Evaluation of Residential Lot Level Stormwater Management Practices

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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:

Dean Young
Project Manager, Sustainable Technologies
Toronto and Region Conservation Authority
5 Shoreham Drive,
Downsview, Ontario
M3N 1S4

Tel: 289-268-3904
E-mail: dyoung@trca.on.ca

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

Tel: 289-268-3902
E-mail: tvanseters@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 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

Progressive approaches to stormwater management, often referred to as Low Impact Development (LID), attempt to mimic pre-development hydrology through improved site design and distributed lot level practices that treat runoff as close to the source as possible. Lot level practices include engineered structures such as rain gardens, soakaways and permeable pavements that filter, infiltrate and evaporate runoff. They can also include non-structural practices such as directing roof downspouts to gently sloping landscaped areas that contain topsoil of sufficient permeability, depth and quality to infiltrate and evaporate a significant portion of runoff during wet weather. Such practices help to reduce runoff volume, maintain groundwater levels and sustain stream flows during dry periods. They also reduce pollutant loads to receiving waters by retaining or breaking down pollutants in the engineered structures and soil.

While performance of individual lot level best practices in the geologic and climatic contexts of southern Ontario is becoming well understood through local studies (TRCA, 2008; Drake et al., 2012; Young et al. 2013), little information is available that quantifies overall runoff reduction benefits associated with widespread implementation of these practices at a catchment (i.e. community) scale. Although draining roof downspouts to landscaped areas is standard for new residential developments in the Greater Toronto Area, not much is known about the effectiveness of this practice to manage runoff. Furthermore, there is little known about how much more effective it could be by increasing topsoil depth and quality in the landscape areas receiving roof drainage. This study helps to address this knowledge gap by evaluating at the catchment scale, the hydrologic benefits of widespread application of two types of lot level stormwater management practices in newly constructed residential developments:

- Increased topsoil depth; and
- Rear yard infiltration trenches with grass swale pretreatment.

To verify conclusions drawn from the catchment scale evaluation of increased topsoil depth and to characterize what further benefits could be achieved with addition of a compost blanket amendment (i.e. increased topsoil depth and quality), evaluations of test boxes designed to simulate turf grass landscaped areas exposed to natural precipitation were also conducted.

Study Sites

<u>Catchment Scale Evaluations</u>
The residential subdivision in which these lot level practices have been implemented is the community of Box Grove, located in Markham, Ontario. The evaluation involved simultaneous monitoring of storm sewer flows from three catchments of similar slope, soil type and impervious cover. One catchment served as an untreated control while the other two represented treated catchments where certain lot level stormwater practices have been implemented on a widespread basis (i.e. multiple lots). Measured total runoff volumes and flow rates per hectare of drainage area from each catchment were compared on a storm event basis and cumulatively over a two and a half year monitoring period.

In this study a 3.06 hectare catchment containing 58 residential lots of conventional design serves as the control catchment. In the Control catchment (CTL) 10 to 15 cm of stockpiled site topsoil was to be applied to landscaped areas over compacted subsoil, which is conventional construction practice. A 3.43 hectare catchment containing 52 residential lots serves as one of the treated catchments, in which a greater depth of topsoil was applied to landscaped areas. In the Increased Topsoil Depth (ITD) catchment stockpiled site topsoil was to be applied to all landscaped areas to a typical depth of 30 cm and up to 120 cm along 3.5 metre (m) wide swales oriented along rear lot lines. In order to understand the hydrologic benefits of increased topsoil depth alone, the subsoil was not decompacted (e.g. tilled or scarified), nor was the topsoil amended with compost. A 2.85 hectare catchment containing 60 residential lots serves as the second treated catchment, where runoff from rear draining portions of roofs and yards from approximately 30 of the lots is directed to three infiltration trenches via grass swales oriented along rear lot lines.

