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COMPOST BIOFILTERS FOR HIGHWAY STORMWATER RUNOFF TREATMENT

A Thesis

Presented to

The Faculty of Graduate Studies

of

The University of Guelph

by

KAREN FINNEY

In partial fulfillment of requirements

for the degree of

Master of Science

January, 2010

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Your file *Votre référence*
ISBN: 978-0-494-60417-5
Our file *Notre référence*
ISBN: 978-0-494-60417-5

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ABSTRACT

COMPOST BIOFILTERS FOR HIGHWAY STORMWATER RUNOFF TREATMENT

Karen Finney
University of Guelph, 2009

Advisor:
Professor B. Gharabaghi

Highway stormwater runoff negatively affects the water quality of receiving lakes and rivers. Pollutants that build up on roads and other impervious surfaces are harmful to aquatic life and surrounding ecosystems. Woody compost or 'overs' have been found to be effective in removing highway pollutants including suspended solids, heavy metals and petroleum hydrocarbons (PHC). Overs have also been found to be effective as a filtration media when assembled inside a mesh casing to form a compost biofilter.

In the summer of 2007 a full scale on site compost biofilter was erected on Hwy. 8 in Kitchener, Ontario. Samples were automatically collected pre and post filtration, and flow data was recorded using weirs and level loggers.

A relationship between the upstream water level and the outlet flow rate was developed. The flow through capacity of the compost biofilter was found to be 90-100 L/s. The biofilter was found to be effective in the removal of suspended solids, heavy metals and PHC. The biofilter had a removal efficiency of 42% for TSS, 32% for zinc, 29% for copper and 66% for PHC.

The Ontario Provincial Water Quality Objective (PWQO) for TSS was 25 mg/L. In total 9 out of 20 events exceeded the objectives for TSS in Highway 8 runoff (i.e. Inlet Concentration); however, only 4 out of 20 events exceeded the objectives for TSS after filtration through the biofilter (i.e. Outlet Concentration). The PWQO for Zinc is 20 µg/L. In total 15 out of 20 events exceeded the objectives for Zinc in Highway 8 runoff; however, only 5 out of 20 events exceeded the objectives for Zinc after filtration through the biofilter. The PWQO for Copper is 5 µg/L. All 20 events exceeded the objectives for Copper in Highway 8 runoff. Australian Water Quality Guidelines for Fresh Waters (ANZECC, 1992) for Polycyclic aromatic hydrocarbons (PAH) maximum recommended concentration in freshwater is 3 µg/L. In total 18 out of 20 events exceeded the objectives for PAH in Highway 8 runoff; however, only 6 out of 20 storm events exceeded the objectives for PAH after filtration through the biofilter.

Using the obtained data from the highway site it was observed that the build-up of pollutants on a highway are governed by antecedent dry days (ADD), and average annual daily traffic (AADT), while the wash-off of the pollutants are influenced by the rainfall depth and rainfall intensity.

The compost biofilter was found to be effective in reducing the concentrations of pollutants found in highway runoff. Although a reduction in removal efficiency over time was not observed, the life span for the installed biofilter was estimated to be around 6 years before decommission.

Acknowledgments

I would like to thank the financial and in-kind contributions of the Ontario Ministry of Transportation (Highway Infrastructure Innovations Funding Program), the Ontario Centres of Excellence, Filtrexx Canada, Toronto and Region Conservation Authority, All Treat Farms, Region of Waterloo, Region of Peel and the Ontario Ministry of the Environment in support of this research project.

I would also like to thank my advisor, Dr. Bahram Gharabaghi for his guidance and patience throughout the project. Dr. Gharabaghi has spent a tremendous amount of time making this project what it has evolved to. I would also like to thank the graduate staff, particularly Lucy Cremasco, Susan Lewis, Mary Payne, Joanne Ryks and John Whiteside; for guiding me through many of the fine details of my thesis.

I would like to thank my family, mom, dad, my sister Laura, her fiancé Brad and Daivs. I would also like to thank my new in-laws Anne and Phillip Andres and my new brother Dan. Both families have been my source for love, encouragement and support throughout my thesis experience. A huge thank-you goes out to my fellow graduate students, particularly Amanda Farquharson, Vahid Taleban, Nandana Perera, Conrad Stang and Joel Citulski, for always being there when I needed a good laugh or a friend to talk to.

A special thank you goes out to my environmental high school teacher, Glenn MacGowan for initiating and nurturing my interest and passion for the environment. I would also like to thank Bill, Lyn and Rob James at CHI for providing me with employment that further strengthens my skills in a friendly and pleasant environment.

I would like to conclude my acknowledgments with a special thank you to my husband, Patrick Andres, for being my other half in every way.

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Abbreviations

AADT – Annual Average Daily Traffic
ADD – Antecedent Dry Days
ARM – Storm and Agricultural Runoff Management Model
CCME - Canadian Council of Ministers of the Environment
CWS PAH - Canadian Wide Standard for Petroleum Hydrocarbons
DCIA – Directly Connected Impervious Areas
DOT – Department of Transportation
DSVNFR – Downstream V-Notch Flow Rate
EIA – Effective Impervious Areas
EMC – Event Mean Concentration
GRCA – Grand River Conservation Authorities
IDF - Intensity-duration-frequency curve
LCD – Liquid Crystal Display
MOE – Ontario Ministry of the Environment
MTO – Ministry of Transportation in Ontario
NPS – Non-Point Source Pollutant Loading Model
NDPES - National Pollutant Discharge Elimination System
PAH – Polycyclic Aromatic Hydrocarbons
PWQO – Provincial Water Quality Objectives
SFS – Spectral Fluorescence Signatures
STORM – Storage, Treatment, Overflow Runoff Model
SWMM – Stormwater Management Model
SWMP – Stormwater Management Practices
TRCA – Toronto and Region Conservation Authority
TSS – Total suspended solids
USEPA – United States Environmental Protection Agency
USVNFR – Upstream V-Notch Flow Ra

1. Introduction

In a 1988 report to the US Congress, USEPA stated that urban stormwater runoff in the U.S.A is the fourth most extensive cause of water quality impairment of rivers, and the third most extensive source of water quality impairment of lakes (USEPA, 1990; Novotny, 1991; Novotny and Olem, 1994). Similarly, a report published in 1992 reported that urban stormwater runoff in the U.S.A is the second largest source of impairment of lakes and estuaries, and is also the third largest source of impairment of rivers (Lee and Jones-Lee, 1994).

Impervious roads made from asphalt and other common building materials have been found to have increased pollutant loads when compared to the runoff from natural areas. Roads, curbs and gutters are often used for water diversion to prevent flooding; however, these conveyance systems lead to higher pollutant levels and have been found to be harmful to surrounding water ecosystems (Makepeace, 1995; and Wiland, B., and Malina, 1976).

Total suspended solids in water increases the turbidity level, affecting fish survival (Pitt and Bozeman, 1980; Ferrara, 1986; Schueler, 1987; NCDOT, 1997; and Tsihrintiz and Hamid, 1995). Sediment is stressful to fish as it creates an environment that is oxygen deprived. The excess sediment also buries fish eggs preventing them from hatching (Aird, 2008; Tsihrintiz and Hamid, 1997; and Hentey et al., 2000).

Heavy metals found in highway runoff have also been noted as being a significant problem in waterways because at certain concentrations, zinc and copper are toxic to fish and aquatic micro-invertebrates (Tsihrintiz and Hamid, 1995). Oil and grease originating from automobile usage, as well as improper disposal of petroleum hydrocarbon products, is also toxic to aquatic organisms and affects fish reproduction (Lee and Jones-Lee, 1994).

Urbanization has resulted in the altering of water courses for the purpose of development and maintaining proper stormwater storage. Natural streams have been filled with concrete, dammed, widened, straightened and rerouted for the cause of development and profit (Aird, 2008).

Traditional stormwater management was primarily concentrated on flood prevention with little focus on contaminant removal (Seelsaen et al., 2007).

Grass swales and filter strips are common methods for reducing water velocity and promoting ponding, allowing for suspended solids to settle (Clarifica Inc., 2004; Kaighn and Yu, 1996; Yousef et al., 1985; and Gharabaghi et al., 2006b). Historical swale performance tests generally focused on the mass discharges as opposed to concentration to determine removal efficiency. Swales normally infiltrate a large quantity of flowing water, resulting in mass discharge decreases (Maestre and Pitt, 2006). Most swales operate with relatively deep water, and any filtering benefits of the grass are usually minimal. Very shallow flows in swales do have particulate pollutant concentration reductions, but these are rarely observed during moderate to large flows (Pitt and McLean, 1986).

Similar to swales, vegetative buffer zones are also often used to protect streams from being impacted by nearby residences or developments. They are planted with native species of trees, shrubs and perennials to protect waterways (Aird, 2008). They also create a natural boundary, preventing rural animals from trampling areas around streams, resulting in erosion and water contamination due to fecal runoff. Vegetative buffer zones are also used to filter stormwater runoff and serve to provide natural habitats for birds, butterflies and small animals (Aird, 2008). Swales are commonly used to assist in stream restoration, using natural materials in order to create curves, meanders, settling pools and cascading rock structures to provide similar protection of pre-developmental conditions.

Riprap is a common method of diverting runoff in order to settle out potential pollutants. Riprap consists of natural stone, solid pre-cast concrete blocks or large pieces of concrete

(Toronto and Conservation, 2008). Rock check dams consist of rock piled with a maximum upstream slope of 2:1 and maximum downstream slope of 4:1. They allow for the settling of particles by allowing for ponding behind the dam (Dorman et al., 1996).

Silt fences, stow logs, straw bales and sediment traps are common methods of trapping pollutants from runoff. It is important that proper installation and upkeep is conducted when treating stormwater with these BMPs as they often become damaged or full during storm events (Toronto and Conservation, 2008).

Compost has been used in highway projects in order to control and treat stormwater runoff that is often contaminated with petroleum hydrocarbons and metals (Glanville, 2001). On a separate but related note, to address solid waste issues in Ontario, the government proposed a 60% waste diversion strategy to divert non-hazardous solid waste from landfill sites (MOE, 2004). This diversion created a surplus (roughly 100,000 tonnes per year) of composted yard waste, in particular the coarser material (larger than ½ inch in size a.k.a. the ‘overs’) throughout Ontario. Compost “overs” are made up of two key constituents, namely non-humic and humic substances. The humic portion of compost has been found to be responsible for compost's ability to absorb heavy metals, oil & grease, nutrients and other organic matter (Seelsaen et al., 2007). The humus content of compost catalyzes the hydrocarbon degradation process and microbial activity is ten times greater in compost than in soils (USEPA, 1998). Compost’s natural absorbency of contaminants has been proven in several studies using compost blankets and bench-scale studies. Compost is a rich source of micro-organisms, which can degrade petroleum hydrocarbons to innocuous compounds such as carbon dioxide and water (Khan *et al.*, 2006). These microbes are capable of fully digesting the oil and grease that has been lodged within the compost media (Seelsaen et al., 2007). The ability of compost to naturally absorb and break down contaminants found in stormwater highway runoff makes compost a natural, organic filter media to implement as a biofilter. Gharabaghi et al. (2007 and 2009) showed that the compost ‘overs’ can be effectively used as compost biofilters for stormwater runoff treatment.

Testing of compost's ability to trap and biodegrade contaminants has been limited to mulch covers; however, the use of compost as a biofilter for treatment of stormwater runoff (as a flow-through medium to remove contaminants) is a new idea and there has been limited study to determine the effectiveness of these control measures. USEPA (1997) tested a compost biofilter made of specially-tailored leaf compost and reported sediment removal efficiency of 90%, oil and grease removal efficiency of 85%, and heavy metals removal efficiency of 82-98%.

Recently, the application of biofilters made from a mesh photodegradable tubular sock in combination with a compost filter media has been found to also be an effective method of stormwater treatment that has an advantage of being able to be implemented on-site (Gharabaghi *et al.*, 2007).

Compost from Canadian waste stream has not yet been tested for its effectiveness in stormwater runoff treatment since using compost as a biofilter for removal of suspended sediments and sediment-bound contaminants is a relatively new idea. Currently there is little research available on the use of compost as a filter media. The compost producers and compost applicators require scientific confirmation in order to provide clients a proven legitimate design that will work to reduce pollutants from entering the waterways. This new application for compost will be of significant environmental and economic benefit to society.

2. Background

Urban stormwater runoff has become a widely recognized source of pollutants to receiving waters (Driscoll, 1990; and Davis et. al., 2001). The Ontario Water Resources Act (1990), the Urban Waste Water Treatment Directive of the European Union (1991), the Clean Water Act in the United States (1999), the Canadian Fisheries Act (2002), the Ontario Clean Water Act (2006), and most recently the Ontario Lake Simcoe Protection Act (2008) are all examples of the Federal and Provincial Government initiatives to protect our precious water resources. These legislations have motivated government agencies, private sector and academia to develop research programs to find innovative solutions for treatment of contaminated urban runoff and to adopt new guidelines/proactive policies that require municipalities to incorporate best management practices in their official growth plans and for retrofit of existing urban areas (Bradford and Gharabaghi, 2004; and Gharabaghi et al., 2006).

Highway stormwater affects the quality of receiving bodies of water by conveying contaminants that have accumulated on roadway surfaces (Khan et al., 2006). The degradation of the road and traffic-related pollution are responsible for the majority of contaminants found in urban runoff (Pitt, 2003). This is mainly because road surfaces accumulate tire wear, car fumes and other pollutants that are both harmful for the aquatic life as well as toxic to humans (Wada et al., 2004).

2.1. Processes of Contaminant Build-up and Wash-off

Although stormwater runoff quality originates from a variety of sources, the primary processes include atmospheric deposition, average daily vehicular traffic, road surface and tire wear, rainfall washoff and contaminant transport by runoff (Tsihrintiz and Hamid, 1997; and Barrett, 1995). Atmospheric deposition occurs when airborne particles originating from dust, aerosols and various gases are washed out of the atmosphere by wet (episodic) and dry (continual) deposition. Particles removed by wet deposition are removed from the atmosphere by rain, sleet, snow or fog. Dry deposition deposits

particles in the absence of precipitation, namely by adsorption, impaction and settling (Little and Wiffen, 1978). This type of scrubbing is responsible for a significant amount of pollution. Once the pollutants have accumulated on the road surface the rainfall and runoff washes the surface resulting in the transport of the contaminants (Khan et al., 2006, Tsihrintiz and Hamid, 1995).

The climate and vegetation of the area is important as arid-region highways receive significantly more sediment bound toxin transport via the winds than areas that are more vegetated (Chui et al., 1982). Land use is an essential factor when looking at stormwater contamination. Residential, Commercial and Industrial areas all contribute differently to stormwater contamination (Tsihrintiz and Hamid, 1995; Barrett et al., 2004). Heavy metal contamination originating from automobiles is of particular interest because of their accumulation and toxicity to the natural environment. Oil and grease concentrations in runoff are also a concern as oil and grease contribute significantly to the contaminant load from urban areas (Hong et. al., 2006).

Heavy metals such as cadmium, lead, copper and zinc in highway runoff entering waterways at high-concentrations have become of significant interest to regulating agencies (Li et al., 2005; Bell, et al., 1979). Davis et al. (2001) performed a series of experiments quantifying the mass loading and concentration of heavy metals in urban stormwater runoff. Vehicle brake emissions were found to contribute to copper concentrations and tire wear significantly contributed to zinc concentrations in runoff.

Polycyclic aromatic hydrocarbons have moderate to high acute (short- term) toxicity to aquatic life and birds. Some cause damage and death to agricultural and ornamental crops. They have moderate to high chronic (long-term) toxicity to aquatic life. Polycyclic aromatic hydrocarbons are moderately persistent in the environment, and may bioaccumulate (Fam et al., 1987). The concentrations of polycyclic aromatic hydrocarbons found in fish and shellfish is expected to be much higher than the environment from which it was taken. However, polycyclic aromatic hydrocarbons do

not dissolve easily in water. They sorb to dust or dirt particles and settle to the bottom of lakes and rivers. Microorganisms will break them down in soil or water over a period of weeks to months. Mixed microbial populations in sediment/water systems may degrade some polycyclic aromatic hydrocarbons, with degradation progressively decreasing with increasing molecular weight. Polycyclic aromatic hydrocarbons (PAH) maximum recommended concentration in freshwater is 3.0 micrograms per Litre (Australian Water Quality Guidelines for Fresh Waters ANZECC, 1992).

Shinya (2000), examined urban stormwater runoff quality in Osaka, Japan. The study consisted of four rainfall events and samples were collected along a major highway. The highway had an Annual Average Daily Traffic (AADT) of 75,000 vehicles/day and the surrounding land was zoned commercial and high density residential. Samples were tested for pH, TOC, TSS, heavy metals and PAHs. The analysis of all the parameters tested was much higher during the initial period of the event (i.e. first-flush effect). These concentrations were found to be much higher than the safe limits for aquatic life. Khan et al. (2006) reported that oil and grease emissions from vehicles originating from crank case drippings and partially combusted fuels and leaks can cause toxicity to aquatic life and depress oxygen concentration.

2.2. Key Factors Affecting Highway Runoff Quality

Highway stormwater runoff quality, specifically TSS and heavy metals, depends on several key factors that determine flow rate and pollutant concentrations. These factors include Average Annual Daily Traffic (AADT), Antecedent Dry Days (ADD), rainfall intensity, and rainfall depth (Gupta et al., 1981; Barrett et al., 1993). Traffic-related contaminant accumulation (build-up) on the road is proportional to the traffic volume and the antecedent dry period (Tsihrintiz and Hamid, 1995; Charbeneau, Chui et al., 1982; Irish et al., 1998). A study conducted by Stenstrom et al. (1984) found that the only dependant storm characteristic that influences PAH concentrations found in runoff is rainfall depth.

Barrett (1995) looked at the characterization of highway runoff in the Austin, Texas area. The study included 3 sites along the MoPac expressway. The first site was a mixed residential/commercial site with an AADT of 60,000 vehicles/day; the second site was a residential/undeveloped area with an only an AADT of 8,780 vehicles/day and the third site was a commercial/high density area with an AADT of 4,800 vehicles/day. It was concluded that the highest concentration of constituents was at the site with the highest traffic volume.

The antecedent dry days (ADD) or the dry days between rainfall events is an important variable that controls the contaminant build-up (Huber and Dickinson, 1988). A study conducted by Burton and Pitt (2001) produced a regression analysis from various locations with ADD values ranging from 18-100 days. It was concluded that the concentrations of the contaminants were proportional to the ADD. Another study conducted by Irish et al. (1998) concluded that heavy metal concentrations in highway runoff were influenced by traffic count as well as the antecedent dry period.

2.3. Compost Biofilters

One new sustainable, technology being explored for use in runoff treatment is the use of woody compost filled into mesh tubular material known as a “sock” (Taleban et al., 2009). Compost biofilters are a relatively new method being considered for highway runoff treatment. The compost biofilter is advantageous over other stormwater management plans as it not only removes contaminants but also acts as a dam reducing the flow of incoming water while promoting ponding upstream of the biofilter (Tyler, 2001). The longevity of compost biofilters has been limited; however, research conducted by Keener, et al. (2006) found that the flow-through rate changes over time, as does the ponding depth, due to the accumulation of solids trapped within the compost filters.

Compost has proven to be effective for use as a soil amendment, topdressing and filtering agent (Taleban et al., 2009). Compost has been used for slope stabilization, stormwater filtration, erosion and sediment control and as a tool to establish vegetation in vulnerable areas (Faucette et al., 2005). Ettlin et al. (1993) found that yard waste was effective for slope stabilization and erosion control on slopes up to 42%. A study conducted in Portland, Oregon concluded that yard and waste compost was effective at reducing erosion and improving water quality when compared to conventional erosion and sediment control measures (Portland Metro, 1994).

Compost is made up of a combination of both organic and inorganic constituents. These two key components can be further divided into two categories: non-humic and humic substances. Non-humic substances, including proteins, amino acids and carboxylic acids derived from sugar, are compounds that have identifiable chemical characteristics. Humic substances are mostly organic matter that have high molecular weights, have a blackish brown colour, and have a high affinity to complex metal ions (Seelsaen et al., 2007).

When using compost as a filter media the humic component of the compost becomes essential when removing contaminants from stormwater. This is because humic substances perform like a polyelectrolyte, removing the toxins from the stormwater via adsorption or ion-exchange (Clark and Pitt, 1999).

It has been found that compost has a high capacity for absorbing heavy metals, oil & grease, nutrients and organic matter due to the natural humic components found in most compost varieties (Seelsaen et al., 2007). The study performed by Grimes et al., 1999 demonstrated that one gram of household compost was able to remove 97.7% of lead, 95.9% of zinc and 92.4% copper from a metal solution made up at a concentration of 100 mg/L (Grimes et al., 1999).

Another study performed by Jang et al. (2005) evaluated whether mulch has a potential use as a feasible method for removing heavy metals. It was concluded that hardwood mulch was effective at removing heavy metals found in runoff (Jang *et al.*, 2005).

A separate study by Seelsaen *et al.* found that common hardwood mulch sorbed 23.3% of copper, 47.3% of lead and 8.3% of lead, consistent with the Irving-Williams relationship between humic components of the compost and the heavy metal affinities associated with them (Seelsaen *et al.*, 2007).

Once the contaminant is trapped or absorbed by the compost material, it is desorbed by hydrocarbon-degrading microbes. These microbes, found in coarse, high-organic-carbon mulch filter media, are capable of fully digesting the hydrocarbons that have become trapped within the filter if given the appropriate contact time (Hong *et al.*, 2006). This breakdown of the trapped hydrocarbons makes compost an ideal natural filter media for the degradation of oil and grease introduced into the environment by anthropogenic means.

In a study conducted by Maestre and Pitt (2006) it was concluded that no seasonal effects on concentrations of contaminants were observed except bacteria was lower in the winter and higher in the summer.

2.4. Compost Specifications

Due to the many different types of compost available, it is important to standardize the compost used as the filtration media. Currently, compost filter media used for different applications have the following specifications according to the Greater Colden Horseshoe Area Conservation Authorities, (2006), Erosion and Sediment Control Guidelines for Urban Construction;

- Filter media derived from Compost used shall be weed free and derived from a well-decomposed source of organic matter. The compost shall be produced using an aerobic composting process meeting or exceeding , M.O.E. 101, C.C.M.E. Type “A” and Type “AA” regulations, and Compost Quality Alliance Program C-31 (C.Q.A.) including time and temperature data indicating effective weed,

pathogen and insect larvae kill;

- The compost should be free of any refuse, contaminants or other materials toxic to plant growth. Non-composted products will not be accepted. Test methods for the items below should follow USCC TMECC guidelines for laboratory procedures;
- pH – 5.0-8.0 in accordance with TMECC 04.11-A, “Electrometric pH Determinations for Compost”;
- Particle size – 99% passing a 50 mm sieve and a minimum of 70% greater than 9.38 mm sieve, in accordance with TMECC 02.02-B, “Sample Sieving for Aggregate Size Classification”;
- Moisture content of less than 60% in accordance with standardized test methods for moisture determination;
- Material shall be relatively free (<1% by dry weight) of inert or foreign man-made materials; and
- A sample shall be submitted to the engineer for approval prior to being used and must comply with all local and provincial and federal regulations.

2.5. Stormwater Monitoring

Sampling programs vary, depending on the site requirements, characteristics and objectives. Most stormwater monitoring programs use automated samplers for collecting flow-weighted composite samples as the analyses of a flow weighted sample provides event mean concentration, EMC (Khan et al., 2006). A study by the Wisconsin Department of Natural Resources compared the accuracy and affordability of four different types of sampling methods (Roa-Espinosa and Bannerman, 1995). The methods included: flow-weighted composite sampling, time-discrete sampling, time-composite sampling, and “first-flush” sampling during the first 30 minutes of runoff. It was concluded that the time-composite samples at outfalls was the best method due to simplicity, low cost, and provided good comparisons to flow-weighted sampling (assumed to be the most accurate) (Maestre and Pitt, 2006; and Shiu Ma et al., 2009).

Although manual sampling is recommended for TSS accuracy, automatic sampling is actually better for capturing the first flush effects, if present, where manual sampling would miss these samples as there may be delays getting to the site on time for collection (Burton and Pitt, 2001; Maestre and Pitt, 2006; and Shiu Ma et al., 2009).

Automatic samplers are recommended for larger sampling programs, when better representations of flows are needed, and especially when site access is difficult or unsafe. Because of the Autosampler's flexibility and programming features, samplers can initiate sampling very close to the beginning of the flow (Maestre and Pitt, 2006). Samplers also have the capability to capture representative samples for the entire duration of the storm although the sampler must be programmed to obtain these samples at appropriate times (Burton and Pitt, 2001).

Although automatic samplers are ideal when collecting stormwater samples at different intervals, the monitoring equipment may be unreliable at times and difficult to precisely program (Jones et al., 2008). Automatic samplers have several problems associated with them including broken sensors, heat/cold, jams, clogging, improper trigger times and the effects of lightning (Jones et al., 2008). Other problems associated with monitoring programs can be blamed on human error (Jones et al., 2008). Dead batteries, poor communication and forgetting crucial equipment can be avoided with proper attention to details surrounding the program.

Autosamplers also have a tendency to be less effective in sampling larger particulates ($>500\ \mu\text{m}$) preventing the most accurate TSS samples from being obtained (Maestre and Pitt, 2006). A study conducted by Maestre and Pitt, (2006), examined samples obtained through automatic samplers and manual samplers. It was found that in residential and commercial land uses, TSS concentrations obtained through automatic samplers were twice the concentrations then the ones obtained manually. Total zinc concentrations were higher when using manual sampling methods compared to using automatic samplers (Maestre and Pitt, 2006).

3. Research Objectives

The main objectives of this research project include:

- (1) determine flow-through properties of the biofilter and to develop relationships for hydraulic design of the biofilter;
- (2) determine the effectiveness of the biofilter in removal of sediments, heavy metals and petroleum hydrocarbons from stormwater runoff;
- (3) determine the longevity of the biofilter; and
- (4) develop a simple design method for site-specific applications.

4. Methodology

In August of 2007 a monitoring program was established alongside Highway 8 in Kitchener. This program was initiated in order to quantify flow and water quality in highway runoff, as well as to determine the compost biofilter flow-through capacity and removal efficiency for a variety of pollutants. The monitoring site selected in Kitchener, Ontario, had a catchment area of approximately 0.85 ha. The site was fully equipped with a series of flow gauges, a rain gauge and flow-weighted auto-samplers in order to obtain the hydrological data required for a comprehensive analysis.

4.1. Site Selection

Field monitoring was conducted to evaluate the effectiveness of the compost biofilter in removing various contaminants, including sediments, heavy metals, and petroleum hydrocarbons from stormwater runoff and to determine the factors that influence the runoff pollutant loading. The field site was selected in the summer of 2007 with the assistance of Ministry of Transportation (MTO). The specific site is on the east side of Highway 8 near Cameo Drive in the stretch beside the roadway in the ditch. There are four lanes on the road and its Average Annual Daily Traffic (AADT) was approximately 100 000 vehicles per day.

This site was selected as a typical medium-sized catchment area site with a medium to high magnitude of traffic load and located within a 25 minute travel time to the University of Guelph (see Figure 1). The site also had a well-defined drainage area and had ample space for instrumentation that was accessible for operation.

Figure 1 - Overview of the site on the East Side of Highway 8 Near Cameo Drive

A raingage was installed on a secure site close to where the samples were being obtained. The raingage accuracy was verified using data from Environment Canada for the region of Waterloo. This comparison can be seen in Figure 2.

Figure 2 - Environment Canada Rain Gage (about 10 km distance from the site) Data in Comparison to Installed site Rain Gage at Hwy 8 site

The gage installed was calibrated against the Region of Waterloo International airport which was located about 8 km away from the biofilter site. The gage was installed in order to capture the major characteristics of the storm including accurate intensities and volumes. Although the data from the Region of Waterloo could have been obtained and used for the purpose of this project, it was determined that rain patterns can vary substantially in a small area difference. It can be seen in Figure 2 that the majority of the storms used to calibrate the gage were smaller in depth, this is due to the fact that during a rain season there are more smaller events then there are larger ones, however the larger storm events are of greater interest to calibrations as they will have the most variation in a 8 km radius.

4.2. Flow Measurement

A V-notch weir was installed in Rock Check #2 for measuring flow rate. This was done by building a plywood v-notch weir that was buried within the rocks and into the clay core of the rock check. A second v-notch weir was installed downstream from the biofilter. Originally a broad crest weir was installed; however, it was found to have uncertainty making water levels making the outlet flow rates difficult to calculate. The second 90° v-notch weir was installed on July 8, 2008. This allowed for better monitoring of the flow rate leaving the biofilter (see Figure 3; and Figure 4).

Figure 2.0 - Rock Check One
with V-notch Weir

Figure 3 - Cross section A-A, installation of v-notch weir on rock check #2

Figure 4 - Installed V-Notch Weir

4.3. Compost Biofilter Installation

The installation of the biofilter was completed in July 2007 by Filtrexx Canada. The installation was performed using a Filtrexx blower truck, assembling the filter bags on site. The biofilter was assembled by initially blowing a filter bag frame and base, then raw compost was blown into the middle of the biofilter configuration, then more blown biofilters were stacked on top of the raw material to prevent loss of material. This was done to save costs on the biofilter installation and potentially supply more pore space for contaminants to settle on (see Figure 5 and 6).

Figure 5 - Biofilter after installation

Figure 6 - Biofilter Aerial View (all dimension in m)

4.4. Sampling Program

The stormwater samples were collected from both upstream and downstream of the biofilter using two ISCO 3700 Portable Samplers. The autosamplers were triggered using two ISCO 4150 Area-Velocity flow Loggers. The Area-Velocity flow loggers measures both velocity and depth of flow and was used to measure flow in conjunction with an upstream and downstream weir. The autosamplers were set so the inlet sampler would initiate sample collection when the water level reached 15 cm while the outlet was initiated when the water level reached 10 cm. Collection began immediately after the inlet area-velocity logger detected the specified water level. Subsequent samples were taken during the first four hours at ten minute intervals. Following each storm event the site was visited and samples were collected, preserved within 24 hours and prepared for analysis. Automatic sampler samples were collected with a 1 L polypropylene wedge

shaped containers. These bottles were chosen as they were specifically designed for the ISCO auto samplers in such a way to allow 24 samples to be collected during a storm event. Once collected, the samples were divided and half of the samples were put into 500 mL high density polyethylene wide mouth containers and treated with nitric acid for TSS and heavy metal testing while the other half were stored in 1 L wide mouth amber glass jars and treated with sulphuric acid for Polycyclic aromatic hydrocarbons (PAH) and particle size distribution (PSD) analysis (American Public Health Association, 1998). To ensure quality control, a rain gage was installed close to the sampling site.

