Permeable Pavement and Bioretention Swale Demonstration Project
at
Seneca College, King Campus

Toronto and Region Conservation Authority

Interim Report #1

March 2005
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Appendix A – Soil Properties
1. Introduction

The Toronto and Region Conservation Authority (TRCA) has recently reconstructed a portion of an existing parking lot at the King Campus of Seneca College with a permeable pavement structure and a bioretention swale. The long term performance and effectiveness of both technologies for stormwater management control will be assessed through a comprehensive monitoring program.

1.1. Background

Urban development has been shown to have significant impacts on natural watercourses and hydrologic dynamics. These impacts include increased risks of downstream flooding, accelerated channel erosion, increased water pollution, decreased groundwater recharge, and alterations to aquatic habitat.

Vehicular traffic accounts for much of the build-up of contaminants on parking surfaces. Wear from tires, brake and clutch linings, engine oil and lubricant drippings, combustion products and corrosion, all account for a build up of sediment particles, metals, and oils and grease. Furthermore, degradation of road surfaces also generates derivatives from asphalt, and runoff from residential driveways and parking areas can contain driveway sealants, oil, salt, and car care products. Consequently, the variety of different elements and compounds that runoff a parking lot can accumulate and degrade local water courses over time (MOE, 2001) (Table 1.1).

Table 1.1. Typical Sources of Contaminants in Runoff from Parking Lots.
(Burton and Pitt, 2002)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulates</td>
<td>Pavement wear, vehicles, atmosphere, maintenance</td>
</tr>
<tr>
<td>Nitrogen, phosphorus</td>
<td>Atmosphere, roadside fertilizer application</td>
</tr>
<tr>
<td>Lead</td>
<td>Tire wear (lead oxide, filler material, lubricating oil and grease, bearing wear), metal deterioration</td>
</tr>
<tr>
<td>Zinc</td>
<td>Tire wear (filler materials), motor oil (stabilizing additive), grease, metal deterioration</td>
</tr>
<tr>
<td>Iron</td>
<td>Auto body rust, steel highway structures (guard rails, etc.), moving engine parts, metal deterioration</td>
</tr>
<tr>
<td>Copper</td>
<td>Metal plating, bearing and bushing wear, moving engine parts, brake lining wear, fungicides and insecticides, metal deterioration</td>
</tr>
<tr>
<td>Cadmium</td>
<td>Tire wear (filler material), insecticide application, metal deterioration</td>
</tr>
<tr>
<td>Chromium</td>
<td>Metal plating, moving engine parts, break lining wear, metal deterioration</td>
</tr>
<tr>
<td>Nickel</td>
<td>Diesel fuel and gasoline (exhaust), lubricating oil, metal plating, bushing wear, brake lining wear, asphalt paving, metal deterioration</td>
</tr>
<tr>
<td>Manganese</td>
<td>Moving engine parts</td>
</tr>
<tr>
<td>Cyanide</td>
<td>Anticake compound (ferric ferrocyanide, sodium ferrocyanide, yellow prussiate of soda) used to keep de-icing salt granular</td>
</tr>
<tr>
<td>Sodium, Calcium, Chloride</td>
<td>De-icing salts</td>
</tr>
<tr>
<td>Sulphate</td>
<td>Roadway beds, fuel, de-icing salts</td>
</tr>
<tr>
<td>Petroleum, Oil, and Grease</td>
<td>Spills, leaks, or blow-by of motor lubricants, antifreeze and hydraulic fluids, asphalt surface leachate, fuel and oil spills and leaks</td>
</tr>
<tr>
<td>PAHs</td>
<td>Asphalt, fuel and oil spills and leaks</td>
</tr>
<tr>
<td>Suspended Solids</td>
<td>Sanding in winter, tire wear, tire tread deposits</td>
</tr>
<tr>
<td>Other metals</td>
<td>Metal deterioration</td>
</tr>
</tbody>
</table>
The pollutants present in stormwater runoff vary with each watershed, however, certain pollutants are associated with specific land uses. The United States Environmental Protection Agency (USEPA) observed several sources of urban pollution and estimated their typical yields to local watercourses per year (Table 1.2). While pollutant loads to watercourses will vary, Table 1.2 does give some perspective of what could be expected in the GTA.

### Table 1.2. Typical Urban Area Pollutant Yields (lb/acre/year or kg/ha/year).
(Burton and Pitt, 2002)

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Total Solids</th>
<th>Suspended Solids</th>
<th>Chloride</th>
<th>Total Phosphorus</th>
<th>TKN</th>
<th>NH₃</th>
<th>NO₃ plus NO₂</th>
<th>BOD₅</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>2100</td>
<td>1000</td>
<td>420</td>
<td>1.5</td>
<td>6.7</td>
<td>1.9</td>
<td>3.1</td>
<td>62</td>
</tr>
<tr>
<td>Parking lot</td>
<td>1300</td>
<td>400</td>
<td>300</td>
<td>0.7</td>
<td>5.1</td>
<td>2.0</td>
<td>2.9</td>
<td>47</td>
</tr>
<tr>
<td>High-density residential</td>
<td>670</td>
<td>420</td>
<td>54</td>
<td>1.0</td>
<td>4.2</td>
<td>0.8</td>
<td>2.0</td>
<td>27</td>
</tr>
<tr>
<td>Medium-density residential</td>
<td>450</td>
<td>250</td>
<td>30</td>
<td>0.3</td>
<td>2.5</td>
<td>0.5</td>
<td>1.4</td>
<td>13</td>
</tr>
<tr>
<td>Low-density residential</td>
<td>65</td>
<td>10</td>
<td>9</td>
<td>0.04</td>
<td>0.3</td>
<td>0.02</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>Freeways</td>
<td>1700</td>
<td>880</td>
<td>470</td>
<td>0.9</td>
<td>7.9</td>
<td>1.5</td>
<td>4.2</td>
<td>NA</td>
</tr>
<tr>
<td>Industrial</td>
<td>670</td>
<td>500</td>
<td>25</td>
<td>1.3</td>
<td>3.4</td>
<td>0.2</td>
<td>1.3</td>
<td>NA</td>
</tr>
<tr>
<td>Parks</td>
<td>NA</td>
<td>3</td>
<td>NA</td>
<td>0.03</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Shopping center</td>
<td>720</td>
<td>440</td>
<td>36</td>
<td>0.5</td>
<td>3.1</td>
<td>0.5</td>
<td>1.7</td>
<td>NA</td>
</tr>
<tr>
<td>Land Use</td>
<td>COD</td>
<td>Lead</td>
<td>Zinc</td>
<td>Chromium</td>
<td>Copper</td>
<td>Cadmium</td>
<td>Arsenic</td>
<td></td>
</tr>
<tr>
<td>Commercial</td>
<td>420</td>
<td>2.7</td>
<td>2.1</td>
<td>0.15</td>
<td>0.4</td>
<td>0.03</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Parking lot</td>
<td>270</td>
<td>0.8</td>
<td>0.8</td>
<td>NA</td>
<td>0.06</td>
<td>0.01</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>High-density residential</td>
<td>170</td>
<td>0.8</td>
<td>0.7</td>
<td>NA</td>
<td>0.03</td>
<td>0.01</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Medium-density residential</td>
<td>50</td>
<td>0.05</td>
<td>0.1</td>
<td>0.02</td>
<td>0.03</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Low-density residential</td>
<td>7</td>
<td>0.01</td>
<td>0.04</td>
<td>0.002</td>
<td>0.01</td>
<td>0.001</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Freeways</td>
<td>NA</td>
<td>4.5</td>
<td>2.1</td>
<td>0.09</td>
<td>0.37</td>
<td>0.02</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Industrial</td>
<td>200</td>
<td>0.2</td>
<td>0.4</td>
<td>0.6</td>
<td>0.10</td>
<td>0.05</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Parks</td>
<td>NA</td>
<td>0.005</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Shopping center</td>
<td>NA</td>
<td>1.1</td>
<td>0.6</td>
<td>0.04</td>
<td>0.09</td>
<td>0.01</td>
<td>0.02</td>
<td></td>
</tr>
</tbody>
</table>

In the development of an effective stormwater management plan, it is critical to understand the hydrologic cycle process to ensure that the measures are selected and implemented in an appropriate manner (MOE, 2002). The Ministry of the Environment (MOE) suggests that integrated planning is the most effective approach to stormwater management--this is simply a treatment train concept. One of their suggestions is a reduction in “Car Habitat” (MOE, 2003). Two of their recommended approaches are decreasing lot sizes and incorporating effective parking lot runoff designs.

Research has shown that permeable pavement and bioretention swales in parking lots can mitigate the impacts of stormwater runoff by infiltrating runoff volumes and reducing pollutant loads to nearby watercourses. A permeable pavement or bioretention system allows runoff to infiltrate through voids in the pavement or through curb-side swales. Since runoff is infiltrated into the soil naturally, it reduces the need for treatment and eliminates the need for underground or site
consuming detention facilities. In most cases, space normally reserved for detention facilities, in turn, can be used for other developments (Table 1.3) (City of Tacoma, 2003).

**Table 1.3. Water Quality Benefits of Various Stormwater Management Practices.**
(Michele and Adams et al., 2000)

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Infiltration</th>
<th>SW Wetlands</th>
<th>SW Ponds</th>
<th>Filtration</th>
<th>Swales</th>
<th>SW Dry Ponds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Suspended Solids</td>
<td>85</td>
<td>76</td>
<td>80</td>
<td>86</td>
<td>81</td>
<td>47</td>
</tr>
<tr>
<td>Total Phosphorous</td>
<td>70</td>
<td>49</td>
<td>51</td>
<td>59</td>
<td>34</td>
<td>19</td>
</tr>
<tr>
<td>Zinc</td>
<td>99</td>
<td>44</td>
<td>66</td>
<td>88</td>
<td>71</td>
<td>26</td>
</tr>
</tbody>
</table>

Permeable pavement systems rely almost exclusively on pollutant removal through infiltration processes. Bioretention swales may not be as efficient as permeable pavements in terms of infiltration, as such systems are generally small in surface area relative to the size of the tributary paved area. However, bioretention swales offer alternative potential water quality benefits through such mechanisms as nutrient uptake and other biological processes. There is therefore value in carrying out monitoring of field applications of both permeable pavement and bioretention swales to assess their suitability as stormwater management options for managing existing and new development.

