PERFORMANCE ASSESSMENT OF A SWALE AND PERFORATED PIPE STORMWATER INFILTRATION SYSTEM, TORONTO, ONTARIO

a report prepared by the

STORMWATER ASSESSMENT MONITORING
AND PERFORMANCE (SWAMP) PROGRAM

for

Great Lakes Sustainability Fund of the Government of Canada
Ontario Ministry of Environment and Energy
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NOTICE

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THE SWAMP PROGRAM

The Stormwater Assessment Monitoring and Performance (SWAMP) Program is an initiative of the Government of Canada's Great Lakes Sustainability Fund, the Ontario Ministry of Environment and Energy, the Toronto and Region Conservation Authority, and the Municipal Engineers Association. A number of individual municipalities and other owner/operator agencies have also participated in the SWAMP studies.

Over the past 15 years, the Great Lakes Basin has experienced rapid urban growth. Stormwater runoff associated with this growth is a major contributor to the degradation of water quality and the destruction of fish habitats. In response to these environmental concerns, a variety of stormwater management technologies have been developed to mitigate the impacts of urbanisation on the natural environment. These technologies have been studied, designed and constructed on the basis of computer models and pilot-scale testing, but have not undergone extensive field-level evaluation in Ontario. The SWAMP Program was developed to address this need.

The SWAMP Program's objectives are:

* to monitor and evaluate the effectiveness of new or innovative stormwater management technologies; and
* to disseminate study results and recommendations within the stormwater management industry.

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Additional information concerning SWAMP and the sponsoring agencies is included in Appendix A.

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- the Government of Canada's Great Lakes Sustainability Fund
- the Ontario Ministry of Environment and Energy
- the Toronto and Region Conservation Authority
- the Municipal Engineers Association of Ontario

Funding support for this project was provided by the Great Lakes 2000 Cleanup Fund (superseded by the Great Lakes Sustainability Fund), the Ontario Ministry of Environment and Energy (OMOEE) and the City of Toronto (formerly the City of North York). The OMOEE also provided office facilities and logistic support for the SWAMP program. The Laboratory Services Branch of the OMOEE provided laboratory analyses. Administrative support to the SWAMP program was provided by the Toronto and Region Conservation Authority. The stormwater infiltration system evaluated in this report was conceived and designed by Raffi Bedrosyan and design staff from the City of Toronto. Staff at the City of Toronto also provided assistance with the hydrant test and drainage area calculations.

The following individuals provided technical advice and guidance:

- Dale Henry — Ontario Ministry of Environment and Energy
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- Raffi Bedrosyan — City of Toronto (formerly City of North York)

EXECUTIVE SUMMARY

In 1997, an innovative swale and perforated pipe infiltration stormwater system was constructed in a low density residential neighbourhood within the Wilket/Milne Creek subwatershed of the Don River. The system was intended to provide runoff quantity and quality control as part of the Wilket/Milne Creek Regeneration Plan and Don Watershed Management initiatives undertaken by the City of North York (now part of the City of Toronto) and the Toronto and Region Conservation Authority (TRCA). Use of this stormwater management approach was expected to provide significant improvements over the former ditched road network while avoiding the need to construct new storm sewer outfalls.

In 1998, a joint agreement was entered into by the City of North York, Ministry of Environment and Energy, the Government of Canada's Great Lakes 2000 Clean-up Fund (superseded by the Great Lakes Sustainability Fund) and TRCA to monitor the facility under the Stormwater Assessment Monitoring and Performance (SWAMP) program. The objectives of this monitoring study were to evaluate system performance in terms of runoff quality and quantity, identify benefits and limitations of the facility, and provide recommendations for improvements and further research needs.

Infiltration System Design

Figure 1 shows a simplified schematic of the infiltration system. The system consists of two components; a grassed swale (0.3 m deep x 3.0 m wide) and an underground infiltration trench (2 x 2 m in cross-section) located below the swale. The trench is lined with filter cloth and filled with granular 'A' gravel. The swale receives drainage from sidewalks, driveways and adjacent grassed areas. Runoff from the roadway is routed to catchbasins and subsequently directed to the infiltration trench via a 250 mm diameter lateral pipe. This lateral connects with a central 150 mm diameter filter cloth-wrapped perforated pipe laid within the trench aggregate at about 700 mm above the trench base.

At the downstream–most point in the trench, another 150 mm diameter pipe routes discharge water from the trench to a central storm sewer. A 250 mm diameter overflow relief pipe is connected to each catchbasin at 300 mm above the level of the infiltration lateral and drains into the central storm sewer. By design, the free water level within the trench must rise above 1.0 m from the base of the trench to engage the overflow relief pipe. Goss traps in the catchbasins, located at the lateral into the filtration trench and at the overflow lateral to the central storm sewer, reduce the amount of floating material that enters the pipes.