4.5. Sample Analysis

Samples collected were tested for heavy metal concentrations (zinc and copper), TSS, particle size distribution and for PAH concentrations. The samples were analysed using standard methods or have been verified by standard methods.

The machine used to test the samples collected for total concentration of copper and zinc from the site is referred to as a Graphite Furnace Atomic Absorption Spectrophotometer and is manufactured by Shimadzu Corporation. The spectrophotometer uses the principle that most compounds break apart into atoms that are in the gas phase when sufficiently high temperatures are applied to the compounds. All atoms are classified into those having low energies (ground state) and those having high energies (excited state) (Shimadzu, 2007). The atom that is at the ground state will absorb the surrounding energy to be put into the excited state. The difference between the two levels of energies is fixed by the element and wavelength of light to be absorbed (Shimadzu, 2007).

Atomic Spectroscopy vaporizes samples from 2000-6000 K. The atomic concentrations are determined by measuring adsorption or emission at characteristic wavelength. Atomic Spectroscopy uses a hollow cathode lamp (HCL) that gives off light characteristic to the elemental wavelength being measured, measuring the atomic density (Shimadzu, 2007).

The particular type of atomization that was used is the furnace method. This method offers greater sensitivity than the flame method and requires less sample than other methods. The furnace type used is known as a graphite furnace. The spectrophotometer works by injecting 1 to 100 uL of sample into the oven via a hole in the centre of the specific graphite tube in the machine. For this project 10-20, uL was injected for sample analysis. Once the sample is injected, a light beam travels through each end of the graphite tube through windows on either end of the tube. The maximum temperature recommended for this graphite furnace is 2550°C. Due to the high temperature of this particular method Ar gas is required to form a surrounding atmosphere to prevent the oxidation of the graphite tube the sample resides in. The graphite furnace holds the atomized sample in the graphite tube for a residence time of no more than seven seconds, usually less, which results in high sensitivity.

In order to perform a sample analysis the digested water sample was first placed on the graphite platform and, if necessary, a matrix modifier was added. The sample was then evaporated to dryness, charred and atomized using high temperature ramping. The absorption signal was generated and depending how it compared with the standards making up the calibration curve, the concentration was determined.

The controls such as gain, slit width, flame type, and wavelength were set in accordance to the manufacture's manual. Compressed gasses including Argon and Oxygen were checked to ensure safety. The appropriate lamp was positioned and was adjusted to the correct current and to allow the lamp to electronically stabilize. The lamp was adjusted using the spectrophotometer software to achieve maximum absorbance. The background correction device was utilized in order to minimize interfering substances such as gaseous molecular particles, smoke or salt particles present in the source-light path. This step was essential as the metals being tested for were determined by heat-vaporization techniques using a graphite furnace. The wavelength was adjusted by setting the monochromator reading to the recommended wavelength for a particular element and slowly changing the monochromator fine adjustment until the maximum light passage is obtained.

Once the spectrophotometer was up to operating standards the calibration of the instrument was conducted. This was completed by initially turning on the furnace and the trivet and setting the gasses and water to the manufactured specified flow rates. A blank sample containing all reagents (nitric acid and matrix modifiers), except for the elements in interest, was analyzed and set to read zero. A standard solution containing the analyte at a concentration that would give an absorbance between 0.2 and 0.6 and that will be within the linear absorbance range for the test elements was analyzed to check for the machines sensitivity. Five standard solutions were prepared using concentrations suggested by the operational manual. These standards as well as blanks were regularly checked throughout the sampling program to ensure consistency.

Once calibration was complete the unknown samples were prepared as directed in the operational manual. In order to ensure the dissolved metals as well as the sediment bound metals were detected, a nitric acid digest 3030E was completed before analyzing the samples using the spectrophotometer. The samples were processed using the calibration curve obtained to determine the concentrations. A calibration standard was run for every 10 samples, to check if the calibration curve still held. For quality assurance the standards tested between samples was plotted with on the same plot as the calibration curve. If the R^2 value was lower then 0.85 then the sampler was stopped to allow the machine to re-calibrate.

The samples being tested for metal concentrations were digested in the Soil and Nutrient Lab located at the University of Guelph. All samples tested for heavy metals were acid-digested at the University of Guelph Laboratory Services Division using 3030 E. Nitric Acid Digestion. Standard Method 3120B was used to test for the heavy metal verification in the Soil and Nutrient Lab (Standard methods for the examination of water and wastewater, 18th Ed., 1992).

Total Suspended Solids

Total suspended solids were measured according to ASTM standard method (ASTM D3977-97C) using a 0.45 μm filter paper. The TSS samples were tested in the fluid mechanics lab at the engineering department at the University of Guelph. To conduct TSS sample analysis four samples were selected per run and recorded on a lab sheet. Four metal weighing tins were obtained, labelled and individually wrapped micropore filters were placed inside each of the weighing tins. These tins were weighed for the initial masses and then, using tweezers the filters were carefully removed from the tins and placed on top of the filtration funnels. A filtration filter cup was secured over the filter and was then clamped together to seal the filtration unit. Once the chosen samples were adequately mixed, 150 milliliters were obtained in a clean 250-milliliter graduated cylinder and was poured into the filtration unit. The vacuum pump was turned on and the water was drawn out of the filter into the Erlenmeyer flasks. Once all the water was removed from the samples, the vacuum was turned off and the filters were carefully removed using tweezers. The filters were placed back into the weighing tins and placed in the oven at 98-108 degrees Celsius for 24 hours. Once the sample had dried, the tins were re- weighed and placed in appropriate storage for future possible variation.

Particle Size Distribution

The particle size distribution was tested using a Mastersizer 2000 particle size analyzer by Mavern. This instrument was selected for its wide range (0.02 μm – 2000 μm), accuracy (+/- 1%) and speed (< 2 min/sample analysis). The mastersizer is located in the environmental lab in the engineering department at the University of Guelph.

The Mastersizer works by using the optical unit to capture the actual scattering pattern from a field of particles. It then calculates the size of the particles that create that pattern using the Fraunhofer model as well as the Mie theory. The Fraunhofer model can predict the scattering pattern that is created when a solid, opaque disk of a known size is passed

through a laser beam and the Mie Theory predicts the way light is scattered by spherical particles and deals with the way light passes through, or is absorbed by, the particle. The Mastersizer works backwards, using these theories, to determine the particle size distribution. Using the mastersizer 2000 particles between two and 1000 μm in diameter were quantified for 20 rainfall events during the rainy seasons of 2007 and 2008.

LDI Machine Sample Analysis

A Laser Diagnostics International Instant Screener (LDI) has been acquired through a Canadian Foundation for Innovation grant and was used for recognition and measurement of petroleum hydrocarbon contaminants using the Spectral Fluorescence Signature (SFS) technology. The spectral image of organic compounds show characteristic excitation and emission wavelengths providing a unique SFS signature (see Figure 7; and Figure 8) In a fluorescence experiment, nitrogen laser excites a sample in a cuvette, and resulting fluorescence spectrum is spread out on a grating and measured with a detector array. The characteristic output is displayed as intensity vs. wavelength.

Figure 7 - Spectral Fluorescence Signature

Figure 8 - Real-Time SFS Analysis

The advantages to this type of sampling are the machines high sensitivity and capability to provide rapid analysis without time-consuming sample pre-treatment with a PAH detection limit of 0.1 – 1.0 ppb, is far more appropriate method to use when sampling, when compared to the ALS lab that uses gas chromatography with a detection limit of 100 ppb, a complete table of the methods for PAH detection limits can be found on Table

1. When comparing the detection limits with the water quality standards for PAH the SFS signature method was found to better represent the array of samples more accurately.

Table 1 - PAH detection limits for different test methods

Method	Detection Limit (ppb)
Mass Spectrometry	< 0.01
Liquid Chromatography	0.01 – 0.1
Spectrofluorometry	0.1 – 1.0
IR – spectroscopy	10 – 100
Gas chromatography	100
Colorimetry	1000

Characteristic spectral structure of SFS is used for substance recognition, while the level of fluorescence intensity is a measure of quantity (Vo-Dinh, 1981). SFS of compounds of interest are measured and stored in a database for the rapid optical screening tool (ROST). Laboratory sample preparation uses hexane as an extraction solvent for the petroleum hydrocarbons removed and accumulated in the biofilter. The detection threshold of the SFS method routinely reaches sensitivity levels in the parts-per-million range and in many cases, parts-per-billion (Lambert, 2003).

This machine is an Instant Screener designed to measure a wide range of samples containing fluorescing organic compounds from an aromatic nature (LDI, 2007). This machine works by reading samples spectral fluorescence signatures (SFS). A SFS is the total sum of excitation and emission fluorescence spectra represented by a matrix of fluorescence intensity along the coordinates of excitation/emission wavelengths. The advantages to this type of sampling are the machines high sensitivity and capability to provide rapid analysis without time-consuming sample pre-treatment.

ALS Verification Methods

The analysis by two methods to determine bias was performed on one of every ten PAH unknown samples. Both procedures from the research lab and the ALS lab were carried out around the same time. These methods were done to ensure that both procedures were able to cover the applicable concentration range accurately.

Analytical methods used in the ALS lab for analysis of CCME (Canadian Council of Ministers of the Environment) petroleum hydrocarbons comply with the Reference method for the CWS PAH (Canadian Wide Standard for Petroleum Hydrocarbons). Samples were divided into three categories of testing, F2, F3 and F4. In samples where PAHs (polycyclic aromatic hydrocarbons) were analyzed, F2-Naphth represents the result where Naphthalene has been subtracted from F2. F3-PAH represents a result where the sum of Benzo(a)anthracene, Benzo(b)fluoranthene, Benzo(k) fluoranthene, Dibenzo(a,h)anthracene, Fluoranthene, Indeno (1,2,3-cd) pyrene, Phenanthrene, and Pyrene has been subtracted from F3.

The following quality control criteria have been met for the F2-F4 hydrocarbon Ranges. All extraction and analysis holding times were met. Instrument performance showing C10, C16 and C34 response factors within 10% of their average. Instrument performance showing C50 response factor within 30% of the average of the C10, C16 and C34 response factors. Linearity of Diesel of motor oil response within 15% throughout the calibration range.

For aqueous samples, the hydrocarbons are extracted using solvent partition with hexane. The hexane extracts from aqueous samples are then treated with silica gel to remove polar contaminants. The concentrated extract is analyzed by gas chromatography (GC) using flame ionization detection (FDI) and 100% polydimethylsiloxane column.

The F2 fraction is determined by integrating the area in the chromatogram from the apex of nC₁₀ to the apex nC₁₆ and calculated using external calibration using a standard mix

containing nC_{10} , nC_{16} , and nC_{34} . Similarly, the F3 fraction extends from the apex of nC_{16} to the apex nC_{34} and the F4 fraction covers the area from the apex nC_{34} to the apex nC_{50} . If the chromatogram does not return to the baseline by the time nC_{50} elutes, a gravimetric detection of the F4 is performed.

4.6. Event Mean Concentration Calculations

Event Mean Concentration or EMC is defined as the flow and time-weighted average concentration collected over the storm event and is equal to the total mass emission, divided by the total runoff volume for a specific pollutant (see Equation 1) (Huber, 1993). The EMC is a better representation of concentration as it takes the flow of the runoff to be accounted for.

EMC is the ratio of the contaminant loading and the volume of the samples collected in each event, EMC is usually expressed in units of (mg/L) or (μ g/L).

Equation 1 - EMC Equation

$$\bar{C} = L / R$$

Where

L - loading rate / event, mg

$\bar{C}$ -event mean concentration, mg/L

The contaminant loading for an event is determined by summing the individual sample loadings for each sampling period, provided that flow rate data is available for the sampling period (see Equation 2).

Equation 2 - Loading for event equation

$$L = \sum_{i=1}^n R_i C_i$$

Where

R_i – volume proportional to flow rate at time i . L

C_i – Concentration at time i , mg/L

n = number of samples during a single storm event

In this particular study the EMCs for copper, lead, PAH and TSS were calculated for both the inlet of the biofilter as well as the outlet of the biofilter. Using the EMCs the removal efficiency for each storm was determined.

4.7. Runoff and Contaminant Modelling

A water runoff model for a potential biofilter installation site may be required to estimate peak flow and water levels for a drainage area. The best way to represent the site conditions and apply scenarios in order to determine the hydraulic response is the use of a computer model.

When characterizing runoff it is important to be able to best produce a validated model that can be used with a certain degree of confidence. There are a variety of runoff models available to better describe runoff characteristics. STORM (Storage, Treatment, Overflow Runoff Model), SWMM (Stormwater Management Model), NPS (Non-Point Source Pollutant Loading Model) and ARM (Storm and Agricultural Runoff Management Model) are all models that are available to describe the hydraulic responses of highway runoff and contaminant loading (Zoppa, C., 2001).

In terms of the magnitude, the goals of urban water quality modelling are to characterize runoff and to provide input to receiving water analysis (Tsihrintiz and Hamid, 1997). The analysis and solution goals to the problem are to determine the effects, sizes and

variable combinations and to perform frequency analysis of quality parameters (Tsihrintiz and Hamid, 1997).

SWMM is among the most widely used water quality simulation models (Tsihrintiz and Hamid, 1997). SWMM is capable of characterizing runoff that may consist of up thirty different constituents (Tsihrintiz and Hamid, 1997). SWMM was chosen to best characterize the stormwater runoff as it has been found to be user friendly and works with a GIS interface to better assist in land characterisation. SWMM is a finite element program used to simulate flow hydrographs in an urban area. SWMM also can be used to simulate the fate of contaminants including heavy metals and total suspended solids (Tsihrintiz et al., 1997). SWMM incorporates simulations for both single-event and continuous simulations. These simulations can be preformed for almost all main components of a rainfall including runoff values, quality and the cycles for a watershed (Tsihrintiz et al., 1995).

5. Results and Discussions

This section provides the preliminary results of the study, including flow through capacity of the biofilter, particle size distribution results and heavy metal, TSS, and petroleum hydrocarbon Event Mean Concentration (EMC) removal.

5.1. Flow-Through Capacity of the Biofilter

On July 8th 2008 a downstream v-notch weir was constructed and installed in place of the broad crested weir. This was done due to the small difference in water depths observed during rainfall events. The small differences in water depths made obtaining accurate mass balances of the hydraulic responses difficult to calculate.

Once the 90° v-notch weir was installed, the storms post-installation were analyzed for lag-time, storm duration and inlet and outlet flow rates. A mass balance was then calculated. Due to varied extent of ponding prior to the downstream v-notch weir, a correction factor was applied to each event based on the initial and final sensor depths.

An assumed hydraulic conductivity for silty sand was assumed to be in the range of 10^{-4} - 10^{-8} cm/s allowing for some infiltration. Storms occurring back-to-back have closer volumetric mass balances. This is consistent with the hydraulic system as there would be less water ponding prior to the biofilter and the soils would be saturated, thus preventing infiltration losses.

Using the V-notch weir, the flow was measured upstream of the biofilter. Also, two ISCO 4150 Area-Velocity Flow Loggers were installed on both sides of the biofilter, to measure the water level at both inlet and outlet.

Flow-through capacity of the biofilter was calculated using water level and flow data from seven storms. These seven storms were chosen as they happened after the

downstream v-notch weir was installed; ensuring accurate flow rates for both the upstream and downstream (see Figure 10 - Figure 16).

Due to ponding prior to the downstream weir a correction factor was applied so the standing water from previous storms was not taken into account in the volumetric balance. The correction factors varied from 2.8 cm to 10.3 cm. This is due to the fact that the bottom of the weir was approximately 10 cm from the ground. For each storm the downstream level reading before the runoff reached the outlet was subtracted (see Figure 9).

Longitudinal Slope of the Ditch is Approximately 4%

Figure 9 - Downstream mass balance correction factor

Figure 10 - July 11-08 Flow Rate Hydrographs from upstream and downstream v-notch weirs

The correction factor used to balance July 11 was 2.8 cm. This was the initial level recorded by the level logger prior to the storm runoff reaching the outlet of the biofilter.

Figure 11 - July 22-08 Flow Rate Hydrographs from upstream and downstream v-notch weirs

The correction factor used to balance July 22 was 10.3 cm. This was the initial level recorded by the level logger prior to the storm runoff reaching the outlet of the biofilter.

Figure 12 - 30 July-08 Flow Rate Hydrographs from upstream and downstream v-notch weirs

The correction factor used to balance July 30 was 2.2 cm. This was the initial level recorded by the level logger prior to the storm runoff reaching the outlet of the biofilter.

Figure 13 - Aug 18-08 Flow Rate Hydrographs from upstream and downstream v-notch weirs

The correction factor used to balance August 18 was 4.5 cm. This was the initial level recorded by the level logger prior to the storm runoff reaching the outlet of the biofilter.

Figure 14 - Sept 7-08 Flow Rate Hydrographs from upstream and downstream v-notch weirs

The correction factor used to balance September 7 was 7.95 cm. This was the initial level recorded by the level logger prior to the storm runoff reaching the outlet of the biofilter.

Figure 15 - Sept 9-08 Flow Rate Hydrographs from upstream and downstream v-notch weirs

The correction factor used to balance September 9 was 9.3 cm. This was the initial level recorded by the level logger prior to the storm runoff reaching the outlet of the biofilter.

Figure 16 - Sept 13 Flow Rate Hydrographs from upstream and downstream v-notch weirs

The correction factor used to balance September 13 was 9.8 cm. This was the initial level recorded by the level logger prior to the storm runoff reaching the outlet of the biofilter.

The flow-through capacity for the biofilter was calculated using monitoring data from 20 storm events (see Figure 17). The flow-through capacity (i.e. without overtopping) per unit cross-sectional area perpendicular to the flow direction for the compost material tested was $10 \text{ L s}^{-1} \text{ m}^{-2}$. The compost biofilter at Hwy 8 had a cross-sectional area of 9 m^2 perpendicular to flow direction and the flow-through capacity was approximately 90 L/s based on measured flow and water level data.

Figure 17 - Biofilter Flow Through Rate in Relation to Water Height Against Biofilter

The curve presented in Figure 17 illustrates an strong exponential trend that the data obtained from the seven storms produced. Using this curve, the flow rates for the other storms can be calculated.

Gan et al., (2007), presented a linear relationship that concluded that the higher the total rainfall depth the larger the volume of runoff. This relationship was verified by creating a similar plot using data from Hwy.8 (see Figure 18). This relationship, in combination with the flow rate curve and runoff coefficient relationships (see Figure 19), were used to help determine the flow rate hydrographs for storms prior to the downstream v-notch weir installation as well as the days where there were equipment malfunctions (see Table 2).

Figure 18 - Relationship between rainfall depth and runoff depth for Hwy 8, Kitchener

Figure 19 – Relationship between runoff coefficient and rainfall volume

Table 2 - Mass Balance for Storms

Date	Inflow Volume (m³)	Outflow Volume (m³)	Precipitation (mm)	Rainfall Volume (m3)	Runoff Coefficient (%)
11-Jul-08*	615.45	609.23	79.47	675.50	0.91
12-Jul-08*	5.26	4.81	2.63	22.36	0.24
22-Jul-08*	318.15	317.91	48.9	415.65	0.78
23-Jul-08*	5.47	5.37	1.2	10.20	0.16
30-Jul-08*	260.59	258.78	43.16	366.86	0.61
18-Aug-08*	142.38	140.54			
7-Sep-08*	229.59	227.73	35	297.50	0.77
9-Sep-08*	62.8	63.22	11.6	98.60	0.67
13-Sep-08*	285.52	284.71	42.6	362.10	0.79
9-Sep-07		36.02	9	76.5	0.47
11-Sep-07		36.1	8.5	72.25	0.50
26-Sep-07		14.49	4.2	35.7	0.17
2-Oct-07		5.52	2.4	20.4	0.05
6-Oct-07		98.93	26.5	225.25	0.44
10-Oct-07		44.35	12	102	0.43
23-Oct-07		42.02	12	102	0.41
31-Oct-07		7.7	2.5	21.25	0.36
7-May-08		46.6	10.8	91.8	0.51
14-May-08		6.23	3.6	30.6	0.20
17-May-08		4.06	2.4	20.4	0.20
3-Jun-08		12.11	7.4	62.9	0.19
15-Jun-08		150.13	19.74	167.79	0.89
22-Jun-08		46.21	9.7	82.45	0.56
26-Jun-08		0.72	0.5	4.25	0.17
17-Jul-08		39.45	9.7	82.45	0.48

* Storms balanced using both upstream and downstream weir flow rates

The inflows for the seven storms used to calibrate the flow through capacity curve correlated to the water height against the biofilter, are displayed in Table 2. Once the curve was established, the inflow hydrographs for the other storms were calculated.

This method in determining the upstream flow provided upstream data where logger data was lost or missing due to on site troubleshooting and provided accurate flow through rates during smaller events.

5.2. TSS Removal Efficiency and Contaminant Event Mean Concentration

The Ontario Provincial Water Quality Objective (PWQO) for Total Suspended Solids (TSS) is 25 mg/L. In total, 9 out of 20 storm events had exceedance above guidelines for TSS in Highway 8 runoff (i.e. Inlet Concentration); however, only 4 out of 20 storm events had exceedance above guidelines for TSS after filtration through the biofilter (i.e. Outlet Concentration). That is, the biofilter reduced the number of exceedances by half. The average inlet TSS concentration for the 20 storm events was 50 mg/L and the biofilter had an average TSS removal efficiency of 42% reducing the average outlet TSS concentration to 18 mg/L below the PWQO guidelines (see Table 3).

Table 3 - Concentrations and Biofilter Removal Efficiencies of TSS

Date	Inlet Concentration (mg/L)	Outlet Concentration (mg/L)	Removal (%)
September 9, 2007	33.6	29.7	12
September 11, 2007	95.8	25.0	74
September 26, 2007	18.0	15.2	16
October 2, 2007	14.8	6.0	59
October 6, 2007	47.6	21.4	55
October 10, 2007	95.7	12.8	87
May 7, 2008	232.9	29.3	87
May 14, 2008	29.1	21.0	28
May 17, 2008	23.0	19.9	13
June 3, 2008	20.6	16.8	18
June 16, 2008	21.1	20.7	2
June 23, 2008	14.8	11.6	22
June 27, 2008	22.3	12.9	42
July 11, 2008	15.8	11.0	30
July 12, 2008	48.8	12.9	73
July 17, 2008	15.8	13.1	18
July 22, 2008	165.2	35.6	78
July 23, 2008	10.9	8.3	24
July 30, 2008	68.7	31.0	55
August 18, 2008	17.3	11.0	37
Mean	50.6	18.3	42
Standard Deviation	57.8	8.31	27

Note: Environmental guidelines

The Ontario Provincial Water Quality Objective (PWQO) for Total Suspended Solids (TSS) is 25 mg/L. In total, 9 out of 20 storm events had exceedance above guidelines for TSS in Highway 8 runoff (i.e. Inlet Concentration); however, only 4 out of 20 storm events had exceedance above guidelines for TSS after filtration through the biofilter (i.e. Outlet Concentration). That is, the biofilter reduced the number of exceedances by half. The average inlet TSS concentration for the 20 storm events was 50 mg/L and the biofilter had an average TSS removal efficiency of 42% reducing the average outlet TSS concentration to 18 mg/L below the PWQO guidelines.

Particle Size Distribution

Particle size distribution of both inlet and outlet samples was obtained using the Mastersizer 2000 instrument. In order to have a more detailed removal efficiency, sediment particles were classified into 4 particle size classes: class 1 consisted of particles finer than 5.75 microns (clay-size particles), class 2 consisted of particles between 5.75 and 19.95 microns (fine silt), class 3 consisted of particles between 19.95 and 60.23 microns (medium silt) and class 4 consisted of particles larger than 60.36 microns (course silt). Classes have been chosen according to ASTM standard for classification of particle size in the BS 1377.

In a controlled setting, testing on the same size diameter compost biofilter socks with comparable compost media was found to remove 30% of the class 1, 50% for class 2, 80% for class 3 and 4 particulates. When particle size distribution tests were performed on samples collected from the full scale Hwy. 8 site the compost biofilter was found to be effective at removing particles from all four classes however the distributaries vary between events (see Figure 20).

Figure 20 – Average Particle size distribution for suspended solids in Highway 8 stormwater runoff

In Figure 20 the average PSDs are illustrated. The error bars indicate the observed natural variability between the storm events.

Heavy Metal EMC Removal Efficiency

Heavy metal concentrations were measured using a graphite furnace spectrophotometer located at the University of Guelph. Compost biofilters were found to significantly reduce the heavy metal contaminants from highway runoff. The two metals found in significant concentrations were Zinc and Copper.

The spectrophotometer results were compared with the standard #3120B ICP method at the Soil and Nutrient Laboratory (see Figure 21).

Figure 21 - Soil and Nutrient Lab Zinc Removal Efficiencies Compared to Spectrometer Zinc and Copper Removal Efficiencies

The Ontario Provincial Water Quality Objective (PWQO) for Zinc is 20 µg/L. In total 15 out of 20 storm events had exceedance above guidelines for Zinc in Highway 8 runoff (i.e. Inlet Concentration); however, only 5 out of 20 storm events had exceedance above

guidelines for Zinc after filtration through the biofilter (i.e. Outlet Concentration). That is, the biofilter reduced the number of exceedances to one-third. The average inlet Zinc concentration for the 20 storm events was 25 µg/L and the biofilter had an average Zinc removal efficiency of 32% reducing the average outlet Zinc concentration to 16 µg/L below the PWQO guidelines (see Table 4).

Table 4 - EMC Concentrations and Biofilter Removal Efficiencies for Zinc

<i>Date</i>	<i>Inlet EMC (µg/L)</i>	<i>Outlet EMC (µg/L)</i>	<i>Removal Efficiency (%)</i>
September 9, 2007	23.49	10.59	55
September 11, 2007	30.26	12.77	58
September 26, 2007	34.39	23.81	31
October 2, 2007	27.80	17.99	35
October 6, 2007	36.61	28.75	21
October 10, 2007	20.43	12.08	41
October 23, 2007	25.79	12.82	50
October 31, 2007	25.70	16.62	35
May 7, 2008	49.98	19.31	61
May 14, 2008	12.66	10.64	16
May 17, 2008	19.11	16.37	14
June 3, 2008	5.46	3.55	35
June 16, 2008	26.25	9.75	63
June 23, 2008	21.07	19.54	7
June 27, 2008	18.24	23.49	0
July 11, 2008	28.40	22.46	21
July 12, 2008	4.65	3.52	24
July 17, 2008	23.39	19.68	16
July 22, 2008	36.20	19.43	46
July 23, 2008	12.38	6.45	48
July 30, 2008	33.27	26.87	19
<i>Mean</i>	<i>24.55</i>	<i>16.02</i>	<i>32</i>
<i>Standard Deviation</i>	<i>10.76</i>	<i>7.17</i>	<i>22</i>

Note: Environmental guidelines

The Ontario Provincial Water Quality Objective (PWQO) for Zinc is 20 µg/L. In total, 15 out of 20 storm events had exceedance above guidelines for Zinc in Highway 8 runoff (i.e. Inlet Concentration); however, only 5 out of 20 storm events had exceedance above guidelines for Zinc after filtration through the biofilter (i.e. Outlet Concentration). That is, the biofilter reduced the number of exceedances to one-third. The average inlet Zinc concentration for the 20 storm events was 25 µg/L and the biofilter had an average Zinc removal efficiency of 32% reducing the average outlet Zinc concentration to 16 µg/L below the PWQO guidelines.

The Ontario Provincial Water Quality Objective (PWQO) for Copper is 5 µg/L. All 20 storm events had concentrations exceeding above the guidelines for Copper in Highway 8 runoff (i.e. Inlet Concentration). The average inlet Copper concentration for the 20 storm events was 32 µg/L and the biofilter had an average Copper removal efficiency of 29% reducing the average outlet Copper concentration to 21 µg/L which is still above the PWQO guidelines (see Table 5).

Table 5 - EMC Concentrations and Biofilter Removal Efficiencies for Copper

DATE	Inlet EMC (µg/L)	Outlet EMC (µg/L)	Removal Efficiency (%)
September 9, 2007	33.99	19.35	43
September 11, 2007	29.72	15.14	49
September 26, 2007	35.94	17.93	50
October 2, 2007	28.08	10.31	63
October 6, 2007	22.90	12.32	46
October 10, 2007	36.33	24.65	32
October 23, 2007	35.45	26.71	25
October 31, 2007	62.76	25.98	59
May 7, 2008	26.30	25.42	3
May 14, 2008	21.44	32.93	0
May 17, 2008	38.36	28.88	25
June 3, 2008	27.14	24.82	9
June 16, 2008	24.14	14.66	39
June 23, 2008	23.16	22.84	1
June 27, 2008	21.06	21.74	0
July 12, 2008	19.25	16.71	13
July 17, 2008	35.43	28.20	20
July 22, 2008	49.95	18.99	62
July 23, 2008	22.54	12.80	43
July 30, 2008	36.06	26.42	27
Mean	31.5	21.34	29
Standard Deviation	10.67	6.32	19

Note: Environmental guidelines

The Ontario Provincial Water Quality Objective (PWQO) for Copper is 5 µg/L. All 20 storm events had exceedance above guidelines for Copper in Highway 8 runoff (i.e. Inlet Concentration). The average inlet Copper concentration for the 20 storm events was 32 µg/L and the biofilter had an average Copper removal efficiency of 29% reducing the average outlet TSS concentration to 21 µg/L which is still above the PWQO guidelines.

A study conducted by Harriston and Wilson (1985) found that significant correlations existed between metals and suspended particles. This is because there are two forms of heavy metals found in stormwater runoff including; dissolved and suspended. The relationships for zinc and copper presented in Figure 22 suggest that the majority of the metals found in stormwater are sediment-bound with a small percentage being dissolved confirming Harriston and Wilson (1985) and Shinya (2000) who found that cadmium, iron, aluminum, lead, zinc and copper were found to be particulate-bound.

Figure 22 - TSS and Heavy Metals Relationship

Petroleum Hydrocarbons EMC removal efficiency

PAH were tested in the University of Guelph using a SFS instant screener. This method was found to be comparable to standard methods. By sending one of every ten PAH unknown samples to the ALS lab in Waterloo, Ontario, PAH concentrations of both methods could be compared. Both procedures from the research lab and the ALS lab were carried out at approximately the same time. These methods were done to ensure that both procedures were able to cover the applicable concentration range accurately (see Figure 23 and 24).

