.

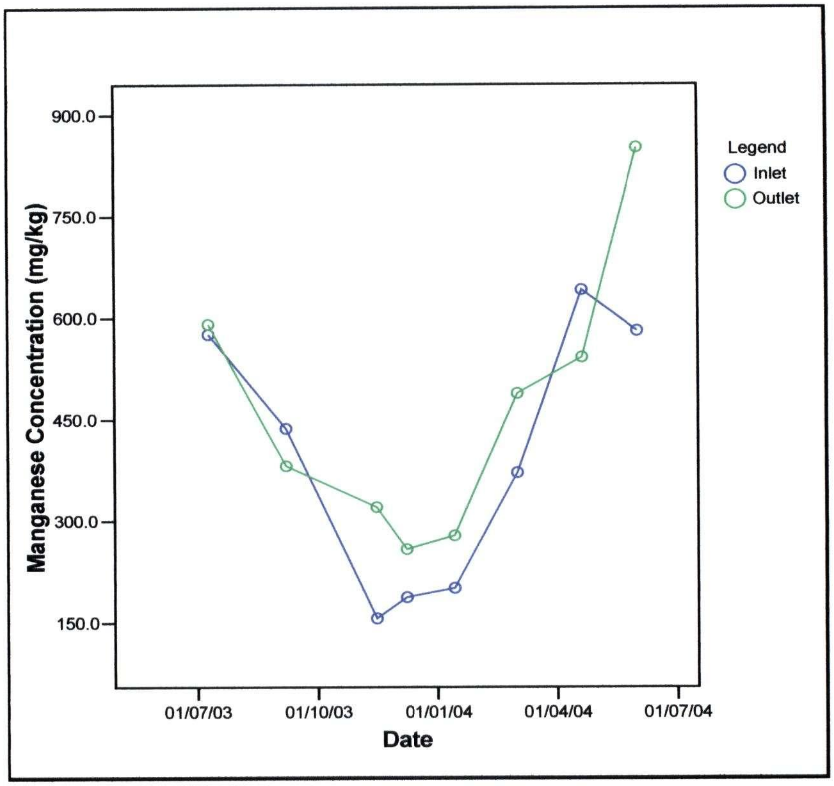

Figure 4.5 Total concentration of manganese in sediments at inlet and outlet of Griffin Park Biofiltration Pond, North Vancouver

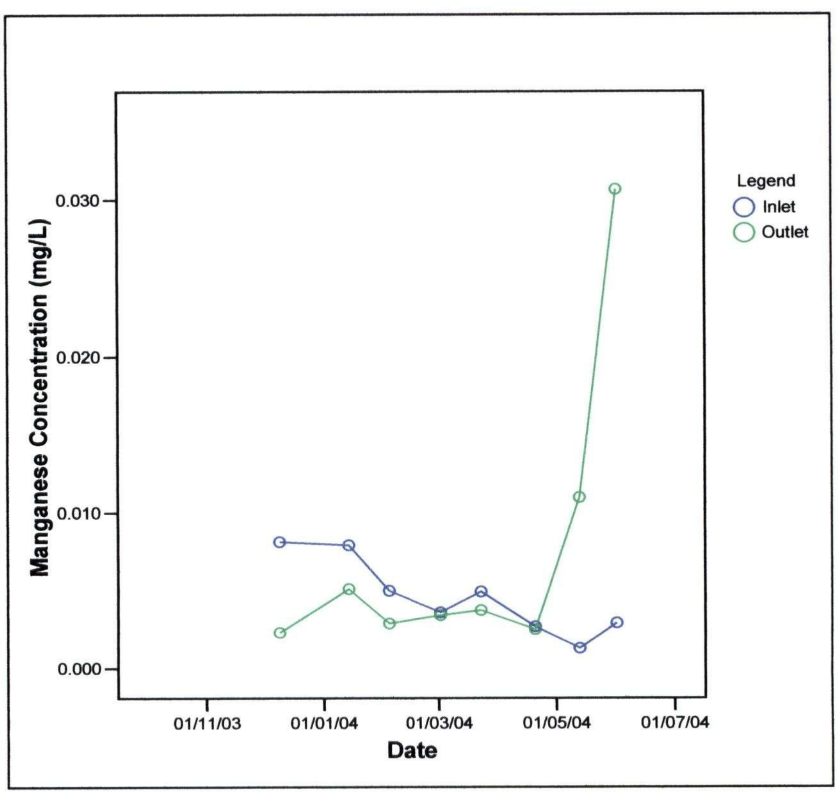

Figure 4.6 Bioavailable manganese concentrations at inlet and outlet of Griffin Park Biofiltration Pond, North Vancouver

4.4.3 Westview Interchange Detention Pond

Water Quality Results

The concentrations of dissolved metals in the Westview Interchange Detention Pond tended to be lower at the outlet, with significant differences for salts and manganese during the wet season. Specific conductivity was low in both seasons, as was pH. The pH at the outlet was found to be significantly less than at the inlet during the wet season, although the differences were relatively small, as in all cases pH values were within 0.64 units of each other. Results of the wet season are summarized in Table 4.31.

Table 4.31 Water quality results for the wet season at Westview Interchange Detention Pond. Results given as median. $n = 7$.

Parameter	Inlet	Outlet	% Difference
Aluminum, mg/L	0.059	0.086	-44.07
Calcium, mg/L	5.056	1.534**	70.51
Iron, mg/L	0.134	0.122	38.93
Potassium, mg/L	1.414	0.725**	46.12
Magnesium, mg/L	0.477	0.157**	68.76
Manganese, mg/L	0.019	0.008**	66.67
Sodium, mg/L	15.136	8.846**	41.06
Silicon, mg/L	1.150	0.380**	67.55
Zinc, mg/L	0.026	0.019	26.92
Temperature, C	8.8	8.3	-1.96
Specific Conductivity, uS/cm	77.4	78.0	9.14
Dissolved Oxygen, mg/L	9.50	8.20	1.09
pH	7.10	6.90**	1.97

**Significant at the 0.05 probability level (Wilcoxin Signed Ranks Test).

The trends were similar for both seasons, although the differences between inlet and outlet were not significant during the dry season. As well, aluminum showed a decrease from inlet to outlet during the dry season. The results of water sampling during the dry season are summarized in Table 4.32.

Table 4.32 Water quality results for the dry season at Westview Interchange Detention Pond. Results given as median. $n = 3$.

Parameter	Inlet	Outlet	% Difference
Aluminum, mg/L	0.179	0.025	57.54
Calcium, mg/L	4.996	1.634	67.29
Iron, mg/L	0.196	0.097	23.98
Potassium, mg/L	1.298	0.744	42.53
Magnesium, mg/L	0.420	0.176	58.10
Manganese, mg/L	0.046	0.016	56.52
Sodium, mg/L	3.900	1.539	24.85
Silicon, mg/L	0.703	0.239	66.00
Zinc, mg/L	0.044	0.026	29.73
Temperature, C	17.0	17.0	4.17
Specific Conductivity, uS/cm	62.2	35.0	43.73
Dissolved Oxygen, mg/L	8.30	9.50	14.88
pH	6.82	6.59	2.18

The dissolved aluminum concentration is interesting as the median percent difference is negative in the wet season and positive in the dry season. While there are sampling times where the inlet concentration is higher than the outlet, there is a pattern of spikes where the inlet and outlet switch between having higher concentrations. This spiky pattern and high dissolved aluminum concentrations illustrate the flashy nature that the totally impervious highway produces in the pond.

The trend of dissolved manganese at the inlet and outlet, as shown in Figure 4.7 shows how the inlet concentration is consistently higher than the outlet, except for March 23, 2004. The flashy nature of the system is also clear from the dissolved manganese results.

Detailed water quality results for the Westview Interchange Detention Pond are provided in Appendix VIII.

Sediment Results

The concentrations of salts found in the sediments during the wet season were significantly higher at the outlet than the inlet. Many other metals also showed negative percent differences, which is summarized in Table 4.33. It is interesting to note that the median percent differences are relatively low for metals and phosphorus, with differences rarely exceeding 10% in either the negative or positive direction. This suggests that concentrations of metals and phosphorus are spread fairly evenly through the pond.

Table 4.33 Sediment quality results for the wet season at Westview Interchange Detention Pond. Results given as median in mg/kg. *n* = 4.

Parameter	Inlet	Outlet	% Difference
Aluminum	6454.1	10447.9*	-35.95
Calcium	3497.9	3007.2*	14.03
Chromium	57.5	69.7	-14.59
Copper	392.7	460.3	-8.07
Iron	12305.2	15144.0	-15.77
Potassium	677.9	1105.8	-53.58
Magnesium	2367.2	3675.3*	-26.48
Manganese	164.4	181.2	-6.26
Sodium	335.2	444.7*	-12.94
Nickel	20.6	17.1	6.15
Phosphorus	796.3	845.1	-2.55
Lead	199.2	234.8	-7.74
Silicon	1658.7	1936.6*	-17.35
Zinc	1030.2	1070.5	-4.09

*Significant at the 0.10 probability level (Wilcoxin Signed Ranks Test).

Results from the dry season produced similar results, although less significant differences were found between the inlet and outlet concentrations of salts. The only metal that produced a significant result was aluminum, which was higher at the outlet than the inlet, as was the case in the wet season. The percent differences between inlet and outlet were low for all parameters, with no differences above 30%. Results are summarized in Table 4.34.

Table 4.34 Sediment quality results for the dry season at Westview Interchange Detention Pond. Results given as median in mg/kg. *n* =4.

Parameter	Inlet	Outlet	% Difference
Aluminum	10241.4	13514.3*	-22.61
Calcium	5253.7	3845.9	24.95
Chromium	81.3	98.9	-16.98
Copper	642.1	488.4	29.30
Iron	20402.2	20858.1	-1.87
Potassium	869.6	1244.9*	-22.96
Magnesium	3845.9	5585.9	-20.11
Manganese	274.6	271.3	-0.97
Sodium	397.3	431.9	0.85
Nickel	26.0	22.8	-14.54
Phosphorus	1193.7	962.3	11.95
Lead	218.3	248.6	3.97
Silicon	2163.4	2455.9	-16.00
Zinc	1072.6	981.5	26.40

*Significant at the 0.10 probability level (Wilcoxin Signed Ranks Test).

It is interesting to consider the concentration of zinc in the sediments at Westview Interchange Detention Pond as they tend to be higher than those in other ponds. In September 2003, the concentration at the inlet was 2127 mg/kg, which is the highest concentration for zinc detected over the sampling period in all ponds. There is also quite a bit of variation in whether the inlet or outlet had a higher concentration of zinc, as can be seen in Figure 4.8.

The particle size analysis performed on the July, January and June sediment samples revealed that the percentage of sand particles generally decreased from inlet to outlet. The percentage of silt and clay particles showed an increase from inlet to outlet, as seen in Table 4.35. The results were consistent across all three sampling times, although no significant differences were found between the inlet and outlet.

Table 4.35 Results of particle size analysis for Westview Interchange Detention Pond. Results are given as median percent. $n = 3$.

Parameter	Inlet	Outlet	Percent Difference
% Sand	62.40	26.59	59.38
% Silt	29.11	60.00	-106.09
% Clay	3.73	12.53	-200.00

Complete sediment results are provided in Appendix IX.

DGT Results

The wet season showed a significantly lower median iron concentration at the outlet than the inlet as measured by the DGT units. It is interesting to note that all detected metals had positive median percent differences, although only iron was significant. Results of the wet season DGT deployments are summarized in Table 4.36.

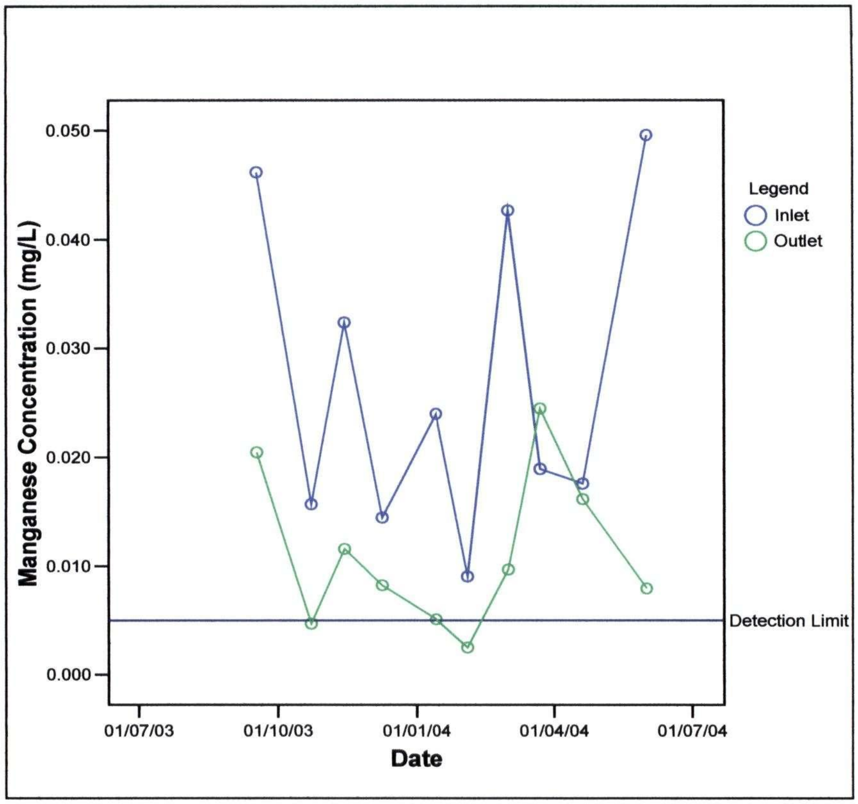

Figure 4.7 Dissolved manganese concentrations at inlet and outlet of Westview Interchange Detention Pond, North Vancouver

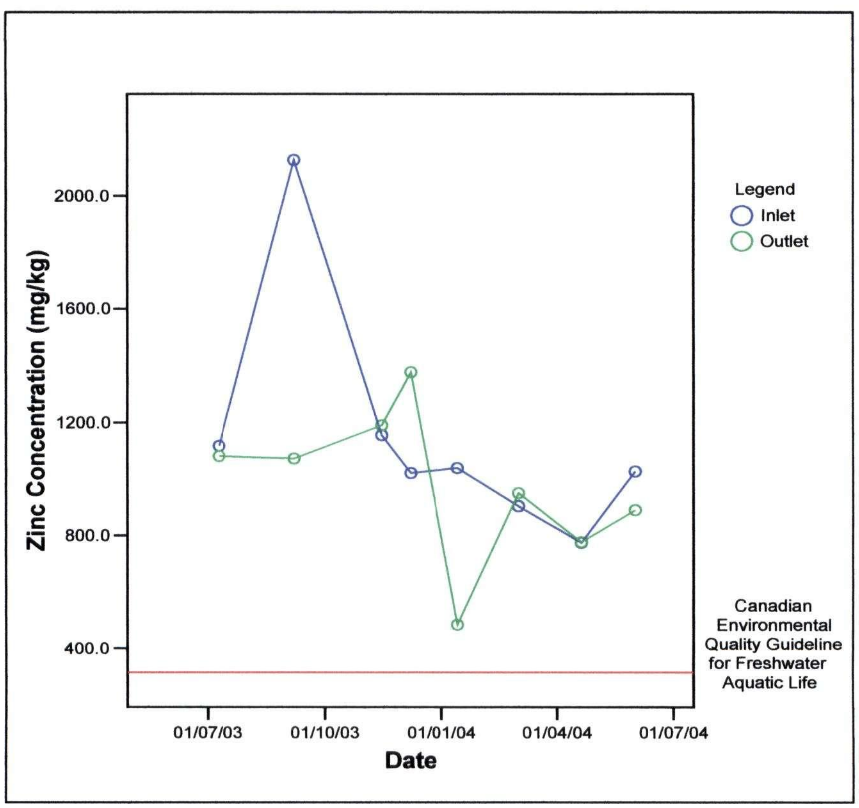

Figure 4.8 Zinc concentrations in the sediment at the inlet and outlet of Westview Interchange Detention Pond, North Vancouver

Table 4.36 DGT results for the wet season at the Westview Interchange Detention Pond. Results are given as median, in mg/L. $n = 4$.

Parameter	Inlet	Outlet	% Difference
Aluminum	0.023	0.004	80.54
Iron	0.054	0.005*	71.65
Manganese	0.019	0.009	53.60
Zinc	0.031	0.032	12.34

The zinc concentrations measured by the DGT units were generally higher at the inlet than the outlet, however the December and January deployment periods produced the opposite result, as shown in Figure 4.9.

The Westview Interchange Detention Pond did not hold enough water through the dry season in order to have DGT units deployed and stay hydrated for the three week period. Therefore, no DGT results are reported for the dry season at this pond.

Complete DGT results from the Westview Interchange Detention Pond are provided in Appendix X.

Effects of Precipitation

Water at the inlet of Westview Interchange Detention pond showed positive correlations between dissolved aluminum and zinc concentrations and the precipitation that fell on the catchment in the previous 24 hours. There were no significant correlations between water at the outlet and precipitation.

Negative correlations were found between inlet concentrations of aluminum and iron in the sediments and the precipitation of the previous 72 hours. The concentrations of calcium, chromium, copper and nickel in the outlet sediments were negatively correlated with the precipitation of the previous 24, 48 and 72 hours. Concentrations of aluminum, iron, magnesium and manganese were negatively correlated with the precipitation of the previous 72 hours only. Lead was negatively correlated with the precipitation of the previous 24 and 48 hours.

The concentrations of bioavailable zinc at the inlet measured by the DGT was positively correlated with the precipitation of the 72 hours before the DGT was removed. At the outlet, the concentrations of iron was correlated with the precipitation of the previous 48 hours before DGT removal, manganese with the previous 24 and 48 hours and zinc with the previous 24 hours.

Detailed results of the correlations between water, sediment and DGT and precipitation for the Westview Interchange Pond are provided in Appendix XI.

4.4.4 Tempe Heights Pond, North Vancouver

Water Quality Results

Tempe Heights Pond displayed some fairly large decreases in dissolved salts and some metals between the inlet and outlet in the wet season. However, there was a significant increase in iron and manganese concentrations between the inlet and outlet. Specific conductivity tended to be high, as values were generally above 200 μS/cm. Dissolved oxygen tended to increase significantly between inlet and outlet, with differences as high as 6 mg/L in December and May. Results of the wet season are presented in Table 4.37.

Table 4.37 Water quality results for the wet season at Tempe Heights Pond. Results given as median. n = 6.

Parameter	Inlet	Outlet	% Difference
Calcium, mg/L	25.201	22.428	16.81
Iron, mg/L	0.111	0.338**	-175.66
Potassium, mg/L	2.791	2.019	33.84
Magnesium, mg/L	3.112	1.964	39.95
Manganese, mg/L	0.013	0.024**	-82.46
Sodium, mg/L	14.126	11.925	19.82
Silicon, mg/L	5.756	3.929	35.83
Zinc, mg/L	0.008	0.005	13.33
Temperature, C	9.6	8.5*	13.62
Specific Conductivity, uS/cm	270.7	190.0	29.29
Dissolved Oxygen, mg/L	7.50	9.00*	-6.94
pH	6.90	6.98	-2.00

*Significant at the 0.1 probability level (Wilcoxin Signed Ranks Test).
**Significant at the 0.05 probability level (Wilcoxin Signed Ranks Test).

The dry season produced similar results, as the median concentration of dissolved iron was significantly higher at the outlet than the inlet. There was also a significant reduction in dissolved zinc concentrations from inlet to outlet, however concentrations were generally low. It is interesting to note that the median percent difference of dissolved manganese is not negative in the dry season as was found in the wet season. The results of the dry season are summarized in Table 4.38.

Table 4.38 Water quality results for the dry season at Tempe Heights Pond. Results given as median. $n = 5$.

Parameter	Inlet	Outlet	% Difference
Calcium, mg/L	26.050	27.970	-6.79
Iron, mg/L	0.286	0.488**	-64.34
Potassium, mg/L	2.539	2.471	2.95
Magnesium, mg/L	3.405	3.343	4.65
Manganese, mg/L	0.016	0.044	0.00
Sodium, mg/L	11.248	12.392	2.31
Silicon, mg/L	5.674	4.736	5.64
Zinc, mg/L	0.010	0.005*	41.18
Temperature, C	17.6	18.0	-2.27
Specific Conductivity, uS/cm	241.0	243.1	3.92
Dissolved Oxygen, mg/L	8.10	8.80**	-25.00
pH	7.01	7.23	-3.02

*Significant at the 0.1 probability level (Wilcoxin Signed Ranks Test).
**Significant at the 0.05 probability level (Wilcoxin Signed Ranks Test).

Detailed results of the water quality sampling at Tempe Heights Pond are provided in Appendix VIII.

Sediment Results

The sediments collected from the inlet and outlet during the wet season did not show any significant differences in Tempe Heights Pond. However, the high median percent differences between the concentrations of certain metals, such as zinc and copper, suggest that the sediments tend to become less contaminated as they move through the pond. However, aluminum, iron and manganese show negative percent differences, from inlet to outlet. Results for wet season sediment sampling are presented in Table 4.39.

Table 4.39 Sediment quality results for the wet season at Tempe Heights Pond. Results given as median in mg/kg. $n = 3$.

Parameter	Inlet	Outlet	% Difference
Aluminum	10710.3	14582.4	-31.10
Calcium	8326.7	5924.4	38.90
Chromium	27.2	20.2	30.94
Copper	300.8	146.1	60.71
Iron	13795.5	17440.0	-30.82
Potassium	558.5	624.8	-4.01
Magnesium	2507.2	2457.1	13.84
Manganese	113.7	204.4	-13.22
Sodium	297.5	386.2	33.25
Nickel	15.0	11.3	41.36
Phosphorus	1261.8	891.0	33.38
Lead	104.1	77.0	28.10
Silicon	1699.4	2509.8	-46.54
Zinc	610.0	295.9	45.13

The dry season sediment sampling did show some significant differences in parameters between the inlet and outlet. The outlet sediments contained significantly higher concentrations of aluminum and iron than the inlets, while zinc, lead, chromium and copper were significantly higher at the inlet. Phosphorus concentrations were also significantly higher at the inlet than the outlet. The difference between wet and dry season suggest that the difference between inlet and outlet sediments is greater in the months where there is little runoff compared to the wet season, even though the patterns in terms of percent difference are similar. The results of the dry season sediment sampling are summarized in Table 4.40.

Table 4.40 Sediment quality results for the dry season at Tempe Heights Pond. Results given as median in mg/kg. $n = 4$.

Parameter	Inlet	Outlet	% Difference
Aluminum	11287.9	15753.4*	-34.72
Calcium	13273.8	7992.9*	38.21
Chromium	37.2	23.0*	42.55
Copper	349.4	158.0*	55.08
Iron	15323.1	18707.8*	-23.54
Potassium	660.4	698.7	-0.02
Magnesium	3352.2	2774.8*	20.83
Manganese	133.7	181.2	-49.95
Sodium	630.5	425.7	45.04
Nickel	19.1	11.3*	49.00
Phosphorus	1533.8	980.5*	38.62
Lead	130.2	85.8*	33.60
Silicon	2051.5	3189.3*	-45.19
Zinc	697.5	331.8*	55.61

*Significant at the 0.1 probability level (Wilcoxin Signed Ranks Test).

Phosphorus was found in higher concentrations at the inlet than the outlet, except in January 2004, where the inlet concentration of phosphorus hit its lowest point of 736 mg/kg. It is reasonable to assume that seasonal effects were a contributor to the concentration of phosphorus, as the levels decrease in the wet season and increase during the dry season at both the inlet and outlet.

The particle size analysis revealed that the percentage of sand particles decreases from inlet to outlet. The percentages of silt and clay increased through the pond, which was quite consistent over the three sampling times. The percent difference from inlet to outlet was quite high for silt and clay in July and June, although no significant differences were found. A summary of the results is provided in Table 4.41.

Table 4.41 Results of the particle size analysis for Tempe Heights Pond. Results are given as median percent. *n* = 3.

Parameter	Inlet	Outlet	Percent Difference
% Sand	96.40	63.35	30.16
% Silt	2.59	25.85	-898.78
% Clay	2.47	9.53	-286.49

Full results of the sediment monitoring are provided in Appendix IX.

DGT Results

DGT units deployed in Tempe Heights Pond showed significantly higher concentrations at the inlet than the outlet for iron, however the reverse was shown for manganese. Although the median percent difference for aluminum is large, the concentrations were relatively low throughout the sampling period. The results are summarized in Table 4.42.

Table 4.42 DGT results in the wet season for Tempe Heights Pond. Results are given as median, in mg/L. *n* = 6.

Parameter	Inlet	Outlet	% Difference
Aluminum	0.004	0.006	-76.75
Iron	0.053	0.015**	73.14
Manganese	0.008	0.014*	-92.14
Zinc	0.011	0.010	9.59

The dry season did not show any significant differences between metals measured by inlet and outlet DGT units. However, the median percent differences follow the same trend as in the wet season. A summary of the results is presented in Table 4.43.

Table 4.43 DGT results in the dry season for Tempe Heights Pond. Results are given as median, in mg/L. $n = 3$.

Parameter	Inlet	Outlet	% Difference
Aluminum	0.003	0.003	0
Iron	0.012	0.002	81.5366
Manganese	0.007	0.008	-10.2638
Zinc	0.009	0.002	66.4581

The manganese concentrations measured by the DGT units are consistently higher at the outlet than the inlet. The temporal trend is shown in Figure 4.10. It is interesting to note the only two cases where the inlet DGT unit measured the higher concentration, in October 2003 and June 2004.

Complete DGT results at the Tempe Heights Pond are presented in Appendix X.

Effects of Precipitation

The water samples taken from the inlet of Tempe Heights pond revealed negative correlations between calcium and silicon and the precipitation that had fallen on the catchment in the previous 24 hours, while magnesium was correlated with the precipitation of the previous 24 and 48 hours. Dissolved aluminum concentrations were negatively correlated with the precipitation of the previous 24 and iron was negatively correlated with the previous 24 and 72 hours. At the outlet, calcium, silicon and dissolved oxygen were negatively correlated with the precipitation of the previous 48 and 72 hours. Concentrations of dissolved zinc were positively correlated with the precipitation of the previous 48 and 72 hours.

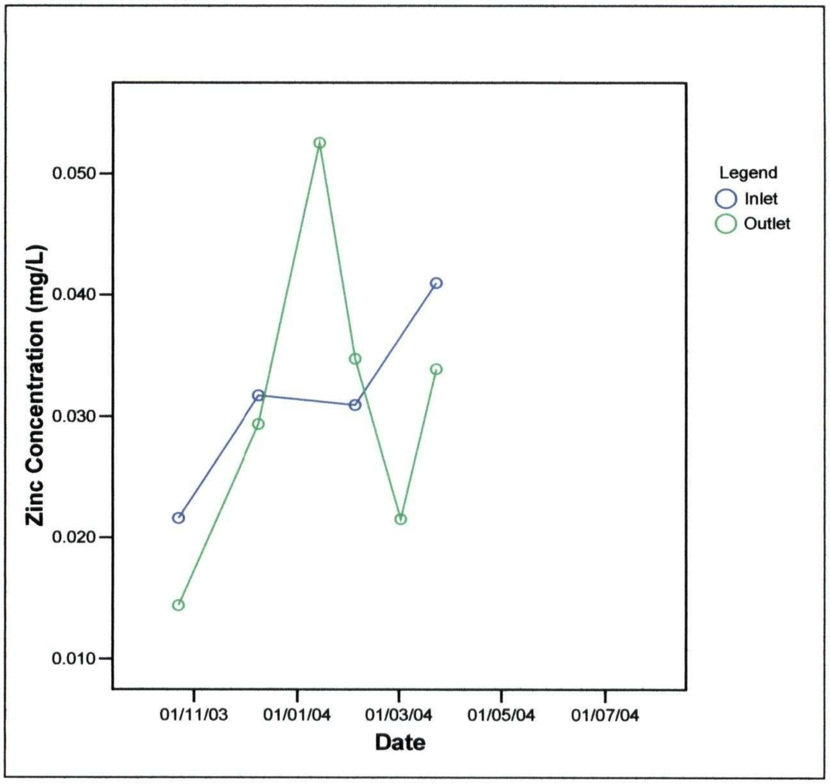

Figure 4.9 Bioavailable zinc concentrations at Westview Interchange Detention Pond, North Vancouver

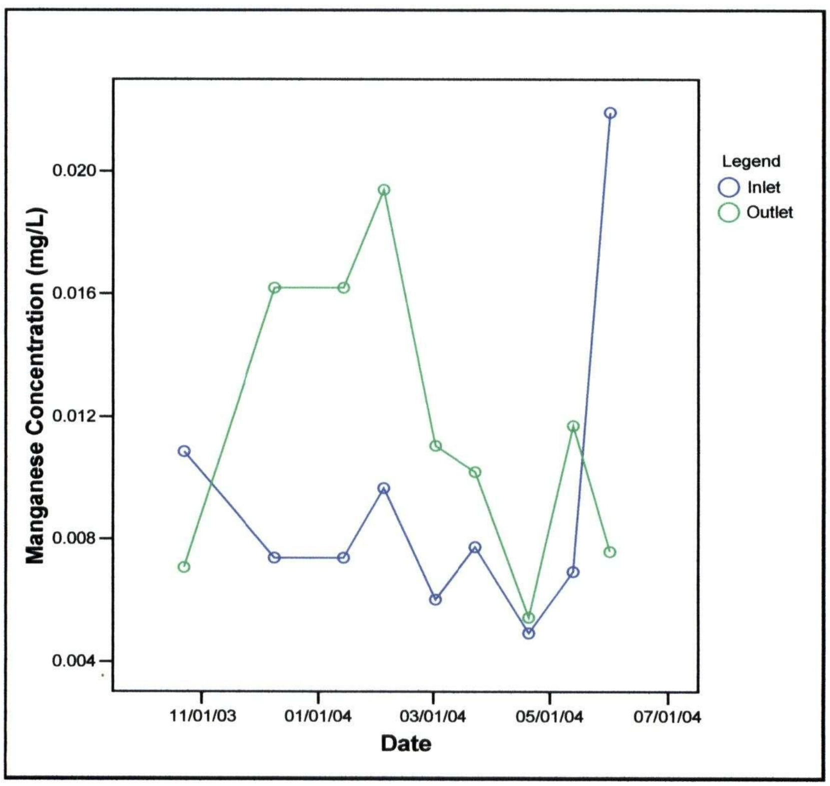

Figure 4.10 Bioavailable manganese concentrations at inlet and outlet of Tempe Heights Pond, North Vancouver

Inlet sediment concentrations of aluminum, calcium, copper, iron, magnesium, manganese and phosphorus were negatively correlated with the precipitation of the previous 24, 48 and 72 hours. Chromium and nickel concentrations were negatively correlated with the precipitation of the previous 72 hours. No significant correlations existed between outlet sediments and precipitation.

The inlet DGT concentration for bioavailable zinc was significantly positively correlated with the precipitation that had fallen in the DGT deployment period. The outlet DGT concentrations of aluminum, iron and zinc were all positively correlated with the precipitation of the deployment period.

Detailed results of the correlations between water, sediment, DGT data and precipitation are provided in Appendix XI.

4.4.5 Oakalla Biofiltration System, Burnaby

Water Quality Results

Water sampling at Oakalla Biofiltration System revealed significant reductions between the inlet and outlet for many dissolved salts and metals during both the wet and dry season. High reductions in iron and manganese were noted in the wet season at each sampling time. Specific conductivity was generally high, with most values above 200μS/cm. Dissolved zinc concentrations did not show significant percent differences, as the metal was only detected at two sampling times and was otherwise below detection limit. Results of the wet season are summarized in Table 4.44.

Table 4.44 Water quality results for the wet season at Oakalla Biofiltration System. Results given as median. $n = 6$.

Parameter	Inlet	Outlet	% Difference
Calcium, mg/L	41.270	29.860**	37.792
Iron, mg/L	0.132	0.059**	57.26
Potassium, mg/L	3.771	3.120**	18.75
Magnesium, mg/L	6.538	4.505**	33.05
Manganese, mg/L	0.131	0.075**	81.05
Sodium, mg/L	16.515	12.776**	18.68
Silicon, mg/L	6.823	5.321**	23.315
Zinc, mg/L	0.005	0.005	0
Temperature, C	9.8	6.5	23.53
Specific Conductivity, uS/cm	305.6	231.0**	22.59
Dissolved Oxygen, mg/L	9.26	8.70	0.00
pH	7.62	7.35	2.26

**Significant at the 0.05 probability level (Wilcoxin Signed Ranks Test).

Similar results were seen in the dry season, although with percent differences significant at the 0.1 probability level instead of 0.05. The results of the dry season are presented in Table 4.45.

Table 4.45 Water quality results for the dry season at Oakalla Biofiltration System. Results given as median. $n = 4$.

Parameter	Inlet	Outlet	% Difference
Calcium, mg/L	38.611	27.067*	36.65
Iron, mg/L	0.200	0.181	12.70
Potassium, mg/L	3.833	1.414*	68.93
Magnesium, mg/L	6.301	4.12*	41.42
Manganese, mg/L	0.189	0.147*	21.71
Sodium, mg/L	17.624	11.544*	30.66
Silicon, mg/L	7.661	4.416*	46.29
Zinc, mg/L	0.005	0.005	0
Temperature, C	13.4	15.4	-4.08
Specific Conductivity, uS/cm	267.9	244.5	19.04
Dissolved Oxygen, mg/L	9.45	8.65*	8.50
pH	7.42	7.31	0.51

*Significant at the 0.1 probability level (Wilcoxin Signed Ranks Test).

The difference in manganese concentrations between the inlet and outlet is consistently positive over the sampling period. The pattern that the inlet and outlet follow is also similar, as can be seen in Figure 4.11. The unusually high value detected in November 2003 is not visible on the graph, however it reached 2.5 mg/L. At the same sampling time, the concentration of dissolved manganese at the outlet was 0.10 mg/L.

Detailed results of the water quality sampling at Oakalla Biofiltration System are provided in Appendix VIII.

Sediment Quality Results

Sediments sampled from the Oakalla Biofiltration System during the wet season did not show any significant differences between the inlet and outlet, although the inlet sediments did tend to have higher metal concentrations than the outlets. Potassium and sodium are interesting to note, as they have high negative median percent differences, indicating that the concentrations were higher at the outlet. The median concentration of manganese at the inlet is also interesting, as it is quite high relative to the values seen in the other four ponds. Results of the wet season sediment sampling are summarized in Table 4.46.

