Evaluation of Residential Lot Level Stormwater Management Practices





Prepared by: Toronto and Region Conservation

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Prepared by:

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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

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

Catchment Scale Evaluations

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.

<u>Test Box Scale Evaluations</u>

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

<u>Implementation of Lot Level Practices in the Catchment Study Area</u>

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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1.0 INTRODUCTION

1.1 Background

Urbanization results in a proliferation of impervious surfaces such as roofs and pavement across the land and compaction of the native soil, which prevents precipitation from infiltrating into the soil to the same extent as it would have prior to development. Urbanization also reduces the portion of land covered by vegetation, thereby reducing the portion of precipitation that returns to the atmosphere via evaporation and transpiration from plants. The net result of typical forms of urban development is a much greater portion of precipitation becoming surface runoff, which increases the flow of stormwater and pollutants into our rivers and lakes during wet weather. This shifts stream flow patterns to more extreme high flows during wet weather and lower flows during dry weather. It also reduces water levels in aquifers and reduces inputs of cool, clean groundwater to streams. If such changes go unmitigated, the health of rivers and lakes receiving urban runoff suffers. To help mitigate the impacts of urban development on the hydrologic cycle and receiving waters, stormwater management practices are integrated into new developments.

The practice of stormwater management continues to evolve to better address all potential impacts of urbanization on water resources. 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 soakaways, rain gardens 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. If integration of lot level practices into the design of residential subdivisions, to supplement end-of-pipe practices like detention ponds, were to become standard, potential exists for new communities to generate significantly less runoff than ones of conventional design. This would help to maintain the pre-development hydrologic cycle and thereby avoid many of the negative impacts of urbanization on receiving waters and the ecosystems they support.

While performance of individual lot level best practices in the climate and geologic 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 pervious areas is standard design practice for new residential developments in the Greater Toronto Area, the effectiveness of this practice for managing runoff has not been well documented. Furthermore, there is little known about how much more effective it could be by increasing topsoil depth and quality in pervious areas. Quantifying the hydrologic benefits of lot level practices helps designers create more effective stormwater management systems. It can also better inform regulators regarding how the design of downstream practices (i.e. detention ponds) could be adjusted to take into account the reduction in runoff volume typically achieved by upstream lot level practices.

This study focuses on two lot level stormwater management practices that are well suited to new residential subdivision developments: i) Applying a deeper than standard layer of topsoil to pervious, landscaped areas (hereafter referred to as increased topsoil depth); and ii) Infiltration trenches aligned along rear yard lot lines that receive overland flows via a grassed swale. Evaluations of the hydrologic benefits of these types of practices have been conducted at two different scales: residential catchments (three catchments, each approximately 3 hectares in area); and test boxes (six test boxes, each 0.2 square metres (m^2) in surface area).

At the catchment scale, cumulative benefits of widespread implementation of these practices have been evaluated by monitoring runoff characteristics of a recently built residential subdivision that features increased topsoil depth in landscaped areas in one portion, and rear yard infiltration trenches in another. Runoff characteristics of the “treated” catchments were compared to a portion of the same subdivision featuring standard topsoil depth and no infiltration trenches as the “control” catchment.

At the micro, or test box scale, hydrologic benefits of increased topsoil depth were examined to verify conclusions drawn from the catchment scale evaluation and further characterize the benefits and rainfall conditions under which benefits are realized. Test box evaluations were also conducted to predict what further benefits could be achieved by combining increased topsoil depth with application of a compost blanket amendment to improve topsoil quality and further alter its runoff characteristics.

1.2 Increased Topsoil Depth and Quality

Healthy, uncompacted soil provides important stormwater management functions including infiltration and temporary storage of runoff, filtration of suspended sediments, adsorption and biological decomposition of pollutants and moderation of peak stream flows and temperatures (Soils for Salmon, 2010). Healthy soils also support vigorous plant growth that intercepts rainfall, returning much of it to the atmosphere through evaporation and transpiration. Standard construction practices involve removal and temporary stockpiling of topsoil during clearing and grading, compaction of subsoil and replacement of a shallow layer of the stockpiled site topsoil, typically 10 to 15 cm deep, on top of the compacted subsoil at the end of construction. This typically produces a poor quality growing environment that requires excessive irrigation and fertilizer applications to establish plantings, raising the potential for these pervious areas to be a source of contaminated runoff during storm events.

A lot level stormwater management practice that has received considerable attention from the land development industry is the application of a deeper than standard layer of topsoil in pervious landscaped areas, particularly those that will receive roof runoff from downspouts. This practice is of particular interest because at the end of construction work on a new development site there is always a surplus of topsoil from clearing and grading that otherwise must be hauled away at a cost to the developer. The simple practice of adjusting grading of pervious areas to be landscaped, applying a deeper layer of topsoil and amending it with compost to increase organic matter content has the potential to reduce costs associated with having to haul it away. It also has the potential to absorb, infiltrate and evapotranspire a greater amount of precipitation than standard landscaping practices in new developments, thereby providing hydrologic benefits (TRCA, 2012). Amending poor quality topsoil or compacted subsoil with compost increases moisture and pollutant retention capacity and permeability, and reduces bulk density and erosivity. In addition to stormwater management benefits, this practice also provides a better growing environment for grass, shrub and tree plantings, requiring less irrigation and fertilizer to become established than plantings in more shallow, unimproved topsoil overlying compacted subsoil.

Previous studies of small-scale test plots have demonstrated the potential that compost amended topsoil has to significantly reduce runoff volume from disturbed urban soils. In an examination of methods to alleviate effects of compaction on the runoff properties of urban soils, Kolsti (1995) compared the hydrologic response of residential lawns established on compacted Alderwood series soil with ones on compost amended soil. Bulk density was found to be reduced by as much as 0.35 g/cm^3 and surface runoff by 29 to 50% (Kolsti, 1995).

At the University of Washington's College of Forest Resources (UW CFR) large plywood beds lined with plastic containing Alderwood series soil and mixtures of soil and organic compost derived from municipal yard waste were used to examine the effects of compost amendment on water and nutrient retention. Water holding capacity was nearly doubled with a 2:1 soil to compost mixture (by volume) and runoff properties were improved with the compost amended soil showing greater lag time between the start of a storm event and the occurrence of a peak runoff rate (Harrison et al., 1997).

The UW CFR test plots were used along with others located on Seattle public school properties in a second study sponsored by the US EPA (Pitt et al., 1999). The study confirmed that amending disturbed urban soils with compost alters soil properties known to affect water retention capacity including porosity, bulk density and structure as well as increasing soil carbon, nitrogen and phosphorus concentrations. Surface infiltration rates of compost amended soil test plots were found to be 1.5 to 10.5 times higher than unamended test plots (Pitt et al., 1999). While malfunctions in testing equipment confounded results regarding effects on runoff volume and peak flows, Pitt et al. (1999) concluded that if a significant percentage of disturbed glacial till soils were amended with compost it would have a significant beneficial effect on catchment hydrology, reducing the volume and rate of runoff from all but the most intense storm events. The need for fertilization to establish and maintain new landscaped areas would also be reduced if not eliminated. Unfortunately, the compost also increased the concentration and flux of nutrients in subsurface flows (i.e., infiltrate) suggesting that further research was needed to determine optimum amounts of compost amendment to benefit disturbed urban soils without associated problems of leaching nutrients to groundwater (Pitt et al., 1999).

In an investigation for the Dane County Land Conservation Department of Wisconsin, Balousek (2003) used test plots to compare a variety of methods of reversing the effects of compaction on the runoff properties of the local silty clay loam glacial till soil. The only method examined that significantly reduced runoff was deep tilling followed by chisel plowing and amendment with compost derived from municipal yard waste. This treatment resulted in runoff reductions from 74 to 91% compared to control plots (Balousek, 2003).

Very few previous studies have examined the cumulative hydrologic benefits of increased topsoil depth in landscaped areas at the neighbourhood or urban catchment scale. However, catchment-scale studies of the hydrologic benefits of directing roof runoff to pervious areas (i.e., downspout disconnection from storm sewers) provide an indication of the effectiveness of this practice with standard topsoil depths and without improvement or compost amendment. In an evaluation of the effectiveness of a municipal downspout disconnection program in Flint, Michigan, Kaufmann et al (1997) found that diverting roof downspouts to pervious areas that had previously been connected to sanitary sewers reduced mean flow volumes by over 25% with reductions ranging from 25% to 62% for rainfall depths between 6 millimetres (mm) and 25.4 mm.

Amending soils that have become compacted through construction activities with compost and requiring higher standards for the depth and quality of topsoil applied in landscaped areas have become accepted stormwater best management practices in many jurisdictions in the United States (McDonald, 2005) and are included in several recently updated design guidelines. Washington State Department of Ecology have provided guidelines for post-construction soil quality and depth as a runoff treatment best management practice in their stormwater management manual since 2005. Their guidelines specify that following completion of construction, topsoil in all pervious landscaped areas must have a minimum organic matter content of ten percent (10%) by dry weight in planting beds and five percent (5%) in turf areas. The topsoil layer must have a minimum depth of 20 cm and subsoils should be scarified to a depth of at least 10 cm except where limited by the presence of shallow tree roots (WDOE, 2005; Soils for Salmon, 2010). Different compost and tilling depths are recommended depending on the type of vegetation to be planted (i.e., turf versus tree and shrub plantings). It is noted that where topsoil already meets the organic matter quality standards and is not compacted, compost amendment is not required. Minnesota guidelines recommend different compost and tilling depths depending on the type of vegetation to be planted and anticipated level of foot traffic (MPCA, 2008). Pennsylvania guidelines require scarification of compacted subsoil to a depth of 50 cm prior to amendment (PDEP, 2006). Virginia guidelines recommend different depths of compost application and tillage or scarification depending on the hydrologic soil group classification of the subsoil and the ratio of impervious drainage area to soil amendment area (VA DCR, 2009). The Low Impact Development Center recommends that topsoil should be sampled and tested to determine amendment quantities required to meet topsoil quality standards and that subsoil should be scarified to a depth of 15 to 20 cm prior to amendment (LID Center, 2011). Guidelines for the practice of increased topsoil depth and quality in landscaped areas located on compacted or disturbed subsoil recommended by Toronto and Region Conservation (TRCA, 2012) represent a hybrid of the previously mentioned guidelines and are summarized in Table 1.1.

Table 1.1: Recommended standards for soil depth and quality in landscaped and disturbed areas in TRCA jurisdiction (TRCA, 2012)

Planting Area Type	Minimum Topsoil Depth (cm)	Topsoil Organic Matter Content (% dry weight)	Minimum Uncompacted Soil depth (cm)
Turf grass	20	5 to 10%	30
Planting bed	20	10 to 15%	30
Tree pit	60	10 to 15%	90

Previous test plot scale studies suggest that the practice of applying (or creating through deep tilling and compost amendment of disturbed subsoil) an uncompacted topsoil layer at least 30 cm in depth that contains 5 to 15% organic matter content (by dry weight) to landscaped areas could provide many benefits including cost savings to developers, runoff reduction and improved growing environments for plantings. However, there have been no published evaluations of the cumulative runoff reduction benefits of increased topsoil depth and quality when implemented at a neighbourhood or urban catchment scale, nor under the climatic and geologic conditions that exist in southern Ontario. Guidelines regarding application of this practice for stormwater management benefits (TRCA, 2012) and compost quality and use exist in Ontario (OMOE, 2004) and do not represent a barrier to widespread implementation. Upon consulting with the land development industry regarding the feasibility of widespread implementation of this practice it was suggested that the hydrologic benefits of increased topsoil depth alone should be evaluated first. Their main concern with the practice of increased topsoil depth and quality is the technical feasibility of subsoil decompaction and applying and incorporating compost amendments on large construction sites (e.g. entire subdivisions of landscaped areas) where equipment access and the presence of shallow underground infrastructure may be limiting or complicating factors. Therefore, the catchment scale evaluation study and residential community on which it focuses were designed to allow evaluation of the hydrologic benefits of increased topsoil depth alone (i.e. no subsoil decompaction nor compost amendment of stockpiled site topsoil). To examine and quantify what further benefits could be achieved by combining increased topsoil depth with compost amendment, the test box evaluation component of this study was designed and added in 2011/12.

1.3 Infiltration Trenches

Another lot level practice that has received interest from the development industry is infiltration trenches aligned along the front, side or rear yard lot lines of residential properties that receive roof and yard runoff via grass swales. Infiltration trenches are rectangular trenches lined with geotextile fabric and filled with clean granular stone or other void forming material, typically installed underground with no surface footprint. A perforated pipe along the length of the trench delivers runoff into it where it filters through the granular material and geotextile and gradually infiltrates into the underlying native soil which provides further filtration and contaminant removal, primarily through adsorption to soil particles and organic matter. They can also be referred to as infiltration galleries or linear soakaways or when oriented in parallel with conventional storm sewers, they can be referred to as perforated pipe or exfiltration systems. Grass swales are vegetated open channels designed to convey, treat and attenuate stormwater runoff. Vegetation in the swale slows the flow of water to allow sedimentation, filtration through the root zone and soil matrix, evapotranspiration, and infiltration into the underlying native soil. Orienting a grass swale and infiltration trench along residential lot lines integrates it well with typical yard layouts.

Such systems may provide long lasting hydrologic benefits with minimal maintenance because roofs and yards typically accumulate fewer contaminants than paved surfaces making the practices that treat these runoff source areas less prone to premature clogging with fine sediments. Incorporating a grass swale to convey runoff to the infiltration trench also helps to settle and filter out suspended sediments prior to it entering the trench, thereby further extending its useful lifespan. Such designs are particularly attractive to developers, regulators and property owners whom all cite minimal surface footprint area and maintenance requirements as important factors influencing the feasibility of applying of lot level practices. Guidelines for the design of infiltration trenches and grass swales have been part of provincial stormwater management guidelines in Ontario since 2003 (OMOE, 2003) and are included in the Low Impact Development Stormwater Management Planning and Design Guide for the Greater Toronto Area (CVC & TRCA, 2010).

The hydrologic benefits of such stormwater infiltration practices in the southern Ontario context of climate and post-glacial geology are already well documented. In a study examining two newly constructed residential neighborhoods with grass swale and perforated pipe systems in Nepean, Ontario, runoff volumes were observed to be 99% and 86% less than a similar conventional pipe system (Paul Wisner and Assoc., 1994). Follow-up studies in 1999 (J.F. Sabourin and Assoc., 1999) and 2006 (J.F. Sabourin and Assoc., 2008) showed that the systems continued to infiltrate similar volumes of runoff. In 1998, peak flows were 90% less than those observed for the conventional system and runoff volumes were 94% and 70% of the conventional system flows (J.F. Sabourin and Assoc., 1999). In 2006, peak flows were between 47% and 86% less than those from the conventional system and runoff volumes were 86% and 73% of the conventional system flows (J.F. Sabourin and Assoc., 2008). In a similar study, performance of two perforated pipe systems installed in Etobicoke and North York, Ontario, that receive roof and road runoff from low density residential areas was examined with regard to effects on runoff quantity (SWAMP, 2002). The Etobicoke and North York exfiltration systems were observed to exfiltrate 95% and 89% of all runoff from storms greater than 5 mm, respectively over the two years of monitoring (SWAMP, 2005; SWAMP, 2002).

While numerous studies of the hydrologic performance of individual lot level stormwater management practices have been previously published (TRCA, 2009), there are few catchment scale evaluations of the cumulative benefits from widespread implementation. A previous evaluation in the City of Burnsville, Minnesota compared runoff characteristics of a residential catchment of conventional design to a nearby one of similar size and development density where 17 front yard rain gardens had been newly installed to treat road runoff. Both catchments were located on sandy soils. Rain gardens were designed to be able to temporarily store runoff from a 23 mm storm event over the contributing drainage area. Over two May to September monitoring seasons, the rain garden catchment was observed to generate 89 to 92% less runoff than the conventionally designed catchment (Barr Engineering, 2006). The Jordan Cove Watershed Project is another previous catchment scale study which evaluated cumulative runoff quantity benefits of a variety of practices implemented in a residential subdivision in Waterford, Connecticut (Clausen, 2007). Runoff quantity from a conventionally designed catchment was compared to a nearby one of similar size designed with several low impact development best management practices (BMP) including narrower streets and shared driveways, as well as permeable pavement, roadway bioretention (i.e., dry swales) and front-yard rain gardens. During the two year post-construction monitoring period, stormwater flow per unit drainage area in the BMP catchment was 61% lower than in the traditionally designed catchment and peak discharge rates were 80% lower (Clausen, 2007). However, this study was not designed to evaluate how each type of BMP contributed to the overall benefits observed.

While previous evaluations of the performance of individual lot level practices have demonstrated that they can be highly effective at reducing runoff volume, few studies have compared their effectiveness at the catchment scale and none in the climatic and geologic contexts of southern Ontario. As with compost amended topsoil, guidelines for the design of infiltration trenches exist in Ontario and do not represent a barrier to widespread implementation.

1.4 Study Objectives

This study evaluates, at the catchment scale, the cumulative 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.

Parallel monitoring of stormwater flow rates and volumes from three adjacent residential catchments of similar size and development density (i.e. percent impervious cover) allows evaluation of the effectiveness of each type of practice to reduce runoff in comparison to an untreated control catchment of conventional design and construction. This evaluation also provides evidence of whether or not these practices can be effective in the geologic and climatic contexts of southern Ontario and without efforts to reverse compaction of subsoil caused during construction.

This study also evaluates at the test box scale, the hydrologic benefits of:

- Increased topsoil depth; and
- Increased topsoil depth and quality (compost blanket amendment)

Parallel monitoring of runoff and infiltration volume, evapotranspiration (using a gravimetric method) and topsoil moisture in duplicate test boxes exposed to natural precipitation allows evaluation of the effectiveness of each practice to reduce runoff in comparison to test boxes containing standard topsoil depth and no compost blanket amendment. This evaluation will verify conclusions drawn from the catchment scale evaluation of increased topsoil depth and characterize what further benefits could be achieved with addition of a compost blanket amendment.

2.0 STUDY DESIGN

2.1 Catchment Scale Evaluations

2.1.1 Study area description

The residential subdivision in which these lot level practices have been implemented is the community of Box Grove, located in Markham, Ontario which is just north of Toronto. Drainage from the community enters the Little Rouge River, which is a tributary to the Rouge River that flows to the north shore of Lake Ontario at the boundary between Toronto and Pickering. The tributary of the Little Rouge River that receives drainage from the community supports cool water aquatic habitat. Target species for fisheries management in the Little Rouge River are rainbow trout, rainbow darter, pearl dace, rosyfaced shiner, central mudminnow and hornyhead chub, many of which are highly sensitive to changes in stream temperature, flow and sediment regimes (TRCA, 2010). To help mitigate potential impacts of urbanization on the Rouge River, Low Impact Development (LID) stormwater management practices have been recommended as a means to control runoff volume, contaminant loads and channel erosion (TRCA, 2007).

The catchment scale evaluation study has been designed based on the “paired watershed” approach described by Clausen and Spooner (1993) where two, or in this case three adjacent watersheds or catchments with similar characteristics are monitored simultaneously. One catchment serves as an untreated control while the other two represent treated catchments where certain lot level stormwater practices have been implemented on a widespread basis (i.e. multiple lots). The three catchments have similar characteristics with respect to slope, soil type and impervious cover, all primary factors affecting runoff response. Measured total runoff volumes and peak flow rates per hectare of drainage area from each catchment were compared on a storm event basis and cumulatively over the monitoring period.