Figure 23 - Petroleum Hydrocarbon Removal Efficiency Laboratory Compressions

The r^2 found in Figure 23 has a value of 0.70. This trend illustrates that there was a relationship between the two lab methods. Due to the nature of volatile compounds and varying sample handling methods, there is room for discrepancy in the plotted data.

Figure 24 - ALS Lab in comparison to LDI Lab for Engine oil (F2 and F3 concentrations)

The concentrations reported by the ALS lab showed a trend similar to the LDI machine results. There was a larger difference in the results presented for the higher concentrations of engine oil in Figure 24, resulting in a r^2 value of 0.66. Differing sample handling and preparation for each method could explain the difference in the samples with higher concentrations of VOCs.

A calibration curve was developed for the constituents, engine oil point 295/340, found present in the SFS obtained from the runoff water samples. This calibration curve was added to the library to allow for the concentrations of the constituent by comparing the SFS to the curve (see Figure 25).

Figure 25 - LDI Calibration Curve for Engine Oil Point 295/340

Polycyclic aromatic hydrocarbons have moderate to high acute (short- term) toxicity to aquatic life and birds. Some cause damage and death to agricultural and ornamental crops. They have moderate to high chronic (long-term) toxicity to aquatic life. Polycyclic aromatic hydrocarbons are moderately persistent in the environment, and can bioaccumulate. The concentrations of polycyclic aromatic hydrocarbons found in fish and shellfish are expected to be much higher than the environment from which it was taken. However, polycyclic aromatic hydrocarbons do not dissolve easily in water. They absorb to dust or dirt particles and settle to the bottom of lakes and rivers. Microorganisms will break them down in soil or water over a period of weeks to months. Mixed microbial populations in sediment/water systems may degrade some polycyclic aromatic hydrocarbons, with degradation progressively decreasing with increasing molecular weight. Polycyclic aromatic hydrocarbons (PAH) maximum recommended concentration in freshwater is 3.0 micrograms per Litre (Australian Water Quality Guidelines for Fresh Waters ANZECC, 1992).

In total, 18 out of 20 storm events had exceedance above guidelines for PAH in Highway 8 runoff (i.e. Inlet Concentration); however, only 6 out of 20 storm events had exceedance above guidelines for PAH after filtration through the biofilter (i.e. Outlet Concentration). That is, the biofilter reduced the number of exceedances to one-third. The average inlet PAH concentration for the 20 storm events was 8.2 µg/L and the biofilter had an average PAH removal efficiency of 66% reducing the average outlet PAH concentration to 2.7 µg/L which is below the ANZECC guidelines (see Table 6).

Table 6 - EMC Concentrations and Biofilter Removal Efficiencies of PAH

Date	Inlet EMC (µg/L)	Outlet EMC (µg/L)	Removal Efficiency (%)
September 9, 2007	10.1	1.4	86
September 11, 2007	4.3	1.5	65
September 26, 2007	10.5	2.2	79
October 2, 2007	11.5	2.1	82
October 6, 2007	5.4	0.3	94
October 10, 2007	8.5	3.3	61
October 23, 2007	3.8	2.1	46
October 31, 2007	11.0	2.8	74
May 7, 2008	8.6	2.4	72
May 14, 2008	4.6	3.3	28
May 17, 2008	9.7	4.1	58
June 3, 2008	12.8	3.6	72
June 16, 2008	8.7	2.3	74
June 23, 2008	10.4	4.0	62
June 27, 2008	3.0	1.3	56
July 12, 2008	3.6	1.3	65
July 17, 2008	11.2	2.8	75
July 22, 2008	5.3	1.7	67
July 23, 2008	2.9	1.4	52
July 30, 2008	16.7	9.3	44
Mean	<i>8.17</i>	<i>2.67</i>	<i>66</i>
Standard Deviation	<i>4.09</i>	<i>1.86</i>	<i>16</i>

Note: Environmental guidelines

Australian Water Quality Guidelines for Fresh Waters (ANZECC, 1992) for Polycyclic aromatic hydrocarbons (PAH) maximum recommended concentration in freshwater is 3.0 micrograms per Litre (i.e. 0.000003 g/L). In total, 18 out of 20 storm events had exceedance above guidelines for PAH in Highway 8 runoff (i.e. Inlet Concentration); however, only 6 out of 20 storm events had exceedance above guidelines for PAH after filtration through the biofilter (i.e. Outlet Concentration). That is, the biofilter reduced the number of exceedances to one-third. The average inlet PAH concentration for the 20 storm events was 8.2 µg/L and the biofilter had an average PAH removal efficiency of 66% reducing the average outlet PAH concentration to 2.7 µg/L which is below the ANZECC guidelines.

The Australian Water Quality Guidelines were used to determine if the obtained PAH concentrations were within a healthy range. Canadian standards were not used for comparisons because in Canada there are no set concentrations for PAHs. Instead exceedances are measured through physical attributes of the water. Typical observations are the rainbow sheen left by PAHs as well as the smell that is left in water from the PAHs.

Overall the concentrations of TSS, Lead, Copper and PHC found in highway stormwater runoff prior to biofilter treatment were found in higher concentrations than the water sampled post biofiltration. Although the concentrations varied between storms, the concentrations were consistently lower after the water was gravitationally filtered through the biofilter. Based on these observations it is concluded that the compost biofilter is effective in reducing pollutants found in highway stormwater runoff.

Limitations and Factor of Safety

When examining the removal efficiencies on each event it can be concluded that there is variability within the data that needs to be accounted for when designing and implementing compost biofilters on a highway site. Due to the standard deviations for the mean average removal efficiencies found in Table 3, Table 4, Table 5 and Table 6 it is recommended that a factor of safety of 2-3 be applied to the design.

One way to improve the biofilter removal efficiency would be to use a multi-barrier approach for the biofilters. This method is common for stormwater treatment sites and was seen on the highway 8 site with multiple rock check dams that influenced ponding allowing for fine particulates to settle out. The benefits of using a multi-barrier approach is that the compost biofilters would not overtop as quickly and the biofilters downstream would have a longer life span as the biofilter most upstream would become clogged with the larger particulates

5.3. Characterization of Pollutant loading

Throughout literature it has been found that there are four main factors influencing the build-up and wash-off of pollutants including; antecedent dry days (ADD), total rainfall depth, average annual daily traffic (AADT) and rainfall intensity (Tsihrintiz and Hamid, (1995); Wada et al. (2004); Gupta and Kobringer (1981); Hewitt and Rashed (1992); Kerri (1985); Marsalek (1991); Wu et al. (1998); and Irish et al. (1998)). Trends suggesting that similar parameters govern the pollutant loading observed on highway 8 were observed from the highway runoff analysis.

Pollutant Build-Up

There are two variables that dictate the build-up of pollutants deposited on highways and other impervious surfaces; AADT and ADT.

Average annual daily traffic (AADT) was one parameter that was not obvious as a governing parameter within the data. This could be because the analysis was on one site and therefore the database contained only four traffic numbers based on annual counts. Extensive statistical studies conducted including Barrett and Michel (1995); Irwin and Losey (1978); Kayhanian et al. (2003); Moe (1978); Stotz (1987); and Irish Jr. et al. (1998) used data from many different sites or use specific time traffic counts to confirm that the AADT highly influences the contaminant buildup on highways.

In order to determine if AADT was an influencing parameter and if the data obtained from highway 8 was within range of other sites, the EMCs for pollutants were plotted in relation to the AADT for 16 sites from Table 7, including highway 8, in Figure 26.

Figure 26 - Observed pollutant EMC trend for AADT

Table 7 - EMC Data for Highway Stormwater Runoff Studies

Reference	Site	Drainage Area (m ²)	AADT (vehicles/day)	Land Use	TSS (mg/L)	Cu (µg/L)	Zn (µg/L)
Deletic and Maksimovi, 1998	Miljak, Yugoslavia	211	435	Res./com.	96 – 673	-	-
	Lund, Sweden	270	15-20	Carpark	5-417		
Stotz and Krauth, 1994	Weins., Germany	550	34 675		64	49	441
					49	88	737
Legret and Pagotto, 1999	Nantes, France	3 200	12 000	Bypass, rural	77	45	356
Wu et al., 1998	HB, N.C.	1 497	12 000	Rural/res.	283	24.2	
	NC49, N.C.	2 307	21 500	Rural/res.	93	11.5	
	185, N.C.	4 452	5 500	Rural/res.	30	4.6	
Barrett et al., 1998	W35, Tex.	5 341	58 150	Com./res.	129	37	222
	CH, Tex.	526	8 780	Rural/res.	91	7	44
	WC, Tex.	104 600	47 240	Com./res.	19	12	3
Stotz, 1987	A81, Germany	13 000	41 000	Rural	137	97	360
	A6, Germany	25 200	47 000	Rural	181	117	245
	A8, Germany	250 000	52 100	Rural	252	58	163
Sansalone and Buchberger, 1997	Milcreek, Ohio	300	150 000	Urban	5-11	43-325	459 – 15 244
Flint et al., 2007	Mount Rainier, Md.	5 600		Ultra-urban	420	110	220
Gan et al., 2007	Pear River Delta, South China	135	22 170	Com./res.	415.7	140	1760
				Vegetable Field	111.1	90	70
Nie et al., 2008	Pear River Delta, South China Shanghai, China	110 400	31000 30000	Highway	25 - 250	96 – 588	770 - 6250

Li., et al., 2008	State University , Austin, Texas	185	50 000	Commercial	116	1.4	11.7
	State University , Austin, Texas	218	50 000	Commercial	172	1.6	12
	State University , Austin, Texas	185	50 000	Commercial	124	1.4	11
	Loop 360, Austin, Texas	185	43 000	Commercial	118	48	17
	Loop 360, Austin, Texas	185	35 000	Commercial	84	26	14
	Loop 360, Austin, Texas	185	35 000	Commercial	173	40	17
Finney et al., 2009	Hwy 8, Kitchener, On	8500	89 400	Highway	51	25	32

Figure 26 presents linear trends for the AADT from other sites as well as the data obtained from the highway 8 site. There are many discrepancies between sites including geographic location that results in scatter within the data however a common linear trend of the EMCs increasing with the traffic count within a particular site.

The AADT values used for Hwy 8 were predicted from a table provided by MTO with values going up to 2005. By plotting these values, a linear relationship was present and the AADT values for 2007 and 2008 were interpolated (Figure 27 and Table 8).

Figure 27 - Ontario Ministry of Transportation Hwy 8 Average Annual Daily Traffic Data for 1988 – 2005 period and calculated data for the 2006 – 2009 period.

Table 8 - Hwy 8 Average Annual Daily Traffic Data for 1988 - 2005

Highway	Location Description	Year	AADT [*]	SADT ^{**}	SAWDT ^{***}	WADT ^{****}
FAIRWAYRD IC						
8	(WBL)KITCHENER	1988	54,350	57,000	61,400	51,000
		1989	57,050	59,900	64,400	54,100
		1990	59,450	63,600	68,900	56,400
		1991	61,200	64,800	70,300	59,300
		1992	61,600	65,200	70,800	59,100
		1993	61,600	64,000	69,600	57,200
		1994	68,300	72,400	79,200	62,200
		1995	71,100	73,900	81,100	66,100
		1996	73,900	78,600	86,500	70,200
		1997	76,700	80,500	89,700	72,100
		1998	79,500	84,600	93,000	75,500
		1999	82,300	87,600	96,300	78,200
		2000	82,600	87,900	97,300	77,600
		2001	84,800	90,700	100,100	79,700
		2002	87,000	92,700	102,300	81,500
		2003	89,200	94,600	105,300	83,800
		2004	90,600	95,700	106,100	85,600
		2005	93,800	99,300	109,700	88,000

Note:

*AADT: Annual Average Daily Traffic; defined as the average 24 hr, two way traffic for the period Jan 1st to Dec 31st.

**SADT: Summer Average Daily Traffic; defined as the average 24 hr, two way traffic for the period July 1st to Aug 31st, including weekends.

***SAWDT: Summer Average Weekday Traffic; defined as the average 24 hr, two way traffic for the period Jul 1st to Aug 31st, excluding weekends.

****WADT: Winter Average Daily Traffic; defined as the average 24 hr, two way traffic for the period Jan 1st to Mar 31st, including weekends.

The second trend observed was trend of a build-up of pollutants over a period of dry weather. Figure 28 shows that the EMCs of pollutants increase as ADD increases. After about 7 days it can be seen that the EMCs plateau. This is caused by wind, vehicular transport and other parameters displacing and re-distributing the pollutants (Vaze and Chiew, 2002). It was for this reason a power relationship was chosen to accurately observe this trend in the data. The scattering within the data is due to the nature of pollutant distribution. There are many parameters influencing the location of pollutants including; wind, weather patterns, recreational and construction activities.

Figure 28- Observed pollutant EMC trend for ADD

Pollutant Wash-off

There are two parameters that influence the wash-off of the built-up pollutants found on highways and other impervious areas; total rainfall depth and rainfall intensity.

Total rainfall depth has been identified throughout literature as being a governing parameter in estimating the pollutant build-up. Figure 29 illustrates a linearar relationship between pollutants EMCs based on the total rainfall depth for the storm.

Figure 29 - Observed pollutant EMC trend for total rainfall (mm)

A power relationship was also chosen to present this trend observed in the data as the EMCs based on the total rainfall plateaus after about 14 mm of rain. This trend suggests that the pollutants found in runoff are not available in unlimited quantities rather are characterized by the amount of pollutant available.

A study conducted by Pitt (2003) determined that the concentration of TSS decreases with higher rainfall amounts when the rainfall intensities are similar. A similar plot was developed that confirmed this trend (see Figure 26).

Figure 30 - Total Suspended Solids (TSS) Mean Event Concentration versus Total Event Rainfall Depth.

Based on the work presented in Pitt (2003) the mass loading for each storm for zinc, copper and PAHs were determined and washout ranges for both small and large storms were calculated. This was done to further observe the trends of the loading on the highway site (see Table 9).

Table 9 - Comparisons of Observed Washoff

	<i>Zinc Washoff (mg/m²)</i>	<i>Copper Washoff (mg/m²)</i>	<i>PAH Washoff (mg/m²)</i>
Light Rains	0.01 – 0.16	0.01 – 0.18	0.05 – 0.06
Heavy Rains	0.30 – 2.05	0.37-1.87	0.05-0.51

Rainfall intensity was another parameter that was suggested as being an influencing parameter for the estimation of pollutants. Figure 31 illustrates a linear trend that was observed for the EMCs on the highway 8 site for rainfall intensity.

Figure 31 - Observed pollutant EMC trend for rainfall intensity

The scattering within the data is due to the nature of pollutant distribution after a storm. There are many parameters influencing the washoff of pollutants including; wind, weather and vehicular traffic during an event.

Pollutant removal estimation for compost biofilters

The inlet EMC was the only variable that showed a significant trend dictating the removal efficiency for the compost biofilter. Figure 32 illustrates a trend that the higher the EMC found in the stormwater runoff the greater the removal efficiency.

Figure 32 - EMCs for compost biofilter removal (%)

One method that can be used for predicting the EMC for an installed biofilter would be to calculate the EMC for the outlet of the biofilter knowing the inlet EMC and the average removal of a pollutant.

Equation 3 - Removal efficiency example using a compost biofilter

$$\text{Removal Efficiency (\%)} = (\text{TSS}_{\text{in}} - \text{TSS}_{\text{out}}) / \text{TSS}_{\text{in}}$$

$$\text{Removal Efficiency (\%)} \times \text{TSS}_{\text{in}} = \text{TSS}_{\text{in}} - \text{TSS}_{\text{out}}$$

$$\text{TSS}_{\text{out}} = \text{TSS}_{\text{in}} (1 - \text{Removal Efficiency (\%)})$$

This method would be limited to the deviation for each pollutant removal as the removal efficiency for pollutants vary between events.

5.4. *SWMM Modelling*

An initial step in designing a compost biofilter is to determine the maximum flow rate or intensity the biofilter for design. The maximum values are required as they provide valuable design information in order to prevent overtopping of the biofilter. Because biofilters are designed for “gravity flow” to convey highway runoff, the physical site conditions are required. One method to determine runoff response to a specific site is to create a SWMM5 model. For this study, a SWMM5 model was created to demonstrate the important inputs and calibration techniques used to best represent the site responses as well as to verify the flow through equation developed in Figure 17.

The model consisted of simple features including a single 0.85 ha sub-catchment area consisting of a series of culverts connected with two v-notch weirs, two storage ponds and a rain gage (see Figure 33). In order to best represent the biofilter site on Hwy. 8, surveying data was entered into SWMM5 to capture the ditch slope through calculated elevations. The curve number method was selected to represent the permeable infiltration areas and a curve number of 80 was selected.

Figure 33 - SWMM Model Map View

In order to calibrate the SWMM5 model, two larger storms; 11 July, 2008 and 30 July, 2008, were selected for the model calibration due to their high maximum intensities and flow rates. These storms, as well as two other storms with known intensities were entered into SWMM5 as a time series files with intensity values for selected time steps during the selected event (see Appendix G). The model was run for each storm event. Once completed, data was exported and compared against actual upstream and downstream hydrographs obtained from the installed instruments on site. The model was calibrated to capture both the peak flow rate and the volume of water passing through the sub-catchment (see Appendix G). The calibration was performed by fine-tuning the

assumed parameters of the site including; soil properties, initial pond volumes and the percent impermeable values.

Figure 34 - 11 July 2008 Actual hydrographs in comparison to SWMM model hydrographs

Figure 35 - 30 July 2008 Actual hydrographs in comparison to SWMM model hydrographs

Because the biofilter was installed when the site was equipped with monitoring equipment, the biofilter needed to be represented in the model. This was achieved through modelling the compost biofilter to be “lumped” as a storage pond in the

SWMM5 model. This allowed for the water to pond similarly to how the water would against the biofilter as well as allows for the water flow rates to better represent the outlet flow rates after leaving the biofilter. Two storms were used to calibrate the downstream biofilter including 11 July; and 30 July 2008 and were verified using downstream data from 22 June; and 22 July 2008. A comparison of the known v-notch flow rates for the upstream v-notch calibration storms can be found in Table 10 and the downstream v-notch calibration and verification storms can be found in Table 9.

Table 10 - USVN volume and peak flow comparisons

Date	Rainfall Depth (mm)	USVN Volume (m³)	SWMM USVN Volume (m³)	USVNFR (L/s)	SWMM USVNFR (L/s)
11 July 2008	79.5	615.45	630.27	63.33	73.54
30 July 2008	40.0	223.85	289.79	93.24	91.6

Table 11 - DSVN volume and peak flow comparisons

Date	Rainfall Depth (mm)	Calculated DSVN Volume (m³)	SWMM DSVN Volume (m³)	Calculated DSVN Peak Flow (L/s)	SWMM DSVN Peak Flow (L/s)
22 June 2008	9.7	36.25	57.13	29.43	25.71
11 July 2008	79.5	553.33	592.40	30.81	51.94
17 July 2008	9.7	39.47	59.91	7.88	5.11
30 July 2008	40.0	216.47	290.95	75.64	49.74

When comparing the hydrographs of the two events used to calibrate the model it can be concluded that the peak flows and basic shape of the hydrographs were captured. A SWMM5 model can provide essential information about a site including peak flow rates and water volume. Using a SWMM5 model the design flow rate can be obtained; from

there the maximum water level during an event can be determined using the flow through equation in Figure 17. See example below;

Example #1 – Determining cross sectional area of a biofilter

Determine the cross sectional area of a biofilter that is to be installed in a ditch beside a highway that has a 2-year peak flow rate of 160 L/s, a bottom width of 4 m and has a slide slope of 2:1.

Solution:

Equation 4 - Height of biofilter without overtopping for Example 1

$$Q_{\max} = 160 \text{ L/s}$$

$$W = 4 \text{ m}$$

$$S = 2$$

$$H = \ln \frac{(Q_{\max} / 0.0173)}{0.0091}$$

$$H = \ln \frac{(160 \text{ L/s} / 0.0173)}{0.0091}$$

$$H = 1003 \text{ mm}$$

The height of the biofilter without overtopping is 1003 mm or approximately 1 m.

This means that the maximum height of water against the biofilter will be 1 m. A factor of safety of 2 will be used making the required height of the biofilter 2 m. Using the calculated dimensions of the biofilter the cross sectional area can then be determined using Equation 5.

Equation 5 - Cross sectional area of a trapezoid for Example 1

$$b_1 = 4 \text{ m}$$

$$b_2 = 6 \text{ m}$$

$$H = 2 \text{ m}$$

$$A_{\text{trapezoid}} = ((b_1 * b_2) / 2) * H$$

$$A_{\text{trapezoid}} = ((4 \text{ m} + 6 \text{ m}) / 2) * 2 \text{ m}$$

$$A_{\text{trapezoid}} = 24 \text{ m}^2$$

Therefore the cross sectional area of the biofilter in a ditch with a 4 m base width and 2:1 slope and 2 m high would have a 6 m top length with a cross sectional area of 24 m². In order to check if the dimensions of the biofilter are accurate the seepage velocity can be calculated using Equation 6.

Equation 6 - Seepage velocity check for Example 1

$$V_{seepage} = \frac{Q_{max}}{A_{trapezoid}} * \frac{m^3}{1000L}$$

$$V_{seepage} = \frac{160L/s}{24m^2} * \frac{m^3}{1000L}$$

$$V_{seepage} = 0.0067$$

Because the seepage velocity value is close to 0.01 it can be confirmed that the cross sectional area for the biofilter is appropriate to prevent overtopping in a 2-year storm.

6. Biofilter Longevity

One important factor that was investigated was the longevity, or life span, of the compost biofilter. A study conducted by Taleban et al. (2008) tested the longevity of the same diameter of compost biofilter sock in a controlled flume setting on the Guelph Grass Institute at the University of Guelph. Synthetic stormwater was introduced to the flume with a series of compost biofilters placed in a single row parallel to each other, downstream of the flume. Tests investigated by Taleban (2008), found that over time, as the suspended solids accumulated within the pore-spaces of the compost biofilter, the sediment removal decreased. For this investigation, five rolls of 45 cm (18") sock reduced from 66% removal to 54% removal, after 20 consecutive runs with the highest flow rate being 2 L/s (Taleban, 2008).

The compost biofilter study conducted on Hwy. 8 was a full scale site with un-controlled variables. The compost biofilter dimensions were designed to be able to filter stormwater with significantly higher flows than the single layer filter used for the bench scale testing, without overtopping. During the duration of the compost biofilter installation the biofilter was exposed to 52 events over a two year duration. During this time, a significant decrease in removal efficiency was not observed. One of the reasons why a change in removal efficiency was not observed was due to the small number of events passing through the biofilter in comparison to the dimensions of the biofilter tested on the controlled small scale site. If the compost biofilter was exposed to more events, it is predicted that a decrease in removal efficiency would be observed. Based on work done by Taleban, 2007, the longevity of the biofilter can be predicted as follows;

Average TSS Removal Efficiency (%)	42
Total # of Storms passing through filter	52
Average runoff of storms (m ³)	98.43
Average TSS Concentration (mg/L)	51
Average Porosity of Compost - Peel (%)	49

Volume of runoff passing through filter = $98.43 \text{ m}^3 \times 52 \text{ events} = 5000 \text{ m}^3$

Volume of masses in biofilter = $5000 \text{ m}^3 \times 51 \text{ g/m}^3 \times (1\text{kg}/1000\text{g}) \times 0.42 = 107 \text{ kg}$

An assumed density for the sediment based on Taleban, 2007, is 1 kg/L, therefore the volume of sediment in the biofilter is approximately 0.12 m^3 .

Total volume available in biofilter = $(6 \text{ m} \times 5 \text{ m} \times 0.5 \text{ m}) \times 0.49 = 7.35 \text{ m}^3$

Amount of biofilter pore space occupied by sediment = $0.12 \text{ m}^3 / 7.35 \text{ m}^3 = 1.6\%$

Based on research presented by Taleban, 2007, the porosity can decrease by up to 4 - 6%, therefore it is estimated that the compost biofilter could be installed for up to 6 seasons.

7. Conclusions

In the summer of 2007 a full-scale site was selected in consultation with the MTO, located on the east side of highway 8 near Cameo Drive, in Kitchener. The installation of the full-scale biofilter was completed by Filtrexx Canada in July of 2007. With technical assistance and equipment from Toronto and Region Conservation Authority (TRCA), automatic samplers and water level sensors were deployed for monitoring flow rate and water quality. An ISCO 3700 portable flow-weighted sampler collected 24 runoff samples at inlet and 24 samples at outlet for each monitored storm event for a total of 20 storm events during the 2007 and 2008 monitoring program. An ISCO 4150 Area-Velocity flow logger monitored the water level, flow and velocity.

The biofilter was found to be effective in the removal of suspended solids, heavy metals and PHC. TSS, zinc, copper and PHC had removal efficiencies of 42%, of 32%, 29% and 66%.

The Ontario Provincial Water Quality Objective (PWQO) for Total Suspended Solids (TSS) is 25 mg/L. In total 9 out of 20 storm events exceeded the objectives for TSS in Highway 8 runoff (i.e. Inlet Concentration); however, only 4 out of 20 storm events exceeded the objectives for TSS after filtration through the biofilter (i.e. Outlet Concentration). The Ontario Provincial Water Quality Objective (PWQO) for Zinc is 20 µg/L. In total 15 out of 20 storm events exceeded the objectives for Zinc in Highway 8 runoff; however, only 5 out of 20 storm events exceeded the objectives for Zinc after filtration through the biofilter. The Ontario Provincial Water Quality Objective (PWQO) for Copper is 5 µg/L. All 20 storm events exceeded the objectives for Copper in Highway 8 runoff. Australian Water Quality Guidelines for Fresh Waters (ANZECC, 1992) for Polycyclic aromatic hydrocarbons (PAH) maximum recommended concentration in freshwater is 3 µg/L. In total 18 out of 20 storm events exceeded the objectives for PAH in Highway 8 runoff; however, only 6 out of 20 storm events exceeded the objectives for PAH after filtration through the biofilter.

Using the obtained data from the highway site it was observed that the build-up of pollutants on a highway are governed by antecedent dry days (ADD), and average annual daily traffic (AADT), while the wash-off of the pollutants are influenced by the rainfall depth and rainfall intensity.

The compost biofilter was found to be effective in reducing the concentrations pollutants found in highway stormwater runoff. Although a reduction in removal efficiency over time was not observed however the life span for the installed biofilter was estimated to be around 6 years before decommission.

During the two year duration of the monitoring program compost biofilter was exposed to 52 storm events. During this time very little, to no, significant decrease in stormwater runoff treatment efficiency (i.e. pollutant removal efficiency) was observed however a total longevity of 6 years was estimated for a biofilter with similar dimensions.

US Environmental Protection Agency Stormwater Management Model USEPA SWMM was used in this study as a design/analysis tool to estimate peak flow and water levels in the ditch and through the biofilter. The USEPA SWMM model was suitable for this study and accurately predicted runoff peak flow rate, runoff volume and water levels.

There are many existing urban stormwater management technologies which stabilize and filter out stormwater runoff contaminants, but often these do not meet the provincial water quality guidelines. With proper design, compost biofilters, when used alone, or in combination with other stormwater management systems, will continue to improve runoff water quality.

Recommendations for future research involving compost biofilters is the monitoring of the compost biofilters during the colder months as well as the effects of the first flush

when the highest pollutant concentrations are washed off of the roads and other impervious areas.

Further research is recommended into the disposal of the compost biofilter once it is removed. One potential option would be to treat the compost by first shaking-off the polluted sediments that are trapped in the media with a large mechanical shaker for proper disposal and recycling the organic material back into the composting process.

References

- Aird, J. 2008. Restoration of Streams and Buffer Zones. *Stormwater*. 9(2).
- American Public Health Association. 1998. Standard methods for the examination of water and wastewaters, 20th Ed., Washington, D.C.
- ANZECC. 1992. Australian Water Quality Guidelines & New Zealand Environment & Conservation Council, Canberra.
- Randall J. Charbeneau, Jaehak Jeong, and Michael E. Barrett. 2009. Physical Modeling of Sheet Flow on Rough Impervious Surfaces. *J. Hydrologic Engrg.* 135(487).
- Barrett, M. E., Irish, L. B., Malina, J. F., Jr., and Charbeneau, R. J. 1998. Characterization of highway runoff in Austin, Texas area. *J. Environ. Eng.* 124(2): 131–137.
- Barrett, M. E., Lantin, A., and Austrheim-Smith, S. 2004. Stormwater pollutant removal in roadside vegetated buffer strips. *Transportation Research Record. Transportation Research Board, Washington, D.C.* 1890:129–140.
- Barrett, M. E., Walsh, P. M., Malina, J. F., Jr., and Charbeneau, R. J. 1998b. Performance of vegetative controls for treating highway runoff. *J. Environ. Eng.*, 124(11), 1121–1128.
- Barrett, M. E., Zuber, R. D., Collins, E. R., III, Malina, J. F., Jr., Charbeneau, R. J., and Ward, G. H. 1995. A review and evaluation of literature pertaining to the quantity and control of pollution from highway runoff and construction, Center for Research in Water Resources, Univ. of Texas at Austin, 2(239).
- Barrett, M. E., J. F. Malina, and R. J. Charbeneau. 1998. An evaluation of geotextiles for temporary sediment control. *Water Environmental Restoration* 70(3):283-290.
- Barrett, M. E. 1995. Characterization of highway runoff in Austin, Texas area. Technical report – University of Texas at Austin, Center for research in Water Resources, 263,(30).
- Bell, J. H., and Wanielista, M. P. 1979. Use of overload flow in stormwater management on interstate highways. *Transportation Research Board, Washington, D.C.* 736: 13–21.

