# Performance Evaluation of Permeable Pavement and a Bioretention Swale

Seneca College, King City, Ontario

Prepared by Toronto and Region Conservation

Final Report

November 2008

# Performance Evaluation of Permeable Pavement and a Bioretention Swale
# Seneca College, King City, Ontario

A report prepared by:

Toronto and Region Conservation
under the
Sustainable Technologies Evaluation Program

November 2008

## NOTICE



## PUBLICATION INFORMATION

Reports conducted under the Sustainable Technologies Evaluation Program (STEP) are available at www.sustainabletechnologies.ca. For more information about this or other STEP studies, please contact:

Tim Van Seters
Manager, Sustainable Technologies
Toronto and Region Conservation Authority
5 Shoreham Drive,
Downsview, Ontario
M3N 1S4

Tel: 416-661-6600, Ext. 5337
Fax:416-661-6898
E-mail: Tim_Van_Seters@trca.on.ca

# THE SUSTAINABLE TECHNOLOGIES EVALUATION PROGRAM

The Sustainable Technologies Evaluation Program (STEP) is a multi-agency program, led by the Toronto and Region Conservation Authority (TRCA). The program was developed to provide the data and analytical tools necessary to support broader implementation of sustainable technologies and practices within a Canadian context. The main program objectives are to:

- monitor and evaluate clean water, air and energy technologies;
- assess barriers and opportunities to implementing technologies;
- develop tools, guidelines and policies, and
- promote broader use of effective technologies through research, education and advocacy.

Technologies evaluated under STEP are not limited to physical structures; they may also include preventative measures, alternative urban site designs, and other innovative practices that help create more sustainable and liveable communities.

For more information about STEP, please contact:

Glenn MacMillan
Senior Manager, Water and Energy
Toronto and Region Conservation Authority
Tel: 416-661-6600 Ext. 5212
Fax:416-661-6898
Email: Glenn_MacMillan@trca.on.ca

# ACKNOWLEDGEMENTS

Funding support for this project was generously provided by

- Government of Canada's Great Lakes Sustainability Fund[1];
- Environment Canada;
- Fisheries and Oceans Canada;
- Ontario Ministry of the Environment;
- Regional Municipalities of Toronto, York and Peel;
- Town of Markham;
- Oak Ridges Moraine Foundation;
- Pat and John McCutcheon Charitable Foundation;
- Interlocking Concrete Pavement Institute;
- Cement Association of Canada, and
- Wal-Mart Canada

The following organizations provided In-kind contributions to the project:

- Seneca College (site for the study, labour, solar panel, wind turbine, and web support);
- Unilock (permeable pavers);
- EMCO (Atlantis infiltration and tank system materials);
- Hanson Canada (sampling vault), and
- Layfield Plastics (liner materials).

[1] 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 this report was subject to technical review, it does not necessarily reflect the views of the Sustainability Fund or Environment Canada.

# EXECUTIVE SUMMARY

## Background

Many of the adverse impacts of urban development on watercourses stem from the loss of natural infiltration and evapotranspiration functions when pervious vegetated areas are replaced with buildings and paved surfaces. As less rainwater infiltrates and evapotranspires, more runs off over the surface, causing increased flood risk, channel erosion, poor water quality, and degradation of aquatic habitat. Permeable pavement and bioretention swales are two examples of stormwater practices that help prevent these undesired consequences by filtering stormwater and preserving or re-instating natural hydrologic functions that existed prior to development.

While these stormwater infiltration practices have been implemented in some areas of the Greater Toronto Area (GTA), broader uptake has been limited by concerns about their long term effectiveness, the potential for infiltrated stormwater to contaminate soil and groundwater resources, and other factors. Initiated in the fall of 2004, this three year demonstration project helps to address these concerns by evaluating the benefits and limitations of the technologies under climate and soil conditions representative of watersheds in the GTA. An international review of literature on permeable pavements and bioretention swales provides a context for the study.

## Study Sites

The main site for this study is located on a parking lot at Seneca College's King Campus in the Township of King, roughly 25 km north of Toronto. The parking lot is often full during the school year, but is used less frequently during the summer, except during special events. Several older permeable pavement (n=7) and bioswale (n=5) sites in the Greater Golden Horseshoe were also surveyed to assess the effect that age may have on various aspects of the two infiltration practices.