In this study a 3.06 hectare catchment containing 58 residential lots of conventional design serves as the Control (CTL) catchment (Figure 2.1). In the Control catchment 10 to 15 cm of stockpiled site topsoil was to be applied to pervious areas (i.e. landscaped areas) over the compacted subsoil, which is conventional construction practice. A 3.43 hectare catchment containing 52 residential lots, where increased topsoil depth was applied to landscaped areas, serves as one of the treated catchments (Figure 2.1). In this catchment stockpiled site topsoil was to be applied to all pervious areas to a typical depth of 30 cm and up to a depth of 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. Roofs and sidewalks drain to pervious landscaped areas in all three catchments, as is required for all new developments by the City of Markham, but roads and driveways do not. Therefore, any hydrologic benefit observed in the Increased Topsoil Depth (ITD) catchment will be limited to the portion of runoff generated from roofs, sidewalks and pervious areas. It was anticipated that hydrologic benefits will only be significant or consistently observed during medium to high depth (e.g. 15 mm total depth or greater) or high intensity storm events, when pervious areas begin to generate runoff.

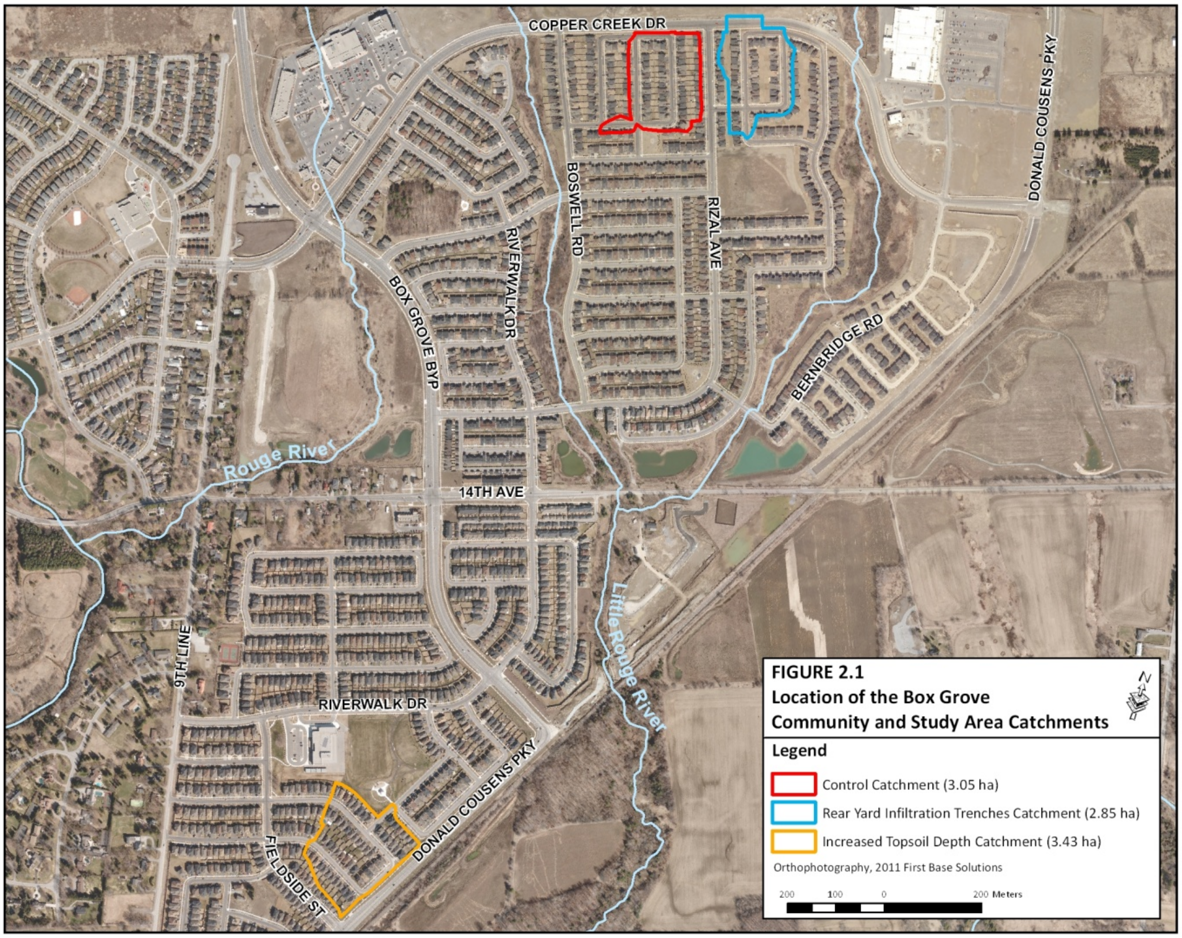


Figure 2.1: Location of the Box Grove community and study area catchments

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 (Figure 2.1). It is estimated that about 1.0 hectare of the 2.85 hectare catchment (35%) is within the drainage area of an infiltration trench. The dimensions of each trench are 1.2 m wide by 1.25 m deep with length varying from 9.8 to 15.4 m (Figure 2.2). Assuming that the 19 mm diameter clear stone that fills the trenches provides 35% void space, their water storage capacities range from 5.15 to 8.09 cubic metres (m^3). Once the trenches are full of water, overflows drain to storm sewers that lead to a wet detention pond for treatment prior to being released to the Little Rouge River. Again, since roofs drain to pervious landscaped areas in this catchment and roads and driveways do not, any hydrologic benefits in the Rear Yard Infiltration Trenches (RYIT) catchment will be limited to runoff generated from roofs and pervious areas that drain to an infiltration trench. Therefore, similar to the Increased Topsoil Depth catchment, it can be anticipated that hydrologic benefits in this catchment will also only be significant or consistently observed during medium to high rainfall depth (e.g. 15 mm total depth or greater) or high intensity storm events, when pervious areas begin to generate runoff.

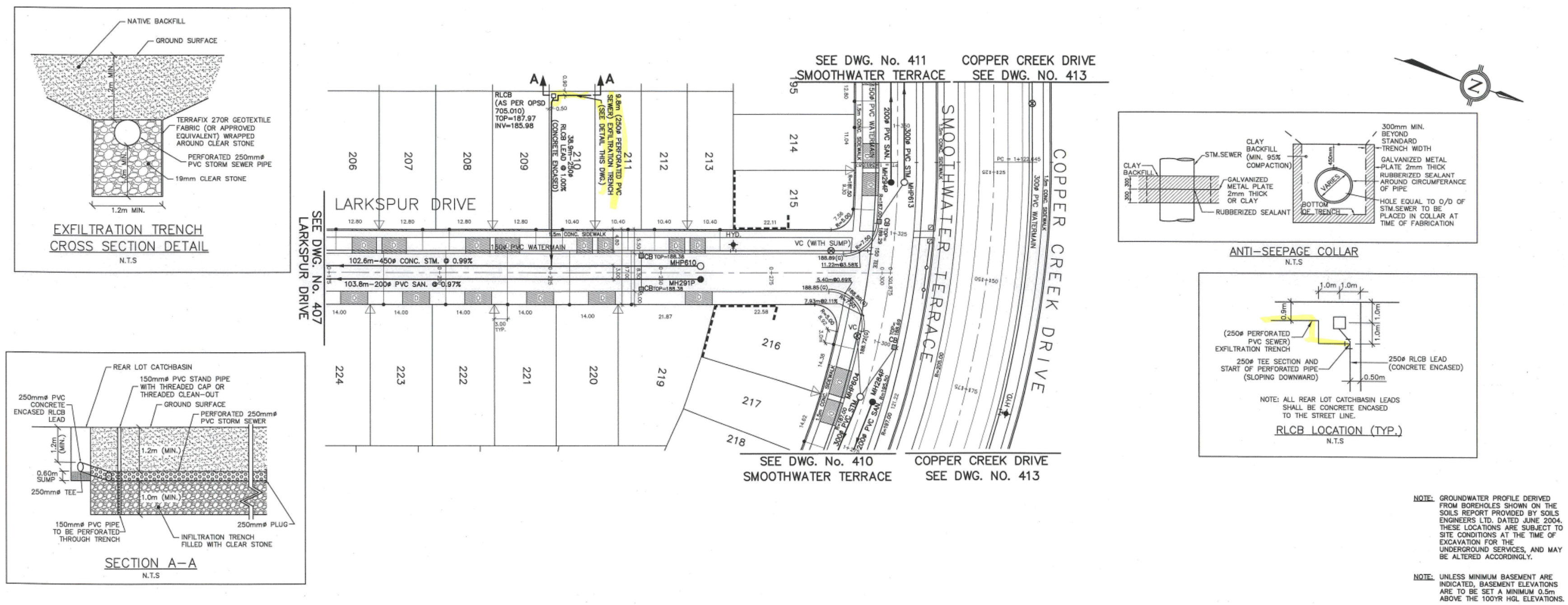


Figure 2.2: Design drawing showing a typical configuration of the rear yard infiltration trenches

Borehole investigations indicate the surficial soil layer (i.e. subsoil) below the topsoil consists of glacial drift deposits of sandy silt till and silty sand till to depths of at least two metres below the ground surface (Soil-Eng Limited, 2004). Based on grain size analyses of soil samples taken during drilling of boreholes, it is estimated that the sandy silt till deposits in an uncompacted state would have a coefficient of permeability of approximately 1×10^{-6} cm per second (cm/s), which represents an infiltration rate of 12 millimetres per hour (mm/h) based on their approximate relationship (OMMAH, 1997). The coefficient of permeability of the silty sand till deposits in an uncompacted state is estimated to be 1×10^{-5} cm/s, which represents an infiltration rate of approximately 30 mm/h (OMMAH, 1997). Such soil would be classified as Hydrologic Soil Group C which is considered to have limited potential for effective infiltration of stormwater. At depths greater than two metres below ground surface a layer of more permeable silty fine sand of variable extent (coefficient of permeability of approximately 1×10^{-4} cm/s or infiltration rate of 50 mm/h) was encountered in some boreholes in the vicinity of the Rear Yard Infiltration Trenches catchment. Such soils are considered to have moderate potential for effective stormwater infiltration. The presence of this silty fine sand layer contributed to the decision to include infiltration trenches in this portion of the community. The silty fine sand layer was not encountered in boreholes in the vicinity of the Control and Increased Topsoil Depth catchments (Soil-Eng Limited, 2004; Woerns, 2005).

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. Table 2.1 summarizes the characteristics of each catchment in terms of total area, percent impervious cover and runoff source area type. Due to differences in the drainage area of the catchments, measured runoff volume was normalized by drainage area on an event by event basis to allow reasonable comparisons to be made. It is notable that impervious cover in the Control catchment is slightly higher (5% greater) than in the Increased Topsoil Depth and Rear Yard Infiltration Trenches catchments and that differences exist between the catchments in terms of the portion of impervious cover that is directly connected to storm sewers (i.e. % roads and driveways). The portion of impervious cover that is directly connected to storm sewers in the Control catchment is 42%, 38% in the Increased Topsoil Depth catchment and 48% in the Rear Yard Infiltration Trenches catchment. These differences needed to be considered when interpreting comparisons of runoff characteristics between the catchments.

Table 2.1: Study area catchment characteristics

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

Notes: [1]Pervious cover includes yards and other landscaped areas (e.g., gardens, boulevards etc.).

2.1.2 Monitoring locations and equipment

Monitoring parameters, locations and equipment were selected to provide the information needed to determine runoff volume and flow rate on an event by event basis, and to compare results from the Increased Topsoil Depth (ITD) and Rear Yard Infiltration Trench (RYIT) catchments to the Control (CTL) catchment to evaluate runoff reduction benefits of widespread application of these best management practices.

Precipitation during the July 2010 to April 2011 and December 2011 monitoring periods was measured with a four season (i.e., heated) 8 inch diameter tipping bucket rain gauge installed at Milne Dam (east side of McCowan Road, just south of Highway 7), located approximately 3 kilometres (km) northwest of the Box Grove community. Following the 2010 monitoring season it was decided that installing a gauge closer to the study area catchments was desirable to reduce the potential for differences in precipitation during small or highly localized storm events. During the May to November 2011and April to November 2012 periods, precipitation was monitored with a three season tipping bucket rain gauge installed on the roof of a permanent stream gauge hut located on the main channel of the Rouge River as it crosses 14th Avenue, approximately 1.5 km from the three catchments under study (Figure 2.1).

To measure stormwater flow from the study catchments, area velocity sensors were installed in storm sewer pipes at the locations noted in Figures 2.3 and 2.4. The sensors provide continuous data on water level and flow velocity at five minute intervals. The area velocity sensors in the Control and Increased Topsoil Depth catchments were installed in July 2010. Sensors in the Rear Yard Infiltration Trenches catchment were not installed until mid-September 2010 to allow construction and landscaping in the catchment to be completed prior to initiation of monitoring. In addition to sensors located at the outlet of the catchments, in April 2011 one additional area velocity sensor was installed in each catchment. The additional sensors were installed in storm sewer locations that receive flows from smaller subcatchments that are nested within the larger catchments. This was done to provide contingency in the study design in the event that a sensor at a catchment outlet malfunctions, as was the case in the Increased Topsoil Depth catchment during a portion of the fall 2010 monitoring season. Rating curve relationships between instrument readings of water level (mm) and flow rate (L/s) were established for each area velocity sensor over periods when both the water level and velocity portions of the sensor were functioning trouble-free. At each monitoring location the velocity sensor portion of the instrument malfunctioned and produced unreliable velocity data several times over the monitoring period. Therefore, the rating curve relationships were used to calculate flow values from water level readings over the entire monitoring period, because the water level portions of the instruments were subject to much less frequent malfunctions. Charts and equations describing the rating curve relationships applied at each sensor location are provided in Appendix A. The accuracy of water level readings from each instrument was checked several times throughout the study with slight adjustments made to the sensor settings when found out of calibration.

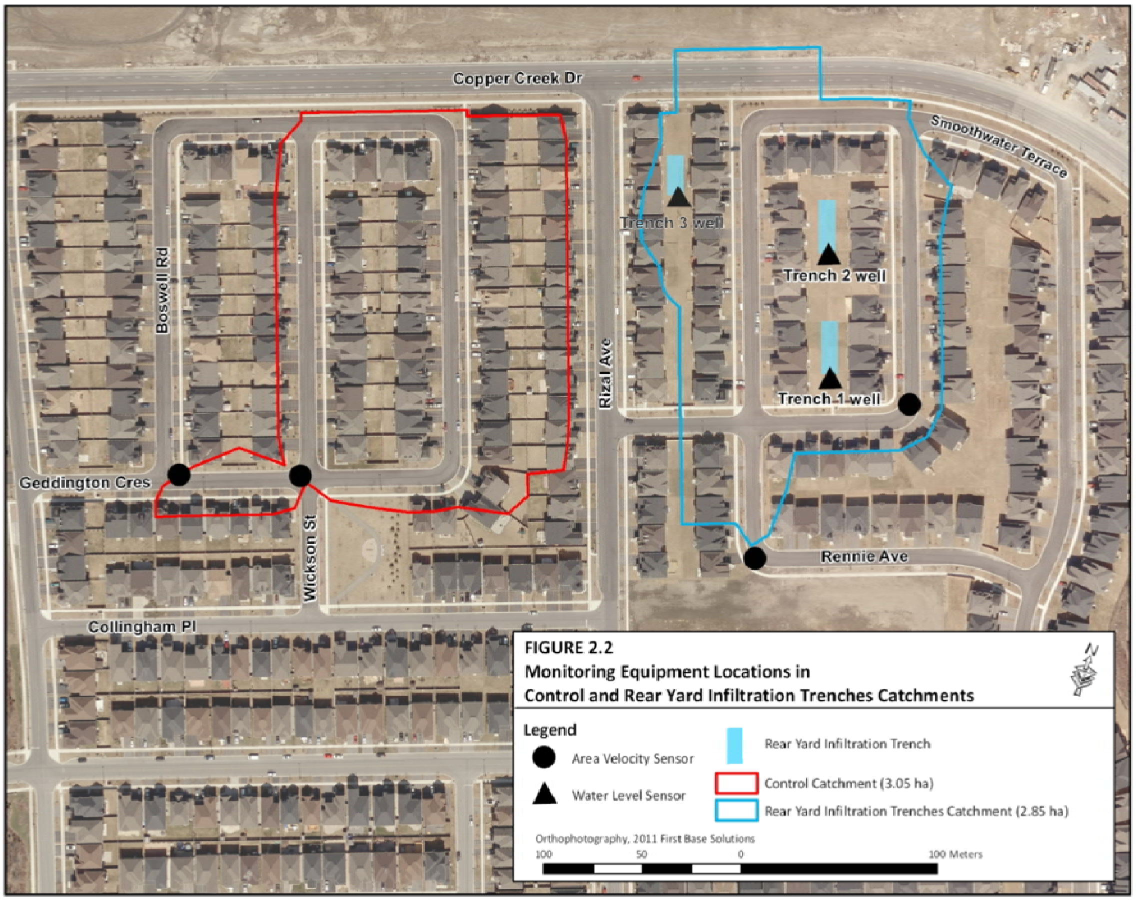


Figure 2.3: Monitoring equipment locations in Control and Rear Yard Infiltration Trenches catchments

In the Rear Yard Infiltration Trenches catchment, calibrated pressure transducers were installed in wells designed for monitoring water levels in the infiltration trenches. The pressure transducer sensors provide continuous measurements of water level at five minute intervals in two of the three trenches present in the catchment. The water levels sensors were installed to the bottom of the wells (hereafter referred to as Trench 1 well and Trench 2 well) which were intended to correspond with the bottom elevation of each infiltration trench. A well in the third trench was to be constructed but it could not be located and is believed to have been buried during final grading and landscaping activities. In June 2011 a drive point piezometer was driven into Trench 3 to the base of the trench to serve as a monitoring well and a pressure transducer was installed in the piezometer casing (hereafter referred to as Trench 3 well).

Figure 2.4: Monitoring equipment locations in the Increased Topsoil Depth catchment

2.2 Test Box Evaluations

2.2.1 Test box study design

The test box evaluation component of this 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 were installed and exposed to natural precipitation and monitored for runoff and infiltration volume (following the storm event) and evapotranspiration loss and topsoil moisture over time during the 2012 monitoring season.

The test boxes were installed in pits slightly larger than the boxes to maintain soil temperatures close to natural conditions. The six pits were dug, lined with geotextile and a 10 cm layer of gravel. The pits were drained with a gravel subdrain and trench that conveys any water or interflow collecting in them away from the site.

The different soil treatments evaluated in terms of runoff and soil moisture retention characteristics are as follows:

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

Two boxes were constructed for each soil treatment using topsoil obtained from a construction site nearby 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 holes using a tripod and winch and weighed using a scale (Figure 2.5).

Due to gradual settlement of the soils placed in the test boxes over a two month period after they were constructed and installed in June 2012, the surface of the sod in several boxes sunk lower than the level of the drainage hoses, which made the runoff volume data unreliable during this period. On August 7, 2012, topsoil was added to boxes where the sod surface had sunk. After this date, the sod surfaces of the test boxes did not exhibit substantial sinking. Therefore, analysis of runoff volume data from test box monitoring was limited to the monitoring period from August 8 to November 23, 2012, which was the date when the boxes were uninstalled.