Developments in all three catchments consist entirely of fully detached residences on roughly 350 square metre (m^2) lots, with varying portions composed of residential roads, driveways and sidewalks. Roofs and sidewalks drain to landscaped areas in all three catchments but roads and driveways do not so any hydrologic benefits in the treated catchments will be limited to runoff generated from roofs, sidewalks and pervious areas that drain to the lot level practices. The table below summarizes the characteristics of each catchment in terms of total area, percent pervious and impervious cover and impervious cover type. Impervious cover in the Control catchment is slightly higher (5% greater) than in the Increased Topsoil Depth and Rear Yard Infiltration Trenches catchments and slight differences exist in the portion of impervious cover that drains directly to storm sewers (i.e. % roads and driveways). Site subsoils are glacial drift deposits of sandy silt till and silty sand till to at least two metres depth below the ground surface. At depths greater than two metres below ground surface a layer of more permeable silty fine sand of variable extent exists below the Rear Yard Infiltration Trenches catchment only.

Parameter	**Control catchment (CTL)**		**Increased Topsoil Depth catchment (ITD)**		**Rear Yard Infiltration Trenches catchment (RYIT)**	
	Area (ha.)	%	Area (ha.)	%	Area (ha.)	%
Drainage area	3.05	100	3.43	100	2.85	100
Total pervious cover[1]	1.06	34.7	1.38	40.3	1.15	40.2
Total impervious cover	1.99	65.3	2.05	59.7	1.70	59.8
Roofs	1.05	34.4	1.18	34.3	0.79	27.9
Driveways	0.29	9.6	0.33	9.6	0.24	8.4
Roads	0.54	17.8	0.45	13.2	0.58	20.3
Sidewalks	0.11	3.5	0.09	2.6	0.09	3.2

Test Box Scale Evaluations

This component of the study was conducted on the Kortright Centre for Conservation property, located at 9550 Pine Valley Drive in Vaughan, Ontario. A gently sloping plot of land at the conservation area is where six (6) test boxes designed to simulate turf grass landscaped areas subjected to three different soil treatments were installed. The test boxes were installed in dug pits slightly larger than the boxes to maintain soil temperatures close to natural conditions. The different soil treatments examined were as follows:

1. Standard topsoil depth (10 cm), no compost amendment;
2. Increased topsoil depth (25 cm) with compost blanket (5 cm depth) amendment; and
3. Increased topsoil depth (30 cm), no compost amendment.

The test boxes were exposed to natural precipitation and monitored for runoff and infiltration volume following each storm event, and evapotranspiration loss and change in topsoil moisture between storm events over a summer to fall 2012 monitoring season.

Two boxes were constructed for each soil treatment using topsoil obtained from a construction site near the Box Grove community and were monitored side-by-side. Each box contained a 30 cm deep layer of sandy silt till subsoil that was compacted. The surface of each test box was planted with turf grass (rolls of sod) of the same variety. The 48 cm wide by 44 cm long (surface area of 2.112 m^2) test boxes were constructed to allow collection of runoff from the turf grass surface in 6 litre (L) bottles and infiltrated water in 4 L bottles. They were also designed to include a wooden frame support that allowed the boxes and attached bottles to be hoisted from their pits using a tripod and winch and weighed using an industrial grade hanging scale.

Monitoring Parameters and Locations

Catchment Scale Evaluations

Monitoring parameters, locations and equipment were selected to provide the information needed to measure rainfall depth and intensity in the community and runoff volume and flow rate from each catchment on a storm event basis. Monitoring was initiated in July 2010 and continued until November 2012. Rainfall was measured with a tipping bucket rain gauge located less than three kilometres west of the catchments, which provided continuous data on rainfall depth at five minute intervals. Area velocity sensors were installed in storm sewer pipes at the catchment outlets to provide runoff volume and flow rate data. Flow volume from each catchment was calculated by summing flow rate values on a storm event basis and for all events reliability captured over the monitoring period. Due to differences in catchment size, measured runoff volume and flow rate values were normalized by drainage area to allow reasonable comparisons of runoff characteristics between the catchments to be made.