For monitoring purposes, the parking lot at Seneca College was divided into three equal sized sections (286 $m^2$ each) consisting of permeable interlocking concrete pavers (PICP), asphalt draining to a bioretention swale (24 $m^2$), and a conventional asphalt control area (Figure 1). Parking lot runoff was collected both at the road surface level (asphalt and PICP) and as infiltrate from the soils approximately 1.5 meters beneath the PICP and bioretention swale (hereafter referred to as the bioswale). The PICP and bioswale areas were lined with impermeable plastic membranes overlaid with weeping tile to allow monitoring of water passing through the granular base course (60 cm) and soils.

The native soils below the PICP are clay loam with infiltration rates at the low end of the recommended range for these types of infiltration practices, but not uncharacteristic of soil permeability in many other parts of the GTA. The bioswale soils are a more permeable loam garden soil topped with cedar mulch and graded to form a shallow depression for temporary storage of runoff for storms up to approximately 15 mm. Drought and salt tolerant plants are planted on top of the swale. Flows overtopping the depression are directed towards grass swales, ultimately infiltrating into the ground. The seasonally high groundwater table is well over 3 m below the base of both installations.

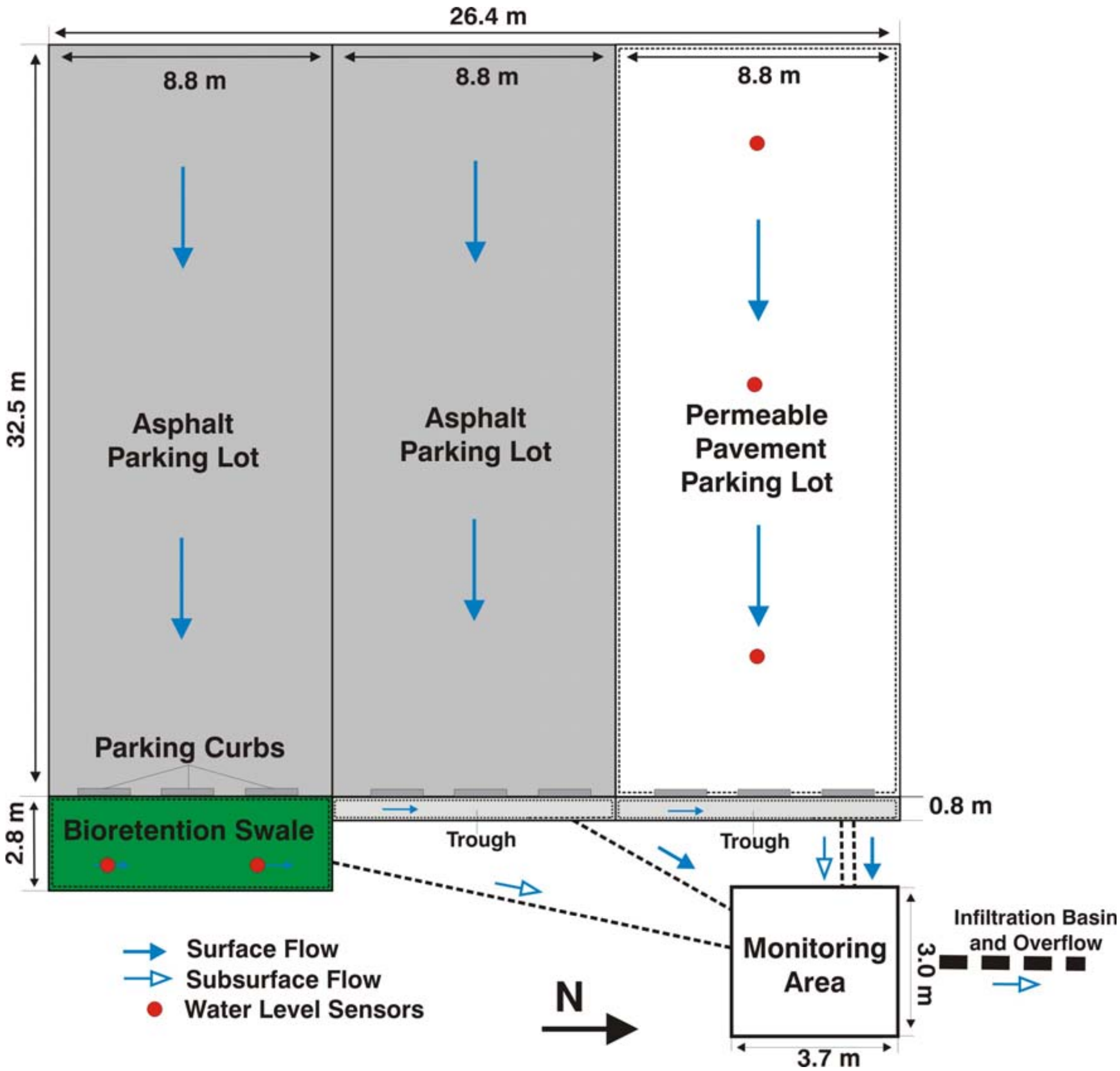


**Figure 1:** Parking lot design, plan view

## Materials and Methods

Rainfall was measured using a standard tipping bucket rain gauge and logger set to record at 5 minute intervals. Surface flows and infiltrate from underdrains were measured using four magnetic induction flow meters connected to a single data logger located in an underground sampling vault. Starting in September 2006, water level fluctuations within the granular base reservoir and on the surface of the bioswale were monitored continuously with pressure transducers embedded in slotted wells with lock-down caps. Three sensors were located within the base, 55 cm below the pavers, and two were embedded in the surface soil of the bioswale (Figure 1).

Water quality samples were collected using four automated water samplers connected directly to the flow meters and triggered when flow rates exceeded 0.005 L/s. Samples were flow proportioned and submitted to the Ontario Ministry of the Environment Laboratory for analysis of general chemistry (*e.g.*

pH, alkalinity, total suspended solids), nutrients (phosphorus and nitrogen), metals and polycyclic aromatic hydrocarbons (PAHs).

Sediment cores were extracted from the bioswale, the native soils (or subgrade) beneath the PICP base course, and a reference site unimpacted by runoff to document potential effects of stormwater infiltration on soil quality. The cores were cut into 76 mm segments to a depth of at least 300 mm, and submitted to the Ontario Ministry of the Environment laboratory for chemical analysis. Seven older permeable pavement sites and five older bioswale sites in the GTA were sampled in the same manner. These older sites were a useful addition to the study as changes in soil chemistry often only become evident after at least 3 to 5 years of operation. Observations of pavement structural condition, surface infiltration, durability, and swale vegetation were also recorded at these sites.