Table 4.46 Sediment quality results for the wet season at Oakalla Biofiltration System. Results given as median in mg/kg. n = 3.

Parameter	Inlet	Outlet	% Difference
Aluminum	13246.1	12542.1	-6.14
Calcium	10103.0	5316.5	49.51
Chromium	28.5	32.7	22.10
Copper	81.1	89.3	22.38
Iron	18916.0	16701.3	30.19
Potassium	560.2	871.9	-59.25
Magnesium	3102.1	3023.3	8.15
Manganese	2932.1	958.5	78.69
Sodium	204.0	399.0	-57.61
Nickel	14.1	14.5	13.77
Phosphorus	1343.1	978.4	16.93
Lead	52.2	30.8	50.50
Silicon	2862.1	1139.8	52.33
Zinc	361.5	350.6	44.19

The dry season produced similar patterns in the sediment quality as the wet season. Highly positive median percent differences were seen in manganese and zinc, while potassium remained negative. Results are presented in Table 4.47.

Table 4.47 Sediment quality results for the dry season at Oakalla Biofiltration System. Results given as median in mg/kg. n = 3.

Parameter	Inlet	Outlet	% Difference
Aluminum	17623.8	21765.6	-18.89
Calcium	13051.9	6819.6	47.75
Chromium	36.7	31.4	19.61
Copper	107.5	71.0	33.97
Iron	23396.5	22836.6	17.93
Potassium	947.9	1219.8	-28.68
Magnesium	4798.3	5326.5	-5.95
Manganese	2604.8	781.5	74.26
Sodium	472.4	484.0	7.00
Nickel	22.7	17.9	19.46
Phosphorus	1389.1	1184.3	12.91
Lead	52.7	32.9	37.57
Silicon	3297.1	1779.9	26.51
Zinc	599.8	226.5	62.82

Despite the high concentration of manganese at the inlet, the outlet sediments had consistently lower values, except for November 2003 where the inlet concentration was relatively low. The trend of manganese in the sediments is presented in Figure 4.12.

The results of the particle size analysis showed large decreases in the percentage of sand particles from inlet to outlet. The increases in silt and clay particles were quite large through all three samples analysed, however they were not significant. Results are summarized in Table 4.48.

Table 4.48 Results of the particle size analysis for Oakalla Biofiltration System. Results are given as median percent. n =3.

Parameter	Inlet	Outlet	Percent Difference
% Sand	94.07	25.54	72.82
% Silt	3.93	57.60	-1340.00
% Clay	1.93	19.33	-866.67

Detailed results of the sediment sampling program at Oakalla Biofiltration System are provided in Appendix IX.

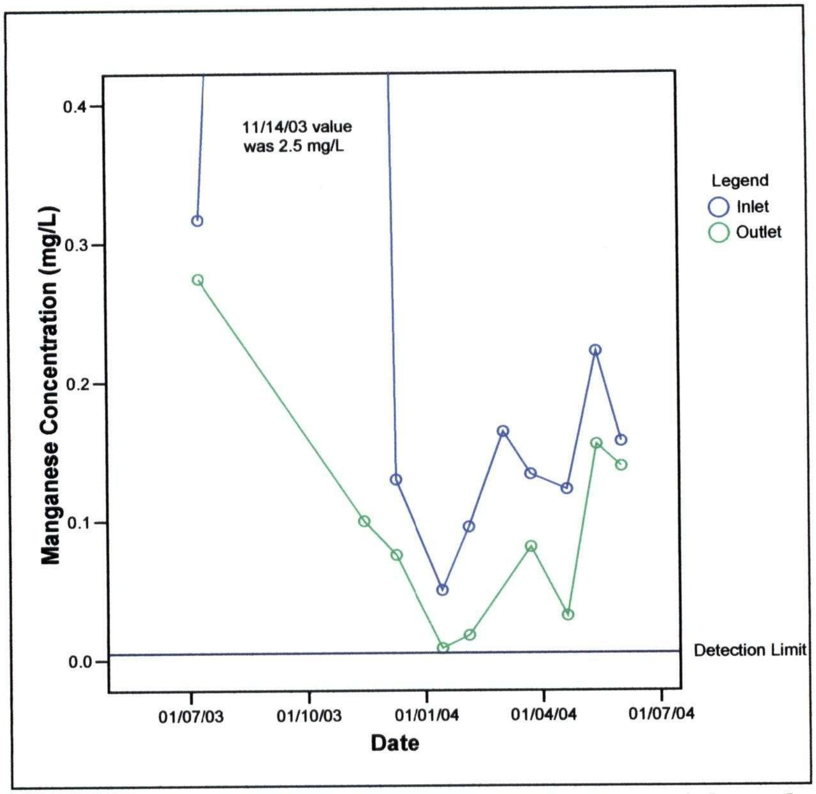

Figure 4.11 Dissolved manganese concentrations at inlet and outlet of Oakalla Biofiltration System, Burnaby.

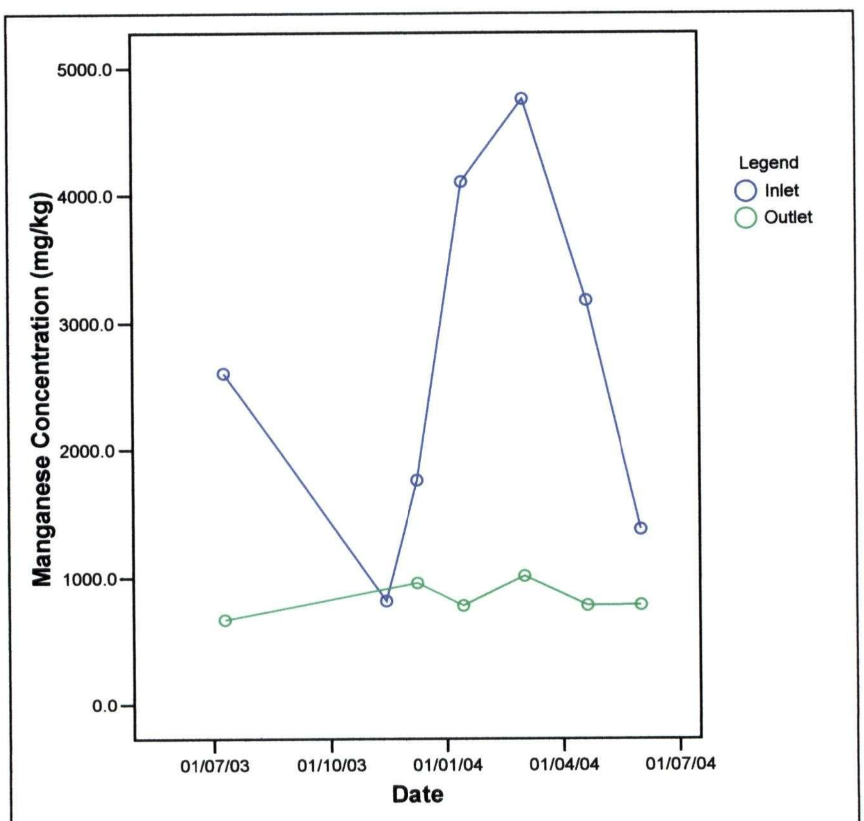

Figure 4.12 Manganese concentrations in sediments at inlet and outlet of Oakalla Biofiltration System, Burnaby.

DGT Results

The wet season DGT deployments resulted in significantly higher inlet concentrations than the outlet in all four detected metals. The results are summarized in Table 4.49.

Table 4.49 DGT results for the wet season in Oakalla Biofiltration System. Results are given as median in mg/L. *n* = 4.

Parameter	Inlet	Outlet	% Difference
Aluminum	0.011	0.003*	70.90
Iron	0.017	0.006*	71.95
Manganese	0.081	0.016*	80.77
Zinc	0.009	0.004*	46.11

*Significant at the 0.1 probability level (Wilcoxin Signed Ranks Test).

The dry season showed positive percent differences between inlet and outlet DGT concentrations for all detected metals. However, there were no statistically significant differences since there were only two sets of DGT units that were successfully deployed during the dry season. A summary of the results is presented in Table 4.50.

Table 4.50 DGT results for the dry season in Oakalla Biofiltration System. Results are given as median in mg/L. *n* = 2.

Parameter	Inlet	Outlet	% Difference
Aluminum	0.013	0.003	39.58
Iron	0.017	0.003	19.95
Manganese	0.069	0.025	62.46
Zinc	0.006	0.002	78.25

Manganese was measured to have high percent differences in both seasons. The consistent nature of the pattern can be seen in Figure 4.13.

Complete DGT results of the Oakalla Biofiltration System are presented in Appendix X.

Effect of Precipitation

The inlet concentrations of magnesium, manganese sodium and silicon were all negatively correlated with the precipitation of the previous 24, 48 and 72 hours. Calcium and potassium were negatively correlated with the precipitation of the previous 24 and 48 hours. The only positive correlations with the inlet water were between dissolved aluminum concentrations and the precipitation of the previous 24 and 48 hours. Temperature at the inlet was negatively correlated with the precipitation that had fallen 48 and 72 hours prior to sampling. At the outlet, the concentrations of dissolved calcium, magnesium, manganese and silicon were negatively correlated with the precipitation that had fallen in all three time periods, as was the specific conductivity. Dissolved sodium concentrations were negatively correlated with the precipitation of the previous 48 and 72 hours and pH with the previous 72 hours.

The inlet sediment concentration of calcium was found to be positively correlated with the precipitation that had fallen in the previous 24 hours. No other significant correlations were found between sediment concentrations and precipitation of the four time periods.

The concentration of bioavailable zinc measured by the DGT at both the inlet and outlet was found to be significantly correlated to the rainfall of the deployment period. No other significant correlations between DGT concentrations and precipitation were found.

Complete correlation results are provided in Appendix XI.

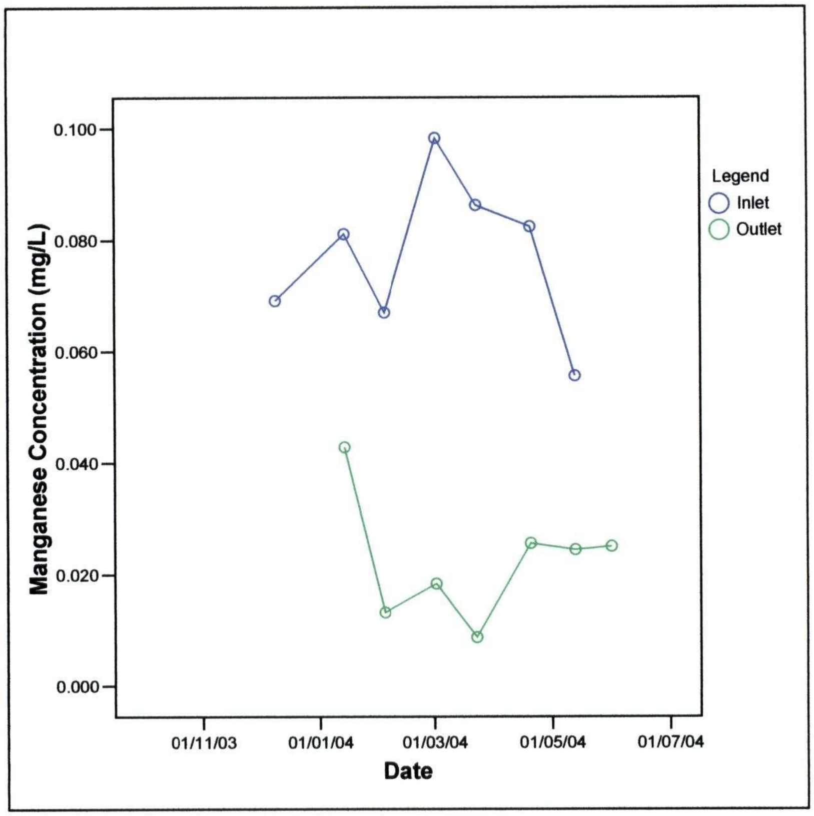

Figure 4.13 Bioavailable manganese concentrations at inlet and outlet of Oakalla Biofiltration System, Burnaby

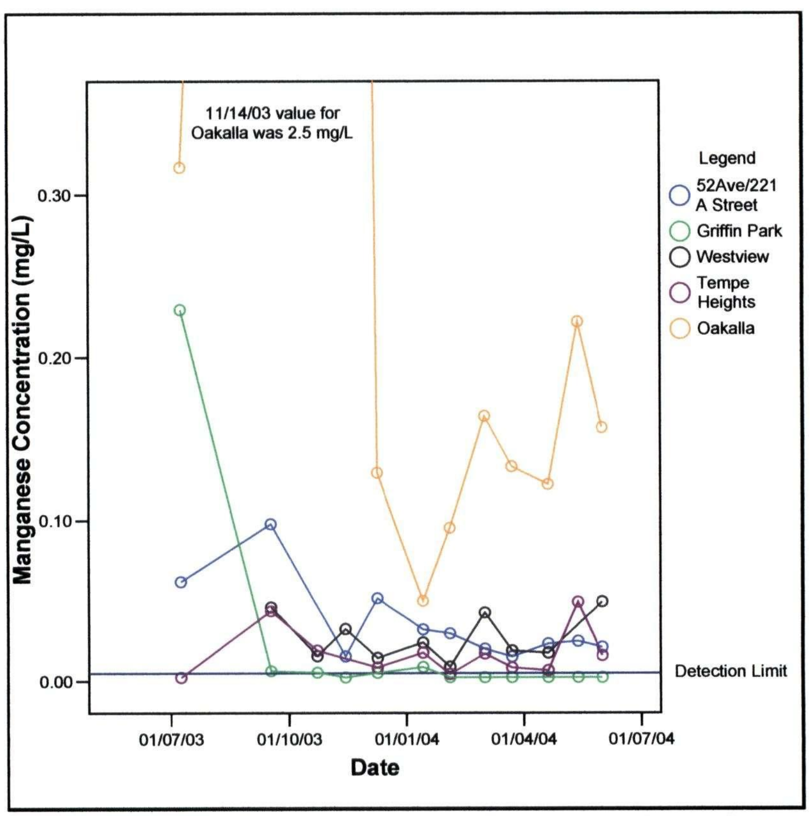

Figure 4.14 Inlet concentrations of dissolved manganese for all five ponds.

4.5 Between Pond Comparisons

The water, sediment and DGT results were compared across all 5 ponds to see if significant differences occurred at the inlet, outlet and in the percent difference between the two. All parameters that were identified through a factor analysis were used in the Mann Whitney test of significance. This section discusses the significant differences between the ponds in terms of inlet, outlet and percent difference for water, sediment and DGT results during the wet and dry seasons. All results of significance tests are provided in Appendix XII.

4.5.1 Differences Between Water Quality Of All 5 Ponds

The water sampled at the inlet of the ponds showed significant differences in dissolved magnesium concentrations between all ponds during both the wet and dry season except for Westview Interchange Detention Pond and Griffin Park Biofiltration Pond. The Oakalla Biofiltration System showed significantly higher manganese concentrations in the inlet water than the other ponds in the wet season, while Griffin Park Biofiltration Pond had significantly lower concentrations than other ponds. Trends for dissolved manganese at the inlets of the ponds can be seen in Figure 4.14. Significantly lower concentrations of dissolved iron concentrations were found in Griffin Park Biofiltration Pond than all other ponds except the 52Ave/221A Street Detention Facility in Langley in the wet season. No significant differences in iron occurred in the dry season. It is interesting to note that specific conductivity differed significantly between many ponds at their inlets in both the wet and dry season. Specific conductivity results at the inlets of all ponds can be seen in Figure 4.15.

Similar trends were seen at the outlets of the ponds, where dissolved magnesium concentrations and specific conductivity differed significantly between most ponds. Iron concentrations were significantly lower at the outlet of the Oakalla Biofiltration System than all other ponds during the wet season, while the dry season showed significantly higher concentrations of iron at the outlet of Tempe Heights Pond than all other ponds.

The percent differences between inlet and outlet showed significant differences across ponds, especially for manganese and iron concentrations. The percent difference for dissolved magnesium also showed significant differences across ponds, primarily at Griffin Park Biofiltration Pond, where it was lower than the other ponds.

4.5.2 Differences Between Sediment Results Of All 5 Ponds

Sediment sampling at the inlets of the ponds revealed significant differences in copper, manganese, lead and zinc in many of the ponds. The trends of copper and manganese can be seen in Figures 4.16, 4.17 respectively. The results of zinc concentrations in inlet sediments are shown in Figure 4.18 and the trend of lead concentrations is similar for all five ponds. It is interesting to note that the Westview Interchange Pond showed significantly higher chromium concentrations in both the wet and dry seasons than the other ponds. Phosphorus concentrations in the inlet sediment at Griffin Park Biofiltration pond were significantly higher than the 52Ave/221A Street Detention Facility in Langley and the Westview Interchange Pond in both the wet and dry seasons as well as the Oakalla Biofiltration System in the dry season. It is also interesting to note that no significant differences were found in the inlet sediments between the 52Ave/221A Street Detention Facility in Langley and the Oakalla Biofiltration System in either the wet or dry season.

The outlet sediments were also found to differ significantly between concentrations of in copper, manganese, lead and zinc between most ponds. Chromium concentrations were higher at the Westview Interchange Pond than most ponds as in the inlets, except with the Oakalla Biofiltration System in the wet season. The 52Ave/221A Street Detention Facility in Langley and the Oakalla Biofiltration System did not differ significantly for any parameters at the outlet sediments.

Percent differences between inlet and outlet sediment concentrations of manganese were higher at the Oakalla Biofiltration System than all other ponds in the wet season except the 52Ave/221A Street Detention Facility in Langley and the Westview Interchange Detention Pond in the dry season. The percent difference of copper concentrations differed significantly between four of the ponds. Very few cases of significance exist for percent difference of iron and zinc in the sediments between the ponds.

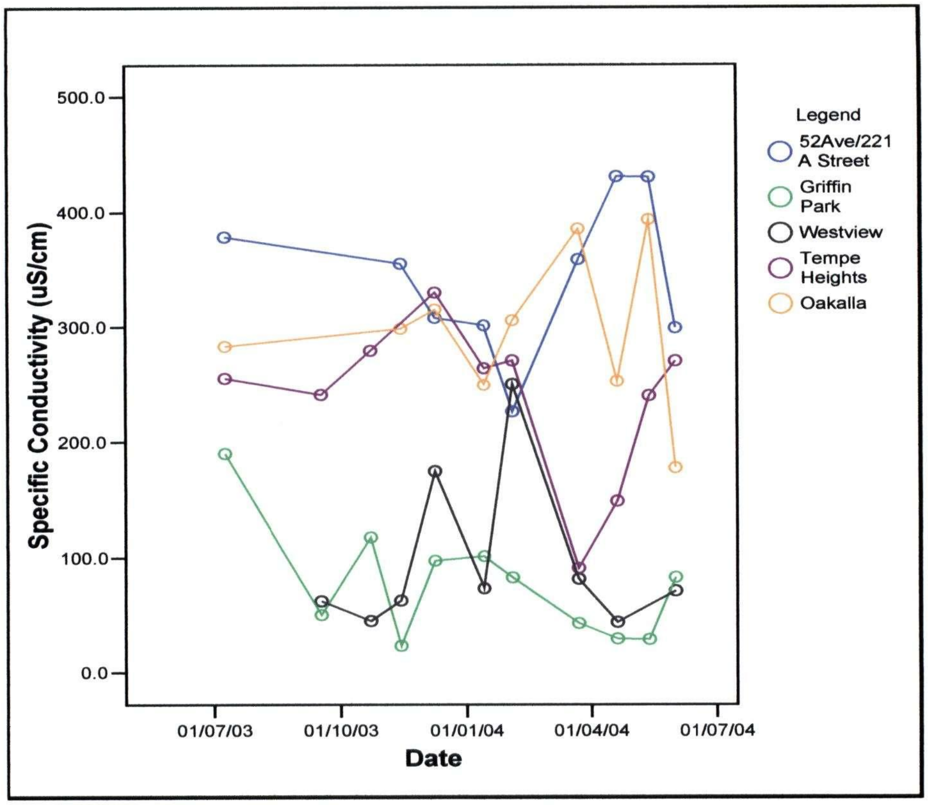

Figure 4.15 Specific conductivity at the inlets of all five ponds.

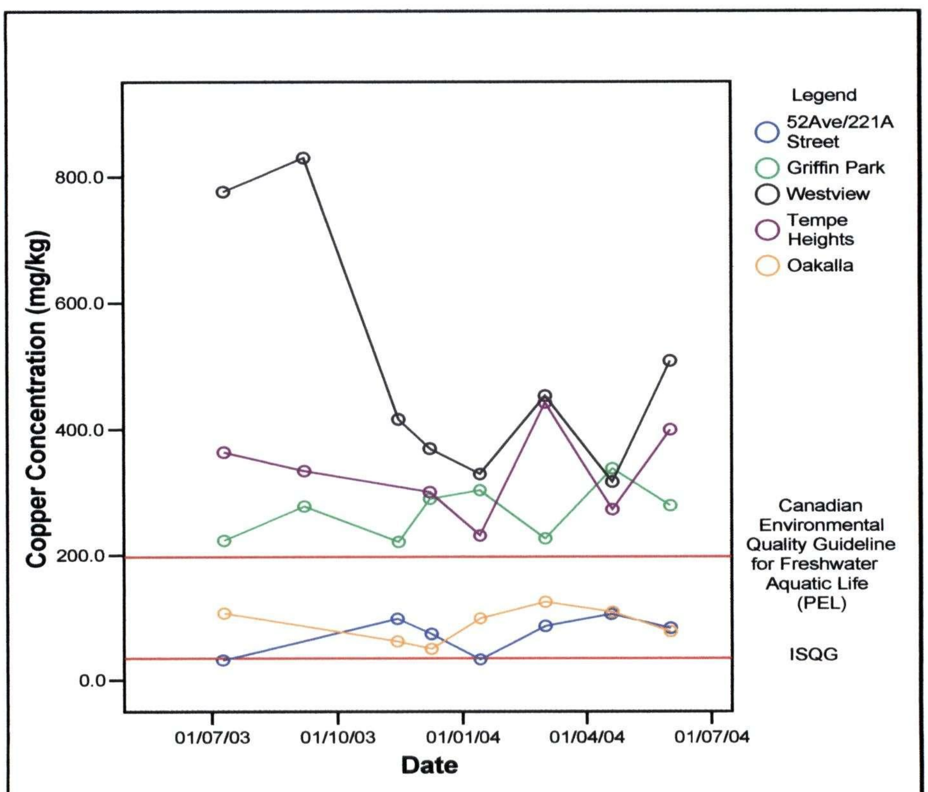

Figure 4.16 Copper concentrations in inlet sediments of all five ponds.

Particle size analyses for all of the inlets and outlets did not reveal and significant differences between the five ponds. The analysis was run on the sediment samples at three times through the sampling period, which provided only a small sample size from which to perform statistical tests. However, the 52Ave/221A Detention Facility in Langley was the only pond to vary through the year in either increases or decreases of a particular size fraction from inlet to outlet. All other ponds generally decreased in percent sand particles and increased in percent silt and clay particles from inlet to outlet.

4.5.3 Differences Between DGT Results of all 5 Ponds

The DGT units that were deployed at the inlets of the ponds showed significant differences in bioavailable manganese and zinc between most ponds in the wet and dry seasons, with the Westview Interchange Detention Pond having significantly higher zinc concentrations than all other ponds. The trends of these two metals are presented in Figures 4.19 and 4.20 respectively. Iron concentrations were significantly lower at the 52Ave/221A Street Detention Facility in Langley than all ponds in the wet season except Griffin Park Biofiltration Pond. It should be noted that low sample sizes of DGT units in the dry season for Oakalla Biofiltration System and Westview Interchange Pond prohibited tests of significance.

DGT units at the outlet showed significantly lower bioavailable manganese concentrations between Griffin Park Biofiltration Pond and all other ponds during the wet season. Bioavailable zinc concentrations differ between most ponds in the wet season, except the 52Ave/221A Street Detention Facility in Langley, which did not show any significant differences from Griffin Park Biofiltration Pond, Tempe Heights Pond or Oakalla Biofiltration System. Aluminum concentrations at the outlet were significantly higher at the 52Ave/221A Street Detention Facility in Langley and all other ponds except Tempe Heights Pond. The only significant difference in the dry season occurred between the 52Ave/221A Street Detention Facility in Langley and Tempe Heights Pond for bioavailable iron and zinc.

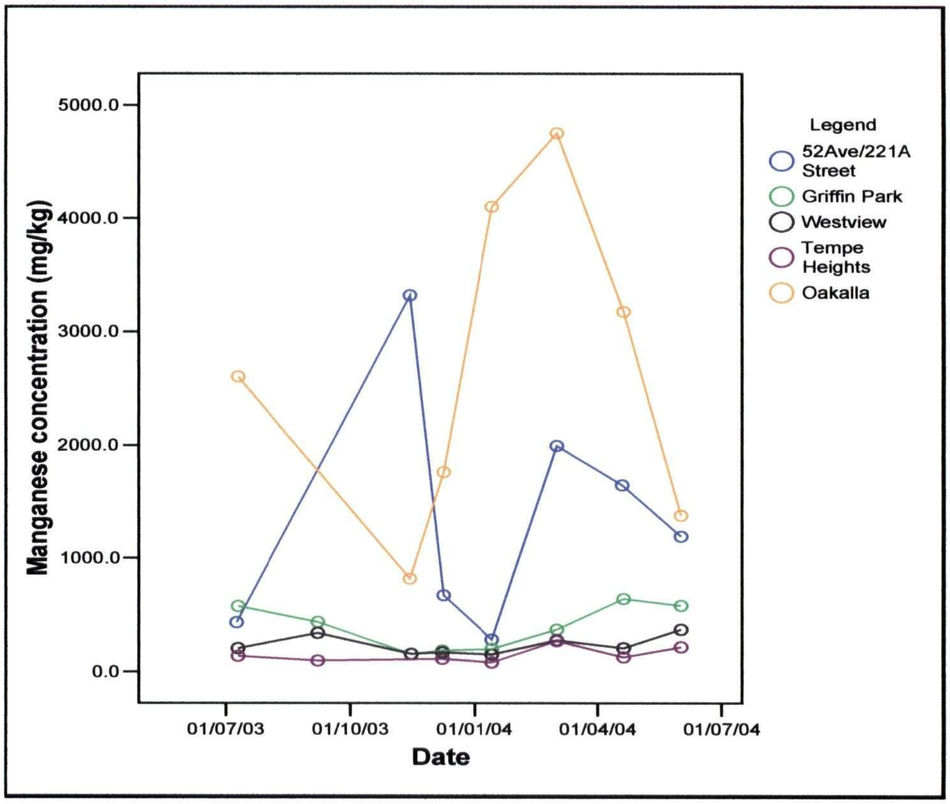

Figure 4.17 Manganese concentrations in inlet sediments of all five ponds.

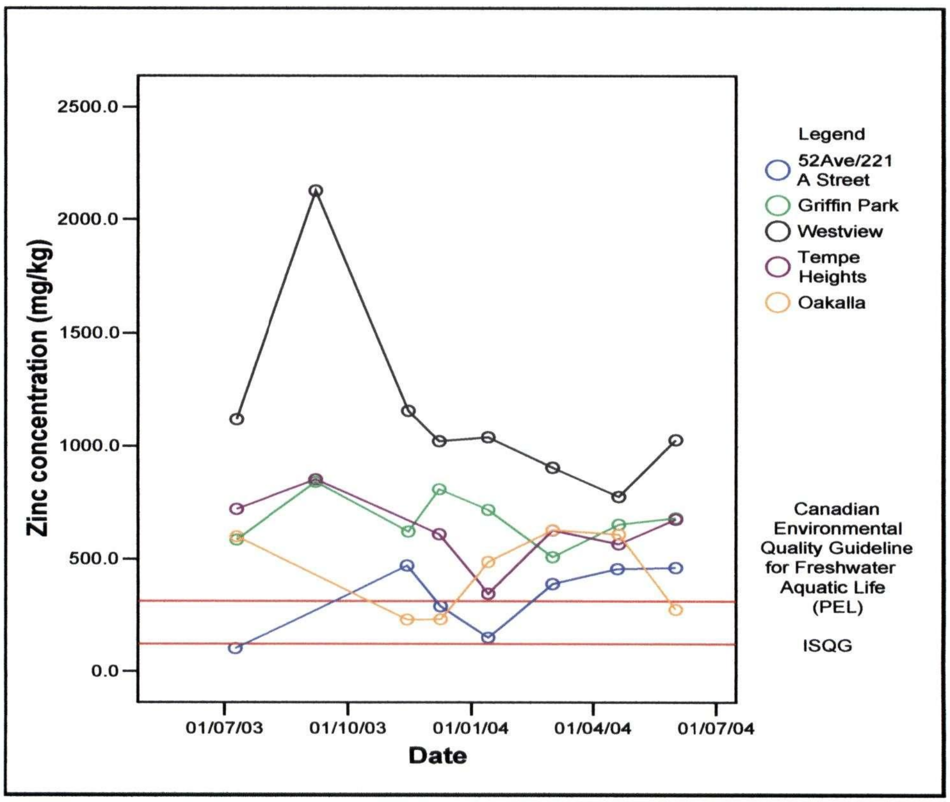

Figure 4.18 Zinc concentrations in inlet sediments of all five ponds.

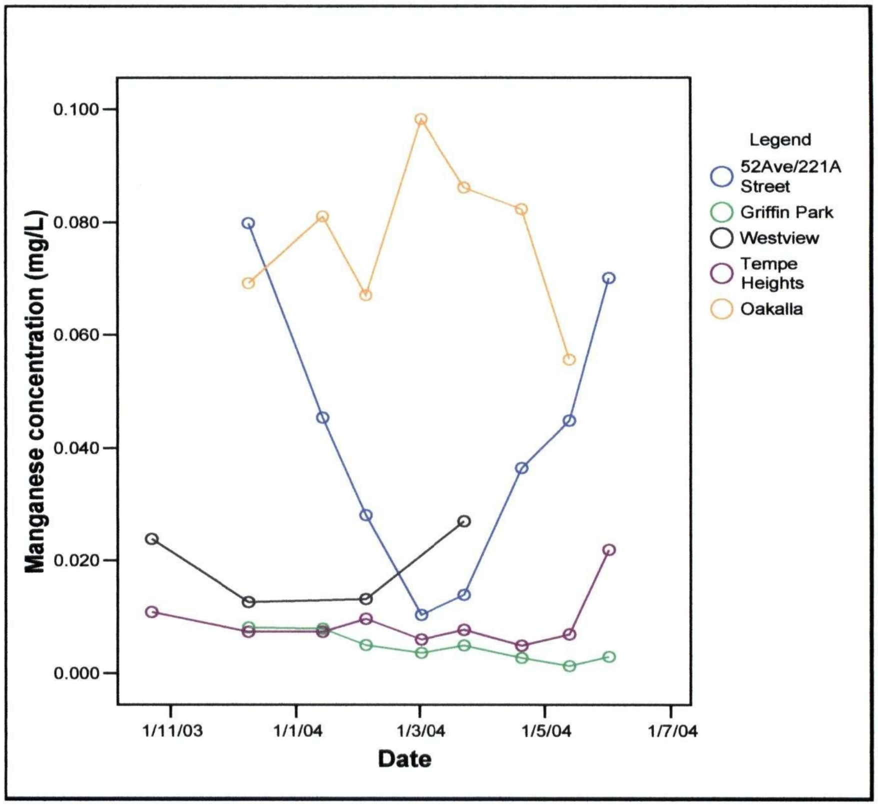

Figure 4.19 Bioavailable manganese concentration at inlets of all five ponds

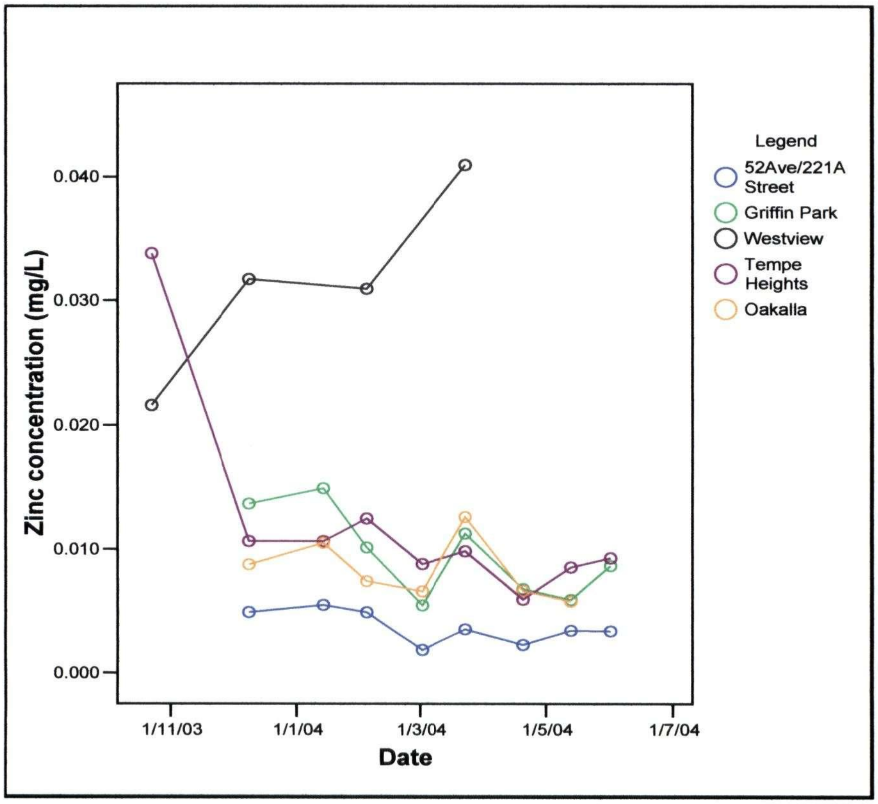

Figure 4.20 Bioavailable zinc concentration at inlets of all five ponds.

The percent difference of bioavailable manganese and zinc differed significantly between most of the ponds in the wet season. The percent difference in bioavailable manganese and zinc for all five ponds can be seen in Figures 4.21 and 4.22 respectively. The 52Ave/221A Street Detention Facility in Langley was the only pond to show significant differences in percent difference of bioavailable iron from the other ponds as it was often highly negative.