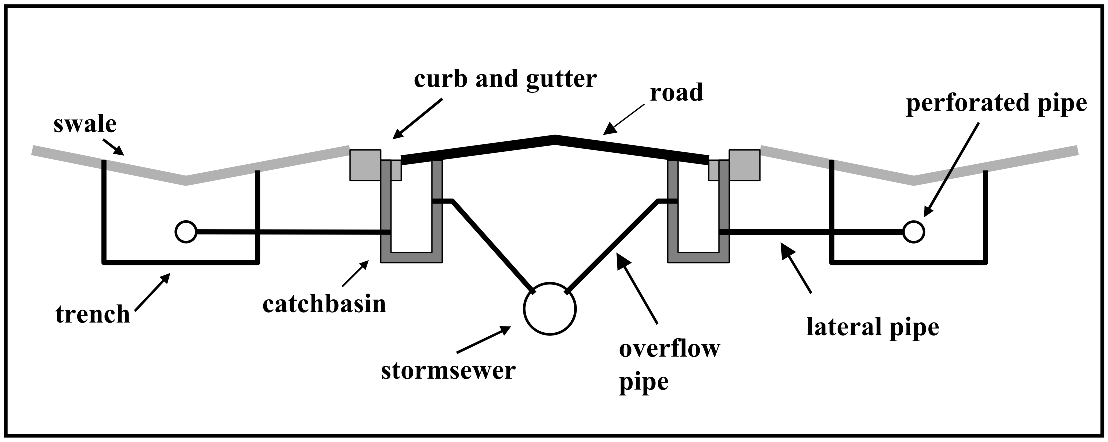

Figure 1: Simplified schematic of the infiltration system.

Study Approach

The performance assessment of the infiltration system was based on co-ordinated monitoring of rainfall, runoff and water quality. Pollutant concentrations and flow rates at the infiltration system inlet could not be directly monitored because of the multiplicity of overland flow and catchbasin inputs to the system. Therefore, water samples and flow measurements were taken from a nearby reference site with a conventional stormwater sewer system and similar land use. Performance of the infiltration system was assessed by comparing flow statistics and pollutant loads at the reference site with a similar set of measurements at the infiltration system outlet. Detailed impervious area estimates of roads, roofs and driveways provided the basis for comparing the two sites. Additional insights on the hydraulic capacity of the system were gained by conducting fire hydrant tests.

Study Results

Water quantity

A total of 21 small storms (< 5 mm rainfall), 12 medium sized storms (5 to 15 mm) and 8 large storms (>15 mm) were monitored from June to December in 1998 and 1999. Based on the reference site influent data set, flow reduction from the inlet to the outlet for storms with more than 5 mm of rain averaged 89%, ranging from a low of 77% to a high of 98%. The runoff coefficient, which is a measure of the proportion of catchment rainfall converted to stormwater runoff, was only 0.02 (or 2%) at the infiltration system outlet, compared to an estimate of 0.19 (or 19%) at the inlet.

Although the drainage area of the infiltration system site was more than five times larger than the reference site, peak flows at the infiltration system outlet were much smaller, averaging 7 and 42 L/s at the infiltration system and reference sites, respectively. Even during large storms, outlet peak flows were consistently less than 20 L/s. Most small storms (less than 5 mm) generated only negligible outflow, indicating that influent runoff was infiltrated to the surrounding soils.

A set of two 'hydrant tests' conducted on the downstream 100 m of the system indicated that the maximum inflow rate to each catchbasin without causing overflow was 11 L/s. This flow rate is roughly equivalent to a surface runoff rate within the study area of 554 m^3/hr, or a rainfall intensity of 16.0 mm/hr. However, a set of simple calculations based on the system geometry and data collected at the site indicates that the total capacity of the system to store, infiltrate and discharge runoff during a storm event would be approximately equivalent to 938 m^3 of surface runoff over the first hour of runoff, which in terms of rainfall, is roughly equivalent to an intensity of 28 mm/hr. Comparison of the hydraulic capacity of the system (554 m^3/hr) based on the maximum inflow rate, and the capacity of the system based on storage, infiltration and discharge (938 m^3/hr), suggests that system throughput is restricted to less than might be expected based on pipe and soil friction alone. Air entrapment within the pipes or gravel is suggested as a possible source of flow restriction.

Based on the difference between the volume of water pumped during the hydrant test and the volume of water exiting the system, together with the duration of the test, the unsaturated hydraulic conductivity of the soil surrounding the trench was crudely estimated at 1.4×10^{-5} m/s. This average infiltration rate corresponds to that of silty sand, and is just less than the 2×10^{-5} to 8×10^{-5} m/s estimate of average unsaturated hydraulic conductivity presented in the soils investigation report for the study area. Areas with soil infiltration rates less than 4.2×10^{-6} m/s are not considered suitable for perforated pipe infiltration systems.

Water quality

Water samples from 13 separate rainfall events were collected for this study between June 1998 and December 1999. Samples were analyzed for particle size and the major groups of pollutants found in stormwater runoff including heavy metals, nutrients, oil and grease, and total suspended and dissolved solids.