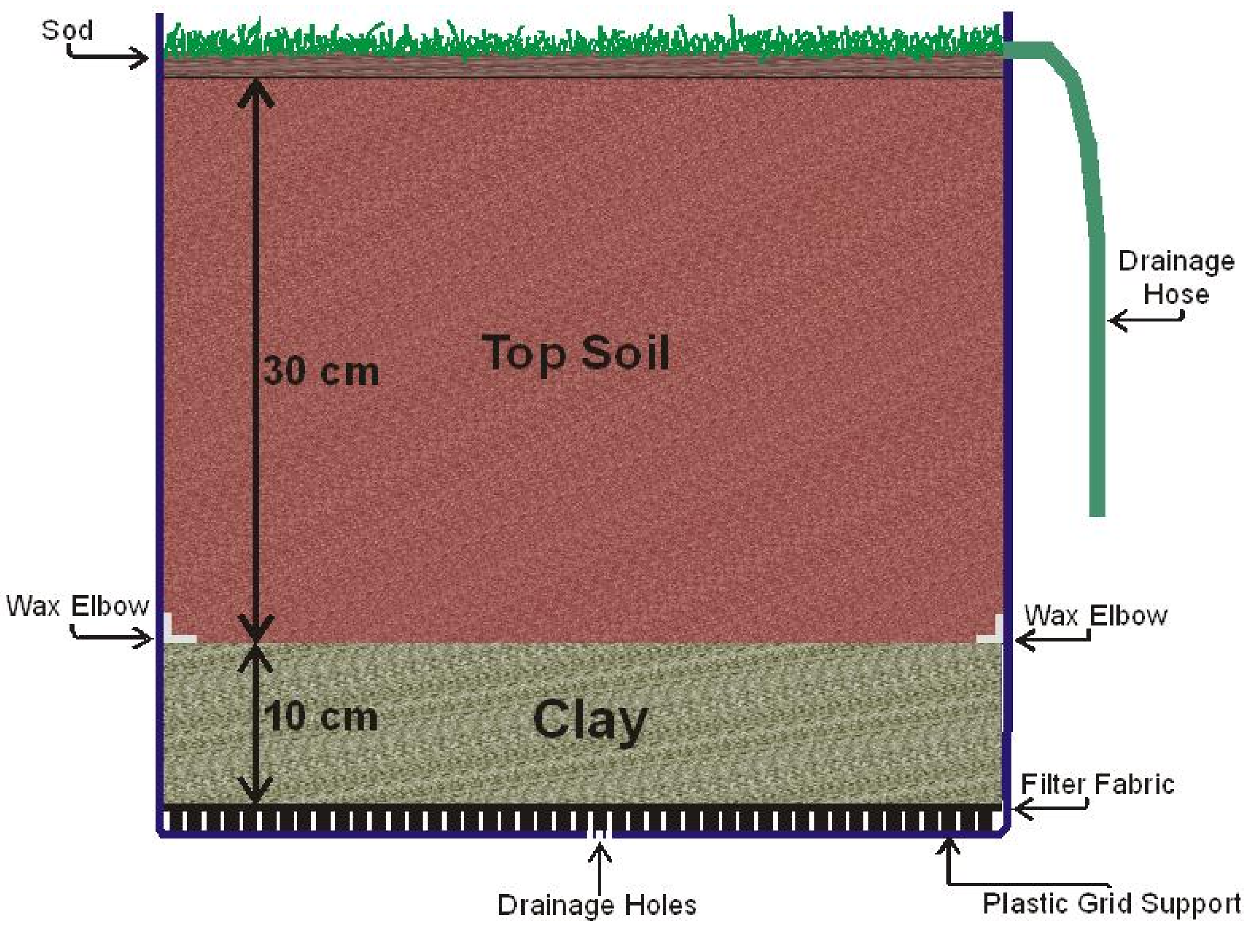


Figure 2.5: Test box design

2.2.2 Monitoring parameters and equipment

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 using an industrial grade hanging scale 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.

3.0 RESULTS AND DISCUSSION

3.1 Catchment Scale Evaluations

3.1.1 Precipitation

Figure 3.1 illustrates monthly totals for precipitation over the July 2010 to December 2012 monitoring period alongside climate 'normals' (monthly averages from 1971 to 2000) from the nearest rain gauge with a sufficient period of record ("Metro Toronto Zoo" climate station; Environment Canada, 2011). In 2010, July was considerably wetter than normal, while November and December were considerably drier. Overall, total precipitation during July to December 2010 was only 4% less than normal. Spring of 2011 was one of the wettest on record mainly due to much higher than normal rainfall in May (nearly double the normal amount). The wet spring was followed by a fairly normal summer, despite a 15 day period without rain in July (July 7 to 21). October 2011 was much wetter than normal. Overall, total precipitation in 2011 was 13% greater than normal. Spring of 2012 was very dry with 56% less precipitation than normal. This was followed by a wetter than normal summer season and a much wetter than normal October 2012. Overall, total precipitation in 2012 was 20% less than normal.

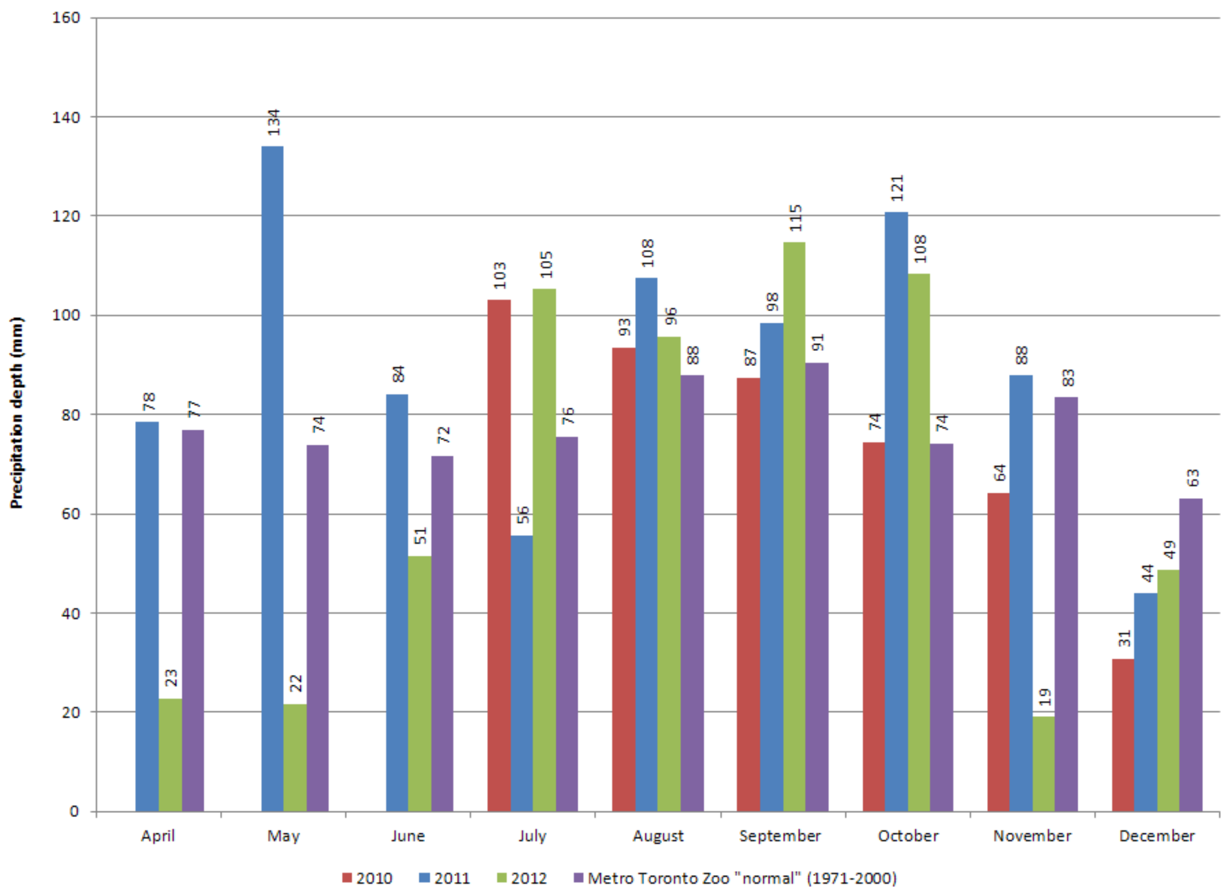


Figure 3.1: Monthly precipitation totals – Box Grove community study area and local climate 'normals'

Table 3.1 provides a breakdown of the number of storm events[1] that occurred over the monitoring period according to precipitation depth ranges. Over this period a total of 99 storm events occurred when total precipitation depth was greater than 5.0 mm. The largest storm event in terms of total precipitation depth occurred on July 23, 2010 when 52.8 mm of rain fell within 5.5 hours, representing an event slightly larger than the ten year return period, six hour storm event for this area[2]. Another notable event in terms of total depth began on November 28, 2011 and continued for 27 hours, depositing 50.6 mm of rain in total. This event exceeded the two year return period, 24 hour storm event for this area[3]. The maximum intensity storm occurred on August 9, 2011 when precipitation was recorded at a rate of 36.6 mm/h between 11:35 AM and 12:30 PM and 8.4 mm/5 minute interval between 11:45 and 11:50 AM. This event exceeded the five year return period, one hour and two hour events for this area[4]. The rain event of longest duration was the November 28, 2011 event described previously. Another particularly long lasting wet period occurred May 14 to May 20, 2011, when eight rain events totaling 64.2 mm depth occurred over six consecutive days. In 2012 another particularly long lasting period of wet weather occurred October 26 to November 2, 2012, when ten rain events totaling 65.2 mm depth occurred over eight consecutive days as the remnants of Hurricane Sandy reached southern Ontario.

Table 3.1: Number of storm events during the July 2010 to December 2012 monitoring period by storm event size

Precipitation depth (mm)	Number of storm events			
	July to Dec. 2010	Apr. to Dec. 2011	Apr. to Dec. 2012	July 2010 to Dec. 2012
0.4 – 1.8	14	37	26	77
2.0 – 5	10	38	30	78
5.2 – 15	15	26	23	64
15.2 – 25	5	7	9	21
25.2 – 35	3	3	1	7
35.2 – 45	1	3	1	4
>45	1	1	0	2
Total	**49**	**115**	**90**	**253**
Total > 5.0 mm [1]	**25**	**40**	**34**	**99**
Total > 15.0 mm	**10**	**16**	**11**	**37**

Notes: [1] Analysis of the runoff characteristics of each catchment has been limited to storm events greater than 5.0 mm in depth in an effort to reduce bias towards very small events that occur with much greater frequency, but do not consistently produce runoff from urban catchments, or produce so little runoff that systematic error in flow measurements makes the accuracy of the data questionable.

3.1.2 Inspection and testing

During summer 2010, field inspections were conducted to verify whether or not the lot level stormwater management best practices intended for each catchment area had been implemented and whether or not

[1] Individual storm events are defined as precipitation totaling a minimum of 0.4 mm depth with a minimum antecedent dry period of 3 hours.
[2] The ten year return period, six hour storm event for this area can be estimated from historical data from the Toronto Buttonville Airport climate station (located approximately 12 kilometres west of the study area catchments) for the years 1986 to 2003 and is 51.6 mm depth of rainfall in six hours (Environment Canada, 2004).
[3] The two year return period, 24 hour storm event for this area, based on historical climate data from the Toronto Buttonville Airport climate station, is 45.7 mm depth of rainfall in 24 hours (Environment Canada, 2004).
[4] The five year return period, 1 hour storm event for this area, based on historical climate data from the Toronto Buttonville Airport climate station, is 32.4 mm depth of rainfall and the 2 hour event is 34.6 mm (Environment Canada, 2004).

the finished products met their design specifications. In each catchment, actual topsoil depth and quality in pervious areas was estimated through soil cores taken from lawns in both the front and rear yards. Soil cores extended to 30 cm below the sod and were visually examined and measured to determine the depth of topsoil that had been applied during construction. The topsoil portions of the soil cores were collected and submitted to the Ontario Ministry of the Environment's soil testing laboratory for characterization in terms of grain size distribution, nutrients, pH and organic matter content.

Inspection and testing of topsoil depth showed that in both the Control (CTL) and Rear Yard Infiltration Trenches (RYIT) catchments, an average of 15 to 16 cm of topsoil had been applied to both front and rear yard lawn areas (Table 3.1) and that depth varied considerably (i.e. between 7 and 24 cm). In the Increased Topsoil Depth (ITD) catchment it was found that topsoil depth in front yard lawn areas was also about 15 cm on average, rather than the 30 cm that was specified in community design, and that depth also varied considerably (i.e. between 8 and 23 cm). In rear yard lawn areas in the Increased Topsoil Depth catchment, testing showed that greater than 30 cm of topsoil had been applied in most areas (i.e. between 17 and 120 cm). The results of this field inspection and testing work suggest that differences between the Control and Increased Topsoil Depth catchments in terms of runoff characteristics will be limited to differences in the quantity of flow reaching storm sewers from rear yard areas only. It also suggests that topsoil depth and quality are not substantially different between the Control and Rear Yard Infiltration Trenches catchments.

Testing of topsoil quality from the three study area catchments showed that the soil is a silty loam in all three catchments and that organic matter content was very consistent, ranging from 2.6 to 2.8% (Table 3.1).

Testing of the permeability of the subsoil at 30 cm depth below ground surface in each catchment was also undertaken using a Guelph permeameter to determine if significant differences exist, which could also affect catchment runoff characteristics. Results of permeameter testing showed considerable variability in measured values over each catchment (Table 3.2). Subsoil permeability in the Control and Rear Yard Infiltration Trenches catchments was very similar. Subsoil in the Increased Topsoil Depth catchment was found to be less permeable than in the Control and Rear Yard Infiltration Trenches catchments. Despite the differences observed, all subsoils were found to be equally or more permeable than a typical sandy silt (typical infiltration rate of 12 mm/h) or silty sand (typical infiltration rate of 30 mm/h) glacial till subsoil, as expected based on information from geotechnical investigations (Soil Eng Limited, 2004).

Table 3.2: Results of topsoil depth and quality testing in study area catchments

Parameter	Unit	Catchment Average			
		CTL	ITD Front Yard	ITD Back Yard	RYIT
Depth [1]	cm	15.2	14.7	>30	16.2
Organic Matter [1]	% dry weight	2.8	2.6	2.6	2.8
Nitrogen, total Kjeldahl [1]	mg/g dry weight	0.8	0.8	0.8	0.9
Phosphorus, total [1]	mg/g dry weight	0.8	0.9	0.9	0.8
pH	none	7.5	7.5	7.6	7.4
% Sand [1]	% volume	18.6	27.0	16.6	8.7
% Silt [1]	% volume	57.5	51.5	58.5	62.6
% Clay [1]	% volume	23.9	21.4	24.9	28.7
Soil Texture	none	Silty loam	Silty loam	Silty loam	Silty loam

Notes: [1] Mean values based on measurements of at least six soil core samples taken from each catchment.

Table 3.3: Results of permeameter testing of subsoil in study area catchments

Parameter	Control (CTL)		Increased Topsoil Depth (ITD)		Rear Yard Infiltration Trenches (RYIT)	
	K_{fs} (cm/s) [1]	i (mm/h) [2]	K_{fs} (cm/s) [1]	i (mm/h) [2]	K_{fs} (cm/s) [1]	i (mm/h) [2]
Mean	6×10^{-4}	60	2×10^{-5}	25	7×10^{-4}	70
Minimum	7×10^{-6}	23	2×10^{-6}	16	4×10^{-5}	37
Maximum	2×10^{-3}	104	8×10^{-5}	44	1×10^{-3}	96

Notes: [1] Field saturated hydraulic conductivity (K_{fs}) values are based on field measurements using a Guelph permeameter and the two head method.
[2] Infiltration rate (i) values are calculated from measured K_{fs} values based on the approximate relationship between hydraulic conductivity and infiltration rate (OMMAH, 1997).

Inspections of the three infiltration trenches installed in the Rear Yard Infiltration Trenches catchment were also conducted. Inspections involved locating monitoring wells that were to be part of each trench design and measuring the depth to the bottom of the well to determine if they extended to the expected bottom elevation of the trench, based on design specifications. Unfortunately, only two monitoring wells were located despite considerable excavation efforts. The well at infiltration trench #1 was found without a cap and partially buried. Measurement of the well depth showed that the well was approximately 75 cm shallower than expected, suggesting that it was partly filled with sediment. The well at infiltration trench #2 was found with a cap but buried and sodded over (Figure 3.2) and the well depth measurement confirmed that it extended to the depth that corresponds with the expected elevation of base of the trench. A drive-point piezometer was driven into infiltration trench #3 to the depth that corresponds with the expected elevation of the base of the trench in an attempt to create a monitoring well.

Upon initial inspection of the properties where rear yard infiltration trenches were installed, which was done prior to completion of construction and landscaping in the catchment, it was observed that few erosion and sediment controls were in place to protect the catchbasins and trenches from accumulating sediment except for a piece of geotextile under each catchbasin inlet grate (Figure 3.2). Following completion of landscaping, sediment accumulated in the catchbasins was cleaned out, however, through testing by STEP staff, described below, it was determined that the inlet pipes to the infiltration trenches remained clogged with sediment.

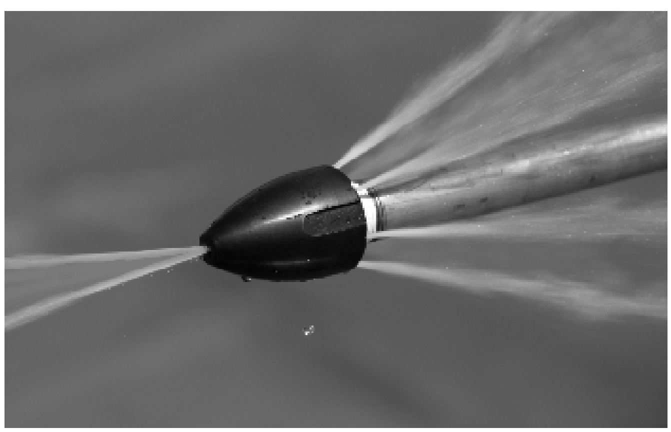
Figure 3.2: Images of the state in which rear yard infiltration trench catchbasins were found during construction and trench #2 well after landscaping was completed. (Clockwise from top left: RYIT #1 catchbasin during construction; RYIT #3 catchbasin during construction; RYIT #2 well found buried and sodded over after landscaping); RYIT #2 catchbasin during construction;

Once trench wells were located, the well tops were raised, the depth of the wells were measured, water level sensors were installed and tests were conducted to determine if the wells responded to water level changes in the trenches. At trenches #1 and #2, 650 L of water was poured into each well casing. Water levels in trench well #1 rose sharply and fell sharply, indicating that the well screens were not clogged and that it did not extend to the bottom of the trench. Water levels at trench well #2 rose sharply and fell very gradually, indicating that the well screens were not clogged and that it did extend to the bottom of the trench. At trench #3, only 20 L of water was poured into the piezometer well, due to the smaller size of the casing. The piezometer did not overflow, indicating that the well screens were not clogged, however it was not enough water to observe a water level change in the trench.