### 1.2. Study Objectives and Structure

The overall objectives of the study are to assess the long term performance and effectiveness of permeable pavement and bioretention swales for stormwater management. While it will become clear from the next section that a considerable amount of research has been conducted on these measures, there have been few practical applications of such measures in Southern Ontario. Furthermore, there is little data available regarding the migration of pollutants through the soil underlying permeable pavements, and data regarding the performance of such measures under winter conditions in a Southern Ontario climate is almost non-existent. This project will examine permeable pavement and bioretention swales under climate and soil conditions representative of the TRCA watersheds.

Once the monitoring component of the project has been completed, the TRCA will model scenarios to predict the sum benefits (e.g. water quality, peak storm flow, water budget) of permeable pavement and/or bioretention swales at sub-watershed and watershed scales. The results will be made available for watershed and sub-watershed planning purposes by municipalities and conservation authorities. If proven successful, it is anticipated that the data will be used to assist the TRCA in its discussions with developers and municipalities through the development plan review/approvals process of stormwater management plans within the Greater Toronto Area (GTA). Findings will also be used to determine solutions for potential retrofit at sites that have stormwater management problems.
In addition to disseminating the findings of the study through papers and conferences, public awareness of the project will be increased through the use of the internet, via the websites Sustainable Technologies Evaluation Program and the TRCA (www.sustainabletechnologies.ca, www.trca.on.ca).

The next section provides an in depth review of available literature regarding permeable pavements and bioretention swales. Section 2 describes the study site and documents the construction of the permeable parking lot, bioretention swale and the runoff (surface and sub-surface) collection systems for monitoring purposes. Section 4 outlines the monitoring protocols for the study, including the runoff streams to be measured and sampled, the frequency of sampling and the range of water quality parameters that will be measured in laboratory testing. While the parking lot and sample collection systems have been constructed, monitoring has not yet commenced. Results, as they become available, will be presented and analyzed in Section 5. Finally, the conclusions arising from the study are presented in Section 6 and our many project partners are acknowledged in Section 7.
2. Literature Review

2.1. Permeable Pavement

2.1.1. Types of Permeable Pavement

The term permeable pavement is used in general to describe pavements that allow stormwater to infiltrate into a gravel-filled reservoir below the pavement surface. This reservoir provides temporary storage of stormwater before it infiltrates into the subsoil (CWP, 2000). While all varieties of permeable pavements are designed to reduce surface runoff volumes, permeable pavement designs can differ significantly. Three main categories of permeable pavement are commonly used;

- Modular interlocking concrete block pavers
- Porous asphalt or concrete
- Plastic lattice or grid systems

Modular interlocking concrete block pavement consists of impervious concrete blocks that allow water to infiltrate into a reservoir through inter-block voids or intra-block voids. The voids in this type of pavement may be filled with gravel or soil and grass. Plastic grid systems consist of plastic interlocking units with virtually no impervious surface area. Grid spaces may be planted with grass or left unplanted and filled with gravel. The grids are designed to provide structural stability and prevent settling while providing a large amount of void space for infiltration of stormwater. Porous asphalt pavement consists of standard bituminous asphalt in which the finer aggregates have been removed. Removal of these fine materials results in an asphalt with a matrix of pores that allows water to permeate through to the sub-pavement reservoir and infiltration bed. Porous concrete works on the same principle as porous asphalt with the finer aggregates omitted from the concrete mix resulting in increased void space. The following review of the potential benefits of permeable pavement is limited to results associated with interlocking concrete block pavers, as this is the type of pavement being evaluated in this study.

2.1.2. Performance

2.1.2.1. Water Balance Control

Permeable pavement systems are intended to mimic the pre-development hydrologic cycle by reducing stormwater volumes while promoting groundwater recharge and maintaining or augmenting baseflows. Several field monitoring studies of concrete block pavers have demonstrated these water quantity benefits. For instance, at a Public Works parking lot in Renton, Washington, Booth and Leavitt (1999) reported virtually no surface runoff from planted (i.e. Turfstone) and unplanted concrete block pavement for all rain events during the autumn and early winter of 1996/97. A second study conducted at the same site four years later monitored 15 precipitation events (Brattebo and Booth, 2003). Findings were similar to those of the initial study,
indicating almost no runoff from the permeable pavements, except during one 44 mm rain event, when 3% of the total precipitation was observed as surface runoff. In both studies, subsurface flow measurements showed a significant lag in subsurface flow response to rainfall (Brattebo and Booth, 2003; Booth and Leavitt, 1999).

Field research led by William James at the University of Guelph in Ontario has focused on investigating the performance of permeable concrete block pavements in comparison to other traditional pavements such as impervious asphalt and concrete. Outdoor experiments conducted by James and graduate students have concluded that this type of permeable pavement provides a 90% reduction in surface runoff volume compared to traditional impervious pavements (James, 2002). Details on the length of the study period and the number of events upon which this result is based were not provided.

In attempting to mimic the natural hydrologic cycle by allowing rainfall to infiltrate into the subsoil, it is anticipated that groundwater recharge from precipitation will also be improved significantly at sites where permeable pavement is installed. Depending upon site design and subsoil type, permeable pavement may allow as much as 70-80% of rainfall to recharge groundwater (Gburek and Urban, 1980). Since most field studies of permeable pavement were conducted on relatively small areas, there were no attempts to quantify how increased groundwater recharge may affect stream baseflows.

2.1.2.2. Stormwater Quality Improvement

Research has shown that urban runoff contains elevated concentrations of suspended solids, oil and grease, nutrients, bacteria, heavy metals, pesticides and chloride from road salt (OMOE, 2003). Stormwater infiltration technologies have the potential to improve the quality of urban stormwater by allowing water to percolate through the subsurface media. Percolation allows many contaminants to be removed or broken down through processes such as adsorption, decomposition and several other chemical and biological reactions with the soil and biota (Pitt et al, 1996).

While permeable pavements can be effective at improving the quality of infiltrated water, their effectiveness will depend on the characteristics of the soil below the gravel sub-base. The soil organic content and sorption capacity are particularly important factors (Pitt et al, 1996). Stormwater runoff contaminants that pose the greatest risk of contaminating groundwater via surface percolation are nitrate, a few pesticides, polycyclic aromatic hydrocarbons, enteroviruses, and salts such as chloride (Pitt et al, 1996). The potential for contamination of groundwater is largely dictated by the concentration of these parameters in the stormwater and the extent to which pre-treatment of stormwater is employed. The threat of chloride contamination may be especially high below a permeable pavement parking lot installation in cold-weather climates where road salt may be used as a de-icing agent.

Several studies have found that the majority of heavy metals in urban runoff may be removed via infiltration through soil (Schueler, 1991, Nightingale, 1978). Research conducted by Nightingale (1978) which investigated the accumulation of lead, zinc and copper in soils of urban runoff retention basins concluded that lead, zinc and copper are attenuated in the upper 15 cm of soil.
From 15 to 30 cm below the surface of the retention basins, concentrations of these contaminants were at normal background levels (Nightingale, 1978). In the Washington study discussed earlier (Brattebo and Booth, 2003), stormwater concentrations of copper, zinc and motor oil were significantly improved through infiltration via a permeable concrete block pavement installation. The study found that 88 and 100% of asphalt runoff samples exceeded Washington receiving water standards for zinc and copper, respectively. By contrast, only 6 and 17% of permeable block pavement infiltrate samples (n=18) exceeded the standards for copper and zinc, and motor oil was consistently below analytical detection limits, even though the soil through which water infiltrated was only 10 cm deep. A study conducted at Guelph University also found that concentrations of zinc and iron showed the largest reduction as a result of infiltration through a permeable pavement installation (Shahin, 1994). Several studies have also documented the attenuation of other heavy metals in the soils below stormwater infiltration installations. Soil concentrations of lead, arsenic, nickel and copper showed a sharp decline with depth in a study that monitored several groundwater recharge basins in Fresno, California (Salo et al., 1986).

2.1.2.3. Heat flux

Permeable pavement installations have also been studied as a means of reducing the heating effects of impervious surfaces on ambient air temperature. Varieties of permeable pavement which allow for greater evapotranspiration (as compared to asphalt or concrete) will have less of a negative impact on the thermal environment (Asaeda and Vu Thanh, 2000). A Japanese study which investigated the thermal characteristics of various pavements, including both permeable and impermeable varieties, concluded that unplanted permeable concrete block pavement did not perform better than asphalt in terms of decreasing the radiative heating of the thermal environment (Asaeda and Vu Thanh, 2000). The porous block pavement provided rapid drainage of stormwater and dried rapidly after a rainfall event. Evaporation from this pavement was therefore found to be similar to that of the asphalt pavement.

2.1.3. Site Selection Criteria

There are several factors to be considered in determining whether a site is suitable for a permeable pavement installation. The most important in terms of groundwater contamination risk is the level of contaminants expected in the stormwater that is to be infiltrated. As discussed in Section 2.1.2.2, certain contaminants such as nitrate, chloride and enteroviruses can pose a high risk of groundwater contamination if their concentrations in the stormwater runoff are high (Pitt et al., 1996). For this reason, stormwater infiltration practices are not normally recommended in areas with highly contaminated runoff such as gas stations (CWP, 1997).

The depth to the water table at a prospective site is also an important consideration in preventing groundwater contamination below a permeable pavement installation. According to the Centre for Watershed Protection Best Management Practices (CWP BMP) Manual for cold climates (1997), the minimum distance between the bottom of an infiltration installation and the water table should be between two and four feet (CWP, 1997). It is also important that a prospective site be located a safe distance from any water supply wells. A distance of 100 feet is recommended (CWP, 1997),
but in areas with steep hydraulic gradients or high conductivity soils, a larger buffer zone around
the well may be warranted.