- Boyd, G and Gardner, N. 1990, Urban Stormwater: An overview for municipalities, Public Works, December, pp. 39-42.
- Bradford A, B. Gharabaghi. 2004. Evolution of Ontario's stormwater management planning and design guidance. Water Quality Research Journal of Canada. 39(4):343-355.
- Burton A., Pitt R. 2002. Stormwater Effects Handbook. A Toolbox for Watershed Engineers. Boca Raton, Florida: Lewis Publishers.
- Charbeneau, R. J., and Barrett, M. E. 1998. Evaluation of methods for estimating stormwater pollutant loads. Water Environ. Res., 70(7): 1295–1302.
- Chiu, T. W., Mar, B. W., and Horner, R. R. 1982. Pollutant loading model for highway runoff. J. Envir. Engrg. ASCE, 108(6): 1193–1210.
- Clarifica Inc., 2004. Assessment of construction sediment control ponds to protect receiving waters, Toronto and Region Conservation Authority, Toronto.
- Clark, S., Pitt, R., Field, R., Fan E, Heaney J, Wright L, Burian S. 2003. Annotated bibliography of urban wet weather flow literature from 1996 through 2002. U.S. Environmental Protection Agency, Urban Watershed Management Branch, Ed., NJ.
- Davis, A. P., Shokouhian, M., & Ni, S. 2001. Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources. *Chemosphere*, 44(5): 997-1009.
- Dixon, W. J. 1953. Processing data for outliers. *Biometrics*, 9, 74–89.
- Dorman, M. E., Hartigan, J. P., Steg, R. F., and Quaebarth, T. F. 1996. Retention, detention, and overland flow for pollutant removal from highway stormwater runoff. Federal Highway Administration, Washington, D.C. 01(FHWA-RD-96-095),
- Driscoll, E. D., Shelley, P. E., and Strecker, E. W. 1990. Pollutant loadings and impacts from highway stormwater runoff. Analytical investigation and research report. Federal Highway Administration, Washington, D.C. 3(FHWA-RD-88-000).
- Ettlin, L., and B. Stewart. 1993. Yard debris compost for erosion control. *BioCycle: Journal of Composting and Organics Recycling*. JG Press. Emmaus, PA. 34(12):46-47.
- Fam, S., Stenstrom, M. K., and Silverman, G. 1987. Hydrocarbons in urban runoff. *J. Environ. Eng.* 113 : 1032–1046.

- Faucette L.B., C.F. Jordan, L.M. Risse, M. Cabrera, D.C. Coleman, L.T. West. 2005. Evaluation of Storm Water from Compost and Conventional Erosion Control Practices in Construction Activities. *Journal of Soil and Water Conservation*. 60:6.
- Ferrara, R. A. 1986. Toxic Pollutants: Impact and Fate in Receiving Waters, in H.C. Torno, Springer-Verlag, Berlin, Heidelberg, 423-435.
- Gharabaghi, B., Fata, A. Van Seters, T., Rudra, R.P. MacMillan, G., Smith, D., J.Y., Bradford, A., and Tesa, G. 2006. Evolution of sediment control pond performance at construction sites in the Greater Toronto Area. *Canadian Journal of Civil Engineering*. 33(11): 1335-1344.
- Gharabaghi, B., Rudra, R. P., and Goel, P. K. 2006b. Effectiveness of vegetative filter strips in removal of pollutants from overland flow. *Water Quality Research Journal of Canada*. 41(3): 275-282.
- Glanville, T.D., R.A. Persyn, and T.L.Richard. 2001. Impacts of compost application on highway construction sites in Iowa. ASAE Annual International Meeting. Sacramento, CA. Paper 01-012076.
- Greater Golden Horeshoe Area Conservation Authorities. 2006. Erosion and Sediment Control Guideline for Urban Construction.
- Grimes, S.M., Taylor, G.H., and Cooper, J. 1999. The availability and binding of heavy metals in compost derived from household waste. *Journal of Chemical Technology and Biotechnology* 74: 1125-1130.
- Gupta, M. K. and Kobringer, N.P. 1981. Constituents of highway runoff Federal Highway Administration, Washington D.C., U.S.A. 4(FHWA/RD-81/042)
- Gupta, M. K., Agnew, R. W., Gruber, D., and Kreutzberger, W. 1981. Constituents of highway runoff. Fed. Hwy. Administration, Washington, D.C. 4(FHWD-RD-81-045).
- Harris, Daniel C. 1995. Quantitative Chemical Analysis, 4th ed. W.H. Freeman and Highway Runoff in Austin Texas. *J. Environ. Eng.* 124(131).
- Harrison, R. M., and Wilson, S. J. 1985. The chemical composition of highway drainage waters. I: Major ions and selected trace metals." *Sci. Total Environ.*, 43: 63-77.
- Henley, W.A., M.A. Patterson, R.J. Neves, and D.A. Lemly. 2000. Effects of sedimentation and turbidity of lotic food webs: A concise review for natural resource managers. *Reviews in Fisheries Science*. 8(21):125-139.

- Hewitt, C. H., and Rashed, M. B. 1992. Removal rates of selected pollutants in the runoff waters from a major rural highway. *Water Res.*, 26(3): 311–319.
- Hong, Eunyoung, Seagren, E.A., Davis, A.P. 2006 Sustainable Oil and Grease Removal from Synthetic Stormwater Runoff Using Bench-Scale Bioretention Studies. *Water Environment Research- ProQuest Agricultural Journals*.78(2).
- Horner, R. R., Burges, S. J., Ferguson, J. F., Mar, B. W., and Welch, E. B. 1979. Highway runoff monitoring. Washington State Dept. of Transportation. Rep. No. WA-RD-39.3.
- Huber, W. 1993. Contaminant transport in surface water."Handbook of hydrology, D. R. Maidmen. McGraw–Hill, New York, 14.1–14.50.
- Huber, W.C., and Dickinson, R.E. 1988. Storm Water Management Model, Version 4: User's Mannual. Environmental Research Laboratory Office of Research and Development, U.S. Environmental Protection Agency, Athens, Georgia.
- Irish, L. B., Barrett, M. E., Malina, M. E., Jr., and Charbeneau, R. J. 1998. "Use of regression models for analyzing highway stormwater loads. *J. Environ. Eng.*, 124(10), 987–993.
- Irish, L. B., Lesso, W. G., Barrett, M. E., Malina, J. F., Jr., and Charbeneau, R. J. 1995. An evaluation of the factors affecting the quality of highway runoff in the Austin, Texas area."Tech. Rep. No. CRWR 264.
- Irwin, G. A., and Losey, G. T. 1978. Water-quality assessment of runoff from a rural highway bridge near Tallahassee, Florida. Report No. 79-1.
- Jang, A., Seo, Y., and Bishop, P.L. 2005. The removal of Heavy Metals in Urban Runoff by sorption on mulch. *Enviromental pollution* 133: 117 – 121.
- Kaighn, R. J., Jr., and Yu, S. L. 1996). Testing of roadside vegetation for highway runoff pollutant removal. *Transp. Res. Rec.* 1523, Transp. Res. Board, Nat. Res. Council, Washington, D.C., 116–123.
- Kayhanian, M., Singh, A., Suverkropp, C., and Borrum, S. 2003. Impact of annual average daily traffic on highway runoff pollutant concentrations. *J. Environ. Eng.*, 129(11) : 975–990.

- Keener, H., B. Faucette, M. Klingman. 2006. Flow-Through Rates and Evolution of Solids Separation of Compost Filter Media vs. Silt Fence in Erosion Control Applications. ASAE Annual International Conference, Portland.
- Khan, S., Lau, S.-L., Kayhanian, M., Stenstrom, M.K. 2006. Oil and grease measurement in highway runoff - Sampling time and event mean concentrations. *Journal of Environmental Engineering* 132(3): 415.
- Lau, S.-L., and Stenstrom, M. K. 1997. Solid phase extraction for oil and grease analysis. *Water Environ. Res.*, 69(3): 68–374.
- Laxen, D. P. H., and Harrison, R. M. 1977. The highway as a source of water pollution: An appraisal of the heavy metal lead. *Water Res.*, 11:1–11.
- Lee, F. and Jones-Lee, A. 1994, Are real water quality problems being addressed by current structural best management practices, *Public works*, 53-55.
- Lee, H., and Stenstrom, M. K. 2005. Utility of stormwater monitoring. *Water Environ. Res.*, 77(3): 219–228.
- Li, Y., Lau, S.-L., Kayhanian, M., and Stenstrom, M. K. 2005. Particle size distribution in highway runoff." *J. Environ. Eng.*, 131(9): 1267–1276.
- Little, P., and Wiffen, R. D. 1978. Emission and deposition of lead from exhausts—II: Airborne concentrations, particle size, and deposition of lead near motorways. *Atmos. Environ.*, 12:1331–1341.
- Maestre, Alexander and Pitt, Robert. 2006, Identification of Significant Factors Affecting Stormwater Quality Using the NSQD, Stormwater and Urban Water Systems Modelling Proceedings. CHI Guelph, Ont. 14:287-326.
- Makepeace, D. K., Smith, D. W., and Stanley, S. J. 1995. Urban stormwater quality: Summary of contaminant data. *Critical Rev. in Envir. Sci. and Technol.*, 25(2):93–139.
- Marsalek, D.K., 1995. Pollutant loads in urban stormwater: Review of methods for planning-level estimates. *JAWRA Journal of the American Water Resource Association*, 27(2): 283–291.
- Ministry of the Environment and Energy (MOEE). 2004. Water Management Policies Guidelines Provincial Water Quality Objectives of the Ministry of Environment and Energy.

- Moe, R. D., Bullin, J. A., and Polasek, J. C. 1978. Characteristics of highway runoff in Texas. Federal Highway Administration, Washington, D.C. No. FHWA-RD-78-197
- N.C. DOT. 1997. Best management practices for protection of surface waters, North Carolina Dept. of Transp., Raleigh, N.C.
- Novotny, V. and Olem, H. 1994, Water Quality – Prevention Identification and Management of Diffuse Pollution, Van Nostrand Reinhold, New York, U.S.A.
- Novotny, V. 1991. Urban diffuse pollution: Sources and abatement, Water Environ. Technol. 3: 60-65.
- Pitt R., and McLean K. 1986. The Incorporation of Urban Runoff Controls in the Wisconsin Priority Watershed Program. In: Advanced Topics in Urban Runoff Research (Urbonas B., Roesner L.A. Ed.). Engineering Foundation and ASCE. New York, NY: 290-313.
- Pitt, R. 2003. Sources of Stormwater Pollutants, Including Pollutant Buildup and Washoff. Extracted from Stormwater Quality Management. CRC Press, New York.
- Pitt, R. and Bozeman, M. 1980. Water Quality and biological effects of urban runoff on Coyote Creek, Phase I – Preliminary Survey Report, EPA-600/2-80-104.
- Portland Metro. 1994. Summary of projects using yard debris compost for erosion prevention and control. Final report. June 1994. Solid Waste Department, Planning Department 600 NE Grand Ave. Portland, OR 97232-2736.
- Roa-Espinosa A., Bannerman R. 1995. Monitoring BMP effectiveness at industrial sites. In: Conference on Stormwater NPDES Related Monitoring Needs. ASCE: 467-487.
- Schueler, T. R., Kumble, P. A., and Heraty, M. A. 1992. A current assessment of urban best management practices: Techniques for reducing nonpoint source pollution in the coastal zone, Metropolitan Washington Council of Governments, Washington, D.C.
- Seelsaen, N., McLaughlan, R., Moore, S. and Stuetz, R.M., 2007. Influence of compost characteristics on heavy metal sorption from synthetic stormwater. Water Science & Technology. 55(4):219–226.
- Shinya, M. 2000. Characterization of heavy metals and polycyclic aromatic hydrocarbons in urban highway runoff. Water Science and Technology, 42(7):201.

- Jiun-Shiu Ma, Joo-Hyon Kang, Masoud Kayhanian, and Michael K. 2009. Sampling Issues in Urban Runoff Monitoring Programs: Composite versus Grab. Stenstrom, J. *Envir. Engrg.* 135(118).
- Seelsaen, N., McLaughlan, R., Moore, S. and Stuetz, R.M., 2007. Influence of compost characteristics on heavy metal sorption from synthetic stormwater. *Water Science & Technology*. 55(4):219–226.
- Shimadzu Corporation, 2007. Atomic Absorption Spectrophotometer Manual.
- Smith, D. L., and Lord, B. N. 1990. Highway water quality control: Summary of 15 years of research. *Transp. Res. Board, Nat. Res. Council, Washington, D.C. Rec.* 127969–74.
- American Public Health Assoc., American Water Works Assoc., and Water Envir. Fedn., Washington, D.C. 1992. Standard methods for the examination of water and wastewater. 18.
- Stenstrom, M. K., Silverman, G. S., and Bursztynsky, T. A. 1984. Oil and grease in urban stormwaters." *J. Environ. Eng.*, 110(1): 58–72.
- Stotz, G. 1987. Investigation of the properties of the surface water runoff from federal highways in the FRG. *Sci. Total Envir.*, Amsterdam, The Netherlands, 59: 329–337.
- Taleban, V., Finney, K., Gharabaghi, B., McBean, E., Rudra, R., and Van Seters, T. 2009. Effectiveness of Compost Biofilters in Removal of Sediments from Construction Site Runoff. *Water Quality Research Journal of Canada*. 44(1):71-80.
- Taleban, V. 2008. Stormwater Runoff Treatment Using Compost Biofilters. A thesis presented to the University of Guelph for the degree of Master of Science.
- Toronto and Region Conservation. 2008. Erosion and Sediment Control Inspection Guide.
- Tsihrintzis, V.A. and Hamid, R. 1997. Modeling and Management of Urban Stormwater Runoff Quality: A Review. *Water Resources Management* 11:137 – 164.
- Tsihrintzis, V.A., Hamid, R. and Fuentes, H.R. 1995. Calibrated and Verification of Watershed Quality Model SWMM in Sub-Tropical Urban Areas. *Water Resources Engineering*, 1:373-377.
- Tyler, R. 2001. Compost filter berms and blankets take on the silt fence, *Biocycle*. 42(1), 26-31.

- U.S. EPA. 1990. National water quality inventory—1988 report to Congress, U.S. Envir. Protection Agency, Washington, D.C. EPA 440-4-90-003.
- US Environmental Protection Agency (USEPA): 1990, National water quality inventory – 1988 report to congress, Office of the Water Program Operations, Water Planning Division, Washington D.C., U.S.A.
- Vaze, J., Chiew, F., 2002, Experimental study of pollutant accumulation on an urban road. *Urban Water.*, 4:379-389.
- Wiland, B., and Malina, J. F., Jr. 1976. Oil, grease, and other pollutants in highway runoff. Center for Highway Research, Univ. of Texas at Austin, Rep. No. FHWA TX 77-16-1F.
- Wu, J. S., Allan, D. J., Saunders, W. L., and Evett, J. B. 1998. Characterization and pollutant loading estimation for urban and rural highway runoff. *J. Environ. Eng.*, 124(7): 584–592.
- Wu, J. S., and Ahlert, R. C. 1978. Assessment of methods for computing storm runoff loads. *Water Resour. Bull.* 14(2): 429–439.
- Yousef, Y. A., Wanielista, M. P., and Harper, H. H. 1985. Removal of highway contaminants by roadside swales. Transportation Research Board, Washington, D.C. 62–68.

Appendix A - Total Suspended Solids Results

Total Suspended Solids (TSS)

Date	Inlet Sample			Outlet Sample		Removal (%)
	Sample Number	Inlet Concentration (mg/L)	Flow Rate (L/s)	Sample Number	Outlet Concentration (mg/L)	
09-Sep-07	I-A	33.6	0.06	O-A	29.7	12%
11-Sep-07	I-A	95.8	3.47	O-A	25.1	74%
26-Sep-07	I-A	18.0	0.09	O-A	15.2	16%
02-Oct-07	I-A	14.8	0.16	O-A	6.0	59%
06-Oct-07	I-A	47.6	0.05	O-A	21.4	55%
10-Oct-07	I-A	95.7	0.19	O-A	12.8	87%
31-Oct-07	I-A	21.9		O-A	14.0	36%
08-May-08	I-7-B	321.5	0.08	O-7-B	47.9	85%
	I-14-B	231.2	4.03	O-14-B	28.9	87%
14-May-08	I-7-B	29.1	0.54	O-7-B	21.0	28%
	I-14-B	25.6	0.01	O-14-B	21.3	17%
17-May-08	I-7-B	23.0	0.19	O-7-B	19.9	13%
	I-14-B	24.1	0.01	O-14-B	21.0	13%
03-Jun-08	I-7-B	20.6	0.38	O-7-B	16.9	18%
	I-14-B	20.8	0.01	O-14-B	16.0	23%
05-Jun-08	I-7-B	28.0		O-7-B	25.0	11%
	I-14-B	23.7		O-14-B	15.2	36%
15-Jun-08	I-7-B	20.5	10.78	O-7-B	20.4	0%
	I-14-B	23.4	3.06	O-14-B	21.9	7%
22-Jun-08	I-7-B	14.8	3.38	O-7-B	11.6	22%
	I-14-B	15.4	0.04	O-14-B	12.4	20%
27-Jun-08	I-7-B	23.3	0.44	O-7-B	14.0	40%
	I-14-B	21.5	0.01	O-14-B	12.2	43%
11-Jul-08	I-7-B	13.5	48.40	O-7-B	11.5	15%
	I-14-B	19.0	35.60	O-14-B	10.4	45%
12-Jul-08	I-7-B	46.2	0.20	O-7-B	15.9	66%
	I-14-B	53.9	0.10	O-14-B	7.1	87%
17-Jul-08	I-7-B	15.8	0.04	O-7-B	12.8	19%
	I-14-B	16.7	0.44	O-14-B	15.4	7%
22-Jul-08	I-7-B	171.9	4.48	O-7-B	39.6	77%
	I-14-B	130.6	0.86	O-14-B	14.7	89%
23-Jul-08	I-7-B	13.4	0.07	O-7-B	10.6	21%
	I-14-B	10.5	0.41	O-14-B	7.9	25%
30-Jul-08	I-7-B	113.0	5.79	O-7-B	36.8	67%
	I-14-B	37.8	8.29	O-14-B	27.0	29%
05-Aug-08	I-7-B	14.1		O-7-B	13.0	8%
	I-14-B	13.3		O-14-B	11.1	16%
18-Aug	I-7-B	17.6	0.02	O-7-B	10.4	41%
	I-14-B	17.1	0.02	O-14-B	11.7	32%

Appendix B - OMAFRA Heavy Metal Results

Final Report

Report Date: October 29, 2007

Submission #: L07-050751

Attn: KAREN ANNE FINNEY
UNIVERSITY OF GUELPH
SCHOOL OF ENGINEERING
U OF G
GUELPH. ON N1G 2W1

Phone: (519) 824-4120

Quotation #: 01464

Toxicology

Sample ID:	Submitter Sample ID:	Sample Type:	Sampling Date & Time:	Analyte:	Result:	Units:	Notes:
07-0890290	SEPT 9 I-16-1	Water	07/10/09 16:24	Lead	<0.0080	ug/g	
07-0890290	SEPT 9 I-16-1	Water	07/10/09 16:24	Iron	1.4	ug/g	
07-0890290	SEPT 9 I-16-1	Water	07/10/09 16:24	Cadmium	<0.0020	ug/g	
07-0890290	SEPT 9 I-16-1	Water	07/10/09 16:24	Chromium	0.017	ug/g	
07-0890290	SEPT 9 I-16-1	Water	07/10/09 16:24	Cobalt	<0.0040	ug/g	
07-0890290	SEPT 9 I-16-1	Water	07/10/09 16:24	Copper	0.013	ug/g	
07-0890290	SEPT 9 I-16-1	Water	07/10/09 16:24	Molybdenum	<0.012	ug/g	
07-0890290	SEPT 9 I-16-1	Water	07/10/09 16:24	Nickel	<0.0040	ug/g	
07-0890290	SEPT 9 I-16-1	Water	07/10/09 16:24	Zinc	0.049	ug/g	
07-0890290	SEPT 9 I-16-1	Water	07/10/09 16:24	Manganese	0.083	ug/g	
07-0890291	SEPT 9 I-16-2	Water	07/10/09 16:24	Lead	<0.0080	ug/g	
07-0890291	SEPT 9 I-16-2	Water	07/10/09 16:24	Iron	1.6	ug/g	
07-0890291	SEPT 9 I-16-2	Water	07/10/09 16:24	Cadmium	<0.0020	ug/g	
07-0890291	SEPT 9 I-16-2	Water	07/10/09 16:24	Chromium	0.018	ug/g	
07-0890291	SEPT 9 I-16-2	Water	07/10/09 16:24	Cobalt	<0.0040	ug/g	
07-0890291	SEPT 9 I-16-2	Water	07/10/09 16:24	Copper	0.015	ug/g	
07-0890291	SEPT 9 I-16-2	Water	07/10/09 16:24	Molybdenum	<0.012	ug/g	
07-0890291	SEPT 9 I-16-2	Water	07/10/09 16:24	Nickel	<0.0040	ug/g	
07-0890291	SEPT 9 I-16-2	Water	07/10/09 16:24	Zinc	0.054	ug/g	
07-0890291	SEPT 9 I-16-2	Water	07/10/09 16:24	Manganese	0.092	ug/g	

Legend: NA - Not Analyzed, ND - Not Detected, UNS - Unsuitable, < MDL - < Method Detection Limit, TR - Trace, TNTC - Too numerous to count,
NQ - Non-quantifiable, INS - Insufficient, >ULQ - > Upper limit of quantitation

SM

Submission #: L07-050751

Sample ID:	Submitter Sample ID:	Sample Type:	Sampling Date & Time:	Analyte:	Result:	Units:	Notes:
07-0890292	SEPT 9 O-16-1	Water	07/10/09 16:24	Lead	<0.0080	ug/g	
07-0890292	SEPT 9 O-16-1	Water	07/10/09 16:24	Iron	0.72	ug/g	
07-0890292	SEPT 9 O-16-1	Water	07/10/09 16:24	Cadmium	<0.0020	ug/g	
07-0890292	SEPT 9 O-16-1	Water	07/10/09 16:24	Chromium	0.010	ug/g	
07-0890292	SEPT 9 O-16-1	Water	07/10/09 16:24	Cobalt	<0.0040	ug/g	
07-0890292	SEPT 9 O-16-1	Water	07/10/09 16:24	Copper	0.019	ug/g	
07-0890292	SEPT 9 O-16-1	Water	07/10/09 16:24	Molybdenum	<0.012	ug/g	
07-0890292	SEPT 9 O-16-1	Water	07/10/09 16:24	Nickel	0.0049	ug/g	
07-0890292	SEPT 9 O-16-1	Water	07/10/09 16:24	Zinc	0.029	ug/g	
07-0890292	SEPT 9 O-16-1	Water	07/10/09 16:24	Manganese	0.037	ug/g	
07-0890293	SEPT 9 O-16-2	Water	07/10/09 16:24	Lead	<0.0080	ug/g	
07-0890293	SEPT 9 O-16-2	Water	07/10/09 16:24	Iron	0.71	ug/g	
07-0890293	SEPT 9 O-16-2	Water	07/10/09 16:24	Cadmium	<0.0020	ug/g	
07-0890293	SEPT 9 O-16-2	Water	07/10/09 16:24	Chromium	0.0097	ug/g	
07-0890293	SEPT 9 O-16-2	Water	07/10/09 16:24	Cobalt	<0.0040	ug/g	
07-0890293	SEPT 9 O-16-2	Water	07/10/09 16:24	Copper	0.019	ug/g	
07-0890293	SEPT 9 O-16-2	Water	07/10/09 16:24	Molybdenum	<0.012	ug/g	
07-0890293	SEPT 9 O-16-2	Water	07/10/09 16:24	Nickel	0.0056	ug/g	
07-0890293	SEPT 9 O-16-2	Water	07/10/09 16:24	Zinc	0.030	ug/g	
07-0890293	SEPT 9 O-16-2	Water	07/10/09 16:24	Manganese	0.036	ug/g	
07-0890294	SEPT 9 I-6-1	Water	07/10/09 16:24	Lead	0.016	ug/g	
07-0890294	SEPT 9 I-6-1	Water	07/10/09 16:24	Iron	2.9	ug/g	
07-0890294	SEPT 9 I-6-1	Water	07/10/09 16:24	Cadmium	<0.0020	ug/g	
07-0890294	SEPT 9 I-6-1	Water	07/10/09 16:24	Chromium	0.014	ug/g	
07-0890294	SEPT 9 I-6-1	Water	07/10/09 16:24	Cobalt	<0.0040	ug/g	
07-0890294	SEPT 9 I-6-1	Water	07/10/09 16:24	Copper	0.029	ug/g	
07-0890294	SEPT 9 I-6-1	Water	07/10/09 16:24	Molybdenum	<0.012	ug/g	
07-0890294	SEPT 9 I-6-1	Water	07/10/09 16:24	Nickel	0.0051	ug/g	
07-0890294	SEPT 9 I-6-1	Water	07/10/09 16:24	Zinc	0.11	ug/g	
07-0890294	SEPT 9 I-6-1	Water	07/10/09 16:24	Manganese	0.16	ug/g	
07-0890295	SEPT 9 I-6-2	Water	07/10/09 16:24	Lead	0.016	ug/g	
07-0890295	SEPT 9 I-6-2	Water	07/10/09 16:24	Iron	2.9	ug/g	
07-0890295	SEPT 9 I-6-2	Water	07/10/09 16:24	Cadmium	<0.0020	ug/g	
07-0890295	SEPT 9 I-6-2	Water	07/10/09 16:24	Chromium	0.015	ug/g	
07-0890295	SEPT 9 I-6-2	Water	07/10/09 16:24	Cobalt	<0.0040	ug/g	
07-0890295	SEPT 9 I-6-2	Water	07/10/09 16:24	Copper	0.030	ug/g	

Legend: NA - Not Analyzed, ND - Not Detected, UNS - Unsuitable, < MDL - < Method Detection Limit, TR - Trace, TNTC - Too numerous to count, NQ - Non-quantifiable, INS - Insufficient, >ULQ - > Upper limit of quantitation

SM

Submission #: L07-050751

Sample ID:	Submitter Sample ID:	Sample Type:	Sampling Date & Time:	Analyte:	Result:	Units:	Notes:
07-0890295	SEPT 9 I-6-2	Water	07/10/09 16:24	Molybdenum	<0.012	ug/g	
07-0890295	SEPT 9 I-6-2	Water	07/10/09 16:24	Nickel	0.0050	ug/g	
07-0890295	SEPT 9 I-6-2	Water	07/10/09 16:24	Zinc	0.12	ug/g	
07-0890295	SEPT 9 I-6-2	Water	07/10/09 16:24	Manganese	0.16	ug/g	
07-0890296	SEPT 9 O-6-1	Water	07/10/09 16:24	Lead	<0.0080	ug/g	
07-0890296	SEPT 9 O-6-1	Water	07/10/09 16:24	Iron	1.6	ug/g	
07-0890296	SEPT 9 O-6-1	Water	07/10/09 16:24	Cadmium	<0.0020	ug/g	
07-0890296	SEPT 9 O-6-1	Water	07/10/09 16:24	Chromium	0.015	ug/g	
07-0890296	SEPT 9 O-6-1	Water	07/10/09 16:24	Cobalt	<0.0040	ug/g	
07-0890296	SEPT 9 O-6-1	Water	07/10/09 16:24	Copper	0.022	ug/g	
07-0890296	SEPT 9 O-6-1	Water	07/10/09 16:24	Molybdenum	<0.012	ug/g	
07-0890296	SEPT 9 O-6-1	Water	07/10/09 16:24	Nickel	0.0048	ug/g	
07-0890296	SEPT 9 O-6-1	Water	07/10/09 16:24	Zinc	0.052	ug/g	
07-0890296	SEPT 9 O-6-1	Water	07/10/09 16:24	Manganese	0.067	ug/g	
07-0890297	SEPT 9 O-6-2	Water	07/10/09 16:24	Lead	<0.0080	ug/g	
07-0890297	SEPT 9 O-6-2	Water	07/10/09 16:24	Iron	1.6	ug/g	
07-0890297	SEPT 9 O-6-2	Water	07/10/09 16:24	Cadmium	<0.0020	ug/g	
07-0890297	SEPT 9 O-6-2	Water	07/10/09 16:24	Chromium	0.014	ug/g	
07-0890297	SEPT 9 O-6-2	Water	07/10/09 16:24	Cobalt	<0.0040	ug/g	
07-0890297	SEPT 9 O-6-2	Water	07/10/09 16:24	Copper	0.022	ug/g	
07-0890297	SEPT 9 O-6-2	Water	07/10/09 16:24	Molybdenum	<0.012	ug/g	
07-0890297	SEPT 9 O-6-2	Water	07/10/09 16:24	Nickel	0.0045	ug/g	
07-0890297	SEPT 9 O-6-2	Water	07/10/09 16:24	Zinc	0.050	ug/g	
07-0890297	SEPT 9 O-6-2	Water	07/10/09 16:24	Manganese	0.066	ug/g	

Notes & Details:

Methods of Analysis TOXI-024

Sample Received:

October 17, 2007

Supervisor:

Nick Schrier MSc (519) 767 6215

Date Authorized:

October 29, 2007

Legend: NA - Not Analyzed, ND - Not Detected, UNS - Unsuitable, < MDL - < Method Detection Limit, TR - Trace, TNTC - Too numerous to count, NQ - Non-quantifiable, INS - Insufficient, >ULQ - > Upper limit of quantitation

SM

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These test results pertain only to the samples tested.

Should you have any questions regarding these results, please do not hesitate to call.

