Evaluation of Underground Stormwater Infiltration Systems

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Evaluation of Underground Stormwater Infiltration Systems

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NOTICE

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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 helps 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 for implementing technologies;
- develop supporting 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 products or devices; they may also include preventative measures, alternative urban site designs, and other innovative practices that help create more sustainable and liveable communities.

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EXECUTIVE SUMMARY

Background

Stormwater infiltration practices are an integral part of progressive approaches to stormwater management. These practices help to reduce the volume of urban runoff discharged to watercourses thereby minimizing flood risk and preventing alterations to the stream flow regime and channel form. They help to maintain groundwater levels and sustain stream flows during dry periods. They also reduce pollutant loading to receiving watercourses by reducing runoff volume and retaining or breaking down pollutants in the engineered structures and underlying native soil. They can be designed for application at the ground surface (e.g., permeable pavement, bioretention, infiltration basins) or below ground (e.g., infiltration chambers, trenches, soakaways, and pervious pipe exfiltration systems). An advantage of underground infiltration technologies is that they can be located below parking lots, roads, parkland or other landscaped areas. In densely developed urban areas, where the value of land is very high, this often makes them preferable to surface practices.

Despite their advantages stormwater management system designers are often reluctant to recommend the application of infiltration practices on fine textured soils due to their limited permeability and concerns over the size of facilities that would be required to meet regulatory requirements. Since most of the designated urban growth areas in the Greater Toronto Area and other urban centres in southern Ontario are located on fine-textured glacial till soil, there is considerable interest in how effective infiltration practices are in such contexts. This study helps to address this knowledge gap by evaluating the effectiveness of three underground stormwater infiltration systems constructed over fine-textured glacial till soils draining roof runoff from industrial/commercial developments located in the Greater Toronto Area.

Study Sites

The three underground stormwater infiltration systems evaluated in this study are:

- An infiltration chamber system servicing the Elgin Mills Crossing commercial development in Richmond Hill, Ontario;
- An infiltration trench system servicing the Mayfield Industrial Park in Bolton, Ontario; and
- An infiltration chamber system servicing the Bramport commercial centre in Brampton, Ontario.

The table below provides an overview of design characteristics of each system.

The Elgin Mills Crossing infiltration chamber system is installed under the parking lot of a shopping centre development in Richmond Hill, Ontario. The chamber system receives roof runoff from two large commercial buildings (combined roof area of 25,449 m^2). The StormTech SC-740® stormwater infiltration chamber system was installed to maintain average annual infiltration volume over the site to pre-development levels, thereby helping to maintain aquifer water levels and groundwater discharge to the Rouge River tributary adjacent to the site, and minimize the increase in runoff caused by the development. Native subsoil at the site is sandy silt glacial till, which underlies the entire site. The low permeability sandy silt till deposits overlie a lens-shaped deposit composed mainly of more permeable

silty fine sand at shallow depths. The chambers were strategically located near the river valley over an area where the gravel base could intersect with the silty fine sand lens to help ensure that pre-development groundwater discharge rates and volumes to the Rouge River would be maintained. The infiltration chamber system and contributing storm sewers were designed to temporarily store 955 m^3 of runoff which is roughly equivalent to a 41 mm precipitation event over the combined roof drainage area, assuming 10% loss of precipitation to evaporation. The seasonally high water table in the vicinity of the chamber system is estimated to be between 2 to 3 m below the ground surface in April and May, raising the possibility that groundwater levels may reach elevations above the base of the chamber system during the spring, which would affect drainage times.

Facility Name and Type	Drainage Area (m^2)	Storage Capacity (m^3)	Infiltration Volume Target (m^3/y)	Native subsoil texture	Assumed Subsoil Hydraulic Conductivity (cm/s)
Elgin Mills Crossing infiltration chamber system	25,449	955	14,494	Sandy silt glacial till	1×10^{-6}
Mayfield Industrial Park infiltration trench #1	14,962	126	6,015	Clayey silt glacial till	1×10^{-6}
Mayfield Industrial Park infiltration trench #2	20,101	126	8,081	Clayey silt glacial till	1×10^{-6}
Mayfield Industrial Park infiltration trench #3	23,268	126	9,380	Clayey silt glacial till	1×10^{-6}
Mayfield Industrial Park infiltration trench #4	14,420	184	6,456	Clayey silt glacial till	1×10^{-6}
Bramport infiltration chamber system	33,500	1,192	0	Sandy silty clay glacial till	1×10^{-6}