The soil characteristics and topography at a prospective site help ensure proper drainage. A
suitable permeable pavement site should have soils with a clay content of less than 30%, a silt/clay
content of less than 40%, and a percolation rate between 0.13 and 7.6 cm per hour (CWP, 2000).
Areas with cracked soils that allow contaminants to move rapidly through the vadose zone into the
groundwater would not be suitable. Furthermore, adequate infiltration will be facilitated at sites
that do not have steep slopes (CWP, 1997). Slopes should be less than 15% in order to ensure
adequate drainage and to prevent erosion of the aggregate materials in the void spaces (SCDEP,
2004).

Clogging of void spaces can impair the long-term function of a permeable pavement installation.
Clogging may occur during construction, or as a result of sand application for vehicle safety during
winter months (CWP, 1997). Permeable pavement is not recommended for areas with high vehicle
traffic volumes such as public roads and highways, due to the increased loads of sand and dirt that
may be transported to the pavement surface via vehicle tires (Tan et al, 2003).

2.1.4. Operation and Maintenance Considerations

Table 2.1 lists the type and frequency of maintenance recommended for a permeable pavement
installation from various sources.

Table 2.1: Permeable Pavement Recommended Maintenance

<table>
<thead>
<tr>
<th>Source</th>
<th>Site inspections</th>
<th>Ensuring drainage between storm events</th>
<th>Vacuum Sweeping of pavement</th>
<th>Check Pavement for deterioration</th>
<th>Restoring Permeability</th>
<th>Replace base and/or pavement</th>
</tr>
</thead>
<tbody>
<tr>
<td>CWP, 1997</td>
<td>Monthly</td>
<td>Monthly</td>
<td>3-4x per year</td>
<td>1x per year</td>
<td>not specified</td>
<td>not specified</td>
</tr>
<tr>
<td>James, 2004</td>
<td>recommended but no schedule specified</td>
<td>recommended but no schedule specified</td>
<td>frequently</td>
<td>1x per year</td>
<td>not specified</td>
<td>not specified</td>
</tr>
<tr>
<td>Lake County Forest Preserves, 2003</td>
<td>not specified</td>
<td>not specified</td>
<td>2x per year</td>
<td>not specified</td>
<td>once every 4-5 years</td>
<td>Base - once every 25 years</td>
</tr>
<tr>
<td>California Stormwater Quality Association, 2003</td>
<td>not specified</td>
<td>not specified</td>
<td>2-3x per year</td>
<td>not specified</td>
<td>as needed (max 15-20 yrs)</td>
<td>as needed (max 15-20 yrs)</td>
</tr>
<tr>
<td>Urban Drainage and Flood Control District, 2004</td>
<td>Routinely (as needed)</td>
<td>routinely</td>
<td>1x per year</td>
<td>not specified</td>
<td>every 1-5 years (determined by inspection)</td>
<td>Every 10-25 years depending upon traffic</td>
</tr>
</tbody>
</table>
The accumulation of contaminants in the soil beneath a permeable pavement installation is an important maintenance consideration which has the potential to become costly if soils need to be removed, disposed of and replaced. A German study investigating the impacts of highway runoff on roadside soils concluded that the age of roadside soils was positively correlated with the concentrations of polycyclic aromatic hydrocarbons and several heavy metals. However, the study also determined that leaching of contaminants to the groundwater was limited, even for soil ages greater than 20 years. Soil characteristics such as organic content and pH were found to be important factors controlling the buffering capacity of the soils (Dierkes and Geiger, 1999).

A study by Legret et al (1999) used a mathematical model to simulate the transfer of heavy metals into the soil below a porous pavement installation. The study found that soil may be contaminated by heavy metals and mineral oils over at least a one-metre radius in the long term (30 years). Contamination levels were relatively low, however, as concentrations were still below Dutch standards for unpolluted soil (Legret et al, 1999).

2.1.5. Cost Comparisons

The capital cost of installing permeable block pavement will vary on a site-by-site basis. James (2004) reported a cost of approximately $21 per square metre for permeable pavement and $19 per square metre for traditional impervious asphalt.

In estimating capital costs, the relative durability of permeable pavement compared to asphalt is an important consideration. A research summary conducted by the Lake County Forest Preserves reported that two permeable pavement sites in Pennsylvania lasted as long or longer than impervious asphalt. (Lake County Forest Preserves, 2003). Maintenance costs for permeable pavement installations will vary significantly from one site to the next based on various factors such as weather conditions and the need for vacuuming. Impervious asphalt will also require maintenance such as crack sealing, patching and eventual replacement (Lake County Forest Preserves, 2003). An overall comparison of maintenance costs must be conducted on a site-by-site basis due to the many variables that influence these costs.

High permeable pavement capital costs may be offset by cost savings in other areas. For example, installing permeable pavement may reduce storage requirements for end-of-pipe facilities. This lower storage requirement can constitute a significant cost savings by reducing construction costs and minimizing the amount of land that would be used by these stormwater management practices (James, 2004).

2.2. Literature Review: Bioretention Swale

A bioretention swale (or bioswale) is a stormwater best management practice that treats stormwater runoff from an impervious area by using soil and both woody and herbaceous plants to remove contaminants through various physical and biological processes (USEPA, 1999)
2.2.1. Performance

The ability of a bioswale to remove stormwater contaminants may be significantly greater than that of other stormwater infiltration practices due to microbial activity and plant uptake (USEPA, 1999). Studies conducted at the University of Maryland found that bioswales are capable of removing 93-98% heavy metals, 70-83% of phosphorus and 68-80% of total Kjeldahl nitrogen. Most of these contaminants are removed within the first two feet of soil (Table 2.2).

Table 2.2: Percent Removal of Stormwater Contaminants in a Bioswale by Depth
(Modified from Davis et al. (1998) in USEPA, 1999)

<table>
<thead>
<tr>
<th>Depth</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>P</th>
<th>TKN</th>
<th>NH4</th>
<th>NO3</th>
<th>TN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1'</td>
<td>90</td>
<td>93</td>
<td>87</td>
<td>0</td>
<td>37</td>
<td>54</td>
<td>-97</td>
<td>-29</td>
</tr>
<tr>
<td>2'</td>
<td>93</td>
<td>99</td>
<td>98</td>
<td>73</td>
<td>60</td>
<td>86</td>
<td>-194</td>
<td>0</td>
</tr>
<tr>
<td>3'</td>
<td>93</td>
<td>99</td>
<td>99</td>
<td>81</td>
<td>68</td>
<td>79</td>
<td>23</td>
<td>43</td>
</tr>
</tbody>
</table>

2.2.2. Site Selection Criteria and Design Considerations

Several aspects of site selection are common to permeable pavement and bioretention installations, such as runoff quality and groundwater contamination considerations. These are discussed in section 1.2.3. Considerations that are unique to a potential bioswale site include drainage area size, slope and the ability to disperse runoff flows so that they are uniformly distributed (Prince George’s County Dept. of Environmental Resources, 2002). The Prince George’s County Design Manual for Bioretention (2002) and the Metropolitan Council Urban Small Sites BMP Manual (2003) both suggest that bioswales should not be used for sites larger than 2 acres due to increased clogging potential and the limited feasibility of conveying runoff volumes from a large site to the bioswale. For the same reasons, it is also recommended that the drainage area have a maximum slope of 20% (Prince George’s County Dept. of Environmental Resources, 2002).

With respect to climate, it is important to consider whether the bioswale area will be used for snow storage during the winter in a cold climate area. If this is the case, plants used will need to be non-woody and particularly tolerant to salt (Metropolitan Council, 2003). Further siting and design specifications recommended by various sources are summarized in Table 2.3.
<table>
<thead>
<tr>
<th>Source</th>
<th>Unit Area Bioswale needed per unit drainage area</th>
<th>Max. ponding depth</th>
<th>Max. drainage time</th>
<th>Vegetation type</th>
<th>Characteristics of ground cover/mulch</th>
<th>Infiltration Rate</th>
<th>Composition</th>
<th>Layer Thickness</th>
<th>Sand Layer characteristics</th>
<th>Depth to water table</th>
</tr>
</thead>
<tbody>
<tr>
<td>USEPA, 1999</td>
<td>• 5-7% of drainage area multiplied by runoff coefficient • Drainage area should be 0.1-0.4 ha • Min. size: 4.6x 12.2 m</td>
<td>15 cm</td>
<td>4 days</td>
<td>• Tolerant native • Dominated by understory trees with discrete soil zones, a mature canopy, and a distinct sub-canopy of understory trees, a shrub layer, and herbaceous ground cover • 1000 trees &amp; shrubs per acre</td>
<td>• 5.0 - 7.6 cm of fine shredded hardwood mulch or shredded hardwood chips • aged at least 6 months</td>
<td>&gt;1.25 cm/hr</td>
<td>• Sandy loam, loamy sand or loam texture • 10-25% clay content, 1.5 - 3% organic content, &lt;500ppm soluble salts. • pH: 5.5 - 6.5</td>
<td>1.2 m</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>New Jersey Dept. of Environmental Protection, 2003</td>
<td>–</td>
<td>46 cm</td>
<td>3 days</td>
<td>• Native plant material when possible. • Perimeter: trees • Inner saturated areas: shrubs and herbaceous species • Density: 1000 stems per acre</td>
<td>• 5-10 cm shredded hardwood or chips</td>
<td>sufficient to fully drain the stormwater quality design storm runoff volume within 72 hours</td>
<td>10-15% clays, 65% sands, 20-25% silt • pH: 5.5 - 6.6</td>
<td>0.9 m</td>
<td>• Thickness: 30 cm • Medium aggregate concrete sand • 2x permeability of design permeability rate of planting soil</td>
<td>&gt;0.3 m to seasonal high water table</td>
</tr>
<tr>
<td>Metropolitan Council, 2003</td>
<td>5 - 10% of impervious drainage area</td>
<td>15 - 23 cm</td>
<td>–</td>
<td>Should replicate a forested or grassland ecosystem and withstand stresses (i.e. frequent inundation and inter-event drying)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>1.2 m</td>
<td>Thickness: 30 cm</td>
<td>0.9 m</td>
</tr>
<tr>
<td>Prince George's County Dept. of Environmental Resources, 2002</td>
<td>Calculated on a site-specific basis</td>
<td>15 cm</td>
<td>2 days</td>
<td>• Hardy, perennial, native plant species. • Site-specific - must be determined based on the need for tolerance of various stressors (i.e. fluctuations in soil moisture, ponding, contaminant loads)</td>
<td>• shredded hardwood • aged at least one year</td>
<td>1.27 cm/hr</td>
<td>• 50-60% sand, 20-30% leaf compost, 2-30% topsoil • pH: 5.5 - 6.5 • 1.5-3% organic content</td>
<td>0.8 - 1.2 m</td>
<td>• Thickness: 30 cm • sand with grain size of 0.05 - 0.10 cm</td>
<td>0.6 m</td>
</tr>
</tbody>
</table>
2.2.3. Operation and Maintenance considerations