4.5.4 Comparison of Contaminant Removal in all Five Ponds

Overall, the contaminant removal showed a wide range of results, reflecting the influence of pond design and inlet water quality on water quality improvement. A summary of the results of the percent reduction of several key parameters is presented in Table 4.51.

Table 4.51 Median percent reduction of selected metals, calcium and magnesium in each pond.

		Water						Sediment						Bioavailable (DGTs)				
Season		D	E	F	G	I		D	E	F	G	I		D	E	F	G	I
Wet	Al	-316	0	-44	-	-		12	-74	-36	-31	-6		-155	78	81	-77	71
	Ca	39	17	71	17	38		45	34	14	39	50		-	-	-	-	-
	Fe	-260	-128	39	-176	57		13	-34	-16	-31	30		-8	73	72	73	72
	Mg	43	11	69	40	33		-9	29	-26	14	8		-	-	-	-	-
	Mn	20	-167	67	-82	81		60	-38	-6	-13	79		74	35	54	-92	81
	Zn	0	0	27	13	0		51	65	-4	45	44		-38	20	12	10	46
Dry	Al	0	0	58	-	-		19	-25	-23	-35	-19		-17	79	-	0	40
	Ca	28	-5	67	-7	37		54	59	25	38	48		-	-	-	-	-
	Fe	-488	-287	24	-64	13		16	-3	-2	-24	18		-277	0	-	82	20
	Mg	35	-1	58	5	41		-2	21	-20	21	-6		-	-	-	-	-
	Mn	-191	-133	57	0	22		73	5	-1	-50	74		-117	-735	-	-10	62
	Zn	0	0	30	41	0		64	52	26	56	63		58	42	-	66	78

D = 52Ave/221A Street Detention Facility, Langley, E = Griffin Park Biofiltration Pond,
F = Westview Interchange Detention Pond, G = Tempe Heights Pond, I = Oakalla Biofiltration System

The results indicate that:

(a) almost all ponds are effective in reducing zinc concentrations in the water, sediment and bioavailability (between 0 and 78% removal in the bioavailable fraction);

(b) most ponds are effective in reducing calcium and magnesium in the water and sediments, with up to 71% and 69% removal from the water respectively;

(c) most ponds are not effective in reducing aluminum, iron and manganese in the water and sediments. However, the bioavailable fraction of these metals is reduced, particularly in the wet season, where removals of up to 81% were seen, with some exceptions;

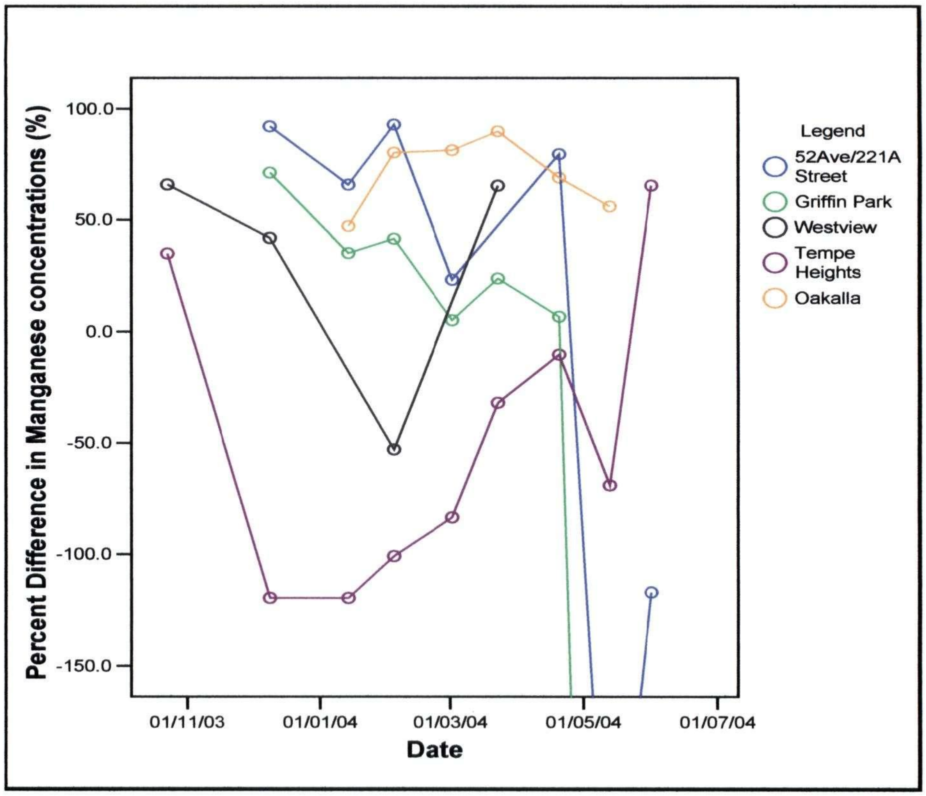

Figure 4.21 Percent difference of bioavailable manganese concentrations between inlet and outlet of all five ponds.

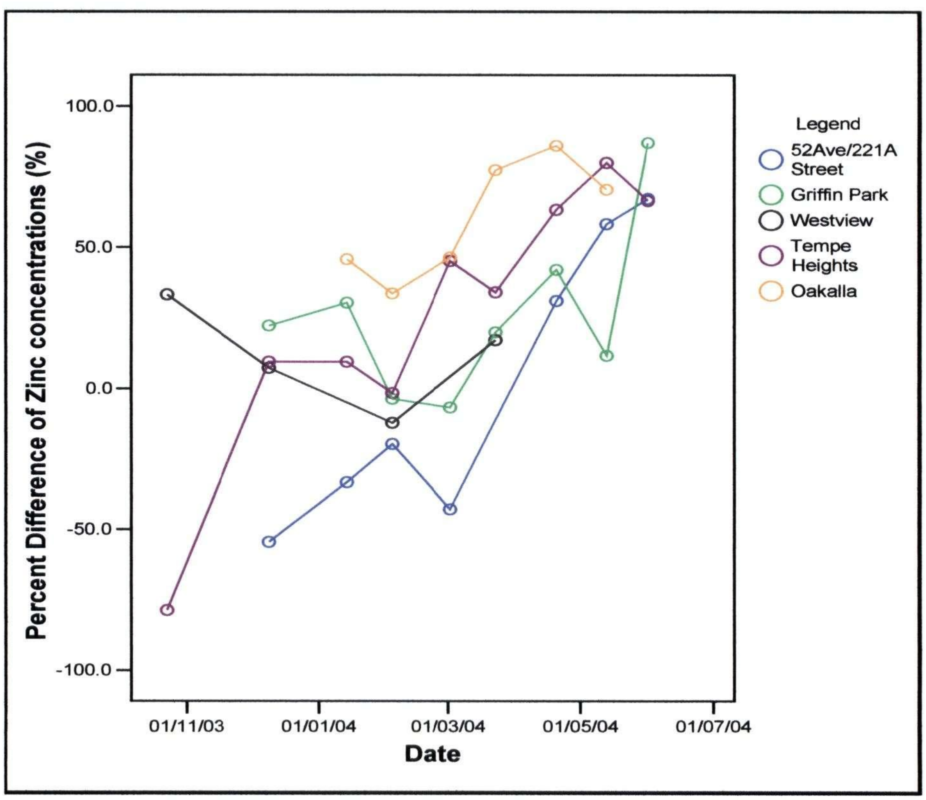

Figure 4.22 Percent difference of bioavailable zinc concentration between inlet and outlet of all five ponds.

(d) the 52Ave/221A Street Detention Facility is effective in reducing all metals and calcium in the sediment, between 12 and 73% but not magnesium. The removal of metals from the water and in bioavailability was not found to be effective;

(e) the Griffin Park Biofiltration Pond was not effective in reducing aluminum, iron and manganese in the water and sediments. However, the reduction in bioavailable metals is effective, up to 79%;

(f) the Westview Interchange Detention Pond is effective in reducing all metals as well as calcium and magnesium in water and bioavailability, however the retention of metals in sediments is not effective;

(g) Tempe Heights Pond is effective in reducing zinc in water, sediment and bioavailability by up to 82%, however other metals were not reduced successfully;

(h) Oakalla Biofiltration System is effective in reducing all metals, as well as calcium and magnesium, in sediment (except aluminum), water and bioavailability, with reductions of up to 81%.

4.5.5 Comparison of Results to the Canadian Environmental Quality Guidelines for Freshwater Aquatic Life

In addition to the comparison of inlet samples to the Canadian Environmental Quality Guidelines for Freshwater Aquatic Life in section 4.3, the outlet samples were compared to the guidelines. The improvement of the water and sediment quality was assessed by the change in the percentage of samples exceeding the guidelines at the outlet versus the inlet.

The outlet water samples exceeded guidelines at least 30% of the time for aluminum at the 52Ave/221A Street Detention Facility. The guideline for iron was exceeded 73% of the time at Tempe Heights Pond and guidelines for both aluminum and zinc were exceeded over 20% of the time at the outlet of Westview Interchange Detention Pond. Results are summarized in Table 4.52.

Table 4.52 Summary of water samples at outlet that exceed the Canadian Environmental Quality Guidelines. Results given in percent. $n = 12$.

Parameter	Guideline Concentration (µg/L)	Percentage of Samples at Outlet Exceeding Guideline				
		D	E	F	G	I
Al	5-100 (100 was used)	45	0	30	0	0
Fe	300	9	17	0	73	0
Zn	30	0	8	20	9	0

D = 52Ave/221A Street Detention Facility, E = Griffin Park Biofiltration Pond,
F = Westview Interchange Detention Pond, G = Tempe Heights Pond, I = Oakalla Biofiltration System

The high levels of zinc at the inlet of the Westview Interchange Pond that were above the guidelines (see Table 4.12) were reduced through the pond, resulting in 67% less samples that exceeded the guideline at the outlet. The percentages of aluminum and iron samples exceeding the guideline were also reduced from inlet to outlet. However, more samples at the outlets of some ponds exceeded the guidelines than at the inlets, as can be seen by the negative percent changes in Table 4.53.

Table 4.53 Percent Change of Water Samples Exceeding the Canadian Environmental Quality Guidelines for Freshwater Aquatic Life from Inlet to Outlet

Parameter	Guideline Concentration (µg/L)	Percent Change of Samples Exceeding Guideline from Inlet to Outlet				
		D	E	F	G	I
Al	5-100 (100 was used)	-150	0	40	0	0
Fe	300	0	-100	100	-300	0
Zn	30	0	0	67	0	0

D = 52Ave/221A Street Detention Facility, Langley, E = Griffin Park Biofiltration Pond,
F = Westview Interchange Detention Pond, G = Tempe Heights Pond, I = Oakalla Biofiltration System

The concentration of copper and zinc in the sediments exceeded the interim sediment guideline or the probable effects level at the outlet of each pond. This suggests that a risk is posed to the aquatic habitats of the receiving waters should sediment become resuspended and exit the pond. Results are summarized in Table 4.54.

Table 4.54 Summary of sediment samples at outlet that exceed the Canadian Environmental Quality Guidelines. Results given in percent. n = 8.

Parameter	Guideline	Guideline Concentration (µg/kg)	Percentage of Samples at Outlet Exceeding Guideline				
			D	E	F	G	I
Cr	ISQG	37 300	29	0	38	0	17
	PEL	90 000	0	0	63	0	0
Cu	ISQG	35 700	71	100	100	100	100
	PEL	197000	0	100	100	0	0
Pb	ISQG	35 000	9	25	100	86	17
	PEL	91 300	0	75	100	14	0
Zn	ISQG	123 000	55	88	100	57	67
	PEL	315 000	9	12	100	43	33

There was little remediation of copper through the ponds, as the percentage of samples exceeding the guideline was not reduced from inlet to outlet, except at Tempe Heights Pond. Samples exceeding guidelines for chromium, lead and zinc were reduced through all ponds except the Westview Interchange Detention Pond, where either no change or an increase in violations of the guidelines was found. The results of the percent change in samples exceeding sediment quality guidelines from inlet to outlet are provided in Table 4.55. Note that a negative percent change in ISQG violations and a positive change in PEL violations indicate that the concentrations were less at the outlet than the inlet although still exceeded the ISQG.

Table 4.55 Percent Change of Sediment Samples Exceeding the Canadian Environmental Quality Guidelines for Freshwater Aquatic Life from Inlet to Outlet

Parameter	Guideline	Guideline Concentration (µg/kg)	Percentage Change of Samples Exceeding Guideline from Inlet to Outlet				
			D	E	F	G	I
Cr	ISQG	37.3	33	100	57	100	42
	PEL	90	0	0	-400	0	0
Cu	ISQG	35.7	0	0	0	0	0
	PEL	197	0	0	0	100	0
Pb	ISQG	35	67	75	0	-500	80
	PEL	91.3	0	25	0	83	0
Zn	ISQG	123	-200	13	0	43	-56
	PEL	315	75	88	0	57	42

D = 52Ave/221A Street Detention Facility, Langley, E = Griffin Park Biofiltration Pond,
F = Westview Interchange Detention Pond, G = Tempe Heights Pond, I = Oakalla Biofiltration System

Overall, the water and sediment quality at the Westview Interchange Pond proved to be the worst of all five ponds, with limited remediation shown in the sediments.

4.6 Correlations Between Catchment Characteristics and Inlet Water and Sediment Quality

Spearman's rank correlation tests performed on catchment characteristics and inlet water and sediment quality revealed significant correlations between several parameters. The results are discussed below for dissolved metal concentrations measured from water and sediment samples at the inlet and bioavailable metal concentrations measured by DGT units at the inlet. The three catchment characteristics included in the correlations were the catchment area, average daily traffic and percent impervious cover. A summary of the results is provided in Table 4.56 and complete results of the correlation tests are provided in Appendix XIII. Note that a positive correlation between a parameter and a catchment characteristic indicates that as the value of the characteristic increases, a higher concentration of the parameter is found at the inlet. Conversely, a negative correlation indicates that as the value of the characteristic increases, the concentration of the parameter at the inlet decreases.

Table 4.56 Correlations ($p<0.05$) Between Catchment Characteristics and Inlet Results for Various Parameters

Season	Catchment Characteristic	Water	Sediment	Bioavailable (DGT)
Wet	Catchment Area	Al, Fe, Mn	Cr, (- P)	Al, Mn
	Average Daily Traffic	Al, Zn (- Ca, Mg, Mn)	Cr, Cu, Pb, Zn (- Al, Ca, Fe, Mn)	Zn, (- Mn)
	Percent Impervious Cover	Fe, Zn (-Ca,Mg, Mn)	Cu, Pb, Zn (- Al, Ca, Fe, Mg, Mn)	Fe, Zn, (- Mn)
Dry	Catchment Area	Al, Mn	Cr, Mg (- Ca, P)	Mn (- Zn)
	Average Daily Traffic	Zn (- Ca, Mg, Mn)	Cr, Cu, Pb, Zn (- Al, Ca, Mg, Mn)	Zn (- Mn)
	Percent Impervious Cover	Fe, Zn (- Ca, Mg)	Cr, Cu, Pb, Zn (- Al, Fe, Mg, Mn)	Zn (- Mn)

The results of the correlation tests were fairly consistent between wet and dry seasons for all catchment characteristics. Average daily traffic and percent impervious cover were correlated with similar metals in the inlet water, sediment and bioavailable fraction. It is interesting to note that average daily traffic and percent impervious cover are negatively correlated with the manganese concentrations in water, sediment and DGT samples, but positively correlated with copper and zinc concentrations. The catchment area is negatively correlated with phosphorus concentrations in inlet water, sediment and bioavailable fractions.

4.7 Correlations Between Pond Characteristics and Percent Difference of Water and Sediment Quality

Spearman's rank correlation tests were performed between the percent difference of water, sediment and DGT parameters and the surface area of the pond, the percent vegetation in the pond and the estimated volume of the pond. A positive correlation between the percent difference of a parameter and a pond characteristic indicates that as the value of the characteristic (i.e. volume) increases, a higher concentration of the parameter is found at the inlet of the pond than the outlet. A summary of the results is presented in Table 4.57 and complete correlation results are provided in Appendix XIV.

Table 4.57 Correlations ($p<0.05$) Between Pond Variables and Percent Difference for Various Parameters

Season	Pond Characteristics	Water	Sediment	Bioavailable (DGT)
Wet	Surface Area	Ca, Mg, Mn (- Al, Zn)	Al, Fe, Mn (- Cu, Ni, P, Zn)	Mn (- Al, Fe)
	Volume	Ca, Mg, Mn (- Al, Zn)	Fe, Mn (- Cu, Ni, P, Zn)	Mn (- Al, Fe)
	Percent Vegetation	(- Ca, Mg, Zn)	Ca, Fe, Mg, P, Pb	Mn, Zn
Dry	Surface Area	-	Al, Mn (- Mg, Ni, P)	Mn (- Al, Fe)
	Volume	-	Al, Fe, Mn (- Mg, Ni, P)	Mn (- Al, Fe)
	Percent Vegetation	-	Fe, Mn	Al

The correlations between both surface area and volume with reduction of metals in the water, sediment and bioavailable fractions are similar in the wet and dry season. All of the pond characteristics are correlated with a reduction in bioavailable manganese in the wet season, however percent vegetation was the only characteristic correlated with the reduction of bioavailable zinc. The reduction of copper, nickel, zinc and phosphorus in the sediments was negatively correlated with surface area and volume of the ponds, meaning that as the area and volume increases, the concentrations in the sediments increases through the pond. The percent vegetation, however, was positively correlated with the reduction in concentrations of these contaminants in the sediments.

4.8 Relationship Between Zinc Concentrations and Catchment Characteristics

The consistently positive correlations found between the traffic volumes of the pond catchments and the concentrations of zinc in the water, sediment and DGT units suggested that the traffic volumes might be a predictor of zinc contamination in the ponds. Therefore, a simple regression line was fit to the data in order to determine if such a relationship exists. The same consistent results were shown between zinc concentrations and the percent impervious cover of the catchment, therefore the same procedure was performed on these variables as well.

Both the inlet and outlet concentrations of zinc in the water, sediment and DGT units were plotted against the average daily traffic volume and percent impervious cover. The R squared value, which is the coefficient of determination that signifies how well the points fit to a line, were determined from the slope of the best fit line. The data from the whole year produced a strong result between the concentration of bioavailable zinc measured by the DGT unit at the inlet and the traffic volume as well as the percent impervious cover. The concentration of zinc found in the sediments at the outlet also produced a strong result against both the traffic and percent impervious cover of the catchment. Results of the simple regression line and coefficients of determination for traffic volumes and zinc concentration at the inlet are provided in Figures 4.23 and 4.24, and percent imperviousness and zinc concentrations are provided in Figures 4.25 and 4.26.

Other coefficients of determination were below 0.6 and are therefore not included.

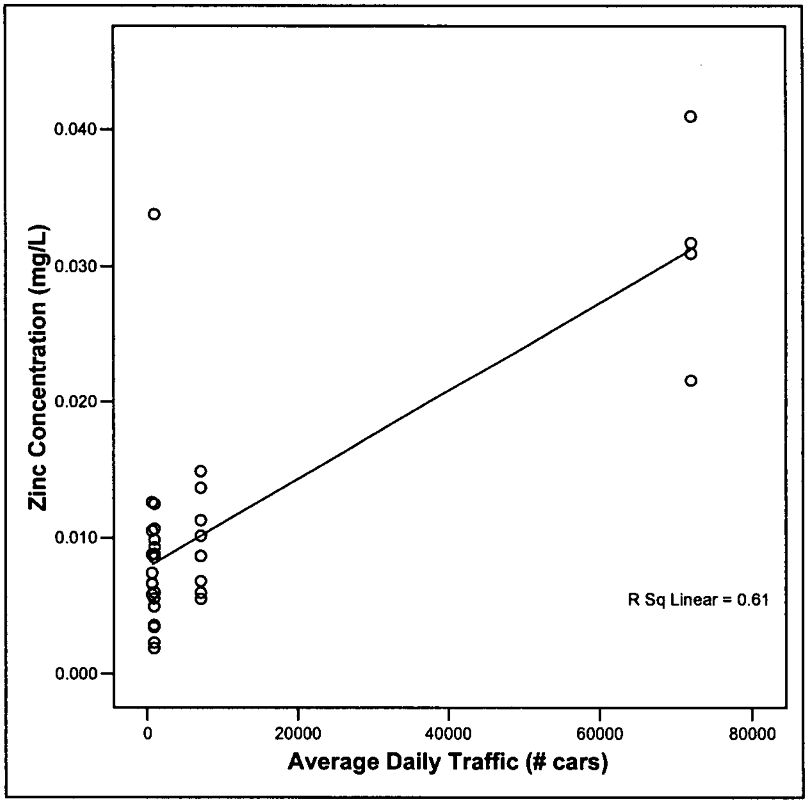

Figure 4.23 Relationship between bioavailable zinc at the inlets and average daily traffic volumes

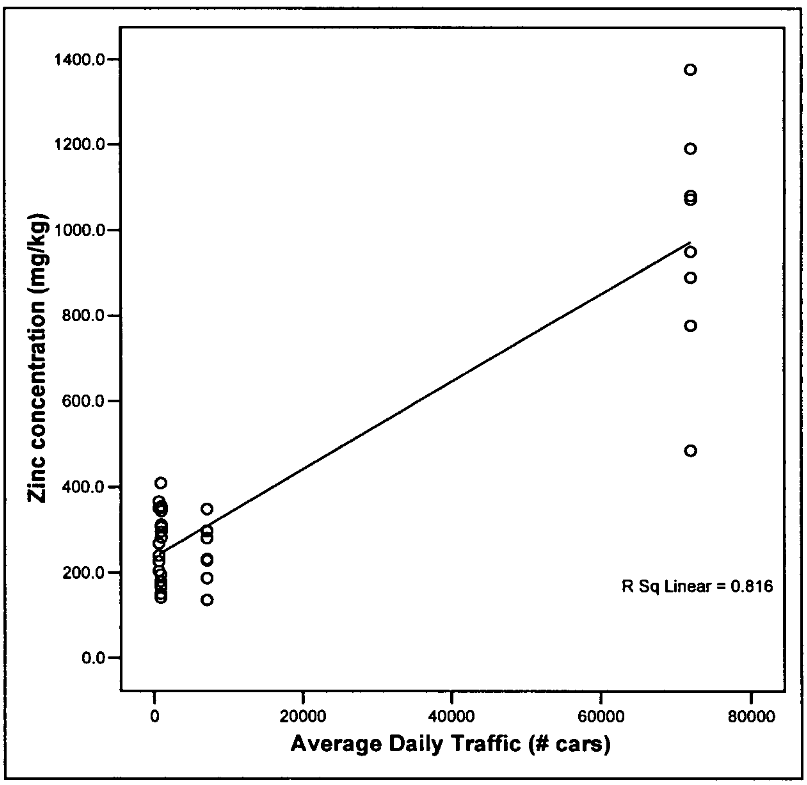

Figure 4.24 Relationship between total zinc in the sediments at the outlets and average daily traffic volumes

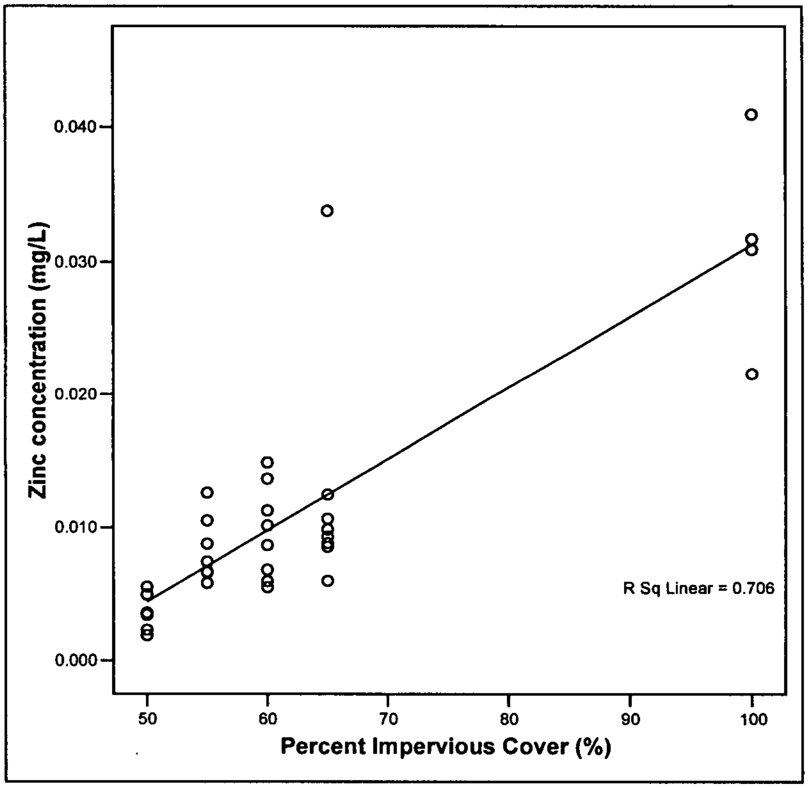

Figure 4.25 Relationship between bioavailable zinc measured at the inlets and percent impervious cover

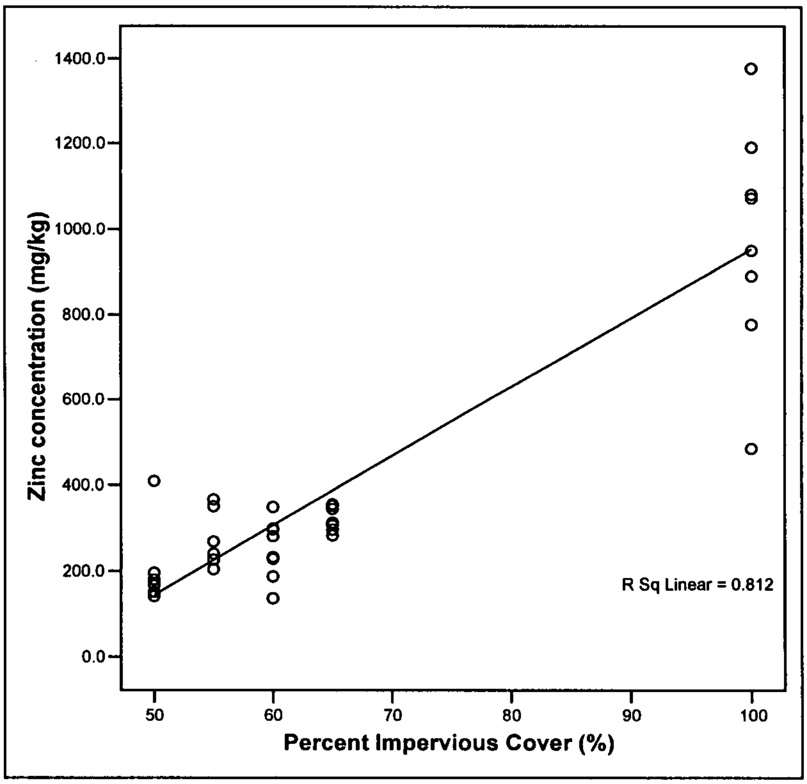

Figure 4.26 Relationship between total zinc in the sediments at the outlets and percent impervious cover

Chapter V Discussion

Discussions of the results obtained from this study are first dealt with in terms of the quality of the water and sediments in the ponds compared to Canadian Environmental Quality Guidelines and an overview of each individual pond. A discussion of the overall effectiveness of the ponds follows, as well as the factors affecting inlet concentrations and contaminant removal. A synopsis of the success of the DGT technique is also included.

5.1 Comparison of Water and Sediment Quality to Canadian Environmental Quality Guidelines

The inlet water and sediments which showed the highest percentages of samples that exceeded the Canadian Environmental Quality Guidelines for Freshwater Aquatic Life were from the Westview Interchange Detention Pond, where 60% of water samples exceeded the guideline for zinc, 12.5% of sediment samples exceeded the guideline for chromium and 100% of sediment samples exceeded guidelines for copper, lead and zinc. This is attributed to the input of metals from exhaust emissions, lubrication losses, degradation of tires, brake linings and other automobile related causes from the major highway. Copper and zinc concentrations in the sediments at Griffin Park Biofiltration Pond and Tempe Heights Pond exceeded guidelines 100% of the time, indicating effects of the automobile use in those catchments, which were second and third in traffic volume after Westview Interchange Detention Pond.

The contaminant removal from the water column was evident in the percent changes of violations of guidelines from inlet to outlet in all ponds. The increases seen in aluminum and iron in the water of some ponds is likely due to chemical transformations due to variations in sediment water interactions, but is not of major concern since they are not most toxic to aquatic organisms (Buffle et al, 1994). However, the copper and zinc concentrations in the sediments exceeded the interim sediment guideline over 50% of the time at the outlets of all ponds. This poses a risk to aquatic organisms in the receiving waters should the sediments become resuspended and released from the outlet. In addition, the Westview Interchange Detention Pond acts as an infiltration basin when water levels are not high enough to exit the outlet, which is a concern in terms of possible effects on groundwater. These concerns should be investigated in subsequent studies.

The Canadian Environmental Quality Guidelines for Freshwater Aquatic Life are useful in obtaining an idea of the risk posed by the water and sediment to aquatic life in receiving waters. However, the guidelines provide values of individual metal concentrations but do not look at the overall effect of many different metals being over criteria simultaneously. This will pose an increased risk for aquatic organisms over time, which is not reflected by single metal concentrations in individual samples. Integrated samples, such as with the use of DGT units, is preferable as the measurement of metals that are available to an organism for an extended period of time is more useful in assessing the toxicity of metals in stormwater. Also, the absence of a guideline for manganese in freshwater and freshwater sediments is a limitation as concentrations cannot be compared directly to tested criteria and assessed against violations of other metal guidelines.

5.2 Individual Ponds

5.2.1 52Ave/221A Street Detention Facility, Langley

Water quality trends at the detention facility indicate that the concentration of contaminants generally decreases from inlet to outlet by up to 43%. However, the main exception to this is dissolved iron, which had significantly higher concentrations at the outlet than the inlet. Since the design of the detention facility introduces runoff from a small inlet from 52 Avenue and a ditch along 221A Street, it is possible that more iron is entering the detention facility throughout the pond and therefore increasing the concentration of iron and at the outlet. The water sampled from the small inlet from 52nd Avenue and the ditch along 221A Street did show higher concentrations of iron than the main inlet.

The sediments collected from the detention facility were higher in contaminant concentration at the inlet of the pond than at the outlet. This suggests that metals that have adsorbed onto the sediments in the first part of the pond undergo some remediation through the pond and the sediments that could be released from the outlet are less contaminated. However, there was no evidence that the difference in contaminant concentration is significant. The area of the pond before the bridge is vegetated with cattails, and sediments become trapped near areas of vegetation, providing opportunities for metal uptake by plants and microbial degradation. The sediments that were sampled from the point just before the bridge, where the cattail vegetation begins, generally showed similar concentrations as the inlet. This indicates that the remediation of the sediments would take place within the heavy vegetation around the bridge and towards the outlet, as the sampling point at the outlet revealed lower concentrations.

The particle size analysis did not produce consistent results, which may be due to ineffective sedimentation processes throughout the sampling period. Portions of the pond were often dry even during the end of the wet season, which suggested that a continuous flow was not present and may be affecting the contaminant removal capacity of the system.

The results of the bioavailable metals measured by the DGT units showed that in general concentrations were higher at the inlet than outlet, especially manganese, which showed a significant decrease. As the water moves through the pond, the bioavailable fraction is being reduced, which is beneficial to receiving streams. In the dry season, results showed negative percent differences in bioavailable aluminum, iron and manganese between the inlet and outlet. This suggests that as water levels lowered, the sediment and water interactions could have changed which influenced the levels of bioavailable metals in the water.

It should be kept in mind that the purpose for the construction of this pond was for detention of water to reduce stormwater flow, and water quality improvement was not specifically designed for. However, the evidence of reduction of bioavailable metals through the wet season and remediation of the sediments for some metals indicates that the pond does mitigate some of the effects of the stormwater runoff on receiving waters.

Results for bioavailable aluminum, iron and zinc at the inlet as well as aluminum and zinc at the outlet correlated positively with precipitation. The DGT units adsorb metals onto the cation exchange resin over the deployment of approximately three weeks, taking into account the metals that are in the stormwater during times of high and low flows. Since the correlation tests revealed that periods of high precipitation corresponded to higher levels of some metals adsorbed to the resin, this indicates that the stormwater passing through the system was in fact bringing consistently more metals in the runoff. It is important to note that it is not evident from the DGT results when the accumulated metals were adsorbed or the length of antecedent dry periods. Therefore, the actual pollutant loading is not known, however the DGT results do give a value that integrates the pollutants that have gone through the system and will include any spikes due to heavy rainfall.

5.2.2 Griffin Park Biofiltration Pond, North Vancouver

Water quality results from Griffin Park Biofiltration Pond showed slightly higher concentrations of most parameters at the inlet of the pond than the outlet, with up to 17% difference. The pond does contain extensive vegetation that should provide some remediation and increase the detention time, as the water will be slowed down as it moves through the plants. The meandering shape of the water flow will also encourage deposition of sediments, which would increase the time available for uptake of metals and nutrients by surrounding vegetation. However, there are only two significant differences between inlet and outlet water concentrations, dissolved iron and manganese in the wet season. These differences were negative, meaning the concentrations had increased through the pond. The low inlet concentrations of these metals may be a factor in the poor retention of iron and manganese (Goulet et al., 2001).

The iron and manganese concentration, as well as aluminum, also increased in the sediments from inlet to outlet, while other constituents showed a significant decrease in concentration. Anthropogenic metals, such as copper and zinc, are undergoing remediation of up to 67%, while some of the more geologically based metals are undergoing changes in states through the pond. The remediation of copper and zinc is likely due to the microbial decomposition and plant uptake through the pond.

The particle size analyses suggest that sand particles are deposited near the inlet of the pond and silt and clay particles are carried through to the outlet area. This is expected as the pond meanders and has deposition sites that would allow for the settling of some of the coarser particles.

The decrease in bioavailable metals from the inlet to the outlet of the pond is evident by the results of the DGT units in the wet season, where positive percent differences exist for all detected metals. The uptake by the vegetation in the pond likely has affected the decrease in bioavailable metals. The high values of manganese at the outlet in May and June of 2004 may have been affected by the low water levels that allowed the DGT units at the outlet to become biofouled and buried in sediment. Therefore the resins may have been accumulating manganese from sediment instead of being only affected by the stormwater.

