AN EXPERIMENT ASSESSING THE POTENTIAL FOR COMPOST-AMENDED LAWN TOPSOIL TO INHIBIT STORM QUICKFLOW

DANIEL PORTEOUS

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ABSTRACT

Urbanisation creates immense challenges for the environment due to increasing impervious surface coverage enhancing quickflow discharge in the catchment. This makes increasing surface infiltration and soil water retention in urban areas a matter of high importance. Lawns, forming a substantial fraction of suburban space, are a potentially useful medium in this regard. Four lawn test plots were constructed by the Toronto and Region Conservation Authority (TRCA) to examine the usefulness of increased topsoil depth and organic matter content (using compost) in improving soil characteristics and limiting quickflow discharge from lawns. Results indicated each lawn met TRCA-recommended soil guidelines, but the addition of compost did not produce discernable decreases in quickflow discharge, although infiltration rates were substantially increased. However, several limitations to the TRCA experiment were identified. A critique and a set of recommendations for experimental design improvement are included and explored.

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1. INTRODUCTION

1.1. Background

Urban expansion and development is known to have significant hydrological impacts upon the catchment. Construction of impermeable surfaces such as roads, parking lots and rooftops, the removal of vegetation and the compaction of soil, and the increased drainage connectivity because of sewer systems and gutters coalesce to increase the volume and velocity of stormwater (Arnold & Gibbons, 1996; Paul & Meyer, 2001). This enhanced flow discharge in the form of quickflow (runoff + soil interflow) creates new, widespread pressures on the built and natural environment in the form of flooding, pollution, and erosion (Foley *et al*., 2005).

One commonly overlooked area of study is the suburban environment. Suburbia constitutes large expanses of urban sprawl, and while normally 'greener' than denser urban areas due to more grass and tree cover, still faces similar concerns regarding infiltration, flooding, and pollutant exportation despite this. Indeed, suburban areas can be major exporters of diffuse pollutants in surface runoff, having some of the highest pollutant mass loading rates in urban areas overall (Lee & Bang, 2000). Areas of turfed soil such as lawns, parks and grass verges constitute 10-80% of surface cover in urban environments (Legg *et al*., 1996). However, these soils are too often thin and their quality poor, resulting in an impeded capacity to serve as runoff buffers, accommodate infiltrating rainwater, and retain moisture (Pitt & Lantrip, 2000; Woltemade, 2010). While best management practices (BMPs) such as the application of mulch and plant cultivation are now commonly used as stormflow control measures, these solutions are not an aesthetically desirable approach for the residential lawn. However, improvements can be made *below* the surface by improving soil quality while maintaining appearances desired by homeowners, landscapers and municipal authorities. Moreover, more retentive soils would also benefit plant life and increase general lawn health (Cogger, 2005).

Increasing topsoil depth and organic matter (OM) content are two possible amendment solutions to improve the water retention of soils in turfed areas (thereby impeding quickflow generation), and is something that has been explored in previous research. For instance, Pitt *et al.* (1999) observed promising increases in infiltration and water retention in turfed soil when using 2:1 topsoil-compost blends. Other studies have identified similar results and benefits, which will be discussed in greater detail in the next chapter. Naturally, the potential benefits to both general lawn health and stormwater abatement are matters of interest to environmental managers and developers. In 2012, the Toronto and Region Conservation Authority (TRCA) published a report entitled: *Preserving and Restoring Healthy Soil: Best Practices for Urban Construction*, in which it outlined recommendations for topsoil depth, subsoil scarifying depth, and OM content of soils in new residential developments (see Table 1). The purpose of the recommendations is to enhance soil quality, which would therefore reduce the need for fertilisers, while also increasing the infiltration capacity of lawn topsoil and its water retention capabilities (referred to as field capacity). This, if noticeably beneficial, would be implemented as a BMP to improve soil health in the growing Greater Toronto Area (GTA) and reduce urban quickflow. The TRCA's Sustainable Technologies Evaluation Programme (STEP) now intends to showcase the potential benefits of compost-amendment of topsoil used for residential development and promote the widespread use of this practice in the GTA. At the Kortright Centre for Conservation in Vaughan, Ontario, STEP began an experiment to test the performance of several topsoil amendment configurations that utilise increased depth and quality. Here the long term flow discharge from these soils under rainfall is to be examined. This is experiment is similar to that of Pitt *et al.*, (1999), amongst others, albeit using different compost concentrations and distribution. The initiation of this experiment provided an opportunity to further examine the hydrological dynamics of the configurations and contribute a more comprehensive understanding of the results. While knowing which topsoil configurations produce more desirable results is useful, knowing the specifics of *why* opens up opportunities for potential improvement and understanding, contributes to a more detailed assessment, and builds a solid basis upon which to compare and contrast the results of previous experiments.