According to the Prince George’s County Department of Environmental Resources Bioretention Manual, the maintenance of a bioswale should involve several common gardening practices such as weeding, irrigating, fertilizing, trimming and overall maintenance of plant health. In circumstances when drainage appears to be comprised (i.e. water remains ponded for longer than guidelines specify), it may be necessary to investigate whether clogging is occurring and in which layer. The soil bed should be checked for clogging twice per year (New Jersey Department of Environmental Protection, 2003). Actions to correct clogging in a bioswale may include raking the surface, punching holes through the soil bed, or re-installing the entire bioswale as a last resort (Prince George’s County Dept. of Environmental Resources, 2002). Over the long-term it may also become necessary to address soil contamination concerns that are common to stormwater infiltration practices by, for instance, excavating and replacing the soil. There are several studies that address the migration of contaminants in soils below a stormwater infiltration installation. Some of this research is discussed in section 2.1.4.

2.2.4. Cost Comparisons

The cost of installing a bioswale will depend on various factors including the bioswale size, vegetation types used and whether or not the construction will be a retrofit or a new installation (USEPA, 1999). Retrofitting will significantly increase the construction costs due to the need for demolition of existing structures and pavements (USEPA, 1999). Implementing bioretention near the source of stormwater runoff has the potential to significantly minimize the amount of storm drainage infrastructure needed. Several case studies from Prince George’s County, Maryland have found that integrating bioretention facilities at a site may ultimately reduce development costs by 15-20% in comparison with costs associated with more traditional stormwater BMPs (Prince George’s County Dept. of Environmental Resources, 2002).
3.  Seneca College Parking Lot

3.1.  Study Area
As stated previously, the TRCA has installed permeable pavement and a bioretention swale at an existing parking lot at Seneca College’s King Campus for a long term (3 year) monitoring demonstration project. The campus is located at the north-west corner of Dufferin Street and 15th Sideroad in the Township of King, and is within the Oak Ridges Moraine (ORM) (Figures 3.1 and 2.2). The area is within the Humber River Watershed, and drains to a tributary of the East Humber River (Figure 3.3).

Figure 3.1. The Oak Ridges Moraine and the Township of King.
A number of factors influenced the selection of the site. The existing parking lot at Seneca College was constructed without a storm sewer network. Instead, runoff drains by overland sheet flow to the edges of the parking lot, and then through a large vegetated area between the parking lot and the receiving water body, Eaton Lake. Permeable parking lots and bioretention swales are ideally suited to such drainage systems. Furthermore, the soils underlying the parking lot have reasonable infiltration rates, and the local groundwater table is more than 3 m below ground surface. Permeameter testing in July 2004, prior to reconstruction of the parking lot, indicated that the field saturated hydraulic conductivity ($K_{fs}$) was in the order of $10^{-5}$ cm/s to $10^{-4}$ cm/s (See Appendix A). While at the low end of the recommended range (MOE, March 2003), the permeameter testing confirmed that the soils at the site have sufficient infiltration capacity for the evaluation of a permeable parking lot design. Finally, as the parking area is associated with Seneca College, there is the potential for the site to be used for educational purposes in environmental science and engineering courses, as well as the potential for Seneca College students to assist with the maintenance of the site and collection of data.
3.2. Permeable Parking Lot Design and Construction

Planning and design of the project was completed in August 2004. It was decided that the study portion of the existing parking lot would be divided into three essentially equal areas. The northern third of the lot would be reconstructed with a permeable pavement structure, the middle third would remain unaltered and serve as a control area for the study, and a bio-retention swale would be constructed to treat runoff from the existing asphalt paving over the south third of the area. Typically, measures such as permeable paving and bio-retention swales can be constructed with a minimum of disturbance and do not require sewers for the collection of runoff.

However, as the evaluation of the different measures for the control of stormwater necessitates a comprehensive monitoring program, it was recognized that a collection system for both surface and subsurface flow would be required. Runoff from surface and subsurface sources are intercepted and piped to a sampling vault located near the north-east corner of the parking area. It should be noted that runoff passing through the sampling vault discharges to an infiltration gallery. An
overflow from the infiltration gallery is provided to prevent ensure that storm drainage does not back up into the sampling vault.

The final design is presented in plan view on Figure 3.4, and a section through the permeable pavement structure is shown on Figure 3.5.

Figure 3.4. Parking Lot Design, Plan View.
Figure 3.5. Permeable Pavement Design, Cross Section.
The permeable pavement parking lot was constructed, according to the design drawings, during the period from August 27 to September 15, 2004. The existing asphalt over the northern third of the study area was removed and taken to a recycling facility, and the area was then excavated to a depth of more than 1 m. The excavation was lined with an impermeable plastic membrane, drainage tiles were placed on top of the plastic liner, and the excavation was filled to an average depth of 1 m using the previously removed soil. The drainage tiles were connected to a collection system to direct water that has infiltrated through the soil layer to a sampling vault for quantity and quality monitoring. In addition, a collection trough was provided at the edge of the parking area to collect surface runoff from the permeable pavement area and direct it to the sampling vault for quantity and quality monitoring. The depth of soil of 1 m was selected as it is generally acknowledged that most pollutants in storm water will be removed by adsorption and held within the first metre depth of soil. To provide an adequate structural foundation for the parking lot, additional measures were required. The replaced native soil was compacted to approximately 100% Standard Proctor Maximum Dry Density (SPMDD), consistent with the degree of compaction of the original undisturbed soils under the parking lot (See Appendix A). A geoweb material was then placed over the compacted soil and covered with a layer of granular material, which was also compacted to 97% SPMDD. Finally, the permeable pavers were installed and the voids between the pavers were then filled with screenings for public safety. The various stages of construction are shown in Figure 3.6.
3.3. Bioretention Swale Design and Construction

A typical section of a bioretention swale is shown in Figure 3.7. The swale constructed for the Seneca College parking lot was generally consistent with this detail. An area adjacent the downstream edge of the parking lot was excavated, an underdrain was installed at the base of the excavation, and approximately 1 m of excavated soil was then replaced and compacted. Finally, suitable soil media and plants were placed at the top of the swale, which was graded to form a shallow depression to hold parking lot runoff for infiltration. For monitoring purposes, the entire excavation was lined with an impermeable plastic membrane, such that all material passing vertically through the trench is collected in the underdrain and directed to the sampling vault for quantity and quality monitoring. Note that, for the bioretention swale, only the runoff infiltrating through the vertical depth of the swale will be collected. During severe rainfall events, the depression area in the swale may be overtopped, in which case the excess runoff will continue to flow towards the receiving water body by way of the pre-construction flow paths. However, a collection trough was also installed at the end of the middle section of parking lot, which will act as
a control area. This trough will collect runoff from the control area and direct it to the sampling vault for quality and quantity monitoring. A photograph of the bioretention swale upon completion of final grading (but prior to planting) is provided as Figure 3.8. Note that the collection trough for the control area is also visible in the foreground of Figure 3.8.

![Figure 3.7. Typical Bioretention Component Column.](https://example.com/figure3_7)

(Prince George’s County, 2002)
3.4. Parking Lot Maintenance

Over the three year life of the monitoring project, no additional maintenance of the parking lot is anticipated. Seneca College staff have been directed to subject the study area to its standard parking lot maintenance schedules. It is expected that this will include the application of sand and de-icing materials and snow plowing in winter, and may include sweeping, vacuuming and heavy machinery parking. However, the parking lot will be observed for any degradation of the permeable pavement structure. The durability of the structure over time will be used to aid in estimating life-cycle costs for cost-benefit analyses relative to conventional stormwater management systems.
4. Monitoring Program

The target for the first year of monitoring will be to collect water quantity and temperature data for all events and water quality data during 15 events, representing a range of event sizes. Soil tests (e.g. chemistry, infiltration capacity) will be conducted only once at the end of the three study period to avoid possible influences on monitoring results caused by disturbance to the sub-base and soil. A list of parameters to be monitored includes the following:

a. water quantity
   i. rainfall
   ii. surface runoff from control site and permeable pavement
   iii. volumes and rates of water infiltrated through permeable the pavement and bioretention swale
   iv. ponding depths (bioswale)
b. water quality
   i. surface runoff concentrations and loads (control and permeable pavement sites)
   ii. event concentrations and loads of water infiltrated through the permeable pavement and bioretention swale
c. soil quality
   i. depth profiles of soil quality from the permeable pavement and bioretention swale sites
d. temperature
   i. air
   ii. control and permeable pavement (surface and water)
   iii. soil (surface)
   iv. infiltrated water
e. soil compaction
f. durability and maintenance
   i. permeable pavement
   ii. bioretention swale
   iii. maintenance schedule (e.g. plowing, repairs, plant care, etc.)

Monitoring equipment will be powered by energy generated from solar panels installed on site, though the system will also be connected to the existing electrical system at Seneca College for backup power supply when needed. A brief description of each of the monitoring components is provided in the following subsections.

4.1. Water Quantity

4.1.1. Rain

Rainfall will be measured onsite using a single 0.2 mm tipping bucket gauge and logger located on the roof of a nearby building. The gauge will be capable of measuring snow (water equivalent) and rain. A manual gauge on-site and a permanent TRCA raingauge station located approximately 5 km from the campus at Bathurst Street and Jefferson Side Road will be used as backup measurements for rainfall in case the on-site tipping bucket rain gauge malfunctions. During the winter, the depth of snowfall and plowing/deicing operations on the pavement will be carefully
documented (with pictures if necessary) in order to assess impacts on measured runoff rates and stormwater quality.