The Mayfield Industrial Park infiltration trench system is installed below parking and landscaped areas in a commercial/industrial area in Bolton, Ontario. The system is composed of four trenches (referred to as Mayfield Trenches 1, 2, 3 and 4) that receive runoff from the roofs of two large buildings in the industrial park. The system was designed to maintain average annual infiltration volume over the lots at pre-development levels and reduce post-development runoff volume to the Humber River tributary to which drainage from the site is directed. Native subsoil at the site is low permeability clayey silt glacial till which underlies the entire site. Mayfield Trenches 1, 2 and 3 receive runoff from roof drainage areas ranging from 14,962 m^2 to 23,268 m^2. Each infiltration trench, control manhole and contributing storm sewer pipe provides temporary storage of 126 m^3 of roof runoff. Based on this storage volume and the size of each roof drainage area, it can be estimated that Mayfield Trenches 1, 2 and 3 should be able to capture roof runoff from storm events up to 9.4, 7.0 and 6.0 mm in depth respectively, assuming 10% loss of water to evaporation. Mayfield Trench 4 receives runoff from a 14,420 m^2 roof area and provides temporary storage of 184 m^3 of runoff. Based on this storage volume and the roof drainage area, it can be estimated that Mayfield Trench 4 should be able to capture roof runoff from storm events up to 14 mm in depth, assuming 10% loss of water to evaporation. Seasonally high water table elevations in the vicinity of the trench system are estimated to be between 14 to 19 metres below the base of the trench system, so groundwater levels should not affect trench drainage times.

The Bramport infiltration chamber system is installed below a parking lot in a shopping centre development in Brampton, Ontario. The CULTEC Recharger V8HD® subsurface stormwater chamber system receives roof, road and parking lot runoff from a 33,500 m^2 drainage area via two storm sewer inlets and a catchbasin inlet directly above it and ultimately drains to a warm water tributary of the Humber River. The system was designed to provide temporary storage and controlled release of runoff from storms up to the 100 year return period event with the opportunity for infiltration. However, the water storage capacity of the system (1,192 m^3) was sized assuming no infiltration would be achieved, because the characteristics of the native subsoil and underlying geology encountered during geotechnical investigations suggested low levels of permeability. Native subsoil at the site is low permeability sandy silty clay glacial till which underlies the entire site. The chamber system covers an area of 1,520 m^2, including an 833 m^2 area below the western half of the chamber system where the underlying gravel bed is 0.3 m deeper than the bed below the remainder of the system and has no outlet. This gravel bed storage area provides 100 m^3 of water storage in addition to what was required to meet flood control requirements. It was included in the design of the system to act like a permanent pool to provide better retention of sediment. It also allows monitoring of water levels to evaluate whether or not the additional gravel bed storage area drains between storm events and to estimate the post-development infiltration rate of the native subsoil if drainage does occur. Seasonally high water table elevations in the vicinity of the infiltration chamber system are estimated to be between 2.5 and 4.6 metres below ground surface and that perched groundwater likely occurs in places at shallow depths during wet seasons, which could periodically affect drainage times.

Monitoring Locations and Parameters

Monitoring at the Elgin Mills Crossing infiltration chamber system site was initiated in September 2008 and continued to the end of July 2011. Rainfall was measured with a three season tipping bucket rain gauge located less than one kilometre south of the site. Winter precipitation data (daily totals) were taken from the Buttonville Airport meteorological station located approximately 5 km southeast of the site. An area velocity sensor was installed in a storm sewer pipe that conveys flows from the chamber system control manhole to downstream storm sewers to provide information on the volume of outflow from the system for each storm event and cumulatively over the whole monitoring period. Continuous water level measurements in the inlet side of the control manhole at 5 minute intervals using calibrated pressure transducers provided the basis for calculating drainage times and infiltration rates. A pressure transducer was also installed to collect continuous water level measurements in a well located 20 metres from the chamber system and installed to an elevation that corresponds to a depth of one metre below the base of the system. Well water level data was collected over a June 3, 2009 to December 13, 2010 monitoring period and provided the basis for determining if water table elevation reaches the base of the chamber system.