Table 1. *TRCA-recommended depth and organic matter standards for developers. From Preserving and Restoring Healthy Soil: Best Practices for Urban Construction (TRCA, 2012)*

Planting area type	Topsoil organic matter (% dry weight)	Topsoil depth	Subsoil scarifying depth	Total soil depth
Turf area	5 – 10%	20 cm	10 cm	30 cm
Planting bed	10-15%	20 cm	10 cm	30 cm
Tree pit	10-15%	60 cm	30 cm	90 cm

Increasing daily precipitation and precipitation intensity are a high likelihood in many parts of the world per most climate change models, notably towards the higher latitudes, (IPCC, 2007; Trenberth, 2011), which is particularly relevant to US and Canadian Urban areas such as Toronto are expected to experience more intense storms as the 21st century progresses and face increasing flood risk (Willems *et al*., 2012). This is a concern even under the more moderate CO_2 emission scenarios such the International Panel on Climate Change (IPCC) SRES A1b development scenario, which predicts rapid economic growth and balanced energy source emphasis.

The PRECIS Regional Climate Model (Providing REgional Climates for Impacts Studies), developed by the United Kingdom's Met Office, offers predictions for precipitation changes under a range of climate change scenarios at local scales. The PRECIS model is capable of estimating increases in rainfall intensity in the Greater Toronto Area over the next century using different emission scenarios. Displayed in Figure 1 are storm intensity-duration-frequency (IDF) curves for the 25 x 25 km grid square in which the TRCA's Kortright Centre for Conservation falls. In Table 2, it is seen that percentage increases in intensity are predicted to be larger the longer the return period. For instance, between 2035 and 2056, two, five and 10 year storms are expected to increase in mean 24hr intensity by 14.7%, 22% and 24% respectively. This increases to 25.1%, 33.3% and 35.5% for 2065 – 2095. These results represent the P50 (median) probability scenario.

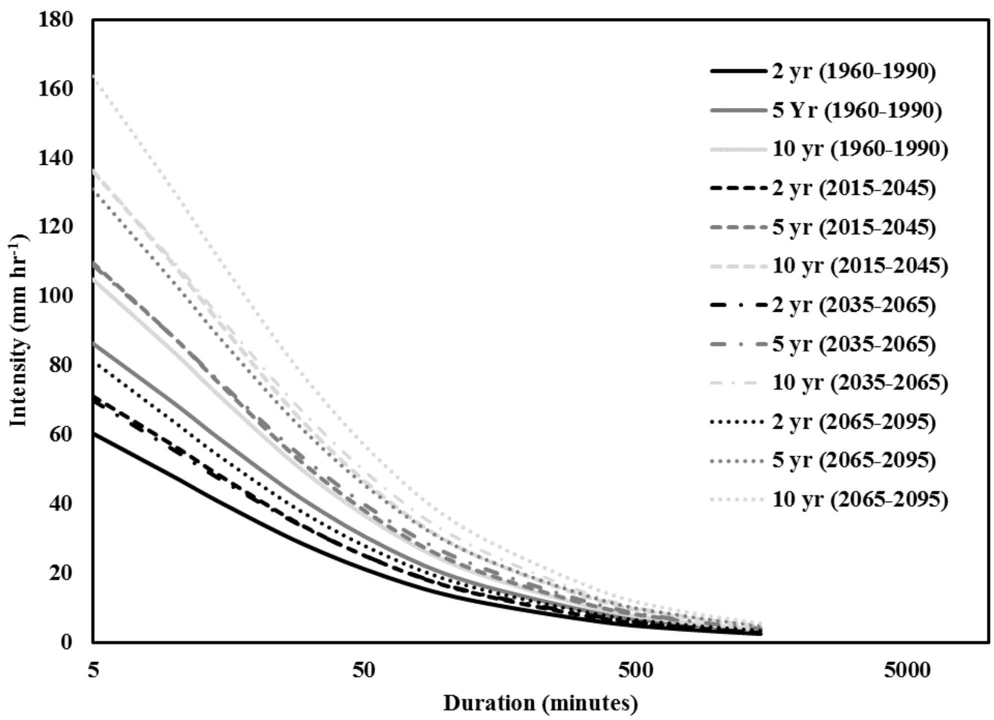


Figure 1. *Storm intensity-duration-frequency (IDF) curves for: [43.9059, -79.3672] 1960 – 1990, 2015 – 2045, 2035 – 2065, and 2065 – 2095 using the PRECIS model under the IPCC A1B emission scenario, P50.*

Table 2. *PRECIS model predictions for rainfall intensity by return period at Kortright (Vaughan, ON) assuming 24 hr duration. Includes percentage increase of mean storm intensity from 1960 – 1990 levels.*

		Return Period		
		2 Year	**5 Year**	**10 Year**
Time Period		**24 hr mean intensity (mm hr^{-1})**		
1960 – 1990		24.4	35.1	42.5
2015 – 2045		29	44.4	54.6
	% increase:	15.9	20.8	22.2
2035 – 2065		28.6	45	56
	% increase:	14.7	22	24
2065 – 2095		32.6	52.7	65.9
	% increase:	25.1	33.3	35.5

This reaffirms the need for improving the retentive properties of urban catchments, as increasing storm intensity is likely to have even more devastating impacts on infrastructure, property damage, and the potential loss of human life due to extreme flooding (Willems *et al*., 2012).