4.1.2. Flow
The flow rates of surface runoff (permeable pavement and control) and infiltrated water (permeable pavement and bioswale) will be measured using four Endress and Hauser electromagnetic flow metres located in the underground sampling vault. Electromagnetic flow metres operate according to Faraday’s principle of electromagnetic induction which states that a conductor (water) moving through an electromagnetic field generates a voltage proportional to its velocity. Proper function of the metres requires that they be continuously submerged in water. This will be achieved by installing the meters within reverse slope pipes (Figure 4.1). The sensor will be positioned away from the lowest point in the drain and a sediment cleaning valve will be installed to avoid the risk of solids accumulation.

![Flow Metre Setup](image)

**Figure 4.1. Flow meter setup**

All four flow metres will be connected to a single Endress and Hauser Memograph logger. Data will be logged continuously and recorded at 5 minute intervals. All flow will be directed to a single 6” outlet and into a combined infiltration trench and overflow structure.

4.1.3. Ponding depths
Ponding depths on the bio-retention swale will be measured by a device that floats vertically upwards with increasing water depth such that the maximum ponding depth and overflow during each event can be recorded. Direct observations can also be made during a large storm event to characterize the relationship between flow inputs and ponding/infiltration.

4.1.4. Infiltration capacity
A Guelph permeameter was used to assess the infiltration capacity of the soil prior to site selection and during the construction period. Results of tests are provided in Appendix A. Additional tests will be conducted at the end of the three year study period on the permeable pavement and
bioswale soils to determine whether or not flow through the system is causing the system to clog. Observations of surface runoff response to rainfall will provide an additional measure of changes in infiltration rates over the study period.

4.2. Water Quality

Four ISCO 6712 automated water samplers installed within the sampling vault will be programmed to collect water samples based on a pre-programmed sequence at each of the four water quantity monitoring stations. Automated samplers will be triggered and paced by the Memograph logger. Flow proportioned composite samples for each rain event will be preserved and submitted immediately following collection (i.e. within 24 hours) to the Ontario Ministry of the Environment laboratory services branch in Etobicoke for analysis of typical pollutants found in urban runoff (Table 4.1). Samples will be analyzed discretely for total suspended and dissolved solids during a select number of large events in order to characterize the timing of pollutant inputs and outputs from the system.

Table 4.1: Selected Water Quality Parameters to be Monitored

<table>
<thead>
<tr>
<th>Variable</th>
<th>units</th>
<th>MDL</th>
<th>Guideline*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride</td>
<td>mg/L</td>
<td>0.2</td>
<td>250</td>
</tr>
<tr>
<td>Mercury</td>
<td>ug/L</td>
<td>0.02</td>
<td>0.2</td>
</tr>
<tr>
<td>Oxygen demand; chemical</td>
<td>mg/L as O2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td>mg/L</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td>mg/L</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Fluoride</td>
<td>mg/L</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Sulphate</td>
<td>mg/L</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Phenolics; 4-AAP</td>
<td>ug/L</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Oxygen demand; biochemical</td>
<td>mg/L as O2</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Solids; suspended</td>
<td>mg/L</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Solvent extractable</td>
<td>mg/L</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Conductivity</td>
<td>uS/cm</td>
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<td></td>
</tr>
<tr>
<td>pH</td>
<td>none</td>
<td>-</td>
<td>6.5-9.5</td>
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<tr>
<td>Alkalinity; total fixed endpt</td>
<td>mg/L CaCO3</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Turbidity</td>
<td>FTU</td>
<td>0.01</td>
<td>5</td>
</tr>
<tr>
<td>Nitrogen; ammonia+ammonium</td>
<td>mg/L</td>
<td>0.002</td>
<td>1.4</td>
</tr>
<tr>
<td>Nitrogen; nitrite</td>
<td>mg/L</td>
<td>0.001</td>
<td>0.06</td>
</tr>
<tr>
<td>Nitrogen; nitrate+nitrite</td>
<td>mg/L</td>
<td>0.005</td>
<td></td>
</tr>
<tr>
<td>Phosphorus; phosphate</td>
<td>mg/L</td>
<td>0.0005</td>
<td></td>
</tr>
<tr>
<td>Phosphorus; total</td>
<td>mg/L</td>
<td>0.002</td>
<td>0.03</td>
</tr>
<tr>
<td>Nitrogen; total Kjeldahl</td>
<td>mg/L</td>
<td>0.02</td>
<td>3.2</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>c/100mL</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>Fecal streptococcus</td>
<td>c/100mL</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Pseudomonas aeruginosa</td>
<td>c/100mL</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>units</td>
<td>MDL</td>
<td>Guideline*</td>
</tr>
<tr>
<td>------------------------</td>
<td>-------</td>
<td>-----</td>
<td>------------</td>
</tr>
<tr>
<td><strong>Aluminum</strong></td>
<td>ug/L</td>
<td>11</td>
<td>75</td>
</tr>
<tr>
<td><strong>Barium</strong></td>
<td>ug/L</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td><strong>Beryllium</strong></td>
<td>ug/L</td>
<td>0.02</td>
<td>11</td>
</tr>
<tr>
<td><strong>Calcium</strong></td>
<td>mg/L</td>
<td>0.005</td>
<td></td>
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<tr>
<td><strong>Cadmium</strong></td>
<td>ug/L</td>
<td>0.6</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Cobalt</strong></td>
<td>ug/L</td>
<td>1.3</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>Chromium</strong></td>
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<td>1.4</td>
<td>8.9</td>
</tr>
<tr>
<td><strong>Copper</strong></td>
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<td>1.6</td>
<td>5</td>
</tr>
<tr>
<td><strong>Iron</strong></td>
<td>ug/L</td>
<td>0.8</td>
<td>300</td>
</tr>
<tr>
<td><strong>Magnesium</strong></td>
<td>mg/L</td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td><strong>Manganese</strong></td>
<td>ug/L</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td><strong>Molybdenum</strong></td>
<td>ug/L</td>
<td>1.6</td>
<td>10</td>
</tr>
<tr>
<td><strong>Nickel</strong></td>
<td>ug/L</td>
<td>1.3</td>
<td>25</td>
</tr>
<tr>
<td><strong>Lead</strong></td>
<td>ug/L</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td><strong>Strontium</strong></td>
<td>ug/L</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td><strong>Titanium</strong></td>
<td>ug/L</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td><strong>Vanadium</strong></td>
<td>ug/L</td>
<td>1.5</td>
<td>7</td>
</tr>
<tr>
<td><strong>Zinc</strong></td>
<td>ug/L</td>
<td>0.6</td>
<td>20</td>
</tr>
<tr>
<td><strong>Phenanthrene</strong></td>
<td>ng/L</td>
<td>10</td>
<td>30</td>
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<tr>
<td><strong>Anthracene</strong></td>
<td>ng/L</td>
<td>10</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Fluoranthene</strong></td>
<td>ng/L</td>
<td>10</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Pyrene</strong></td>
<td>ng/L</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td><strong>Benzo(a)anthracene</strong></td>
<td>ng/L</td>
<td>20</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Chrysene</strong></td>
<td>ng/L</td>
<td>10</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>7,12-dimethylbenz(a)anthracene</strong></td>
<td>ng/L</td>
<td>10</td>
<td></td>
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<tr>
<td><strong>Benzo(b)fluoranthene</strong></td>
<td>ng/L</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td><strong>Benzo(k)fluoranthene</strong></td>
<td>ng/L</td>
<td>10</td>
<td>0.2</td>
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<td><strong>Benzo(e)pyrene</strong></td>
<td>ng/L</td>
<td>10</td>
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<td><strong>Benzo(a)pyrene</strong></td>
<td>ng/L</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td><strong>Perylene</strong></td>
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<td>20</td>
<td></td>
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<tr>
<td><strong>Dibenzo(a,h)anthracene</strong></td>
<td>ng/L</td>
<td>20</td>
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<tr>
<td><strong>Benzo(g,h,i)perylene</strong></td>
<td>ng/L</td>
<td>20</td>
<td>0.02</td>
</tr>
</tbody>
</table>

**Note:**
MDL: Mean Detection Limit
*Provincial Water Quality Objectives (PWQO) used where applicable. In cases where PWQOs were not available, Canadian Water Quality Guidelines for freshwater habitat was used.

### 4.3. Soil Quality

Up to six 50 cm soil cores will be extracted from the permeable pavement and bioswale sites at the end of the study period and analyzed in 10 cm increments for the variables listed in Table 4.2. The depth profiles of soil chemistry will be useful to trace the migration of contaminants through soil over time, and determine the depth of soil that may require periodic removal and disposal.
To provide a baseline for comparison, samples of the soils from both sites were extracted and analyzed for soil chemistry during the construction period. Pre-construction and baseline soil quality results are provided in Appendix A.