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Page 3 of 3
October 29, 2007

UNIVERSITY of GUELPH

LABORATORY SERVICES

Submitter Sample ID	Micro Elements	Micro Elements	Micro Elements	Micro Elements
	1	1	1	1
	Iron	Lead	Zinc	Copper
	1	1	1	1
	ug/mL	ug/mL	ug/mL	ug/mL
I-8-A-2 SEPT 9	0.95	0.011	0.035	<0.0040
O-10-A-2 SEPT 9	1.2	<0.0080	<0.0040	<0.0040
I-18-A-2 SEPT 9	1.4	<0.0080	0.011	<0.0040
I-24-A-1 SEPT 9	1.3	<0.0080	0.0066	<0.0040
O-6-A-1 SEPT 26	0.71	<0.0080	<0.0040	0.028
O-6-A-2 SEPT 26	0.73	<0.0080	<0.0040	0.027
I-6-A-1 SEPT 26	1.8	0.011	0.045	0.033
I-6-A-2 SEPT 26	1.9	0.011	0.045	0.034
O-16-A-1 SEPT 26	0.6	<0.0080	<0.0040	0.022
O-16-A-2 SEPT 26	0.59	<0.0080	<0.0040	0.021
O-6-A-1 OCT 2	0.43	<0.0080	<0.0040	0.019
O-6-A-2 OCT	0.45	<0.0080	<0.0040	0.019
I-6-A-1 OCT 2	0.97	<0.0080	<0.0040	0.023
I-6-A-2 OCT2	0.96	<0.0080	<0.0040	0.023
O-10-A-1 OCT 2	0.83	<0.0080	<0.0040	0.02
O-10-A-2 OCT 2	0.35	<0.0080	<0.0040	0.017
I-10-A-1 OCT 2	0.38	<0.0080	<0.0040	0.017
I-10-A-2 OCT2	0.73	<0.0080	<0.0040	0.021
O-6-A-1 OCT6	1.2	<0.0080	<0.0040	0.017
O-6-A-2 OCT 6	1.2	<0.0080	0.0076	0.018
I-6-A-1 OCT 6	2.4	0.012	0.032	0.02
I-6-A-2 OCT 6	2.4	0.012	0.029	0.02
O-16-A-1 OCT 6	0.5	<0.0080	<0.0040	0.011
O-16-A-2 OCT 6	0.49	<0.0080	<0.0040	0.011
I-16-A-1 OCT 6	1.3	<0.0080	<0.0040	0.015
I-16-A-2 OCT 6	2.4	<0.0080	0.0075	0.017

UNIVERSITY of GUELPH

LABORATORY SERVICES

Submitter Sample ID	Micro Elements	Micro Elements	Micro Elements	Micro Elements
	Iron	Lead	Zinc	Copper
	ug/mL	ug/mL	ug/mL	ug/mL
I-6-1 SEPT 11	5.2	0.032	0.11	0.036
I-6-2 SEPT 11	5.2	0.03	0.11	0.036
O-6-1 SEPT 11	2.3	0.01	0.0048	0.02
O-6-2 SEPT 11	2.3	0.01	0.0076	0.02
I-16-1 SEPT 11	4.3	0.022	0.061	0.029
I-16-2 SEPT 11	4.2	0.02	0.056	0.027
O-16-1 SEPT 11	1.4	<0.0080	<0.0040	0.015
O-16-2 SEPT 11	1.4	<0.0080	<0.0040	0.015

Final Report

Report Date: December 13, 2007

Submission #: L07-057662

Attn: KAREN ANNE FINNEY
UNIVERSITY OF GUELPH
SCHOOL OF ENGINEERING
U OF G
GUELPH. ON N1G 2W1

Phone: (519) 824-4120

Quotation #: 01464

Soil and Nutrient

Sample ID:	Submitter Sample ID:	Sampling Date/Time:	Sample type:	Other:
07-0942606	OCT 17 O-4 A 1		Water	Done
07-0942607	OCT 17 O-4 A 2		Water	Done
07-0942608	OCT 17 I-4 A 1		Water	Done
07-0942609	OCT 17 I-4 A 2		Water	Done
07-0942610	OCT 17 O-6 A 1		Water	Done
07-0942611	OCT 17 O-6 A 2		Water	Done
07-0942612	OCT 17 I-6 A 1		Water	Done
07-0942613	OCT 17 I-6 A 2		Water	Done
07-0942614	OCT 17 O-8 A 1		Water	Done
07-0942615	OCT 17 O-8 A 2		Water	Done
07-0942616	OCT 17 I-8 A 1		Water	Done
07-0942617	OCT 17 I-8 A 2		Water	Done
07-0942618	OCT 17 O-10 A 1		Water	Done
07-0942619	OCT 17 O-10 A 2		Water	Done
07-0942620	OCT 17 I-10 A 1		Water	Done

Legend: NA - Not Analyzed, ND - Not Detected, UNS - Unsuitable, < MDL - < Method Detection Limit, TR - Trace, TNTC - Too numerous to count,
NQ - Non-quantifiable, INS - Insufficient, >ULQ - > Upper limit of quantitation

SM

Submission #: L07-057662

Sample ID:	Submitter Sample ID:	Sampling Date/Time:	Sample type:	Other:
07-0942621	OCT 17 I-10 A 2		Water	Done
07-0942622	OCT 17 O-12 A 1		Water	Done
07-0942623	OCT 17 O-12 A 2		Water	Done
07-0942624	OCT 17 I-12 A 1		Water	Done
07-0942625	OCT 17 I-12 A 2		Water	Done
07-0942626	OCT 17 O-16 A 1		Water	Done
07-0942627	OCT 17 O-16 A 2		Water	Done
07-0942628	OCT 17 I-16 A 1		Water	Done
07-0942629	OCT 17 I-16 A 2		Water	Done
07-0942630	OCT 17 O-22 A 1		Water	Done
07-0942631	OCT 17 O-22 A 2		Water	Done
07-0942632	OCT 17 O-18 A 1		Water	Done
07-0942633	OCT 17 O-18 A 2		Water	Done
07-0942634	OCT 17 I-18 A 1		Water	Done
07-0942635	OCT 17 I-18 A 2		Water	Done
07-0942636	OCT 23 O-2 A 1		Water	Done
07-0942637	OCT 23 O-2 A 2		Water	Done
07-0942638	OCT 23 I-2 A 1		Water	Done
07-0942639	OCT 23 I-2 A 2		Water	Done
07-0942640	OCT 23 I-4 A 1		Water	Done
07-0942641	OCT 23 I-4 A 2		Water	Done

Notes & Details:

Methods of Analysis Non-routine

Sample Received:

Supervisor:

Date Authorized:

Legend: NA - Not Analyzed, ND - Not Detected, UNS - Unsuitable, < MDL - < Method Detection Limit, TR - Trace, TNTC - Too numerous to count,
NQ - Non-quantifiable, INS - Insufficient, >ULQ - > Upper limit of quantitation

SM

Submission #: L07-057662

November 27, 2007

Nick Schrier MSc (519) 767 6226

December 13, 2007

Toxicology

Sample ID:	Submitter Sample ID:	Sample Type:	Sampling Date & Time:	Analyte:	Result:	Units:	Notes:
07-0942610	OCT 17 O-6 A 1	Water		Lead	<0.0080	ug/g	
07-0942610	OCT 17 O-6 A 1	Water		Iron	0.71	ug/g	
07-0942610	OCT 17 O-6 A 1	Water		Cadmium	<0.0020	ug/g	
07-0942610	OCT 17 O-6 A 1	Water		Chromium	0.0082	ug/g	
07-0942610	OCT 17 O-6 A 1	Water		Cobalt	<0.0040	ug/g	
07-0942610	OCT 17 O-6 A 1	Water		Copper	0.016	ug/g	
07-0942610	OCT 17 O-6 A 1	Water		Molybdenum	<0.012	ug/g	
07-0942610	OCT 17 O-6 A 1	Water		Nickel	<0.0040	ug/g	
07-0942610	OCT 17 O-6 A 1	Water		Zinc	0.027	ug/g	
07-0942610	OCT 17 O-6 A 1	Water		Manganese	0.015	ug/g	
07-0942611	OCT 17 O-6 A 2	Water		Lead	<0.0080	ug/g	
07-0942611	OCT 17 O-6 A 2	Water		Iron	0.71	ug/g	
07-0942611	OCT 17 O-6 A 2	Water		Cadmium	<0.0020	ug/g	
07-0942611	OCT 17 O-6 A 2	Water		Chromium	0.0082	ug/g	
07-0942611	OCT 17 O-6 A 2	Water		Cobalt	<0.0040	ug/g	
07-0942611	OCT 17 O-6 A 2	Water		Copper	0.016	ug/g	
07-0942611	OCT 17 O-6 A 2	Water		Molybdenum	<0.012	ug/g	
07-0942611	OCT 17 O-6 A 2	Water		Nickel	<0.0040	ug/g	
07-0942611	OCT 17 O-6 A 2	Water		Zinc	0.026	ug/g	
07-0942611	OCT 17 O-6 A 2	Water		Manganese	0.015	ug/g	
07-0942612	OCT 17 I-6 A 1	Water		Lead	0.0084	ug/g	
07-0942612	OCT 17 I-6 A 1	Water		Iron	1.6	ug/g	
07-0942612	OCT 17 I-6 A 1	Water		Cadmium	<0.0020	ug/g	
07-0942612	OCT 17 I-6 A 1	Water		Chromium	0.014	ug/g	
07-0942612	OCT 17 I-6 A 1	Water		Cobalt	<0.0040	ug/g	
07-0942612	OCT 17 I-6 A 1	Water		Copper	0.023	ug/g	
07-0942612	OCT 17 I-6 A 1	Water		Molybdenum	<0.012	ug/g	
07-0942612	OCT 17 I-6 A 1	Water		Nickel	0.0052	ug/g	
07-0942612	OCT 17 I-6 A 1	Water		Zinc	0.061	ug/g	
07-0942612	OCT 17 I-6 A 1	Water		Manganese	0.039	ug/g	
07-0942613	OCT 17 I-6 A 2	Water		Lead	<0.0080	ug/g	
07-0942613	OCT 17 I-6 A 2	Water		Iron	1.5	ug/g	

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SM

Submission #: L07-057662

Sample ID:	Submitter Sample ID:	Sample Type:	Sampling Date & Time:	Analyte:	Result:	Units:	Notes:
07-0942613	OCT 17 I-6 A 2	Water		Cadmium	<0.0020	ug/g	
07-0942613	OCT 17 I-6 A 2	Water		Chromium	0.014	ug/g	
07-0942613	OCT 17 I-6 A 2	Water		Cobalt	<0.0040	ug/g	
07-0942613	OCT 17 I-6 A 2	Water		Copper	0.022	ug/g	
07-0942613	OCT 17 I-6 A 2	Water		Molybdenum	<0.012	ug/g	
07-0942613	OCT 17 I-6 A 2	Water		Nickel	0.0051	ug/g	
07-0942613	OCT 17 I-6 A 2	Water		Zinc	0.060	ug/g	
07-0942613	OCT 17 I-6 A 2	Water		Manganese	0.037	ug/g	
07-0942626	OCT 17 O-16 A 1	Water		Lead	<0.0080	ug/g	
07-0942626	OCT 17 O-16 A 1	Water		Iron	0.60	ug/g	
07-0942626	OCT 17 O-16 A 1	Water		Cadmium	<0.0020	ug/g	
07-0942626	OCT 17 O-16 A 1	Water		Chromium	0.0071	ug/g	
07-0942626	OCT 17 O-16 A 1	Water		Cobalt	<0.0040	ug/g	
07-0942626	OCT 17 O-16 A 1	Water		Copper	0.014	ug/g	
07-0942626	OCT 17 O-16 A 1	Water		Molybdenum	<0.012	ug/g	
07-0942626	OCT 17 O-16 A 1	Water		Nickel	<0.0040	ug/g	
07-0942626	OCT 17 O-16 A 1	Water		Zinc	0.025	ug/g	
07-0942626	OCT 17 O-16 A 1	Water		Manganese	0.014	ug/g	
07-0942627	OCT 17 O-16 A 2	Water		Lead	<0.0080	ug/g	
07-0942627	OCT 17 O-16 A 2	Water		Iron	0.60	ug/g	
07-0942627	OCT 17 O-16 A 2	Water		Cadmium	<0.0020	ug/g	
07-0942627	OCT 17 O-16 A 2	Water		Chromium	0.0069	ug/g	
07-0942627	OCT 17 O-16 A 2	Water		Cobalt	<0.0040	ug/g	
07-0942627	OCT 17 O-16 A 2	Water		Copper	0.014	ug/g	
07-0942627	OCT 17 O-16 A 2	Water		Molybdenum	<0.012	ug/g	
07-0942627	OCT 17 O-16 A 2	Water		Nickel	<0.0040	ug/g	
07-0942627	OCT 17 O-16 A 2	Water		Zinc	0.024	ug/g	
07-0942627	OCT 17 O-16 A 2	Water		Manganese	0.013	ug/g	
07-0942628	OCT 17 I-16 A 1	Water		Lead	0.0082	ug/g	
07-0942628	OCT 17 I-16 A 1	Water		Iron	1.5	ug/g	
07-0942628	OCT 17 I-16 A 1	Water		Cadmium	<0.0020	ug/g	
07-0942628	OCT 17 I-16 A 1	Water		Chromium	0.011	ug/g	
07-0942628	OCT 17 I-16 A 1	Water		Cobalt	<0.0040	ug/g	
07-0942628	OCT 17 I-16 A 1	Water		Copper	0.020	ug/g	
07-0942628	OCT 17 I-16 A 1	Water		Molybdenum	<0.012	ug/g	
07-0942628	OCT 17 I-16 A 1	Water		Nickel	<0.0040	ug/g	

Legend: NA - Not Analyzed, ND - Not Detected, UNS - Unsuitable, < MDL - < Method Detection Limit, TR - Trace, TNTC - Too numerous to count, NQ - Non-quantifiable, INS - Insufficient, >ULQ - > Upper limit of quantitation

SM

Submission #: L07-057662

Sample ID:	Submitter Sample ID:	Sample Type:	Sampling Date & Time:	Analyte:	Result:	Units:	Notes:
07-0942628	OCT 17 I-16 A 1	Water		Zinc	0.056	ug/g	
07-0942628	OCT 17 I-16 A 1	Water		Manganese	0.043	ug/g	
07-0942629	OCT 17 I-16 A 2	Water		Lead	<0.0080	ug/g	
07-0942629	OCT 17 I-16 A 2	Water		Iron	0.60	ug/g	
07-0942629	OCT 17 I-16 A 2	Water		Cadmium	<0.0020	ug/g	
07-0942629	OCT 17 I-16 A 2	Water		Chromium	0.0065	ug/g	
07-0942629	OCT 17 I-16 A 2	Water		Cobalt	<0.0040	ug/g	
07-0942629	OCT 17 I-16 A 2	Water		Copper	0.011	ug/g	
07-0942629	OCT 17 I-16 A 2	Water		Molybdenum	<0.012	ug/g	
07-0942629	OCT 17 I-16 A 2	Water		Nickel	<0.0040	ug/g	
07-0942629	OCT 17 I-16 A 2	Water		Zinc	0.032	ug/g	
07-0942629	OCT 17 I-16 A 2	Water		Manganese	0.023	ug/g	

Notes & Details:

Methods of Analysis TOXI-024

Sample Received:
November 27, 2007

Supervisor:
Nick Schrier MSc (519) 767 6215

Date Authorized:
December 13, 2007

Legend: NA - Not Analyzed, ND - Not Detected, UNS - Unsuitable, < MDL - < Method Detection Limit, TR - Trace, TNTC - Too numerous to count,
NQ - Non-quantifiable, INS - Insufficient, >ULQ - > Upper limit of quantitation

SM

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These test results pertain only to the samples tested.

Should you have any questions regarding these results, please do not hesitate to call.

Page 5 of 5

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Printed:

December 14, 2007

Final Report

Report Date: December 13, 2007

Submission #: L07-058524

Attn: KAREN ANNE FINNEY
UNIVERSITY OF GUELPH
SCHOOL OF ENGINEERING
U OF G
GUELPH. ON N1G 2W1

Phone: (519) 824-4120

Quotation #: 01464

Soil and Nutrient

Sample ID:	Submitter Sample ID:	Sampling Date/Time:	Sample type:	Other:
07-0948772	O 4 A 1 OCT 23		Water	Done
07-0948773	O 4 A 2 OCT 23		Water	Done
07-0948774	O 6 A 1 OCT 23		Water	Done
07-0948775	O 6 A 2 OCT 23		Water	Done
07-0948776	I 6 A 1 OCT 23		Water	Done
07-0948777	I 6 A 2 OCT 23		Water	Done
07-0948778	O 8 A 1 OCT 23		Water	Done
07-0948779	O 8 A 2 OCT 23		Water	Done
07-0948780	I 8 A 1 OCT 23		Water	Done
07-0948781	I 8 A 1 OCT 23		Water	Done
07-0948782	O 10 A 1 OCT 23		Water	Done
07-0948783	O 10 A 2 OCT 23		Water	Done
07-0948784	I 10 A 1 OCT 23		Water	Done
07-0948785	I 10 A 2 OCT 23		Water	Done
07-0948786	O 12 A 1 OCT 23		Water	Done
07-0948787	O 12 A 2 OCT 23		Water	Done
07-0948788	I 12 A 1 OCT 23		Water	Done

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SM

Submission #: L07-058524

Sample ID:	Submitter Sample ID:	Sampling Date/Time:	Sample type:	Other:
07-0948789	I 12 A 2 OCT 23		Water	Done
07-0948790	O 16 A 1 OCT 23		Water	Done
07-0948791	O 16 A 2 OCT 23		Water	Done
07-0948792	I 16 A 1 OCT 23		Water	Done
07-0948793	I 16 A 2 OCT 23		Water	Done
07-0948794	O 18 A 1 OCT 23		Water	Done
07-0948795	O 18 A 2 OCT 23		Water	Done
07-0948796	O 20 A 1 OCT 23		Water	Done
07-0948797	O 20 A 2 OCT 23		Water	Done
07-0948798	O 22 A 1 OCT 23		Water	Done
07-0948799	O 22 A 2 OCT 23		Water	Done
07-0948800	O 24 A 1 OCT 23		Water	Done
07-0948801	O 24 A 2 OCT 23		Water	Done
07-0948802	I 2 A 1 OCT 26		Water	Done
07-0948803	I 2 A 2 OCT 26		Water	Done
07-0948804	I 4 A 1 OCT 26		Water	Done
07-0948805	I 4 A 2 OCT 26		Water	Done
07-0948806	I 6 A 1 OCT 26		Water	Done
07-0948807	I 6 A 2 OCT 26		Water	Done
07-0948808	I 8 A 1 OCT 26		Water	Done
07-0948809	I 8 A 2 OCT 26		Water	Done
07-0948810	I 10 A 1 OCT 26		Water	Done
07-0948811	I 10 A 2 OCT 26		Water	Done
07-0948812	I 12 A 1 OCT 26		Water	Done
07-0948813	I 12 A 2 OCT 26		Water	Done
07-0948814	I 16 A 1 OCT 26		Water	Done

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SM

Submission #: L07-058524

Sample ID:	Submitter Sample ID:	Sampling Date/Time:	Sample type:	Other:
07-0948815	I 16 A 2 OCT 26		Water	Done
07-0948816	I 18 A 1 OCT 26		Water	Done
07-0948817	I 18 A 2 OCT 26		Water	Done
07-0948818	I 22 A 1 OCT 26		Water	Done
07-0948819	I 22 A 2 OCT 26		Water	Done
07-0948820	I 24 A 1 OCT 26		Water	Done
07-0948821	I 24 A 2 OCT 26		Water	Done
07-0948822	O 2 A 1 OCT 31		Water	Done
07-0948823	O 2 A 2 OCT 31		Water	Done
07-0948824	I 2 A 1 OCT 31		Water	Done
07-0948825	I 2 A 2 OCT 31		Water	Done
07-0948826	O 4 A 1 OCT 31		Water	Done
07-0948827	O 4 A 2 OCT 31		Water	Done
07-0948828	I 4 A 1 OCT 31		Water	Done
07-0948829	I 4 A 2 OCT 31		Water	Done
07-0948830	O 6 A 1 OCT 31		Water	Done
07-0948831	O 6 A 2 OCT 31		Water	Done
07-0948832	I 6 A 1 OCT 31		Water	Done
07-0948833	I 6 A 2 OCT 31		Water	Done
07-0948834	O 8 A 1 OCT 31		Water	Done
07-0948835	O 8 A 2 OCT 31		Water	Done
07-0948836	I 8 A 1 OCT 31		Water	Done
07-0948837	I 8 A 2 OCT 31		Water	Done
07-0948838	O 10 A 1 OCT 31		Water	Done
07-0948839	O 10 A 2 OCT 31		Water	Done
07-0948840	I 10 A 1 OCT 31		Water	Done
07-0948841	I 10 A 2 OCT 31		Water	Done
07-0948842	O 12 A 1 OCT 31		Water	Done
07-0948843	O 12 A 2 OCT 31		Water	Done

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SM

Submission #: L07-058524

Sample ID:	Submitter Sample ID:	Sampling Date/Time:	Sample type:	Other:
07-0948844	I 12 A 1 OCT 31		Water	Done
07-0948845	I 12 A 2 OCT 31		Water	Done
07-0948846	O 16 A 1 OCT 31		Water	Done
07-0948847	O 16 A 2 OCT 31		Water	Done
07-0948848	I 16 A 1 OCT 31		Water	Done
07-0948849	I 16 A 2 OCT 31		Water	Done
07-0948850	O 18 A 1 OCT 31		Water	Done
07-0948851	O 18 A 2 OCT 31		Water	Done
07-0948852	I 18 A 1 OCT 31		Water	Done
07-0948853	I 18 A 2 OCT 31		Water	Done
07-0948854	O 22 A 1 OCT 31		Water	Done
07-0948855	O 22 A 2 OCT 31		Water	Done
07-0948856	I 22 A 1 OCT 31		Water	Done
07-0948857	I 22 A 2 OCT 31		Water	Done
07-0948858	O 24 A 1 OCT 31		Water	Done
07-0948859	O 24 A 2 OCT 31		Water	Done
07-0948860	I 24 A 1 OCT 31		Water	Done
07-0948861	I 24 A 2 OCT 31		Water	Done
07-0948862	O 2 A 1 NOV 5		Water	Done
07-0948863	O 2 A 2 NOV 5		Water	Done
07-0948864	O 4 A 1 NOV 5		Water	Done
07-0948865	O 4 A 2 NOV 5		Water	Done
07-0948866	O 6 A 1 NOV 5		Water	Done
07-0948867	O 6 A 2 NOV 5		Water	Done
07-0948868	O 8 A 1 NOV 5		Water	Done
07-0948869	O 8 A 2 NOV 5		Water	Done

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SM

Submission #: L07-058524

Sample ID:	Submitter Sample ID:	Sampling Date/Time:	Sample type:	Other:
07-0948870	O 10 A 1 NOV 5		Water	Done
07-0948871	O 10 A 2 NOV 5		Water	Done
07-0948872	O 12 A 1 NOV 5		Water	Done
07-0948873	O 12 A 2 NOV 5		Water	Done
07-0948874	O 16 A 1 NOV 5		Water	Done
07-0948875	O 16 A 2 NOV 5		Water	Done
07-0948876	O 18 A 1 NOV 5		Water	Done
07-0948877	O 18 A 2 NOV 5		Water	Done
07-0948878	O 22 A 1 NOV 5		Water	Done
07-0948879	O 22 A 2 NOV 5		Water	Done
07-0948880	O 24 A 1 NOV 5		Water	Done
07-0948881	O 24 A 2 NOV 5		Water	Done

Notes & Details:

Methods of Analysis Non-routine

Sample Received: December 03, 2007
Supervisor: Nick Schrier MSc (519) 767 6226

Date Authorized: December 13, 2007

Toxicology

Sample ID:	Submitter Sample ID:	Sample Type:	Sampling Date & Time:	Analyte:	Result:	Units:	Notes:
07-0948774	O 6 A 1 OCT 23	Water		Lead	<0.0080	ug/g	
07-0948774	O 6 A 1 OCT 23	Water		Iron	1.4	ug/g	
07-0948774	O 6 A 1 OCT 23	Water		Cadmium	<0.0020	ug/g	
07-0948774	O 6 A 1 OCT 23	Water		Chromium	0.011	ug/g	
07-0948774	O 6 A 1 OCT 23	Water		Cobalt	<0.0040	ug/g	

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SM

Submission #: L07-058524

Sample ID:	Submitter Sample ID:	Sample Type:	Sampling Date & Time:	Analyte:	Result:	Units:	Notes:
07-0948774	O 6 A 1 OCT 23	Water		Copper	0.014	ug/g	
07-0948774	O 6 A 1 OCT 23	Water		Molybdenum	<0.012	ug/g	
07-0948774	O 6 A 1 OCT 23	Water		Nickel	<0.0040	ug/g	
07-0948774	O 6 A 1 OCT 23	Water		Zinc	0.035	ug/g	
07-0948774	O 6 A 1 OCT 23	Water		Manganese	0.041	ug/g	
07-0948775	O 6 A 2 OCT 23	Water		Lead	<0.0080	ug/g	
07-0948775	O 6 A 2 OCT 23	Water		Iron	1.5	ug/g	
07-0948775	O 6 A 2 OCT 23	Water		Cadmium	<0.0020	ug/g	
07-0948775	O 6 A 2 OCT 23	Water		Chromium	0.011	ug/g	
07-0948775	O 6 A 2 OCT 23	Water		Cobalt	<0.0040	ug/g	
07-0948775	O 6 A 2 OCT 23	Water		Copper	0.014	ug/g	
07-0948775	O 6 A 2 OCT 23	Water		Molybdenum	<0.012	ug/g	
07-0948775	O 6 A 2 OCT 23	Water		Nickel	<0.0040	ug/g	
07-0948775	O 6 A 2 OCT 23	Water		Zinc	0.036	ug/g	
07-0948775	O 6 A 2 OCT 23	Water		Manganese	0.041	ug/g	
07-0948776	I 6 A 1 OCT 23	Water		Lead	0.015	ug/g	
07-0948776	I 6 A 1 OCT 23	Water		Iron	3.5	ug/g	
07-0948776	I 6 A 1 OCT 23	Water		Cadmium	<0.0020	ug/g	
07-0948776	I 6 A 1 OCT 23	Water		Chromium	0.015	ug/g	
07-0948776	I 6 A 1 OCT 23	Water		Cobalt	<0.0040	ug/g	
07-0948776	I 6 A 1 OCT 23	Water		Copper	0.030	ug/g	
07-0948776	I 6 A 1 OCT 23	Water		Molybdenum	<0.012	ug/g	
07-0948776	I 6 A 1 OCT 23	Water		Nickel	0.0057	ug/g	
07-0948776	I 6 A 1 OCT 23	Water		Zinc	0.12	ug/g	
07-0948776	I 6 A 1 OCT 23	Water		Manganese	0.13	ug/g	
07-0948777	I 6 A 2 OCT 23	Water		Lead	0.015	ug/g	
07-0948777	I 6 A 2 OCT 23	Water		Iron	3.5	ug/g	
07-0948777	I 6 A 2 OCT 23	Water		Cadmium	<0.0020	ug/g	
07-0948777	I 6 A 2 OCT 23	Water		Chromium	0.015	ug/g	
07-0948777	I 6 A 2 OCT 23	Water		Cobalt	<0.0040	ug/g	
07-0948777	I 6 A 2 OCT 23	Water		Copper	0.029	ug/g	
07-0948777	I 6 A 2 OCT 23	Water		Molybdenum	<0.012	ug/g	
07-0948777	I 6 A 2 OCT 23	Water		Nickel	0.0057	ug/g	
07-0948777	I 6 A 2 OCT 23	Water		Zinc	0.11	ug/g	
07-0948777	I 6 A 2 OCT 23	Water		Manganese	0.12	ug/g	
07-0948790	O 16 A 1 OCT 23	Water		Lead	0.0090	ug/g	

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SM

Submission #: L07-058524

Sample ID:	Submitter Sample ID:	Sample Type:	Sampling Date & Time:	Analyte:	Result:	Units:	Notes:
07-0948790	O 16 A 1 OCT 23	Water		Iron	2.2	ug/g	
07-0948790	O 16 A 1 OCT 23	Water		Cadmium	<0.0020	ug/g	
07-0948790	O 16 A 1 OCT 23	Water		Chromium	0.0092	ug/g	
07-0948790	O 16 A 1 OCT 23	Water		Cobalt	<0.0040	ug/g	
07-0948790	O 16 A 1 OCT 23	Water		Copper	0.019	ug/g	
07-0948790	O 16 A 1 OCT 23	Water		Molybdenum	<0.012	ug/g	
07-0948790	O 16 A 1 OCT 23	Water		Nickel	<0.0040	ug/g	
07-0948790	O 16 A 1 OCT 23	Water		Zinc	0.053	ug/g	
07-0948790	O 16 A 1 OCT 23	Water		Manganese	0.062	ug/g	
07-0948791	O 16 A 2 OCT 23	Water		Lead	0.0096	ug/g	
07-0948791	O 16 A 2 OCT 23	Water		Iron	2.3	ug/g	
07-0948791	O 16 A 2 OCT 23	Water		Cadmium	<0.0020	ug/g	
07-0948791	O 16 A 2 OCT 23	Water		Chromium	0.0097	ug/g	
07-0948791	O 16 A 2 OCT 23	Water		Cobalt	<0.0040	ug/g	
07-0948791	O 16 A 2 OCT 23	Water		Copper	0.020	ug/g	
07-0948791	O 16 A 2 OCT 23	Water		Molybdenum	<0.012	ug/g	
07-0948791	O 16 A 2 OCT 23	Water		Nickel	0.0046	ug/g	
07-0948791	O 16 A 2 OCT 23	Water		Zinc	0.055	ug/g	
07-0948791	O 16 A 2 OCT 23	Water		Manganese	0.065	ug/g	
07-0948792	I 16 A 1 OCT 23	Water		Lead	0.015	ug/g	
07-0948792	I 16 A 1 OCT 23	Water		Iron	3.8	ug/g	
07-0948792	I 16 A 1 OCT 23	Water		Cadmium	<0.0020	ug/g	
07-0948792	I 16 A 1 OCT 23	Water		Chromium	0.014	ug/g	
07-0948792	I 16 A 1 OCT 23	Water		Cobalt	<0.0040	ug/g	
07-0948792	I 16 A 1 OCT 23	Water		Copper	0.027	ug/g	
07-0948792	I 16 A 1 OCT 23	Water		Molybdenum	<0.012	ug/g	
07-0948792	I 16 A 1 OCT 23	Water		Nickel	0.0060	ug/g	
07-0948792	I 16 A 1 OCT 23	Water		Zinc	0.11	ug/g	
07-0948792	I 16 A 1 OCT 23	Water		Manganese	0.13	ug/g	
07-0948793	I 16 A 2 OCT 23	Water		Lead	0.016	ug/g	
07-0948793	I 16 A 2 OCT 23	Water		Iron	3.4	ug/g	
07-0948793	I 16 A 2 OCT 23	Water		Cadmium	<0.0020	ug/g	
07-0948793	I 16 A 2 OCT 23	Water		Chromium	0.012	ug/g	
07-0948793	I 16 A 2 OCT 23	Water		Cobalt	<0.0040	ug/g	
07-0948793	I 16 A 2 OCT 23	Water		Copper	0.025	ug/g	
07-0948793	I 16 A 2 OCT 23	Water		Molybdenum	<0.012	ug/g	