1.2. Aims and objectives

This thesis aims to assess the topsoil amendment configurations proposed by the TRCA for their performance in both moisture retention and their potential for diminishing storm quickflow. Additionally, it aims to improve on the experiment by analysing additional parameters, as well as identify potential flaws and limitations. For instance, while the STEP experiment measures outflow discharge from the lawn plots, no means of studying the three-dimensional flow of moisture through them was present. The addition of soil moisture monitoring allows this, which could be used to help better explain the discharge patterns observed and track the movement of moisture through each plot over time. Furthermore, this thesis also aims to build a strong theoretical background to contextualise the experiment as a BMP and argue for its implementation (where applicable). A comprehensive review of the theoretical background and research into the hydrological impacts of urbanisation on water and soils, best management practices, and the role of topsoil amendment will be included. The specific objectives of the study are to:

- Evaluate the physical properties of the soils used in the STEP experiment.
- Examine relationships between storm intensity/duration and quickflow discharge from the lawns constructed in the STEP experiment.
- Determine the best topsoil configuration for infiltration capacity and moisture retention.
- Identify any flaws or limitations of the configurations and STEP's experiment design.

1.3. Hypotheses

Presented for this thesis are the following hypotheses:

1. Compost-amended lawn topsoil will have significantly higher infiltration capacities versus the un-amended topsoil.

2. Topsoil blended with compost will have higher hydraulic conductivity than the un-amended plots.

3. Compost-amended plots will have higher field capacities versus the un-amended plots.

4. Compost-amended plots will retain significantly more moisture from a storm event than the un-amended plots.

5. Compost-amended plots will have lower flow discharge versus un-amended plots overall.

6. Compost-amended plots will have significantly higher volumetric moisture contents compared to the un-amended plots 24 hours after a storm event.

2. URBANISATION: HYDROLOGICAL IMPACTS AND MANAGEMENT

In this literature review, a broad overview of research pertaining to urbanisation's hydrological impacts, runoff abatement strategies will be explored. This will provide a theoretical framework, scientific justification and rationale upon which the topsoil study in this thesis is based.

2.1. Urban runoff impacts

As catchments are urbanised from a natural state, quickflow discharge will typically experience a dramatic increase due to the greater extent of impervious surface coverage (in the form of manmade materials such as asphalt and concrete, or through the severe compaction of soil) and the loss of pervious and vegetated cover (Leopold, 1968; Sanders, 1986; Arnold & Gibbons, 1996). Observations made by Arnold & Gibbons in the US suggested that surface runoff discharge doubles as the percentage of impermeable surface cover increases from near zero to 10–20%, it triples at 35–50%, and increases fivefold with 75–100% impermeable surface coverage. This profoundly highlights the important role of surface permeability within the catchment and its influence on runoff discharge. An analysis of satellite data by Elvidge *et* al. (2007) determined that approximately 0.43% of dry land on Earth is comprised of constructed impervious surfaces. Impervious surfaces in Canada amounted to approximately 352.7m^2 per capita, and was surpassed only by the United Arab Emirates at 379.7m^2 per capita. The extent of this coverage has all but certainly increased since the time of publication due to continuous urban development and a rising population

In Figure 2, a conceptual hydrograph exemplifying the effects of urbanisation on flow in the catchment is shown .Increased peak discharge and a shortened peak discharge lag time (or peak discharge delay) are clearly observable.

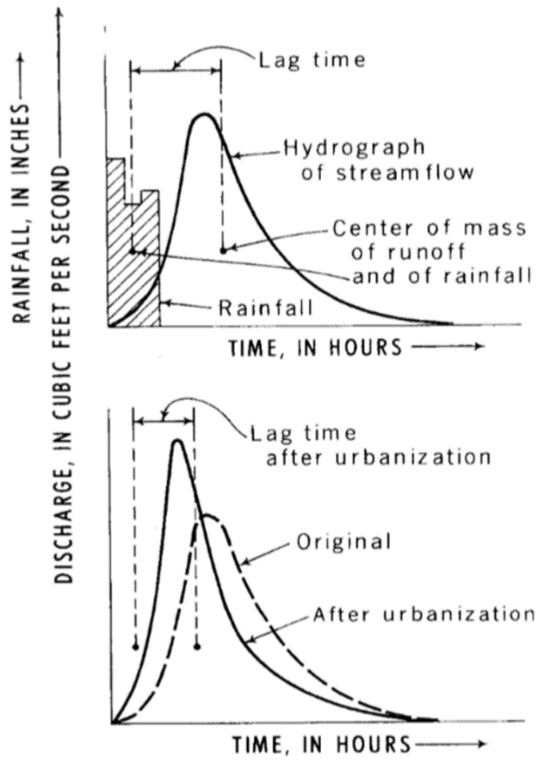


Figure 2. *Conceptual example of unit hydrographs relating runoff and rainfall, with significant parameters and features defined (Leopold, 1968).*