Table 4.2: Selected Soil Quality Parameters to be Monitored.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Reporting Method Detection Limit</th>
<th>GCSO*</th>
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<tr>
<td><strong>General Chemistry</strong></td>
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<td></td>
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</tr>
<tr>
<td>Chloride, water extractable</td>
<td>ug/g dry</td>
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<td>58</td>
</tr>
<tr>
<td>Mercury</td>
<td>ug/g dry</td>
<td>0.01</td>
<td>0.16</td>
</tr>
<tr>
<td>Sodium</td>
<td>ug/g dry</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Potassium</td>
<td>ug/g dry</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Fluoride</td>
<td>ug/g dry</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Sulphate; water soluble</td>
<td>ug/g dry</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Conductivity</td>
<td>uS/cm</td>
<td>-</td>
<td>470</td>
</tr>
<tr>
<td><strong>Metals</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td>ug/g dry</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Barium</td>
<td>ug/g dry</td>
<td>0</td>
<td>190</td>
</tr>
<tr>
<td>Beryllium</td>
<td>ug/g dry</td>
<td>0</td>
<td>1.2</td>
</tr>
<tr>
<td>Calcium</td>
<td>ug/g dry</td>
<td>0</td>
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<tr>
<td>Cadmium</td>
<td>ug/g dry</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Cobalt</td>
<td>ug/g dry</td>
<td>0</td>
<td>19</td>
</tr>
<tr>
<td>Chromium</td>
<td>ug/g dry</td>
<td>0</td>
<td>67</td>
</tr>
<tr>
<td>Copper</td>
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</tr>
<tr>
<td>Iron</td>
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</tr>
<tr>
<td>Magnesium</td>
<td>ug/g dry</td>
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</tr>
<tr>
<td>Manganese</td>
<td>ug/g dry</td>
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<tr>
<td>Molybdenum</td>
<td>ug/g dry</td>
<td>0</td>
<td>2.5</td>
</tr>
<tr>
<td>Nickel</td>
<td>ug/g dry</td>
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<td>43</td>
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<tr>
<td>Lead</td>
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<td>Strontium</td>
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<td>Titanium</td>
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<tr>
<td>Vanadium</td>
<td>ug/g dry</td>
<td>0</td>
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<tr>
<td><strong>Nutrients</strong></td>
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<tr>
<td>Nitrogen; total Kjeldahl</td>
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<td>Phosphorus; total</td>
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<tr>
<td>Escherichia coli</td>
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<tr>
<td>Fecal streptococcus</td>
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<tr>
<td>Pseudomonas aeruginosa</td>
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Table 4.2 cont’d

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<tr>
<td>Acenaphthene</td>
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</tr>
<tr>
<td>Fluorene</td>
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</tr>
<tr>
<td>Phenanthrene</td>
<td>ng/g dry</td>
</tr>
<tr>
<td>Anthracene</td>
<td>ng/g dry</td>
</tr>
<tr>
<td>Fluoranthene</td>
<td>ng/g dry</td>
</tr>
<tr>
<td>Pyrene</td>
<td>ng/g dry</td>
</tr>
<tr>
<td>Benzo(a)anthracene</td>
<td>ng/g dry</td>
</tr>
<tr>
<td>Chrysene</td>
<td>ng/g dry</td>
</tr>
<tr>
<td>Benzo(b)fluoranthene</td>
<td>ng/g dry</td>
</tr>
<tr>
<td>Benzo(k)fluoranthene</td>
<td>ng/g dry</td>
</tr>
<tr>
<td>Benzo(e)pyrene</td>
<td>ng/g dry</td>
</tr>
<tr>
<td>Benzo(a)pyrene</td>
<td>ng/g dry</td>
</tr>
<tr>
<td>Perylene</td>
<td>ng/g dry</td>
</tr>
<tr>
<td>Indeno(1,2,3-c,d)pyrene</td>
<td>ng/g dry</td>
</tr>
<tr>
<td>Dibenzo(a,h)anthracene</td>
<td>ng/g dry</td>
</tr>
<tr>
<td>Benzo(g,h,i)perylene</td>
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<table>
<thead>
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</tr>
<tr>
<td></td>
<td>-</td>
<td>200</td>
</tr>
</tbody>
</table>

Note:
* Guideline for use of Contaminated Sites in Ontario - background typical range soil concentrations for agricultural use.
† Source: 1998 survey of farming practices and fertilizer use in the Stouffville and Reesor Creeks Watershed for AGNPS Model application.

4.4. Temperature

The temperature of surface runoff and infiltrated water will be logged continuously at 15 minute intervals during the summer period to assess the potential thermal impact of infiltrated runoff on groundwater, or on receiving waters where an underdrain that discharges to a stream is included as part of the system.

The temperature of pavement and soil surfaces would be useful to determine relative contributions of permeable pavement, bio-swale and control surfaces to the greenhouse effect. Since it is difficult to get a representative temperature from vegetated areas, surface temperatures will be measured with a radiation thermometer, which measures long-wave radiation (8-14 micron waveband) emitted by surfaces placed within its field-of-vision. Measurements will be taken during hot smog days when heat emitted from urban surfaces can contribute to poor air quality.

4.5. Soil Compaction

Soil compaction was tested to ensure that the excavated soil during the installation of the liner was backfilled to 97% compaction (typical of native soils). Results concluded that the average measured degree of compaction of the subgrade (clayey silt, trace gravel) and Granual “A” (base) was approximately 100% and 97% Standard Proctor Maximum Dry Density (SPMDD).
respectively. Project SPMDD specifications were 98% and 95% respectively. Native soil backfill particle size distribution results can be seen in Appendix A.

4.6. Durability and maintenance

The site will be inspected regularly for rutting, settling, shifting, erosion (bioswale), and damage to plants or pavement surfaces. The density of parked cars on the respective lots will be reported to characterize the intensity of site use relative to potential applications of the technology elsewhere. Maintenance schedules for winter snow removal and summer plant care will also be reported.
5. Monitoring Results and Analysis

At the time of writing this interim report, monitoring equipment has not yet been installed in the sampling vault at the Seneca College parking lot. It is anticipated that the equipment will be installed and monitoring will commence in late March or early April 2005. Monitoring will continue through 2007, and a final report will be prepared in March 2008.
6. Summary and Conclusions

Permeable pavements and bioretention swales have the potential to provide effective management of stormwater runoff from parking areas. However, to date, there have been few practical applications of these measures in Southern Ontario. Furthermore, data regarding the migration of pollutants through soil under permeable pavements and regarding the performance during winter months is extremely limited.

The TRCA has recently constructed a permeable pavement structure and bioretention swale at the King Campus of Seneca College. This site is located on the Oak Ridges Moraine within the Township of King. Monitoring of runoff and subsurface flow from the parking lot will be initiated in the very near future, and soil testing will be completed at the conclusion of the project. Throughout and following the three year monitoring program, results will be collected, analyzed and used to evaluate their potential use at other new and retrofit parking lots. The findings will be disseminated through a variety of sources, and results will also be incorporated into watershed and sub-watershed planning.
7. Acknowledgements

Numerous partners have provided the funding and services needed to initiate and maintain this valuable research project. The various partners to date are listed in Table 7.1.

Table 7.1. Project Funding Partners

<table>
<thead>
<tr>
<th>Partner</th>
<th>Contribution</th>
<th>Equipment and Labour</th>
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<tr>
<td>RAP MOU</td>
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<td>Oak Ridges Moraine Foundation</td>
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</tr>
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<td>The Pat and John McCutcheon Charitable</td>
<td>Funding</td>
<td>-</td>
</tr>
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<td>Foundation</td>
<td></td>
<td></td>
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<tr>
<td>GLSF*</td>
<td>Funding</td>
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</tr>
<tr>
<td>City of Toronto</td>
<td>Funding</td>
<td>-</td>
</tr>
<tr>
<td>Wal-Mart Canada</td>
<td>Funding</td>
<td>-</td>
</tr>
<tr>
<td>Department of Fisheries and Oceans Canada</td>
<td>Funding</td>
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<tr>
<td>Seneca College</td>
<td>In-kind</td>
<td>Maintenance, Study Area, Labour</td>
</tr>
<tr>
<td>Toronto and Region Conservation</td>
<td>In-kind</td>
<td>Monitoring Equipment</td>
</tr>
<tr>
<td>The Ministry of the Environment</td>
<td>In-kind</td>
<td>Lab Services</td>
</tr>
<tr>
<td>Hanson Canada</td>
<td>In-kind</td>
<td>Sampling Vault</td>
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<tr>
<td>Unilock</td>
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<td>Permeable Pavement</td>
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<td>Atlantis Infiltration System</td>
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</tr>
<tr>
<td>Layfield Plastics</td>
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<td>Liner Materials</td>
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*The Great Lakes Sustainability Fund is a component of the Federal Government’s Great Lakes program. The Sustainability Fund provides the resources to demonstrate and implement technologies and techniques to assist in the remediation of Areas of Concern and other priority areas in the Great Lakes. Although the proceeding report was subject to technical review, it does not necessarily reflect the views of the Sustainability Fund or Environment Canada.
8. References


The United States Environmental Protection Agency (USEPA), 2002. *Considerations in the Design of Treatment Best Management Practices (BMPs) to Improve Water Quality*. 

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APPENDIX A

SOIL PROPERTIES
PERMEAMETER TESTING – PRE-CONSTRUCTION AND POST-CONSTRUCTION
## Seneca King Campus - Permeameter Tests

<table>
<thead>
<tr>
<th>Measurement Number</th>
<th>Date</th>
<th>GPS</th>
<th>Depth (cm)</th>
<th>Steady state (R1)</th>
<th>Steady state (R2)</th>
<th>R1</th>
<th>R2</th>
<th>Reservoir Constant</th>
<th>Kfs (cm/sec)</th>
<th>Soil Type</th>
<th>Pict</th>
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<td>KC-1</td>
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<td>618625</td>
<td>36</td>
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<td>0.000036</td>
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<td>47</td>
<td>1.25</td>
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<td>0.0208</td>
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</table>
COMPACTION TESTING
January 19, 2005

Toronto Region Conservation Authority  
5 Shoreham Drive 
Downsview, Ontario 
M3N 1S4

Attention: Mr. Mark Preston, Fax: 416-392-9726

c.c. Mr. Derek Smith, Fax: 416-661-6898

RE: FIELD AND LABORATORY TEST RESULTS 
KING CAMPUS, SENECA COLLEGE 
TOWNSHIP OF KING, ONTARIO

Dear Sir:

This report presents the results of field density (compaction) and laboratory testing carried out at the above project site, for the purpose of determining the degree of compaction achieved and the quality of the Granular ‘A’ material being utilized as granular base within the gravel parking lots.

1. SITE VISITS

The site was visited by a member of our engineering field staff on September 1 and 2, 2004. A total of five (5) field density (compaction) tests were conducted using a nuclear density gauge on the Granular ‘A’ material and on the subgrade.

In addition, during our site visits, one sample of the Granular ‘A’ material and one sample of the subgrade soils were retrieved from the site and brought back to our laboratory for testing.

It should be noted that in addition to the compaction tests, field inspections were carried out on the gravel parking lot, please refer to ‘Field Inspection Record’ attached.
2. **FIELD TEST RESULTS**

The average measured degree of compaction of the subgrade (*Clayey Silt, trace to some Gravel*) was about 101 percent Standard Proctor Maximum Dry Density (SPMDD), and all test results ranged between 100 and 102 percent SPMDD. The average measured water content of the subgrade was about 14.3 percent by weight.