Based on measured rainfall depth and runoff volume, catchment runoff coefficients were calculated for each storm event and used to calculate mean values for all events less than or equal to 15.0 mm in depth but greater than 5.0 mm (i.e. small to medium size events), and all events greater than 15.0 mm in depth (i.e. large events) captured over the monitoring period. For each catchment, total runoff volume over the monitoring period was calculated according to these storm event depth ranges and used to calculate runoff reduction ratios for the Increased Topsoil Depth and Rear Yard Infiltration Trenches catchments, relative to the Control catchment.

In the Rear Yard Infiltration Trenches catchment, calibrated pressure transducers were installed in wells designed for monitoring water levels in the three infiltration trenches. These sensors provided the means to determine under what rainfall conditions the trenches begin to receive runoff and the rate at which they drain. The pressure transducer sensors provided continuous measurements of trench water levels at five minute intervals.

Test Box Scale Evaluations

During the May to November 2012 monitoring period, precipitation at the test box site was monitored by a tipping bucket rain gauge located 0.5 km from the site. Within 48 hours of the end of a storm event the volume of runoff and infiltrate collected in the bottles was measured, the box/frame/bottles apparatus was weighed and topsoil moisture at 10 cm depth below the surface of the sod was measured using a hand held soil moisture probe. The bottles were then removed and emptied and the apparatus was reweighed. The weight of the apparatus was measured every 72 hours thereafter, until the next storm event occurred or until no change in weight was observed for three straight measurements. Topsoil moisture was measured each time the boxes were weighed. The measured data were examined to quantify differences in the fate of precipitation between the different soil treatments over the monitoring period and to examine how the compost blanket amendment affected topsoil moisture.

Study Findings

Implementation of Lot Level Practices in the Catchment Study Area

Inspection and testing to determine if implementation of the lot level stormwater management practices prescribed in the Box Grove residential community met their design specifications identified several deficiencies which affected their runoff reduction performance and raise important considerations regarding future design and implementation of such practices on private properties.

1. In the Increased Topsoil Depth catchment only about 15 cm of topsoil was applied in front yards, rather than the 30 cm that was specified in design documents.
2. In the Rear Yard Infiltration Trenches catchment owners of the three properties where the trenches are located were not aware of the presence, function or maintenance requirements of the structural stormwater management practice on their properties. At one property a deck and shed were constructed over top of the rear yard catchbasin and infiltration trench monitoring well, preventing access for monitoring, inspection and maintenance purposes.
3. Inlets to the infiltration trenches were inaccessible from the rear yard catchbasins, making inspection and maintenance of the trenches a complex process involving the use of a closed circuit camera and specialized cleaning equipment. Also, the design of the tee connection that was intended to deliver water from the storm sewer pipe leading from the catchbasin into the infiltration trenches is not the most reliable means of directing flows to the trenches and prone to failure.
4. Erosion and sediment controls put in place after the infiltration trenches had been constructed and prior to stabilization of the upstream drainage area were inadequate to prevent clogging of the trench inlets with sediment. Inlets to all three trenches were observed to be partly or fully clogged, necessitating an attempt to unclog them through the use of sewer cleaning equipment.

<u>Runoff Reduction</u>

Increased Topsoil Depth
The Increased Topsoil Depth catchment was observed to consistently exhibit lower mean runoff coefficients than the Control catchment for all storm event depth ranges examined. When total runoff depth over the monitoring period was compared, it was found that for small to medium size storm events the Increased Topsoil Depth catchment produced 22% less runoff per unit area than the Control catchment. For large storm events (i.e. greater than 15 mm in depth) the Increased Topsoil Depth catchment produced about 27% less runoff per unit area than the Control catchment. These findings suggest that the 22% less runoff observed from the Increased Topsoil Depth catchment during small to medium size events is likely due to differences in catchment land cover. The observation that runoff reduction increased to 27% when examined for only large storm events suggests that these are the conditions when increased topsoil depth in rear yards begin to provide runoff reduction benefits and that the magnitude of the benefit is in the order of 5% less runoff over the monitoring period. These results suggest that application of increased topsoil depth in rear yard areas alone, with no efforts made to reverse subsoil compaction prior to topsoil spreading, nor to amend site topsoil with compost to increase organic matter content, only provides minor runoff reduction benefits when examined at a catchment scale.