Temperature sensors were installed on the PICP and bioswale late in 2006 to assess freeze-thaw cycles and surface and subsurface air and water temperatures year round. The sensors were embedded inside the pavers and conventional asphalt, in the granular filled paver drainage cells, below the pavers in the bedding course, within the base course (50-55 cm deep), and below the bioswale surface at the same depth. Measurements were continuous throughout the summer and winter.

## Study Findings

### Runoff and Infiltration

Among the 71 runoff events monitored, only one produced surface flow from the PICP. This storm was the largest event monitored, producing 72 mm of rain over a period of 5.5 hours. The overflow volume during this event was less than 10% of total runoff from the asphalt pavement. The bioswale overflowed during events greater than approximately 20 mm, but most of the annual runoff infiltrated into the ground and was released back to the atmosphere through evapotranspiration. While the reduction in runoff in both cases was probably enhanced to some degree by the presence of a liner and underdrain, the results nevertheless suggest that these technologies can contribute to restoring or maintaining infiltration functions in an urban landscape, even on low permeability clay-based soils.

In addition to reducing surface runoff, these infiltration practices also helped to delay and reduce peak flows by storing water and releasing it slowly over several days. Peak infiltrate flows were less than 5% of asphalt peak flows. The slower and more controlled flows help protect downstream watercourses and infrastructure by reducing flood risk and preventing stream erosion caused by post-development changes to the flow regime.

The 60 cm base course was thicker than it needed to be. Water levels in the base reservoir rarely exceeded two thirds of the full base depth (60 cm). Storage per unit depth may have been increased further had clear washed stone been used, instead of granular ‘A’, which includes fines. Relationships between rainfall and water level rise in the base reservoir indicated that the effective porosity of the granular ‘A’ base (<5%) was only a fraction of that specified in the design of the installation (35%).

Winter data show the PICP functioning well during cold weather with air temperatures as low as -25°C. The base course layer continued to function as an effective storage unit, even during sub-zero temperatures. Minimum base course temperatures in 2007 and 2008 were -2°C and -5°C, respectively. The probability of ice formation in the base course tended to increase during the late winter period when snow melt or rain was followed by a sudden drop in temperatures. A similar phenomenon was not evident in the early winter because higher base course temperatures provided a good buffer against sudden changes in air temperature.

The bioswale also performed well during the winter. Soil temperatures remained above freezing and infiltration occurred throughout cold weather. There was no evidence of melt waters backing up onto the parking lot as a result of ice and snow build-up around the perimeter of the swale.