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SM

Submission #: L07-058524

Sample ID:	Submitter Sample ID:	Sample Type:	Sampling Date & Time:	Analyte:	Result:	Units:	Notes:
07-0948793	I 16 A 2 OCT 23	Water		Nickel	0.0051	ug/g	
07-0948793	I 16 A 2 OCT 23	Water		Zinc	0.099	ug/g	
07-0948793	I 16 A 2 OCT 23	Water		Manganese	0.12	ug/g	
07-0948806	I 6 A 1 OCT 26	Water		Lead	0.0094	ug/g	
07-0948806	I 6 A 1 OCT 26	Water		Iron	1.6	ug/g	
07-0948806	I 6 A 1 OCT 26	Water		Cadmium	<0.0020	ug/g	
07-0948806	I 6 A 1 OCT 26	Water		Chromium	0.020	ug/g	
07-0948806	I 6 A 1 OCT 26	Water		Cobalt	<0.0040	ug/g	
07-0948806	I 6 A 1 OCT 26	Water		Copper	0.027	ug/g	
07-0948806	I 6 A 1 OCT 26	Water		Molybdenum	<0.012	ug/g	
07-0948806	I 6 A 1 OCT 26	Water		Nickel	0.0044	ug/g	
07-0948806	I 6 A 1 OCT 26	Water		Zinc	0.084	ug/g	
07-0948806	I 6 A 1 OCT 26	Water		Manganese	0.068	ug/g	
07-0948807	I 6 A 2 OCT 26	Water		Lead	0.010	ug/g	
07-0948807	I 6 A 2 OCT 26	Water		Iron	1.6	ug/g	
07-0948807	I 6 A 2 OCT 26	Water		Cadmium	<0.0020	ug/g	
07-0948807	I 6 A 2 OCT 26	Water		Chromium	0.020	ug/g	
07-0948807	I 6 A 2 OCT 26	Water		Cobalt	<0.0040	ug/g	
07-0948807	I 6 A 2 OCT 26	Water		Copper	0.027	ug/g	
07-0948807	I 6 A 2 OCT 26	Water		Molybdenum	<0.012	ug/g	
07-0948807	I 6 A 2 OCT 26	Water		Nickel	0.0041	ug/g	
07-0948807	I 6 A 2 OCT 26	Water		Zinc	0.080	ug/g	
07-0948807	I 6 A 2 OCT 26	Water		Manganese	0.066	ug/g	
07-0948814	I 16 A 1 OCT 26	Water		Lead	<0.0080	ug/g	
07-0948814	I 16 A 1 OCT 26	Water		Iron	0.97	ug/g	
07-0948814	I 16 A 1 OCT 26	Water		Cadmium	<0.0020	ug/g	
07-0948814	I 16 A 1 OCT 26	Water		Chromium	0.025	ug/g	
07-0948814	I 16 A 1 OCT 26	Water		Cobalt	<0.0040	ug/g	
07-0948814	I 16 A 1 OCT 26	Water		Copper	0.018	ug/g	
07-0948814	I 16 A 1 OCT 26	Water		Molybdenum	<0.012	ug/g	
07-0948814	I 16 A 1 OCT 26	Water		Nickel	<0.0040	ug/g	
07-0948814	I 16 A 1 OCT 26	Water		Zinc	0.052	ug/g	
07-0948814	I 16 A 1 OCT 26	Water		Manganese	0.040	ug/g	
07-0948815	I 16 A 2 OCT 26	Water		Lead	<0.0080	ug/g	
07-0948815	I 16 A 2 OCT 26	Water		Iron	1.1	ug/g	
07-0948815	I 16 A 2 OCT 26	Water		Cadmium	<0.0020	ug/g	

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SM

Submission #: L07-058524

Sample ID:	Submitter Sample ID:	Sample Type:	Sampling Date & Time:	Analyte:	Result:	Units:	Notes:
07-0948815	I 16 A 2 OCT 26	Water		Chromium	0.027	ug/g	
07-0948815	I 16 A 2 OCT 26	Water		Cobalt	<0.0040	ug/g	
07-0948815	I 16 A 2 OCT 26	Water		Copper	0.019	ug/g	
07-0948815	I 16 A 2 OCT 26	Water		Molybdenum	<0.012	ug/g	
07-0948815	I 16 A 2 OCT 26	Water		Nickel	<0.0040	ug/g	
07-0948815	I 16 A 2 OCT 26	Water		Zinc	0.069	ug/g	
07-0948815	I 16 A 2 OCT 26	Water		Manganese	0.041	ug/g	
07-0948830	O 6 A 1 OCT 31	Water		Lead	<0.0080	ug/g	
07-0948830	O 6 A 1 OCT 31	Water		Iron	1.6	ug/g	
07-0948830	O 6 A 1 OCT 31	Water		Cadmium	<0.0020	ug/g	
07-0948830	O 6 A 1 OCT 31	Water		Chromium	0.0068	ug/g	
07-0948830	O 6 A 1 OCT 31	Water		Cobalt	<0.0040	ug/g	
07-0948830	O 6 A 1 OCT 31	Water		Copper	0.023	ug/g	
07-0948830	O 6 A 1 OCT 31	Water		Molybdenum	<0.012	ug/g	
07-0948830	O 6 A 1 OCT 31	Water		Nickel	0.0077	ug/g	
07-0948830	O 6 A 1 OCT 31	Water		Zinc	0.046	ug/g	
07-0948830	O 6 A 1 OCT 31	Water		Manganese	0.044	ug/g	
07-0948831	O 6 A 2 OCT 31	Water		Lead	<0.0080	ug/g	
07-0948831	O 6 A 2 OCT 31	Water		Iron	1.8	ug/g	
07-0948831	O 6 A 2 OCT 31	Water		Cadmium	<0.0020	ug/g	
07-0948831	O 6 A 2 OCT 31	Water		Chromium	0.0069	ug/g	
07-0948831	O 6 A 2 OCT 31	Water		Cobalt	<0.0040	ug/g	
07-0948831	O 6 A 2 OCT 31	Water		Copper	0.024	ug/g	
07-0948831	O 6 A 2 OCT 31	Water		Molybdenum	<0.012	ug/g	
07-0948831	O 6 A 2 OCT 31	Water		Nickel	0.0094	ug/g	
07-0948831	O 6 A 2 OCT 31	Water		Zinc	0.048	ug/g	
07-0948831	O 6 A 2 OCT 31	Water		Manganese	0.045	ug/g	
07-0948832	I 6 A 1 OCT 31	Water		Lead	0.015	ug/g	
07-0948832	I 6 A 1 OCT 31	Water		Iron	3.1	ug/g	
07-0948832	I 6 A 1 OCT 31	Water		Cadmium	<0.0020	ug/g	
07-0948832	I 6 A 1 OCT 31	Water		Chromium	0.011	ug/g	
07-0948832	I 6 A 1 OCT 31	Water		Cobalt	<0.0040	ug/g	
07-0948832	I 6 A 1 OCT 31	Water		Copper	0.035	ug/g	
07-0948832	I 6 A 1 OCT 31	Water		Molybdenum	<0.012	ug/g	
07-0948832	I 6 A 1 OCT 31	Water		Nickel	0.0065	ug/g	
07-0948832	I 6 A 1 OCT 31	Water		Zinc	0.10	ug/g	

Legend: NA - Not Analyzed, ND - Not Detected, UNS - Unsuitable, < MDL - < Method Detection Limit, TR - Trace, TNTC - Too numerous to count, NQ - Non-quantifiable, INS - Insufficient, >ULQ - > Upper limit of quantitation

SM

Submission #: L07-058524

Sample ID:	Submitter Sample ID:	Sample Type:	Sampling Date & Time:	Analyte:	Result:	Units:	Notes:
07-0948832	I 6 A 1 OCT 31	Water		Manganese	0.11	ug/g	
07-0948833	I 6 A 2 OCT 31	Water		Lead	0.013	ug/g	
07-0948833	I 6 A 2 OCT 31	Water		Iron	2.8	ug/g	
07-0948833	I 6 A 2 OCT 31	Water		Cadmium	<0.0020	ug/g	
07-0948833	I 6 A 2 OCT 31	Water		Chromium	0.010	ug/g	
07-0948833	I 6 A 2 OCT 31	Water		Cobalt	<0.0040	ug/g	
07-0948833	I 6 A 2 OCT 31	Water		Copper	0.034	ug/g	
07-0948833	I 6 A 2 OCT 31	Water		Molybdenum	<0.012	ug/g	
07-0948833	I 6 A 2 OCT 31	Water		Nickel	0.0062	ug/g	
07-0948833	I 6 A 2 OCT 31	Water		Zinc	0.10	ug/g	
07-0948833	I 6 A 2 OCT 31	Water		Manganese	0.11	ug/g	
07-0948846	O 16 A 1 OCT 31	Water		Lead	<0.0080	ug/g	
07-0948846	O 16 A 1 OCT 31	Water		Iron	1.2	ug/g	
07-0948846	O 16 A 1 OCT 31	Water		Cadmium	<0.0020	ug/g	
07-0948846	O 16 A 1 OCT 31	Water		Chromium	<0.0060	ug/g	
07-0948846	O 16 A 1 OCT 31	Water		Cobalt	<0.0040	ug/g	
07-0948846	O 16 A 1 OCT 31	Water		Copper	0.020	ug/g	
07-0948846	O 16 A 1 OCT 31	Water		Molybdenum	<0.012	ug/g	
07-0948846	O 16 A 1 OCT 31	Water		Nickel	0.0043	ug/g	
07-0948846	O 16 A 1 OCT 31	Water		Zinc	0.040	ug/g	
07-0948846	O 16 A 1 OCT 31	Water		Manganese	0.030	ug/g	
07-0948847	O 16 A 2 OCT 31	Water		Lead	<0.0080	ug/g	
07-0948847	O 16 A 2 OCT 31	Water		Iron	1.1	ug/g	
07-0948847	O 16 A 2 OCT 31	Water		Cadmium	<0.0020	ug/g	
07-0948847	O 16 A 2 OCT 31	Water		Chromium	0.0063	ug/g	
07-0948847	O 16 A 2 OCT 31	Water		Cobalt	<0.0040	ug/g	
07-0948847	O 16 A 2 OCT 31	Water		Copper	0.019	ug/g	
07-0948847	O 16 A 2 OCT 31	Water		Molybdenum	<0.012	ug/g	
07-0948847	O 16 A 2 OCT 31	Water		Nickel	<0.0040	ug/g	
07-0948847	O 16 A 2 OCT 31	Water		Zinc	0.038	ug/g	
07-0948847	O 16 A 2 OCT 31	Water		Manganese	0.029	ug/g	
07-0948848	I 16 A 1 OCT 31	Water		Lead	0.011	ug/g	
07-0948848	I 16 A 1 OCT 31	Water		Iron	2.0	ug/g	
07-0948848	I 16 A 1 OCT 31	Water		Cadmium	<0.0020	ug/g	
07-0948848	I 16 A 1 OCT 31	Water		Chromium	0.0082	ug/g	
07-0948848	I 16 A 1 OCT 31	Water		Cobalt	<0.0040	ug/g	

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SM

Submission #: L07-058524

Sample ID:	Submitter Sample ID:	Sample Type:	Sampling Date & Time:	Analyte:	Result:	Units:	Notes:
07-0948848	I 16 A 1 OCT 31	Water		Copper	0.025	ug/g	
07-0948848	I 16 A 1 OCT 31	Water		Molybdenum	<0.012	ug/g	
07-0948848	I 16 A 1 OCT 31	Water		Nickel	0.0045	ug/g	
07-0948848	I 16 A 1 OCT 31	Water		Zinc	0.076	ug/g	
07-0948848	I 16 A 1 OCT 31	Water		Manganese	0.070	ug/g	
07-0948849	I 16 A 2 OCT 31	Water		Lead	0.010	ug/g	
07-0948849	I 16 A 2 OCT 31	Water		Iron	2.1	ug/g	
07-0948849	I 16 A 2 OCT 31	Water		Cadmium	<0.0020	ug/g	
07-0948849	I 16 A 2 OCT 31	Water		Chromium	0.0084	ug/g	
07-0948849	I 16 A 2 OCT 31	Water		Cobalt	<0.0040	ug/g	
07-0948849	I 16 A 2 OCT 31	Water		Copper	0.026	ug/g	
07-0948849	I 16 A 2 OCT 31	Water		Molybdenum	<0.012	ug/g	
07-0948849	I 16 A 2 OCT 31	Water		Nickel	0.0049	ug/g	
07-0948849	I 16 A 2 OCT 31	Water		Zinc	0.074	ug/g	
07-0948849	I 16 A 2 OCT 31	Water		Manganese	0.071	ug/g	
07-0948866	O 6 A 1 NOV 5	Water		Lead	<0.0080	ug/g	
07-0948866	O 6 A 1 NOV 5	Water		Iron	0.75	ug/g	
07-0948866	O 6 A 1 NOV 5	Water		Cadmium	<0.0020	ug/g	
07-0948866	O 6 A 1 NOV 5	Water		Chromium	0.0092	ug/g	
07-0948866	O 6 A 1 NOV 5	Water		Cobalt	<0.0040	ug/g	
07-0948866	O 6 A 1 NOV 5	Water		Copper	0.017	ug/g	
07-0948866	O 6 A 1 NOV 5	Water		Molybdenum	<0.012	ug/g	
07-0948866	O 6 A 1 NOV 5	Water		Nickel	<0.0040	ug/g	
07-0948866	O 6 A 1 NOV 5	Water		Zinc	0.029	ug/g	
07-0948866	O 6 A 1 NOV 5	Water		Manganese	0.023	ug/g	
07-0948867	O 6 A 2 NOV 5	Water		Lead	<0.0080	ug/g	
07-0948867	O 6 A 2 NOV 5	Water		Iron	0.75	ug/g	
07-0948867	O 6 A 2 NOV 5	Water		Cadmium	<0.0020	ug/g	
07-0948867	O 6 A 2 NOV 5	Water		Chromium	0.010	ug/g	
07-0948867	O 6 A 2 NOV 5	Water		Cobalt	<0.0040	ug/g	
07-0948867	O 6 A 2 NOV 5	Water		Copper	0.018	ug/g	
07-0948867	O 6 A 2 NOV 5	Water		Molybdenum	<0.012	ug/g	
07-0948867	O 6 A 2 NOV 5	Water		Nickel	0.0047	ug/g	
07-0948867	O 6 A 2 NOV 5	Water		Zinc	0.031	ug/g	
07-0948867	O 6 A 2 NOV 5	Water		Manganese	0.023	ug/g	
07-0948874	O 16 A 1 NOV 5	Water		Lead	<0.0080	ug/g	

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SM

Submission #: L07-058524

Sample ID:	Submitter Sample ID:	Sample Type:	Sampling Date & Time:	Analyte:	Result:	Units:	Notes:
07-0948874	O 16 A 1 NOV 5	Water		Iron	0.83	ug/g	
07-0948874	O 16 A 1 NOV 5	Water		Cadmium	<0.0020	ug/g	
07-0948874	O 16 A 1 NOV 5	Water		Chromium	0.0094	ug/g	
07-0948874	O 16 A 1 NOV 5	Water		Cobalt	<0.0040	ug/g	
07-0948874	O 16 A 1 NOV 5	Water		Copper	0.013	ug/g	
07-0948874	O 16 A 1 NOV 5	Water		Molybdenum	<0.012	ug/g	
07-0948874	O 16 A 1 NOV 5	Water		Nickel	<0.0040	ug/g	
07-0948874	O 16 A 1 NOV 5	Water		Zinc	0.025	ug/g	
07-0948874	O 16 A 1 NOV 5	Water		Manganese	0.030	ug/g	
07-0948875	O 16 A 2 NOV 5	Water		Lead	<0.0080	ug/g	
07-0948875	O 16 A 2 NOV 5	Water		Iron	0.89	ug/g	
07-0948875	O 16 A 2 NOV 5	Water		Cadmium	<0.0020	ug/g	
07-0948875	O 16 A 2 NOV 5	Water		Chromium	0.010	ug/g	
07-0948875	O 16 A 2 NOV 5	Water		Cobalt	<0.0040	ug/g	
07-0948875	O 16 A 2 NOV 5	Water		Copper	0.014	ug/g	
07-0948875	O 16 A 2 NOV 5	Water		Molybdenum	<0.012	ug/g	
07-0948875	O 16 A 2 NOV 5	Water		Nickel	<0.0040	ug/g	
07-0948875	O 16 A 2 NOV 5	Water		Zinc	0.028	ug/g	
07-0948875	O 16 A 2 NOV 5	Water		Manganese	0.032	ug/g	

Notes & Details:

Legend: NA - Not Analyzed, ND - Not Detected, UNS - Unsuitable, < MDL - < Method Detection Limit, TR - Trace, TNTC - Too numerous to count,
NQ - Non-quantifiable, INS - Insufficient, >ULQ - > Upper limit of quantitation

SM

Submission #: L07-058524

Methods of Analysis TOXI-024

Sample Received:
December 03, 2007

Supervisor:
Nick Schrier MSc (519) 767 6215

Date Authorized:
December 13, 2007

Legend: NA - Not Analyzed, ND - Not Detected, UNS - Unsuitable, < MDL - < Method Detection Limit, TR - Trace, TNTC - Too numerous to count,
NQ - Non-quantifiable, INS - Insufficient, >ULQ - > Upper limit of quantitation

SM

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These test results pertain only to the samples tested.

Should you have any questions regarding these results, please do not hesitate to call.

Results Report

L08-026934

Date Generated: 6/25/2008

Created By: Nick Schrier

Submitter Sample	Micro Elements	1	Cadmium	Micro Elements	1	Iron	Micro Element	1	Lead	Micro Element	1	Nickel	Micro Elements	1	Zinc	Micro Elements	1	Copper	Micro Elements	1
	ug/mL (ppm)		ug/mL (ppm)		ug/mL (ppm)		ug/mL (ppm)		ug/mL (ppm)		ug/mL (ppm)		ug/mL (ppm)		ug/mL (ppm)		ug/mL (ppm)		ug/mL (ppm)	
0-6 B1 MAY 8	0.00026		0.0011		0.0099		3.3		0.0099		0.0047		0.056		<0.038					
0-6-B2 MAY 8	0.00017		0.0015		0.0095		3.1		0.0095		0.0036		0.051		<0.038					
0-16-B1 MAY 8	0.00017		<0.00090		<0.0090		1.6		<0.0090		0.0026		0.039		<0.038					
0-16-B2 MAY 8	0.00017		<0.00090		<0.0090		1.6		<0.0090		<0.0025		0.036		<0.038					
I-6 B1 MAY 8	0.001		0.0081		0.043		16		0.043		0.014		0.25		0.084					
I-6 B2 MAY 8	0.00073		0.0064		0.034		13		0.034		0.011		0.2		0.064					
I-16-B1 MAY 8	0.00038		0.0046		0.022		8.3		0.022		0.0084		0.14		0.049					
I-16-B2 MAY 8	0.0006		0.0058		0.026		9.7		0.026		0.0098		0.16		0.058					
0-6-B1 MAY 14	0.00062		<0.00090		<0.0090		1.2		<0.0090		<0.0025		0.033		<0.038					
0-6-B2 MAY 14	0.00061		<0.00090		<0.0090		1.4		<0.0090		0.0025		0.032		<0.038					
0-16-B1 MAY 14	0.00029		<0.00090		<0.0090		1.1		<0.0090		0.0025		0.031		<0.038					
0-16-B2 MAY 14	<0.00014		<0.00090		<0.0090		1		<0.0090		<0.0025		0.031		<0.038					
I-6-B1 MAY 14	0.00019		<0.00090		<0.0090		0.93		<0.0090		<0.0025		0.027		<0.038					
I-6-B2 MAY 14	0.00011		<0.00090		<0.0090		0.98		<0.0090		0.0025		0.025		<0.038					
I-16-B1 MAY 14	<0.00014		<0.00090		<0.0090		0.33		<0.0090		<0.0025		0.015		<0.038					
I-16-B2 MAY 14	0.000057		<0.00090		<0.0090		0.33		<0.0090		<0.0025		0.015		<0.038					
0-6-B1 MAY 17	0.0001		<0.00090		<0.0090		0.78		<0.0090		<0.0025		0.032		<0.038					
0-6-B2 MAY 17	<0.00014		<0.00090		<0.0090		0.69		<0.0090		<0.0025		0.028		<0.038					
0-16-B1 MAY 17	<0.00014		<0.00090		<0.0090		0.72		<0.0090		<0.0025		0.031		<0.038					
0-16-B2 MAY 17	0.000057		<0.00090		<0.0090		0.71		<0.0090		<0.0025		0.033		<0.038					
I-6-B1 MAY 17	<0.00014		<0.00090		<0.0090		1		<0.0090		<0.0025		0.029		<0.038					
I-6-B2 MAY 17	<0.00014		<0.00090		<0.0090		0.99		<0.0090		0.0029		0.028		<0.038					
I-16-B1 MAY 17	<0.00014		<0.00090		<0.0090		0.97		<0.0090		<0.0025		0.04		<0.038					
I-16-B2 MAY 17	0.000075		<0.00090		<0.0090		0.89		<0.0090		0.0027		0.036		<0.038					

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Submitter Sample ID	Micro Elements	Micro Elements	Micro Elements	Micro Elements
	Iron	Lead	Zinc	Copper
	ug/g	ug/g	ug/g	ug/g
1-6-B2 JUN3/08	0.72	<0.0090	0.031	<0.038
1-6-B1 JUN3/08	0.62	<0.0090	0.031	<0.038
1-16-B2 JUN3/08	0.71	<0.0090	0.031	<0.038
1-16-B1 JUN3/08	0.64	<0.0090	0.03	<0.038
0-6-B2 JUN 3/08	<0.45	<0.0090	0.023	<0.038
0-6-B1 JUN 3/08	<0.45	<0.0090	0.022	<0.038
0-16-B2 JUN 3/08	<0.45	<0.0090	0.026	<0.038
0-16-B1 JUN 3/08	<0.45	<0.0090	0.027	<0.038
0-6-B2 JUN 5/08	0.58	<0.0090	0.037	<0.038
0-6-B1 JUN 5/08	0.57	<0.0090	0.036	<0.038
0-16-B2 JUN 5/08	<0.45	<0.0090	0.03	<0.038
0-16-B1 JUN 5/08	<0.45	<0.0090	0.03	<0.038
0-6-B2 JUN 15/08	<0.45	<0.0090	0.028	<0.038
0-6-B1 JUN 15/08	0.45	<0.0090	0.028	<0.038
I-6-B2 JUN 15/08	0.62	<0.0090	0.043	<0.038
I-6-B1 JUN 15/08	0.81	<0.0090	0.042	<0.038
I-16-B2 JUN 15/08	0.53	<0.0090	0.033	<0.038
I-16-B1 JUN 15/08	0.55	<0.0090	0.033	<0.038
0-6-B2 JUN 22/08	<0.45	<0.0090	0.026	<0.038
0-6-B1 JUN 22/08	<0.45	<0.0090	0.029	<0.038
0-16-B2 JUN 22/08	<0.45	<0.0090	0.021	<0.038
0-16-B1 JUN 22/08	<0.45	<0.0090	0.021	<0.038
I-6-B2 JUN 22/08	0.45	<0.0090	0.025	<0.038
I-6-B1 JUN 22/08	0.44	<0.0090	0.023	<0.038
I-16-B2 JUN 22/08	<0.45	<0.0090	0.018	<0.038
I-16-B1 JUN 22/08	<0.45	<0.0090	0.018	<0.038
0-6-B2 JUN 26/08	1.1	<0.0090	0.033	<0.038
0-6-B1 JUN 26/08	1.3	<0.0090	0.038	<0.038
0-16-B2 JUN 26/08	0.82	<0.0090	0.026	<0.038
0-16-B1 JUN 26/08	0.78	<0.0090	0.026	<0.038
I-6-B2 JUN 26/08	0.76	<0.0090	0.023	<0.038
I-6-B1 JUN 26/08	0.78	<0.0090	0.024	<0.038

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Submitter Sample ID	Micro Elements	Micro Elements	Micro Elements	Micro Elements
	Iron	Lead	Zinc	Copper
	ug/g	ug/g	ug/g	ug/g
1-6-B2 JUN3/08	0.72	<0.0090	0.031	<0.038
1-6-B1 JUN3/08	0.62	<0.0090	0.031	<0.038
1-16-B2 JUN3/08	0.71	<0.0090	0.031	<0.038
1-16-B1 JUN3/08	0.64	<0.0090	0.03	<0.038
0-6-B2 JUN 3/08	<0.45	<0.0090	0.023	<0.038
0-6-B1 JUN 3/08	<0.45	<0.0090	0.022	<0.038
0-16-B2 JUN 3/08	<0.45	<0.0090	0.026	<0.038
0-16-B1 JUN 3/08	<0.45	<0.0090	0.027	<0.038
0-6-B2 JUN 5/08	0.58	<0.0090	0.037	<0.038
0-6-B1 JUN 5/08	0.57	<0.0090	0.036	<0.038
0-16-B2 JUN 5/08	<0.45	<0.0090	0.03	<0.038
0-16-B1 JUN 5/08	<0.45	<0.0090	0.03	<0.038
0-6-B2 JUN 15/08	<0.45	<0.0090	0.028	<0.038
0-6-B1 JUN 15/08	0.45	<0.0090	0.028	<0.038
I-6-B2 JUN 15/08	0.62	<0.0090	0.043	<0.038
I-6-B1 JUN 15/08	0.81	<0.0090	0.042	<0.038
I-16-B2 JUN 15/08	0.53	<0.0090	0.033	<0.038
I-16-B1 JUN 15/08	0.55	<0.0090	0.033	<0.038
0-6-B2 JUN 22/08	<0.45	<0.0090	0.026	<0.038
0-6-B1 JUN 22/08	<0.45	<0.0090	0.029	<0.038
0-16-B2 JUN 22/08	<0.45	<0.0090	0.021	<0.038
0-16-B1 JUN 22/08	<0.45	<0.0090	0.021	<0.038
I-6-B2 JUN 22/08	0.45	<0.0090	0.025	<0.038
I-6-B1 JUN 22/08	0.44	<0.0090	0.023	<0.038
I-16-B2 JUN 22/08	<0.45	<0.0090	0.018	<0.038
I-16-B1 JUN 22/08	<0.45	<0.0090	0.018	<0.038
0-6-B2 JUN 26/08	1.1	<0.0090	0.033	<0.038
0-6-B1 JUN 26/08	1.3	<0.0090	0.038	<0.038
0-16-B2 JUN 26/08	0.82	<0.0090	0.026	<0.038
0-16-B1 JUN 26/08	0.78	<0.0090	0.026	<0.038
I-6-B2 JUN 26/08	0.76	<0.0090	0.023	<0.038
I-6-B1 JUN 26/08	0.78	<0.0090	0.024	<0.038

LABORATORY SERVICES

Results Report

L08-039414

Date Generated: 9/12/2008

Created By: Nick Schrier

Submitter Sample ID	Micro Elements	Micro Element	Micro Element	Micro Elements
	Iron	Lead	Zinc	Copper
	ug/g	ug/g	ug/g	ug/g
JUL 22 I-6 B/1	8.3	0.02	0.11	<0.038
JUL 22 I-6 B/2	7.9	0.02	0.11	<0.038
JUL 22 I-16 B/1	4.7	0.012	0.075	<0.038
JUL 22 I-16 B/2	6	0.014	0.088	<0.038
JUL 22 O-6 B/1	0.63	<0.0090	0.025	<0.038
JUL 22 O-6 B/2	0.6	0.0014	0.023	<0.038
JUL 22 O-16 B/1	0.64	<0.0090	0.023	<0.038
JUL 22 O-16 B/2	0.65	0.0011	0.022	<0.038
JUL 17 I-6 B/1	0.62	<0.0090	0.038	<0.038
JUL 17 I-6 B/2	0.36	<0.0090	0.026	<0.038
JUL 17 I-16 B/1	0.71	<0.0090	0.034	<0.038
JUL 17 I-16 B/2	0.69	<0.0090	0.033	<0.038
JUL 17 O-6 B/1	0.51	<0.0090	0.026	<0.038
JUL 17 O-6 B/2	0.49	<0.0090	0.023	<0.038
JUL 17 O-16 B/1	0.51	<0.0090	0.023	<0.038
JUL 17 O-16 B/2	0.5	<0.0090	0.024	<0.038
JUL 30 I-6 B/1	6.2	0.046	0.22	0.067
JUL 30 I-6 B/2	6.7	0.045	0.23	0.068
JUL 30 I-16 B/1	1.7	0.01	0.07	0.017
JUL 30 I-16 B/2	1.7	0.011	0.069	0.017
JUL 30 O-6 B/1	2	0.011	0.078	0.02
JUL 30 O-6 B/2	2.4	0.014	0.084	0.023
JUL 30 O-16 B/1	0.71	<0.0090	0.036	<0.038
JUL 30 O-16 B/2	0.75	<0.0090	0.034	<0.038
JUL 23 I-6 B/1	0.27	<0.0090	0.011	<0.038
JUL 23 I-6 B/2	0.25	<0.0090	0.013	<0.038
JUL 23 I-16 B/1	0.24	<0.0090	0.012	<0.038
JUL 23 I-16 B/2	0.24	<0.0090	0.014	<0.038
JUL 23 O-6 B/1	0.24	<0.0090	0.014	<0.038
JUL 23 O-6 B/2	0.25	<0.0090	0.011	<0.038
JUL 23 O-16 B/1	0.34	<0.0090	0.015	<0.038
JUL 23 O-16 B/2	0.36	<0.0090	0.016	<0.038

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Submitter Sample I	Micro Elements	Micro Elements	Micro Elements	Micro Elements
	Iron	Lead	Zinc	Copper
	ug/g	ug/g	ug/g	ug/g
JUL 22 I-6 B/1	8.3	0.02	0.11	<0.038
JUL 22 I-6 B/2	7.9	0.02	0.11	<0.038
JUL 22 I-16 B/1	4.7	0.012	0.075	<0.038
JUL 22 I-16 B/2	6	0.014	0.088	<0.038
JUL 22 O-6 B/1	0.63	<0.0090	0.025	<0.038
JUL 22 O-6 B/2	0.6	0.0014	0.023	<0.038
JUL 22 O-16 B/1	0.64	<0.0090	0.023	<0.038
JUL 22 O-16 B/2	0.65	0.0011	0.022	<0.038
JUL 17 I-6 B/1	0.62	<0.0090	0.038	<0.038
JUL 17 I-6 B/2	0.36	<0.0090	0.026	<0.038
JUL 17 I-16 B/1	0.71	<0.0090	0.034	<0.038
JUL 17 I-16 B/2	0.69	<0.0090	0.033	<0.038
JUL 17 O-6 B/1	0.51	<0.0090	0.026	<0.038
JUL 17 O-6 B/2	0.49	<0.0090	0.023	<0.038
JUL 17 O-16 B/1	0.51	<0.0090	0.023	<0.038
JUL 17 O-16 B/2	0.5	<0.0090	0.024	<0.038
JUL 30 I-6 B/1	6.2	0.046	0.22	0.067
JUL 30 I-6 B/2	6.7	0.045	0.23	0.068
JUL 30 I-16 B/1	1.7	0.01	0.07	0.017
JUL 30 I-16 B/2	1.7	0.011	0.069	0.017
JUL 30 O-6 B/1	2	0.011	0.078	0.02
JUL 30 O-6 B/2	2.4	0.014	0.084	0.023
JUL 30 O-16 B/1	0.71	<0.0090	0.036	<0.038
JUL 30 O-16 B/2	0.75	<0.0090	0.034	<0.038
JUL 23 I-6 B/1	0.27	<0.0090	0.011	<0.038
JUL 23 I-6 B/2	0.25	<0.0090	0.013	<0.038
JUL 23 I-16 B/1	0.24	<0.0090	0.012	<0.038
JUL 23 I-16 B/2	0.24	<0.0090	0.014	<0.038
JUL 23 O-6 B/1	0.24	<0.0090	0.014	<0.038
JUL 23 O-6 B/2	0.25	<0.0090	0.011	<0.038
JUL 23 O-16 B/1	0.34	<0.0090	0.015	<0.038
JUL 23 O-16 B/2	0.36	<0.0090	0.016	<0.038