There are simple ways of quantifying the effects of increasing surface imperviousness within the catchment. Runoff coefficients are commonly used in civil engineering and environmental engineering literature and primarily serve as a representation of surface infiltration characteristics. These are frequently cited in municipal manuals and have been established for the estimation of runoff discharge over a given area. The *Rational Method*, which draws from an empirical model developed in the late 19th century to predict runoff discharge, is commonly used in conjunction with these coefficients for calculating area runoff estimates (Todini, 1988). This equation is expressed as:

$$Q_p = C * i * A \tag{1}$$

Where Q_p is peak runoff discharge ($m^3\ s^{-1}$), C is the runoff coefficient (0-1) with higher values equating to higher runoff-to-rainfall ratios, i is mean rainfall intensity ($mm\ hr^{-1}$), and A is the area of the catchment or subcatchment (km^2), (Young *et al.*, 2009). Although a simplification of an arguably complex phenomenon, the Rational Method offers a general estimation for engineers and environmental scientists. From this simple equation, the factors contributing to runoff discharge are made very clear. When one of these factors increases, so will Q_p. As the weather cannot be controlled, C is the factor most directly influenced by humans through urbanisation.

However, it is not simply an overall impervious surface coverage (ISC) increase that leads to the rapid delivery of stormwater into the catchment. The hydrological connectivity of the catchment is something often enhanced as a result of urbanisation. Roads, sewers, gutters and ditches act as expressways for runoff collecting in the catchment, and greatly enhance the catchment delivery ratio), where water that may have been otherwise detained and eventually lost to evapotranspiration is exported rapidly to rivers and streams (Hatt *et al.*, 2004; Mueller & Thompson, 2009). A related infrastructural impact is that of sewer overflows. Stormwater can overload sewer systems – particularly older systems with limited capacities – and produce large, sudden spills into the surrounding environment, resulting in localised flooding and the rapid delivery of metals, hydrocarbons, sewage and organic compounds stored within the sewers into receiving water bodes (Mulliss *et al.*, 1997; Gasperi *et al.*, 2008).

Where ISC increases, infiltration consequently decreases. As a result, subsurface water held in soils and aquifers is often more depleted than would be expected in a more pervious catchment, and urbanisation is commonly followed by a lowering of the water table (Arnold & Gibbons, 1996). This is known to have potentially detrimental effects on the structural integrity of substrates that can result in ground subsidence, causing structural damage to roads and buildings (Stramondo et al., 2008). In some instances, however, urban infrastructure may inadvertently act to recharge subsurface water. For instance, leaking drainpipes and water mains have sometimes been found to recharge shallow aquifers and even maintain higher-than-average water tables in dry periods of the year (Lerner, 2002), provided the leaks are large enough. River and stream baseflow conditions can be lowered due to the lowered supply of soil water contributing to throughflow discharge (Walsh *et al.*, 2005; Shephard *et al.*, 2006). This also includes a reduced contribution from groundwater ridging, springs, and upwelling Additionally, the increase of overland flow into river systems from ISC has significantly affected their downstream flow regimes and their channel morphology as a result. This has become a worldwide phenomenon, with commonly observed changes to channel morphology being downcutting and loss of sinuosity (Chin, 2006), and widening of the channel (Gregory *et al*., 1992; Puzzuto *et al*., 2000).

The hydrological impacts of urbanisation are therefore complex, but it is clear that surface permeability and stormwater retention within the catchment exacerbate flooding and pressure on infrastructure when minimised.

2.2. Pollution

These major changes to the runoff hydrograph and the delivery of water through the catchment has incurred numerous chemical impacts on water bodies and resulted in a prominent and damaging environmental health issue (Brabec *et al*., 2002). A range of pollutants from different sources have coalesced in these environments and pose unique challenges. In the urban catchment, sources of pollutants can be divided into two groups: diffuse and point. Point sources release pollutants from specific locations (e.g. a factory drain outlet), whereas diffuse pollutants are collected over wide areas, typically from surfaces and transported via surface runoff. Indeed, there is a long established relationship between ISC and water quality, where areas with lower proportions of ISC usually exhibit lower levels of pollution in comparison to less pervious catchments (Paul & Meyer, 2001; Morgan *et al*., 2007). The roads, parking lots and roofs of the urban landscape accumulate an array of contaminants on their surfaces which are eventually exported into water bodies in surface runoff, where greater runoff volume is understood to export greater contaminant loads (Schueler *et al*., 1987). Depositions of metals copper (Cu), zinc (Zn) and aluminium (Al) from vehicle and building wear, and Cu and lead (Pb) from atmospheric deposition are notable examples observed commonly in Europe and North America (Davis *et al.*, 2001; Gromaire-Mertz *et al.*, 1999). Hydrocarbons from automobile leaks and atmospheric deposition of industrial effluent are common, and pose a threat to aquatic species through biological accumulation (Paul & Meyer, 2001). Chloride (Cl^-) pollution from de-icing salts used on roads, parking lots and sidewalks is a growing concern, and is often seen above recommended levels in the North Eastern US and Canada (Kaushal *et al*, 2005), and accumulating in soils and groundwater over long time periods (Howard & Haynes, 1993). This has been observed to pose significant risk to aquatic organisms (Kaushal *et* al., 2005; Roberts & Prince, 2009). Macronutrients Nitrate (NO_3^-) from road surfaces and roofs (Kojima *et al*., 2011) and Phosphate (PO_4^-) from fertilisers (such as those used on lawns) are common constituents of urban surface runoff (Groffmann *et al*., 2004). Although macronutrients are also found in runoff in rural and undeveloped environments, it is not usual for concentrations or mass loading rates to be several times higher – or even orders of magnitude higher – in urban catchments, making them of particular concern due to risk of eutrophication and the hypoxia (rapid loss of dissolved oxygen) of water bodies (Roberts & Prince, 2009). While dense urban and industrial areas may often be thought of as the primary suppliers of contaminants. However, Lee & Bang (2000) observed that suburbanised portions of wider catchments can have higher pollutant mass loading rates.