Tests of surface infiltration showed that older PICP sites tended to have lower rates (36 mm/h) than newer installations (1200 mm/h). The use of sand instead of gravel as a bedding layer and joint filler, and in some cases as a winter maintenance practice, were identified as possible factors contributing to lower infiltration rates at older sites. Current guidelines from most jurisdictions recommend using clear stone free of sand or fine particles in the base and surface joints of PICPs.

## Water Quality

The potential for infiltrated stormwater to contaminate groundwater was determined by comparing the quality of asphalt runoff with the quality of water after infiltration through one metre of soil below the two installations (hereafter referred to as the ‘infiltrate’). Relative to asphalt runoff, the PICP and bioswale infiltrates were characterized by significantly higher levels ($\alpha$=0.05) of pH, hardness (as $CaCO_3$), and alkalinity. These properties of the water help to buffer the effects of acid precipitation and reduce the aquatic toxicity of trace metals in surface water. Median PICP concentrations of zinc, phosphorus, total suspended solids and oil and grease (extractable solvents) were significantly lower ($\alpha$=0.05) than those in asphalt runoff. PAHs were rarely detected, but concentrations were generally higher in asphalt runoff. The organic bioswale soils acted as a source of phosphorus, ammonia, and organic nitrogen resulting in significantly higher ($\alpha$=0.05) concentrations of these constituents in bioswale infiltrate relative to both the asphalt and PICP infiltrate.

Chloride and sodium were the major groundwater contaminants of concern. Infiltrate concentrations of both constituents were frequently above drinking water standards. These soluble constituents are highly mobile, and are able to bypass treatment processes of most conventional stormwater practices. The road salts may have also increased the mobility of trace metals as concentrations of several trace metals rose midway through the second winter of monitoring. Several studies have shown relationships between de-icing chemicals and increased mobility of metals, particularly the more soluble metals such as cadmium and zinc. The observed rise in metal concentrations may also be attributed to higher surface loading and preferential pathways through cracks in the soil matrix or along the liner. In this study, cadmium and lead were of greatest concern as both were occasionally observed in infiltrate samples at concentrations above drinking water standards. The processes governing the transport of metals through soils under permeable pavements and bioswales where road salts are applied is a topic that requires further investigation.

Temperature

The temperature of the asphalt surface exceeded 20°C roughly 12% more often than the pavers, suggesting that PICPs may help to mitigate against heat induced smog and other undesirable effects associated with the urban heat island. The lighter colour (*i.e.* higher reflectivity) of the pavers and their ability to dissipate heat through open joints may explain much of the difference. During the winter, asphalt and PICP surface temperatures were very similar. The main winter benefit of the PICP lay in its ability to infiltrate snowmelt and thereby reduce ponding and ice build-up.

Soil Quality

Soil sampling of 7 older PICP parking lots and 5 older swales or ditches suggest that long term accumulation of contaminants in soils beneath the pavements and swales was not a significant concern. Contaminant levels at all sites were generally below Ontario soil 'background' concentrations for non-agricultural land uses. There were a few exceptions, but even in these cases, concentrations were still well below levels that would trigger the need for remediation or landfilling.

At the Seneca site, soil cores were extracted for analysis from the swale and PICP subgrade in 2005, and again in late 2007. Although more samples would be needed to establish a statistically significant difference, the absence of any change in swale or PICP subgrade soil chemistry over this time period is consistent with generally low soil contamination observed at other older sites.

Durability

Visual observations from older PICP sites showed that, from a structural point of view, the pavements continued to meet the expectations of users, with few signs of slumping or heaving. Tests using a Portable Falling Weight Deflectometer at the Seneca and Earth Rangers sites during the fall, winter and spring indicated that the asphalt and PICPs were comparable in strength. Both pavement types were weaker during the summer, rendering them more susceptible to damage from heavy truck loading during this time.

## Recommendations

Results of this study indicate that permeable pavements and bioretention swales can be effective measures for maintaining or restoring infiltration functions on parking lots and other low volume traffic areas. The following recommendations on PICP and bioswale design and maintenance are based on study findings and observations. Suggested topics for further research in the GTA are listed in the final section.