At the infiltration system outlet, average event mean concentrations (AEMCs) were greater than at the conventional system for 61% of the parameters analyzed, 64% of which were significantly higher at the 95% confidence level.

Outlet concentrations for total suspended solids (TSS) averaged 259 mg/l at the infiltration system outlet, compared to an average of only 29 mg/l at the conventional sewer reference site. The discrepancy in TSS concentrations between the reference site and infiltration system outlet was an unexpected finding. By design, settling within the catchbasins was to have provided some pre-treatment of suspended solids, with further removal occurring within the infiltration trench before the water is discharged to the outflow pipe at the downstream end of the system. Possible explanations for the discrepancy in TSS concentrations between sites may include: (i) higher sediment loading rates at the infiltration system site, possibly due to frequent construction activity observed during the monitoring period; (ii) leakage of material through holes in the filter cloth wrapped around the outflow pipe, perhaps caused by rodents in the pipe; and (iii) bypass overflow into the storm sewer, which by design is flushed only during large storm events, and would therefore be subject to higher rates of sediment buildup from wind-blown dust and animals living in the pipe than the reference site. This comparison of concentrations should not be confused with the mass of suspended solids discharged from the two systems.

Other typical stormwater contaminants such as copper, lead, phosphorous and zinc had lower outlet concentrations relative to the reference site, although these still exceeded provincial guidelines for the protection of aquatic habitat in receivng waters. Only two parameters (mercury and oil/grease) had concentrations below the detection limit in one or more of the samples collected.

The particle size distributions from both the infiltration system and the reference site exhibited a large amount of variability. However, the average distrubutions suggest that the median particle size at the infiltration site (5.3 μm) was larger than that of the reference site (3.0 μm). As with TSS concentrations, this was an unexpected result, further suggesting that particulate material may have originated from overflow situations or an extraneous source.

Load-based removal efficiency calculations were based on two events for which composite samples were collected at both the reference site and infiltration system monitoring stations. The volumetric reduction in flow by the infiltration system for the two events was 91%. By comparison, overall load-based removal efficiencies were 91% for nutrients (average of nitrogen and phosphorus species), 51% for metals and, due to much higher concentrations at the infiltration system outlet (as explained above), only 24% for total suspended solids. Removal efficiencies above 80% were noted for mercury, all nitrogen species (TKN, ammonia, nitrates, nitrites), total phosphorus, phosphate, BOD, COD, titanium, cobalt, nickel, zinc and copper. Annual or seasonal removal efficiencies would probably be greater than cited above since 100% removal was achieved during several small events.

Conclusions and Recommendations

The results of this study indicate that the swale and perforated pipe infiltration system met most of its design objectives, including substantial reductions in total runoff and peak flow rates, removal of contaminants through infiltration and soil storage, and increased groundwater recharge. The relatively low TSS removal rate at the infiltration system outlet is a concern, but is likely due to a combination of construction activities during the study and the need for maintenance or minor modification to one or more elements of the system (*e.g.* goss traps, filter cloth, perforated pipe, sewer pipe), rather than an inherent defect in the system design.

The following recommendations are provided based on study findings:

System remediation and operation:

- The type of goss trap employed in the catch basins at this site should be examined to determine if they impose a restriction on system throughput.
- If the goss trap is found to restrict system throughput, the trap should be modified (*e.g.* add a breather to prevent air entrapment) and another hydrant test should be conducted to assess the full capacity of the filter bed to store, infiltrate and discharge runoff. Alternatively, the hydraulic capacity of the system could be assessed by pumping water directly into the perforated pipe.
- The invert of the system outlet pipe should be relocated well above the bottom elevation of the trench to provide additional net storage within the trench and increase infiltration rates. This configuration would further reduce outlet runoff.
- Individual catchbasins should be regularly inspected for goss trap clogging or excessive debris or sediment build-up.

Follow-up monitoring:

- After 10 years of system operation, soil and groundwater quality below infiltration trenches should be assessed against the pre-construction soil and water quality dataset to determine chemical impacts (if any) on groundwater resources.
- Hydraulic parameters documented in this study (*e.g*. inlet-outlet lag times, overflow thresholds, outlet runoff coefficients) should be used as a baseline against which follow-up monitoring can be compared. Changes in parmeters such as lag times or outlet runoff coefficients would provide a warning that specific components of the system may be in need of maintenance or repair.

Proposed future research:

- To provide a better basis for modeling system performance under different site conditions, continuous measurements of runoff and rainfall should be supplemented with information on water level changes in the filter beds and catchbasins and an additional flow measurement in the infiltration system overflow storm sewer upstream of the point at which the filter bed outflow pipe drains into the storm sewer. These additional measurements would permit independent assessment of the normal and overflow pathways through the facility and provide an improved understanding of system performance during rainfall events.
- Long-term effects may be examined and/or predicted by conducting tests on a model system. The model could be loaded more frequently than full-scale system permitting measurement of the fate of most pollutants.

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