Monitoring at the Mayfield Industrial Park infiltration trench system site was initiated in July 2009 and continued to the end of June 2011. Rainfall was measured with a three season tipping bucket rain gauge located within 5 km of the site. Winter precipitation data (daily totals) were taken from the Lester B. Pearson International Airport meteorological station located approximately 20 km southwest of the site. Continuous water level measurements in the inlet sides of the control manholes at 5 minute intervals using calibrated pressure transducers provided the basis for calculating drainage times and infiltration rates. Pressure transducers were also installed on the outlet sides of the control manholes for a portion of the monitoring period to determine if the control manholes were leaking.

Monitoring at the Bramport infiltration chamber system site was initiated in June 2009 and continued to the end of July 2011. Rainfall was measured with a three season tipping bucket rain gauge located within 5 km of the site. Winter precipitation data (daily totals) were taken from the Lester B. Pearson International Airport meteorological station located approximately 12 km southeast of the site. Calibrated pressure transducers were installed in observation port wells that extend to the depth of the deepest portion of the gravel base in which the chambers were installed to estimate post-development infiltration rates in the undrained 0.3 m deep gravel bed area under the western half of the chamber system. An area velocity sensor was installed in the pipe connecting the control manhole to the chamber system to provide an indication of when flow from the chamber system into the control manhole had ceased, confirming that subsequent water level declines in the observation port well reflect losses to infiltration only.

Study Findings

At all the sites examined in this study, post-development infiltration rate of the underlying native subsoil was lower than expected resulting in slower than expected drainage of stored runoff and in some cases more frequent occurrence of overflow than anticipated. In the case of the Bramport system, it was observed that the portion of the gravel bed below the chamber system that has no outlet does not drain between storm events. In both the Elgin Mills Crossing and Mayfield Industrial Park infiltration systems it was observed that infiltration rates decreased exponentially as water levels (i.e. hydraulic head) in the systems declined. Observed infiltration rates for the Elgin Mills Crossing and Mayfield Industrial Park infiltration systems did not exhibit significant seasonal variation. This is due to the fact that the base of each system is approximately 2.5 to 3.5 metres below ground surface and therefore is well insulated from surface temperature fluctuations throughout the year. The infiltration systems examined required longer than 72 hours to fully drain once filled to capacity and the control manholes contained standing water for much of the year, which raises the question of whether or not they provide mosquito breeding habitat.

Although these systems did not achieve their drainage time design objectives, two of the three stormwater infiltration systems evaluated provided substantial reductions in runoff volume from their roof drainage areas. In the case of the Elgin Mills Crossing infiltration chamber system, even though the control manhole was observed to be leaking a small amount of water around the weir plate and the system drained slower than expected, monitoring indicates that during a normal precipitation year, the system reduces runoff from the roof drainage area in the order of 90% and infiltrates the volume of water necessary to match what would have infiltrated over the lot area prior to development. In the case of the Mayfield Industrial Park infiltration trench system, it was possible to conclude that the system is not achieving the design objective of fully compensating for the loss of infiltration caused by development of the site. In a normal precipitation year it is estimated that Mayfield Trenches 1 and 3 reduce runoff from their respective roof drainage areas in the order of 16% and Mayfield Trench 4 reduces roof runoff by approximately 36%. It was estimated through modeling that water storage capacity of the trenches would need to be between 1.9 and 4.5 times greater than the trenches currently provide in order to infiltrate the targeted volume of roof runoff that would mitigate the loss of infiltration on an average annual basis. If the

Mayfield trenches had been sized as such, it is estimated that they would reduce runoff from their respective roof drainage areas in the order of 53 to 61%. While the Mayfield Industrial Park infiltration trenches are draining more slowly than expected, results of this evaluation suggest that if they had been designed based on better knowledge of the permeability of the native subsoil, they could fully compensate for the loss of infiltration caused by the development through infiltration of roof runoff alone. This finding is significant considering that infiltration practices are widely considered to have limited effectiveness on fine-textured soils.

Deficiencies in the function of control manholes designed to retain water in the infiltration systems were observed in 3 of the 5 facilities monitored, which suggests that improvements to control manhole design, material specifications, or construction and inspection practices are warranted. Visual inspection of the stormwater infiltration systems at a time when the facilities were filled to a level above the elevation of the outflow sewer pipe invert would have revealed that some of the control manholes were leaking.