Catchbasins that collect runoff from grass swales oriented along rear yard lot lines and the storm sewer pipes they drain to were inspected again after landscaping and sediment removal was completed to better understand how runoff is delivered to the trenches. It was found that the trench inlet pipe that is intended to deliver runoff to the infiltration trenches is connected to the storm sewer pipe leading from the catchbasin by a tee connection that is inaccessible from the catchbasin. Only through the use of a closed circuit camera was it possible to inspect the trench inlet pipes. Upon inspection with the closed circuit camera it was determined that the inlets to all three infiltration trenches remained partially or fully clogged with sediment.

To determine whether or not the storm sewer pipes leading from the catchbasins deliver water to the trenches, 650 L of water was poured into each catchbasin while monitoring water levels in the trench wells. At all three trenches, no response in well water level was observed, while flow in the downstream storm sewers was observed within minutes. This confirmed that the inlet pipes to the trenches #2 and #3 were fully clogged or simply not allowing water to flow into the trenches due to the configuration of the tee connection. As the trench #1 well did not extend to the base of the trench, the 650 L of water poured into the catchbasin would not have been enough to raise water levels in the trench to a degree that would register a water level change in the monitoring well if it was delivered to the trench. However, since flow was observed in the downstream storm sewer minutes after pouring the water into the catchbasin, it was concluded that the trench #1 inlet was either partially or fully clogged as well.

In June 2012, efforts to unclog the inlets to the infiltration trenches were undertaken through the use of equipment that is routinely used to unclog municipal drains and sewers (Figure 3.3). A pressurized jet stream of water was directed at each tee connection via a hose and twisting penetrator sewer cleaning nozzle inserted into a PVC pipe with a 90 degree bend (to direct the jet stream at the inlet) until flow of water into each trench inlet pipe was achieved. Closed circuit camera inspection of the trench #1 inlet pipe confirmed that the procedure was successful at unclogging the inlet pipe at the tee connection. Closed circuit camera inspection of the trench #2 and #3 inlet pipes at the tee connection was not done after the attempt to unclog them. However, during the unclogging procedure, water was observed to be flowing into the inlet pipe and not backing up, indicating that the inlet at the tee connection was clear of sediment.



(Source: Shamrock Pipe Tools)

Figure 3.3: Twisting penetrator sewer cleaning hose nozzle used during attempt to unclog rear yard infiltration trench inlets

3.1.3 Infiltration trench well water levels

Monitoring of water levels in the trench wells showed that infiltration trench #1 received runoff from its drainage area during at least 18 rain events over the monitoring period. Water level responses observed in trench #1 well occurred only during large storm events (i.e. 15 mm in depth or greater) with maximum rainfall intensities of at least 6.6 mm/h. Typical water level response was a rapid rise during intense periods of rainfall followed by a gradual decline (Figures 3.4 and 3.5), suggesting that trench #1 was receiving runoff from its drainage area and that the trench was draining 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 (Table 3.4), which is what would be expected of a sandy silt glacial till subsoil. At this infiltration rate, if the 1.25 m deep trench was ever completely filled with water, it would require 4.7 days to fully drain (1250 mm ÷ 11 mm/h). These results support implementation of stormwater infiltration practices in future developments in the region that will be located on similar sandy silt glacial till subsoils.

It is notable that the maximum water level observed in the trench #1 well over the monitoring period was equivalent to a water level in the trench of approximately 900 mm (72% full) which occurred during the very intense August 9, 2011 storm event (41.2 mm rain depth, maximum rain intensity of 36.6 mm/h), which exceeded the 5 year return period, 1 and 2 hour storms for the region. During this event, no water level change was detected in the wells of infiltration trenches #2 and #3, suggesting that their trench inlets were either clogged or something else was preventing runoff from entering the trenches.

Table 3.4: Infiltration rates observed in rear yard infiltration trench #1 over the monitoring period

Drainage Event Start	Starting Water Level (mm)	Drainage Event End	Ending Water Level (mm)	Change in Water Level (mm)	Elapsed Time (h)	Infiltration Rate (mm/h)[1]
6/24/2011 16:55	62	6/24/2011 21:20:00	-6	68	4.42	5.4
8/9/2011 13:40:00	96	8/9/2011 15:25:00	-2	97	1.75	19.5
9/30/2011 4:00:00	24	9/30/2011 4:55:00	-8	32	0.92	12.2
10/20/2011 8:35:00	35	10/20/2011 11:30:00	-8	43	2.92	5.2
8/11/2012 3:10:00	93	8/11/2012 5:25:00	13	79	2.25	12.4
					MEAN:	10.9

Notes:[1] Infiltration rate (mm/h) is calculated as the change in water level (mm) times 0.35 (assumed 35% void space in the trench) divided by the elapsed time (h).

The well in infiltration trench #2 indicated water level changes during only four (4) periods over the course of the study, including the period after the attempt to unclog the inlet. Unlike the water level responses observed in the trench #1 well, when water levels rose in the trench #2 well, the rise was gradual and peaked hours after rainfall had subsided (e.g. Figure 3.4). Considering this, and the fact that water level changes observed were typically very small (e.g. maximum water level measured over the study period was only 350 mm during the 50.6 mm storm event of November 28, 2011) it is believed that they represent instances when the trench was intercepting shallow, laterally moving groundwater (i.e. interflow) and not instances when the trench was receiving runoff. While the test of pouring 650 L of water into the catchbasin while monitoring water levels in the trench #2 well was never repeated after the attempt to unclog the inlet, it is believed that trench #2 never received runoff from its catchment during the monitoring period. It is suspected that this is due to the configuration of the tee that connects the trench inlet pipe with the storm sewer pipe leading from the catchbasin, which may be preventing flows from entering the inlet pipe and simply conveying them to the downstream storm sewer. Figure 3.5 illustrates water levels in trench #1 and #2 wells during a particularly wet period between July 15 and August 12, 2012, after the attempt to unclog the trench inlets. It shows water levels in the trench #1 well responding to the series of large and intense storm events that occurred during this period while the trench well #2 water levels show no response.

Water level monitoring in the infiltration trench #3 well indicated no water level changes over the course of the monitoring period (e.g. Figure 3.4). After the attempt to unclog the trench inlet, it was only possible to monitor water levels in the piezometer well for a short time in July 2012 before property owners constructed a deck and shed over the catchbasin, which prevented any further access to the piezometer. During this period no large or high intensity storm events occurred. The test of pouring 650 L of water into the catchbasin while monitoring water levels in the trench #3 well was never repeated after the attempt to unclog the inlet either. This prevents any direct conclusions from being made regarding whether or not infiltration trench #3 received flows from its drainage area after the attempt to unclog the inlet pipe.

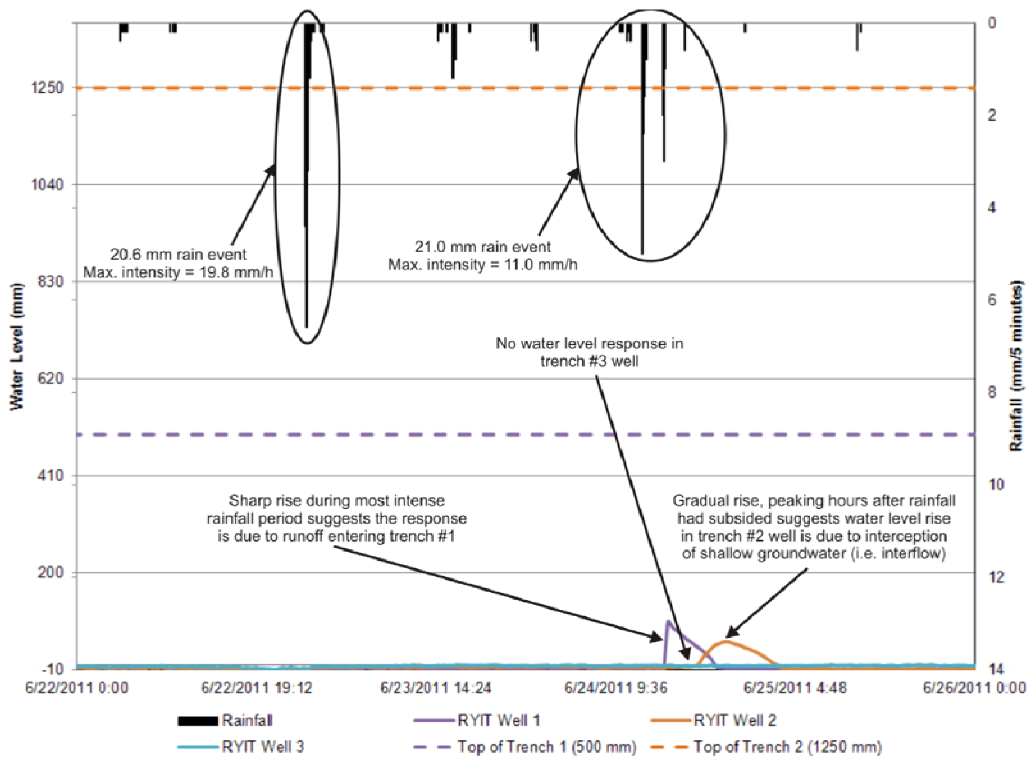


Figure 3.4: Water levels in rear yard infiltration trench wells in response to the June 24, 2011 storm event

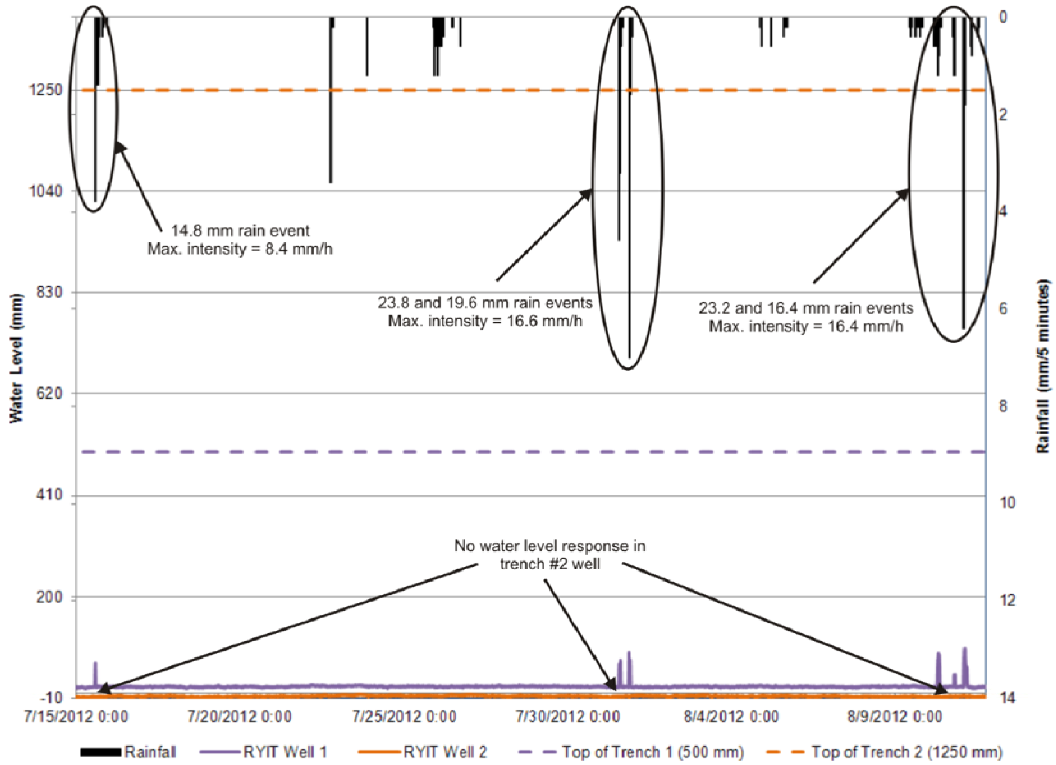


Figure 3.5: Water levels in rear yard infiltration trench wells in response to the July 15, July 31 and August 10 and 11, 2012 storm events

3.1.4 Runoff coefficients

Comparisons of the runoff characteristics of each study area catchment were made by calculating runoff volume and depth (volume divided by the catchment area) and runoff coefficients for each storm event captured over the monitoring period. Mean runoff coefficients were calculated for events greater than 5.0 mm in depth, events greater than 15.0 mm depth and events greater than 5.0 mm but less than 15.0 mm in depth. Total precipitation depth and total runoff depth from each catchment were also calculated for these event depth ranges, and used to calculate runoff reduction ratios for each treated catchment (see Section 3.1.5).

Analysis of the runoff characteristics of each catchment was limited to storm events greater than 5.0 mm in depth in an effort to reduce bias in the results towards the very small events (i.e. 5.0 mm depth or less) that occur with much greater frequency, but do not consistently produce runoff from urban catchments, or produce so little runoff that systematic error in flow measurements makes the accuracy of the volumetric data questionable. Runoff characteristics were examined for events greater than 15.0 mm in depth as well, in an attempt to determine if they change substantially for large storm events that are more likely to produce runoff from pervious areas, and which are believed to be the only types of storm events where the lot level practices implemented would consistently provide runoff reduction benefits. Additionally, in an attempt to determine whether or not differences in runoff characteristics between the catchments are due to factors other than the lot level best practices implemented (e.g. differences in impervious cover or proportion of impervious cover that is directly connected to storm sewers), examination was also done for events greater than 5.0 mm but less than 15.0 mm in depth. It is believed that pervious areas do not produce substantial volumes of runoff during these small to medium size storm events, regardless of the depth of topsoil applied, which was supported by results of monitoring water levels in the well of infiltration trench #1 (Section 3.1.3) and the test box scale monitoring, described in Section 3.2.

Runoff volume is calculated by multiplying the area-velocity sensor flow rate measurements (on 5 minute intervals) by a five (5) minute flow duration to arrive at a volume and then summing the total flow volume resulting from each storm event. The runoff coefficient is simply the ratio of runoff depth (i.e. runoff volume divided by the catchment area) to precipitation depth (Equation 3.1). A higher runoff coefficient value indicates that a greater portion of rainfall typically becomes runoff from the catchment and enters the storm sewer system.

Equation 3.1:

$$R = D_{re}/D_{pe}$$

Where;

R = runoff coefficient (unitless ratio)
D_{re} = Depth of runoff by storm event (mm water depth over the drainage area)
D_{pe} = Depth of precipitation by storm event (mm water depth over the drainage area)

and;

$$D_{re} = \text{measured runoff volume } (m^3)/\text{catchment area } (m^2)*1000$$

Tables 3.5 and 3.6 describe and compare runoff coefficients for the Control and Increased Topsoil Depth catchments, and the Control and Rear Yard Infiltration Trenches catchments, respectively. All three water level sensor portions of the area-velocity flow measurement instruments installed at the catchment outlet locations malfunctioned at some time during the monitoring periods, and multiple times in some locations. Therefore, comparisons of runoff characteristics between the catchments can be made only for events when both the control and treatment catchment sensors were producing reliable data, which were not always the same storm events for all three catchments. Additionally, Table 3.6 describes and compares runoff coefficients for the Control and Rear Yard Infiltration Trenches catchments separately for time periods before and after the attempt to unclog the trench inlets to show how they changed. A detailed breakdown of rainfall depth, intensity, runoff depth, and runoff coefficient values for all storm events greater than 5.0 mm depth over the study period is provided in Appendix B.

Table 3.5: Comparison of runoff coefficients for Control and Increased Topsoil Depth catchments, for various storm event depth ranges over the monitoring period

Event depth range	N[1]	Runoff coefficient							
		Control				Increased Topsoil Depth			
		Mean	Min.	Max.	Std. Dev.	Mean	Min.	Max.	Std. Dev.
All events > 5 mm	38	0.34	0.07	0.87	0.22	0.25	0.01	0.79	0.18
All events > 15 mm	17	0.42	0.11	0.67	0.16	0.31	0.09	0.58	0.17
5 mm < Events < 15 mm	21	0.28	0.07	0.87	0.23	0.21	0.01	0.79	0.17

Notes: [1] Number of storm events that occurred over the monitoring period of this size range when both catchment sensors were functioning reliably.

Table 3.6: Comparison of runoff coefficients for Control and Rear Yard Infiltration Trenches catchments, for various storm event depth ranges over the monitoring period

Event depth range	N[1]	Runoff coefficient							
		Control				Rear Yard Infiltration Trenches			
		Mean	Min.	Max.	Std. Dev.	Mean	Min.	Max.	Std. Dev.
All events > 5 mm BEFORE unclogging attempt	46	0.36	0.07	0.85	0.19	0.43	0.18	0.84	0.15
All events > 15 mm BEFORE unclogging attempt	17	0.42	0.11	0.67	0.18	0.47	0.20	0.64	0.12
5 mm < Events < 15 mm BEFORE unclogging attempt	29	0.32	0.07	0.85	0.19	0.41	0.18	0.84	0.16
All events > 5 mm AFTER unclogging attempt	18	0.27	0.00	0.57	0.14	0.23	0.00	0.43	0.11
All events > 15 mm AFTER unclogging attempt	9	0.30	0.02	0.57	0.14	0.26	0.02	0.43	0.11
5 mm < Events < 15 mm AFTER unclogging attempt	9	0.21	0.00	0.32	0.11	0.17	0.00	0.43	0.07

Notes: [1] Number of storm events that occurred over the monitoring period of this size range when both catchment sensors were functioning reliably.

As shown in Table 3.5, the Increased Topsoil Depth catchment was observed to exhibit a lower mean runoff coefficient than the Control catchment for all storm event depth ranges examined and that differences were quite consistent (difference ranges from 0.07 to 0.11). The fact that mean runoff coefficients were lower in the Increased Topsoil Depth catchment during small to medium sized storm events (i.e. those greater than 5.0 mm but less than 15.0 mm in depth) raises the possibility that the observed differences could be due to differences in total impervious cover and proportion of impervious cover that is directly connected to storm sewers (i.e. % roads and driveways), rather than the increased topsoil depth implemented in rear yard areas.

As shown in Table 3.6, the Rear Yard Infiltration Trenches catchment was observed to exhibit slightly higher mean runoff coefficients than the Control catchment for all storm event depth ranges examined before the attempt to unclog the trench inlets. As described in the previous section, 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, so this result is not surprising. The presence of catchbasins in three rear yards in the Rear Yard Infiltration Trenches catchment was likely contributing to higher runoff rates being observed, as rear yards in the Control catchment did not include them and while two trenches were clogged, they were enhancing the rate at which runoff was being delivered to downstream storm sewers.

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. Water level monitoring results from the trench #2 well after the attempt to unclog the inlet confirms that it continued to not receive runoff from its drainage area. While it was not possible to determine if the attempt to unclog the trench #3 inlet was successful, these results suggest that it was not, or that other another factor was preventing runoff from entering the trenches (e.g. configuration of the tee connection).

Both before and after the attempt to unclog the trench inlets, differences in mean runoff coefficients between the Rear Yard Infiltration Trenches catchment and Control catchment were very similar regardless of the size of storm event (Table 3.6), suggesting that differences were due to catchment land cover differences and not due the lot level stormwater practices. Based on this evidence it can be concluded that any runoff reduction benefit achieved by the functioning trench or trenches was very small and largely undetectable through the comparison of mean catchment runoff coefficients alone.

3.1.5 Runoff reduction ratio

In an attempt to further characterize and quantify the runoff reduction benefits of these lot level best practices, runoff reduction ratios were calculated for the various storm event depth ranges of interest to determine if the magnitude of runoff reduction differed substantially according storm event depth and if any conclusions could be made regarding under what conditions these practices provide the most benefit.