The average measured degree of compaction of the Granular ‘A’ material (*granular base of the parking lot area*) was about 97 percent SPMDD, and all test results ranged between 95 and 100 percent SPMDD. The average measured water content of the Granular ‘A’ material was about 3.2 percent by weight.

The individual test locations and results are enclosed.

3. **SPECIFICATIONS**

It is understood that the project specifications for subgrade surface to be compacted to a minimum of 98 percent SPMDD. Based on the field test results, compaction of the subgrade in the areas tested, generally met the specifications.

It is understood that the project specifications for Granular ‘A’ material to be compacted to a minimum of 95 percent SPMDD (*at the gravel parking lot*). Based on the field test results, compaction of the Granular ‘A’ material in the areas tested, generally met the specifications.

4. **LABORATORY TEST RESULTS**

Enclosed are the results of laboratory testing (standard Proctor compaction and sieve gradation analysis) on a sample of the Granular ‘A’ material. The laboratory test results indicate the material generally met specifications for OPSS 1010. It is noted that the sample was marginally outside the gradation limits in 9.5mm, 4.75mm and 1.18mm sieves, however this should have minimal detrimental effect on the overall structure of the gravel parking lot.
We trust the foregoing information is sufficient for your present requirements. If you have any questions, please do not hesitate to contact us.

Yours truly,

**Terraprobe Testing Ltd.**

Levent Ozcan, M.Sc., P.Eng.  
Project Manager

Matthew Julien, M.A.Sc., P.Eng.  
Associate

Enclosure  
Field Density Test Results (2 pages)  
Field Inspection Record (1 page)  
Laboratory Test Results (3 pages)
**FIELD DENSITY TEST RESULTS**

**Project:** King Campus, Seneca College  
**File No.:** 2-04-0400

**Location:**  
**Test Date:** September 1, 2004

**Client:** Toronto Regional Conservation Authority  
**Test Techn.:** Altaf Mian

**Contractor:** Toronto Regional Conservation Authority  
**Compaction Equipment:** Smooth Drum Roller

**Area Tested:** Pilot project by the parking lot

### Laboratory Compaction Method:

- **Material Tested:** Clayey Silt, trace to some gravel (Lab No. 2089)
- **Opt. Wc:** 14.4%
- **Maximum Lab Density:** 1.905 T/m³

<table>
<thead>
<tr>
<th>Material Tested</th>
<th>Water Content</th>
<th>% of Max. Lab Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>13.9</td>
<td>102%</td>
</tr>
</tbody>
</table>

### Field Test Method:

- **Method:** Nuclear Gauge

### Test Results

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Test Location</th>
<th>Test Depth Elev.</th>
<th>Material *</th>
<th>Dry Density (T/cu.m.)</th>
<th>Water Content (%)</th>
<th>% of Max. Lab Density</th>
<th>Recommendations **</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 feet below grade at centre</td>
<td>2' BSG</td>
<td>A</td>
<td>1.936</td>
<td>13.9</td>
<td>102%</td>
<td>X</td>
</tr>
<tr>
<td>2</td>
<td>3 feet below grade at centre</td>
<td>3' BSG</td>
<td>A</td>
<td>1.903</td>
<td>14.5</td>
<td>100%</td>
<td>X</td>
</tr>
</tbody>
</table>

### Abbreviations:

- BSG - Below Subgrade
- APO - Above Pipe Obvert
- FG - Finished Grade
- BFG - Below Finished Grade
- BFB - Below Finished Base
- SG - Subgrade

### Recommendations:

- X - Test Results Meet Spec.
- Y - Results Slightly Below Spec., Recompress
- Z - Result Below Spec., Recompress & Retest

### Comments:

- Preliminary to be confirmed after laboratory testing
- Final

**Received By:**

BRAMPTON (905) 796-2650, Fax 796-2250  ■ BARRIE (705) 739-8355, Fax, 739-8389  ■ SUDBURY (705) 670-0460, Fax 670-0558  ■ STONEY CREEK (905) 643-7560, Fax 643-7559

2-04-0400Sept1.04.wpd
# Field Density Test Results

**Project:** Seneca College King Campus  
**Location:** Township of King, Ontario  
**Client:** Toronto Regional Conservation Authority  
**Contractor:** Toronto Regional Conservation Authority  
**Compaction Equipment:** Vibratory Smooth Drum Roller  
**Area Tested:** Pavement area (Pilot Project)  
**Test Date:** September 2, 2004

**Laboratory Compaction Method:** Standard Proctor  
**Field Test Method:** Nuclear Gauge

**Maximum Lab Density**  
<table>
<thead>
<tr>
<th>Opt. Wc</th>
<th>Material Tested *</th>
<th>Compaction Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.123 T/m³ @ 7.0%</td>
<td>A Granular &quot;A&quot; (Lab No 2094)</td>
<td>95%</td>
</tr>
</tbody>
</table>

**Test Results**

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Test Location</th>
<th>Test Depth Elev.</th>
<th>Material *</th>
<th>Dry Density (T/cu.m.)</th>
<th>Water Content (%)</th>
<th>% of Max. Lab Density</th>
<th>Recommendations **</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Centre</td>
<td>0.3m BFG</td>
<td>A</td>
<td>2.033</td>
<td>3.0</td>
<td>96</td>
<td>X</td>
</tr>
<tr>
<td>2</td>
<td>Middle - east portion</td>
<td>0.3m BFG</td>
<td>A</td>
<td>2.020</td>
<td>3.5</td>
<td>95</td>
<td>X</td>
</tr>
<tr>
<td>3</td>
<td>Middle - west portion</td>
<td>0.3m BFG</td>
<td>A</td>
<td>2.118</td>
<td>3.0</td>
<td>100</td>
<td>X</td>
</tr>
</tbody>
</table>

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**Comments**  
- Results Preliminary to be confirmed after laboratory testing
- Results Final

**Abbreviations:**
- BSG - Below Subgrade
- APO - Above Pipe Obvert
- FG - Finished Grade
- BFB - Below Finished Base
- SG - Subgrade

**Recommendations:**
- X - Test Results Meet Spec.
- Y - Results Slightly Below Spec., Recompact
- Z - Result Below Spec., Recompact & Retest
### FIELD INSPECTION RECORD

<table>
<thead>
<tr>
<th>Project</th>
<th>Seneca College, King Campus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>King City, Ontario</td>
</tr>
<tr>
<td>Client</td>
<td>Toronto Regional Conservation Authority</td>
</tr>
<tr>
<td>Contractor</td>
<td>Toronto Regional Conservation Authority</td>
</tr>
<tr>
<td>File / Report No.</td>
<td>2-04-0400</td>
</tr>
<tr>
<td>Date / Time</td>
<td>September 1 &amp; 2, 2004</td>
</tr>
<tr>
<td>Inspector</td>
<td>Altaf Mian</td>
</tr>
<tr>
<td>Weather</td>
<td>15-23°C, cloudy</td>
</tr>
</tbody>
</table>

**NOTES:** PERMEABLE PAVEMENT AREA - PILOT PROJECT

I inspected the above mentioned project on September 1 & 2 in order to take the compaction tests of till and granular A material respectively.

Derek told me that Granular “A” specified would be 95% - no drawings were available at site. Thickness of the materials was found more than specified, i.e. 300mm to 450mm. Placing and compaction of the material was not witnessed and only a few tests were taken. Despite the fact that a noticeable deflection and a spongy ness was noticed.

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**SKETCH**

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2-04-0400Sept1&2.04.wpd
PROJECT: Seneca College, King Campus
LOCATION: Town of King, Ontario
CLIENT: TRCA
SAMPLE DESCRIPTION: Granular 'A'
SAMPLE LOCATION: Permeable pavement
SAMPLE SUPPLIER: Lafarge

FILE No.: 2-04-0400
LAB No.: 2094
SAMPLE DATE: Sept. 2, 2004
SAMPLED BY: A.M.

MAXIMUM DRY DENSITY (t/m³): 2.123
CORRECTED DRY DENSITY (t/m³):
OPTIMUM WATER CONTENT (%): 7.0

STANDARD PROCTOR COMPACTION

Zero Air Voids Line
Gs = 2.68 Assumed
### Grain Size Distribution

**U.S. Standard Sieve Sizes**

<table>
<thead>
<tr>
<th>GRAIN SIZE (mm)</th>
<th>% RETAINED</th>
<th>MIT SYSTEM</th>
<th>COARSE</th>
<th>MEDIUM</th>
<th>FINE</th>
<th>SAND</th>
<th>SILT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000.00</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>100.00</td>
<td>10%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.00</td>
<td>20%</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1.00</td>
<td>30%</td>
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<tr>
<td>1.00</td>
<td>40%</td>
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<tr>
<td>0.05</td>
<td>50%</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>0.01</td>
<td>60%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.003</td>
<td>70%</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>0.001</td>
<td>80%</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>0.0003</td>
<td>90%</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>0.0001</td>
<td>100%</td>
<td></td>
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</tbody>
</table>

### Sieve Analysis Table

<table>
<thead>
<tr>
<th>SIEVE SIZE</th>
<th>PERCENT PASSING</th>
<th>GRANULAR 'A'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>SPECIFIED</td>
<td>SAMPLE</td>
</tr>
<tr>
<td>1.06&quot;</td>
<td>26.5</td>
<td>100</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>19.0</td>
<td>85</td>
</tr>
<tr>
<td>.530&quot;</td>
<td>13.2</td>
<td>65</td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>9.5</td>
<td>50</td>
</tr>
<tr>
<td>No. 4</td>
<td>4.75</td>
<td>35</td>
</tr>
<tr>
<td>No. 16</td>
<td>1.180</td>
<td>15</td>
</tr>
<tr>
<td>No. 50</td>
<td>0.300</td>
<td>5</td>
</tr>
<tr>
<td>No. 200</td>
<td>0.075</td>
<td>2</td>
</tr>
</tbody>
</table>