The suspended and dissolved contaminants are typically washed from surfaces at higher concentrations during earlier periods of storms. This is known as the 'first flush' effect. Sediments and contaminants build up on surfaces over time, and can do so to great effect the longer the dry antecedent conditions (Deletic & Maksimovic, 1998; Lee & Bang, 200; Lee *et al*., 2002). The large volume of quickflow generated within the catchment mobilises these substances quickly and transports them at high concentrations within a short space of time into receiving water bodes. In more pervious, natural catchments, peak flow discharge is reached less suddenly. Sufficient flow energy is needed to move solids longer distances, flows takes more time to develop and reach a high velocity, and must navigate less direct pathways through more absorbent media, creating more favourable conditions for pollution mitigation (Hatt *et al*., 2004; Mueller & Thompson, 2009). It is no surprise, therefore, that urbanised catchments with more 'green' space more often that not experience less severe first flush effects and mitigated pollutant deliveries (Deletic, 1998; Goonetilleke *et al*., 2005). Riparian buffer zones, for example, are vegetated spaces in riparian zone of urban river channels which are known to act as valuable sinks for suspended sediments and solutes like NO_3^- (Hefting & de Klein, 1998). Cunningham *et al*. (2010) observed that concentrations of N species diminished significantly and biotic indices improved downstream of low ISC in streams in New York. These permeable, vegetated areas can reduce runoff flow velocity and allow solute-bearing surface runoff to infiltrate into the soil where macronutrients in particular can accumulate and be metabolised by plant species or immobilised by soil bacteria (Lowrence *et al.*, 1984, and Orleans *et al.*, 1994)

While the absence of the impervious asphalt and concrete of the built environment would suggest improvement, the *condition* of the soils and vegetation in its place is of high importance and defines their utility. This means that grass, other plant life and greenery being present does not necessarily guarantee a lesser environmental impact (consider again Lee & Bang's observations in suburban catchments in South Korea). Urbanisation has a range of impacts on soil, vegetation, and their abilities to allow water to infiltrate the ground and be retained.

2.3. Management responses

Due to the immediate – and often disastrous – impacts of urbanisation on the catchment, intense efforts have been made to counteract or restrict the worsening hydrological effects. These strategies have taken different forms, often with very different foci, but, as a whole, attempt to reduce the possible damage runoff may have on homes and infrastructure. Though varied, methods can be divided into two main categorisations: centralised or decentralised. Centralised methods, which are more traditional, aim to capture excess storm water and divert it to detention facilities through sewer systems or spillways (Barbosa *et al*., 2012). These methods, therefore, do not actually decrease runoff volume within the catchment, but simply try to divert it away from vulnerable areas and to places where it can be better managed. The stored runoff may then be released later. An advantage here is that some facilities are capable of storing stormwater for long periods of time, which becomes useful during times of drought, for example. Contaminated runoff can be more conveniently treated when stored centrally and released under controlled conditions. (Freni, *et al*., 2010). However, the effectiveness of centralised techniques depends on the volume and discharge the infrastructure can reasonable accommodate. If the storage and spill capacity is exceeded, storm runoff continues unimpeded (Freni *et al.*, 2010; Barbosa *et al.*, 2012). The necessary infrastructure must also be able to reach through the entire urban catchment, lest some areas go unprotected. This can be expensive and oftentimes an engineering impracticality.

Decentralised methods, under which topsoil amendment falls, offer a different approach. Rather than diverting runoff, this approach seeks to inhibit runoff at its source by encouraging surface infiltration. A commonly used technique to limit surface runoff generation is the implementation of infiltration devices (for example, gravel traps and permeable pavements). Being one of the most successful BMPs, their benefits are commonly twofold: the mitigation of runoff discharge through enhanced infiltration, and the removal of certain contaminants (Scholz & Graboweicki, 2007). For instance, it has been observed that permeable asphalts used in parking complexes have the capacity to remove >90% of 'heavy' metal ions in runoff (Boving *et al.*, 2008). Nonetheless, infiltration BMPs are not limited to artificial materials and technologies. Basic additions to surfaces in the form of mulches may often result in similar benefits, lowering quickflow discharge and filtering out contaminants. Positive effects observed from mulch application include significant increase in surface infiltration rate and P removal (Hsieh & Davis, 2005a), the removal of suspended sediments and debris (Hsieh & Davis, 2005b), and hardwood mulches have been shown to have impressive metal ion adsorption capabilities (Jang *et al*., 2005). Provided a harder surface is not required, this method has become popular as it is cheaper and more aesthetically pleasing than using permeable pavements or asphalts, as well as making good use of by-products from the timber and forestry industry. Another simple yet effective alteration to an unpaved surface is digging swales, which may also be filled with gavels and mulches for added effect. Swales are cheap to excavate and have been found to reduce runoff discharge from parking lots by up to a third (Rushton, 2001).