Runoff reduction ratios were calculated by summing the total runoff depth for all events that occurred during the monitoring period that fall within the event depth ranges of interest for the Control and treatment catchments (i.e. Increased Topsoil Depth and Rear Yard Infiltration Trenches catchments) and dividing the difference between the control catchment total and treatment catchment total by the control catchment total as described in Equation 3.2.

Equation 3.2:

$$\text{Runoff reduction ratio} = (D_{rt}\ \text{control} - D_{rt}\ \text{treated}) / D_{rt}\ \text{control}$$

Where;

D_{rt} = Depth of runoff, total for events within the event depth range (mm water depth over the drainage area)

This approach to calculating a runoff reduction ratio is superior to calculating a mean value from storm event based runoff reduction ratios as it does not bias the results towards storm event sizes that occur most frequently during the monitoring period and implicitly accounts for antecedent conditions (Geosyntec Consultants, 2009).

Table 3.7 describes the runoff reduction ratios observed for the Increased Topsoil Depth catchment and Rear Yard Infiltration Trenches catchments over the monitoring period. Results from the comparison of the Increased Topsoil Depth catchment with the Control catchment indicate that for small to medium size storm events (i.e. events greater than 5.0 mm but less than 15.0 mm in depth), the ITD catchment produced about 22% less runoff. When runoff reduction ratio is calculated for large events (i.e. greater than 15.0 mm in depth) results indicate that the ITD catchment produced about 27% less runoff. These findings suggest that the 22% less runoff observed from the ITD catchment during small to medium size events is likely due to differences in catchment land cover. As mentioned previously, impervious cover in the Control catchment is 5% greater than in the ITD catchment and the proportion of impervious cover that is directly connected to storm sewers (i.e. % roads and driveways) is 4% higher in the Control catchment, which could account for the observed difference in runoff volumes during small to medium size storm events. The observation that runoff reduction increases to 27% during large storm events suggests that these are the conditions when increased topsoil depth in rear yards begins to provide runoff reduction benefits and that the magnitude of the benefit is more in the order of 5% less runoff (0.27 – 0.22). These results suggest that application of increased topsoil depth 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 very minor runoff reduction benefits when examined at a catchment scale. The magnitude of benefit observed is not surprising considering that this best management practice only treats runoff from a minor portion of impervious surfaces in the catchment. Roofs draining to rear yard areas represent about 29% of impervious cover in the ITD catchment area (assuming half of all roofs drain to rear yards). Furthermore, this best management practice only provides benefits during large and intense storm events when landscaped areas constructed with a conventional depth of topsoil begin to generate runoff. Rain events greater than 15 mm in depth represented about 72% of the total depth captured by monitoring of the ITD catchment over the monitoring period.

Table 3.7: Runoff reduction ratios observed over the monitoring period by event depth range

Catchment Comparison	Runoff Reduction Ratio					
	Events >5 mm		Events >15 mm		5 mm< Events <15 mm	
	Ratio	N[1]	Ratio	N[1]	Ratio	N[1]
ITD vs. CTL	0.26	38	0.27	17	0.22	21
RYIT after unclogging attempt vs. CTL	0.15	18	0.14	9	0.16	9

Notes: [1] Number of storm events that occurred over the monitoring period of this size range when both catchment sensors were functioning reliably.

While overall runoff reduction ratio for the Increased Topsoil Depth catchment over the monitoring period was quite small (i.e. in the order of 5 to 27%), it is clear from examination of event hydrographs during large and intense storm events that the deeper topsoil applied to rear yard areas provided more substantial benefits during some of these infrequent events. Figure 3.6 shows that substantial runoff reduction was observed during the September 2, 2010 storm event that deposited 17.6 mm of rainfall in just over an hour. During this large and high intensity event, both peak flow (normalized to catchment drainage area) and runoff depth were substantially lower in the Increased Topsoil Depth catchment than the Control catchment (62% less runoff depth). Another example of an event where substantial runoff reduction was observed is the August 9, 2011 storm event (Figure 3.7) that deposited 42.2 mm of rainfall at a maximum intensity of 36.6 mm per hour (the most intense event during the study period, exceeding the 5 year return period one hour and two hour events for this region). During this very large and intense rain event the Increased Topsoil Depth catchment produced 51% less runoff depth than the Control catchment and peak flow rate was much less. Assuming that the Increased Topsoil Depth catchment typically generates about 22% less runoff than the Control due to differences in land cover alone, these results suggest that additional topsoil applied to rear yards can achieve runoff reductions in the order to 20 to 40% per unit area during some of the most intense storm events captured over the monitoring period.

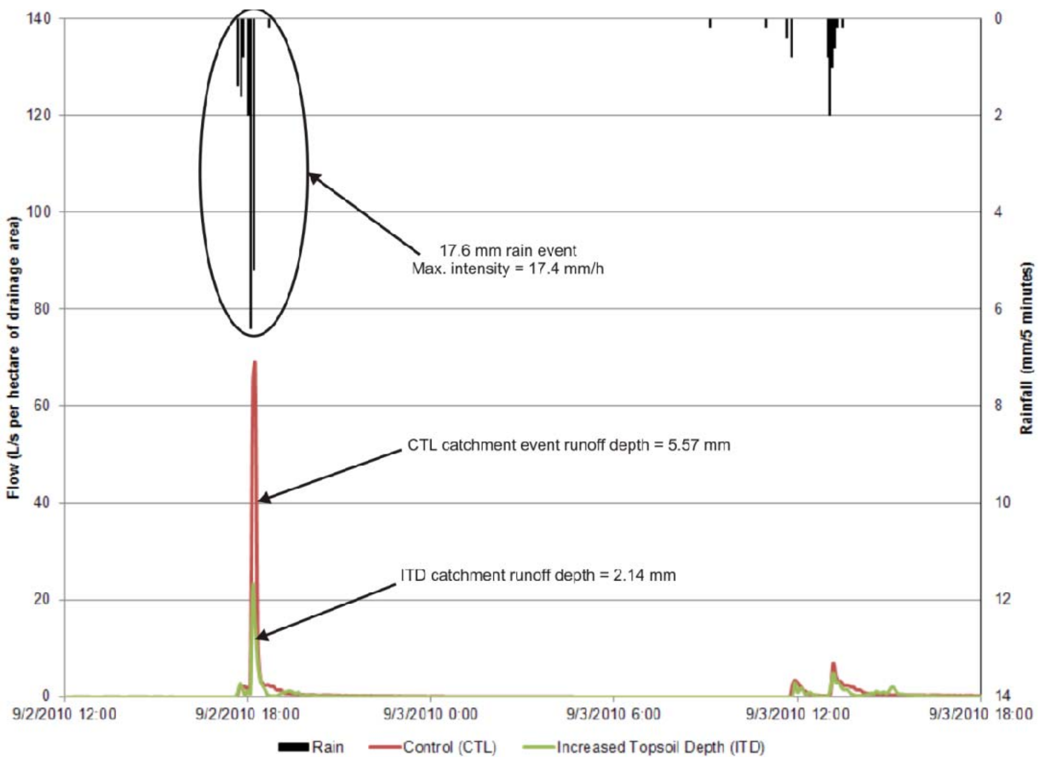


Figure 3.6: Comparison of storm hydrographs for the September 2, 2010 storm event (large depth and high intensity storm)

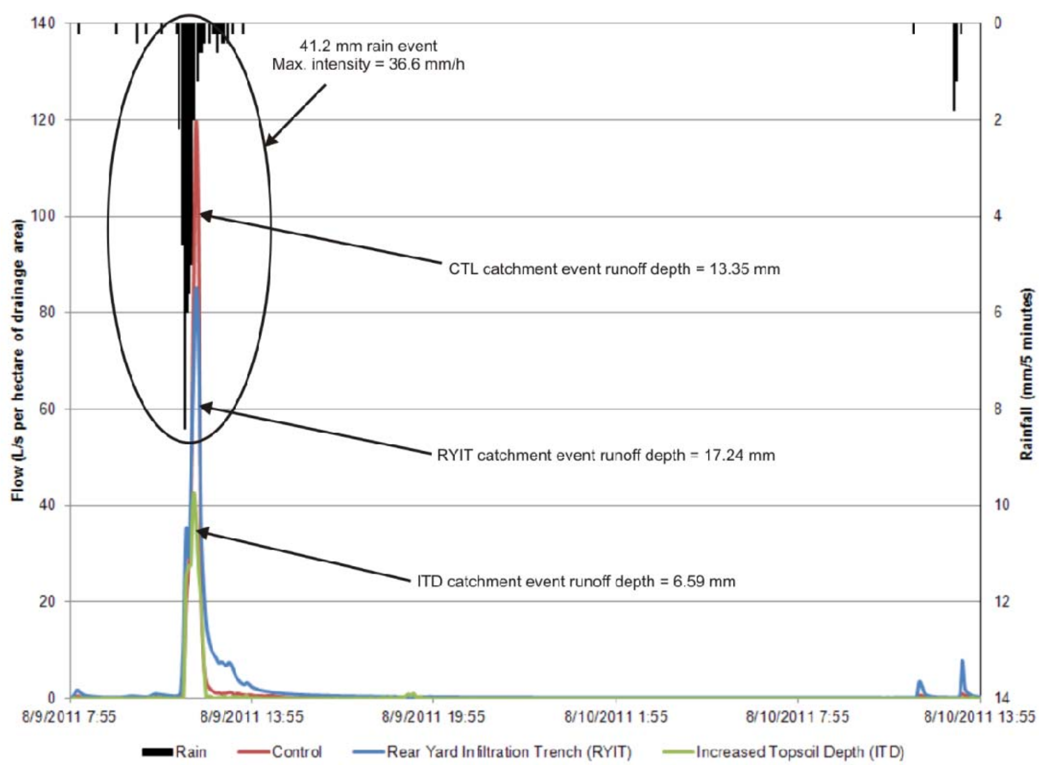


Figure 3.7: Comparison of storm hydrographs for the August 9, 2011 storm event (large depth and very high intensity storm)

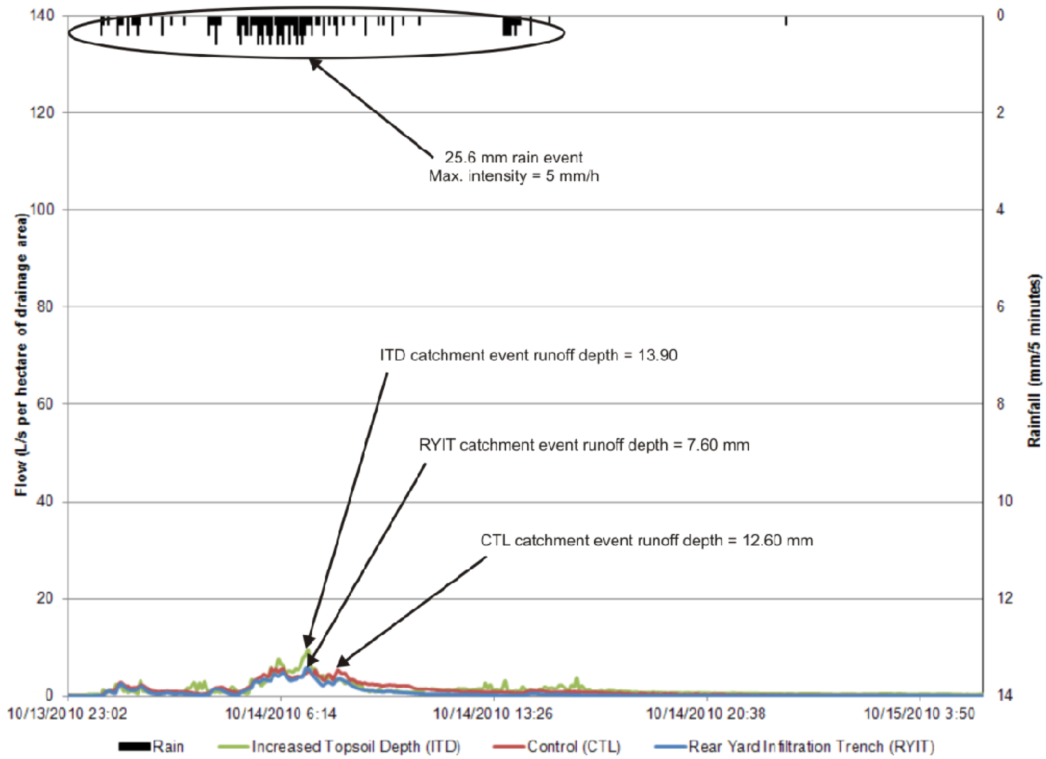


Figure 3.8: Comparison of storm hydrographs for the for the October 13, 2010 storm event (large depth, low intensity storm)

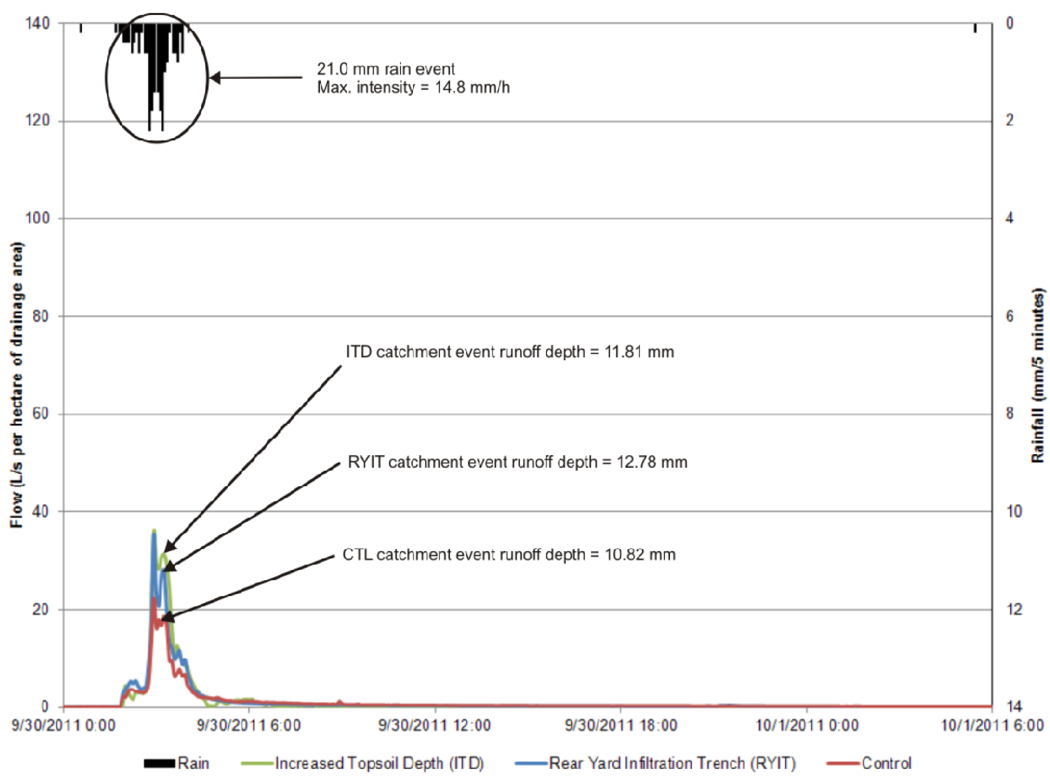


Figure 3.9: Comparison of storm hydrographs for the September 30, 2011 storm event (large depth, high intensity event with very wet weather prior)

Also evident from examination of storm event hydrographs is that rainfall intensity seems to be a factor influencing when runoff reduction benefits of increased topsoil depth are realized. Figure 3.8 shows that during the large depth but low intensity storm event on October 14, 2010 that deposited 25.6 mm of rainfall at a maximum intensity of 5.0 mm per hour, peak flow rate and runoff depth from the Increased Topsoil Depth and Control catchments were very similar (ITD catchment produced 10% more runoff depth than the Control catchment). It is postulated that rear yard areas in both catchments do not consistently produce runoff during low intensity rain events, which is also supported by results from monitoring of rear yard infiltration trench #1 water levels (Section 3.1.3, Appendix B) and test box scale monitoring (Section 3.2). If rear yards only consistently produce runoff during large and intense storm events, it is not surprising that the observed runoff reduction ratios for the Increased Topsoil Depth catchment were small, because they occur at a fairly low frequency in southern Ontario.

While substantial runoff reduction benefits were observed in the Increased Topsoil Depth catchment during some large and intense storm events, another factor influencing whether or not this is the case seems to be antecedent soil moisture. As illustrated in Figure 3.9, runoff depths from all three study area catchments were very similar during the large and intense storm event of September 30, 2011. A ten day period of very wet weather preceded this event, over which 60.6 mm of rain fell. It is postulated that rain from the previous storm events had largely saturated the rear yard soils in all the catchments, and that during the September 30, 2011 event, they all produced runoff to a similar degree. 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.

In contrast, results from comparison of overall runoff depth from the Rear Yard Infiltration Trenches catchment with the Control catchment indicate that the Rear Yard Infiltration Trenches catchment produced about 14 to 16% less runoff depth over the monitoring period after the attempt to unclog the trench inlets (Table 3.7). No substantial differences were observed in runoff reduction ratios for the different event depth ranges, suggesting that the differences in runoff depth observed between the two catchments is likely due to differences in catchment land cover alone (e.g. impervious cover in the Control catchment is 5% greater than in the Rear Yard Infiltration Trenches catchment, while the proportion of impervious cover that is directly connected to storm sewers is 7% less). These results are consistent with those from the comparison of mean runoff coefficients described in the previous section. 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.

While mean runoff coefficient and overall runoff reduction ratio results from the Rear Yard Infiltration Trenches catchment after the attempt to unclog the trench inlets suggest that little or no net benefits were being achieved by the functioning infiltration trench(es), it is clear from examination of event hydrographs during large and intense storm events that substantial benefits were observed during some of these infrequent events. Figure 3.10 shows that substantial runoff reduction was observed during the August 27, 2012 storm event that deposited 27.4 mm of rainfall within an hour. During this large and high intensity event, both peak flow (normalized to catchment drainage area) and runoff depth were substantially lower in the Rear Yard Infiltration Trenches catchment than the Control catchment (36% less runoff depth).

As indicated previously, rainfall intensity was also found to be a factor influencing whether or not runoff reduction benefits are realized in the Rear Yard Infiltration Trenches catchment. As shown in Figure 3.11, peak flow and runoff depth from both the Rear Yard Infiltration Trenches catchment and Control catchment were very similar during the September 8, 2012 storm event, during which 40.8 mm of rain fell at a maximum intensity of only 10.8 mm/h. Over the course of this large depth but low intensity storm event it was observed that the Rear Yard Infiltration Trenches catchment produced about 13% less runoff depth than the Control catchment, which is believed to be attributable to differences in land cover between the catchments alone. It is notable that water levels in trench #1 were observed to rise in response to rainfall during this event, indicating that the quantity and intensity of rainfall was high enough to generate runoff from rear yard pervious areas.