**Granular 'A'**

- Crushed Particles: Measured 70.9%, Specified Min. 50%

**Note:** Shading denotes not meeting specifications
PROJECT: Seneca College, King Campus
LOCATION: King City, Ontario
CLIENT: TRCA
SAMPLE DESCRIPTION: TIII
SAMPLE LOCATION: Permeable Pavement
SAMPLE SUPPLIER: Native

MAXIMUM DRY DENSITY (t/m³): 1.814
CORRECTED DRY DENSITY (t/m³): 1.905
OPTIMUM WATER CONTENT (%): 14.4

STANDARD PROCTOR COMPACTION

Zero Air Voids Line
Gs = 2.68 Assumed
SOIL CHEMISTRY – PRE CONSTRUCTION
CERTIFICATE OF ANALYSIS FOR ONTARIO REGULATION 558/00
TCLP - LEACHATE QUALITY CRITERIA (INORGANICS)

Data Pertain To Specific Sample(s) Tested

<table>
<thead>
<tr>
<th>CONTAMINANT</th>
<th>SCHEDULE 4 Concentration (mg/L)</th>
<th>Method Detection</th>
<th>CONTROL SAMPLE</th>
<th>SAMPLE DATA (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Limit (mg/L)</td>
<td></td>
<td>38502</td>
<td>SPL04-01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Blank</td>
</tr>
<tr>
<td>Arsenic</td>
<td>2.5</td>
<td>0.001</td>
<td>0.258</td>
<td>0.270</td>
</tr>
<tr>
<td>Barium</td>
<td>100</td>
<td>0.01</td>
<td>0.750</td>
<td>0.762</td>
</tr>
<tr>
<td>Boron</td>
<td>500</td>
<td>0.01</td>
<td>0.833</td>
<td>0.786</td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.5</td>
<td>0.005</td>
<td>0.033</td>
<td>0.035</td>
</tr>
<tr>
<td>Chromium</td>
<td>5.0</td>
<td>0.01</td>
<td>0.133</td>
<td>0.135</td>
</tr>
<tr>
<td>Cyanide Free</td>
<td>20.0</td>
<td>0.005</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Fluoride</td>
<td>150</td>
<td>0.05</td>
<td>1.03</td>
<td>1.03</td>
</tr>
<tr>
<td>Lead</td>
<td>5.0</td>
<td>0.02</td>
<td>0.630</td>
<td>0.658</td>
</tr>
<tr>
<td>Mercury</td>
<td>0.1</td>
<td>0.0001</td>
<td>0.0268</td>
<td>0.0298</td>
</tr>
<tr>
<td>(Nitrate+Nitrite)-N</td>
<td>1000</td>
<td>0.01</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Selenium</td>
<td>1.0</td>
<td>0.001</td>
<td>0.019</td>
<td>0.0192</td>
</tr>
<tr>
<td>Silver</td>
<td>5.0</td>
<td>0.005</td>
<td>0.0417</td>
<td>0.043</td>
</tr>
<tr>
<td>Initial pH (units)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fluid No.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fluid pH (units)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Final pH (units)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Sample Disposal: 30 Days from the Reporting Date.
All Results except pH are expressed in mg/L (parts per million).
Note: "+" means the result exceeds the Schedule 4 concentration.
Method:
As, Se: HG-FAAS (EPA 3005/7062/7742)  Cyanide Free: Auto-Color (EPA 365.1)
Hg: CV-AAS (EPA 245.1)  Fluoride: ISE (EPA 340.2)
Metals: ICP-AES (EPA 3005/200.7)  (NO3 + NO2)-N: Auto-Color (EPA 353.2)
CERTIFICATE OF ANALYSIS - GUIDELINE FOR USE AT CONTAMINATED SITES IN ONTARIO (GENL. & INORGANIC)

Data Pertain To Specific Sample(s) Tested

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>Soil Remediation Criteria (µg/g)</th>
<th>Method Detection</th>
<th>CONTROL SAMPLE</th>
<th>SAMPLE DATA (µg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tables A &amp; B Res./Ind. Comm</td>
<td></td>
<td></td>
<td>Blank</td>
</tr>
<tr>
<td>Dry Matter (%)</td>
<td>-</td>
<td></td>
<td>-</td>
<td>88.1</td>
</tr>
<tr>
<td>pH (units)</td>
<td>5 to 9</td>
<td></td>
<td>7.4</td>
<td>100</td>
</tr>
<tr>
<td>E C (µmhos/cm)</td>
<td>700/1400</td>
<td>N.A./N.A.</td>
<td>147.3</td>
<td>145</td>
</tr>
<tr>
<td>SAR</td>
<td>5/12</td>
<td>N.A./N.A.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Arsenic</td>
<td>20/40</td>
<td>40/N.V.</td>
<td>75</td>
<td>76.0</td>
</tr>
<tr>
<td>Cadmium</td>
<td>12/12</td>
<td>41/41</td>
<td>3.4</td>
<td>3.3</td>
</tr>
<tr>
<td>Chromium (VI)</td>
<td>8/8</td>
<td>600/1100</td>
<td>0.89</td>
<td>0.88</td>
</tr>
<tr>
<td>Chromium (total)</td>
<td>750/750</td>
<td>2500/5000</td>
<td>6.4</td>
<td>7.1</td>
</tr>
<tr>
<td>Cobalt</td>
<td>40/80</td>
<td>2500/3400</td>
<td>2.8</td>
<td>2.7</td>
</tr>
<tr>
<td>Copper</td>
<td>225/225</td>
<td>2500/2500</td>
<td>690</td>
<td>754</td>
</tr>
<tr>
<td>Lead</td>
<td>200/100</td>
<td>1000/N.V.</td>
<td>233</td>
<td>173</td>
</tr>
<tr>
<td>Mercury</td>
<td>10/10</td>
<td>57/57</td>
<td>0.05</td>
<td>0.3</td>
</tr>
<tr>
<td>Molybdenum *</td>
<td>40/40</td>
<td>550/550</td>
<td>0.28</td>
<td>0.3</td>
</tr>
<tr>
<td>Nickel</td>
<td>150/150</td>
<td>710/710</td>
<td>2</td>
<td>197</td>
</tr>
<tr>
<td>Boron(HWE) *</td>
<td>1.5/2.0</td>
<td>2.0/N.V.</td>
<td>0.02</td>
<td>1</td>
</tr>
<tr>
<td>Cyanide Free</td>
<td>100/100</td>
<td>100/300</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Selenium *</td>
<td>10/10</td>
<td>2500/2500</td>
<td>15</td>
<td>13.8</td>
</tr>
<tr>
<td>Silver</td>
<td>20/40</td>
<td>2500/5000</td>
<td>467</td>
<td>451</td>
</tr>
<tr>
<td>Antimony *</td>
<td>13/40</td>
<td>44/44</td>
<td>15,000</td>
<td>14.3</td>
</tr>
<tr>
<td>Barium</td>
<td>750/1500</td>
<td>2500/4100</td>
<td>215</td>
<td>199</td>
</tr>
<tr>
<td>Beryllium *</td>
<td>1.2/1.2</td>
<td>1.23/1.1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Vanadium</td>
<td>200/200</td>
<td>910/910</td>
<td>19</td>
<td>18.8</td>
</tr>
</tbody>
</table>

a) Table A: Surface soil criteria for a potable groundwater condition
b) Table B: Surface soil criteria for a non-potable groundwater condition
c) Table C: Sub-surface soil criteria for a potable groundwater condition

Sample Disposal: 30 Days from the Reporting Date.

* Control Sample Unit is µg/mL for the specified parameter instead of µg/g unless otherwise specified.

Method:
- pH: Extraction/Electrometric (EPA 9045)
- EC: Extraction/Electrometric (EPA 120.1)
- As, Se, Sb: Digestion/HGFAAS (EPA 3050A/7062/7742)
- Hg: Digestion/CV-AAS (EPA 7471A/245.5)
- SAR: Extraction/I CP-AES (EPA 200.7)
- Metals: Digestion/ICP-AES (EPA 3050A/200.7)
- Cyanide Free: Extraction/Auto-Color (EPA 335.4)
- B (HWE): Extraction/ICP-AES
- Cr(VI): Alkaline Digestion/Colorimetry (EPA 3060A/7196)
SOIL CHEMISTRY – POST CONSTRUCTION
Program Code 0700801
Program: RESEARCH PROGRAM
Study: WATER TREATMENT RESEARCH
Project: TECHNICAL ADVISORY
Activity: 
Organization: DWSP

Org. Id: 2202

Mail this copy to:
LACHMANIUK, PAT
MOE - STANDARDS DEVELOPMENT BRANCH
40 ST. CLAIR AVE. WEST. 7TH FLR.
NORTH YORK, ONT
M4V 1M2

Final reports to: LACHMANIUK, PAT

Inquires to: RUSTY MOODY
Telephone: 416-235-5863
LORRAINE PETERS
Telephone: 416-235-5860

LOGIN DESCRIPTION: YORK UNIVERSITY GREEN ROFF TRCA DEREK SMITH DOWNSVIEW 416-661-6600 EXT-5362/416-357-0313
<table>
<thead>
<tr>
<th>Field Id</th>
<th>Station ID</th>
<th>Sample Location Description</th>
<th>Sampling Date</th>
<th>Time</th>
<th>Zone</th>
<th>Sampler Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>SENECA P.P. SOIL</td>
<td>02 SEP 2004</td>
<td>5</td>
<td></td>
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</tr>
</tbody>
</table>

**MOE*LIMS Products Requested:**

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<thead>
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<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SO</td>
<td>E3012A</td>
<td>ORGC3012</td>
<td>SO</td>
<td>E3059A</td>
<td>HG3059</td>
<td>SO</td>
<td>E3073A</td>
<td>MET3073</td>
</tr>
<tr>
<td>SO</td>
<td>E3116A</td>
<td>TNP3116</td>
<td>SO</td>
<td>E3137A</td>
<td>PH3137</td>
<td>SO</td>
<td>E3138A</td>
<td>COND3138</td>
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<tr>
<td>SO</td>
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<td>PART3328</td>
<td>SO</td>
<td>E3371A</td>
<td>ECFSPS3371</td>
<td>SO</td>
<td>E3425</td>
<td>PAH3425</td>
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<table>
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