BMPs and infiltration techniques are not necessarily limited to the ground. Green roofs are an excellent example of 'water sensitive urban design' that has grown in popularity in the 21st century. By replacing impervious roof surfaces with soils and vegetated surfaces, green roofs have been shown to perform well in reducing runoff volume in urbanised catchments, while also have the additional benefit of greatly inhibiting the early concentrated flush of surface contaminants (Bliss et al., 2009; Czemiel-Berndtsson, 2010). A study estimated that runoff in the Brussels region – a sizeable urban area – could be diminished by 2.7% if only 10% of buildings used green roof installations (Mentens *et al*., 2006). The authors used data gathered from green roofs in Germany and empirical model to make this determination.

The simplest approach to impeding the rapid increase in imperviousness of the catchment, however, would be to maintain green spaces or encourage their regrowth. Grass and tree cover in particular are often very effective in decreasing runoff and quickflow discharge and impeding the exports of pollution to the wider catchment (Davis, 2005). This surface vegetation and leaf litter decreases runoff velocity, giving more time for water to infiltrate the ground, where suspended or dissolved contaminants such as organic compounds and nutrients are then metabolised by plants or immobilised by bacteria before potentially entering waterways (Orleans et al., 1994, in Hefting & de Klein, 1998). Plant canopies and leaf litter are also capable of intercepting rainfall, which may then evaporate back into the atmosphere, decreasing peak runoff discharge in the catchment (Sanders, 1986; Armson *et al*., 2013). Parks and green spaces can have runoff coefficients as low as 0.26 (Sanders, 1986), making them valuable assets in keeping discharge low. Armson *et al.* (2013) found that even a single field maple (*Acer campestre*) planted in a 9 m^2 asphalted area would decrease runoff discharge by ≤62% compared to asphalt only, due primarily to increased infiltration. Furthermore, plants may be used to reverse the impacts of topsoil compaction. Bartens *et al*. (2008), for instance, successfully increased the infiltration capacities of compacted soils through tree planting. The roots of red maple (*Acer rubrum*) and black oak (*Quercus velutina*) were able to penetrate the compacted soils used in the experiment and managed to increase infiltration rates by an average of 153%.

Nevertheless, with demand for housing high and increasing amounts of space needed for urban infrastructure, maintaining large plant life and wooded areas is not always an option. Lyytimäki *et al*., (2008) stress that vegetated spaces, while having certain advantages, can have drawbacks and may become nuisances themselves. For instance, trees and large vascular plant life can require regular cutting and coppicing in order to remain unobtrusive, can cause root damage to roads and sidewalks, serve as habitats for pests, and spread allergens. But not all green space has to be vegetated by large fauna to have noticeably beneficial hydrological effects, as often turf and grasses will suffice. Grass-covered slopes can have significantly higher infiltration rates compared to bare slopes (Zhan *et al.,* 2007). It was also observed by Armson *et al*., (2013) that grass can decrease runoff from surrounding asphalt surfaces by up to 99% (in fact higher than the tree-planted area in their experiment). Barrett *et al*. (1998) identified that grassy areas left near highways were effective in removing the majority of suspended solids, lowering runoff turbidity as a result, as well providing significant removal of metal ions and N and P species. Lawns, which form a substantial proportion of suburban ground cover, therefore offer a potentially valuable medium for stormwater retention and quickflow mitigation. However, their capabilities in doing so rely on their physical properties and appropriate maintenance and development procedures. The quality and characteristics of the soils upon which lawns are established are particularly important.

2.4. Soil properties and quickflow

Although the vegetation colonising the soils is of considerable importance and has been shown to have an array of beneficial effects, the soils themselves and their qualities have a key determining roll in the infiltration, subsurface movement, and storage of water within the catchment. Soil texture, structure, and even chemical composition all play important parts.

2.4.1. Porosity

Macropores established in the soil's surface, created through erosion or biological activity, can have act to increase surface infiltration rates and throughflow by increasing hydraulic conductivity (Beven & Germann, 1982; Edwards *et al*., 1988). Oftentimes it is macropores that are responsible for a substantial proportion of soil quickflow (McCraig, 1983, Nieber *et al*., 1991). Water will generally flow more quickly through macropore, but more slowly through micropores which comprise the soil matrix, inhibited by tighter pore spaces and tensile forces (Beven & Germann, 1982). A phenomenon know as *pipe flow* occurs when large channels which appear deep in the soil column above less permeable layers such as clays and bedrock where sudden lateral flows initiate (McCraig, 1983). Here are interconnecting channels are created where water may flow rapidly downslope. 'Old water' water may also become stored in these macropores and then pushed through in later rainfall events, resulting in the rapid delivery of quickflow into stream channels even under relatively low rainfall intensities – this is known as *piston flow*, and its significance in quickflow generation was discovered through the use of chemical tracers and stable isotope analysis (Pierce *et al*., 1986; Sklash *et al*. 1986).