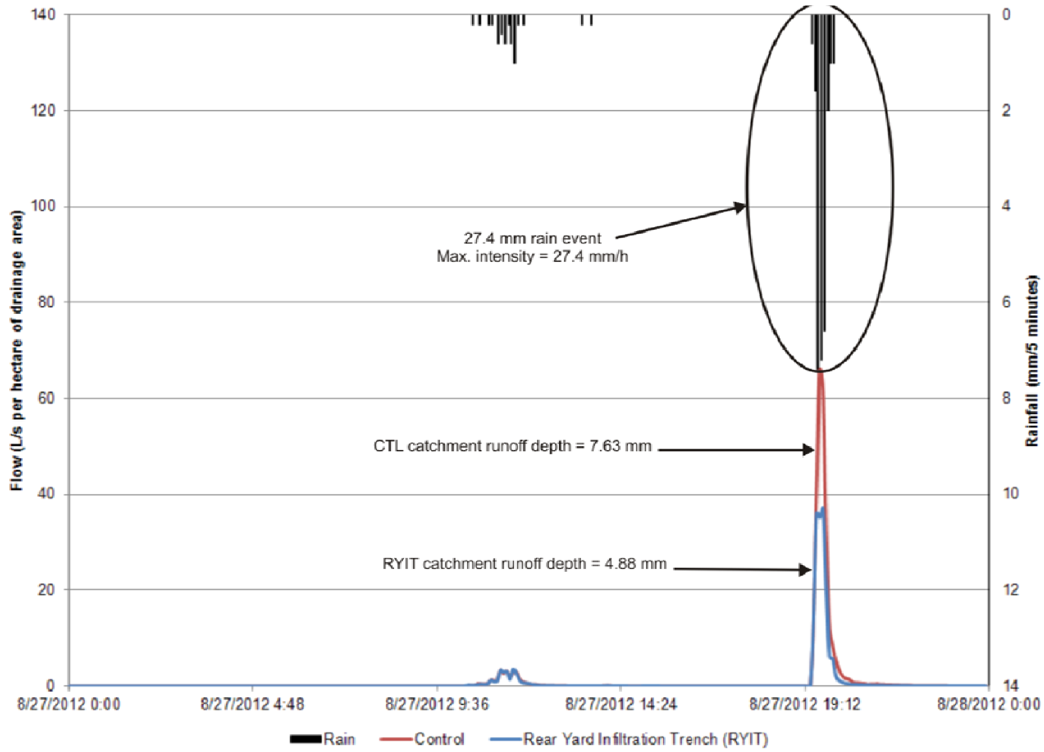


Figure 3.10: Comparison of storm hydrographs for the August 27, 2012 storm event (large depth, high intensity storm)

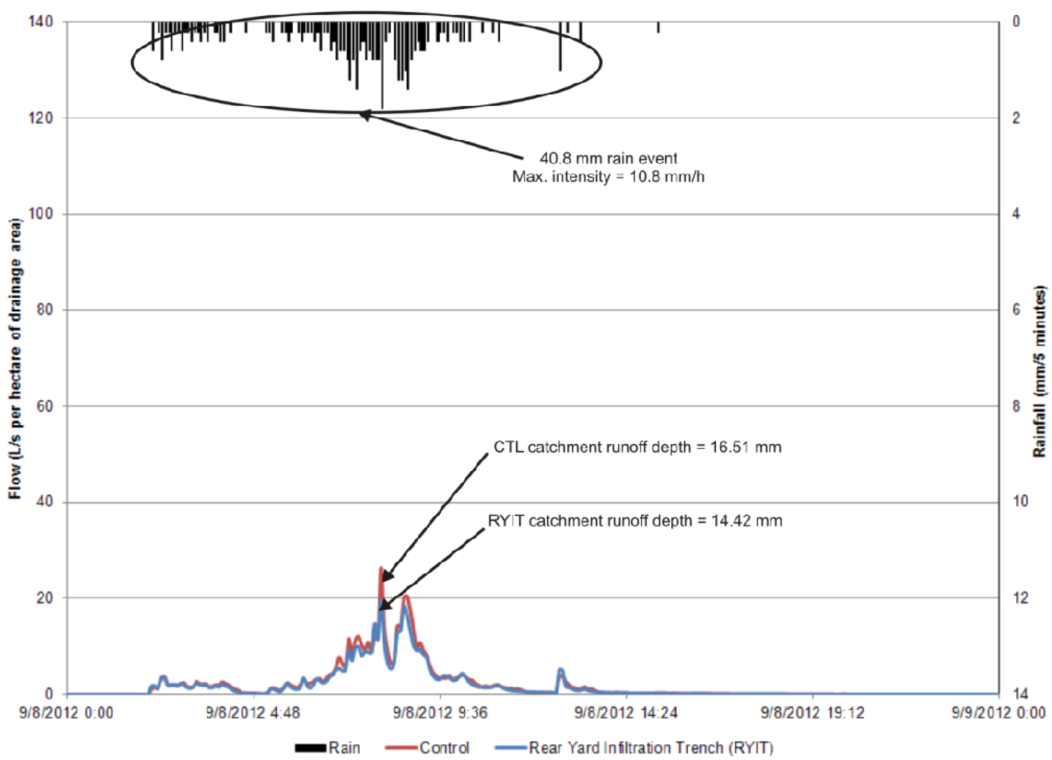


Figure 3.11: Comparison of storm hydrographs for the September 8, 2012 storm event (large depth, low intensity storm)

3.2 Test Box Evaluations

3.2.1 Precipitation

Over the June 9 to November 23, 2012 monitoring period a total of 557.6 mm of rain fell at the test box site. The largest and most intense storm event over this period occurred on July 25, 2012 when 77.8 mm of rainfall was recorded with a maximum rainfall intensity of 43.0 mm/h, representing an event larger than the ten year return period, one hour to 12 hour storm events for this area[5]. The second largest and most intense storm event over this period occurred on September 4, 2012 when 43.4 mm of rainfall occurred with a maximum rainfall intensity of 30.2 mm/h, representing an event larger than the two year return period, one hour to 12 hour storm events for this area[6]. Over this period runoff was observed from at least one test box during 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.

Over the August 9 to November 23, 2012 monitoring period, representing the period after sod levels were reset to address soil settling issues, a total of 355.2 mm of rain fell at the test box site, representing a total mass of rain delivered to each test box of about 75.02 kilograms (kg) based on the test box surface area of 2.112 m^2 (0.3552 m * 2.112 m^2 * 100 kg/m^3 water).

The observation that runoff was not consistently produced from the grassed test boxes during storms less than 15.6 mm in depth and 11.4 mm/h maximum intensity, is consistent with results from monitoring of rear yard infiltration trench #1 well water levels at the Box Grove community site, which indicated that no storms less than 15 mm in depth and 6.6 mm/h maximum intensity produced a response in trench #1 well water levels over the monitoring period. These results support the postulation put forward in this study that grassed pervious areas constructed with 10 to 15 cm of topsoil typically do not produce runoff during events less than 15 mm in depth. They also suggest that focusing examination of runoff characteristics of the treated catchments examined in this study on events greater than 15 mm in depth is a sound approach to quantifying their runoff reduction benefits.

3.2.2 Gravimetric analysis

Table 3.8 summarizes the results from the gravimetric analyses of the test boxes over the August 8 to November 23, 2012 monitoring period, after the sod levels were reset to address settling issues in some boxes. These results provide an indication of the overall fate of precipitation that fell on each test box and provide insight into where substantial differences between treatments were detected.

[5] The ten year return period, one hour storm event for this area can be estimated from historical data from the Toronto Keele - Finch climate station (located approximately 10 kilometres southeast of the Kortright Centre for Conservation property) for the years 1964 to 1987 and is 40.0 mm depth of rainfall (Environment Canada, 2004). The ten year return period 12 hour storm event for this area is 67.0 mm depth of rainfall (Environment Canada, 2004).

[6] The two year return period, one hour storm event for this area can be estimated from historical data from the Toronto Keele - Finch climate station (located approximately 10 kilometres southeast of the Kortright Centre for Conservation property) for the years 1964 to 1987 and is 23.7 mm depth of rainfall (Environment Canada, 2004). The two year return period 12 hour storm event for this area is 38.1 mm depth of rainfall (Environment Canada, 2004).

Table 3.8: Summary of gravimetric analyses of test boxes over the August 9 to November 23, 2012 monitoring period

Treatment[1]	Runoff		Infiltrate		Water Storage[2]		Total Runoff, Infiltrate and Storage		ET[3]	
	kg	%	kg	%	kg	%	kg	%	kg	%
STD Box 1	1.00	1.3	14.79	19.7	3.80	5.1	19.59	26.1	55.44	73.9
STD Box 2	0.78	1.0	13.76	18.3	5.60	7.5	20.14	26.8	54.89	73.2
STD Mean	0.89	1.2	14.28	19.0	4.70	6.3	19.86	26.5	55.16	73.5
ITDCB Box 3	0.00	0	11.32	15.1	8.10	10.8	19.42	25.9	55.60	74.1
ITDCB Box 4	0.00	0	8.88	11.7	7.70	10.3	16.58	22.1	58.44	77.9
ITDCB Mean	0.00	0	10.10	13.5	7.90	10.5	18.00	24.0	57.02	76.0
ITD Box 5	0.00	0	8.83	11.8	7.60	10.1	16.43	21.9	58.58	78.1
ITD Box 6	0.55	0.7	10.77	14.3	4.60	6.1	15.92	21.1	59.10	78.8
ITD Mean	0.27	0.4	9.80	13.1	6.10	8.1	16.17	21.5	58.84	78.4

Notes: [1] STD = Standard Topsoil Depth; ITDCB = Increased Topsoil Depth With Compost Blanket; ITD = Increased Topsoil Depth.
[2] Water storage was calculated by summing the changes in the weight of each test box over the monitoring period, to determine the net quantity of water that remained stored in the box at the end of the period.
[3] Evapotranspiration (ET) calculated as the difference between the total mass of rainfall received by each box minus the total mass of water that became runoff, infiltrate and that remained stored in the box at the end of the period.

Based on the runoff mass values in Table 3.7 it can be concluded that the Standard Topsoil Depth (STD) test boxes produced the greatest amount of runoff, as expected, albeit very little in terms of total rainfall. The Increased Topsoil Depth (ITD) test boxes also produced very little runoff over this period, even during the very large and intense storm event of September 4, 2012. Based on differences in mean total runoff mass between the Standard Topsoil Depth and Increased Topsoil Depth test boxes, the Increased Topsoil Depth test boxes produced 69% less runoff over the monitoring period than the Standard Topsoil Depth boxes. The Increased Topsoil Depth With Compost Blanket (ITDCB) test boxes produced no runoff over this period, suggesting that addition of the compost blanket increased water holding capacity of the soil and provided a runoff reduction benefit.

In the Standard Topsoil Depth test boxes the total quantity of rainfall that infiltrated through the topsoil and subsoil was greater than in the increased topsoil depth boxes. There was not a substantial difference in total quantity of infiltrate between the Increased Topsoil Depth With Compost Blanket test boxes and the Increased Topsoil Depth test boxes, suggesting that the addition of the compost blanket did not result in greater infiltration.

In terms of water storage, calculated by summing the net change in weight of each box over the monitoring period, Table 3.7 shows that the Increased Topsoil Depth With Compost Blanket test boxes stored more water than the Increased and Standard Topsoil Depth boxes, also suggesting that the addition of the compost blanket increased the water holding capacity of the soil.

In terms of the total percentage of rainfall that was returned to the atmosphere through evapotranspiration (ET), slight differences were observed between the three treatments with the Increased Topsoil Depth test boxes exhibiting the highest rate of evapotranspiration (mean value of 78%) followed by the Increased Topsoil Depth With Compost Blanket test boxes (mean value of 76%).

Overall, the results indicate that the Standard Topsoil Depth boxes produced the most runoff and also infiltrated the most precipitation but evapotranspired the least. The Increased Topsoil With Compost Blanket boxes stored the most water at the end of the monitoring period while the quantity of rain that infiltrated and evapo-transpired was similar to the Increased Topsoil Depth boxes. While it is not clear why substantial differences were observed between the treatments in terms of the quantity of rainfall that was infiltrated, these results suggest that the practice of applying increased topsoil depth (25 to 30 cm) to grassed pervious areas should produce less runoff than the standard 10 cm depth and that additional runoff reduction and water storage benefits can be provided by amending topsoil with compost, which is what was expected based on the literature review. These results also support the results from the catchment scale evaluation of runoff reduction benefits of increased topsoil depth in the Box Grove community (Section 3.1), which indicated that over the monitoring period, between 5 and 27% less runoff was produced from the Increased Topsoil Depth catchment during storm events greater than 15 mm in depth.

3.2.3 Soil moisture

Soil moisture at 10 cm depth below the surface of the sod was measured throughout the monitoring period to evaluate the effect that the compost blanket amendment had on the water holding capacity of the soil. Mean soil moisture values were calculated for each time the Increased Topsoil Depth With Compost Blanket and Increased Topsoil Depth boxes were measured and the results were plotted over time along with rainfall depth (Figures 3.12 and 3.13) to evaluate if differences were observed between the treatments. 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. Observed differences in soil moisture at 10 cm depth between the two treatments were found to be significant based on a Paired t-Test (two tailed) comparing mean soil moisture values averaged over the whole monitoring period ($P = 1.8 \times 10^{-8}$).

These results support the results from gravimetric analyses described previously which indicated 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. These results 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. So this practice could help conserve water, save property owners money and reduce the amount of time and effort they spend maintaining their lawns.

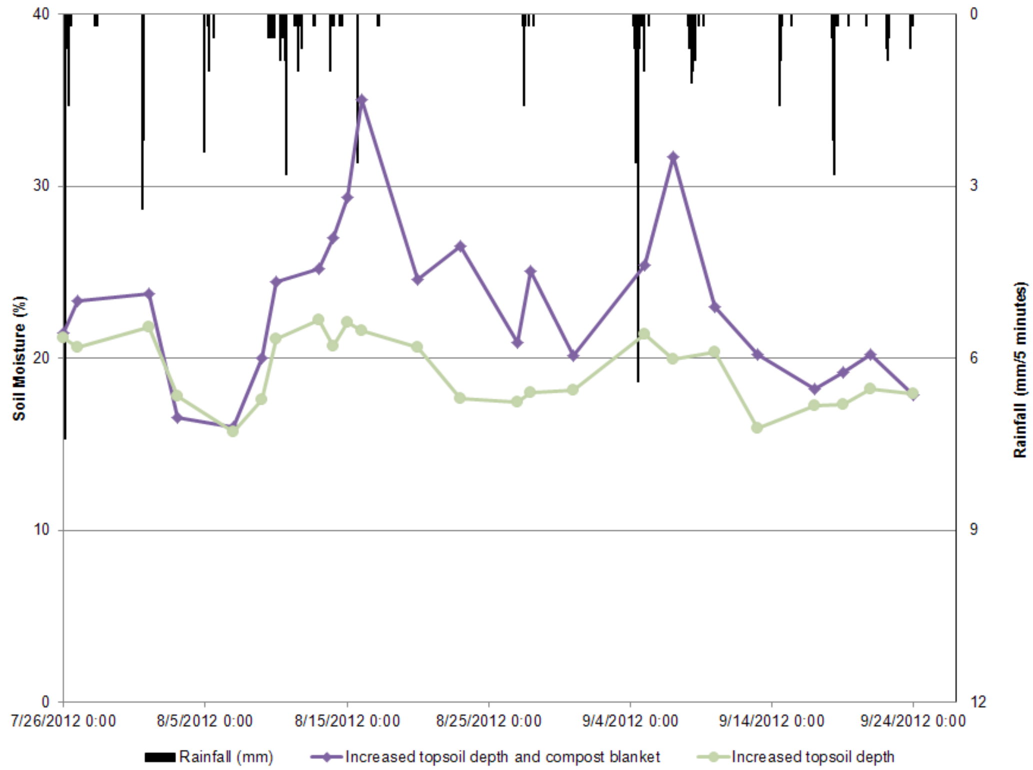


Figure 3.12: Comparison of mean soil moisture at 10 cm depth over the summer 2012 monitoring period

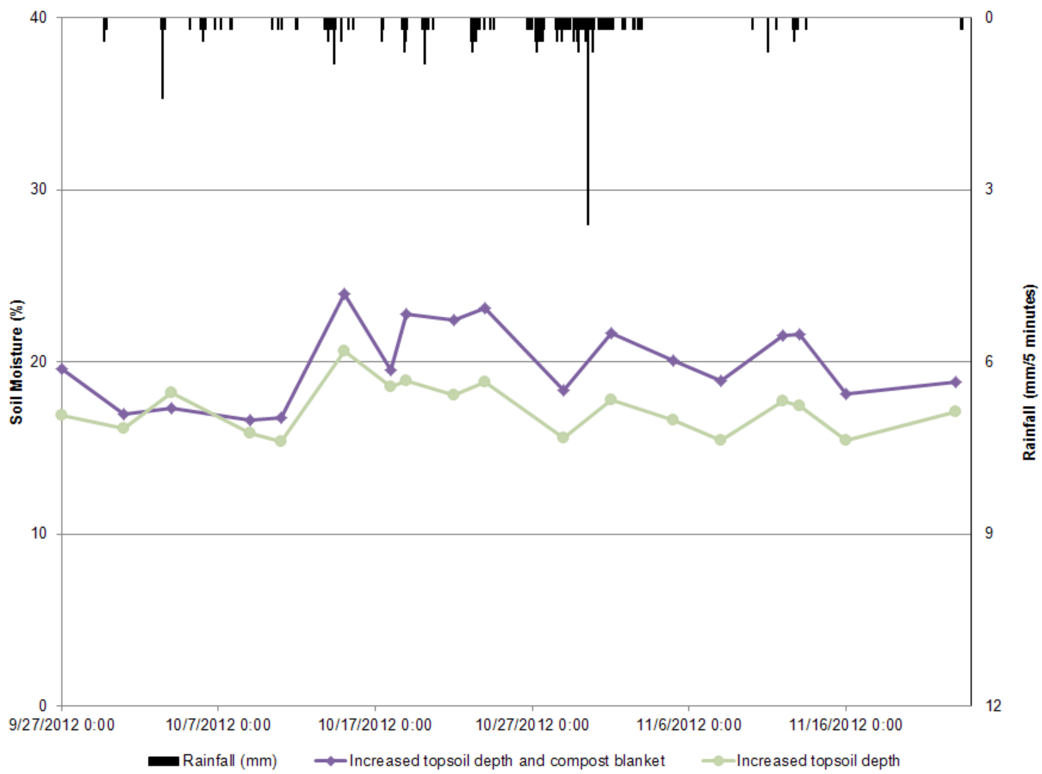


Figure 3.13: Comparison of mean soil moisture at 10 cm depth over the fall 2012 monitoring period

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 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.

Regarding the implementation of increased topsoil depth in a portion of the Box Grove community, it was determined through field testing that only about 15 cm of topsoil was applied in front yards, rather than the 30 cm that was specified in design documents. If 30 cm of topsoil was reapplied in front yards and boulevards between sidewalks and roads, in addition to the 30 to 120 cm applied in rear yards, an additional 6,780 m^2 of impervious cover would have drained to pervious areas with increased topsoil depth, potentially doubling the overall runoff reduction ratio. Field testing also determined that topsoil depth in landscaped areas varied considerably in all parts of the community. While it is acknowledged that this is largely unavoidable due to uneven soil surfaces produced by grading equipment and common to any construction site, it suggests that 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. It is also notable that the topsoil placed in pervious areas contained only about 2 to 3% organic matter. Minimum standards for topsoil quality in turf grass areas recommended in several guidelines are between 5 and 10% organic matter, in order to ensure the topsoil has the porosity and water holding capacity needed to provide stormwater management benefits and support healthy vegetation (e.g. Soils for Salmon, 2010; TRCA, 2012). If topsoil with organic matter content of at least 5% had been applied, or if the stockpiled topsoil from the site had been amended with compost to achieve the recommended standard of 5 to 10% organic matter content, runoff reduction benefits of increased topsoil depth may have been greater. Lastly, it is notable that prior to reapplication of topsoil in areas to be landscaped in the Increased Topsoil Depth catchment, no efforts were made to reverse compaction of subsoils caused during construction. If compacted subsoils had been tilled or scarified to a minimum depth of 10 cm prior to reapplication of topsoil, as recommended in existing guidelines (TRCA, 2012), greater runoff reduction benefits may have been observed.