Precipitation from the previous days and weeks was negatively correlated to the concentration of the inlet and outlet water samples. This indicates that dilution was playing a role or that the pollutants had been washed into the pond at the beginning of the storm before sampling. The concentrations of dissolved zinc were positively correlated to precipitation, which indicates that high levels of zinc are being carried with the stormwater throughout the storm.

The manganese and zinc ions adsorbed in the DGT units at the inlet were positively correlated to the precipitation that had entered the pond. The positive correlation between bioavailable zinc at the outlet and precipitation could indicate that the rates of removal of bioavailable zinc did not increase through the pond when there was more water, therefore the outlet concentration was still higher than during times of lower runoff.

5.2.3 Westview Interchange Detention Pond, North Vancouver

Water samples taken at the Westview Detention Pond showed median percent differences of over 60% for some constituents, indicating that the pond is generally successful in pollutant removal from the water column. The pond is mainly full only during the wet season, and as there is no vegetation, the majority of the pollutant removal will be due to sedimentation. During the drier months, any runoff that enters the pond is generally not a high enough volume to exit from the raised outlet, resulting in the stormwater infiltrating the underlying soil. In fact, this was noted throughout the wet season, except in October when the water levels did rise well above the outlet.

The sediment quality results do not show high percent differences between the inlet and outlet, indicating that the sediments at the outlet have not undergone much remediation. This is primarily due to the fact that there is no vegetative barrier for the water to pass through, so it essentially flushes right through the pond. The poor quality of the sediments poses a concern for possible negative effects on groundwater quality and resuspension of metals to the water column.

The particle size analysis revealed that sand particles were more prevalent at the inlet than the outlet, suggesting that the deposition of these coarse particles was taking place before that of the silt and clay particles. The silt and clay tended to be in higher percentages at the outlet, which is expected as the heavier sand particles should fall out of the water column before the lighter, finer ones.

The bioavailable fraction of the metals showed positive percent differences between inlet and outlet of up to 81%. However, the median percent difference for zinc was only 12%, suggesting that the removal of bioavailable zinc was not as effective, possibly due to high inlet concentrations which could not be remediated as effectively, especially since there is no vegetation for uptake and dissolved oxygen production.

Precipitation of the 24 hours prior to sampling was correlated to the inlet concentrations of dissolved aluminum and zinc. The totally impervious catchment from the highway would produce flashy runoff, meaning that pollutants would be carried directly to the stream in a short time period. The high percent differences between inlet and outlet in the wet season, as well as the fact that no correlation exists between outlet concentrations and precipitation, indicate that the sedimentation taking place is functioning even in times of high flow. DGT results indicate that increases in rainfall brought more bioavailable metals to the pond.

5.2.4 Tempe Heights Pond, North Vancouver

The concentrations of dissolved metals and salts decreased from inlet to outlet, with the exception of iron and manganese, which both increase significantly from inlet to outlet during the wet season and iron in the dry season as well. This indicates that there may be a release of these metals from the sediments into the dissolved phase. The other constituents show evidence of being remediated through the pond, likely through uptake by cattails at the inlet and sedimentation and microbial degradation through the pond. Dissolved oxygen increases significantly from inlet to outlet, which may be due to the effects of the aerator in the middle of the pond.

Most metals and salts in the sediments decrease in concentration from inlet to outlet, up to 61% for copper. The pond is partially vegetated, which aids in remediation due to increased dissolved oxygen, uptake and impeding water flow to allow for more opportunities for microbial decomposition. However, the complex interactions of iron and manganese may be affected by the organic matter in the sediments, as there is evidence of an increase in concentrations in both the dissolved and total sediment fractions. Resuspension of sediments and sorbed metals by carp in the pond may also be affecting the effectiveness of the pond. The aerator may provide some additional dissolved oxygen, however levels were not significantly higher than other ponds, even when the aerator was on during measurements. The remediation of metals such as copper and zinc in the sediments suggest that the pond is functioning to some extent and is benefiting the receiving waters. The particle size analysis showed that sedimentation was proceeding as expected, which is likely partially responsible for the positive results seen in the pond.

The results from the DGT units show that bioavailable iron and zinc tend to decrease through the pond while manganese and aluminum tend to increase. The increase in bioavailable manganese and aluminum suggest that release from the sediments is possible, due to oxidation-reduction conditions.

The water and sediment quality results at the inlet were negatively correlated with precipitation, suggesting effects of dilution. The bioavailable fraction of zinc at the inlet and outlet was correlated with precipitation, which suggests that the runoff contained higher levels of zinc when rainfall increased, as the volume and velocity of the runoff would carry the metal from the roadways in the catchment.

5.2.5 Oakalla Biofiltration System, Burnaby

The water quality results at the Oakalla Biofiltration System showed significantly higher contaminant concentrations at the inlet than the outlet, by 0 to 81%. Sediments also showed lower metal concentrations at the outlet than the inlet by up to 79%, indicating that remediation has taken place. Bioavailable metals measured by the DGT units were reduced from the inlet to the outlet by between 20 and 81% in both seasons.

The consistent removal of contaminants is likely due to the wetland environment of the system. The organic soils provide humic substances that contain large numbers of hydroxyl and carboxylic groups that serve as cation binding sites. The vegetation also provides metal uptake and produces dissolved oxygen at the water sediment interface. Microbial decomposition in the pond is likely high due to the plant matter and high redox potential on the surface of the sediment layer. The biofiltration system also has an inflow of water all year round, which maintains the wetland environment and remediation continues even throughout the dry season. The meandering shape, vegetation and several settling pools likely aid with the sedimentation process, which was indicated by the consistent settling of heavy particles near the inlet and lighter ones at the outlet.

Precipitation of the previous 24, 48 and 72 hour periods was negatively correlated with several metals in the water at the inlet and outlet. The higher volumes of runoff produced by increased rainfall likely resulted in the volume of the pond increasing, thereby reducing concentrations. Metal concentrations in the sediments of the pond did not generally correlate with precipitation, indicating that even in times of high flow, the water sediment interactions may be similar. The results of the DGT units only correlated to the precipitation of the deployment period for zinc. Since the concentrations of bioavailable zinc at both the inlet and outlet were correlated to precipitation, it is reasonable to assume that higher levels of zinc are brought into the pond with the runoff.

5.3 Between Pond Comparisons

5.3.1 Water Quality

Significant differences in water quality existed between the ponds for several key parameters. The inlet water at the Oakalla Biofiltration System was significantly higher in manganese concentration at the inlet than all other ponds, with a median concentration of 0.131 mg/L. Possible reasons for these differences include higher concentrations of manganese in the soils of the Oakalla Biofiltration System as the wetland soils at the inlet may release manganese into the water column. Gasoline used in automobiles may also be contributing to the higher concentrations; however the daily traffic at this catchment is not the highest of all five ponds. It is most likely that the wetland nature of this system is contributing to the high dissolved manganese levels in the water and the bioavailable fraction measured by the DGT units. The levels of aluminum in the water at the Westview Interchange Detention Pond were significantly higher than those at Tempe Heights Pond and the Oakalla Biofiltration System, indicating the effects of high traffic volumes.

Significantly high specific conductivity measured in the ponds corresponded to those ponds where significantly higher dissolved magnesium concentrations were found. This is expected as the specific conductivity reflects the amount of ionic material dissolved in the water. The pH of the systems was generally within one unit of each other, and near neutral, which suggests minimal effects on the processes occurring in the ponds.

5.3.2 Sediment Quality and Texture

The Westview Interchange Detention Pond was significantly higher in zinc and chromium concentrations at the inlet and outlet, which suggests that the traffic from the highway introduced consistently more zinc and chromium which adsorbs to the sediment particles and limited remediation occurs through the pond. The significantly higher levels of manganese found at the Oakalla Biofiltration System are likely related to the wetland soils in the area, where more cation binding sites provide opportunities for sorption. Copper, lead and phosphorus concentrations in the sediments were significantly different between most ponds, suggesting that each system has different capacities for retaining these metals in the sediments, which will depend on the inlet concentration as well as the nature of the water and sediment dynamics of the particular pond. The organic matter in the sediments will affect the sorption of sediments, as it will provide more hydrophilic binding sites and retain higher amounts of metals.

There were no significant differences between the percentage of sand, silt and clay at the inlets or outlets of the five ponds. The small sample number of three does not provide enough information for detailed statistical tests, however the results did suggest that throughout the year, the heavier sand particles settle at the inlet while the lighter clay and silt particles move through the pond and tend to settle at the outlet. The inconsistent results at the 52 Ave/221A Street Detention Facility demonstrate that pond design, which determines how water moves through the pond, will affect how sedimentation takes place and could result in unpredictable distribution of the finer particles, which hold more contaminants than coarse particles.

5.3.3 DGT Results

The bioavailable portion of the metals in water showed significant differences for many of the ponds, especially manganese and zinc. This is likely due to the anthropogenic nature of zinc that would vary from the different traffic and transportation patterns of the catchments. The differences in bioavailable manganese at the inlet are most likely due to the different nature of the sediments that reflect some geological differences as well as the influx of manganese from automobile use. The significant differences occurred mostly in the wet season. The bioavailability of metals in water will be affected by the ability of the sediments to trap the metal ions, which in turn is affected by the organic matter content and redox potential. The significantly higher levels of zinc measured at the inlet and outlet of the Westview Interchange Pond likely reflect the high traffic volumes of the highway and limited remediation through the pond. The levels of manganese were significantly higher at the Oakalla Biofiltration System, which reflect the wetland nature of the pond and the high manganese concentrations typical of this system.

5.3.4 Overview of Contaminant Removal

The consistent removal of zinc from the water column is likely due to the adsorption of zinc to the clay sediments and subsequent settling to the bottom of the ponds. Aluminum, iron and manganese were retained poorly in most of the ponds, suggesting effects of mobility from sediments and chemical transformations at the water-sediment interface. The geological nature of these metals contributes to their complex transformations, especially in wetland soils. However, the bioavailable metal of these fractions is removed more consistently because the metals would become adsorbed to sediments or up taken by plants through the pond. Also, the DGT units measure the bioavailability over a three-week period, which gives a better integrated sample than individual water samples. The Oakalla Biofiltration System showed the most consistent results in contaminant removal from water, sediments and in the bioavailable fraction. The high removal rates seen from the water and bioavailable fraction, up to 81%, are likely due to a combination of adsorption onto the organic soils and increased microbial degradation due to dissolved oxygen produced by the extensive plants. The range of contaminant removals was wide between the five ponds, from increases in contaminants to 81% removal, reflecting the site-specific nature of water quality improvement capabilities.

5.3.5 Relationship Between Water, Sediment and DGT Results

The most consistent trend between the dissolved, total and bioavailable metals were shown in the zinc concentrations, as the Westview Interchange Detention Pond showed the highest values in all three states, with the sediment and DGT units showing significantly higher results than the other ponds. Also, the outlet water exceeded the Canadian Environmental Quality Guideline for Freshwater Aquatic Life 20% of the time and the outlet sediment 100% of the time, which poses a concern for the receiving waters. Manganese concentrations were also significantly higher in the water, sediment and DGT results at the Oakalla Biofiltration System than the other ponds. This suggests that the three states are related, as the high levels in the dissolved fraction may sorb to sediments and then experience resuspension into the bioavailable fraction and the cycle would continue. The complex nature of the chemical transformations that take place will dictate the form in which the metals are prevalent. However, even with the limited amount of information on the systems, the bioavailable fraction, which is of most concern to aquatic life, tended to be highest in ponds that also exhibited significantly higher levels in the sediment and dissolved in the water.

5.3.6 Effect of Precipitation

The effects of precipitation demonstrated similar trends between the ponds. One trend of particular interest is that of the significantly negative correlation between precipitation of the preceding days and weeks prior to sampling and the concentration of metals at the inlet and often the outlet water. This suggests that more runoff correlates to lower contaminant concentrations, which has been found in similar studies, such as by Hares et al (1999). This, however, does not account for overall loadings since more runoff will lower concentrations but not necessarily overall loadings. Since no flow data was available for the ponds, loadings could not be calculated. However, in order to investigate the possibility of dilution playing a role in the negative correlation between precipitation and inlet water concentration, the data was examined in terms of the probable volume of the pond at the time of sampling. Tempe Heights Pond was used for this purpose as the levels are easily estimated since it did not overflow, even during the large rainstorms of October. It was estimated during field visits during the seasons that the pond was as low as one quarter full in the dry season compared to full in the wet season. An estimate of the loading was calculated by multiplying the concentration of the grab sample by the estimated volume of the pond. This resulted in the actual mass of the pollutant, which could then be compared across seasons. Periods of low rainfall that showed high concentrations were compared to periods of high rainfall that showed low concentrations. A summary of the results is presented in Table 5.1.

Table 5.1 Estimated pollutant loads of manganese at inlet of Tempe Heights Pond. Full volume is estimated at 668800 litres and one-quarter volume at 167200 litres. Wet season results are shaded.

		Estimated Manganese Loadings	
Date	**Concentration (mg/L)**	**At full volume (mg)**	**At 1/4 volume (mg)**
07/09/2003	0.003		501.6
09/07/2003	0.044		**7356.8**
10/23/03	0.019	**12707.2**	
11/14/03	n/a	n/a	
12/09/2003	0.009	6019.2	
01/14/04	0.018	12038.4	
02/04/2004	0.005	3344	
03/02/2004	0.017	11369.6	
03/23/04	0.009	6019.2	
04/20/04	0.007		1170.4
05/13/04	0.049		8192.8
06/01/2004	0.016		2675.2

It can be seen from the values presented in Table 5.1 that high concentrations in the dry season do not necessarily indicate higher amounts of manganese that are present in the stormwater. For example, the concentration of the inlet water was measured as 0.044 mg/L on September 7, 2003. The month of August and the first seven days of September had a depth of 21 mm of rainfall on the catchment. The water sample taken on October 23rd, after a depth of 342 mm of rain had fallen on the catchment, was measured as having a concentration of manganese at 0.019 mg/L. The sample taken on September 7 was from the pond at low volume while in October it was at high volume. When adjusted for this, the actual mass of manganese is 7357 mg in September and 12707 mg in October. Therefore, it is reasonable to assume that dilution plays a role in the negative correlation between precipitation and inlet water contaminant concentrations. Also, the precipitation of the previous 48 and 72 hours was most often negatively correlated to dissolved metal concentrations, suggesting the effects are not seen instantaneously in the ponds.

The sediment concentrations that showed a negative correlation might be affected by high flows that affect resuspension as velocities on the bottom of the pond may increase. The two ponds where precipitation was not correlated to sediment concentrations were the two most vegetated ponds, Griffin Park Biofiltration Pond and Oakalla Biofiltration System. This may indicate that vegetation impedes the flow of water, even during times of increased runoff, which limits the effects on the movement of sediment through the pond and metal adsorption.

The effects of precipitation on the bioavailable fraction measured by the DGT units suggest that over the deployment period, a higher amount of bioavailable metals enter the pond. This is evident from the results of the zinc concentrations measured by the DGT units. Since this is an integrative sampling technique over the course of three weeks, the effects of dilution will not play a major role. As the runoff enters the pond, a sample of the bioavailable metals are adsorbed on the resin, which allows for an estimate of the instantaneous concentration to be made, however the volume of the pond will not affect the values in the same way as the water samples. Therefore, the DGT units provide a clearer indication that as precipitation increases, the higher runoff volumes transport higher levels of contaminants to the inlets of the ponds.

5.4 Comparison to Literature Values

A review of the data reported in Table 5.2 shows that the ponds in this study showed much higher concentrations than others in the literature. The Ann McCrary Pond, built in 1990, is a wet detention pond draining a 3.78 km^2 residential subdivision in Wilmington, North Carolina. The Silver Stream wet detention pond, built in 1991, drains a 0.287 km^2 residential and mixed-use catchment, also in Wilmington. The studies of these ponds made no attempt to sample at a particular point during storms, and sediments were collected from the top 5 cm at the inlet and outlet. The differences in inflow and outflow concentrations reflect the variability inherent in stormwater and the effect of land use activities, such as traffic and percent impervious cover, on the quality of the sediments collected in the ponds. The high values of copper and zinc shown in the Westview Interchange Detention Pond reflect the high traffic volume from the highway catchment. It is interesting to note that the Ann McCrary Pond also showed higher concentrations of iron at the outlet than the inlet, as was seen in several of the ponds in this study.

Table 5.2 Metal concentrations in inlet and outlet sediments in stormwater ponds. Results given as mean values in mg/kg.

Pond	Cu		Fe		Pb		Zn	
	In	Out	In	Out	In	Out	In	Out
52Ave/221 A Street	73.8	44.0	21217.8	18588.0	38.1	19.8	333.0	202.5
Griffin Park	270.0	97.1	21518.6	24131.5	197.4	125.9	676.8	251.2
Westview	499.8	465.5	16978.6	19115.3	229.5	230.1	1145.9	978.2
Tempe Heights	335.0	151.6	14820.0	18874.5	200.0	82.6	628.5	321.1
Oakalla	90.6	78.9	22842.1	20034.6	55.3	35.2	439.0	276.0
Ann McCrary[a]	0.45	0.78	180.3	773.0	1.46	1.45	3.71	3.81
Silver Stream[a]	12.58	0.54	211.6	49.2	8.92	1.57	93.4	1.69

[a] Malllin et al (2002).

Table 5.3 shows the results of several studies of highway runoff entering stormwater ponds. It can be seen that the Westview Interchange Detention Pond has lower manganese and zinc concentrations than other highway ponds. This may be related to the higher traffic density on the M25 in London (Leatherhead pond), or the differences in timing of water sampling, as the two comparative studies were looking at the initial stages of a storm, when concentrations were likely higher.

Table 5.3 Metal concentrations in stormwater at inlets of highway stormwater ponds. Results given as mean values in mg/L.

Pond	Average traffic per day	Mn	Zn
Westview	72 000	0.023	0.043
Leatherhead[a]	140 000	0.329	0.208
Interstate 4[b]	55 000	n/a	0.498

[a] Hares et al (1999)
[b] Yousef et al (1984)

The overall contaminant removal from the stormwater fell within the ranges of other ponds in the literature. This was seen primarily with zinc, as the typical range cited by Urbonas (2000) is –29% to +82% difference between inlet and outlet of wet ponds, dry ponds and wetland basins. The range of zinc removal from the water column in this study for all ponds was 0 to 41%. While factors such as inlet concentration and nature of the pond are important to consider, the general results indicate that these ponds are typical in terms of zinc removal from the water column. Lower detection limits in the analysis of water samples would have aided in further comparisons of metals important to aquatic life.

5.5 Correlation Between Catchment Characteristics and Inlet Water and Sediment Quality

The size of the catchment area can be important in the pollutant loading of the pond, as there is more opportunity for land use activities, such as household product usage and contaminants from the buildings to affect the quality of the stormwater runoff. The significant correlation found between the catchment area and the concentration of chromium in the sediment could be indicative of the urban land use activities. The negative correlation between phosphorus concentrations indicate that larger catchments may be applying less fertilizer to the residential lawns, which could be accurate as the small catchments of Tempe Heights and Griffin Park tend to have large suburban lawns that may result in higher concentrations of phosphorus in the sediments. The larger catchments often have some commercial uses that may not result in high phosphorus concentrations since the main source is likely lawn fertilizers.

The average daily traffic volumes of the catchment were interesting in that they correlated positively to zinc and copper concentrations in the inlet water, sediment and DGT results. This suggests that automobile usage influences the zinc and copper concentrations in the runoff, especially during the wet season when the volume and velocity of the runoff would carry high amounts of these metals to the ponds. The same correlation often does not exist at the outlet due to remediation of the sediments through the ponds. The negative correlation between traffic and manganese concentrations in the sediment and DGT unit is surprising, as manganese is generally associated with a gasoline additive. However, manganese is also prevalent from geological sources, which would influence these results. The positive correlation between the concentration of lead in the inlet sediments and traffic suggests that there may be lead still in some of the sediments from leaded gasoline, or possibly from lead based paints that have been used in urban areas.

The percent imperviousness resulted in similar correlations as with the average daily traffic. This is most likely due to the fact that the majority of impervious surfaces in residential suburbs are roads, which would also typically represent traffic volumes. For instance, the largest traffic volume is found at the Westview Interchange Detention Pond and the catchment is 100% impervious. By contrast, the low traffic volumes at Tempe Heights also correspond to low percent imperviousness. Although this relationship was evident in this study, it may not be typical of all catchments.

5.6 Correlation Between Pond Characteristics and Percent Difference of Water and Sediment Quality

Surface area, percent vegetation and volume, were all found to have some influence on the percent differences seen in the metals. The surface area of the pond is expected to increase the contaminant removal capacity of the pond since there is more area for remediation. The volume of the pond is also assumed to be important, as an increase in the amount of water will allow for more movement of water, which will aid with the sedimentation process. In addition, more opportunities for remediation are expected, as the capacity for storage will be longer than in a smaller volume where the water will presumably leave the pond faster. Similar results for surface area and volume indicate that the two pond characteristics influence the contaminant removal processes in a comparable manner. Positive correlations were only found consistently with the percent difference of manganese concentrations in the water, sediment and DGT units, which suggests that more remediation took place for manganese in the larger ponds. The negative correlation found between sediment concentrations of some metals suggests that high volumes move sediments quickly through the ponds and result in their deposition at the outlet. Therefore, the remediation of sediments does not occur solely based on the area or volume of the pond. For example, increases in sediment concentrations are often found in even the largest ponds, such the 52Ave/221A Detention Facility in Langley.

The percent vegetation correlated to the reduction in bioavailable zinc and manganese, which suggests that the uptake provided by the plant and additional dissolved oxygen produced during photosynthesis has a positive effect on the removal of bioavailable metals. As well, the plant growth is assumed to reduce the velocity of the water through the ponds, which will allow more opportunities for sedimentation and microbial decomposition, which is likely responsible for the positive correlation between percent vegetation and the improvement of sediment quality through the pond.

5.7 Relationship Between Zinc Concentrations and Catchment Characteristics

The strong result from the simple regression line fit to the zinc concentrations and both percent imperviousness and traffic volumes did provide some preliminary evidence of the two catchment characteristics being predictors of zinc accumulation in the sediments of the ponds as well as the bioavailable fraction in the sediments. However, there is a large gap between the traffic volumes as the Westview Interchange Pond collects runoff from a major highway. This results in the regression line being joined between high and low concentrations, with little in between to support the connection. The high outlet concentrations of the Westview pond probably influence the correlation with outlet sediments and traffic. Even though this pond did show significantly more zinc concentrations than the others, which is evident when they are plotted together, the results are not conclusive as areas of intermediary traffic volumes were not part of this study. The results do however provide a reasonable amount of information to support the assumption that the traffic and impervious areas influence the levels of zinc in runoff and collected in stormwater ponds, as zinc has been linked to automobile use in urban catchments.

5.8 Measurement of Bioavailable Metals with Diffusive Gradient in Thin Films (DGT)

The DGT units provided an integrated sampling technique that captured the effects of contaminant spikes due to the first flush phenomenon as well as lower concentrations over the deployment period. The devices were less expensive than automated samplers, which made the study of five ponds simultaneously possible. By having the DGT units deployed for concurrent periods of three weeks, the entire wet season could be monitored instead of the short periods that are usually sampled with automatic samplers. The easy installation due to their small size is an advantage over other sampling methods, as limited disturbance of the ponds was necessary. In addition, the DGT units can be deployed in discrete places in order to minimize their visibility.

The calibration of the DGT units showed that measurement error generally ranges from 15 – 25%. This is not considered sufficient as an analytical measurement for comparison against standards. However, the reliability of the units shown through duplicate sets throughout the sampling period indicates that the results are consistent enough to provide a tool for comparison of different deployment areas within ponds. The measurement of a range of trace metals throughout the deployment period provides information on the overall toxicity to aquatic organisms, rather than single water samples, which take only a snapshot view of the water quality in the ponds. Comparisons across different ponds is possible, however the differences in flow may produce wider error ranges in some sites than others. The wet season results are therefore more reliable, as flow was consistent in most ponds. However, this is a limitation of using DGT units in different types of ponds and varying conditions.

Stormwater ponds provided a unique opportunity to assess the capabilities of DGT units. Practical problems, such as biofouling and decreased accuracy in low flow conditions are challenges that need to be overcome when monitoring stormwater. The rapidly changing water levels due to storm events can lead to dehydration of the resin as well as the entire unit being dislodged when a large pulse of water enters the inlet. These challenges required knowledge of the patterns of water flow in each pond, which takes time before reliable results can be counted on. Overall, the DGT units were useful, as the varying conditions in the ponds could be measured consistently without "chasing" storms, which is unreliable and resource intensive. This was integral to the relevance of the study and increased the knowledge of the effectiveness of stormwater ponds in protecting receiving waters.

Chapter VI Conclusions

6.1 Water and Sediment Quality

Urban stormwater was shown to contain high levels of metals that exceeded Canadian Environmental Quality Guidelines for water and sediments in up to 60% of water samples and 100% of sediment samples. Iron consistently exceeded guidelines in the water and copper, lead and zinc exceeded the guidelines in the sediments. The manganese concentrations in water, sediment and bioavailability were significantly higher at the Oakalla Biofiltration System and sediment concentrations of chromium and zinc were significantly higher at Westview Interchange Pond compared to other ponds. The bioavailable fraction of zinc was also significantly higher at Westview Interchange Pond.

The type of land use, particularly the traffic intensity and percent impervious cover, all seem to contribute to the differences in metal contamination in the incoming water to the ponds. Ranking the inlet metal levels between ponds showed that the highest contamination originated in the Westview catchment area, particularly chromium and zinc, which originates entirely from highway runoff. Griffin Park and Tempe Heights Pond, whose catchments have the second and third highest traffic volumes, exceeded the probable effects level for inlet copper and zinc concentrations. The correlation of traffic volumes to zinc concentrations in the inlet water, sediment and DGT results as well as copper in the sediments supports the hypothesis that auto use would introduce more of these metals to stormwater. Griffin Park Biofiltration Pond and Tempe Heights Pond, which had the smallest catchment areas, showed significantly higher levels of phosphorus in inlet sediments than other ponds, suggesting the residential lawns and parks in these areas may be contributing more fertilizer than the other catchments, which have some commercial uses in surrounding areas. Inlet concentrations of manganese were significantly higher at Oakalla Biofiltration System in water, sediment and DGT results, which was attributed to the wetland nature of the soils.

The quality of water and sediments at the outlets of the ponds may adversely affect habitat and biota in receiving waters should the sediment be released from the outlet or the metals undergo changes to the dissolved state. Concentrations of copper and zinc exceeded the interim sediment guideline in over 50% of the samples at all ponds. The worst overall water quality was seen at the Westview Interchange Detention Pond, where the bioavailable fraction of zinc at the outlet was significantly higher than all other ponds. An additional threat may be posed to groundwater underlying the Westview Interchange Pond as the pond often acts as an infiltration basin.

The effects of precipitation were generally found to be negatively correlated to the inlet dissolved concentrations of most parameters. This is likely due to effects of dilution, as the volume of the ponds increases during periods of rainfall, even though the mass of the contaminants in the ponds is likely higher when runoff increases. However, the concentration of bioavailable zinc was positively correlated to the precipitation that had fallen during the deployment period, indicating that the increased runoff did carry more zinc from the roads than in drier periods.

Evidence was provided in this study suggests that the average daily volume of traffic and percent impervious cover of the catchment is a predictor of the zinc concentrations trapped in the sediments and in the bioavailable fraction in the water. However, since the study sites had a wide gap in daily traffic volumes, from 960 to 72 000 cars, more intermediary evidence is required to support this claim.

6.2 Applicability of Diffusive Gradient in Thin Films (DGT) in Stormwater Monitoring

The use of the DGT units showed sufficient results in the ponds and is a useful tool for comparing concentrations of bioavailable metals in different areas of the ponds. By measuring the accumulation of many metals over the same time period, a better understanding of the overall condition of the stormwater is obtained. The three-week deployment periods allowed for continuous monitoring of the metals in the ponds, which reflected the spikes of the 'first flush' often missed by the individual water samples. However, the error rates shown in the laboratory calibration of 15 – 25% indicate that the accuracy of this technique is not suitable for comparison to quality standards. However, the DGT units provide an inexpensive and practical tool to assess the remediation of bioavailable metals in the ponds.

6.3 Contaminant Removal

The results of this study show that some ponds removed significant amounts of heavy metals from the water column and were effective at remediating metals and phosphorus in the sediments. However, there were some increases in metal concentrations in the water and sediment from inlet to outlet, especially for aluminum, iron and manganese. As well, up to 100% of sediment samples at the outlet exceeded the Canadian Environmental Quality Guideline for Freshwater Aquatic Life for zinc. This suggests that these systems can not necessarily be relied upon to achieve all treatment goals.

The effectiveness of the ponds could be more reliable by implementing a treatment train approach, where several BMPs are used to improve water quality before the stormwater is released to the receiving waters. By reducing the concentrations of metals in the stormwater through each BMP, each system would receive a lower inlet concentration. This would help to reduce the metals being collected in the ponds and pose less of a risk to receiving waters.

The contaminant removal results for each pond did reveal some successful examples of water quality improvement. All ponds were effective in reducing zinc in sediment, water and bioavailability, by up to 72%. Calcium, magnesium, potassium and sodium, which are important nutrients, were also reduced significantly in all ponds. Most ponds were not effective in retaining aluminum, iron or manganese in the water and sediments. However, the bioavailable form of these metals is reduced particularly during the wet period by an average of 29% (range -155% to 81%). The range of contaminant removal in the ponds varied between the ponds, from increases in contaminants by over 400% in the water, to reductions of up to 81% in the water, 79% in the sediments and 82% in bioavailability.

The design of the pond was shown to affect the overall contaminant removal in the ponds. This is useful for predicting factors in the configurations of stormwater ponds that will lead to effective water quality improvement, especially if integrated in a treatment train approach. The most consistent results were observed at the Oakalla Biofiltration System with reductions of up to 81% in water and bioavailability and 79% in sediments. The cation binding capabilities of the organic soils, the dissolved oxygen produced by the 70% vegetative cover and the consistent base flow throughout the year were attributed to the effective contaminant removal. The most ineffective removal of metals from the sediments was observed at the Westview Interchange Pond, where between 36% increase and 26% reduction occurred from inlet to outlet. This demonstrates the effects of the pond having no emergent or submergent vegetation to impede the movement of sediments through the pond and provide dissolved oxygen for microbial decomposition.

In summary, the most effective designs incorporated a combination of vegetation in the pond, a sufficient flow of water throughout at least the wet season, and a shape that produced a consistent sedimentation pattern, such as a meandering channel with depositional areas. These factors help to impede the flow of finer clay particles, allowing increased time for adsorption to sediments, plant uptake and microbial degradation. There was no evidence that larger ponds, in either surface area or volume, were more effective in overall contaminant removal than smaller ponds. Rather, the specific configuration, including the vegetation, base flow and meandering shape, will all have a positive influence on the water quality improvement capabilities of ponds. Used in conjunction with other BMPs, stormwater ponds could be expected to improve the quality urban stormwater runoff.

Chapter VII Recommendations

7.1 Areas of Further Research

The monitoring program did provide sufficient data from which to garner information about the effectiveness of ponds in contaminant removal. However, a more detailed assessment of performance would be obtained by monitoring the water quality throughout storm events to obtain a more accurate depiction of how contaminants enter and travel through the pond during peak runoff times. Since most contaminants are presumed to be in the 'first flush' period, the storm sampling would allow conclusions to be made regarding the timing of pollutant removal. A flow monitor should also be part of this system, as loadings for the inlet and outlet could be calculated. This would eliminate the problems of dilution that were accounted for when concentrations of grab samples were compared across differing periods of rainfall. The flow data would also be interesting to track the fluctuations in water level in the ponds throughout the wet and dry seasons to obtain an idea of infiltration rates and response to rainfall. Water sampling analysis would be improved with the use of an ICP-MS, which would have lower detection limits and therefore capture some metals that are likely present, but were undetected on the ICP-AES.

The sediment data proved to be useful in showing trends of contaminant accumulation and potential toxicity. However, sampling methods could be improved by installing sediment traps to ensure that only the newest sediments were collected. This would more accurately represent the quality of the sediments that were transported with the runoff. The accumulated sediments in the pond would still be interesting to analyze to identify trends in adsorption and how sediments settle through the pond.

The use of DGT units in stormwater ponds was successful in obtaining data for bioavailable metals that are present in stormwater runoff. The results were useful in comparing values between inlet and outlet and across ponds. However, they do not indicate actual loadings or concentrations throughout storms. This would involve more frequent sampling, which would be interesting but costly in time and resources. It would be useful to measure bioavailability with other measures at times when the antecedent dry period was known in order to correlate precipitation data to bioavailability. The use of duplicates and methods of deployment should continue to be investigated in order to increase the reliability of DGT use in the field.

Samples of plant material could be taken to estimate the uptake of contaminants by plant matter versus adsorption with sediments. Microbial populations could also be measured to obtain information on the degradation that may be taking place to these organisms.

There are several parameters of water quality that would be interesting to monitor. Hydrocarbons are expected to be prevalent in stormwater and pose a threat to aquatic ecosystems. As well, viruses and pathogens from urban environments may be undergoing some remediation in the ponds, which would be interesting to investigate. In addition, knowledge of the organic matter present in the ponds would provide some insight into possible adsorption processes taking place. The redox potential of the sediments could be measured and used to explain some of the remediation trends in the ponds.

Investigating fewer ponds more intensely could refine the study. The Westview Interchange Detention Pond and 52Ave/221A Street Detention Facility provided some difficulties for comparison due to differences in design and catchment characteristics. The Westview Pond obtained its runoff from a major highway, which made the comparison with the suburban ponds problematic, as there was only one highway pond to draw conclusions from. Also, the pond often acts as an infiltration pond and the water does not continuously exit the pond as in the others. This made the outlet water difficult to sample, as it was sitting in the pond and not flowing out the outlet. The 52Ave/221A Street Detention Facility was difficult to compare to the other ponds as it had three inlets that brought runoff instead of one as in the other ponds. This made it difficult to conclude the contaminant removal taking place in the pond, since runoff was being added to the system close to the outlet. The other three ponds provided more consistent results and fewer variables that led to stronger comparisons between them. Further studies may wish to focus on these ponds and obtain more information on the contaminant removal taking place.