## Design

- Measurements of water level fluctuations in the PICP base course indicated that, at this particular site, a base course depth of 40 cm would have provided sufficient storage capacity for most rainfall events.
- Applications of PICPs and bioswales on low permeability soils with underdrains in the base reservoir should include a flow restrictor on the drainage pipe to maximize infiltration by allowing water to slowly drain and seep into the ground after an event. Water levels in the base reservoir should be monitored to ensure that the drawdown period is well suited to the particular soil and climate conditions for a given area.
- The potential for de-icing salts to mobilize heavy metals may warrant an increase in the current allowable depth to the seasonally high ground water table from one meter to two or more meters below the base of the PICP or bioswale installation.
- Effective porosity of the granular 'A' sub-base materials was very low, limiting the capacity of the reservoir to detain stormwater runoff. Use of clear washed stone would help improve the storage capacity of the base reservoir.
- Surface infiltration tests in this and other studies confirm that using sand as a bedding layer or applying sand on pavements during the winter slows surface infiltration and significantly increases the risk of premature clogging.
- In bioswales, garden soils with high organic content should be limited to the upper 20 cm and underlain with a sandy soil mix to reduce the export of nutrients through underdrains while maintaining good permeability.

## Operation and Maintenance

- Alternative deicing products such as calcium magnesium acetate should be considered in the winter on permeable parking lots to prevent excessive build-up of sodium and chloride in groundwater.
- Good infiltration through the pavers after 3 years of operation suggested that vacuum washing of PICPs may be needed only once every three to four years. Higher maintenance frequencies may be required in areas with greater traffic volumes.
- Base course water levels should be monitored periodically to provide early warning of potential reductions in subgrade infiltration rates.
- Soil quality results from older PICP and bioswale sites indicate that land fill disposal or remediation of the underlying soils would typically not be required when the pavers or swales need to be replaced.

## Topics for Further Research

- *The quality of effluents from underdrain applications of PICPs.* This study examined water quality after infiltration through the base reservoir and one meter of native soil. In most installations on low permeability soils, the underdrain is placed within the base course to ensure sufficient storage capacity is available for subsequent storms. Monitoring of water quality should be undertaken to determine whether these types of underdrain applications provide an acceptable level of water quality control. Tests should be conducted over varying detention times (*e.g.* 12, 24, 48 hours) as contaminant loading from underdrains will be strongly influenced by residence time in the base reservoir and the volume of water that infiltrates.

- *Impact of de-icing salts on the mobility of metals beneath PICPs and bioswales.* While previous studies have shown that de-icing salts can increase the mobility of some heavy metals in stormwater runoff, few researchers have examined the specific chemical and physical processes responsible for enhanced metal mobility beneath permeable pavements and bioswales. Data collected at the Seneca site suggest that this could be an important issue that requires further investigation.
- *Long term infiltration beneath PICPs and bioswales.* While several studies have examined surface clogging of pavements, few have evaluated the long term effects of stormwater infiltration on the infiltration capacity of subgrade soils and bioswale media. This may be particularly relevant in cold climates where de-icing salts can affect infiltration rates by altering the physical structure of soils.
- *The structural and hydrologic attributes of open and dense graded bases.* In Ontario, most PICP bases have been constructed using standard Ontario 'granular A' media, which includes a mixture of fines, sand and gravel up to 20 mm in diameter. Guidelines from Vancouver and other jurisdictions in the United States and Britain recommend using 'open graded' media (or clear stone), which have a narrower particle size range, and exclude fines. The comparative influence of clear stone and granular 'A' on PICP structural integrity, infiltration and water storage properties needs to be examined further.
- *The role of reactive media in improving water quality.* Heavy metals are a major contaminant of concern in runoff. Further research is needed on the potential for reactive media to reduce the export of heavy metals and other contaminants by retaining them within the base course or bioswale soils.
- *Microbial degradation of hydrocarbons within PICP installations.* Some European studies of permeable pavements have shown that vehicle oils and greases are degraded by microbes living on the geotextile located between the granular media and native soils. The effectiveness of these processes under local conditions, particularly during the winter, is a topic requiring more study.
- *The hydrologic characteristics of PICPs on clay based soils.* Most of the remaining buildable area in the Greater Toronto Area is located on low permeability (hydrologic group C and CD) soils. There has been little PICP research conducted on these types of soils as they are often regarded as providing limited infiltration benefits. This and other studies of infiltration systems in the GTA have demonstrated that these soils can have significant infiltration potential. More monitoring of permeable pavements is needed to quantify the flow reduction and water quality benefit of PICPs on clay based soils.
- *Structural characteristics of PICPs in cold climates.* The pavement structural tests showed greater stiffness during cold weather than in warm weather, but on all three test days, the base was partially filled with water. Further structural tests should be conducted under dry, wet, frozen and partially frozen states, as well as on bases of different depths, to determine the extent to which these different parameters affect the structural integrity of the pavement relative to a conventional asphalt surface.