Regarding the implementation of rear yard infiltration trenches in a portion of the Box Grove community, it was clear through conversations with owners of the three properties where the trenches were located, that they were not well aware of the presence, function or maintenance requirements of the structural stormwater management practice on their properties. Indeed, over the course of the study, one property owner constructed a deck and shed over top of the rear yard catchbasin and infiltration trench monitoring well, which now prevents access for inspection, monitoring and maintenance purposes. 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.

Issues with the design of the rear yard infiltration trenches were also made apparent through the testing and monitoring conducted through this study. The fact that the inlets to the trenches are inaccessible from the rear yard catchbasins makes 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 if installed at the wrong angle. A better design would have been to connect the trench inlet pipes directly to the catchbasin, with the overflow/outlet storm sewer pipe at a higher elevation than the inlet pipe.

From inspections of rear yard infiltration trench locations during construction it was clear that little thought had been put into the erosion and sediment control practices needed to prevent the rear yard catchbasins and infiltration trench inlets from becoming clogged with sediment. If erosion and sediment control practices had been applied that prevented sediment from accumulating in the catchbasins, issues with clogging of trench inlets could have been avoided. Available guidance on construction of stormwater infiltration practices (CVC, 2012) should be provided to contractors when they are a part of the development design and assurances should be put in place to ensure they will be followed to help avoid problems with clogging and as-built conditions not meeting design specifications. It is strongly recommended that stormwater infiltration practices 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.

4.2 Runoff Reduction

4.2.1 Catchment scale evaluations

Evaluation of the runoff reduction benefits of increased topsoil depth and infiltration trenches in rear yard areas of portions of the Box Grove residential community was done by comparing the overall runoff characteristics of the Increased Topsoil Depth catchment and Rear Yard Infiltration Trenches catchment with a Control catchment of conventional design and roughly equivalent area and land cover characteristics, over three spring to fall monitoring periods.

In an attempt to differentiate runoff reduction benefits attributable the lot level practices from differences in runoff characteristics resulting from minor differences in catchment land cover, analysis was focused on comparison of overall runoff from storm events greater than 15 mm in depth with those from events less than or equal to 15 mm but greater than 5 mm in depth. Implicit in this approach is the assumption that pervious areas, regardless of whether a standard or increased depth of topsoil was applied during construction, typically do not generate runoff from storm events less than 15 mm in depth and that the only types of events where the lot level practices implemented would consistently provide runoff reduction benefits would be during large and intense storms[7]. This approach also attempts to reduce bias in the results towards the very small events (i.e. 5 mm depth or less) that occur with much greater frequency, but do not consistently produce runoff from urban catchments, or produce so little runoff that systematic error in flow measurements makes the accuracy of the volumetric data questionable.

Increased Topsoil Depth

Based on comparison of mean runoff coefficients the Increased Topsoil Depth catchment was observed to exhibit lower mean runoff coefficients than the Control catchment for all storm event depth ranges examined and that differences were quite consistent. The fact that mean runoff coefficients were lower in the Increased Topsoil Depth catchment during small to medium sized storm events (i.e. those greater than 5 mm but less than or equal to 15 mm in depth) raised the possibility that the observed differences could be due to minor differences in catchment land cover, rather than the increased topsoil depth implemented in rear yard areas.

When total runoff depth over the monitoring period was compared, it was found that for small to medium size storm events (i.e. events greater than 5 mm but less than 15 mm in depth) the Increased Topsoil Depth catchment produced 22% less runoff 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 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 (total impervious cover in the Control catchment is 5% greater than in the ITD catchment and the proportion of impervious cover that is directly connected to storm sewers is 4% higher in the Control catchment). 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 begins to provide runoff reduction benefits and that the magnitude of the benefit is more in the order of 5% less runoff over the monitoring period. These results suggest that application of increased topsoil depth 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 very minor runoff reduction benefits when examined at a catchment scale. As noted previously, had increased topsoil depth been applied in all pervious areas in the catchment, rather than just in the rear yards, and if the topsoil contained at least 5% organic matter, runoff reduction benefits may have been greater. Furthermore, if efforts had been made to reverse compaction of the subsoil in pervious areas caused during construction (e.g. tilling or scarification prior to reapplication of topsoil) even greater runoff reduction benefits may have been achieved.

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

[7] The validity of this assumption and approach to analysis of runoff results was supported by results of monitoring runoff from grassed test boxes exposed to natural precipitation whereby it was observed that runoff was only generated during storm events of 15 mm in depth or greater and a maximum intensity of 11 mm/h or greater. It was also supported through monitoring of rear year infiltration trench #1 well water levels whereby it was observed that well water levels only showed a rise during storm events 15 mm in depth or greater and a maximum intensity of 6.6 mm/h or greater.

over the monitoring period. However, it is evident in the monitoring data that runoff reduction benefits are not consistently observed during all large storm events and that rainfall intensity and antecedent soil moisture conditions are likely factors influencing whether or not substantial benefits are provided. This suggests that the practice of applying increased topsoil depth to landscaped areas may not consistently produce runoff reduction benefits during large depth but low intensity storm events because pervious areas do not generate substantial runoff volumes during such events. It also suggests that the practice may not be effective during extended periods of wet weather because the soils eventually become saturated and begin to generate runoff to the same degree as a landscaped area constructed with a shallower depth of topsoil.

While it can be concluded that increased topsoil depth alone does provide runoff reduction benefits, in order for designers of stormwater management systems to account for these benefits when designing downstream practices (e.g. infiltration practices, detention ponds) a better understanding of the conditions (i.e. storm event size and intensity) under which this practice provides runoff reduction benefits is needed, in addition to information regarding how to model landscaped areas where this practice has been applied (i.e. runoff coefficients for landscaped areas constructed with increased topsoil depth). To do this, monitoring of runoff from individual landscaped areas constructed with increased topsoil depth that receive roof runoff under a wide range of storm event depths and intensities is needed with capabilities to capture both natural and synthetic rainfall events.

<u>Rear Yard Infiltration Trenches</u>
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. It is not clear whether the inlet remained clogged or if water was not being delivered to the trenches due to the configuration of the connection with the storm sewer pipe leading from the catchbasin.

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 (i.e. events greater than 5 mm but less than 15 mm in depth), 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 (impervious cover in the Control catchment is 5% greater than in the Rear Yard Infiltration Trenches catchment, while the proportion of impervious cover that is directly connected to storm sewers is 1% less). 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.

While these results suggest that little or no runoff reduction benefits were being achieved by the functioning infiltration trench(es), it is clear from examination of event hydrographs during large and intense storm events that substantial benefits were observed during some of these infrequent events. Event based differences in runoff depth between the Rear Yard Infiltration Trenches catchment and Control catchment indicate runoff reductions in the order of 24% were achieved during some of the most intense storm events captured over the monitoring period. However, runoff reduction benefits were not consistently observed during all large storm events.

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. These results support implementation of stormwater infiltration practices in future developments in the region that will be located on similar sandy silt glacial till subsoil.

Considering that rear yard infiltration trenches receive only roof and yard runoff that is pretreated by a grassed swale during conveyance to the trenches, the sediment load they receive is likely very low compared to such practices receiving road or parking lot runoff. When protected from siltation during construction, rear yard infiltration trenches should be a low maintenance lot level stormwater management practice that provides runoff reduction benefits of similar magnitude as increased topsoil depth in rear yards, if not slightly greater depending on the size of the trench.

4.2.2 Test box scale evaluations

Evaluation of the runoff reduction benefits of increased topsoil depth and increased topsoil depth with compost blanket amendment at the test box scale was done by comparing the overall runoff volume generated from duplicate test boxes exposed to natural precipitation over one summer to fall monitoring period. In addition to runoff volume, the total volume of water infiltrated and the change in weight of each test box was monitored periodically over the monitoring period to provide an indication of the overall fate of precipitation that fell on each test box and to provide insight into where substantial differences between treatments were detected.

Over this 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 storm events less than 15 mm in depth.

Overall, the 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, which is what was expected based on the literature review.

Based on periodic measurements of soil moisture at 10 cm depth below the sod surface, it was observed that 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.

4.3 Topics For Further 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 additional soil management best practices are implemented. Additional best practices should 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 practices have been implemented would help inform stormwater management system designers about how to model these areas when designing downstream treatment facilities. To do so, monitoring of runoff and interflow from individual pervious areas receiving drainage from impervious areas (e.g. roof downspouts) should be undertaken, including those constructed according to conventional practices and ones where different soil management best practices have been implemented. This could be done through field monitoring of individual residential yards or experimental test plots where results from both natural and simulated rainfall events could be generated. Such evaluations would also improve the understanding gained from this study regarding 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*. The rear yard infiltration trenches implemented in the Box Grove community are clearly in need of rehabilitation to restore their intended function. As they are located underground and on private property, accessing them may be challenging, particularly in the absence of maintenance agreements between the municipality and property owners or easements that allow municipal staff to inspect them. 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.

5.0 REFERENCES

Balousek, J. 2003. *Quantifying decreases in stormwater runoff from deep tilling, chisel plowing and compost amendment*. Dane County Land Conservation Department. Madison, Wisconsin.

Barr Engineering Company. 2006. *Burnsville Stormwater Retrofit Study*. Prepared of the City of Burnsville. Burnsville, Minnesota.

Clausen, J.C. and Spooner, J. 1993. *Paired Watershed Study Design.* Prepared for U.S. Environmental Protection Agency. Office of Water. Washington, D.C.

Clausen, J.C. 2007. Jordan Cove Watershed Project 2007 Final Report, Department of Natural Resources Management and Engineering, College of Agriculture and Natural Resources, University of Connecticut.

Credit Valley Conservation (CVC). 2012. Low Impact Development Construction Guide. Version 1.0. Mississauga, Ontario.

Credit Valley Conservation and Toronto and Region Conservation (CVC & TRCA). 2010. *Low Impact Development Stormwater Management Planning and Design Guide*. Toronto, Ontario.

Drake, J., Bradford, A., Van Seters, T. 2012. Evaluation of Permeable Pavements in Cold Climates – Kortright Centre, Vaughan. Toronto and Region Conservation Authority.

Environment Canada. 2004. Rainfall intensity-frequency-duration values – Toronto Buttonville Airport. Atmosphere Environment Service. Data Integration Division.

Environment Canada. 2011. National Climate Data and Information Archive. Canadian Climate Normals 1971 – 2000. http://www.climate.weatheroffice.ec.gc.ca. Date accessed: April 27, 2011.

Geosyntec Consultants. 2009. Drawing Appropriate Conclusions Regarding Volume Reduction in Practice- and Site-level Studies of Stormwater BMPs. Acton, Massachusetts.

Harrison, R., Grey, M, Henry, C, Xue, D. 1997. *Field test of compost amendment to reduce nutrient runoff*. University of Washington College of Forest Resources. Seattle, Washington.

J.F. Sabourin and Associates Incorporated. 2008. *20 Year Performance Evaluation of Grassed Swale and Perforated Pipe Drainage Systems.* Project No. 524(02). Prepared for the Infrastructure Management Division of the City of Ottawa. Ottawa, Ontario.

J.F. Sabourin and Associates Incorporated. 1999. *Research Project for the Updated Investigation of the Performance Evaluation of Grass Swales and Perforated Pipe Drainage Systems*. Executive Summary. Prepared for the Infrastructure Management Division of the City of Ottawa. Ottawa, Ontario.

Kaufman, M., Wurtz, M. 1997. Hydraulic and Economic Benefits of Downspout Diversion. *Journal of the American Water Resources Association*. Vol.33, No.2. pp.491-497.

Kolsti, K., Burges, S., Jensen, B. 1995. Hydrologic response of residential-scale lawns on till containing various amounts of compost-amendment. *Water Resources Technical Report #147*. University of Washington. Department of Civil Engineering. Seattle, Washington.

Low Impact Development Center. 2011. *Soil Amendment – Compost Specification*. http://www.lowimpactdevelopment.org/epa03/saspec_print.htm, Date accessed: April 20, 2011.

McDonald, D. 2005. Soil restoration with organics enters mainstream of storm water practices. BioCycle. Vol. 46. No. 4. p20.

Minnesota Pollution Control Agency (MPCA). 2008. *Minnesota Stormwater Manual*. St. Paul, Minnesota. Ontario Ministry of Municipal Affairs and Housing (OMMAH). 1997. *Supplementary Guidelines to the Ontario Building Code 1997. SG-6 Percolation Time and Soil Descriptions*. Toronto, Ontario.

Ontario Ministry of Municipal Affairs and Housing (OMMAH). 1997. Supplementary Guidelines to the Ontario Building Code 1997. SG-6 Percolation Time and Soil Descriptions. Toronto, Ontario.

Ontario Ministry of the Environment (OMOE). 2004. *Interim Guidelines for the Production and Use of Aerobic Compost in Ontario*. Toronto, Ontario.

Paul Wisner and Associates. 1994. *Performance Review of Grass Swale-Perforated Pipe Stormwater Drainage Systems*. Ontario Ministry of the Environment. Queens Printer for Ontario. RAC Project No. 585C.

Pennsylvania Department of Environmental Protection (PDEP). 2006. *Pennsylvania Stormwater Best Management Practices Manual*. Harrisburg, Pennsylvania.

Pitt, R., Lantrip, J., Harrison, R., Grey, M., Henry, C., Xue, D. 1999. *Infiltration through disturbed urban soils and compost-amended soil effects on runoff quality and quantity*. United States Environmental Protection Agency (US EPA). Cincinnati, Ohio.

Soil-Eng Limited. 2004. A Soil Investigation For Proposed Residential and Commercial Development - Box Grove Community North Part of Lots 6, 7 and 8, Concession 9 Town of Markham. Reference No. 0312-S57. June 2004.

Soils for Salmon. 2010. *Building Soil: Guidelines for Implementing Soil Quality and Depth BMP T5.13 in WDOE Stormwater Management Manual for Western Washington*. http:\www.soilsforsalmon.org.

Stormwater Assessment Monitoring and Performance (SWAMP) Program. 2002. *Performance Assessment of a Swale and Perforated Pipe Stormwater Infiltration System, Toronto, Ontario*. Toronto and Region Conservation Authority, Toronto, Ontario.

Stormwater Assessment Monitoring and Performance (SWAMP) Program. 2005. *Synthesis of Monitoring Studies Conducted Under the Stormwater Assessment Monitoring and Performance Program.*. Toronto and Region Conservation Authority, Toronto, Ontario.

Toronto and Region Conservation (TRCA). 2007. *Rouge River Watershed Plan – Towards a Healthy and Sustainable Future*. Report of the Rouge Watershed Task Force. Toronto, Ontario.

Toronto and Region Conservation (TRCA). 2008. *Performance Evaluation of Permeable Pavement and a Bioretention Swale, Seneca College, King City, Ontario*. Sustainable Technologies Evaluation Program (STEP). Toronto, Ontario.

Toronto and Region Conservation (TRCA). 2009. *Review of the Science and Practice of Stormwater Infiltration*. Sustainable Technologies Evaluation Program (STEP). Toronto, Ontario.

Toronto and Region Conservation (TRCA). 2010. *Rouge River Watershed Fisheries Management Plan - Draft, March 2011*. Toronto, Ontario.

Toronto and Region Conservation (TRCA). 2012. *Preserving and Restoring Healthy Soil: Best Practices For Urban Construction*. Sustainable Technologies Evaluation Program (STEP). Toronto, Ontario.

Virginia Department of Conservation and Recreation (VA DCR). 2009. *Stormwater design specification no. 4: Soil compost amendment.* Richmond, Virginia.

Washington State Department of Ecology (WDOE). 2005. *Stormwater Management Manual for Western Washington. Volume 5 – Runoff Treatment BMPs*. Olympia, Washington.

Woerns, N.M. 2005. Box Grove Hydraulic Conductivity Testing and Water Balance Revisions Summary Results. Submitted to Stantec Consulting Limited March 16, 2005.

Young, D. Van Seters, T., Graham, C. 2013. Evaluation of Underground Stormwater Infiltration Systems. Toronto and Region Conservation Authority. Toronto, Ontario.

APPENDIX A:

Rating curve relationships used at each area-velocity sensor location

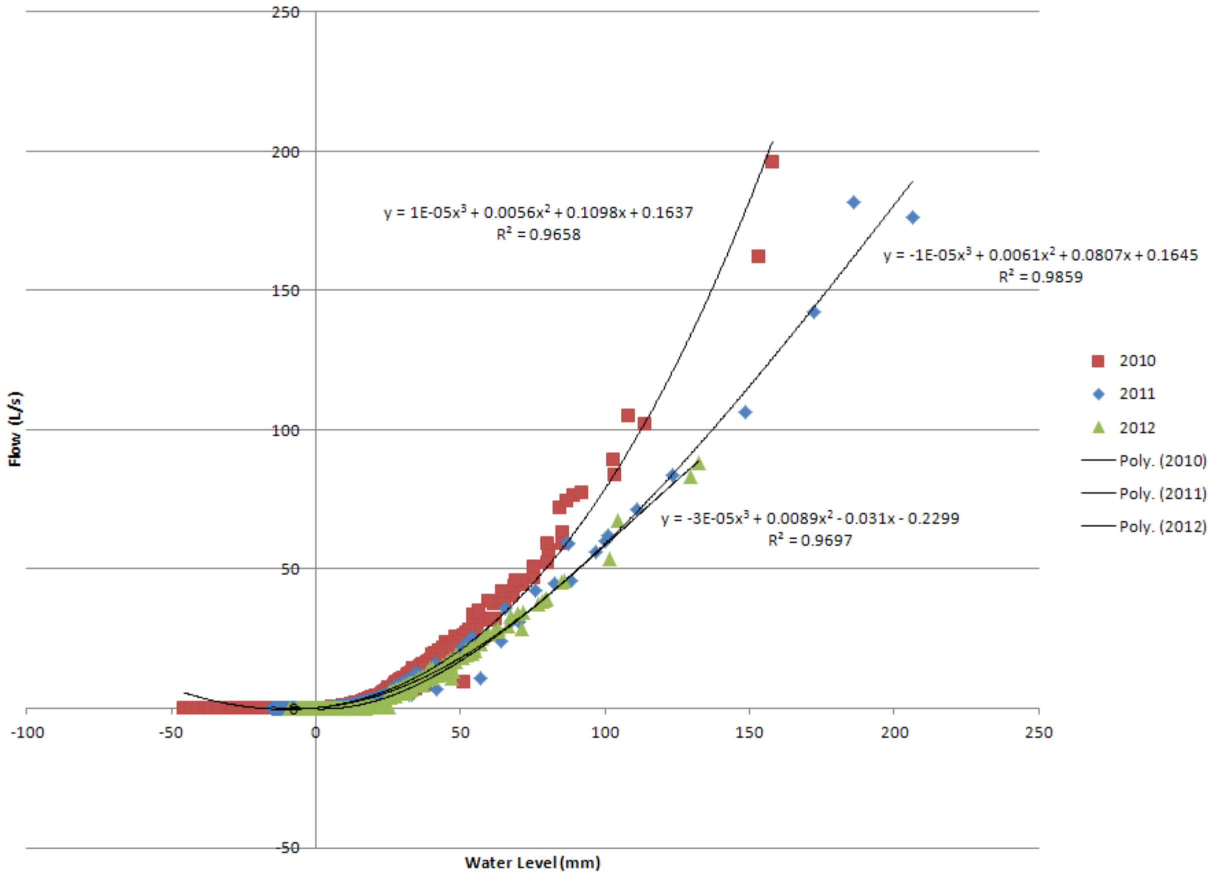


Figure A1: Rating curves for Control catchment area-velocity sensor [1]

Notes: [1] In Spring 2011 the area-velocity sensor at the Control catchment outlet was moved further into the storm sewer in an attempt to reduce turbulence and produce more accurate water level and velocity data. Therefore, a new rating curve was established in 2011. Over the spring and summer 2012 period sensor outputs were compared to the 2011 rating curve relationship, confirming that the 2011 relationship should continue to be applied to calculate flow values from water level sensor readings in 2012.