Final Report

Report Date: October 29, 2007

Submission #: L07-050751

Attn: KAREN ANNE FINNEY
UNIVERSITY OF GUELPH
SCHOOL OF ENGINEERING
U OF G
GUELPH. ON N1G 2W1

Phone: (519) 824-4120

Quotation #: 01464

Toxicology

Sample ID:	Submitter Sample ID:	Sample Type:	Sampling Date & Time:	Analyte:	Result:	Units:	Notes:
07-0890290	SEPT 9 I-16-1	Water	07/10/09 16:24	Lead	<0.0080	ug/g	
07-0890290	SEPT 9 I-16-1	Water	07/10/09 16:24	Iron	1.4	ug/g	
07-0890290	SEPT 9 I-16-1	Water	07/10/09 16:24	Cadmium	<0.0020	ug/g	
07-0890290	SEPT 9 I-16-1	Water	07/10/09 16:24	Chromium	0.017	ug/g	
07-0890290	SEPT 9 I-16-1	Water	07/10/09 16:24	Cobalt	<0.0040	ug/g	
07-0890290	SEPT 9 I-16-1	Water	07/10/09 16:24	Copper	0.013	ug/g	
07-0890290	SEPT 9 I-16-1	Water	07/10/09 16:24	Molybdenum	<0.012	ug/g	
07-0890290	SEPT 9 I-16-1	Water	07/10/09 16:24	Nickel	<0.0040	ug/g	
07-0890290	SEPT 9 I-16-1	Water	07/10/09 16:24	Zinc	0.049	ug/g	
07-0890290	SEPT 9 I-16-1	Water	07/10/09 16:24	Manganese	0.083	ug/g	
07-0890291	SEPT 9 I-16-2	Water	07/10/09 16:24	Lead	<0.0080	ug/g	
07-0890291	SEPT 9 I-16-2	Water	07/10/09 16:24	Iron	1.6	ug/g	
07-0890291	SEPT 9 I-16-2	Water	07/10/09 16:24	Cadmium	<0.0020	ug/g	
07-0890291	SEPT 9 I-16-2	Water	07/10/09 16:24	Chromium	0.018	ug/g	
07-0890291	SEPT 9 I-16-2	Water	07/10/09 16:24	Cobalt	<0.0040	ug/g	
07-0890291	SEPT 9 I-16-2	Water	07/10/09 16:24	Copper	0.015	ug/g	
07-0890291	SEPT 9 I-16-2	Water	07/10/09 16:24	Molybdenum	<0.012	ug/g	
07-0890291	SEPT 9 I-16-2	Water	07/10/09 16:24	Nickel	<0.0040	ug/g	
07-0890291	SEPT 9 I-16-2	Water	07/10/09 16:24	Zinc	0.054	ug/g	
07-0890291	SEPT 9 I-16-2	Water	07/10/09 16:24	Manganese	0.092	ug/g	

Legend: NA - Not Analyzed, ND - Not Detected, UNS - Unsuitable, < MDL - < Method Detection Limit, TR - Trace, TNTC - Too numerous to count,
NQ - Non-quantifiable, INS - Insufficient, >ULQ - > Upper limit of quantitation

SM

Submission #: L07-050751

Sample ID:	Submitter Sample ID:	Sample Type:	Sampling Date & Time:	Analyte:	Result:	Units:	Notes:
07-0890292	SEPT 9 O-16-1	Water	07/10/09 16:24	Lead	<0.0080	ug/g	
07-0890292	SEPT 9 O-16-1	Water	07/10/09 16:24	Iron	0.72	ug/g	
07-0890292	SEPT 9 O-16-1	Water	07/10/09 16:24	Cadmium	<0.0020	ug/g	
07-0890292	SEPT 9 O-16-1	Water	07/10/09 16:24	Chromium	0.010	ug/g	
07-0890292	SEPT 9 O-16-1	Water	07/10/09 16:24	Cobalt	<0.0040	ug/g	
07-0890292	SEPT 9 O-16-1	Water	07/10/09 16:24	Copper	0.019	ug/g	
07-0890292	SEPT 9 O-16-1	Water	07/10/09 16:24	Molybdenum	<0.012	ug/g	
07-0890292	SEPT 9 O-16-1	Water	07/10/09 16:24	Nickel	0.0049	ug/g	
07-0890292	SEPT 9 O-16-1	Water	07/10/09 16:24	Zinc	0.029	ug/g	
07-0890292	SEPT 9 O-16-1	Water	07/10/09 16:24	Manganese	0.037	ug/g	
07-0890293	SEPT 9 O-16-2	Water	07/10/09 16:24	Lead	<0.0080	ug/g	
07-0890293	SEPT 9 O-16-2	Water	07/10/09 16:24	Iron	0.71	ug/g	
07-0890293	SEPT 9 O-16-2	Water	07/10/09 16:24	Cadmium	<0.0020	ug/g	
07-0890293	SEPT 9 O-16-2	Water	07/10/09 16:24	Chromium	0.0097	ug/g	
07-0890293	SEPT 9 O-16-2	Water	07/10/09 16:24	Cobalt	<0.0040	ug/g	
07-0890293	SEPT 9 O-16-2	Water	07/10/09 16:24	Copper	0.019	ug/g	
07-0890293	SEPT 9 O-16-2	Water	07/10/09 16:24	Molybdenum	<0.012	ug/g	
07-0890293	SEPT 9 O-16-2	Water	07/10/09 16:24	Nickel	0.0056	ug/g	
07-0890293	SEPT 9 O-16-2	Water	07/10/09 16:24	Zinc	0.030	ug/g	
07-0890293	SEPT 9 O-16-2	Water	07/10/09 16:24	Manganese	0.036	ug/g	
07-0890294	SEPT 9 I-6-1	Water	07/10/09 16:24	Lead	0.016	ug/g	
07-0890294	SEPT 9 I-6-1	Water	07/10/09 16:24	Iron	2.9	ug/g	
07-0890294	SEPT 9 I-6-1	Water	07/10/09 16:24	Cadmium	<0.0020	ug/g	
07-0890294	SEPT 9 I-6-1	Water	07/10/09 16:24	Chromium	0.014	ug/g	
07-0890294	SEPT 9 I-6-1	Water	07/10/09 16:24	Cobalt	<0.0040	ug/g	
07-0890294	SEPT 9 I-6-1	Water	07/10/09 16:24	Copper	0.029	ug/g	
07-0890294	SEPT 9 I-6-1	Water	07/10/09 16:24	Molybdenum	<0.012	ug/g	
07-0890294	SEPT 9 I-6-1	Water	07/10/09 16:24	Nickel	0.0051	ug/g	
07-0890294	SEPT 9 I-6-1	Water	07/10/09 16:24	Zinc	0.11	ug/g	
07-0890294	SEPT 9 I-6-1	Water	07/10/09 16:24	Manganese	0.16	ug/g	
07-0890295	SEPT 9 I-6-2	Water	07/10/09 16:24	Lead	0.016	ug/g	
07-0890295	SEPT 9 I-6-2	Water	07/10/09 16:24	Iron	2.9	ug/g	
07-0890295	SEPT 9 I-6-2	Water	07/10/09 16:24	Cadmium	<0.0020	ug/g	
07-0890295	SEPT 9 I-6-2	Water	07/10/09 16:24	Chromium	0.015	ug/g	
07-0890295	SEPT 9 I-6-2	Water	07/10/09 16:24	Cobalt	<0.0040	ug/g	
07-0890295	SEPT 9 I-6-2	Water	07/10/09 16:24	Copper	0.030	ug/g	

Legend: NA - Not Analyzed, ND - Not Detected, UNS - Unsuitable, < MDL - < Method Detection Limit, TR - Trace, TNTC - Too numerous to count, NQ - Non-quantifiable, INS - Insufficient, >ULQ - > Upper limit of quantitation

SM

Submission #: L07-050751

Sample ID:	Submitter Sample ID:	Sample Type:	Sampling Date & Time:	Analyte:	Result:	Units:	Notes:
07-0890295	SEPT 9 I-6-2	Water	07/10/09 16:24	Molybdenum	<0.012	ug/g	
07-0890295	SEPT 9 I-6-2	Water	07/10/09 16:24	Nickel	0.0050	ug/g	
07-0890295	SEPT 9 I-6-2	Water	07/10/09 16:24	Zinc	0.12	ug/g	
07-0890295	SEPT 9 I-6-2	Water	07/10/09 16:24	Manganese	0.16	ug/g	
07-0890296	SEPT 9 O-6-1	Water	07/10/09 16:24	Lead	<0.0080	ug/g	
07-0890296	SEPT 9 O-6-1	Water	07/10/09 16:24	Iron	1.6	ug/g	
07-0890296	SEPT 9 O-6-1	Water	07/10/09 16:24	Cadmium	<0.0020	ug/g	
07-0890296	SEPT 9 O-6-1	Water	07/10/09 16:24	Chromium	0.015	ug/g	
07-0890296	SEPT 9 O-6-1	Water	07/10/09 16:24	Cobalt	<0.0040	ug/g	
07-0890296	SEPT 9 O-6-1	Water	07/10/09 16:24	Copper	0.022	ug/g	
07-0890296	SEPT 9 O-6-1	Water	07/10/09 16:24	Molybdenum	<0.012	ug/g	
07-0890296	SEPT 9 O-6-1	Water	07/10/09 16:24	Nickel	0.0048	ug/g	
07-0890296	SEPT 9 O-6-1	Water	07/10/09 16:24	Zinc	0.052	ug/g	
07-0890296	SEPT 9 O-6-1	Water	07/10/09 16:24	Manganese	0.067	ug/g	
07-0890297	SEPT 9 O-6-2	Water	07/10/09 16:24	Lead	<0.0080	ug/g	
07-0890297	SEPT 9 O-6-2	Water	07/10/09 16:24	Iron	1.6	ug/g	
07-0890297	SEPT 9 O-6-2	Water	07/10/09 16:24	Cadmium	<0.0020	ug/g	
07-0890297	SEPT 9 O-6-2	Water	07/10/09 16:24	Chromium	0.014	ug/g	
07-0890297	SEPT 9 O-6-2	Water	07/10/09 16:24	Cobalt	<0.0040	ug/g	
07-0890297	SEPT 9 O-6-2	Water	07/10/09 16:24	Copper	0.022	ug/g	
07-0890297	SEPT 9 O-6-2	Water	07/10/09 16:24	Molybdenum	<0.012	ug/g	
07-0890297	SEPT 9 O-6-2	Water	07/10/09 16:24	Nickel	0.0045	ug/g	
07-0890297	SEPT 9 O-6-2	Water	07/10/09 16:24	Zinc	0.050	ug/g	
07-0890297	SEPT 9 O-6-2	Water	07/10/09 16:24	Manganese	0.066	ug/g	

Notes & Details:

Methods of Analysis TOXI-024

Sample Received:

October 17, 2007

Supervisor:

Nick Schrier MSc (519) 767 6215

Date Authorized:

October 29, 2007

Legend: NA - Not Analyzed, ND - Not Detected, UNS - Unsuitable, < MDL - < Method Detection Limit, TR - Trace, TNTC - Too numerous to count,
NQ - Non-quantifiable, INS - Insufficient, >ULQ - > Upper limit of quantitation

SM

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These test results pertain only to the samples tested.

Should you have any questions regarding these results, please do not hesitate to call.

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Page 3 of 3
October 29, 2007

TABLE 3010-I. CONT.

Element	Flame Atomic Absorption (Direct)	Flame Atomic Absorption (Extracted)	Flame Photometry	Electrothermal Atomic Absorption	Hydride/Cold Vapor Atomic Absorption	Inductively Coupled Plasma (ICP)	ICP/Mass Spectrometry (ICP/MS)	Anodic Stripping Voltammetry	Alternative Methods†
Iron	3111B	3111C		3113B		3120A	3125*		3500-Fe.B
Lead	3111B	3111C		3113B		3120A	3125	3130B	3500-Pb.B
Lithium	3111B		3500-Li.B			3120A	3125*		
Magnesium	3111B					3120A	3125*		3500-Mg.B,C
Manganese	3111B	3111C		3113B		3120A	3125		3500-Mn.B
Mercury					3112B		3125*		
Molybdenum	3111D	3111E		3113B		3120A	3125		
Nickel	3111B	3111C		3113B		3120A	3125		
Osmium	3111D	3111E					3125*		
Palladium	3111B						3125*		
Platinum	3111B						3125*		
Potassium	3111B		3500-K.B			3120A	3125*		3500-K.C
Rhenium	3111D	3111E					3125*		
Rhodium	3111B						3125*		
Ruthenium	3111B						3125*		
Selenium				3113B	3114B,C	3120A	3125		3500-Se.C,D,E
Silicon	3111D	3111E				3120A	3125*		
Silver	3111B	3111C		3113B		3120A	3125		
Sodium	3111B		3500-Na.B			3120A	3125*		
Strontium	3111B		3500-Sr.B			3120A	3125		
Tellurium				3113B			3125*		
Thallium	3111B			3113B		3120A	3125		
Thorium	3111D	3111E					3125*		
Tin	3111B			3113B			3125*		
Titanium	3111D	3111E					3125*		
Uranium							3125		
Vanadium	3111D	3111E		3113B		3120A	3125		3500-V.B
Zinc	3111B	3111C		3113B		3120A	3125	3130B	3500-Zn.B

* Metal is not specifically mentioned in the method, but 3125 may be used successfully in most cases.

† Additional alternative methods for aluminum, beryllium, cadmium, mercury, selenium, silver, and zinc may be found in the 19th Edition of *Standard Methods*.

3010 B. Sampling and Sample Preservation

Before collecting a sample, decide what fraction is to be analyzed (dissolved, suspended, total, or acid-extractable). This decision will determine in part whether the sample is acidified with or without filtration and the type of digestion required.

Serious errors may be introduced during sampling and storage because of contamination from sampling device, failure to remove residues of previous samples from sample container, and loss of metals by adsorption on and/or precipitation in sample container caused by failure to acidify the sample properly.

1. Sample Containers

The best sample containers are made of quartz or TFE. Because these containers are expensive, the preferred sample container is made of polypropylene or linear polyethylene with a polyethylene cap. Borosilicate glass containers also may be used, but avoid soft glass containers for samples containing metals in the microgram-per-liter range. Store samples for determination of silver in light-absorbing containers. Use only containers and filters that have been acid rinsed.

2. Preservation

Preserve samples immediately after sampling by acidifying with concentrated nitric acid (HNO_3) to pH <2. Filter samples for dissolved metals before preserving (see Section 3030). Usually 1.5 mL conc HNO_3 /L sample (or 3 mL 1 + 1 HNO_3 /L sample) is sufficient for short-term preservation. For samples with high buffer capacity, increase amount of acid (5 mL may be required for some alkaline or highly buffered samples). Use commercially available high-purity acid* or prepare high-purity acid by sub-boiling distillation of acid.

After acidifying sample, preferably store it in a refrigerator at approximately 4°C to prevent change in volume due to evaporation. Under these conditions, samples with metal concentrations of several milligrams per liter are stable for up to 6 months (except mercury, for which the limit is 5 weeks). For microgram-per-liter metal levels, analyze samples as soon as possible after sample collection.

* Ultrex, J.T. Baker, or equivalent.

Alternatively, preserve samples for mercury analysis by adding 2 mL/L 20% (w/v) $K_2Cr_2O_7$ solution (prepared in 1 + 1 HNO_3). Store in a refrigerator not contaminated with mercury. (CAUTION: Mercury concentrations may increase in samples stored in plastic bottles in mercury-contaminated laboratories.)

3. Bibliography

STRUEMPLER, A.W. 1973. Adsorption characteristics of silver, lead, calcium, zinc and nickel on borosilicate glass, polyethylene and polypropylene container surfaces. *Anal. Chem.* 45:2251.
FELDMAN, C. 1974. Preservation of dilute mercury solutions. *Anal. Chem.* 46:99.

KING, W.G., J.M. RODRIGUEZ & C.M. WAI. 1974. Losses of trace concentrations of cadmium from aqueous solution during storage in glass containers. *Anal. Chem.* 46:771.
BATLEY, G.E. & D. GARDNER. 1977. Sampling and storage of natural waters for trace metal analysis. *Water Res.* 11:745.
SUBRAMANIAN, K.S., C.L. CHAKRABARTI, J.E. SUETIAS & I.S. MAINES. 1978. Preservation of some trace metals in samples of natural waters. *Anal. Chem.* 50:444.
BERMAN, S. & P. YEATS. 1985. Sampling of seawater for trace metals. *Crit. Rev. Anal. Chem.* 16:1.
WENDLANDT, E. 1986. Sample containers and analytical accessories made of modern plastics for trace analysis. *Gewaess. Wass. Abwass.* 86:79.

3010 C. General Precautions

1. Sources of Contamination

Avoid introducing contaminating metals from containers, distilled water, or membrane filters. Some plastic caps or cap liners may introduce metal contamination; for example, zinc has been found in black bakelite-type screw caps as well as in many rubber and plastic products, and cadmium has been found in plastic pipet tips. Lead is a ubiquitous contaminant in urban air and dust.

2. Contaminant Removal

Thoroughly clean sample containers with a metal-free non-ionic detergent solution, rinse with tap water, soak in acid, and then rinse with metal-free water. For quartz, TFE, or glass materials, use 1 + 1 HNO_3 , 1 + 1 HCl , or aqua regia (3 parts conc HCl + 1 part conc HNO_3) for soaking. For plastic material, use 1 + 1 HNO_3 or 1 + 1 HCl . Reliable soaking conditions are 24 h at 70°C. Chromic acid or chromium-free substitutes* may be used to remove organic deposits from containers, but rinse

containers thoroughly with water to remove traces of chromium. Do not use chromic acid for plastic containers or if chromium is to be determined. Always use metal-free water in analysis and reagent preparation (see 3111B.3c). In these methods, the word "water" means metal-free water.

3. Airborne Contaminants

For analysis of microgram-per-liter concentrations of metals, airborne contaminants in the form of volatile compounds, dust, soot, and aerosols present in laboratory air may become significant. To avoid contamination use "clean laboratory" facilities such as commercially available laminar-flow clean-air benches or custom-designed work stations and analyze blanks that reflect the complete procedure.

4. Bibliography

MITCHELL, J.W. 1973. Ultrapurity in trace analysis. *Anal. Chem.* 45:492A.
GARDNER, M., D. HUNT & G. TOPPING. 1986. Analytical quality control (AQC) for monitoring trace metals in the coastal and marine environment. *Water Sci. Technol.* 18:35.

* Nochromix, Godax Laboratories, or equivalent.

Appendix C - Spectrophotometer Heavy Metal Results

ZINC

Date	Inlet Sample			Outlet Sample			Mean	
	Sample ID	Inlet Concentration (ug/L)	Flow Rate (L/s)	In EMC (ug/L)	Sample Number	Outlet Concentration (ug/L)	Out EMC (ug/L)	Removal (%)
09-Sep-07 171 min	0859439 I-2-1	35.1	0.24		0859446 O-8-2	13.1		63%
	0859445 I-4-1	35.8	1.28		0859447 O-10-1	10.4		71%
	0859434 I-8-1	21.3	1.98		0859429 O-12-1	9.8		54%
	0859455 I-10-1	18.0	1.22		0859460 O-20-2	11.9		34%
	0859450 I-12-1	17.1	0.67		0859442 O-22-2	10.7		38%
	0859448 I-14-2	17.6	0.36		0859427 O-24-1	9.9		44%
	0859449 I-20-1	17.0	0.14	23.49	0859428 O-24-2	9.5	10.59	44%
11-Sep-07 249 min	09/11/07 I-6-A1	29.4	5.47		09/11/07 O-6-2	17.6		40%
	09/11/07 I-8-1	36.2	11.06		09/11/07 O-8-2	13.7		62%
	09/11/07 I-10-1	28.4	9.76		09/11/07 O-10-1	11.5		60%
	09/11/07 I-12-1	28.8	7.11		09/11/07 O-12-2	10.6		63%
	09/11/07 I-18-2	10.6	1.39		09/11/07 O-18-2	8.5		20%
	09/11/07 I-22-1	22.0	0.38		09/11/07 O-22-1	7.7		65%
	09/11/07 I-24-1	22.9	0.21		09/11/07 O-24-1	8.7		62%
26-Sep-07 201 min	9/29/07 I-6-A1	37.7	0.38	30.26	9/26/07 O-6-A2	25.2	12.77	33%
	9/26/07 I-8-A2	34.6	3.21		9/26/07 O-8-A1	23.0		34%
	9/26/07 I-10-A1	33.7	2.14		9/26/07 O-8-A2	24.9		26%
	9/26/07 I-12-A2	31.2	0.14	34.39	9/26/07 O-16-A1	21.9	23.81	30%
02-Oct-07 162 min	10/02/07 I-2-A1	26.6	0.69		10/02/07 O-2-A1	20.3		24%
	10/2/07 I-4-A2	30.8	1.89		10/2/07 O-4-A1	17.2		44%
	10/2/07 I-6-A1	27.4	2.07		10/2/07 O-6-A2	18.8		31%
	10/2/07 I-8-A1	27.7	1.36		10/2/07 O-8-A2	17.3		38%
	10/2/07 I-10-A1	24.7	0.64		10/2/07 O-10-A2	16.8		32%
	10/2/07 I-12-A2	22.6	0.37	27.80	10/2/07 O-12-A1	17.7	17.99	22%
06-Oct-07 191 min	10/6/07 I-2-A2	41.2	0.15		10/6/07 O-2-A1	36.5		11%
	10/6/07 I-4-A1	38.5	29.36		10/6/07 O-2-A2	29.5		23%
	10/6/07 I-6-A1	33.8	15.25		10/6/07 O-6-A2	28.5		16%
	10/6/07 I-10-A2	32.5	3.24	36.61	10/6/07 O-10-A2	22.8	28.75	30%
10-Oct-07 231 min	10/17/07 I-4-A1	21.3	0.43		10/17/07 O-4-A1	7.5		65%
	10/16/07 I-6-A1	26.2	0.39		10/17/07 O-6-A2	13.9		47%
	10/17/07 I-12-A1	18.4	0.53		10/17/07 O-12-A1	16.0		13%
	10/17/07 I-16-A1	17.3	0.24		10/17/07 O-16-A2	10.1		42%
	10/17/07 I-18-A1	14.5	0.14	20.43	10/17/07 O-18-A1	9.6	12.08	34%
23-Oct-07 735 min	10/23/07 I-2-A1	22.3	0.16		10/23/07 O-2-A1	9.5		57%
	10/23/07 I-4-A1	25.9	6.4		10/23/07 O-4-A2	12.2		53%
	10/23/07 I-6-A1	25.7	4.5		10/23/07 O-6-A2	13.7		47%
	10/23/07 I-8-A1	25.8	1.12		10/23/07 O-8-A2	13.0		50%
	10/23/07 I-10-A1	26.4	0.5	25.79	10/23/07 O-10-A1	13.6	12.82	48%
31-Oct-07 261 min	10/31/07 I-6-A2	24.9	4.98		10/31/07 O-6-A1	14.9		40%
	10/31/07 I-8-A1	31.2	1.42		10/31/07 O-8-A2	19.7		37%
	10/31/07 I-10-A2	23.7	0.93		10/31/07 O-10-A2	22.9		3%
	10/31/07 I-16-A1	21.4	0.47		10/31/07 O-16-A1	13.4		37%
	10/31/07 I-22-A1	27.6	0.14	25.70	10/31/07 O-22-A1	15.7	16.62	43%
07-May-08 1120 min	05/08 I-2-B2	51.6	0.18		05/08 O-2-B1	17.0		67%
	05/08 I-4-B1	54.1	0.57		05/08 O-4-B1	33.5		38%
	05/08 I-6-B1	46.6	1.10		05/08 O-6-B2	28.0		40%
	05/08 I-8-B1	49.6	4.93		05/08 O-8-B1	22.3		55%
	05/08 I-10-B1	55.6	3.12		05/08 O-10-B1	12.1		78%
	05/08 I-12-B1	49.9	1.69		05/08 O-10-B2	13.0		74%
	05/08 I-16-B1	37.4	0.57		05/08 O-12-B1	18.9		49%
	05/08 I-18-B1	51.4	0.30		05/08 O-16-B1	17.5		66%
	05/08 I-22-B2	31.5	0.26		05/08 O-22-B2	16.1		49%
	05/08 I-24-B2	37.2	0.22	49.98	05/08 O-24-B1	16.0	19.31	57%
								61%
14-May, 2008 930 min	05/14 I-2-B1	18.1	0.14		05/14 O-2-B2	6.6		63%
	05/14 I-4-B1	9.6	0.25		05/14 O-4-B1	12.6		-32%
	05/14 I-6-B1	16.1	1.14		05/14 O-6-B1	10.4		35%
	05/14 I-8-B1	9.0	1.32		05/14 O-8-B1	9.5		-6%
	05/14 I-10-B1	9.5	0.28		05/14 O-10-B1	13.5		-42%
	05/14 I-12-B1	18.0	0.25		05/14 O-12-B1	10.4		42%

	05/14 I-16-B2	8.5	0.2		05/14 O-16-B2	9.4		-11%	
	05/14 I-18-B2	15.1	0.25		05/14 O-18-B1	13.3		12%	
	05/14 I-22-B1	17.8	0.16		05/14 O-22-B1	11.7		34%	
	05/14 I-24-B2	12.6	0.15		05/14 O-24-B1	14.2		-13%	
				12.66			10.64		16%
17-May-08	05/17 I-2-B1	25.1	0.15		05/17 O-2-B1	17.2		31%	
310 min	05/17 I-4-B1	16.0	0.29		05/17 O-4-B1	15.7		2%	
	05/17 I-6-B1	18.0	1.13		05/17 O-6-B1	17.0		5%	
	05/17 I-8-B1	16.9	1.44		05/17 O-8-B1	18.7		-11%	
	05/17 I-10-B1	18.8	2.29		05/17 O-10-B1	13.4		29%	
	05/17 I-12-B1	20.4	2.21		05/17 O-12-B1	16.5		19%	
	05/17 I-16-B1	20.9	1.44		05/17 O-16-B1	20.0		4%	
	05/17 I-18-B1	22.9	0.99		05/17 O-18-B1	15.2		34%	
	05/17 I-22-B1	14.5	0.47		05/17 O-22-B1	12.9		11%	
	05/17 I-24-B1	12.4	0.28		05/17 O-24-B1	16.7		-35%	
				19.11			16.37		14%
03-Jun-08	06/03 I-2-B2	5.1	0.15		06/03 O-2-B1	4.5		12%	
475 min	06/03 I-4-B1	5.8	0.3		06/03 O-4-B1	4.1		29%	
	06/03 I-6-B1	4.9	0.48		06/03 O-6-B1	2.6		47%	
	06/03 I-8-B1	5.3	0.59		06/03 O-8-B1	2.9		45%	
	06/03 I-10-B1	5.2	1.17		06/03 O-10-B1	2.8		47%	
	06/03 I-12-B1	6.0	0.85		06/03 O-12-B1	4.2		30%	
	06/03 I-16-B1	4.6	0.78		06/03 O-16-B1	4.0		14%	
	06/03 I-18-B1	7.0	0.23		06/03 O-18-B1	3.6		48%	
	06/03 I-24-B1	8.5	0.16		06/03 O-24-B1	7.1		16%	
				5.46			3.55		35%
16-Jun-08	06/15 I-2-B1	26.6	2.17		06/15 O-2-B1	7.5		72%	
500 min	06/15 I-4-B2	27.0	0.43		06/15 O-4-B2	10.4			
	06/15 I-6-B1	27.1	21.89		06/15 O-6-B1	8.8		68%	
	06/15 I-8-B2	25.1	5.14		06/15 O-8-B2	25.9			
	06/15 I-10-B1	26.1	0.85		06/15 O-10-B1	4.9		81%	
	06/15 I-12-B2	32.5	0.44		06/15 O-12-B2	10.1		69%	
	06/15 I-16-B1	24.2	15.29		06/15 O-16-B1	7.1		71%	
	06/15 I-18-B1	28.8	3.54		06/15 O-18-B2	6.9		75%	
	06/15 I-24-B1	30.2	1.47		06/15 O-24-B1	8.3		77%	
				26.25			9.75		63%
23-Jun-08	6/22 I-2-B1	20.4	7.01		6/22 O-2-B1	19.3		5%	
525 min	6/22 I-6-B1	23.9	5.1		6/22 O-6-B1	20.8		13%	
	6/22 I-8-B1	17.3	1.38		6/22 O-8-B1	18.8		-9%	
	6/22 I-10-B1	17.1	0.85		6/22 O-10-B1	18.3		-7%	
	6/22 I-12-B2	16.2	0.4		6/22 O-12-B1	11.9		27%	
	6/22 I-24-B1	25.4	0.18		6/22 O-24-B1	21.7		15%	
				21.07			19.54		7%
26-Jun-08	6/26 I-2-B1	18.0	0.19		6/26 O-2-B2	26.8		-49%	
230 min	6/26 I-4-B2	20.6	0.44		6/26 O-4-B2	26.2		-27%	
	6/26 I-6-B1	20.8	0.40		6/26 O-6-B2	22.4		-8%	
	6/26 I-8-B1	17.3	0.34		6/26 O-8-B2	24.6		-42%	
	6/26 I-10-B2	13.2	0.26		6/26 O-10-B2	20.9		-58%	
	6/26 I-12-B2	17.0	0.22		6/26 O-12-B1	23.4		-38%	
	6/26 I-16-B2	18.3	0.16		6/26 O-16-B2	17.3		6%	
				18.24			23.49		-29%
11-Jul-08	I-2-B1 0331107	34.1	16.93		O-2-B1 0331089	24.5		28%	
729 min	I-4-B1 0331109	24.3	24.69		O-4-B1 0331091	23.3		4%	
	I-6-B1 0331111	22.3	24.38		O-6-B1 0331093	21.7		3%	
	I-8-B1 0331113	24.0	31.69		O-8-B1 0331095	21.9		9%	
	I-10-B1 0331115	41.6	22.88		O-10-B1 0331097	21.1		49%	
	I-12-B1 0331117	27.2	5.66		O-12-B1 0331099	21.9		19%	
	I-16-B1 0331119	26.0	2.66		O-16-B1 0331101	25.8		1%	
	I-18-B1 0331121	31.4	1.6		O-18-B1 0331103	27.9		11%	
	I-24-B1 0331123	28.8	1.17		O-24-B1 0331105	20.9		28%	
				28.40			22.46		21%
12-Jul-08	0331143 I-2-B1	3.9	0.54		0331125 O-2-B1	5.1		-31%	
245 min	0331146 I-4-B2	5.4	1.07		0331127 O-4-B1	3.1		43%	
	0331147 I-6-B1	4.1	0.93		0331129 O-6-B1	3.0		27%	
	0331149 I-8-B1	4.5	0.88		0331131 O-8-B1	3.4		24%	
	0331151 I-10-B1	4.7	0.52		0331133 O-10-B1	4.2		11%	
	0331153 I-12-B1	5.1	0.34		0331155 O-12-B1	3.7		27%	
	0331155 I-16-B1	4.7	0.27		0331137 O-16-B1	3.5		27%	
	0331139 O-18-B1	4.9	0.14		0331157 I-18-B1	2.1		57%	
				4.65			3.52		24%
17-Jul-08	7/17 I-2-B1	24.3	0.58		7/17 O-2-B1	20.3		16%	
210 min	7/17 I-4-B2	22.1	1.28		7/17 O-4-B1	20.3		8%	
	7/17 I-6-B1	22.8	1.36		7/17 O-6-B1	19.1		16%	
	7/17 I-8-B1	25.1	1.01		7/17 O-8-B1	21.1		16%	
	7/17 I-10-B1	24.0	0.79		7/17 O-10-B1	20.3		16%	
	7/17 I-12-B2	25.5	0.49		7/17 O-12-B2	19.9		22%	
	7/17 I-16-B1	22.3	0.44		7/17 O-16-B1	18.0		19%	
	7/17 I-18-B2	21.7	0.42		7/17 O-18-B1	19.0		12%	
	7/17 I-22-B1	22.6	0.25		7/17 O-22-B1	14.1		38%	
	7/17 I-24-B1	23.9	0.16		7/17 O-24-B1	20.1		16%	
				23.39			19.68		16%