7.2 Management Recommendations

Stormwater management in the Lower Fraser Valley will become increasingly important due to urban expansion onto the surrounding hillslopes. Techniques such as detaining and treating stormwater before it is released to receiving waters is an important feature in the overall strategy to help mitigate the problem. However, they do not address the problem in a sufficient manner to be relied upon for compensation of replacing natural land with impervious surfaces. As can be seen from the results of this study, removals of bioavailable metals in the water have a large range, and even include significant *increases* occurring through the pond. The most effective system was shown to incorporate extensive vegetation, wetland type soils, continuous baseflow and several ponding areas. This did provide reliable contaminant removal, however some concentrations in the sediments still exceeded Canadian Environmental Quality Guidelines for Freshwater Aquatic Life, suggesting that this pond alone will not provide adequate stormwater quality improvement. Those ponds with more variable results indicate that additional management solutions need to be implemented.

The first flush of the storm will contain the majority of contaminants and therefore needs to be handled by a larger portion of the watershed than a stormwater pond. A treatment train type system allows for more opportunities for remediation than a single system. This involves directing runoff to pervious areas where possible instead of piping the entire volume out of the area. Efforts such as rainwater harvesting from roof runoff for lawn watering purposes are simple methods will reduce the burden on the stormwater system. Grassed swales and buffer zones should be incorporated into the design of developments in order to reduce the traditional curb and gutter methods of channelling runoff. When runoff is piped from impervious areas, increased contact with vegetation and organic, flooded soils will aid in remediation. Instead of one settling pool, systems can be designed which incorporate grassed channels linking several vegetated ponds. Designing the biofiltration systems to be well matched to the natural landscape and drainage patterns will result in the most effective and lasting efforts. Monitoring programs as well as identifying and resolving any maintenance problems can enhance the systems.

While watershed scale biofiltration systems offer a promising method to mitigate some of the environmental impacts of urbanization, the patterns of development and use of harmful contaminants will become increasingly difficult to mitigate without some alterations. Hillslope developments in the Lower Fraser Valley pose unique stormwater issues, as slope stability and increased velocities of runoff pose a danger to lower level infrastructure. Water quality will become degraded as the runoff carries more contaminants from increased populations and urban uses. Infilling and higher housing densities on lower elevations should be encouraged in order to reduce urban encroachment on hillslopes. However, with any new developments, a step-wise, watershed approach should be taken to reduce urban runoff and provide opportunities for water quality improvement at several stages from source to receiving waters. Reduction of pollutant deposition, through source control and public education on stormwater issues, will help to reduce the pollutant loads entering ponds. Stormwater ponds will be most effective when used in conjunction with low impact design, land use planning and public education to address this larger watershed management challenge.

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Appendix I –
Pond Photos

52Ave/221A Street Detention Facility, Langley

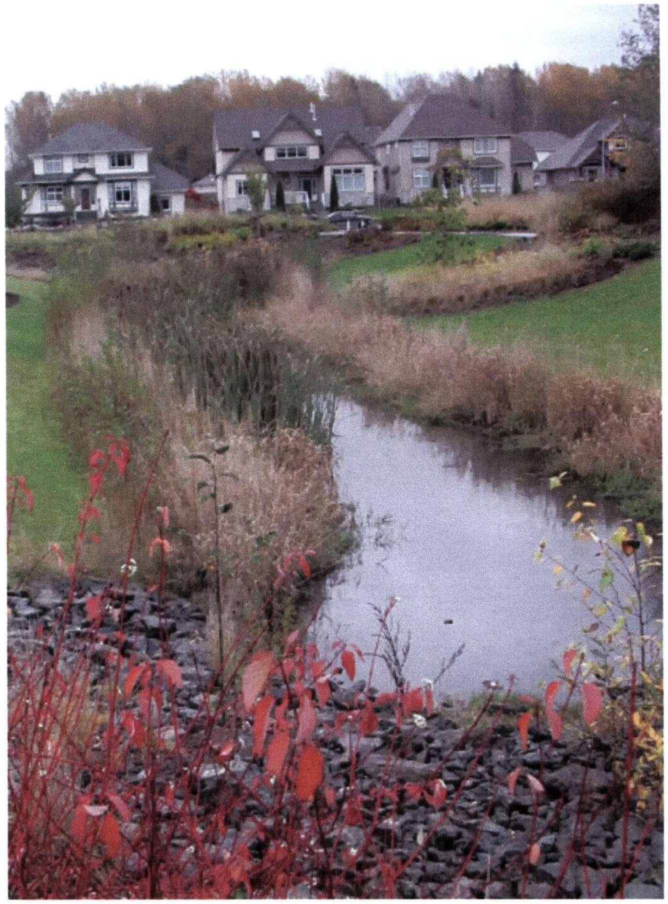


Figure 1-A View of first part of wetland looking towards main inlet from bridge

Figure 1-B View of main outlet (left) and inlet from 221A Street ditch (right)

Griffin Park Biofiltration Pond, North Vancouver

Figure 1-C First bend in pond between inlet and outlet

Figure 1-D Measuring specific conductivity at outlet of pond where water exits and joins Mosquito Creek Baseflow and Salmon Habitat Area downstream.

Westview Interchange Detention Pond, North Vancouver

Figure 1-E Pond looking from the outlet towards the inlet, with Upper Levels Highway in background

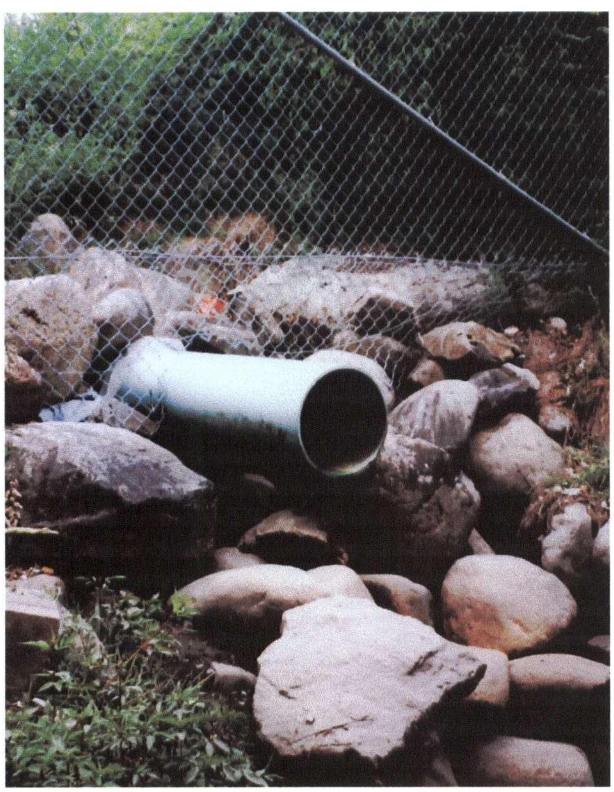


Figure 1-F Inlet pipe during dry season

Tempe Heights Pond, North Vancouver

Figure 1-G Pond looking towards inlet

Figure 1-H Pond looking towards outlet. Grate with happy face is overflow outlet; main outlet is submerged under overflow.

Oakalla Biofiltration System, Burnaby

Figure 1-I Looking towards marsh from inlet in the dry season. Walking bridge is visible over marsh.

Figure 1-J View of ponding area before outlet in wet season

Appendix II –
Pond Catchment Areas

52Ave/221A Street Detention Facility, Langley

Source: Township of Langley (2003)

Catchment boundary

Pond

Griffin Park Biofiltration Pond, North Vancouver

Source: District of North Vancouver (2003)

Catchment boundary

Pond

Westview Interchange Detention Pond, North Vancouver

Source: City of North Vancouver (2003)

Catchment boundary

Pond

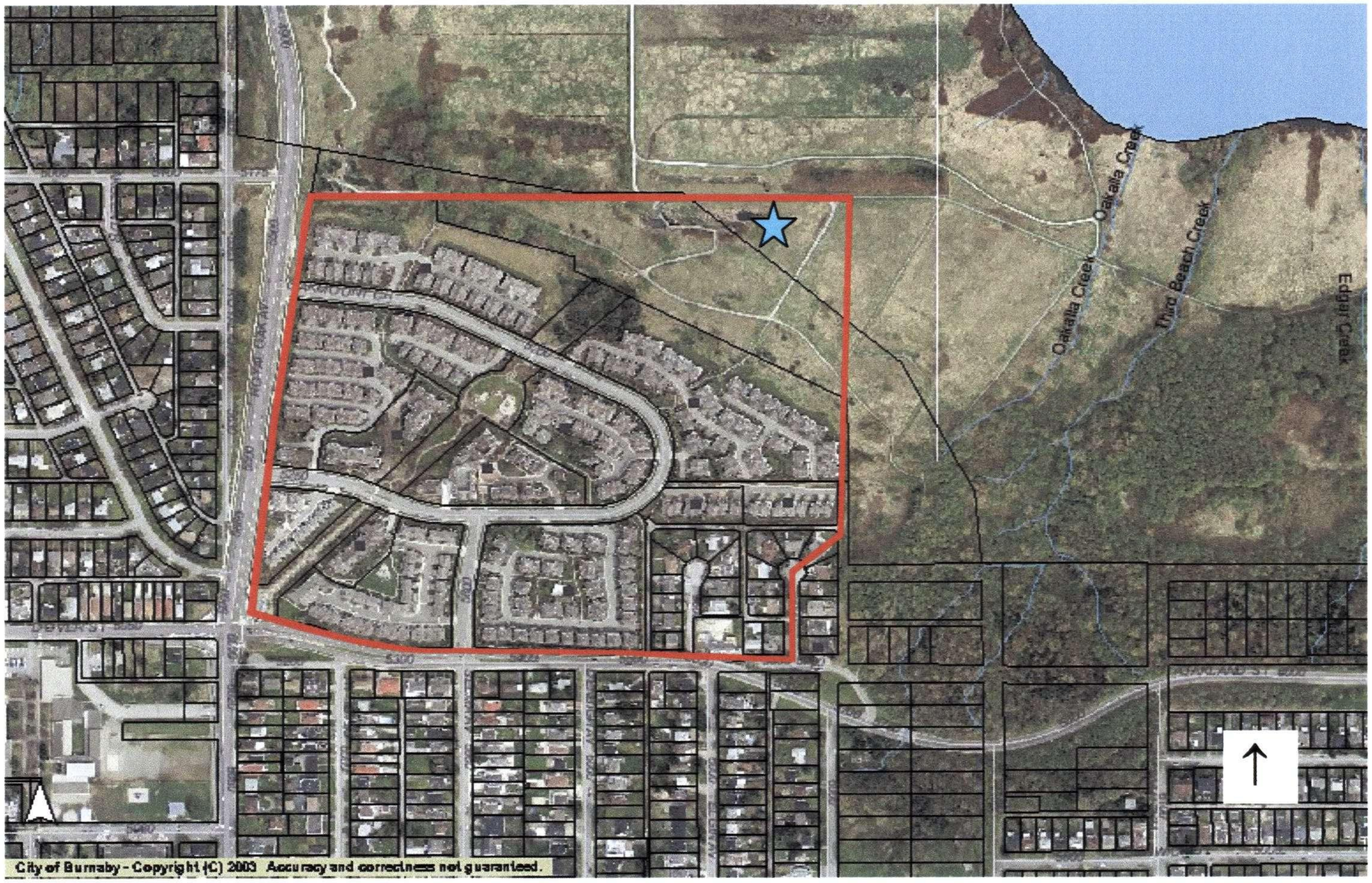
Tempe Heights Pond, North Vancouver

Source: City of North Vancouver (2003)

Catchment boundary

Pond

Oakalla Biofiltration System, Burnaby



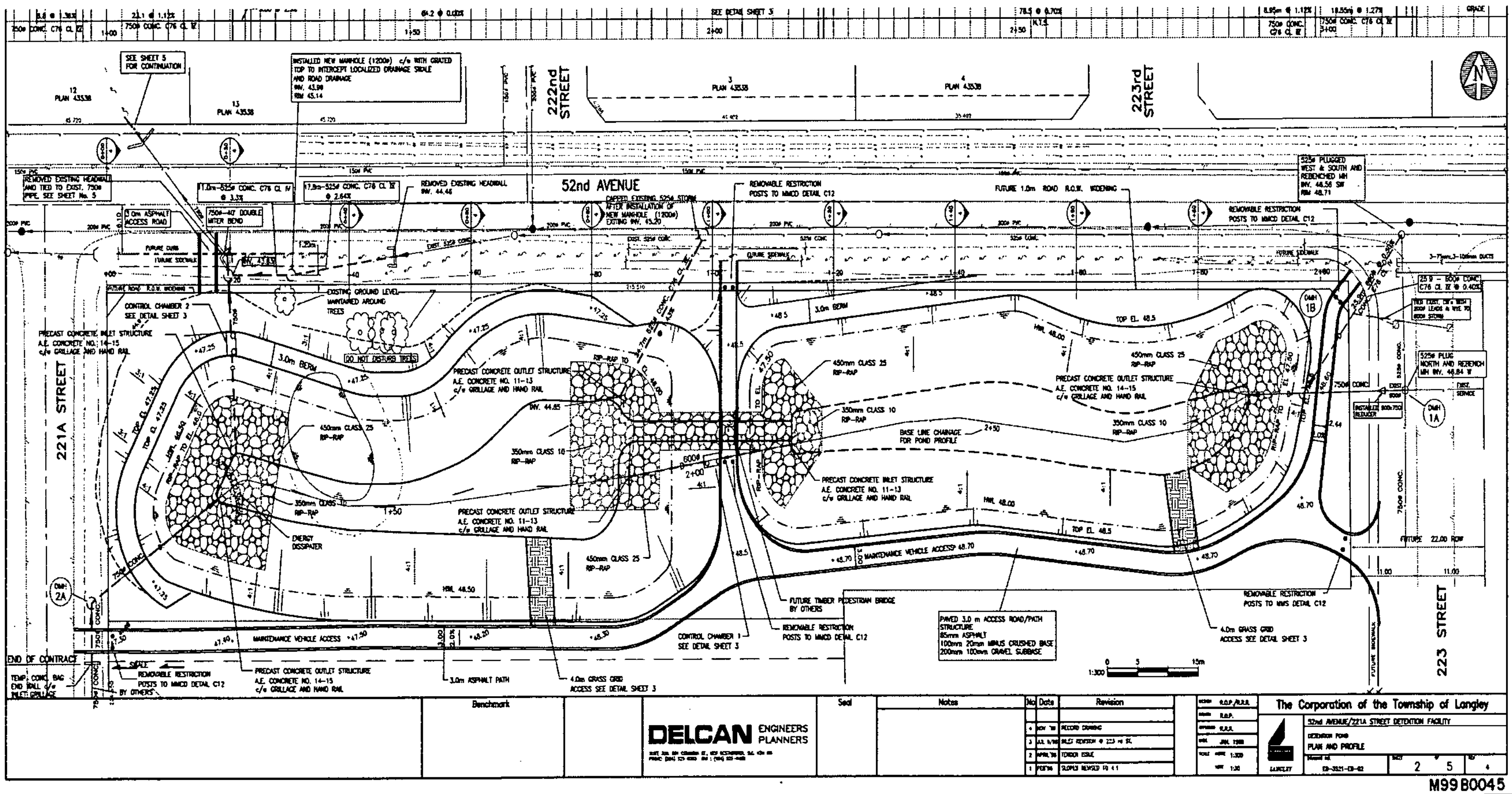
Source: City of Burnaby (2003)

Catchment boundary

Pond

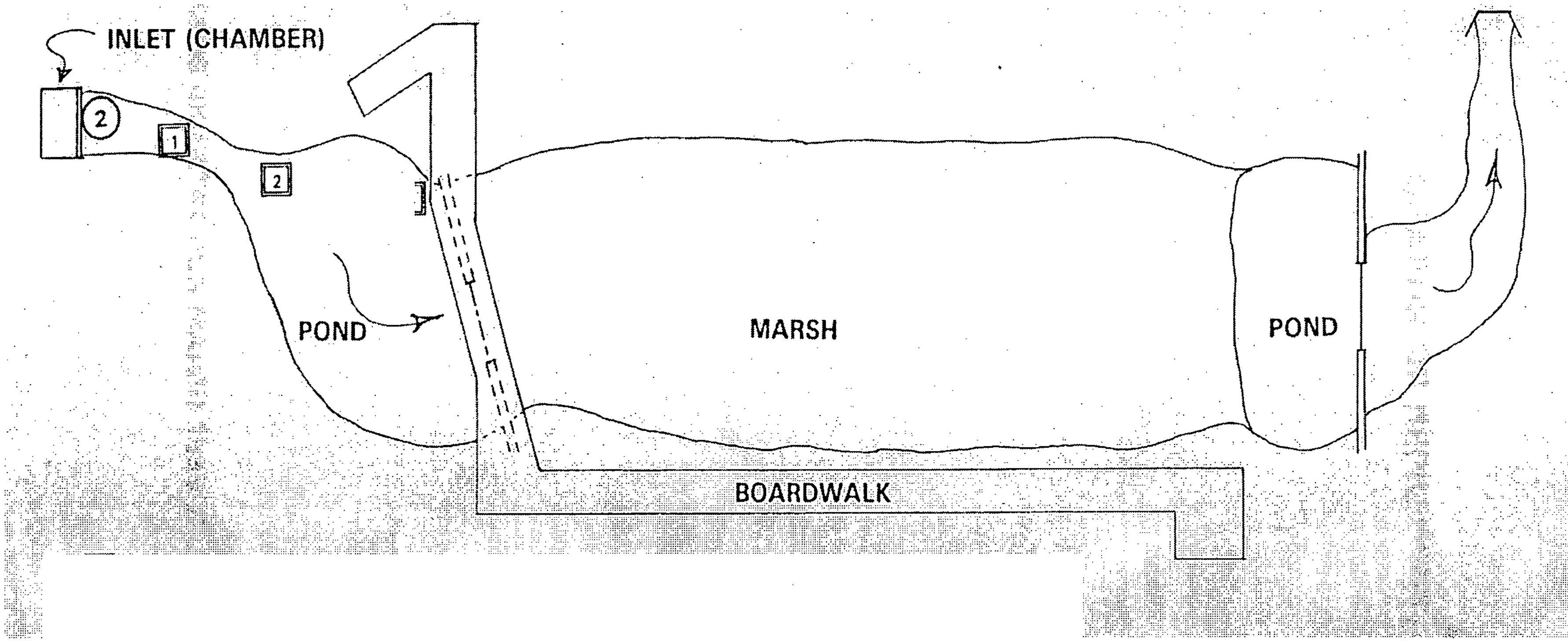
Appendix III – Pond Drawings

52 Ave/221A Streeet Detention Facility, Langley



Source: Delcan (1997)

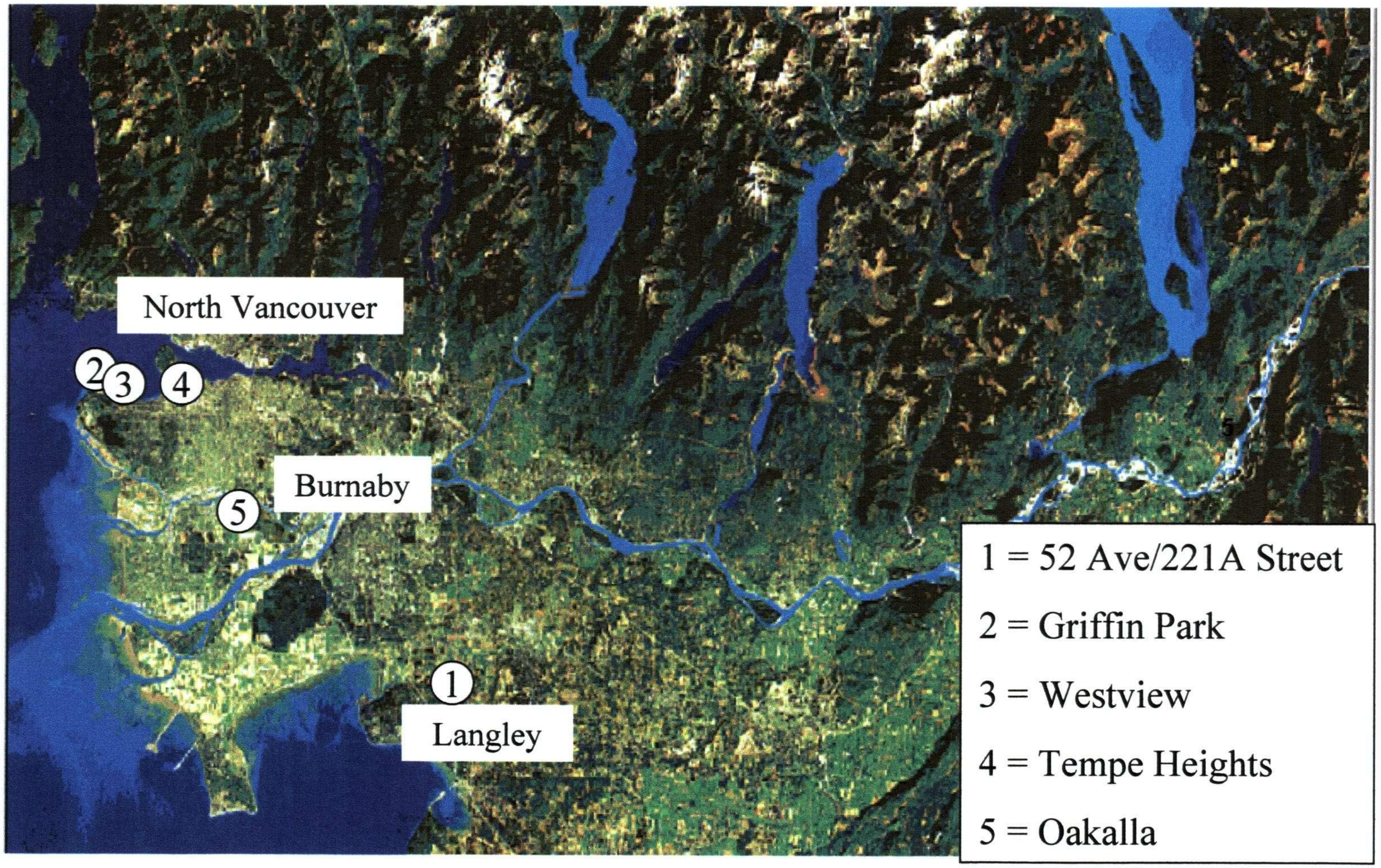
Oakalla Biofiltration System, Burnaby



Source: Craig et al. (2003)

Appendix IV –
Map of Sites

Map of Sites


North Vancouver
Burnaby
Langley
1
2
3
4
5
1 = 52 Ave/221A Street
2 = Griffin Park
3 = Westview
4 = Tempe Heights
5 = Oakalla

Appendix V –
Equations for the Use of Diffusive Gradients in Thin Films (DGT)

Calculating the DGT Measured Concentrations
(DGT Research Ltd., 2002)

1) The mass of metal in the resin gel (M) can be obtained using:

   $$M = Ce\,(V_{HNO3} + Vgel)/fe$$

   where Ce is the concentration of metals in the 1M HNO_3 elution solution (in µg/l), V_{HNO3} is the volume of HNO_3 added to the resin gel, Vgel is the volume of the resin gel, typically 0.16 ml, and *fe* is the elution factor for each metal, typically 0.8.

2) The concentration of metal measured by DGT (C_{DGT}) can be calculated using:

   $$C_{DGT} = M\Delta g/(DtA)$$

   where Δg is the thickness of the diffusive gel (0.8mm) plus the thickness of the filter membrane (0.13 mm), D is the diffusion coefficient of metal in the gel (available in published reports), t is deployment time and A is the exposure area (A=3.14 cm^2).

Appendix VI – Detection Limits

Detection Limits of the Varian Simultaneous ICP-AES

Table 6-A Detection Limits for Water Samples and DGT Units

Parameter	Detection Limit (mg/L)
Al	0.05
Ca	0.1
Cd	0.025
Cr	0.025
Cu	0.05
Fe	0.05
K	0.5
Mg	0.01
Mn	0.005
Na	0.25
Ni	0.1
P	0.2
Pb	0.2
Si	0.15
Zn	0.01

Table 6-B Detection Limits for Sediment Samples

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

Appendix VII – Precipitation Data

Table 7-A Precipitation Data for 52Ave/221A Street Detention Facility, Langley

Note: Data given in millimetres

	2003							2004					
Day	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**May**	**June**
1	.	4.6	.	.	.	.	0.2	.	.	.	.	.	0.2
2	.	.	.	.	.	.	7.8	.	0.6	.	.	.	.
3	.	.	.	.	.	.	.	0.4	3.2	16.8	.	1.4	.
4	.	.	.	.	.	.	5.2	.	6.2	1.4	.	5.4	.
5	.	0.8	.	.	.	.	6.8	.	.	8.2	.	.	9.6
6	.	.	2.2	0.2	.	.	4.8	0.6	7.6	7.2	.	.	0.8
7	.	.	.	4.4	.	.	0.2	12.6	0.4	21.4	.	0.2	0.4
8	.	.	.	.	6.199	.	1.4	8	.	2.8	.	.	.
9	.	.	3.4	.	.	.	.	3.6	.	4.4	.	0.2	0.2
10	1.2	.	.	8.4	1.2	8.2	.	8.6	.	.	.	6.2	3.4
11	.	.	.	.	7.4	.	3.2	0.8	.	.	.	1.2	0.8
12	.	2.8	.	.	11.2	2.6	4	7.6	0.2	.	.	.	6.8
13	0.4	7.2	.	.	.	.	3.8	0.4	.	.	0.4	.	2
14	6	0.4	.	10.2	.	.	2.6	8	6.6	2	0.4	.	.
15	0.2	.	.	.	13.199	6.8	.	2	6.4	.	3.8	.	.
16	.	.	.	8.199	139.585	2	5.8	.	10.4	1.4	1.6	.	.
17	.	.	.	1.6	51.598	18.799	0.4	1.2	4	9.8	.	0.2	.
18	.	.	.	7	0.2	44.397	.	9.8	5.2	4.6	0.2	.	0.4
19	4.8	.	.	.	9.4	7.2	1.4	3.2	1.8	2	0.6	.	.
20	6	.	.	.	37.198	0.4	1.8	.	.	.	2.8	.	.
21	1.6	.	.	.	18.4	.	.	.	.	.	.	6.4	.
22	5	.	.	.	16.599	.	.	4.8	.	.	.	20.399	.
23	0.6	.	.	.	.	12.2	0.6	3.6	0.4	0.4	4.8	.	.
24	.	.	.	.	.	2	2.8	9	.	2.4	.	.	.
25	.	.	.	.	.	2.6	2.2	1	1	11.2	.	13.399	.
26	.	.	.	.	.	.	.	13.2	3.8	3.2	.	.	.
27	.	.	.	.	1.4	.	10.4	5.8	1.2	1	0.2	26.598	.
28	.	.	.	.	14	87.991	0.2	10.8	.	.	.	0.6	.
29	.	.	.	.	.	.	.	33.4	0.6	.	.	4.8	.
30	3.6	.	.	.	.	.	0.6	16.798		9.4	.	1.8	.
31		.	.		.		11.4	0.8		.		2.6	
Monthly Total	29.4	15.8	5.6	39.999	327.578	195.187	77.6	165.998	59.6	109.6	14.8	91.396	24.6

Source: GVRD (2004)

Table 7-B Precipitation Data for Griffin Park Biofiltration Pond, North Vancouver

Note: Data given in millimetres

	2003							2004					
Day	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**May**	**June**
1	.	.	.	.	.	.	3.6	.	.	.	.	.	1
2	.	.	.	.	.	.	13.799	.	1.6	.	.	6	.
3	.	.	.	.	.	.	.	.	8.4	18.4	.	2	.
4	.	.	.	.	.	.	6.8	.	2.8	0.6	.	6	.
5	.	.	.	.	.	.	16	.	7.2	25.998	.	5	2.2
6	.	.	5.4	2.4	0.4	.	9.8	0.4	20.4	14.8	.	.	0.4
7	.	.	.	10.199	.	.	.	40	1.4	33.8	.	3	0.8
8	.	.	.	0.2	.	.	.	7.6	.	0.8	.	.	.
9	.	.	0.4	.	.	.	.	8.2	.	3.8	.	.	.
10	.	.	.	25.6	16.399	14.6	.	11.4	.	.	.	2.8	5.6
11	.	.	5	.	15.6	1.4	8.6	4.4	.	.	.	0.4	1.4
12	0.6	16.799	.	.	18.799	.	8.2	17.8	.	.	.	.	7.8
13	2.2	9.4	.	0.6	.	.	4	4	0.2	.	.	.	5.799
14	.	6.8	.	3.6	.	.	18.799	36	19.6	0.4	3.2	.	.
15	.	.	.	.	0.2	21.6	4	10.399	8.8	0.4	2.4	.	.
16	.	.	.	3.8	.	38.397	39.798	.	10.6	10.8	1.6	.	.
17	.	.	.	3.6	.	30.797	.	3.8	8.2	15.6	3.2	.	.
18	.	.	.	9.6	.	46.397	.	23.2	12	0.8	.	.	.
19	0.4	.	.	.	.	3.2	8	8.6	.	1.4	3	.	.
20	1.6	1.6	.	.	.	.	14.999	.	.	.	15.6	.	.
21	3.2	.	.	.	.	.	.	.	.	.	.	9.4	.
22	1.6	.	.	.	.	.	.	7.4	.	.	.	12.2	.
23	.	.	.	.	.	19.8	6.4	0.8	0.8	4	4.2	.	.
24	.	.	.	.	.	10.2	13.6	11.999	1.4	8.4	.	.	.
25	.	.	.	.	0.4	27.798	0.4	0.8	0.2	9.8	.	12.999	.
26	.	.	0.4	.	.	.	4	18.2	1.6	15	.	0.8	.
27	.	.	.	.	2.2	1.6	12.8	10.6	7.2	3	.	19.399	.
28	.	.	.	.	28.999	93.388	0.2	14.8	.	.	.	8.399	.
29	1	.	.	.	.	.	.	23.2	0.2	.	.	28.199	.
30	9.8	.	.	0.6	.	.	0.2	1.6		18.399	.	0.2	.
31		.	.		.		20	0.4		.		0.4	
Monthly Total	20.4	34.599	11.2	60.199	82.997*	309.177	213.995	265.598	112.6	186.197	33.2	117.196	24.999

Source: GVRD (2004)

* Discrepancy in data: rainfall from Tempe Heights catchment used for statistical purposes

Table 7-C Precipitation Data for Westview Interchange Detention Pond, North Vancouver

Note: Data given in millimetres

	2003							2004					
Day	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**May**	**June**
1	.	.	.	.	.	.	3.6	.	.	.	.	.	1
2	.	.	.	.	.	.	13.799	.	1.6	.	.	6	.
3	.	.	.	.	.	.	.	.	8.4	18.4	.	2	.
4	.	.	.	.	.	.	6.8	.	2.8	0.6	.	6	.
5	.	.	.	.	.	.	16	.	7.2	25.998	.	5	2.2
6	.	.	5.4	2.4	0.4	.	9.8	0.4	20.4	14.8	.	.	0.4
7	.	.	.	10.199	.	.	.	40	1.4	33.8	.	3	0.8
8	.	.	.	0.2	.	.	.	7.6	.	0.8	.	.	.
9	.	.	0.4	.	.	.	.	8.2	.	3.8	.	.	.
10	.	.	.	25.6	16.399	14.6	.	11.4	.	.	.	2.8	5.6
11	.	.	5	.	15.6	1.4	8.6	4.4	.	.	.	0.4	1.4
12	0.6	16.799	.	.	18.799	.	8.2	17.8	.	.	.	.	7.8
13	2.2	9.4	.	0.6	.	.	4	4	0.2	.	.	.	5.799
14	.	6.8	.	3.6	.	.	18.799	36	19.6	0.4	3.2	.	.
15	.	.	.	.	0.2	21.6	4	10.399	8.8	0.4	2.4	.	.
16	.	.	.	3.8	.	38.397	39.798	.	10.6	10.8	1.6	.	.
17	.	.	.	3.6	.	30.797	.	3.8	8.2	15.6	3.2	.	.
18	.	.	.	9.6	.	46.397	.	23.2	12	0.8	.	.	.
19	0.4	.	.	.	.	3.2	8	8.6	.	1.4	3	.	.
20	1.6	1.6	.	.	.	.	14.999	.	.	.	15.6	.	.
21	3.2	.	.	.	.	.	.	.	.	.	.	9.4	.
22	1.6	.	.	.	.	.	.	7.4	.	.	.	12.2	.
23	.	.	.	.	.	19.8	6.4	0.8	0.8	4	4.2	.	.
24	.	.	.	.	.	10.2	13.6	11.999	1.4	8.4	.	.	.
25	.	.	.	.	0.4	27.798	0.4	0.8	0.2	9.8	.	12.999	.
26	.	.	0.4	.	.	.	4	18.2	1.6	15	.	0.8	.
27	.	.	.	.	2.2	1.6	12.8	10.6	7.2	3	.	19.399	.
28	.	.	.	.	28.999	93.388	0.2	14.8	.	.	.	8.399	.
29	1	.	.	.	.	.	.	23.2	0.2	.	.	28.199	.
30	9.8	.	.	0.6	.	.	0.2	1.6		18.399	.	0.2	.
31		.	.		.		20	0.4		.		0.4	
Monthly Total	20.4	34.599	11.2	60.199	82.997*	309.177	213.995	265.598	112.6	186.197	33.2	117.196	24.999

Source: GVRD (2004)

* Discrepancy in data: rainfall from Tempe Heights catchment used for statistical purposes