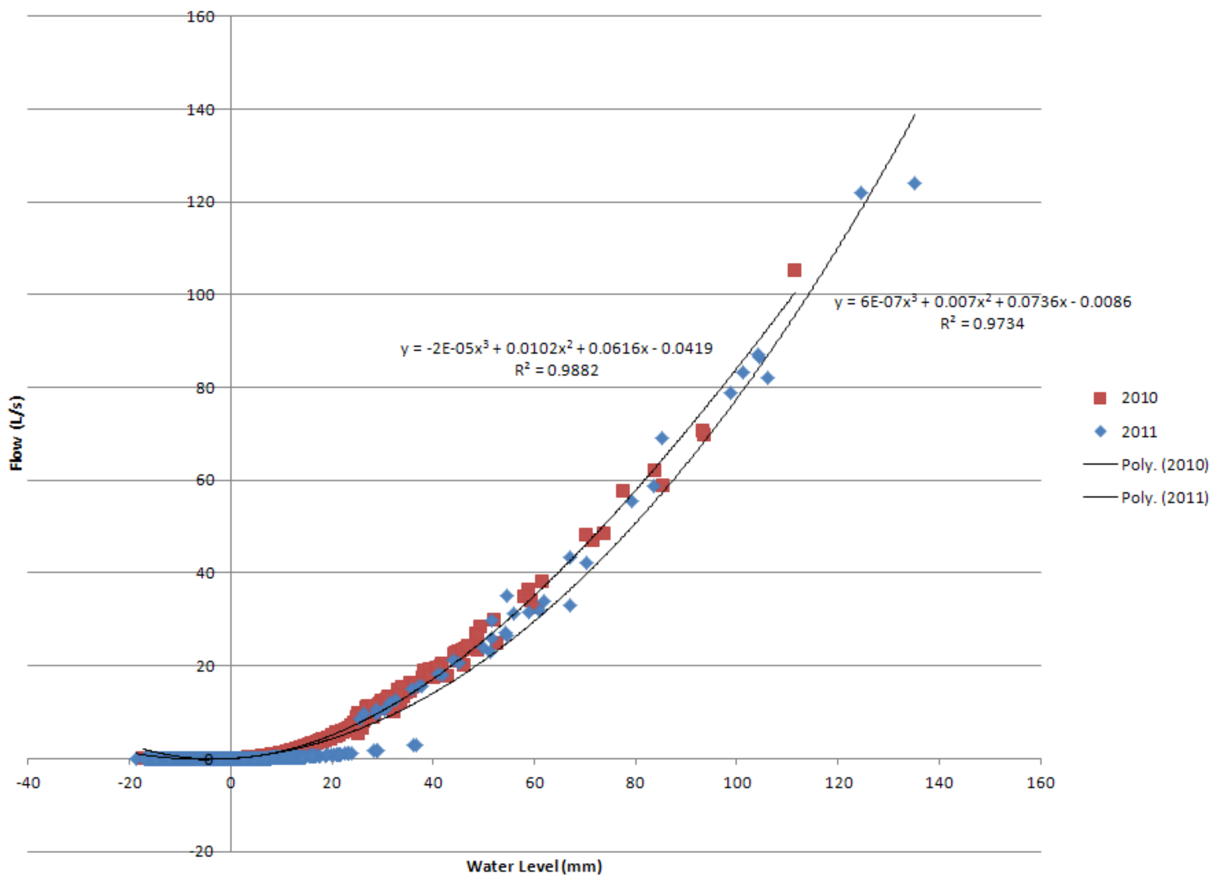


Figure A2: Rating curves for Increased Topsoil Depth catchment area-velocity sensor [1]

Notes: [1] The rating curve relationship established in 2010 was applied to all of 2010 and 2011 water level readings to calculate flow at the sensor location. Sensor outputs during spring and summer 2011 are plotted here separately to illustrate that the relationship observed during this period was very consistent with 2010 data.

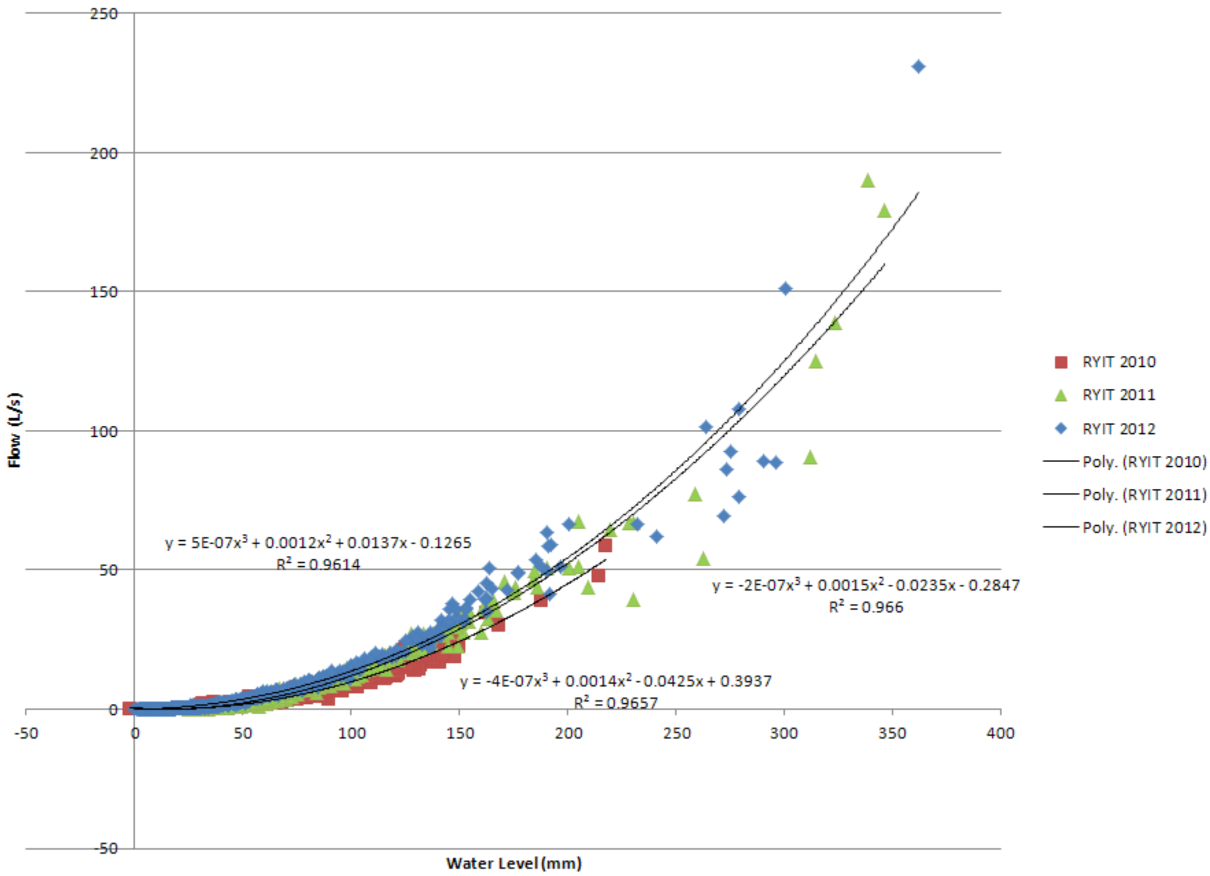


Figure A3: Rating curves for Rear Yard Infiltration Trench catchment area-velocity sensor [1]

Notes: [1] In spring 2011 a chunk of cement in the storm sewer, just upstream of the area-velocity sensor at the Rear Yard Infiltration Trench catchment outlet, was removed in an attempt to reduce turbulence and produce more accurate water level and velocity data. Therefore, a new rating curve was established in 2011 and used to calculate flow values from 2011 water level readings. In spring 2012, due to the occurrence of water ponding in the storm sewer pipe at the area-velocity sensor location, installation of the sensor was adjusted to raise it out of the ponded water in an attempt to produce more accurate water level and velocity data. Therefore, a new rating curve was established in 2012 and used to calculate flow values from 2012 water level readings.

APPENDIX B:

Detailed breakdown of rainfall depth and intensity, runoff depth, and runoff coefficient for each storm event captured over the monitoring period

Table B1: Rainfall depth, rainfall intensity, runoff depth, and runoff coefficient for each storm event captured over the monitoring period

Date	Rain depth (mm)	Max. intensity (mm/ 5 min.)	Max. hourly (mm/h)	Water level response in RYIT #1 well	Runoff depth (mm)			Runoff coefficient		
					CTL	ITD	RYIT	CTL	ITD	RYIT
Jul. 7, 2010	8.6	6.6	8.6	n/a	1.29	0.53	n/a	0.15	0.06	n/a
Jul. 9, 2010	21.8	2	10.4	n/a	13.32	12.63	n/a	0.61	0.58	n/a
Jul. 18, 2010	8.4	3.4	7.6	n/a	2.08	1.54	n/a	0.25	0.18	n/a
Jul. 23, 2010	52.8	4.8	19.6	n/a	25.83	20.02	n/a	0.49	0.38	n/a
Jul. 24, 2010	8.8	1.2	5.4	n/a	7.67	6.92	n/a	0.87	0.79	n/a
Aug. 9, 2010	25.4	6	23.6	n/a	13.09	7.71	n/a	0.52	0.30	n/a
Aug. 15, 2010	9.4	3.4	9.2	n/a	0.75	1.93	n/a	0.08	0.21	n/a
Aug. 21, 2010	41.6	3	14.8	n/a	13.19	9.21	n/a	0.32	0.22	n/a
Aug. 25, 2010	5.6	3.6	5.6	n/a	0.90	1.47	n/a	0.16	0.26	n/a
Sept. 2, 2010	17.6	6.4	17.4	n/a	5.57	2.14	n/a	0.32	0.12	n/a
Sept. 3, 2010	6.4	2	4.8	n/a	1.88	1.45	n/a	0.29	0.23	n/a
Sept. 11, 2010	5.4	0.6	3.2	n/a	1.87	0.68	n/a	0.35	0.13	n/a
Sept. 16, 2010	19.4	0.8	6.4	n/a	7.07	3.92	n/a	0.36	0.20	n/a
Sept. 22, 2010	11.2	4.8	10	n/a	3.35	2.14	n/a	0.30	0.19	0.23
Oct. 13, 2010	25.6	0.6	5	n/a	12.60	13.90	n/a	0.49	0.54	0.30
Oct. 24, 2010	5.2	0.6	2.8	No	0.29	n/a	0.22	0.29	n/a	0.22
Oct. 26, 2010	7.8	1.8	4.8	No	0.43	n/a	0.36	0.43	n/a	0.36
Nov. 16, 2010	25.2	0.8	7	Yes	12.71	n/a	10.83	0.50	n/a	0.43
Nov. 22, 2010	9.4	1.2	7.4	No	2.86	n/a	2.93	0.30	n/a	0.31
Nov. 25, 2010	6.8	0.4	2	No	2.95	n/a	3.02	0.43	n/a	0.44
Nov. 30, 2010	25	0.6	3	Yes[1]	13.27	n/a	13.96	0.53	n/a	0.56
Apr. 10, 2011	6.6	0.8	5.2	No	1.59	n/a	1.57	0.24	n/a	0.24
Apr. 16, 2011	19.6	1.2	5.8	Yes[1]	10.45	n/a	11.42	0.53	n/a	0.58
Apr. 20, 2011	7	1.2	6.4	No	3.29	n/a	3.83	0.47	n/a	0.55
Apr. 23, 2011	5.8	0.6	3.8	No	1.54	n/a	2.26	0.27	n/a	0.39
Apr. 26, 2011	6.2	0.8	4.6	No	1.70	n/a	2.27	0.27	n/a	0.37
May 3, 2011	8.8	0.4	1.2	No	2.57	n/a	3.94	0.29	n/a	0.45
May 15, 2011	30	1	6.4	No	10.97	n/a	14.42	0.37	n/a	0.48
May 15, 2011	11.4	0.2	1.8	No	4.77	n/a	6.47	0.42	n/a	0.57
May 18, 2011	6.8	0.8	4.8	No	2.38	n/a	3.00	0.35	n/a	0.44
May 18, 2011	10	2	6.2	No	6.14	n/a	8.40	0.61	n/a	0.84
May 23, 2011	17.6	8	17.2	Yes	2.39	n/a	3.44	0.14	n/a	0.20
May 25, 2011	12.8	1	7.6	No	2.38	1.76	4.83	0.19	0.14	0.38
May 27, 2011	12.6	2.2	7.8	Yes[1]	3.47	1.79	7.16	0.28	0.14	0.57
June 4, 2011	9.8	0.8	6	No	1.37	0.98	2.82	0.14	0.10	0.29
June 11, 2011	10.6	4.2	7.2	No	2.56	1.31	3.83	0.24	0.12	0.36
June 23, 2011	20.6	6.6	19.8	No	2.35	1.77	6.42	0.11	0.09	0.31
June 23, 2011	5.6	1.2	4.4	No	0.60	0.68	1.61	0.11	0.12	0.29
June 24, 2011	21	5	11	Yes	4.07	2.91	10.13	0.19	0.14	0.48
July 25, 2011	38.8	6.8	20.4	Yes	5.64	5.90	12.85	0.15	0.15	0.33
July 26, 2011	5.8	1.8	5.4	No	0.48	0.40	1.55	0.08	0.07	0.27
Aug. 3, 2011	14	1.2	6.2	No	1.36	0.17	4.43	0.10	0.01	0.32
Aug. 9, 2011	41.2	8.4	36.6	Yes	13.35	6.59	17.24	0.32	0.16	0.42
Aug. 14, 2011	7.8	3.6	6.6	No	0.55	0.20	2.27	0.07	0.03	0.29
Aug. 21, 2011	11	2.8	8.8	No	1.08	1.94	2.53	0.10	0.18	0.23
Aug. 24, 2011	15	2.6	10.6	No	2.10	4.34	5.77	0.14	0.29	0.38
Sept. 19, 2011	15.2	1.2	6.4	No	8.50	6.33	6.95	0.56	0.42	0.46
Sept. 21, 2011	10.8	1.8	6.4	No	5.10	3.97	4.80	0.47	0.37	0.44
Sept. 23, 2011	34.6	4	15.2	Yes	12.59	19.78	17.15	0.36	0.57	0.50
Sept. 30, 2011	21	2.2	14.8	Yes	10.82	11.81	12.78	0.52	0.56	0.61

Table B1 continued: Rainfall depth, rainfall intensity, runoff depth, and runoff coefficient for each storm event captured over the monitoring period

Date	Rain depth (mm)	Max. intensity (mm/ 5 min.)	Max. hourly (mm/h)	Water level response in RYIT #1 well	Runoff depth (mm)			Runoff coefficient		
					CTL	ITD	RYIT	CTL	ITD	RYIT
Oct. 3, 2011	5.4	0.4	1.8	No	4.56	2.59	3.78	0.85	0.48	0.70
Oct. 12, 2011	26.2	1	7.6	No	13.40	8.17	13.41	0.51	0.31	0.51
Oct. 13, 2011	6	2.4	3.2	No	3.56	1.41	2.61	0.59	0.23	0.44
Oct. 19, 2011	40.6	2.6	10.6	Yes	27.29	11.21	26.04	0.67	0.28	0.64
Oct. 25, 2011	20.2	0.6	3.8	No	12.66	3.40	10.99	0.63	0.17	0.54
Nov. 28, 2011	50.6	0.8	6.6	Yes	29.24	n/a	30.36	0.58	n/a	0.60
May 3, 2012	10	2.6	6.6	No	4.97	n/a	6.61	0.50	n/a	0.66
May 8, 2012	5.4	0.4	1.8	No	3.25	n/a	3.76	0.60	n/a	0.70
Jul. 10, 2012	8.8	1	8.8	No	0.01	n/a	0.00	0.00	n/a	0.00
Jul. 15, 2012	14.8	3.8	8.4	Yes	5.93	n/a	5.02	0.40	n/a	0.34
Jul. 22, 2012	6.2	3.4	6	No	0.69	n/a	1.27	0.11	n/a	0.21
Jul. 25, 2012	22.8	1.2	6	No	0.38	n/a	0.47	0.02	n/a	0.02
Jul. 31, 2012	23.8	4.6	15.4	Yes	5.74	n/a	5.84	0.24	n/a	0.25
Jul. 31, 2012	19.6	7	16.6	Yes	6.44	n/a	5.09	0.33	n/a	0.26
Aug. 9, 2012	6	0.4	2	No	1.73	n/a	1.00	0.29	n/a	0.17
Aug. 10, 2012	23.2	1.2	8.2	Yes	8.03	n/a	9.87	0.35	n/a	0.43
Aug. 11, 2012	16.4	6.4	16.4	Yes	9.40	n/a	5.58	0.57	n/a	0.34
Aug. 27, 2012	27.4	7.4	27.4	Yes	7.63	n/a	4.88	0.28	n/a	0.18
Sep. 4, 2012	16.2	3.6	16	Yes	3.05	n/a	2.90	0.19	n/a	0.18
Sep. 4, 2012	19.2	1.4	8.4	Yes	6.71	n/a	6.14	0.35	n/a	0.32
Sep. 8, 2012	40.8	1.8	10.8	Yes	16.51	n/a	14.42	0.40	n/a	0.35
Sep. 14, 2012	11.6	1.2	4.2	No	2.45	n/a	2.19	0.21	n/a	0.19
Sep. 18, 2012	8.6	0.6	3.6	No	2.14	n/a	1.84	0.25	n/a	0.21
Sep. 22, 2012	13.8	0.6	6	No	3.96	n/a	3.41	0.29	n/a	0.25
Oct. 5, 2012	5.2	0.6	2.4	No	1.66	n/a	0.86	0.32	n/a	0.16

Notes: n/a = information not available.
[1.] The timing of the water level response observed in RYIT #1 well in relation to rainfall suggests it was due to interception of shallow groundwater (i.e. interflow) rather than runoff entering the trench.