While overall runoff reduction ratios for the Increased Topsoil Depth catchment over the monitoring period were quite small, it is clear from examination of event hydrographs and comparisons of event runoff depths during large and intense storm events that the deeper topsoil applied to rear yard areas provided substantial benefits during some of these infrequent events. Event based differences in runoff depth between the Increased Topsoil Depth catchment and Control catchment indicate runoff reductions in the range of 20 to 40% per unit area were achieved during some of the most intense storm events captured over the monitoring period.

It is also evident that rainfall intensity is a factor influencing when runoff reduction benefits of increased topsoil depth are realized. Comparison of event hydrographs and catchment runoff depths during some large depth but low intensity rain events showed that peak flow rates and runoff depths from the Control and Increased Topsoil Depth catchments were very similar. This suggests that rear yard areas in the Control catchment did not generate substantial amounts of runoff during large, low intensity rain events.

Antecedent soil moisture content also appeared to influence the potential for increased top soil depth to provide runoff reduction benefits. Runoff depths from the Control and Increased Topsoil Depth catchments were very similar during some large and intense storm events that were preceded by very wet weather. This suggests that the practice of applying increased topsoil depth to landscaped areas may not consistently produce runoff reduction benefits during extended periods of wet weather because the soils eventually become saturated and begin to generate flow to a similar degree as conventionally constructed landscaped areas.

Rear Yard Infiltration Trenches
Based on comparison with the Control catchment, the Rear Yard Infiltration Trenches catchment was observed to exhibit slightly higher mean runoff coefficients for all storm event depth ranges examined

before the attempt to unclog the trench inlets. Water level monitoring in the infiltration trench wells indicated that only one of the three trenches in the catchment was receiving runoff from its drainage area during this period. After the attempt to unclog the trench inlets, mean runoff coefficients in the Rear Yard Infiltration Trenches catchment were slightly lower than the Control catchment, but differences were quite small and the same for all event depth ranges, suggesting that they were due to differences in catchment land cover alone. Based on water level monitoring in trench wells it can be concluded that at least one of the three trenches did not receive runoff from its drainage area after the attempt to unclog the inlets.

When total runoff depth over the monitoring period following the attempt to unclog the trench inlets was compared for small to medium size storm events it was found that the Rear Yard Infiltration Trenches catchment produced about 16% less runoff than the Control catchment. During large storm events the Rear Yard Infiltration Trenches catchment produced about 14% less runoff than the Control catchment. Assuming that pervious areas in the Control and Rear Yard Infiltration Trenches catchments only generate substantial volumes of runoff during large storm events these results suggest that the observed differences in runoff depth are likely due to differences in catchment land cover alone. Based on these combined results, it can be concluded that any runoff reduction benefits achieved by the functioning rear yard infiltration trench(es) occurred too infrequently and affected too small a portion of the total catchment area and total rainfall depth over the monitoring period to be detected through the catchment scale evaluation approach applied in this study.

Through monitoring of water levels in the infiltration trenches it was observed that trench #1 was receiving runoff from its drainage area and that it drained at a steady rate through infiltration into the underlying native soil. Based on the drainage times observed, it is estimated that trench #1 was achieving an infiltration rate of approximately 11 mm/h, which is what would be expected of a sandy silt glacial till subsoil.

Test Box Evaluations

Over the monitoring period runoff was observed from at least one test box during only eight (8) storm events. The smallest, least intense storm to produce runoff in any test box was the June 24, 2012 event when a total of 15.6 mm of rain fell over two back-to-back storms with a maximum rainfall intensity of 11.4 mm/h. This supports the hypothesis that pervious landscaped areas constructed with topsoil of similar quality and depth as that applied in the Box Grove community, do not generate substantial volumes of runoff during small to medium size storm events that are less than 15 mm in depth.