2.4.2. Bulk density

Soil porosity is closely associated with bulk density. The more pore spaces, the less dense the soil (assuming equal particle density). It is best do avoid denser soils when aiming to inhibit quickflow generation, as the typical absence of pore spaces restricts infiltration rates and promotes more rapid runoff generation (Gregory *et* al., 2006; Woltemade, 2010). Furthermore, higher bulk density correlates negatively with hydraulic conductivity (Jabro, 1992), primarily due to the associated packing and loss of porosity. It also decreases the volume of water that could potentially be held. However, it has been observed that high soil bulk density can sometimes yield a higher field capacity (Hill & Sumner, 1967; Archer & Smith, 1972), meaning a greater fraction of water can be held under gravimetric pressure – something useful to plant life and potentially lowering the volume of water that may rapidly enter the wider catchment.

2.4.3. Soil organic matter

Organic matter (OM) or soil organic carbon (SOC) within soil constitutes the bulk of the non-mineral component and is present in the form of leaf litter, woody debris, humus, and any organic compounds that may be incorporated. OM or SOC has notable impacts on soil hydraulic properties as well as soil fertility. Notably, a positive relationship between water holding capacity or field capacity and soil OM content has been commonly observed by researchers (Hudson, 1994). This is due to the organic matter's impact on particle aggradation and pore distribution. OM will begin to change the physical structure of soil depending on the concentration present. Soil organic matter has a lower density than quartz and most minerals, resulting in a lowering of both the soil particle density and the bulk density of the soils as %OM increases. Soil hydraulic conductivity and water holding capacity wall also typically increase (Hudson, 1994; Haynes & Naidu, 1998). There is usually a heightened presence of permanent pores with higher %OM and increased particle aggregation due to its tendency to adhere smaller particles together (Franzluebers *et al*., 2002). This particle aggregation tends to create a more favourable soil structure for the infiltration and percolation of water due to the presence of larger, well-connected pore spaces (Boyle *et al*., 1989). Better-aggregated particles held together by adhesive organics also decreases the likelihood of free fine particles blocking pores in the soil matrix when transported by flowing water. Additionally, Franzluebers (2002) observed significantly higher infiltration rates in soil cores with a high ratio of SOC stratification (here SOC at 0-3cm divided by SOC at 10-12cm). Higher SOC concentrations nearer the surface resulted in larger, more stable pore spaces, and therefore more rapid infiltration at the surface. Lower SOC ratios failed to achieve this surface infiltration to the same degree.

Additionally, the effects of soil OM on soil moisture has notable benefits to plant life (including turf grass). More water held in the soil means more water available for root uptake. Although, until relatively recently, the consensus among agronomists was that increasing OM has little benefit in organic soils, as increasing OM also increases the permanent wilting point (PWP) of plants (the minimal amount of moisture required for plants not to wilt). However, in a comprehensive review of past research, Hudson (1994) concluded field capacity (FC) increases at a much more rapid rate than PWP with increasing OM, meaning the impact of the heightened PWP is offset.

2.5. Impacts of urbanisation on soil

Soil compaction has been found to be a highly significant inhibitor of infiltration capacity that augments runoff volume (Horton *et* al., 1994; Hamilton & Waddington, 1999; Pitt & Lantrip, 2000; Gregory *et* al., 2006; Woltemade, 2010;). Compaction of soil, normally measured using a cone penetrometer and expressed in units of kPa, PSI, or kg cm^{-2}, will decrease pore space, increase bulk density, and limits the volume of water that may be held within or pass through a given volume of soil (Pitt& Lantrip, 2000). Acceptable degrees of compaction vary between soil texture. The TRCA outlines the following requirements, shown in Table 3.

Table 3. *Maximum soil compaction for soil texture recommended by the TRCA, given in units PSI, kg cm^{-2} and kPa,. From: Restoring Healthy Soil: Best Practices for Urban Construction (TRCA, 2012)*

Surface resistance	Sub-surface resistance		
All textures	**Sand-dominated**	**Silt-dominated**	**Clay-dominated**
≤110 PSI	≤260 PSI	≤260 PSI	≤225 PSI
≤7.7 kg cm^{-2}	≤18.3 kg cm^{-2}	≤18.3 kg cm^{-2}	≤15.8 kg cm^{-2}
≤758 kPa	≤1793 kPa	≤1793 kPa	≤1551 kPa

In the built environment, heavy vehicles, construction equipment and materials, and even human footfall act to severely compact the surfaces of soils which, in more natural and unaltered environments, are less vulnerable to such mechanical pressures. For example, Gregory *et al*. (2006) observed a 70-99% decrease in soil infiltration rates at construction sites in Florida due to construction activity and compaction treatments (the latter is done intentionally to increase the soil's structural strength). The researchers also noted that even low levels of compaction would significantly affect infiltration rates. This degree of compaction is not uncommon (Arnold & Gibbons, 1996; De Kimpe; 2000). Compaction can have a negative impact on plant growth, where increased soil density impedes root penetration and loss of pore space reduces the volume of water available at field capacity. This has additional implications, as the establishment of rooted vascular plants would normally increase infiltration (Horton *et al*., 1994, Bartens *et al*., 2008).