Table 7-D Precipitation Data for Tempe Heights Pond, North Vancouver

Note: Data given in millimetres

	2003							2004					
Day	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**May**	**June**
1	.	.	.	.	.	.	3.2	.	0.2	.	.	.	0.8
2	.	.	.	.	.	.	13.999	0.6	1.8	.	.	8.2	.
3	.	.	.	.	.	.	.	.	9.6	22.2	.	1.4	.
4	.	.	.	.	.	.	7.6	.	2.8	1	.	8.4	.
5	.	.		.		.	17.2	.	7	29.798	.	9.6	2.8
6	.	.	6.2	3.8	27.8	.	9.6	.	24	15	.	.	0.2
7	.	.	.	11.399	3.2	.	0.4	42.2	1	38.6	0.2	2.6	1.2
8	.	.	.	0.2	11	.	0.2	8.6	.	1.4	.	0.2	.
9	.	.	1.4	.	4.6		.	9.4	.	4.2	.	.	.
10	.	.	.	33	17.598	16.8	.	15			.	2.4	6
11	.	.	1	0.2	16.2	1.2	9	4.8	.	.	0.4	0.2	1.8
12	1	15.599	.	.	19.999	.	9.4	18.8	.	0.2	.		9
13	1.6	5.2	.	0.4	0.2	.	3.6	5.8	0.2	.	.	.	5.599
14	0.2	7	.	3.6	.	0.2	25.198	42.598	19.6	0.6	3.2	.	0.2
15	.	.	.	.	13.799	21.6	3.6	12.599	10.4	0.6	2	.	.
16	.	.	.	3	135.586	43.997	38.798	.	10.8	15	3	.	.
17	.	.	.	4	80.392	31.597	.	3.6	7.8	16.4	.	.	.
18	.	.	.	12.6	3.6	46.198	.	25.2	15.6	1.6	0.2	.	.
19	0.8	.	.	.	8.4	2	8	10.4	0.2	2	3.8	.	.
20	2.2	1.6	.	.	32.798	0.2	17.599	.	.	.	10.4	.	.
21	4.4	.	.	.	4.8	.	.	.	.	.	.	12.199	.
22	2	.	.	.	8.6	.	.	8.4	.	.	.	14.2	.
23	0.2	.	.	.	.	19.4	6.8	1.6	0.8	3.6	4.4	.	.
24	.	.	.	.		6.4	14.8	12.8	2	10.2	.	.	.
25	.	.	.	.	.	27.2	0.6	0.2	0.4	11.8	.	14.398	.
26	.	.	.	.	.	.	3	21.4	0.8	16.6	.	2.8	.
27	.	.	.	.	2.8	1.6	10.6	12.2	7.6	3.2	.	26.399	.
28	.	.	.	.	32.798	100.989	2.2	19.2	.	.	.	10.799	.
29	1	.	.	.	.	0.2	0.2	25.4	0.4	.	.	30.599	.
30	11.4	.	.	.		.	.	2.2		20.4	.	0.2	.
31		.	.		.		8	0.4		.		1.4	
Monthly Total	24.8	29.399	8.6	72.199	424.17	319.581	213.594	303.397	123	214.398	27.6	145.994	27.599

Source: GVRD (2004)

Table 7-E Oakalla Biofiltration System, Burnaby

Note: Data given in millimetres

	2003							2004					
Day	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**May**	**June**
1	.	.	.	.	.	.	1.4	0.2	.	.	.	.	0.2
2	.	.	.	.	.	.	9	.	0.6	.	.	2.4	.
3	.	.	.	.	.	.	.	.	7.2	23.2	.	0.8	.
4	.	.	.	.	.	.	5.8	.	4.6	2.2	.	0.2	.
5	.	0.2	.	.	.	.	12	.	5	18	.	.	0.8
6	.	.	3.4	1	24.598	2.6	4.2	6.2	18.2	10.4	.	.	.
7	.	.	.	8.999	1	13.4	.	23.2	0.6	28.4	0.2	0.6	0.4
8	.	.	.	.	7.4	3	1.8	3.4	.	2.2	.	.	0.2
9	.	.	2.6	.	0.2	.	.	5	17.199	2.6	.	3.6	.
10	.	.	.	13.4	.	10.8	.	9.2	0.2	.	.	4.6	3.4
11	.	.	.	0.2	8.8	19	5	3.4	.	.	.	0.8	0.6
12	0.4	6.4	.	.	10.6	1	8	10.4	.	.	.	.	6.6
13	0.2	3	0.2	.	.	.	3.8	2.4	.	.	.	.	3.6
14	0.8	3.4	.	4	.	.	9	20.4	17.8	2.6	.	.	0.4
15	.	.	.	.	11.199	11.8	0.4	2.4	5	.	0.6	.	.
16	.	.	.	0.2	127.986	19.8	10.6	.	12.2	4.8	0.2	.	.
17	.	.	.	3	65.596	32.996	.	2	5.6	9.8	0.4	.	.
18	.	.	.	8.6	1.4	43.199	.	18.4	9.2	0.2	.	.	.
19	1	.	.	.	7	3.4	4.4	8.2	0.2	.	2.8	.	.
20	2.4	0.4	.	.	32.398	.	5.6	.	.	.	7.4	.	.
21	0.4	.	.	.	7	.	.	.	.	.	.	6.4	.
22	3.4	.	.	.	5.4	.	.	5.2	.	.	.	21	.
23	.	.	.	.	0.2	14.2	2.6	0.2	.	0.8	6.2	.	0.2
24	.	.	.	.	.	6.6	7.8	1	1	11.2	.	.	.
25	.	.	.	.	.	23.398	.	0.2	0.6	11.4	.	12.799	.
26	.	.	1.4	0.2	.	.	2.6	17.6	1	.	.	1.2	.
27	.	.	0.4	.	1.8	0.4	16	10.2	7.8	.	.	20.799	.
28	.	.	.	.	20.999	110.787	0.4	13.999	.	.	.	0.6	.
29	.	.	.	.	.	.	.	24.4	1.6	.	.	14.6	.
30	9.999	.	.	.	.	.	2.8	5.2		.	.	0.2	.
31		.	.		.		16.8	0.6		.		5.4	
Monthly Total	18.599	13.4	8	39.599	333.576	316.38	130	193.399	115.599	127.8	17.8	95.998	16.4

Source: GVRD (2004)

Appendix VIII –
Water Sampling Results

Table 8-A Water Quality Results at 52Ave/221A Street Detention Facility, Langley (Pond D)

Note: D1 indicates inlet; D2 indicates outlet; D3 indicates sampling point before bridge; D4 indicates small inlet from 52 Avenue; D5 indicates the 221A Street ditch; (dup) indicates a duplicate sample; and (at pipe) indicates sampling occurred from pipe instead of from ditch

Shading indicates value below detection limit

Results given in mg/L

Element	Al	Ca	Fe	K	Mg	Mn	Na	Si	Zn
Detection Limits	**0.05**	**0.1**	**0.05**	**0.5**	**0.01**	**0.005**	**0.25**	**0.15**	**0.01**
Date & Site									
July 9, 2003									
D1	0.006	39.720	0.207	1.961	16.895	0.062	15.173	5.854	-0.005
D2	0.035	44.139	0.193	2.350	19.120	0.207	15.714	9.190	-0.004
Sept. 17, 2003									
D1	0.052	37.227	0.046	2.281	15.904	0.098	13.868	9.853	0.004
D2	0.019	21.874	0.077	1.618	7.595	0.017	8.267	5.428	0.002
Nov. 14, 2003									
D1	0.016	40.553	0.025	2.213	19.417	0.016	15.415	10.408	0.011
D3	0.049	38.075	0.092	2.280	17.611	0.070	14.729	9.459	0.011
D4	0.111	38.357	0.138	2.219	15.976	0.144	34.230	7.963	0.009
D2	0.103	28.119	0.113	2.018	12.447	0.020	12.514	7.932	0.013
Dec. 9, 2003									
D1	0.0322	31.1066	0.0459	1.6079	14.4785	0.0518	12.0667	8.9737	-0.0052
D3	0.0822	29.3146	0.1017	1.6853	13.1371	0.0359	11.9507	8.4258	0.0190
D4	0.1457	27.5170	0.1804	1.5509	11.7505	0.1184	21.1391	7.4560	-0.0076
D2	0.1878	17.0360	0.1339	1.1954	7.3385	0.0089	12.6461	6.5376	-0.0032
D2 (dup)	0.2090	16.7274	0.1497	1.1571	7.2105	0.0087	12.6212	6.5310	-0.0046

Table 8-A Continued

Jan. 14, 2004									
D1	0.283	13.905	0.200	1.349	5.059	0.032	8.440	3.909	0.009
D1 (dup)	0.316	16.063	0.220	1.442	5.988	0.035	9.158	4.530	0.007
D2	0.436	6.063	0.269	1.356	2.029	0.011	45.224	3.079	0.020
Feb. 4, 2004									
D1	0.125	20.753	0.099	1.532	8.666	0.030	9.078	5.949	0.007
D1 (dup)	0.165	21.080	0.124	1.476	8.755	0.030	8.984	6.047	0.003
D2	0.284	8.903	0.194	0.913	3.414	0.002	6.351	3.602	0.003
Mar. 2, 2004									
D1	0.013	37.665	0.019	1.747	18.945	0.020	15.199	9.782	0.005
D1 (dup)	0.010	37.754	0.014	1.641	18.957	0.021	15.073	9.754	-0.001
D3	0.037	36.167	0.057	1.739	17.708	0.191	14.912	8.513	-0.009
D2	0.105	25.473	0.115	1.510	12.031	0.031	15.348	6.441	-0.001
D5	0.298	13.061	0.173	0.720	5.812	0.005	14.765	5.850	0.002
Mar. 23, 2004									
D1	0.030	32.369	0.020	1.421	16.115	0.015	14.813	9.314	0.009
D1 (dup)	0.026	32.140	0.014	1.399	16.015	0.015	14.842	9.288	0.008
D2	0.135	22.719	0.136	1.139	10.504	0.025	13.866	4.908	0.010
D3	0.033	32.056	0.051	1.394	15.468	0.079	14.801	7.650	0.005
D5	0.342	11.684	0.198	0.428	5.116	0.005	11.565	4.955	0.010
D5 (at pipe)	0.330	11.297	0.231	0.483	4.919	0.003	11.307	4.833	0.012

Table 8-A Continued

April 20, 2004									
D1	0.017	41.585	0.011	1.747	21.208	0.023	15.904	10.051	0.018
D1 (dup)	0.014	41.908	0.008	1.644	21.284	0.025	15.521	9.991	0.007
D2	0.024	29.918	0.154	1.339	13.698	0.067	14.871	1.848	0.010
D2 (before outlet)	0.013	33.263	0.174	1.442	15.376	0.078	14.323	1.434	0.009
D3	0.035	38.403	0.111	1.482	18.525	0.099	15.027	5.535	0.007
D5	0.168	16.942	0.117	0.377	7.282	0.011	18.916	3.923	0.011
D5 (lab dup)	0.166	16.640	0.116	0.278	7.171	0.012	18.862	3.912	0.031
May 13, 2004									
D1	0.028	40.569	0.020	1.805	20.313	0.025	14.836	10.248	0.007
D1 (dup)	0.026	40.385	0.017	1.833	20.310	0.022	14.933	10.376	0.007
D2	0.017	28.105	0.499	1.222	11.858	0.041	12.636	2.683	0.009
D3	0.035	35.468	0.263	1.041	16.368	0.002	13.247	5.190	0.007
June 1, 2004									
D1	0.049	29.445	0.044	1.818	12.994	0.021	11.971	8.661	0.008
D1 (dup)	0.045	29.348	0.043	1.744	13.003	0.020	11.952	8.641	0.007
D2	0.065	23.993	0.294	1.166	9.885	0.116	12.749	6.314	0.013
D3	0.045	29.778	0.206	1.658	12.809	0.203	11.892	8.153	0.004
D4	0.231	46.830	0.153	2.222	18.888	0.006	62.075	7.576	0.004
D5	0.434	12.752	0.289	0.553	5.170	0.007	23.172	5.754	0.009

Table 8-B Physical Properties Results at 52Ave/221A Street Detention Facility, Langley (Pond D)

Note: D1 indicates inlet; D2 indicates outlet; D3 indicates sampling point before bridge; D4 indicates small inlet from 52 Avenue; Street ditch; D5 indicates the 221A(dup) indicates a duplicate sample; and (at pipe) indicates sampling occurred from pipe instead of from ditch

Parameter	Temperature (°C)	Conductivity (μS/cm)	Specific Conductivity (μS/cm)	Dissolved Oxygen (mg/L)	pH
Date & Site					
July 9, 2003					
D1	24.3	376.8	378.4	4.8	7.31
D2	27	358.9	349.9	7.1	7.6
Sept. 17, 2003					
D1					
D2					
Nov. 14, 2003					
D1	12.5	270.5	355.1	10	7.61
D2	5.8	129.5	205	8.1	7.3
D3	7.5	231.2	348.2	6.6	7.44
D4	7.2	290.8	444.9	7.6	7.46
Dec. 9, 2003					
D1	10.3	221.4	307.8	6.87	7.47
D2					6.96
D2(dup)	5.3	146.4	234.5	7	7.2
D3					7.39
D4					7.36
Jan. 14, 2004					
D1	8.2	114.5	168.4	10.1	6.87
D1(dup)					6.94
D2	6.1	193	301.2	9.5	6.53
Feb. 4, 2004					
D1	8.5	154.9	226.3	8.9	7.18; 7.31
D1(dup)					7.24; 7.37
D2	4.7	52	85.1	9.1	7.06
Mar. 2, 2004					
D1	9.3	422		9.45	7.29; 7.55
D1(dup)					7.44; 7.59
D2	5.3	395		8.16	7.37
D3					7.44
D5					7.37
Mar. 23, 2004					
D1	10.5	258.1	358.7	11.2	7.34; 7.56
D1(dup)					7.40; 7.55
D2	11.7	61.2	82.2	11.8	7.73; 7.94
D3					7.6
D5					7.49
D5(at pipe)					7.46
April 20, 2004					
D1	12	324.2	430.4	10.7	7.39; 7.53
D1(dup)					
D2	13.9	128.6	161.2	17.8	7.46
D3					
D5					
D5(lab dup)					
May 13, 2004					
D1	14.2	340.9	430	10.2	7.43
D1 (dup)					7.55
D2	21.7	284.1	302.7	1	7.53
June 1, 2004					
D1	14.9	241.5	299.1	9.9	7.2
D1 (dup)					7.32
D2	13.6	211.8	268.5	4.4	7.05
D3					7.15
D4					7.61
D5	13.3	182.4	234.6	8.9	7.41

Table 8-C Water Quality Results at Griffin Park Biofiltration Pond, North Vancouver (Pond E)

Note: E1 indicates inlet; E2 indicates outlet; E3 indicates sampling point in middle of pond; and E4 indicates Mosquite Creek baseflowand (dup) indicates a duplicate sample
Shading indicates value below detection limit
Results given in mg/L

Element	Al	Ca	Fe	K	Mg	Mn	Na	Si	Zn
Detection Limits	**0.05**	**0.1**	**0.05**	**0.5**	**0.01**	**0.005**	**0.25**	**0.15**	**0.01**
Date & Site									
July 10, 2003									
E1	0.060	15.178	7.428	2.628	1.546	0.229	10.588	5.727	0.001
E2	0.030	6.051	0.085	1.118	0.740	-0.001	4.355	4.062	-0.005
July 14, 2003									
E1	0.031	6.622	0.096	0.939	0.621	0.003	3.686	2.837	0.013
E1	0.030	6.291	0.089	0.946	0.581	0.002	3.486	2.614	0.017
E4	0.223	1.556	0.072	0.181	0.227	0.001	1.545	2.250	0.002
Sept. 7, 2003									
E1	0.025	3.998	0.082	1.023	0.372	0.006	2.732	2.241	0.017
E2	0.065	5.417	0.082	1.906	0.553	0.005	3.280	1.402	0.020
E4	0.045	4.553	0.102	0.625	0.561	0.008	4.264	3.792	0.006
Oct. 23,2003									
E1	0.034	12.733	0.079	1.633	1.302	0.006	6.089	4.799	0.009
E2	0.036	10.092	0.244	1.702	1.154	0.016	5.210	4.520	0.010
Nov. 15, 2003									
E1	0.059	1.164	0.067	0.660	0.135	0.004	1.503	0.554	0.031
E2	0.067	1.470	0.124	0.798	0.175	0.010	1.685	0.695	0.033
E2 (dup)	0.060	1.658	0.115	0.867	0.190	0.010	1.747	0.684	0.031
Dec. 8, 2003									
E1	0.0335	9.6852	0.0863	1.7202	1.1675	0.0053	6.4490	4.5733	0.0151
E2	0.0317	8.0721	0.1481	1.4285	0.9607	0.0113	5.3543	4.6252	0.0147

Table 8-C Continued

Element	Al	Ca	Fe	K	Mg	Mn	Na	Si	Zn
Detection Limits	**0.05**	**0.1**	**0.05**	**0.5**	**0.01**	**0.005**	**0.25**	**0.15**	**0.01**
Date & Site									
Jan. 14, 2004									
E1	0.058	9.071	0.091	1.321	1.141	0.009	5.497	3.371	0.012
E2	0.063	7.321	0.087	1.077	0.936	0.009	5.073	2.841	0.010
Feb. 4, 2004									
E1	0.021	6.910	0.065	1.021	0.815	0.000	4.963	3.379	0.003
E2	0.033	5.460	0.174	0.813	0.596	0.014	3.893	3.154	0.006
March 2, 2004									
E1	0.023	5.151	0.065	0.788	0.615	0.000	5.005	3.393	-0.006
E2	0.032	5.092	0.342	0.853	0.585	0.016	5.119	3.441	-0.003
March 23, 2004									
E1	0.063	2.548	0.067	0.556	0.283	0.000	3.535	1.383	0.012
E2	0.083	2.758	0.153	0.685	0.304	0.007	3.838	1.094	0.011
April 20, 2004									
E1	0.034	1.564	0.042	0.593	0.185	0.004	2.193	0.702	0.023
E2	0.047	1.637	0.087	0.663	0.192	0.008	2.360	0.687	0.015
May 13, 2004									
E1	0.031	4.001	0.046	0.415	0.451	-0.002	3.349	2.619	0.007
E2	0.051	4.193	0.475	0.454	0.455	0.006	3.275	2.532	0.007
June 1, 2004									
E1	0.034	7.588	0.064	1.122	0.835	0.004	4.768	3.776	0.005
E2	0.044	6.436	0.273	1.182	0.699	0.017	4.377	2.998	0.006

Table 8-D Physical Properties at Griffin Park Biofiltration Pond, North Vancouver (Pond E)

Note: E1 indicates inlet; E2 indicates outlet; E3 indicates sampling point in middle of pond; and E4 indicates Mosquite Creek baseflow and (dup) indicates a duplicate sample

Parameter	Temperature (°C)	Conductivity (µS/cm)	Specific Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH
Date & Site					
July 10, 2003					
E1	21.2	176.6	190.1	3	7.39
E2	15.6	49.5	60.4	10.4	7.27
E4	15.3	50.2	61.8		
July 14, 2003					
E1					7.02
E1					7.03
E4					6.75
Sept. 7, 2003					
E1	17.7	43.1	50.1	5.5	6.59
E2	16.1	51.9	62.6	6.2	6.39
E4	15	50	61		6.74
Oct. 23,2003					
E1	14.1	93.7	117.9		
E2	12.3	85	110.3		
Nov. 15, 2003					
E1	9.2	16.3	23.2	10.8	6.60;6.70;6.73
E2	9.1	21.5	30.9	9.8	6.55;6.62;6.64
E2(dup)					6.59
Dec. 8, 2003					
E1	9.1	68.7	97.5	9.25	6.91
E2	8	61.5	91.1	5.71	6.63
Jan. 14, 2004					
E1	7.7	68.4	101.4	9.7	6.97
E2	8	59.4	87	9.2	6.81
Feb. 4, 2004					
E1	7	54.3	82.7	8.1	7.18
E2	6.2	39.2	60.8	8.6	6.76
March 2, 2004					
E1	7.7	74.9		11.46	7.35
E2	6.7	77.9		7.27	7.04
March 23, 2004					
E1	10.4	30.8	42.7	9.9	7.41
E2	11.5	35.7	48.2	11.3	7.2
April 20, 2004					
E1	9.7	20.7	29.2	11.5	6.51; 7.09
E2	9.2	21	30.1	10.5	6.45
May 13, 2004					
E1	12.6	22.2	28.7	11.1	7.43
E2	14.9	43.6	54	10.8	7.16
June 1, 2004					
E1	14.2	65.8	82.9	10.5	7.19
E2	14.7	62.4	77.6	9.2	7.08

Table 8-E Water Quality Results at Westview Interchange Detention Pond, North Vancouver (Pond F)

Note: F1 indicates inlet; F2 indicates outlet; and (dup) indicates a duplicate sample
Shading indicates value below detection limit
Results given in mg/L

Element	Al	Ca	Fe	K	Mg	Mn	Na	Si	Zn
Detection Limits	0.05	0.1	0.05	0.5	0.01	0.005	0.25	0.15	0.01
Date & Site									
July 10, 2003	DRY								
F1									
F2									
July 14, 2003	DRY								
F1									
F2									
Sept. 7, 2003									
F1	0.033	4.996	0.082	1.298	0.420	0.046	2.000	0.703	0.044
F2	0.049	1.634	0.097	0.746	0.176	0.020	1.503	0.239	0.041
Oct. 10, 2003									
F1	0.162	13.578	0.330	1.305	1.144	0.058	6.810	1.203	0.101
F2	0.655	5.323	1.102	1.394	0.659	0.073	4.054	0.766	0.252
Oct. 23,2003									
F1	0.059	16.788	0.079	2.637	1.582	0.016	9.491	2.194	0.025
F2	0.085	1.534	0.112	0.397	0.158	0.005	1.362	0.417	0.019
Nov. 15, 2003									
F1	0.370	5.056	0.411	0.928	0.477	0.032	6.378	1.150	0.071
F2	0.086	1.491	0.122	0.500	0.149	0.012	2.721	0.309	0.028
F2 (lab dup)	0.080	1.456	0.116	0.506	0.144	0.011	2.755	0.304	0.029
Dec. 8, 2003									
F1	0.0536	18.5558	0.0992	3.6774	2.1085	0.0145	30.6066	2.0232	0.0260
F2	0.1082	1.7302	0.1358	0.7251	0.2263	0.0082	26.9675	0.3803	0.0195

Table 8-E Continued

Element	Al	Ca	Fe	K	Mg	Mn	Na	Si	Zn
Detection Limits	**0.05**	**0.1**	**0.05**	**0.5**	**0.01**	**0.005**	**0.25**	**0.15**	**0.01**
Date & Site									
Jan. 14, 2004									
F1	0.388	13.804	0.386	1.414	1.223	0.024	28.384	1.316	0.040
F2	0.175	1.128	0.171	0.332	0.147	0.005	8.825	0.427	0.010
Feb. 4, 2004									
F1	0.029	3.065	0.076	4.947	0.220	0.009	47.560	0.437	0.014
F2	0.082	1.324	0.093	3.241	0.130	0.001	28.030	0.292	0.011
March 2, 2004									
F1	0.036	4.376	0.134	1.248	0.365	0.043	15.136	0.535	0.014
F2	0.056	1.755	0.076	0.860	0.187	0.010	9.772	0.362	0.007
March 23, 2004									
F1	0.379	3.068	0.375	0.834	0.315	0.019	6.748	1.012	0.034
F2	0.212	4.544	0.229	0.936	0.403	0.024	8.847	0.690	0.046
April 20, 2004									
F1	0.179	2.143	0.196	0.730	0.233	0.018	3.900	0.635	0.037
F2	0.076	1.823	0.149	0.744	0.183	0.016	3.758	0.403	0.026
June 1, 2004									
F1	0.270	9.586	0.391	1.438	0.725	0.050	10.195	1.343	0.081
F2	0.040	1.234	0.067	0.337	0.122	0.008	1.539	0.208	0.026

Table 8-F Physical Properties at Westview Interchange Detention Pond, North Vancouver (Pond F)

Note: F1 indicates inlet; F2 indicates outlet

Parameter	Temperature (°C)	Conductivity (μS/cm)	Specific Conductivity (μS/cm)	Dissolved Oxygen (mg/L)	pH
Date & Site					
July 10, 2003					
F1	DRY				
F2					
July 14, 2003					
F1	DRY				
F2					
Sept. 7, 2003					
F1	18.2	55.2	62.2	6.5	6.82
F2	17	30	35	5	6.45
Oct. 10, 2003					
F1	13.5	118.3			
F2	12.3	66.9			
Oct. 23,2003					
F1	12.5	34.6	44.8		
F2	12.4	26.4	34.8		
Nov. 15, 2003					
F1	8.5	43.1	62.7	9.7	6.88
F2	8.3	28.7	42.1	8.5	6.7
Dec. 8, 2003					
F1	5.6	109.8	174.7	6.57	7.31; 7.44
F2	5.8	110.4	174.4	8.3	6.8
Jan. 14, 2004					
F1	8.8	50.6	73.3	9.2	7.11
F2	9.1	46.5	66.6	9.1	7.02
Feb. 4, 2004					
F1	5.1	155.3	250	9.7	7.12
F2	5.2	118.1	190	7.6	6.98
March 2, 2004					
F1	9.7	90.1		7.43	6.83
F2	8	88.2		8.03	6.82
March 23, 2004					
F1	11.7	60.5	81.4	10.6	7.23
F2	13.1	69.2	89.3	7.9	6.97
April 20, 2004					
F1	9.6	30.9	43.7	12.1	6.58
F2	9.2	25.7	36.5	10.3	6.59
June 1, 2004					
F1	17	64.2	71.1	8.3	6.88; 6.87
F2	17.3	21.6	25.3	9.5	6.73

Table 8-G Water Quality Results at Tempe Heights Constructed Wetland, North Vancouver (Pond G)

Note: G1 indicates inlet; G2 indicates outlet; G3 indicates sampling point in middle of pond; and (dup) indicates a duplicate sampleShading indicates value below detection limit
Results given in mg/L

Element	Al	Ca	Fe	K	Mg	Mn	Na	Si	Zn
Detection Limits	0.05	0.1	0.05	0.5	0.01	0.005	0.25	0.15	0.01
Date & Site									
July 9, 2003									
G1	0.010	31.599	0.401	2.642	4.074	0.002	13.268	5.674	-0.001
G2	0.023	33.743	0.489	2.564	4.045	-0.004	13.501	5.354	0.002
July 14, 2003									
G1	0.015	16.986	0.179	1.397	1.980	0.025	7.105	3.470	0.042
G3	0.012	17.618	0.399	1.347	1.948	0.019	6.670	3.151	0.015
Sept. 7, 2003									
G1	0.022	27.088	0.286	2.058	3.507	0.044	10.384	5.730	0.051
G2	0.032	26.155	0.470	2.471	3.344	0.015	10.031	4.247	0.030
G2 (dup)	0.026	26.607	0.483	2.507	3.409	0.020	10.447	4.351	0.028
Oct. 10,2003									
G1	0.034	35.849	0.782	2.276	4.732	0.067	14.746	7.484	0.026
G2	0.067	18.641	0.844	1.435	2.188	0.046	6.930	3.310	0.023
Oct. 23, 2003									
G1	0.013	29.683	0.128	4.231	3.348	0.019	13.068	6.287	0.015
G2	0.019	23.337	0.426	2.391	1.967	0.044	7.574	3.757	0.011
Nov. 14, 2003									
G1									
G2									
Dec. 9, 2003									
G1	0.0106	24.5230	0.0947	3.0829	3.1967	0.0087	13.3974	5.9802	0.0119
G1 (dup)	0.0117	25.9267	0.1210	2.9944	3.2036	0.0113	13.0737	5.9736	0.0101
G2	0.0141	21.5198	0.2845	2.3370	1.9614	0.0247	9.9169	4.1009	0.0040

Table 8-G Continued

Element	Al	Ca	Fe	K	Mg	Mn	Na	Si	Zn
Detection Limits	0.05	0.1	0.05	0.5	0.01	0.005	0.25	0.15	0.01
Date & Site									
Jan. 14, 2003									
G1	0.025	25.880	0.105	3.124	2.262	0.018	15.782	3.840	0.008
G1 (dup)	0.026	25.321	0.119	3.129	2.229	0.016	15.507	3.811	0.008
G2	0.027	15.819	0.265	1.732	1.275	0.022	13.933	2.245	0.006
Feb. 4, 2003									
G1	0.004	23.882	0.096	2.500	3.026	0.005	14.855	5.531	0.007
G1 (dup)	0.004	24.221	0.101	2.502	3.049	0.005	14.732	5.513	0.006
G2	0.004	7.102	0.074	0.915	0.729	0.002	4.438	1.442	0.010
March 2, 2004									
G1	0.005	28.915	0.205	2.219	4.304	0.017	17.526	7.224	-0.004
G1 (dup)	0.004	28.405	0.189	2.170	4.246	0.018	17.217	7.182	-0.003
G2	0.010	31.799	0.391	2.079	3.536	0.054	15.132	5.720	-0.007
March 23, 2004									
G1	0.043	6.624	0.117	0.945	0.806	0.009	6.367	1.667	0.037
G1 (dup)	0.041	6.926	0.118	0.919	0.840	0.008	6.477	1.674	0.040
G2	0.043	28.312	0.558	1.959	2.921	0.012	14.572	4.879	0.004
April 20, 2004									
G1	0.015	17.675	0.042	3.481	2.655	0.007	10.617	4.522	0.024
G1 (dup)	0.012	18.848	0.029	3.432	2.869	0.005	11.202	4.856	0.023
G2	0.011	27.970	0.413	2.159	3.343	0.052	12.392	4.665	0.010
May 13, 2004									
G1	0.012	26.050	0.681	1.437	3.220	0.049	11.248	4.827	0.005
G1 (dup)	0.012	25.931	0.704	1.430	3.209	0.054	11.266	4.852	0.005
G2	0.019	25.194	0.741	1.353	3.056	0.044	10.988	4.772	0.003
June 1, 2004									
G1	0.033	24.761	0.123	2.539	3.405	0.016	15.029	6.453	0.010
G1 (dup)	0.043	25.344	0.157	2.599	3.470	0.017	15.380	6.521	0.015
G2	0.016	27.992	0.707	2.580	2.767	0.045	12.485	4.736	0.006

Table 8-H Physical Properties at Tempe Heights Constructed Wetland, North Vancouver (Pond G)

Note: G1 indicates inlet; G2 indicates outlet; G3 indicates sampling point in middle of pond; and (dup) indicates a duplicate sample

Parameter	Temperature (°C)	Conductivity (μS/cm)	Specific Conductivity (μS/cm)	Dissolved Oxygen (mg/L)	pH
Date & Site					
July 9, 2003					
G1	18.7	224.7	255.3	8.8	7.92
G2	21.8	231.7	256.8	10.2	
G3	18.7	220.2	250.7	8	7.61
July 14, 2003					
G1					6.84
G3					7.2
Sept. 7, 2003					
G1	17.6	208	241	4	6.83
G2	18	200.6	231.4	5	7.23
G2 (dup)	18	200.6	231.4	5	7.22
Oct. 10,2003					
G1	15.4	331			
G2	12.6	170.3			
Oct. 23, 2003					
G1	13.8	225.1	279.4		
G2	12.5	139.1	182.7		
Nov. 14, 2003					
G1					
G2					
Dec. 9, 2003					
G1	9.1	229.1	329.9	2.5	6.9
G1 (dup)					6.89
G2	7	140.3	213.9	8.7	6.93
Jan. 14, 2003					
G1	8.5	179.9	263.9	8.5	6.74
G1 (dup)					6.76
G2	8.6	129.2	188	9	6.98; 7.05
Feb. 4, 2003					
G1	8	182.6	270.7	7.5	6.96
G1 (dup)					6.73
G2	6	121.2	190	8.1	6.83
March 2, 2004					
G1	10.1	384		6.84	7.04
G1 (dup)					7.12
G2	8.3	310		10.36	7.54
March 23, 2004					
G1	12.1	69	91	10.5	6.84
G1 (dup)					6.81
G2	12.1	199.1	264.3	10.4	8.38
April 20, 2004					
G1	10.5	107.7	149.1	8.1	6.95
G1 (dup)					7.06
G2	10.4	179.6	248.4	8.3	7.16
May 13, 2004					
G1	18	208.7	240.1	8.2	7.08
G1 (dup)					7.03
G2	19	203.9	230.7	14.9	7.77
June 1, 2004					
G1	14.8	216.5	270.4	6.8	7.01
G1 (dup)					7.03
G2	14.8	196.5	243.1	8.8	7

Table 8-I Water Quality Results at Oakalla Biofiltration System, Burnaby (Pond I)

Note: I1 indicates inlet; I2 indicates outlet; and (dup) indicates a duplicate sample
Shading indicates value below detection limit
Results given in mg/L

Element	**Al**	**Ca**	**Fe**	**K**	**Mg**	**Mn**	**Na**	**Si**	**Sr**	**Zn**
Detection Limits	**0.05**	**0.1**	**0.05**	**0.5**	**0.01**	**0.005**	**0.25**	**0.15**	**0.002**	**0.01**
Date & Site										
July 10, 2003										
I1	0.007	34.683	0.181	3.457	6.458	0.317	16.505	7.698	0.206	-0.004
I2	0.002	33.196	0.175	0.811	5.960	0.275	14.857	6.938	0.194	-0.004
Nov. 15, 2003										
I1	0.016	48.000	1.324	4.221	7.207	2.501	16.502	7.819	0.268	0.019
I2	0.010	29.860	0.059	3.692	4.825	0.100	12.776	5.996	0.171	0.017
Dec. 8, 2003										
I1	0.0375	40.4213	0.1483	3.8398	6.0856	0.1294	16.5277	6.7331	0.2334	-0.0047
I1 (dup)	0.0376	40.5426	0.1597	3.7641	6.1063	0.1302	16.3305	6.7243	0.2341	-0.0057
I2	0.0094	31.9106	0.0746	3.1203	4.5046	0.0753	16.1479	5.3206	0.1748	-0.0053
Jan. 14, 2004										
I1	0.078	26.355	0.119	2.981	3.073	0.050	13.456	3.789	0.141	0.004
I2	0.039	12.284	0.059	1.904	1.386	0.008	10.943	1.958	0.065	0.002
I2 (lab dup)	0.051	12.558	0.069	1.935	1.410	0.009	10.916	1.981	0.066	0.002
Feb. 4, 2004										
I1	0.037	34.817	0.124	3.272	4.941	0.095	14.942	5.228	0.194	0.001
I2	0.010	14.647	0.053	1.609	1.852	0.018	7.111	2.143	0.075	0.001
I2 (lab dup)	0.012	14.437	0.052	1.612	1.839	0.017	7.170	2.144	0.074	0.000