Overall, test box evaluation results indicate that the Standard Topsoil Depth boxes produced the most runoff and evapotranspired the least. The Increased Topsoil Depth With Compost Blanket boxes stored the most water at the end of the monitoring period while the quantity of rain that infiltrated and evapotranspired was similar to the Increased Topsoil Depth boxes. These results suggest that the practice of applying increased topsoil depth (25 to 30 cm) to grassed pervious areas should produce less runoff than a standard 10 cm depth and that additional runoff reduction and water storage benefits can be provided by amending topsoil with compost, as expected.

During both summer and fall months mean soil moisture was almost always higher in the Increased Topsoil Depth With Compost Blanket test boxes than in the Increased Topsoil Depth boxes, indicating that the compost blanket amendment increased the water holding capacity of the soil as expected. These results support the observation that the compost blanket amended test boxes produced less runoff and stored more water at the end of the monitoring period than the Increased Topsoil Depth boxes. They also suggest that applying a compost blanket amendment to topsoil in pervious areas prior to laying sod or planting grass seed would provide the additional benefit of creating a more drought tolerant, lower maintenance lawn that can survive for longer periods without irrigation.

Recommendations

1. The results of this study confirm that applying increased topsoil depth in landscaped areas provides runoff reduction benefits and supports widespread implementation of this lot level stormwater practice in future developments. Applying increased topsoil depth to all pervious areas receiving drainage from impervious surfaces, rather than just in rear yards, and adding a compost blanket amendment prior to planting would increase runoff reduction effectiveness and produce more drought tolerant, lower maintenance landscaped areas.
2. Greater effort is needed in inspecting the depth of topsoil that is reapplied to pervious areas before placement of sod or plantings, particularly where a minimum depth has been specified in the community design.
3. Observations that the one infiltration trench confirmed to be functioning in the Box Grove community drained reliably during the monitoring period supports implementation of stormwater infiltration practices in future developments in the region that will be located on similar sandy silt glacial till subsoil.
4. The long-term sustainability of structural stormwater management practices installed on private property that are not accessible without property owner consent (i.e. no easement or legal requirement to conduct or allow periodic inspections) is questionable. Locating structural stormwater management practices in front yards and within road rights-of-way, or within park or open space properties oriented along the rear lot lines of residential properties would be more sustainable from a long-term inspection, monitoring and maintenance access perspective.
5. Inlets to rear yard infiltration trenches should be accessible from the catchbasins to better facilitate inspection and maintenance.
6. Stormwater infiltration practices should 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.

Topics for Future Research

Topics of interest for further research on the effectiveness of the residential lot level stormwater practices examined in this study include the following:

1. *Runoff reduction benefits of other soil management best practices*. This study examined the runoff reduction benefits of increased topsoil depth in pervious areas alone. It is of interest to develop a better understanding of how the runoff characteristics of pervious areas receiving roof

and sidewalk runoff change when soil management best practices in addition to increased topsoil depth are implemented. Additional best practices include procedures to reverse compaction of subsoil prior to topsoil spreading and compost amendment of topsoil to meet recommended minimum standards for organic matter content. Developing a quantitative understanding of the runoff characteristics of pervious areas where such best practices have been implemented would help inform stormwater management system designers about how to model these areas when designing downstream treatment facilities. Such evaluations would also improve the understanding gained from this study regarding the conditions under which such best practices provide runoff reduction benefits (i.e. rainfall depth, intensity and antecedent conditions).

2. *Maintenance and rehabilitation of lot level practices*. It is of interest to better understand what equipment and procedures could be used to rehabilitate non-functioning infiltration practices, the cost and effectiveness of such procedures and what approaches to implementing such activities on private property are most successful. Further research should be conducted on a variety of aged infiltration practices (e.g. in service for 5 years or more with no maintenance), including ones receiving roof drainage only and both roof and paved surface runoff, to better understand the frequency of inspection and maintenance activities needed to ensure continued function and the effectiveness of various equipment and procedures for restoring their function. Research into successful approaches to assigning responsibility for inspection and maintenance of stormwater management infrastructure located on private property and tracking systems to ensure they are maintained over the long term is also of interest.

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