22-Jul-08									
885 min	7/22 I-6-B1	36.8	22.88	7/22 O-6-B1	20.4	45%			
	7/22 I-8-B1	36.8	15.26	7/22 O-8-B1	14.7	60%			
	7/22 I-10-B2	36.3	6.6	7/22 O-10-B1	19.8	45%			
	7/22 I-12-B1	35.7	4.59	7/22 O-12-B1	28.9	19%			
	7/22 I-18-B1	37.0	3.56	7/22 O-18-B2	18.3	51%			
	7/22 I-22-B2	27.2	1.73	7/22 O-22-B1	23.5	14%			
	7/22 I-24-B1	30.0	1.36	7/22 O-24-B1	20.4	32%			
			36.20		19.43			46%	
23-Jul-08									
755 min	7/23 I-2-B2	11.0	0.53	7/23 O-2-B1	2.5	77%			
	7/23 I-4-B2	12.8	0.8	7/23 O-4-B2	8.2	36%			
	7/23 I-6-B1	11.5	0.29	7/23 O-6-B1	4.6	60%			
	7/23 I-8-B1	9.7	0.16	7/23 O-8-B1	2.8	71%			
	7/23 I-10-B1	7.9	0.15	7/23 O-10-B1	0.8	90%			
	7/23 I-12-B1	10.9	0.85	7/23 O-12-B1	7.4	32%			
	7/23 I-16-B1	8.5	1.28	7/23 O-16-B1	5.7	33%			
	7/23 I-18-B1	20.2	1.04	7/23 O-18-B2	8.5	58%			
	7/23 I-22-B1	11.5	0.2	7/23 O-22-B2	10.1	12%			
			12.38		6.45			48%	
30-Jul-08									
636 min	7/30 I-2-B1	40.4	14.81	7/30 O-2-B1	39.1	3%			
	7/30 I-4-B1	39.1	10.95	7/30 O-4-B1	35.0	10%			
	7/30 I-6-B1	39.2	8.99	7/30 O-6-B1	30.0	23%			
	7/30 I-8-B1	42.6	8.01	7/30 O-8-B1	24.8	42%			
	7/30 I-10-B1	36.1	6.81	7/30 O-10-B1	21.9	39%			
	7/30 I-12-B2	29.3	5.48	7/30 O-12-B1	15.2	48%			
	7/30 I-16-B2	30.2	3.59	7/30 O-16-B1	19.6	35%			
	7/30 I-18-B2	27.6	3.04	7/30 O-18-B1	13.1	53%			
	7/30 I-22-B2	24.2	28.23	7/30 O-22-B2	23.1	5%			
	7/30 I-24-B1	20.4	0.83	7/30 O-24-B1	15.1	26%			
			33.27		26.87			19%	

COPPER

Date	Inlet Sample				Inlet Sample			Removal (%)	Removal (%)
	Sample ID	Inlet Concentration (ug/L)	Flow (L/s)	In EMC (ug/L)	Sample Number	Outlet Concentration (ug/L)	Out EMC (ug/L)		
09-Sep-07	9/9/07 I-18-A1	29.9	0.24		9/9/07 O-18-A1	15.9412		47%	
	07-0859434 I-8-A	28.6	1.98		07-0859458 O-8-A	11.7819		59%	
	9/26/07 I-12-A1	30.9	1.22		9/26/07 O-4-A1	25.2484		18%	
	9/26/07 I-6-A1	50.3	0.67		9/26/07 O-12-A1	29.3969		42%	
	9/26 I-4-A1	46.4	0.36	33.99	9/26/07 O-8-A1	24.5032	19.35	47%	43%
26-Sep-07	10/6/07 I-4-A1	29.7	1.48	29.72	10/6/07 O-12-A1	15.1448	15.14	49%	49%
11-Sep-07	9/11/07 I-8-A1	41.0	7.46		9/11/07 O-4-A1	14.1123		66%	
	9/11/07 I-8-A1	31.1	7.11		9/11/07 O-18-A1	21.5165		31%	
	9/11/07 I-18-A1	28.2	0.38	35.94	9/11/07 O-8-A1	25.8623	17.93	8%	50%
02-Oct-07	10/2/07 I-4-A1	26.4	1.36		10/2/07 O-4-A1	10.425		61%	
	10/2/07 I-8-A1	31.5	0.64	28.08	10/2/07 O-8-A1	10.0704	10.31	68%	63%
10-Oct-07	10/17/07 I-4-A1	23.8	0.21		10/17/07 O-4-A1	14.3483		40%	
	10/17/07 I-8-A1	22.0	0.42		10/17/07 O-8-A1	15.4398		30%	
	10/17/07 I-12-A1	21.1	0.53		10/17/07 O-12-A1	9.835		53%	
	10/17/07 I-18-A1	27.7	0.24	22.90	10/17/07 O-18-A1	10.602	12.32	62%	46%
23-Oct-07	10/23/07 I-12-A1	36.3	2.30	36.33	10/23/07 O-12-A1	24.6522	24.65	32%	32%
31-Oct-07	10/31/07 I-4-A1	36.3	2.6		10/31/07 O-4-A1	28.3		22%	
	21.18 10/31/07 I-12-A1	33.1	0.93	35.45	10/31/07 O-12-A1	22.3	26.71	33%	25%
07-May-08	5/8 I-4-B1	71.1	0.18		5/8 O-4-B1	26.9		62%	
	5/8 I-18-B1	61.1	3.12		5/8 O-8-B1	26.4		57%	
	5/8 I-12-B1	69.3	0.57	62.76	5/8 O-12-B1	23.6	25.98	66%	59%
14-May-08	5/14 I-4-B1	23.5	0.16		5/14 O-4-B1	25.5		-9%	
	5/14 I-8-B1	25.8	1.14		5/14 O-8-B1	24.8		4%	
	5/14 I-12-B1	30.1	0.25		5/14 O-12-B1	25.1		17%	
	5/14 I-18-B1	27.1	0.16	26.30	5/14 O-18-B1	29.9	25.42	-10%	3%
17-May-08	5/17 I-4-B1	20.0	0.29		5/17 O-4-B1	26.7		-33%	
	5/17 I-8-B1	21.6	2.21		5/17 O-18-B1	36.1		-67%	
	05/17 I-12-B1	21.6	0.99		5/17 O-8-B1	29.5		-37%	
	5/17 I-18-B1	21.3	0.28	21.44	5/17 O-12-B1	26.6	32.93	-25%	-54%
03-Jun-08	6/3 I-4-B1	37.7	0.48		6/3 O-4-B1	29.8		21%	
	6/3 I-8-B1	38.6	1.17		6/3 O-8-B1	28.5		31%	
	6/3 I-12-B1	43.1	0.23		6/3/08 O-12-B1	39.0		9%	
	6/3 I-18-B1	33.5	0.23	38.36	6/3 O-18-B1	28.8	28.88	14%	25%
16-Jun-08	6/15/08 I-4-B1	31.8	0.43		6/15 O-4-B1	27.7		13%	
	6/15 I-8-B1	27.0	21.89		6/15 O-8-B1	24.6		9%	
	6/15 I-12-B1	27.7	0.44		6/15 O-12-B1	26.8		3%	
	6/15 I-18-B1	27.7	1.47	27.14	6/15 O-18-B1	27.0	24.82	3%	9%
23-Jun-08	6/22 I-4-B1	27.0	7.01		6/22 O-8-B1	14.7		46%	
	6/22 I-8-B1	19.2	2.2		6/22 O-12-B1	17.9		7%	
	6/22 I-12-B1	13.0	0.85		6/22 O-18-B1	12.8		2%	
	6/22 I-18-B1	24.2	0.4	24.14	6/26 O-4-B1	24.7	14.66		39%
26-Jun-08	6/26 I-4-B1	23.6	0.44		6/26 O-8-B1	23.3		1%	
	6/26 I-8-B1	25.9	0.25		6/26 O-12-B1	25.4		2%	
	6/26 I-12-B1	16.9	0.14		6/26 O-18-B1	16.6		2%	
				23.16			22.84		1%
11-Jul-08	08-0331109 I-4-B	21.0	24.38		08-0331091 O-4-E	20.9		0%	
	08-0331113 I-8-B	21.2	31.69		08-031095 O-8-B	22.2		-5%	
	08-0331117 I-12-E	19.7	1.6		08-0331099 O-12	22.8		-16%	
	08-0331121 I-18-E	20.5	1.17	21.06	08-0331103 O-18	24.6	21.74	-20%	-3%
12-Jul-08	08-0331145 I-4-B	19.0	0.54		08-0331127 O-4-E	17.6		7%	
	08-0331149 I-8-B	19.5	0.93		08-0331131 O-8-E	16.1		17%	
	08-0331157 I-18-E	19.0	0.27	19.25	08-0331135 O-12	17.0	16.71	11%	13%
17-Jul-08	7/17 I-8-B1	33.8	1.28		7/17 O-4-B1	29.5			
					7/17 O-8-B1	33.1		2%	

	7/17 I-12-B1	42.9	0.49		7/17 O-12-B1	16.5		62%
	7/17 I-18-B1	29.2	0.25		7/17 O-18-B1	26.1		11%
				35.43			28.20	20%
22-Jul-08	7/22 I-4-B1	51.5	22.88		7/22 O-4-B1	16.1		69%
	7/22 I-8-B1	49.4	6.6		7/22 O-8-B1	24.7		50%
	7/22 I-12-B1	40.1	1.73		7/22 O-12-B1	29.7		26%
	7/22 I-18-B1	37.6	1.14		7/22 O-18-B1	28.0		26%
				49.95			18.99	62%
23-Jul-08	7/23 I-2-B2	21.0	0.53					
	7/23 I-4-B1	24.2	0.29		7/23 O-4-B1	16.0		34%
	7/23 I-8-B1	20.8	0.15		7/23 O-8-B1	17.6		16%
	7/23 I-12-B1	20.2	0.85		7/23 O-12-B1	15.6		23%
	7/23 I-18-B1	25.0	1.04		7/23 O-18-B1	15.4		38%
				22.54			12.80	43%
30-Jul-08	7/30 I-4-B1	36.3	17.81		7/30 O-4-B1	27.8		23%
	7/30 I-8-B1	37.0	10.95		7/30 O-8-B1	24.9		33%
	7/30 I-12-B1	35.0	5.48		7/30 O-12-B1	26.3		25%
	7/30 I-18-B1	32.9	3.04		7/30 O-18-B1	24.2		26%
				36.06			26.42	27%

Appendix D - ALS Petroleum Hydrocarbon Results

Appendix E - LDI Petroleum Hydrocarbon Results

Petroleum Hydrocarbons (PAH)

Date	Inlet Sample				Outlet Sample			Removal (%)	Mean Removal (%)
	Sample ID	Inlet Concentration (ug/L)	Flow Rate (L/s)	In EMC (ug/L)	Sample Number	Outlet Concentration (ug/L)	Out EMC (ug/L)		
09-Sep-07	I-1-A1	3.5	0.24	10.06	O-1-A1	0.6	1.39	83%	86%
	I-3-A1	26.7	1.28		O-3-A1	3.3		88%	
	I-9-A1	5.8	1.98		O-9-A1	0.7		88%	
	I-11-A1	9.0	1.22		O-11-A1	1.2		87%	
	I-15-A1	0.4	0.67		O-15-A1	0.1		79%	
	I-17-A1	3.5	0.38		O-17-A1	2.4		31%	
	I-23-A1	1.9	0.14		O-23-A1	0.3		84%	
11-Sep-07	I-3-A1	8.0	5.47	4.34	O-3-A1	2.2	1.53	73%	65%
	I-9-A1	2.0	11.06		O-9-A1	1.2		39%	
	I-11-A1	7.0	9.76		O-11-A1	1.7		76%	
	I-13-A1	2.3	7.11		O-13-A1	1.7		26%	
	I-15-A1	3.8	4.15		O-15-A1	0.8		78%	
	I-17-A1	3.0	1.39		O-17-A1	1.8		41%	
	I-19-A1	1.2	0.38		O-19-A1	0.8		30%	
26-Sep-07	I-1-A1	8.8	0.38	10.59	O-1-A1	1.5	2.20	83%	79%
	I-3-A1	10.6	10.83		O-3-A1	2.0		81%	
	I-11-A1	15.8	0.38		O-11-A1	2.6		84%	
	I-13-A1	10.1	3.87		O-13-A1	2.4		77%	
	I-15-A1	10.4	2.29		O-15-A1	3.0		71%	
02-Oct-07	I-1-A1	9.8	1.69	11.55	O-1-A1	1.9	2.08	80%	82%
	I-7-A1	11.7	1.36		O-7-A1	1.8		84%	
	I-9-A1	13.8	0.64		O-9-A1	2.3		83%	
	I-11-A1	16.2	0.37		O-11-A1	3.3		80%	
06-Oct-07	I-1-A1	2.7	0.15	5.44	O-1-A1	0.6	0.34	79%	84%
	I-9-A1	5.8	29.38		O-9-A1	0.4		93%	
	I-11-A1	5.6	15.25		O-11-A1	0.2		96%	
	I-19-A1	1.8	3.24		O-19-A1	0.4		79%	
10-Oct-07	I-1-A1	10.5	0.21	8.52	O-1-A1	2.5	3.29	76%	61%
	I-3-A1	7.8	0.42		O-3-A1	1.7		78%	
	I-5-A1	11.5	0.43		O-5-A1	3.3		71%	
	I-9-A1	6.2	0.39		O-9-A1	2.0		67%	
	I-11-A1	9.3	0.53		O-11-A1	3.2		66%	
	I-13-A1	6.5	0.24		O-13-A1	5.2		21%	
	I-15-A1	6.1	0.14		O-15-A1	4.1		33%	
23-Oct-07	I-1-A1	2.6	0.3	3.82	O-1-A1	1.4	2.08	48%	46%
	I-9-A1	3.7	6.4		O-3-A1	2.0		46%	
	I-5-A1	2.0	4.5		O-5-A1	2.0		23%	
	I-7-A1	3.9	1.12		O-7-A1	2.9		28%	
	I-9-A1	4.1	0.25		O-9-A1	1.2		70%	
	I-11-A1	6.4	2.41		O-11-A1	2.2		66%	
31-Oct-07	I-1-A1	7.1	9.76	11.03	O-1-A1	2.4	2.85	66%	74%
	I-3-A1	14.8	6.63		O-3-A1	2.6		83%	
	I-7-A1	9.5	3.52		O-7-A1	2.1		78%	
	I-9-A1	9.0	1.93		O-9-A1	3.0		67%	
	I-11-A1	17.4	3.52		O-11-A1	3.1		82%	
	I-13-A1	12.0	3.1		O-13-A1	2.9		76%	
	I-15-A1	10.0	2.49		O-15-A1	5.1		49%	
	I-17-A1	14.9	1.44		O-17-A1	3.4		78%	
	I-19-A1	6.2	0.93		O-19-A1	4.1		34%	
	I-21-A1	6.7	0.45		O-21-A1	2.9		56%	
	I-23-A1	13.5	0.33		O-23-A1	3.7		72%	
07-May-08	I-3-B	5.4	1.69	8.62	O-1-B	2.1	2.42	61%	72%
	I-23-B	14.7	0.88		O-23-B	3.0		79%	
14-May-08	I-1-B	3.9	0.25	4.64	O-1-B	3.8	3.33	4%	28%
	I-3-B	4.2	1.32		O-3-B	3.2		24%	
	I-11-B	4.4	0.28		O-11-B	3.0		32%	
	I-13-B	3.2	0.25		O-13-B	2.5		20%	
	I-15-B	7.9	0.16		O-15-B	5.6		29%	
	I-23-B	6.1	0.41		O-23-B	3.3		46%	
17-May-08	I-1-B	5.6	0.15	9.77	O-1-B	4.7	4.11	15%	58%
	I-3-B	5.8	0.29		O-3-B	1.7		70%	
	I-11-B	9.2	1.13		O-11-B	2.5		73%	
	I-13-B	8.9	1.44		O-13-B	4.2		57%	
	I-15-B	10.0	2.21		O-15-B	6.5		35%	
	I-17-B	9.5	1.44		O-17-B	2.4		75%	
	I-19-B	6.3	0.47		O-19-B	2.9		69%	
	I-23-B	8.0	0.28		O-23-B	2.9		69%	
03-Jun-08	I-1-B	14.4	0.15	12.88	O-1-B	4.1	3.62	71%	72%
	I-3-B	15.6	0.3		O-3-B	4.1		73%	
	I-11-B	12.9	0.48		O-11-B	2.2		83%	
	I-13-B	14.5	0.59		O-13-B	4.7		67%	
	I-15-B	11.7	1.17		O-15-B	4.5		62%	
	I-17-B	12.3	0.78		O-17-B	2.6		79%	
	I-19-B	12.0	0.34		O-19-B	2.4		80%	
	I-23-B	13.5	0.2		O-23-B	4.1		70%	
16-Jun-08	I-1-B	8.8	2.17	8.75	O-1-B	2.2	2.25	75%	74%
	I-3-B	8.8	0.43		O-3-B	1.6		82%	
	I-11-B	10.3	21.89		O-11-B	2.3		78%	
	I-13-B	8.3	5.14		O-13-B	1.9		77%	
	I-15-B	7.7	0.85		O-15-B	2.5		67%	
	I-17-B	6.4	0.44		O-17-B	2.2		65%	
	I-19-B	6.9	15.29		O-19-B	2.3		68%	
	I-23-B	7.4	1.47		O-23-B	1.9		74%	
23-Jun-08	I-1-B	7.0	1.17		O-1-B	3.4		52%	
	I-3-B	10.9	7.01		O-3-B	4.2		82%	
	I-11-B	10.8	5.1		O-11-B	3.4		68%	

	I-13-B	10.3	4.09		O-13-B	4.1		60%	
	I-15-B	10.7	1.38		O-15-B	4.6		57%	
	I-17-B	9.9	0.85		O-17-B	5.0		50%	
	I-19-B	10.0	0.4		O-19-B	4.4		56%	
	I-23-B	9.7	0.18		O-23-B	5.1		47%	
				10.46			4.00		62%
26-Jun-08	I-3-B	3.5	0.44		O-15-B	1.3		64%	
	I-11-B	1.4	0.22		O-17-B	1.2		15%	
	I-13-B	3.8	0.16		O-23-B	1.6		59%	
				3.01			1.31		57%
12-Jul-08	I-1-B	3.6	0.54		O-1-B	1.8		50%	
	I-3-B	2.9	1.07		O-3-B	0.9		71%	
	I-11-B	3.9	0.93		O-11-B	1.1		70%	
	I-15-B	4.1	0.52		O-15-B	1.6		60%	
	I-17-B	4.7	0.34		O-17-B	1.6		66%	
	I-19-B	4.0	0.27		O-19-B				
	I-23-B	4.1	0.14		O-23-B	1.1		73%	
				3.67			1.27		65%
17-Jul-08	I-1-B	12.6	0.58		O-1-B	4.7		83%	
	I-3-B	12.6	1.38		O-3-B				
	I-11-B	10.8	1.01		O-11-B	2.6		75%	
	I-13-B	10.5	0.79		O-13-B	2.5		78%	
	I-15-B	12.2	0.49		O-15-B	2.1		53%	
	I-17-B	9.0	0.44		O-17-B	2.5		73%	
	I-19-B	12.8	0.42		O-19-B	2.3		82%	
	I-23-B	12.2	0.25		O-23-B	3.3		73%	
				11.23			2.84		75%
22-Jul-08	I-1-B	4.5	22.88		O-1-B	1.6		63%	
	I-3-B	7.5	8.6		O-3-B	1.7		77%	
	I-19-B	9.2	1.73		O-19-B	3.0		67%	
	I-23-B	4.3	1.36		O-23-B	2.2		46%	
				5.31			1.76		67%
23-Jul-08	I-1-B	9.7	0.53		O-1-B	1.4		62%	
	I-3-B	2.9	0.29		O-3-B	1.3		56%	
	I-11-B	2.6	0.16		O-11-B	1.7		36%	
	I-13-B	3.2	0.15		O-13-B	1.6		50%	
	I-15-B	3.0	0.85		O-15-B	1.9		35%	
	I-17-B	2.5	1.25		O-17-B	1.2		51%	
	I-19-B	3.0	1.04		O-19-B	1.4		54%	
	I-23-B	3.9	0.2		O-23-B	1.0		73%	
				2.96			1.43		52%
30-Jul-08	I-1-B	14.9	10.95		O-1-B	10.0		33%	
	I-3-B	16.5	8.01		O-3-B	10.0		39%	
	I-11-B	23.0	6.81		O-11-B	5.7		75%	
	I-13-B	16.4	5.48		O-13-B	11.1		32%	
	I-15-B	16.0	3.59		O-15-B	6.5		60%	
	I-17-B	16.4	28.23		O-17-B	10.0		39%	
	I-19-B	12.6	1.17		O-19-B	4.0		68%	
				16.77			9.34		44%

Appendix F - Results Summary with Outside References

Pollutants in Highway Stormwater Runoff

Reference	Event Date	Total Rainfall Depth	Average Rainfall Intensity	Antecedent Dry Period	Average Daily Traffic	Event Mean Concentration			TSS
		mm	mm/hr	d	Vehicles/day	TSS mg/L	Cu mg/L	Zn mg/L	
Wu et al. (1998) J. Env. Eng. Vol. 124 No. 7 Table 2	16-Sep-95	26.7	2.5		21500	21			560
	23-Sep-95	20.8	5.1	0.6	21500	9			187
	10-Apr-95	14.5	4.9		21500	24			348
	13-Oct-95	5.1	2.3		21500	49	5.00		249
	24-Jan-96	7.1	1.9	5.1	21500	221	16.00		1571
	3-Jul-96	18.3	2.3	0.7	21500	57	12.00		1043
	19-Mar-96	15.5		2.6	21500	132	15.00		2045
	13-Apr-96	9.7		4.6	21500	136	11.00		1312
	20-Apr-96	8.4	9.9	1.2	21500	139	14.00		1165
	23-Apr-96	14.0	5.4	2.6	21500	88	16.00		1229
	5-Nov-96	8.6	18.0		21500	149	21.00		1287
	23-Sep-96		2.1		5500	4	0.50		112
	10-Apr-95		5.2		5500	5	0.50		301
	20-Oct-95				5500	10	0.50		157
	11-Feb-95		2.0		5500	11	0.50		391
	11-Jul-95				5500	57	0.50		2244
	19-Jan-96	13.1	0.9	5.1	5500	113	9.00		1484
	24-Jan-96	7.8	2.0		5500	39	6.00		304
	27-Jan-96	44.7	11.4	2.6	5500	37	10.00		1654
	2-Feb-96	7.0	0.9	10.7	5500	16	0.50		112
	3-Jun-96		3.2		5500	10	6.00		315
Flint et al. (2007) Journal of Environmental Engineering Vol. 133, Table 4 No. 6, June 1, 2007	19-Jun-02	5.5				70	0.10		386
	27-Jun-02	18.3				170	0.07		3113
	25-Jun-02					1600	0.13	0.99	12352
	25-Sep-02	9.8				86	0.09	0.95	843
	26-Sep-02	4.5		0.1		41	0.02	0.18	184
	10-Oct-02	8.9				210	0.11	0.66	1866
	5-Nov-02	19.9		5.7		115	0.07	0.88	2292
	11-Nov-02	15.8				85	0.06	0.36	1343
	11-Dec-02	24.1		1.5		120	0.03	0.89	2887
	20-Dec-02			6.2		590	0.14	1.29	9727
	3-Feb-03					800	0.29	6.03	3418
	21-Feb-03	0.8		2.4		840	0.18	2.01	664
	6-Mar-03					1300	0.18	1.90	4038
	16-Apr-03	13.2		7.5		185	0.09	1.50	2435
	24-Apr-03			6.9		830	0.10	1.12	3338
	10-May-03	6.8		0.9		190	0.10	0.71	1296
	31-May-03	14.3		3.3		230	0.05	0.55	3279
	9-Jun-03	18.7		1.3			0.06	0.41	
	1-Aug-03	4.9				410	0.22	2.07	2017
	5-Aug-03	0.8					0.10	0.51	
	15-Aug-03	4.3		5.0		430	0.28	2.59	1837
	18-Sep-03	15.4				400	0.08	2.13	6176
Gan et al. (2008) Environ Monit Assess (2008) 140:147-159 Table 3	25-Sep-05	4.1	9.8	0.8	22170	447	0.13	1.49	1834
	26-Feb-06	9.0	2.3		22170	140	0.09	1.78	1259
	22-Mar-06			10.0	22170	801	0.23	3.04	5364
	6-Apr-06	3.6	3.9	6.4	22170	836	0.20	1.83	3008
	23-Apr-06	2.9	4.4		22170	498	0.24	4.40	1445
	17-May-06	3.4	1.1		22170	342	0.25	2.22	1161
	15-Jun-06	9.6	8.3	0.7	22170	245	0.01	0.46	2349
	16-Jul-06	19.6			22170	174	0.05	0.42	3405
	25-Jul-06	10.9	32.7	6.2	22170	519	0.10	1.95	5656
	26-Jul-06	27.2	13.6	1.0	22170	103	0.02	0.39	2793
	6-Apr-06	18.5	15.9	6.4	31000	171	0.16	0.6	3169
	23-Apr-06	17.6	35.2		31000	154	0.27	2.88	2707
	2-May-06	8.5	8.6	0.7	31000	139	0.07	0.39	1177
	6-May-06	26.8	13.4	1.2	31000	61	0.03	0.09	1629
	10-May-06	20.3		3.8	31000	61	0.05	0.29	1238
	31-May-06	16.3	6.7	0.4	31000	143	0.05	0.36	2323
	12-Jun-06	1.3	1.6	2.5	31000	50	0.06	0.3	64
	9-Sep-07	9			99083	34	33.99	23.49	302

Finney et al. (2009) HIFP Report Table 2

11-Sep-07	8.5		1.5	99083	96	29.72	30.26	814
26-Sep-07	4.2			99083	18	35.94	34.39	76
2-Oct-07	2.4			99083	15	28.08	27.8	36
6-Oct-07	26.5		3.1	99083	48	22.9	36.61	1261
10-Oct-07	12		3.0	99083	96	36.33	20.43	1148
23-Oct-07	12		11.0	99083		35.45	25.79	
31-Oct-07	2.5		8.2	99083		62.76	25.7	
7-May-08	10.8	5.25	3.2	101455	233	26.3	49.98	2516
14-May-08	3.6	1.33	2.2	101455	29	21.44	12.66	105
17-May-08	2.4	2.72	2.3	101455	23	38.36	19.11	55
3-Jun-08	7.4			101455	21	27.14	5.46	153
16-Jun-08	19.74			101455	21	24.14	26.25	417
23-Jun-08	9.7	4.9	0.5	101455	15	23.16	21.07	144
11-Jul-08	79.47	20.94	2.2	101455	16		28.4	1257
12-Jul-08	2.63		0.9	101455	49	19.25	4.65	128
17-Jul-08	9.7			101455	16	35.43	23.39	154
22-Jul-08	40	33.86		101455	165	49.95	36.2	6610
23-Jul-08	1.2	1.23	0.4	101455	11	22.54	12.38	13
30-Jul-08	43.16	17.85	6.0	101455	69	36.06	33.27	2966

Appendix G - SWMM intensity graphs

Figure 1 - SWMM intensity (mm/hr) time series for 22 June, 2008

Figure 2 – SWWM intensity (mm/hr) time series for 11 July, 2008

Figure 3 - SWMM intensity (mm/hr) time series for 17 July, 2008

Figure 4 - SWMM intensity (mm/hr) time series for 30 July, 2008