Table 8-I Continued

Element	Al	Ca	Fe	K	Mg	Mn	Na	Si	Sr	Zn
Detection Limits	**0.05**	**0.1**	**0.05**	**0.5**	**0.01**	**0.005**	**0.25**	**0.15**	**0.002**	**0.01**
Date & Site										
March 2, 2004										
I1	0.025	44.149	0.112	3.909	7.439	0.164	20.107	7.220	0.257	-0.011
I1 (lab dup)	0.024	44.375	0.111	3.916	7.467	0.165	20.334	7.231	0.259	-0.012
March 23, 2004										
I1	0.048	42.119	0.139	3.701	6.990	0.133	21.630	6.913	0.260	0.007
I2	0.021	38.802	0.044	3.480	5.871	0.081	20.477	5.358	0.230	0.007
I2 (lab dup)	0.019	39.287	0.042	3.500	5.934	0.081	20.662	5.363	0.233	0.005
April 20, 2004										
I1	0.036	28.489	0.201	2.783	4.980	0.122	12.842	5.175	0.163	0.015
I2	0.015	15.609	0.096	1.738	2.484	0.032	8.814	2.586	0.090	0.006
I2 (lab dup)	0.017	15.765	0.104	1.749	2.505	0.033	8.593	2.586	0.091	0.008
May 13, 2004										
I1	0.026	42.538	0.240	4.209	7.790	0.222	19.021	8.853	0.263	0.004
I2	0.004	29.378	0.187	1.304	4.928	0.155	13.323	4.620	0.182	0.005
I2 (lab dup)	0.004	29.867	0.208	1.291	4.981	0.159	13.340	4.644	0.184	0.003
June 1, 2004										
I1	0.056	42.959	0.199	4.894	6.144	0.157	18.743	7.624	0.247	0.005
I2	0.011	24.757	0.236	1.525	3.311	0.139	9.766	4.211	0.139	0.005
I2 (lab dup)	0.010	24.837	0.236	1.523	3.326	0.140	9.820	4.225	0.139	0.004

Table 8-J Physical Properties at Oakalla Biofiltration System, Burnaby (Pond I)

Note: I1 indicates inlet; I2 indicates outlet; and (dup) indicates a duplicate sample

Parameter	Temperature (°C)	Conductivity (μS/cm)	Specific Conductivity (μS/cm)	Dissolved Oxygen (mg/L)	pH
Date & Site					
July 10, 2003					
I1	19.6	247.1	283.2	11.2	7.19
I2	21.2	242.9	262.7	11	7.51
Nov. 15, 2003					
I1	11	218.6	298.4		7.02
I2	5.1	142.9	231		7.31
Dec. 8, 2003					
I1	9.5	222	315	6.97	7.71
I1 (dup)					7.74
I2	5.8	169.4	267.5	7.4	7.43
Jan. 14, 2004					
I1	8.2	169.1	249.3	10.2	7.32
I2	8	101.8	150.5	9.4	7.21
Feb. 4, 2004					
I1	8.5	209.1	305.6	8.5	7.52
I2	6.5	90.9	140.5	8	7.35
March 2, 2004					
I1	10	424		9.26	7.79
I2	7.3	355		8.84	
March 23, 2004					
I1	10.2	276.2	385.3	9.4	7.91
I2	10.5	255.3	353.2	9.4	7.52
April 20, 2004					
I1	10.9	184.7	252.6	9.6	7.06
I2	10.6	116.3	160.3	9	7.2
I2	10.6	127.9	176.3	6.1	
May 13, 2004					
I1	13.2	304.6	393.4	9.3	7.65; 7.65
I2	17.1	230.8	272.1	8.3	7.42
June 1, 2004					
I1	13.6	139.2	177.7	8.7	7.69; 7.75
I2	13.6	176.8	226.2	3.7	7.14

Appendix IX –
Sediment Sampling Results

Table 9-A Sediment Quality Results at 52Ave/221A Street Detention Facility, Langley (Pond D)

Note: D1 indicates inlet; D2 indicates outlet; D3 indicates sampling point before bridge; D4 indicates small inlet from 52 Avenue; D5 indicates the 221A Street ditch; (dup) indicates a duplicate sample
Shading indicates value below detection limit
Results given in mg/kg

Element	Al	Ca	Co	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	P	Si	Zn
Detection Limit	0.2	0.1	0.1	0.05	0.1	0.1	0.5	0.05	0.01	1	0.1	0.25	0.075	0.025
Date & Site														
09-Jul-03														
D1	15640.252	4213.855	11.338	33.609	32.783	23607.537	942.221	6358.381	433.477	267.929	30.059	797.371	1024.820	102.867
D2	15328.752	5048.965	12.145	36.973	39.880	24311.337	1244.950	7501.341	503.700	282.733	32.151	922.723	937.617	180.563
D2(dup)	12413.352	4461.845	10.627	29.975	37.428	19779.737	1090.940	6511.261	466.263	217.774	26.669	869.800	1079.900	170.762
14-Nov-03														
D1	10652.229	8992.576	16.632	45.604	98.737	18347.300	725.139	3989.046	3318.348	338.497	44.870	1221.350	2078.750	471.913
D2	9275.217	4644.699	9.722	22.269	41.638	15850.792	896.579	4736.897	533.920	197.843	23.249	884.425	1300.752	180.359
D3	10370.920	6639.708	10.102	24.532	53.038	15581.287	797.053	4513.759	629.420	238.569	20.131	880.458	1584.446	187.407
09-Dec-04														
D1	16604.088	13910.996	13.735	35.759	74.699	21908.214	1126.248	5894.363	671.664	502.403	31.370	1189.475	2468.267	293.142
D2	8503.749	3637.496	8.601	20.159	31.602	14540.996	801.363	4532.126	419.543	203.515	18.728	755.133	1020.700	142.643
D3	11737.752	5527.184	10.649	27.416	49.016	16946.332	891.610	5064.481	536.934	206.474	22.997	877.451	1560.386	176.961
D3(dup)	10401.429	4417.556	9.128	25.203	40.078	15542.796	780.503	4602.196	440.661	177.103	20.569	713.754	1139.170	146.082
D4	10895.177	9272.807	9.027	26.342	48.133	16098.709	870.710	4909.491	308.441	291.215	20.855	845.041	1245.802	171.892
14-Jan-04														
D1	8914.563	3456.976	8.341	22.514	32.650	14066.134	851.771	4570.798	275.369	276.787	19.940	699.461	1001.911	148.826
D1(dup)	9891.149	3482.816	8.731	24.827	33.673	15560.096	915.929	5079.006	283.407	283.150	21.384	711.593	940.917	152.085
D2	14757.129	9493.016	19.968	39.743	82.600	20920.296	963.847	5911.706	879.465	475.740	31.981	1080.250	2022.490	408.989
02-Mar-04														
D1	16391.700	7700.390	18.551	45.034	87.050	26138.800	1050.950	7067.434	1995.710	526.680	38.032	1193.940	1558.540	391.378
D2	14622.500	4495.260	11.706	38.198	46.152	22903.000	1167.590	7187.604	349.143	372.982	30.717	946.282	774.605	195.797
D3	18041.200	5731.530	14.781	45.888	59.731	26240.900	1188.070	8042.444	866.488	406.886	35.891	1032.130	1058.760	249.153
D5	14659.901	4199.059	11.005	39.336	35.440	26176.139	1344.228	8687.548	392.516	298.943	32.939	513.065	507.245	74.413
19-Apr-04														
D1	15414.200	8740.440	18.998	41.263	105.981	24487.000	1002.140	6913.044	1647.410	539.906	37.406	1167.670	1712.070	457.328
D2	12928.515	4055.119	11.938	32.596	37.051	20381.782	1116.723	6980.895	425.009	273.052	28.734	785.845	690.307	166.861
01-Jun-04														
D1	12730.100	9339.440	15.078	33.767	83.878	18475.400	853.926	5299.534	1191.590	463.707	31.219	1095.440	1837.560	462.325
D2	10332.800	3586.170	9.677	25.318	31.657	15739.900	882.844	5512.214	323.385	239.558	23.117	674.639	781.105	151.920
D5	12331.881	4041.693	11.411	31.514	32.611	21956.139	1159.149	7711.657	495.073	248.862	29.483	569.979	635.419	88.033
D5(dup)	12029.000	3912.280	11.144	30.059	31.430	20969.900	1108.350	7398.294	474.837	240.324	28.306	555.942	621.217	84.774

Table 9-B Particle Size Results at 52Ave/221A Street Detention Facility, Langley (Pond D)

Note: D1 indicates inlet; and D2 indicates outlet

Results given in percent

Fraction	% Sand	% Silt	%Clay
Site & Date			
July 9, 2003			
D1	12.96	61.33	22.80
D2	11.62	59.13	24.87
Jan. 14, 2004			
D1	27.81	56.33	15.13
D2	86.18	5.93	7.13
June 1, 2004			
D1	91.47	6.42	1.20
D2	49.29	38.48	9.86

Table 9-C Sediment Quality Results at Griffin Park Biofiltration Pond, North Vancouver (Pond E)

Note: E1 indicates inlet; E2 indicates outlet; E3 indicates sampling point in middle of pond; and E4 indicates Mosquite Creek baseflow and (dup) indicates a duplicate sample
Shading indicates value below detection limit
Results given in mg/kg

Element	Al	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	P	Pb	Si	Zn
Detection Limits	0.2	0.1	0.1	0.05	0.1	0.1	0.5	0.05	0.01	1	0.1	0.25	0.25	0.075	0.025
Date & Site															
10-Jul-03															
E1	22797.752	7828.325	6.649	33.956	223.549	38920.337	770.936	2591.151	575.985	596.954	16.952	1685.220	189.674	3949.548	585.420
E2	13827.052	3390.665	4.906	21.610	151.921	38980.237	458.837	2172.791	590.860	263.029	10.743	1021.120	187.774	2772.490	298.112
E4	15985.893	4795.807	2.956	14.057	84.565	19491.522	561.853	3175.852	591.551	313.726	11.524	917.499	237.467	3411.287	152.198
14-Jul-03															
E1	13685.052	6899.535	5.736	28.161	238.695	33734.937	799.909	2662.681	1133.920	407.625	16.431	1430.840	172.051	2312.180	582.082
07-Sep-03															
E1	12606.365	8825.283	2.966	31.383	278.160	18153.758	796.975	2175.541	437.206	298.040	19.428	1680.416	240.992	2669.089	840.074
E2	13219.930	5295.253	0.138	13.347	88.258	21882.273	544.089	1876.719	381.639	238.170	7.791	911.278	288.660	3043.079	187.761
E4	11927.454	4135.223	0.730	19.950	145.107	30069.897	597.912	1753.333	453.799	244.009	10.431	954.978	296.541	2624.515	380.647
15-Nov-03															
E1	9726.149	3892.846	1.822	25.467	221.202	13001.700	415.406	1504.966	156.474	183.602	13.320	1228.000	194.937	1934.840	621.243
E2	18633.829	3028.856	-0.065	14.842	81.260	21252.500	357.405	1182.186	320.465	122.785	6.216	674.402	75.536	3453.130	228.212
08-Dec-03															
E1	8415.346	5056.006	2.529	28.713	289.982	12270.392	540.997	2263.551	187.652	306.983	17.194	1496.198	162.212	1822.881	807.885
E2	9912.801	1798.382	-0.422	7.615	45.388	10977.916	229.965	821.550	258.129	70.464	4.159	386.600	44.820	1923.356	137.388
14-Jan-04															
E1	9485.059	4865.986	2.119	32.906	303.730	15264.896	580.539	2955.186	201.039	417.038	19.721	1265.080	153.303	1552.250	716.804
E2	24371.019	3027.887	-0.241	17.295	87.761	23363.857	406.201	1848.313	278.499	204.006	8.635	724.895	98.169	5085.782	232.015
02-Mar-04															
E1	14024.257	5021.990	1.369	32.102	226.288	23571.485	514.184	3022.944	371.554	338.077	15.901	1338.673	150.149	2028.485	509.158
E2	21818.020	3552.307	0.337	23.082	106.173	27236.040	421.149	2783.647	488.818	215.577	11.313	890.562	94.654	3669.129	280.722
20-Apr-04															
E1	12364.356	9423.079	2.085	47.634	338.303	26487.525	636.327	4089.776	640.966	393.591	24.273	1645.040	254.176	2651.010	652.604
E2	27491.500	3380.350	0.408	23.574	111.716	28000.900	457.319	3019.214	541.962	250.550	11.578	924.019	120.518	4950.880	296.603
01-Jun-04															
E1	11072.673	8488.792	1.440	42.400	279.044	24478.317	581.671	3210.964	580.696	333.018	24.071	1646.446	233.804	2611.396	680.938
E2	16049.604	3329.980	0.180	17.453	104.432	21358.515	428.042	1835.182	851.998	193.966	10.864	883.246	97.440	3658.822	348.740
E3	11711.881	4115.267	1.644	31.717	252.048	14685.446	562.256	2617.875	204.788	355.159	16.997	1258.495	171.779	2081.129	662.609

Table 9-D Particle Size Results at Griffin Park Biofiltration Pond, North Vancouver (Pond E)

Note: E1 indicates inlet; E2 indicates outlet; E3 indicates sampling point in middle of pond and (dup) indicates a duplicate sample

Results given in percent

Fraction	**% Sand**	**% Silt**	**%Clay**
Date & Site			
July 10, 2003			
E1	87.13	7.80	5.07
E2	80.59	8.33	6.13
E3	91.13	5.60	3.27
E3 (dup)	90.40	5.87	3.73
July 14, 2003			
E1	61.84	23.80	9.80
Jan. 14. 2004			
E1	76.36	16.50	6.33
E2	74.98	12.19	11.79
June 1, 2004			
E1	95.54	2.99	0.53
E2	72.72	17.09	6.66
E3	71.03	20.85	2.27

Table 9-E Sediment Quality Results at Westview Interchange Detention Pond, North Vancouver (Pond F)

Note: F1 indicates inlet; F2 indicates outlet; F3 indicates sampling point in middle of pond; F4 indicates sample of clay liner at outlet; and F5 indicates sample of clay liner in middle of pond; and (dup) indicates a duplicate sample
Shading indicates value below detection limit
Results given in mg/kg

Element	Al	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	P	Pb	Zn
Detection Limits	0.2	0.1	0.1	0.05	0.1	0.1	0.5	0.05	0.01	1	0.1	0.25	0.25	0.025
10-Jul-03														
F1	9784.477	3752.658	6.915	72.977	776.550	17635.383	871.179	3836.288	206.456	353.391	20.480	1039.713	214.075	1117.980
F2	14044.705	3884.480	6.790	102.817	620.729	20647.463	1348.545	5646.397	268.779	415.837	24.738	998.515	272.548	1081.743
F3	13718.652	4160.445	8.429	98.961	715.656	19904.537	1200.830	5467.731	268.108	469.075	27.838	940.966	274.239	1344.110
F4	20065.794	4028.698	3.547	30.273	178.880	34203.898	2130.752	9456.179	390.812	428.020	18.064	1022.327	37.721	209.639
F5	17347.552	3791.105	3.027	35.338	373.868	24867.037	1594.530	7223.981	292.427	370.791	16.835	1086.750	86.625	296.136
14-Jul-03														
F1	9216.071	5566.777	11.015	86.539	693.662	21050.730	871.481	3849.476	307.181	442.067	27.773	1082.604	314.011	1663.842
07-Sep-03														
F1	11362.029	6628.186	9.586	95.982	830.087	23169.096	1084.290	3894.666	340.697	392.195	31.491	1347.770	427.632	2127.270
F2	11552.629	3790.146	3.493	94.935	510.293	20076.596	1248.280	3774.636	244.465	340.971	20.671	1079.140	298.138	1072.910
15-Nov-03														
F1	6488.579	3491.116	5.430	58.912	415.746	11589.300	622.789	2101.756	157.501	264.403	22.861	835.463	229.931	1155.820
F2	9163.494	3138.609	5.867	70.754	460.173	13651.386	949.958	3114.818	162.754	309.358	17.722	854.148	241.206	1215.386
F2 (dup)	8437.419	2978.746	5.622	67.050	436.915	12312.700	903.402	2754.946	147.290	276.073	16.391	815.786	234.645	1190.810
08-Dec-03														
F1	6419.563	3504.748	4.074	56.055	369.733	13021.085	584.809	2412.412	171.274	294.050	18.311	750.912	191.230	1021.158
F2	9107.119	3035.726	6.646	72.416	483.750	12790.496	947.953	2940.176	150.250	357.151	17.749	874.483	269.002	1377.530
14-Jan-04														
F1	6377.425	3190.421	4.229	53.000	329.398	11230.590	733.006	2321.907	151.931	376.397	14.862	757.203	180.404	1039.198
F2	11788.742	2691.025	1.034	39.709	239.303	17497.421	1263.653	4410.323	212.135	532.269	13.489	813.664	107.264	485.014
02-Mar-04														
F1	12264.700	4876.490	2.489	89.465	452.594	20394.500	1163.750	5785.284	277.380	635.889	24.579	929.979	207.176	903.597
F2	15461.584	4500.891	2.885	103.210	502.560	25553.762	1348.485	6778.825	330.081	660.371	26.406	902.547	235.009	950.241
20-Apr-04														
F1	10145.600	4456.450	1.844	72.812	340.595	17357.200	915.705	4532.494	237.111	464.483	20.967	896.010	167.386	803.239
F1(dup)	8908.366	4097.723	1.844	67.150	317.003	15303.762	868.027	3855.598	208.461	402.328	19.218	863.895	163.134	774.699
F2	12983.800	3807.320	2.050	90.681	466.478	21068.700	1135.340	5525.444	273.900	448.043	20.812	902.908	199.593	776.848
01-Jun-04														
F1	10698.416	6409.762	3.027	89.138	507.624	23484.851	800.775	3813.528	371.679	413.131	32.165	1462.455	222.604	1027.218
F2	14651.089	4027.188	1.877	102.970	463.831	22975.347	1241.554	6330.489	290.428	536.182	25.110	926.085	224.707	890.153
F3	14415.800	4263.760	3.077	99.602	507.921	22234.700	1266.510	6349.024	285.547	640.686	27.757	889.686	232.480	1113.020

Table 9- F Particle Size Results at Westview Interchange Detention Pond, North Vancouver (

Note: F1 indicates inlet; F2 indicates outlet; F3 indicates sampling point in middle of pond; F4 indicates sample of clay liner at outlet; F5 indicates sample of clay liner in middle of pond; and (dup) indicates a duplicate sample
Results given in percent

Fraction	% Sand	% Silt	%Clay
Date & Site			
July 10, 2003			
F1	62.40	31.07	2.93
F2	25.35	62.60	8.80
F3	21.25	61.53	9.33
F4	2.77	81.87	14.80
F5	10.50	76.27	9.87
July 14, 2003			
F1	78.52	12.27	3.07
Jan. 14, 2004			
F1	59.61	29.11	8.53
F2	26.59	60.00	12.53
June 1, 2004			
F1	93.85	1.86	3.73
F2	37.65	45.69	12.86
F3	28.35	57.58	9.33

Table 9-G Sediment Quality Results at Tempe Heights Constructed Wetland, North Vancouver (Pond G)

Note: G1 indicates inlet; G2 indicates outlet; G3 indicates sampling point in middle of pond; and (dup) indicates a duplicate sample
Shading indicates value below detection limit
Results given in mg/kg

Element	Al	As	B	Ba	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	P	Pb	Se	Si	Sr	Zn
Detection Limits	0.2	0.25	0.1	0.1	0.1	0.1	0.1	0.05	0.1	0.1	0.5	0.05	0.01	0.05	1	0.1	0.25	0.25	0.5	0.075	0.0025	0.025
09-Jul-03																						
G1	13069.152	17.641	7.095	103.974	13884.025	3.953	6.847	39.695	364.204	18023.137	563.401	3171.011	139.019	1.864	381.556	21.316	1685.570	123.890	-0.528	1859.360	69.259	719.877
G2	15427.252	9.480	3.176	79.264	7564.525	2.570	7.372	23.269	157.545	20245.737	722.940	2789.341	226.762	0.910	549.323	11.046	1023.550	80.911	0.312	3116.630	43.441	312.362
G3	16173.752	17.889	3.839	79.867	7321.855	4.172	8.518	25.096	204.461	33297.737	806.985	3218.371	210.245	1.251	686.841	12.477	1096.680	85.930	-1.312	3345.480	42.057	392.899
G3 (dup)	15845.452	17.844	3.788	80.515	7346.225	4.112	8.209	24.448	198.424	33134.137	806.768	3039.581	205.180	0.774	705.044	11.856	1088.030	86.753	-0.718	3529.340	42.103	392.130
14-Jul-03																						
G1	15059.452	26.601	8.633	131.196	23496.325	3.977	7.288	40.869	320.380	18886.437	726.843	4287.001	177.635	1.676	1422.630	20.586	1801.900	101.321	0.116	3204.090	107.504	751.575
G2	13436.652	16.920	4.070	72.119	7459.555	4.596	8.107	24.708	218.349	38421.037	781.897	2968.031	273.412	0.757	831.693	11.829	1101.220	82.411	-0.696	3664.460	42.963	415.742
07-Sep-03																						
G1	10978.544	19.593	7.517	88.213	11625.946	2.100	5.738	34.652	334.569	12742.273	605.222	2348.372	98.136	1.251	434.191	16.932	1569.891	171.638	-0.673	2210.208	59.784	851.825
G2	14358.940	7.486	3.451	75.601	8421.213	0.003	6.631	19.500	155.866	17169.798	674.439	1834.105	143.576	0.407	264.452	8.850	937.377	90.669	-0.960	3335.762	41.346	351.222
08-Dec-03																						
G1	10710.329	11.091	5.479	90.072	8326.716	1.414	6.139	27.218	300.819	13795.496	558.450	2507.206	113.732	1.060	297.501	14.966	1261.760	104.143	-1.065	1699.380	48.397	609.955
G2	12409.633	7.712	1.682	66.570	5087.273	-0.165	5.542	17.457	118.185	14451.679	514.992	1704.026	128.762	0.309	155.214	8.978	760.013	61.777	-1.086	2488.812	29.705	282.429
14-Jan-04																						
G1	6919.237	5.690	4.649	50.397	4577.629	0.409	4.208	19.059	231.155	9249.966	375.816	2017.353	81.847	1.117	242.035	10.463	736.369	63.474	-1.275	945.244	32.304	348.808
G2	14582.405	8.910	2.482	67.828	5924.352	-0.078	6.995	20.246	146.128	17439.996	624.828	2457.115	204.377	0.479	386.187	11.261	890.995	76.977	-1.206	2509.812	36.930	295.922
02-Mar-04																						
G1	13248.500	16.522	7.259	116.808	14987.700	1.582	8.450	39.709	441.882	19284.600	606.215	3924.084	271.481	2.384	597.195	22.998	1605.120	121.245	-0.570	1819.760	93.688	627.196
G1(dup)	12629.200	16.082	6.909	115.292	14905.500	1.576	8.014	37.523	411.772	18118.700	583.093	3703.844	263.381	1.871	558.997	21.305	1576.150	119.601	-0.537	1970.970	92.462	620.134
G2	17368.200	14.104	3.225	78.323	7169.290	0.078	8.879	27.422	162.170	25228.800	630.506	3381.104	280.655	0.844	398.627	13.485	1069.290	87.179	-0.332	2666.640	46.086	344.167
20-Apr-04																						
G1	10960.891	10.789	9.019	86.948	12663.564	1.133	6.234	29.898	273.034	14038.416	842.911	3533.479	128.307	0.018	1074.525	16.286	1310.109	136.598	-0.099	2697.248	74.878	566.548
G2	17375.400	11.215	3.707	79.390	8750.910	0.135	8.334	24.809	162.622	20842.500	746.855	2835.474	197.088	0.631	526.555	11.633	1090.480	100.379	-0.145	3261.910	53.147	355.195
01-Jun-04																						
G1	11597.228	17.630	8.255	109.094	14652.079	1.229	7.643	46.353	399.556	16607.723	715.662	3720.212	218.016	2.285	826.807	25.021	1497.673	119.002	1.077	1892.703	112.233	675.192
G2	16079.505	9.909	2.540	73.230	6040.208	-0.115	8.840	22.814	158.478	16742.871	600.737	2760.231	165.309	1.199	324.910	12.555	929.213	80.310	-0.799	2639.327	38.565	306.445
G2(dup)	15774.356	9.065	2.274	72.106	5941.416	0.680	8.788	22.360	154.852	16465.842	589.367	2707.608	162.233	1.082	318.779	11.845	910.223	79.323	-0.669	2621.545	37.812	299.727
G3	14004.059	15.077	2.273	59.829	27078.911	-0.312	9.841	19.777	147.321	41842.277	543.803	2772.924	247.509	1.050	251.304	12.704	868.863	65.638	0.753	3734.911	79.836	287.398

Table 9-H Particle Size Results at Tempe Heights Constructed Wetland, North Vancouver (Pond G)

Note: G1 indicates inlet; G2 indicates outlet

Results given in percent

Fraction	% Sand	% Silt	%Clay
Date & Site			
July 9, 2003			
G1	96.40	1.13	2.47
G2	13.80	76.67	9.53
G3	50.45	31.47	9.00
July 14, 2003			
G1	93.39	1.67	1.40
G2	52.97	30.80	8.20
Jan. 14, 2004			
G1	70.55	8.07	19.00
G2	63.35	19.93	14.40
June 1, 2004			
G1	96.47	2.59	0.13
G2	67.37	25.85	1.07
G2 (dup)	65.39	25.81	4.46
G3	95.26	2.99	1.47

Table 9-I Sediment Quality Results at Oakalla Biofiltration System, Burnaby (Pond I)

Note: I1 indicates inlet; I2 indicates outlet; I3 indicates sampling point at middle of pond; and (dup) indicates a duplicate sample
Shading indicates value below detection limit
Results given in mg/kg

Element Detection Limits	Al 0.2	Ca 0.1	Cd 0.1	Cr 0.05	Cu 0.1	Fe 0.1	K 0.5	Mg 0.05	Mn 0.01	Na 1	Ni 0.1	P 0.25	Pb 0.25	Si 0.075	Zn 0.025
10-Jul-03															
I1	18307.552	13051.925	3.429	41.817	107.532	27826.237	1083.820	4798.321	2604.780	731.224	22.693	1536.490	52.666	3297.140	599.775
I2	21765.552	6819.615	2.372	31.415	71.001	22836.637	1241.420	5326.491	670.575	484.045	17.866	1338.150	32.880	2423.230	204.229
14-Nov-03															
I1	17012.405	5539.105	-0.352	20.956	62.972	16334.554	529.962	2068.115	817.020	162.301	9.915	1508.535	42.295	3027.861	234.270
09-Dec-03															
I1	11816.129	7729.876	-0.425	18.924	51.184	13980.396	487.328	2852.086	1761.708	163.881	11.305	671.652	27.804	1896.630	235.383
I2	12542.108	5316.501	-0.238	32.675	90.342	16701.283	871.921	3023.333	958.492	258.288	12.155	964.719	30.141	1139.822	366.418
14-Jan-04															
I1	12372.229	14909.706	0.252	35.959	99.176	21497.496	590.502	3352.076	4102.588	244.164	16.808	1177.760	62.202	3259.440	487.703
I2	12109.729	4782.776	-0.360	27.485	76.977	15006.596	857.226	2421.386	780.117	398.953	14.493	978.400	30.790	1553.850	268.315
02-Mar-04															
I1	14120.000	12476.200	0.824	53.192	125.525	34480.500	667.633	5222.744	4754.580	424.929	21.838	1571.100	89.554	2696.340	628.166
I2	17343.663	6298.960	-0.043	41.437	89.296	22851.683	1063.208	4797.192	1013.307	556.972	17.553	1135.604	33.811	1091.129	350.564
20-Apr-04															
I1	13804.300	22986.500	0.607	36.721	109.406	23396.500	720.571	4384.964	3175.030	472.400	15.893	1389.050	69.885	4015.490	609.203
I2	16021.100	5833.230	-0.177	29.520	70.493	18113.700	1051.430	3864.924	781.495	439.346	14.185	1079.640	29.392	1779.880	226.519
01-Jun-04															
I1	17623.762	8884.317	-0.702	31.808	78.400	22378.911	947.919	5377.766	1377.881	340.150	23.494	967.370	43.042	1605.624	278.400
I2	21788.713	6829.089	-0.681	36.320	75.318	24697.426	1219.782	5697.657	785.501	515.007	18.922	1184.257	54.426	1665.485	240.094
I3	14794.257	9463.287	-0.347	33.672	91.358	21169.307	930.385	4239.291	541.844	1538.782	16.233	1214.119	50.048	1950.475	321.724

Table 9-J Particle Size Results at Oakalla Biofiltration System, Burnaby (Pond I)

Note: I1 indicates inlet; I2 indicates outlet; I3 indicates sampling point at middle of pond; and (dup) indicates a duplicate sample

Results given in percent

Fraction	% Sand	% Silt	%Clay
Date & Site			
July 9, 2003			
I1	94.07	4.00	1.93
I2	20.20	57.60	20.73
Jan. 14, 2003			
I1	94.08	3.53	2.00
I1 (dup)	93.85	4.67	1.00
I2	30.43	49.07	19.33
June 1, 2004			
I1	93.95	3.93	1.53
I2	25.54	58.21	14.20
I3	27.62	63.70	5.73

Appendix X –
DGT Results

Table 10-A DGT Unit Results at 52Ave/221A Street Detention Facility, Langley (Pond D)

Note: D1 indicates inlet; D2 indicates outlet; D3 indicates sampling point before bridge; D4 indicates small inlet from 52 Avenue; (dup) indicates a duplicate DGT unit

Shading indicates value below detection limit

Results given in mg/L

Parameter	Al	Fe	Mn	Zn
Date & Site				
Sept.17 to Oct.3				
D1			0.013	0.002
D2		0.008	0.017	0.002
D2(dup)		0.007	0.021	0.003
Nov.14 to Dec.9				
D1	0.018	0.022	0.080	0.005
D2	0.003	0.003	0.011	0.001
D3	0.021	0.023	0.028	0.009
D4	0.022	0.009	0.006	0.008
Dec.9 to Jan.14				
D1	0.006	0.004	0.045	0.006
D1(dup)	0.002	0.003	0.063	0.005
D2	0.011	0.005	0.016	0.007
Jan.14 to Feb.4				
D1	0.004	0.003	0.028	0.005
D2	0.024	0.010	0.005	0.006
Feb.4 to Mar.2				
D1	0.002	0.002	0.010	0.002
D1 (dup)	0.002	0.002	0.010	0.002
D2	0.008	0.002	0.008	0.003
Mar.2 to Mar.23				
D1	0.004	0.003	0.011	0.004
D1 (dup)	0.004	0.003	0.014	0.004
D2				
Mar.23 to Apr.20				
D1	0.003	0.002	0.036	0.002
D1 (dup)	0.003	0.002	0.026	0.002
D2	0.002	0.004	0.007	0.002
Apr.20 to May 13				
D1	0.003	0.002	0.008	0.003
D1 (dup)	0.003	0.002	0.045	0.002
D2	0.002	0.185	0.174	0.001
May 13 to June 1				
D1	0.003	0.003	0.018	0.003
D1 (dup)	0.003	0.003	0.070	0.002
D2	0.003	0.008	0.152	0.001

Table 10-B DGT Unit Results at Griffin Park Biofiltration Pond, North Vancouver (Pond E)

Note: E1 indicates inlet; E2 indicates outlet; and (dup) indicates a duplicate sample
Shading indicates value below detection limit
Results given in mg/L

Parameter	Al	Fe	Mn	Zn
Date & Site				
Nov.14 to Dec.9				
E1	0.027		0.008	0.014
E2	0.008	0.008	0.002	0.011
E2 (dup)	0.003	0.006	0.002	0.011
Dec.9 to Jan.14				
E1	0.018	0.014	0.008	0.015
E2	0.005	0.005	0.005	0.011
E2 (dup)	0.004	0.004	0.006	0.010
Jan.14 to Feb.4				
E1	0.017	0.011	0.005	0.010
E2	0.004	0.003	0.003	0.011
E2 (dup)	0.004	0.003	0.004	0.011
Feb.4 to Mar.2				
E1	0.011	0.002	0.004	0.006
E2	0.006	0.004	0.003	0.007
E2 (dup)	0.005	0.002	0.004	0.006
Mar.2 to Mar.23				
E1	0.017	8.377	0.005	0.011
E2	0.004	0.003	0.004	0.009
E2 (dup)	0.004	0.003	0.006	0.009
Mar.23 to Apr.20				
E1	0.023	0.013	0.003	0.007
E2	0.021	0.012	0.014	0.005
E2 (dup)	0.034	0.002	0.003	0.004
Apr.20 to May 13				
E1	0.028	0.002	0.001	0.006
E2	0.006	0.005	0.015	0.006
E2 (dup)	0.009	0.002	0.011	0.005
May 13 to June 1				
E1	0.034	0.014	0.003	0.009
E2	0.011	0.033	0.038	0.006
E2 (dup)	0.006	1.868	0.031	0.001

Table 10-C DGT Unit Results at Westview Interchange Detention Pond, North Vancouver (Pond F)

Note: F1 indicates inlet; F2 indicates outlet
Shading indicates value below detection limit
Results given in mg/L

Parameter	Al	Fe	Mn	Zn
Date & Site				
Oct.10 - Oct.23				
F1	0.012	0.056	0.024	0.022
F2	0.003	0.014	0.008	0.014
Nov.14 to Dec.9				
F1	0.003	0.008	0.013	0.032
F2	0.003	0.003	0.007	0.029
Dec.9 to Jan.14				
F1				
F2	0.007	0.007	0.010	0.053
Jan.14 to Feb.4				
F1	0.052	0.053	0.013	0.031
F2	0.004	0.034	0.020	0.035
Feb.4 to Mar.2				
F1				
F2	0.006	0.004	0.006	0.022
Mar.2 to Mar.23				
F1	0.035	0.794	0.027	0.041
F2	0.003	0.003	0.009	0.034

Table 10-D DGT Unit Results at Tempe Heights Constructed Wetland, North Vancouver (Pond G)

Note: G1 indicates inlet; G2 indicates outlet
Shading indicates value below detection limit
Results given in mg/L