Sediment accumulation at the bottom of control manholes was also observed in 3 of 5 facilities monitored. While sediment accumulation was not found to be impacting the hydrologic performance of the facilities, it was causing issues with function of the control manholes for evaluating drainage times.

While results from the Elgin Mills Crossing and Mayfield Industrial Park systems support the implementation of stormwater infiltration systems on fine textured soils, monitoring results from the Bramport infiltration chamber system suggest that little or no runoff reduction benefit is being achieved by designing the system to provide the opportunity for infiltration, as was anticipated at the time of its design. It is possible that in the Bramport case, the infiltration chamber system has raised the seasonally high water table or that a perched water table has been created that does not dissipate or drains so slowly that the inter-event periods during this monitoring study were not long enough to observe substantial change in water levels. While results from this study could not confirm whether or not a perched water table has been created, they highlight the importance of careful consideration of the underlying stratigraphy and predevelopment water table elevation when deciding on suitability of the site for stormwater infiltration practices.

Recommendations

1. It is strongly recommended that stormwater infiltration facilities be thoroughly inspected by the construction project manager, system designer or ultimate owner/manager of the infrastructure prior to assumption (i.e. acceptance). Inspection procedures should include continuous water level monitoring over several storm events or a synthetic runoff test to determine if the system is functioning as designed. Contracts that include construction of such stormwater infrastructure should include conditions whereby any defects or deficiencies revealed through final inspection and testing can be corrected prior to assumption.
2. Leakage of water from the inlet side to the outlet side of the control manholes was observed in 2 of the 5 facilities indicating that sealing of the joints between components used to construct the manholes needs to be improved or given more attention during construction.

3. In the control manholes, including an outlet with a valve through the weir plate that can be operated from the outlet side would better facilitate inspection and maintenance by allowing the system to be drained via gravity.
4. Incorporating sumps in the control manholes would help prevent clogging of the bottom perforated pipes from sediment accumulation.
5. Since infiltration rates observed when the systems were full or nearly full were approximately 2.5 times higher than when the systems were half full or less, stormwater infiltration practices to be located on fine-textured soil should be designed to maintain hydraulic head in the water storage reservoirs for longer than the typical target of 48 to 72 hours. This would help maximize the drainage rate and thereby, the volume of water infiltrated on an annual basis. On low permeability, clayey silt soils like those occurring at the Mayfield Industrial Park site this means designing infiltration systems that never fully drain between storm events.
6. A practice that would improve the runoff reduction effectiveness of underground stormwater infiltration systems located on low permeability soils while providing an additional benefit of conserving potable water is to install a submersible pump in the inlet side of the control manhole to draw on the stored water for uses not requiring potable water (e.g. landscape irrigation, vehicle washing), like a rainwater harvesting cistern.
7. In future designs of stormwater infiltration systems located on low permeability soils, it is recommended that the type of covers used on control manholes should contain no holes at all, or screens to help ensure mosquitoes cannot enter them.
8. In locations with fine textured subsoil and seasonally high water table or bedrock surface at least 3.5 metres below ground surface, design criteria for stormwater management systems servicing industrial, commercial and institutional developments, where roof area represents 50% or greater of the lot area, should include maintaining average annual pre-development infiltration volume over the lot through infiltration of roof runoff, where feasible.

Topics For Future Research

1. *Medium to long term evolution of hydrologic performance*. This study examined hydrologic performance of underground stormwater infiltration practices located on fine textured soils within a short time period following their construction (less than 5 years post-construction). Little information is currently available in published reports regarding their performance over longer periods of service. Monitoring drainage times of stormwater infiltration practices located on fine-textured soil over the medium term (10 years post-construction) to long term (20 years post construction) to examine how hydrologic performance evolves over time is of interest to better understand the useful lifespan of such facilities and possibly to evaluate what maintenance or rehabilitative procedures could be undertaken to restore their effectiveness, other than complete reconstruction.
2. *Presence of mosquito larvae*. While grab samples from control manholes of the underground infiltration practices examined in this study indicated no presence of mosquito larvae, considering that such practices may contain standing water for much of the year, additional sampling of a larger number of facilities is of interest to evaluate whether or not they provide mosquito breeding habitat.

3. *Routine operation and maintenance*: Monitoring sediment accumulation in pretreatment structures and control manholes of underground stormwater infiltration practices is of interest to determine accumulation rates, evaluate quality and disposal options and estimate cost of inspection and maintenance over the lifespan of the facilities.

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