Parameter	Al	Fe	Mn	Zn
Date & Site				
Oct.10 - Oct.23				
G1	0.022	0.028	0.011	0.034
G2	0.003	0.006	0.007	0.060
Nov.14 to Dec.9				
G1				
G2				
Dec.9 to Jan.14				
G1	0.002	0.078	0.007	0.011
G2	0.010	0.025	0.016	0.010
Jan.14 to Feb.4				
G1	0.004	0.026	0.010	0.012
G2	0.009	0.027	0.019	0.013
Feb.4 to Mar.2				
G1	0.004	0.022	0.006	0.009
G2	0.003	0.002	0.011	0.005
Mar.2 to Mar.23				
G1	0.003	0.087	0.008	0.010
G2	0.004	0.003	0.010	0.006
Mar. 23 - Apr. 20				
G1	0.002	0.784	0.005	0.006
G2	0.002	0.002	0.005	0.002
Apr. 20 - May 13				
G1	0.003	0.011	0.007	0.009
G2	0.003	0.002	0.012	0.002
May 13 - June 1				
G1	0.003	0.012	0.022	0.009
G2	0.003	0.002	0.008	0.003

Table 10- E DGT Unit Results at Oakalla Biofiltration System, Burnaby (Pond I

Note: I1 indicates inlet; I2 indicates outlet; and (dup) indicates a duplicate DGT unit
Shading indicates value below detection limit
Results given in mg/L

Parameter	Al	Fe	Mn	Zn
Date & Site				
Nov.14 to Dec.9				
I1	0.011	0.017	0.069	0.009
I2				
Dec.9 to Jan.14				
I1	0.025	0.046	0.081	0.011
I2	0.002	0.006	0.043	0.006
Jan.14 to Feb.4				
I1	0.008	0.015	0.067	0.007
I2	0.004	0.006	0.013	0.005
Feb.4 to Mar.2				
I1	0.005	0.015	0.098	0.007
I2	0.003	0.007	0.018	0.004
Mar.2 to Mar.23				
I1	0.057	0.087	0.086	0.013
I2	0.003	0.006	0.009	0.003
Mar.23 to Apr.20				
I1	0.023	0.032	0.082	0.007
I2	0.005	0.021	0.026	0.001
Apr.20 to May 13				
I1	0.003	0.002	0.056	0.006
I2	0.003	0.002	0.024	0.002
I2 (dup)	0.003	0.002	0.025	0.002
May 13 to June 1				
I1				
I2	0.003	0.003	0.025	0.003

Appendix XI –
Correlations with Precipitation

52Ave/221A Street Detention Facility, Langley - Inlet Correlations With Precipitation

Water				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_water	**0.75**	**0.80**	**0.87**	0.31
Ca_water	-0.48	**-0.54**	**-0.53**	**-0.72**
Fe_water	0.25	0.36	0.41	0.13
K_water	-0.42	-0.19	-0.14	**-0.85**
Mg_water	-0.49	**-0.60**	**-0.59**	**-0.63**
Mn_water	0.14	0.43	0.29	-0.06
Na_water	-0.49	**-0.60**	**-0.62**	**-0.65**
Si_water	-0.35	-0.32	-0.23	**-0.52**
Zn_water	0.35	0.14	0.30	-0.09
Temp	-0.52	**-0.54**	-0.39	**-0.72**
Cond.	**-0.67**	**-0.81**	**-0.80**	**-0.78**
Sp. Cond.	-0.40	-0.56	**-0.63**	**-0.60**
DO	0.21	-0.02	0.09	-0.21
pH	-0.52	**-0.64**	-0.51	-0.41

DGT				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_dgt	0.29	0.48	0.52	**0.88**
Fe_dgt	0.22	0.36	0.40	**0.83**
Mn_dgt	-0.15	0.24	0.50	0.31
Zn_dgt	0.37	0.47	0.55	**0.76**

Sediment				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_sed	-0.63	-0.44	**-0.77**	0.16
Ca_sed	-0.33	-0.11	-0.02	0.27
Cr_sed	-0.49	-0.52	-0.36	-0.38
Cu_sed	0.06	0.00	0.11	-0.27
Fe_sed	-0.35	-0.37	**-0.68**	-0.23
K_sed	-0.24	-0.04	-0.50	0.41
Mg_sed	-0.18	-0.19	-0.58	-0.07
Mn_sed	-0.39	-0.48	-0.25	-0.45
Na_sed	0.06	0.15	-0.05	0.22
Ni_sed	-0.49	-0.52	-0.36	-0.38
P_sed	-0.63	-0.59	-0.43	-0.23
Pb_sed	0.16	0.11	0.09	-0.05
Si_sed	-0.43	-0.22	-0.09	0.14
Zn_sed	-0.02	-0.07	0.27	-0.22

52Ave/221A Street Detention Facility, Langley - Outlet Correlations With Precipitation

Water				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_water	0.33	0.23	0.32	**0.82**
Ca_water	**-0.54**	**-0.66**	**-0.62**	**-0.73**
Fe_water	0.19	0.00	0.18	0.28
K_water	-0.41	-0.33	-0.25	**-0.77**
Mg_water	**-0.53**	**-0.67**	**-0.69**	**-0.71**
Mn_water	-0.39	-0.50	**-0.52**	**-0.55**
Na_water	-0.09	-0.27	-0.31	0.06
Si_water	**-0.65**	-0.46	-0.45	-0.24
Zn_water	0.14	-0.02	0.37	-0.01
Temp	-0.20	-0.32	-0.27	**-0.63**
Cond.	**-0.82**	**-0.73**	**-0.64**	-0.52
Sp. Cond.	**-0.75**	**-0.58**	-0.37	-0.49
DO	**0.67**	0.46	0.21	0.19
pH	-0.38	**-0.62**	**-0.80**	-0.52

DGT				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_dgt	0.41	0.52	0.43	**0.93**
Fe_dgt	0.00	0.04	0.11	0.14
Mn_dgt	-0.37	-0.49	-0.18	-0.64
Zn_dgt	0.15	0.29	0.21	**0.75**

Sediment				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_sed	0.57	0.37	0.22	0.00
Ca_sed	0.10	-0.07	0.05	-0.25
Cr_sed	0.57	0.37	0.22	0.00
Cu_sed	0.20	-0.04	0.07	-0.23
Fe_sed	0.30	0.07	-0.05	-0.20
K_sed	0.08	-0.15	-0.32	-0.47
Mg_sed	0.18	-0.04	-0.25	-0.34
Mn_sed	0.24	0.15	0.23	-0.27
Na_sed	**0.67**	0.56	0.34	0.32
Ni_sed	0.47	0.26	0.14	-0.13
P_sed	0.10	-0.07	-0.04	-0.16
Pb_sed	0.20	-0.04	0.07	-0.23
Si_sed	0.02	0.00	0.23	0.02
Zn_sed	0.20	-0.04	0.07	-0.23

Griffin Park Biofiltration Pond, North Vancouver - Outlet Correlations With Precipitation

Water				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_water	0.19	0.03	-0.01	-0.27
Ca_water	-0.44	-0.25	-0.05	**0.67**
Fe_water	**-0.51**	-0.47	-0.41	0.28
K_water	-0.39	-0.23	-0.02	**0.59**
Mg_water	-0.46	-0.27	-0.07	**0.64**
Mn_water	-0.13	0.01	0.10	**0.49**
Na_water	**-0.51**	-0.38	-0.20	**0.65**
Si_water	**-0.65**	-0.48	-0.33	0.35
Zn_water	0.36	0.38	**0.59**	0.23
Temp	-0.16	-0.18	-0.31	**-0.55**
Cond.	**-0.54**	-0.39	-0.28	0.48
Sp. Cond.	-0.37	-0.17	0.03	**0.66**
DO	0.14	0.07	-0.08	-0.30
pH	**-0.53**	-0.57	**-0.68**	0.06

DGT				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_dgt	0.12	0.15	-0.12	**-0.83**
Fe_dgt	-0.05	-0.02	0.14	0.55
Mn_dgt	0.02	-0.02	-0.36	-0.43
Zn_dgt	-0.02	0.02	0.36	**0.88**

Sediment				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_sed	0.56	0.56	0.40	0.07
Ca_sed	-0.27	-0.27	-0.47	-0.59
Cr_sed	-0.07	-0.07	-0.30	-0.12
Cu_sed	-0.29	-0.29	-0.53	-0.39
Fe_sed	-0.10	-0.10	-0.29	-0.29
K_sed	-0.10	-0.10	-0.30	**-0.63**
Mg_sed	-0.07	-0.07	-0.25	-0.27
Mn_sed	-0.27	-0.27	-0.55	-0.44
Na_sed	-0.10	-0.10	-0.28	-0.51
Ni_sed	-0.07	-0.07	-0.31	-0.05
P_sed	-0.20	-0.20	-0.40	-0.56
Pb_sed	0.15	0.15	-0.02	-0.56
Si_sed	**0.61**	**0.61**	0.43	0.22
Zn_sed	-0.12	-0.12	-0.41	-0.20

Westview Interchange Detention Pond, North Vancouver - Inlet Correlations With Precipitation

Water				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_water	**0.57**	0.42	0.41	0.03
Ca_water	-0.29	-0.18	0.08	0.50
Fe_water	0.51	0.26	0.13	-0.43
K_water	-0.50	-0.29	-0.08	**0.63**
Mg_water	-0.25	-0.15	0.10	0.45
Mn_water	0.20	0.02	-0.30	**-0.65**
Na_water	-0.40	-0.36	-0.15	**0.70**
Si_water	-0.21	-0.12	0.13	0.46
Zn_water	**0.56**	0.40	0.20	**-0.61**
Temp	-0.13	-0.15	-0.37	-0.28
Cond.	-0.50	**-0.63**	**-0.64**	0.24
Sp. Cond.	-0.22	-0.37	-0.33	0.36
DO	0.45	0.42	0.37	-0.07
pH	-0.28	-0.29	-0.07	**0.79**

DGT				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_dgt	0.74	0.80	0.00	-0.60
Fe_dgt	0.63	0.20	-0.20	-0.40
Mn_dgt	0.63	0.20	-0.20	-0.40
Zn_dgt	0.63	-0.60	**-1.00**	-0.80

Sediment				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_sed	-0.49	-0.49	**-0.68**	-0.37
Ca_sed	-0.39	-0.39	-0.53	-0.29
Cr_sed	-0.41	-0.41	-0.60	-0.46
Cu_sed	-0.44	-0.44	-0.57	-0.54
Fe_sed	-0.51	-0.51	**-0.68**	-0.27
K_sed	-0.32	-0.32	-0.53	-0.37
Mg_sed	-0.49	-0.49	-0.59	-0.15
Mn_sed	-0.41	-0.41	-0.57	-0.22
Na_sed	-0.20	-0.20	-0.40	0.17
Ni_sed	-0.24	-0.24	-0.46	-0.46
P_sed	-0.24	-0.24	-0.51	-0.54
Pb_sed	-0.07	-0.07	-0.18	**-0.63**
Si_sed	-0.02	-0.02	-0.28	**-0.68**
Zn_sed	0.27	0.27	0.22	**-0.61**

Westview Interchange Detention Pond, North Vancouver - Outlet Correlations With Precipitation

Water				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_water	0.22	0.17	0.36	0.52
Ca_water	-0.24	-0.38	-0.38	-0.13
Fe_water	0.50	0.40	0.49	0.20
K_water	-0.19	-0.28	-0.41	-0.16
Mg_water	-0.25	-0.40	-0.33	0.08
Mn_water	0.30	0.02	-0.20	**-0.64**
Na_water	-0.15	-0.30	-0.22	0.30
Si_water	0.13	0.13	0.30	0.53
Zn_water	0.34	0.16	-0.01	**-0.55**
Temp	0.14	0.06	-0.16	-0.33
Cond.	-0.24	-0.29	-0.21	0.39
Sp. Cond.	0.07	-0.02	0.08	0.27
DO	0.26	0.24	0.25	-0.04
pH	-0.08	-0.06	0.03	**0.80**

DGT				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_dgt	0.22	0.40	0.32	-0.17
Fe_dgt	0.15	**0.72**	0.54	0.14
Mn_dgt	**0.76**	**0.87**	0.60	0.09
Zn_dgt	**0.88**	0.64	0.37	-0.20

Sediment				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_sed	-0.44	-0.44	**-0.67**	0.12
Ca_sed	**-0.68**	**-0.68**	**-0.86**	-0.10
Cr_sed	**-0.71**	**-0.71**	**-0.89**	-0.15
Cu_sed	**-0.76**	**-0.76**	**-0.74**	-0.34
Fe_sed	-0.41	-0.41	**-0.63**	0.05
K_sed	-0.34	-0.34	-0.51	-0.05
Mg_sed	-0.44	-0.44	**-0.67**	0.12
Mn_sed	-0.41	-0.41	**-0.63**	0.05
Na_sed	-0.22	-0.22	-0.38	0.51
Ni_sed	**-0.68**	**-0.68**	**-0.86**	-0.10
P_sed	-0.44	-0.44	-0.56	-0.56
Pb_sed	**-0.63**	**-0.63**	-0.55	-0.39
Si_sed	0.05	0.05	-0.14	**-0.61**
Zn_sed	-0.49	-0.49	-0.29	-0.20

Tempe Heights Pond, North Vancouver - Inlet Correlations With Precipitation

Water				
	Precip_24	**Precip_48**	**Precip_72**	**Precip_dgt**
Al_water	**-0.51**	-0.50	-0.50	-0.30
Ca_water	**-0.56**	-0.34	-0.34	-0.31
Fe_water	**-0.52**	-0.50	**-0.57**	**-0.62**
K_water	0.02	0.31	0.36	0.43
Mg_water	**-0.59**	**-0.51**	-0.49	-0.48
Mn_water	-0.04	0.09	0.15	-0.02
Na_water	-0.20	-0.17	-0.09	0.34
Si_water	**-0.55**	-0.40	-0.31	0.05
Zn_water	0.34	0.34	0.32	-0.06
Temp	-0.38	-0.40	**-0.54**	**-0.70**
Cond.	**-0.76**	**-0.63**	-0.49	0.11
Sp. Cond.	-0.33	-0.07	0.07	**0.66**
DO	0.03	-0.03	-0.22	-0.13
pH	**-0.89**	**-0.85**	**-0.89**	-0.46

DGT				
	Precip_24	**Precip_48**	**Precip_72**	**Precip_dgt**
Al_dgt	**-0.66**	-0.36	-0.27	0.37
Fe_dgt	**0.67**	**0.62**	**0.69**	0.32
Mn_dgt	-0.06	0.13	0.02	0.50
Zn_dgt	-0.03	0.33	0.40	**0.89**

Sediment				
	Precip_24	**Precip_48**	**Precip_72**	**Precip_dgt**
Al_sed	**-0.74**	**-0.74**	**-0.82**	-0.54
Ca_sed	**-0.68**	**-0.68**	**-0.79**	-0.36
Cr_sed	-0.56	-0.56	**-0.71**	-0.38
Cu_sed	**-0.72**	**-0.72**	**-0.79**	-0.27
Fe_sed	**-0.88**	**-0.88**	**-0.93**	-0.29
K_sed	-0.14	-0.14	-0.25	-0.38
Mg_sed	**-0.67**	**-0.67**	**-0.71**	-0.11
Mn_sed	**-0.79**	**-0.79**	**-0.86**	-0.16
Na_sed	-0.14	-0.14	-0.25	-0.38
Ni_sed	-0.56	-0.56	**-0.71**	-0.38
P_sed	**-0.67**	**-0.67**	**-0.75**	**-0.76**
Pb_sed	-0.05	-0.05	-0.11	**-0.90**
Si_sed	0.09	0.09	-0.04	**-0.68**
Zn_sed	-0.32	-0.32	-0.43	**-0.67**

Tempe Heights Pond, North Vancouver - Outlet Correlations With Precipitation

Water				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_water	.	.	.	.
Ca_water	-0.32	**-0.52**	**-0.63**	**-0.62**
Fe_water	-0.30	-0.43	**-0.58**	**-0.53**
K_water	-0.15	-0.13	-0.18	-0.24
Mg_water	-0.30	-0.43	-0.48	**-0.84**
Mn_water	-0.24	-0.18	-0.10	0.03
Na_water	0.06	-0.24	-0.31	-0.27
Si_water	-0.46	**-0.72**	**-0.77**	**-0.60**
Zn_water	0.26	**0.60**	**0.59**	-0.06
Temp	-0.25	-0.26	-0.42	**-0.68**
Cond.	-0.44	**-0.66**	**-0.69**	**-0.75**
Sp. Cond.	0.06	-0.32	-0.45	**-0.63**
DO	-0.53	**-0.62**	**-0.67**	-0.07
pH	-0.33	-0.44	**-0.56**	**-0.61**

DGT				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_dgt	0.30	0.29	0.40	**0.84**
Fe_dgt	0.20	0.34	0.44	**0.82**
Mn_dgt	0.06	-0.06	0.07	0.33
Zn_dgt	0.03	0.39	0.50	**0.89**

Sediment				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_sed	-0.22	-0.22	-0.32	-0.29
Ca_sed	0.05	0.05	-0.04	**-0.88**
Cr_sed	-0.43	-0.43	-0.50	-0.38
Cu_sed	-0.25	-0.25	-0.36	-0.45
Fe_sed	-0.25	-0.25	-0.25	-0.47
K_sed	0.00	0.00	-0.07	**-0.85**
Mg_sed	-0.43	-0.43	-0.50	-0.38
Mn_sed	-0.38	-0.38	-0.43	-0.29
Na_sed	-0.32	-0.32	-0.43	-0.52
Ni_sed	-0.29	-0.29	-0.36	0.18
P_sed	-0.27	-0.27	-0.32	**-0.70**
Pb_sed	0.05	0.05	0.00	**-0.79**
Si_sed	0.09	0.09	0.00	**-0.94**
Zn_sed	0.05	0.05	0.00	**-0.79**

Oakalla Biofiltration System, Burnaby - Inlet Correlations With Precipitation

Water				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_water	**0.55**	**0.62**	0.46	0.20
Ca_water	**-0.65**	**-0.65**	-0.41	-0.33
Fe_water	-0.30	-0.34	-0.35	**-0.71**
K_water	**-0.68**	**-0.58**	-0.41	-0.32
Mg_water	**-0.77**	**-0.93**	**-0.80**	**-0.57**
Mn_water	**-0.83**	**-0.93**	**-0.83**	**-0.80**
Na_water	**-0.54**	**-0.59**	**-0.63**	0.00
Si_water	**-0.81**	**-0.86**	**-0.79**	**-0.73**
Zn_water	0.07	0.01	0.14	-0.50
Temp	-0.48	**-0.60**	**-0.67**	**-0.85**
Cond.	**-0.65**	**-0.78**	**-0.73**	-0.18
Sp. Cond.	-0.44	-0.49	-0.51	0.03
DO	0.27	-0.08	-0.21	-0.50
pH	-0.11	-0.08	-0.14	0.48

DGT				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_dgt	0.63	0.52	0.25	0.43
Fe_dgt	0.52	0.36	0.14	0.36
Mn_dgt	0.07	-0.18	-0.13	-0.04
Zn_dgt	0.44	0.52	0.25	**0.71**

Sediment				
	Precip_24	Precip_48	Precip_72	Precip_dgt
Al_sed	-0.30	-0.52	-0.61	**-0.79**
Ca_sed	**0.67**	0.56	0.50	0.00
Cr_sed	0.04	-0.19	-0.14	-0.25
Cu_sed	0.18	-0.04	0.04	-0.20
Fe_sed	-0.04	-0.26	-0.21	-0.32
K_sed	0.16	-0.04	-0.14	-0.52
Mg_sed	0.12	0.00	0.04	-0.04
Mn_sed	0.30	0.22	0.32	0.38
Na_sed	0.10	-0.04	-0.11	-0.32
Ni_sed	0.16	0.04	0.00	-0.05
P_sed	-0.37	-0.63	-0.57	-0.56
Pb_sed	0.35	0.15	0.25	-0.04
Si_sed	0.30	0.15	0.04	-0.47
Zn_sed	0.18	0.04	0.11	0.00

Oakalla Biofiltration System, Burnaby - Outlet Correlations With Precipitation

Water				
	Precip_24	**Precip_48**	**Precip_72**	**Precip_dgt**
Al_water	**-0.68**	**-0.78**	**-0.89**	-0.30
Ca_water	-0.44	-0.32	-0.26	-0.44
Fe_water	0.13	0.08	0.18	0.30
K_water	**-0.74**	**-0.92**	**-1.00**	**-0.58**
Mg_water	**-0.79**	**-0.86**	**-0.86**	**-0.73**
Mn_water	-0.56	**-0.63**	**-0.74**	-0.02
Na_water	**-0.80**	**-0.90**	**-0.90**	**-0.58**
Si_water	0.00	-0.09	0.01	-0.10
Zn_water	-0.09	-0.25	-0.43	-0.44
Temp	-0.56	**-0.73**	**-0.89**	-0.37
Cond.	**-0.64**	**-0.76**	**-0.85**	-0.21
Sp. Cond.	0.18	-0.20	-0.28	-0.36
DO	-0.44	-0.53	**-0.69**	0.00
pH	0.12	0.07	0.02	0.50

DGT				
	Precip_24	**Precip_48**	**Precip_72**	**Precip_dgt**
Al_dgt	0.20	0.20	0.09	-0.32
Fe_dgt	0.49	0.34	0.50	0.25
Mn_dgt	0.45	0.45	0.56	-0.11
Zn_dgt	0.31	0.45	0.50	**0.93**

Sediment				
	Precip_24	**Precip_48**	**Precip_72**	**Precip_dgt**
Al_sed	-0.30	-0.52	-0.61	**-0.79**
Ca_sed	**0.67**	0.56	0.50	0.00
Cr_sed	0.04	-0.19	-0.14	-0.25
Cu_sed	0.18	-0.04	0.04	-0.20
Fe_sed	-0.04	-0.26	-0.21	-0.32
K_sed	0.16	-0.04	-0.14	-0.52
Mg_sed	0.12	0.00	0.04	-0.04
Mn_sed	0.30	0.22	0.32	0.38
Na_sed	0.10	-0.04	-0.11	-0.32
Ni_sed	0.16	0.04	0.00	-0.05
P_sed	-0.37	-0.63	-0.57	-0.56
Pb_sed	0.35	0.15	0.25	-0.04
Si_sed	0.30	0.15	0.04	-0.47
Zn_sed	0.18	0.04	0.11	0.00

Appendix XII –
Tests of Significance Between Ponds

Significant Differences Between Water Quality Results

Parameters that are significantly different at the 0.05 level					
Wet Season Water Quality at Inlets					
Pond	**Langley**	**Griffin**	**Westview**	**Tempe**	**Burnaby**
Langley	n/a				
Griffon	Mg, Mn, Na, SpCond	n/a			
Westview	Fe, Mg, SpCond	Fe, Mn, Na	n/a		
Tempe	Mg	Fe, Mg, Mn, Na, SpCond	Al, Mg, SpCond	n/a	
Burnaby	Fe, Mg, Mn, Na	Fe, Mg, Mn, Na, SpCond	Al, Mg, Mn, SpCond, pH	Mg, Mn, pH	n/a
Dry Season Water Quality at Inlets					
Pond	**Langley**	**Griffin**	**Westview**	**Tempe**	**Burnaby**
Langley	n/a				
Griffon	Mg, Na, SpCond	n/a			
Westview	Mg, Na, SpCond, pH	none	n/a		
Tempe	Mg, SpCond	Mg, Na, SpCond	Al, Mg, Na, SpCond, pH	n/a	
Burnaby	Mg, Mn	Mg, Na, SpCond	Mg, Mn, Na, SpCond, pH	Mg, Mn, Na, DO	n/a

Significant Differences Between Water Quality Results

Parameters that are significantly different at the 0.05 level					
Wet Season Water Quality at Outlets					
Pond	**Langley**	**Griffin**	**Westview**	**Tempe**	**Burnaby**
Langley	n/a				
Griffon	Al, Mg, Na, pH	n/a			
Westview	Mg, pH	Mg	n/a		
Tempe	Al, Mg, Temp	Mg, Na, SpCond	Al, Fe, Mg, SpCond	n/a	
Burnaby	Al, Fe	Fe, Mg, Na, SpCond, pH	Al, Fe, Mg, Mn, SpCond, pH	Fe	n/a
Dry Season Water Quality at Outlets					
Pond	**Langley**	**Griffin**	**Westview**	**Tempe**	**Burnaby**
Langley	n/a				
Griffon	Mg, Mn, Na, SpCond	n/a			
Westview	Mg, Mn, Na, SpCond, pH	Mg	n/a		
Tempe	Fe, Mg	Fe, Mg, Na, SpCond	Fe, Mg, Na, SpCond, pH	n/a	
Burnaby	Mg	Mg, Mn, Na, SpCond	Mg, Mn, Na, SpCond, pH	Fe	n/a

Significant Differences Between Water Quality Results

Parameters that are significantly different at the 0.05 level					
Wet Season Water Quality Percent Difference					
Pond	**Langley**	**Griffin**	**Westview**	**Tempe**	**Burnaby**
Langley	n/a				
Griffon	Al, Mg, Mn, SpCond	n/a			
Westview	Al, Fe, Na	Fe, Mg, Mn	n/a		
Tempe	Al	pH	Fe, Mn, Temp, pH	n/a	
Burnaby	Al, Fe	Fe, Mg, Mn, SpCond	Temp	Fe, Mn	n/a
Dry Season Water Quality Percent Difference					
Pond	**Langley**	**Griffin**	**Westview**	**Tempe**	**Burnaby**
Langley	n/a				
Griffon	none	n/a			
Westview	none	Fe, Mg, Mn	n/a		
Tempe	none	none	Mg, Na, SpCond	n/a	
Burnaby	Fe	Fe, Mn	none	Fe, Mg, Na	n/a

Significant Differences Between Sediment Quality Results

Parameters that are significantly different at the 0.05 level

Wet Season Sediment Quality at Inlets

Pond	Langley	Griffon	Westview	Tempe	Burnaby
Langley	n/a				
Griffon	Cu, Mg, Mn, Pb, Zn, P	n/a			
Westview	Cr, Cu, Mn, Pb, Zn	Cr, Cu, Zn, P	n/a		
Tempe	Cu, Mg, Mn, Pb	Pb	Cr, Pb, Zn	n/a	
Burnaby	none	Cu, Mn, Pb	Al, Cr, Cu, Mn, Pb, Si, Zn	Cu, Mn, Si	n/a

Dry Season Sediment Quality at Inlets

Pond	Langley	Griffon	Westview	Tempe	Burnaby
Langley	n/a				
Griffon	Cu, Mg, Pb, Si, Zn, P	n/a			
Westview	Al, Cr, Cu, Mg, Mn, Pb, Zn	Al, Cr, Cu, Fe, Mn, Si, Zn, P	n/a		
Tempe	Cu, Fe, Mg, Mn, Pb, Si, Zn, P	Fe, Mn, Pb	Cr, Mg, Pb, Zn	n/a	
Burnaby	none	Cu, Mg, Mn, Pb, P	Al, Cr, Cu, Mg, Mn, Pb, Zn	Al, Cu, Fe, Mg, Mn, Pb	n/a

Significant Differences Between Sediment Quality Results

Parameters that are significantly different at the 0.05 level					
Wet Season Sediments Quality at Outlets					
Pond	**Langley**	**Griffon**	**Westview**	**Tempe**	**Burnaby**
Langley	n/a				
Griffon	Mg, Pb, Si	n/a			
Westview	Cr, Cu, Mn, Pb, Zn	Cr, Cu, Mg, Na, Pb, Zn	n/a		
Tempe	Cu, Mg, Mn, Si	Cu, Zn	Cr, Cu, Pb, Si, Zn	n/a	
Burnaby	none	Cr, Mn, Na, Pb, Si, P	Cu, Mn, Pb, Si, Zn, P	Cr, Cu, Mn, Pb, Si	n/a
				*nb-above were all 0.05	
Dry Season Sediment Quality at Outlets					
Pond	**Langley**	**Griffon**	**Westview**	**Tempe**	**Burnaby**
Langley	n/a				
Griffon	Al, Cr, Cu, Fe, Mg, Pb, Si, Zn, P	n/a			
Westview	Cr, Cu, Mn, Na, Pb, Si, Zn, p	Cr, Cu, Mg, Mn, Na, Si, Zn	n/a		
Tempe	Al, Cr, Cu, Mg, Mn, Pb, Si, Zn, p	Ce, Fe, Mn, Na, Pb	Al, Cr, Cu, Mg, Mn, Pb, Si, Zn	n/a	
Burnaby	none	Cr, Cu, Mg, Na, Pb, Si, P	Al, Cr, Cu, Mg, Mn, Pb, Zn, P	Cr, Cu, Mg, Mn, Pb, Si, Zn	n/a

Significant Differences Between Sediment Quality Results

Parameters that are significantly different at the 0.05 level

Wet Season Sediment Quality Percent Difference					
Pond	**Langley**	**Griffon**	**Westview**	**Tempe**	**Burnaby**
Langley	n/a				
Griffon	Al	n/a			
Westview	Mg	Cr, Cu, Mg, Na, Zn	n/a		
Tempe	none	none	Cu, Si	n/a	
Burnaby	none	Cr, Cu, Mn, Na, Si	Al, Mg, Mn, Si	none	n/a

Dry Season Sediment Quality Percent Difference					
Pond	**Langley**	**Griffon**	**Westview**	**Tempe**	**Burnaby**
Langley	n/a				
Griffon	Fe, Mg	n/a			
Westview	none	none	n/a		
Tempe	Al, Fe, Mg, Si	none	none	n/a	
Burnaby	Al	Mg, Mn	none	Mg, Mn, Si	n/a

Parameters that are significantly different at the 0.05 level

Wet Season DGT Results at Inlets

Pond	Langley	Griffon	Westview	Tempe	Burnaby
Langley	n/a				
Griffon	Mn, Zn	n/a			
Westview	Fe, Zn	Mn, Zn	n/a		
Tempe	Fe, Mn, Zn	Al, Fe	Mn, Zn	n/a	
Burnaby	Fe, Mn, Zn	Mn, Zn	Mn, Zn	Al, Mn	n/a

Dry Season DGT Results at Inlets

Pond	Langley	Griffon	Westview	Tempe	Burnaby
Langley	n/a				
Griffon	Al, Mn, Zn	n/a			
Westview	n/a	n/a	n/a		
Tempe	none	none	n/a	n/a	
Burnaby	none	none	n/a	none	n/a

Parameters that are significantly different at the 0.05 level

Wet Season DGT Results at Outlets

Pond	**Langley**	**Griffon**	**Westview**	**Tempe**	**Burnaby**
Langley	n/a				
Griffon	Al, Mn	n/a			
Westview	Al, Zn	Mn, Zn	n/a		
Tempe	none	Mn, Zn	none	n/a	
Burnaby	Al	Fe, Mn, Zn	Zn	Zn	n/a

Dry Season DGT Results at Outlets

Pond	**Langley**	**Griffon**	**Westview**	**Tempe**	**Burnaby**
Langley	n/a				
Griffon	none	n/a			
Westview	n/a	n/a	n/a		
Tempe	none	none	n/a	n/a	
Burnaby	none	none	n/a	none	n/a

Parameters that are significantly different at the 0.05 level

Wet Season DGT Percent Difference

Pond	**Langley**	**Griffon**	**Westview**	**Tempe**	**Burnaby**
Langley	n/a				
Griffon	Al, Zn	n/a			
Westview	Al, Fe, Zn	none	n/a		
Tempe	Fe, Mn	Al, Mn	Mn	n/a	
Burnaby	Al, Zn	Mn, Zn	Zn	Mn, Zn	n/a

Dry Season DGT Percent Difference

Pond	**Langley**	**Griffon**	**Westview**	**Tempe**	**Burnaby**
Langley	n/a				
Griffon	none	n/a			
Westview	n/a	none	n/a		
Tempe	none	Al	n/a	n/a	
Burnaby	n=2, not valid------------------------------------				n/a

Appendix XIII –
Correlations With Catchment Characteristics and Inlet Results

Correlations ($p<0.05$) Between Catchment Characteristics and Inlet Results for Various Parameters

	Catchment Area		Traffic		Percent Imperviousness	
	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season
Inlets						
Water	Al, Fe, Mn, Na	Al, Mn	Al, Ca (-), K(-),	Ca(-), K(-), Mg(-),	Ca(-), Fe, K(-),	Ca(-), Fe, Mg(-),
			Mg(-), Mn(-), Si(-), Zn,	Mn(-), Na(-), Si(-),	Mg(-), Mn(-), Si(-), Zn,	Na(-), Si(-), Zn
			SpCond(-), pH(-)	Zn, SpCond(-), pH(-)	SpCond(-), pH	
Sediment	Cr, K, P(-)	Ca(-), Cr, K,	Al(-), Ca(-), Cr, Cu,	Al(-), Ca(-), Cr, Cu,	Al(-), Ca(-), Cu, Fe(-),	Al(-), Cr, Cu, Fe(-),
		Mg, P(-)	Fe(-), Mn(-), Pb, Si(-), Zn	Mg(-), Mn(-), Pb, Zn	Mg(-), Mn(-), Pb, Zn	Mg(-), Mn (-), Pb, Zn
DGT	Al, Mn	Mn, Zn(-)	Mn(-), Zn	Mn(-), Zn	Fe, Mn(-), Zn	Mn(-), Zn

Appendix XIV–
Correlations Between Pond Characteristics and Percent Difference Between Parameters

Correlations ($p<0.05$) Between Pond Characteristics and Percent Difference Between Inlet and Outlets for Various Parameters

	Surface Area		Percent Vegetation		Volume	
	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season
Percent Difference						
Water	Al(-), Ca, Mg, Mn, Si, Zn(-), Temp, Cond(-), SpCond(-), pH	pH(-)	Ca(-), K(-), Mg(-), Na(-), Si(-), Zn(-)Temp, pH	none	Al(-), Ca, Mg, Mn, Si, Zn(-), Temp, Cond, SpCond, pH(-)	pH(-)
Sediment	Al, Cu(-), Fe, K(-), Mn, Na(-), Ni(-), P(-), Si, Zn(-)	Al, K(-), Mg(-), Mn, Ni(-), P(-), Si	Ca, Fe, Mg, P, Pb, Si,	Fe, Mn	Cu(-), Fe, K(-), Mn, Na(-), Ni(-), P(-), Si, Zn(-)	Al, Fe, K(-), Mg(-), Mn, Ni(-), P(-), Si
DGT	Al(-), Fe(-), Mn,	Al(-), Fe(-), Mn	Mn, Zn	Al	Al(-), Fe(-), Mn	Al(-), Fe(-), Mn