2.6. Lawn characteristics

A high degree of variability between infiltration rates in turfed soil (specifically lawns) previously disturbed by excavation, grading and compaction has been observed in several previous experiments and was found to be the result of a range of factors. Infiltrations tests performed by Pitt *et al.* (1999) on disturbed urban soils in Birmingham, Alabama, showed considerable variability in infiltration rates between soil textures when examining the degree of compaction and antecedent moisture. The researchers found that sandy soils were most significantly affected by compaction. Non-compacted sandy soils had infiltration capacities ranging from 0.4 – 25 in hr^{-1} and 0.1 – 9 in hr^{-1} for compacted sandy soils. Non-compacted clay soils had rates of 0.1 – 24 in hr^{-1} and only -0.6 – 6.7 in hr^{-1} in non-compacted clay soils. Additionally, soil moisture conditions had little impact on sandy soil infiltration rates overall, whereas moisture conditions were found to be just as important as the degree of compaction in the clay soils. This demonstrates both the importance of soil texture and the high degree of variability that can be found between disturbed urban soils.

In addition to reaffirming the importance of antecedent moisture conditions in runoff generation, Woltemade (2010) observed similar significant differences between infiltration rates in Shippensburg, Pennsylvania, which ranged from 0 – 40 cm hr^{-1} between 108 residential lawn sites. Woltemade determined that lawn age has significant impact on infiltration rates. Lawns established pre-2000 in Shippensburg had mean infiltration rates of 9cm hr^{-1}, whereas post-2000 lawns had an average of 2.8cm hr^{-1}. Legg *et al.* (1996) found similar variability in lawn infiltration and age. Here experiments conducted on 20 lawns in Maddison, Wisconsin, found lawns 1-3 years older than newly established lawns had significantly lower runoff coefficients and higher hydraulic conductivity than their younger counterparts. Furthermore, Law *et al*. (2004) found that soil bulk density under lawns decreases with lawn age. These changes due to age can be due to a number of factors. For example, younger, more recent soil depositions are likely to have accumulated less plant growth and root development, and less activity from invertebrates, both of which act to establish soil macropores. It is also possible that more recent developments made greater use of heavy machinery in lot construction, which would be in concordance with Legg *et al* and their 1996 observations, where recently established lawns were actually found to be more compacted. However, in conflict with other findings (notably those by Pitt *et al*), Hamilton & Waddington (1999) did not find influence of soil texture and other physical characteristics such as bulk density on infiltration to be particularly large. The researchers instead concluded excavation and compaction effects to be the most significant determinants. Specifically mentioned is the influence of soil stratification, for example. Here, landscaping practices which deposit soil in different stages produces a stratified variation in compaction, with more compact layers present below the surface impeding the downward percolation of water. It has been found that soil quality in lawns is often poorer in more recent developments compared to older lawns, where %OM and N is positively correlated with age (Law *et al.*, 2004).

Topsoil however may be almost completely removed, however. This may occur through It is not an uncommon practice to strip topsoil during the development of surrounding infrastructure but not return the bulk of it due to transportation costs and the additional required labour. Typically, only around 30% of the stripped topsoil is reapplied in residential developments the Greater Toronto Area, for example (TRCA, 2012). These subsoil layer (B-horizon), now closer to the surface, lacks the more significant presence of macropores normally seen in topsoil due to the lack of animal and plant activity at that depth. Subsoil also exists under considerable pressure and is naturally compacted by the overburden above, typically giving subsoil a high bulk density.

Furthermore, this lack of biological activity results in a much lower %OM content, which has other hydrological implications for the soil. There are negative impacts on lawn heath due to this. It was discovered by Cheng *et al.* (2014) that turfgrass established on subsoil will produce surface runoff at roughly two times the rate than turfgrass established on healthy topsoil. This was attributed to the subsoil's higher compaction and lower organic matter content. Subsoil makes poor planting soil due its lower quality, resulting in the need for more intensive fertiliser application for easier plant establishment (Loschinkkohl *et al*., 2001). Law *et al*. (2004) found that annual fertiliser application rates in residential lawns is strongly correlated with the bulk density of the underlying soil. Higher soil bulk density increases runoff potential and therefore the loss of applied fertilisers through exportation, necessitating additional fertiliser application to maintain desired effects.

2.7. Lawns and topsoil amendment as BMPs

With the hydrological impacts of urbanisation and current management practices discussed, and the physical properties of soils and the relationship with quickflow generation and water retention explained, it is now pertinent to consider the possible benefits of lawn topsoil amendment as a BMP. Turfed soil (lawns, grass verges etc.) can cover a substantial fraction of suburban space (Legg *et al*., 1996). But the humble lawn has potential in reducing quickflow discharge within a catchment and retaining stormwater. While capable of offering a more pervious surface than concrete or asphalt, lawns may act as immediate disconnecting buffers between rooftops, driveways and sewers, thereby decreasing the hydraulic connectivity that is typically enhanced in an urban environment (Mueller & Thompson, 2009). Moreover, Mueller & Thompson note the importance of the rooftop-to-lawn ratio. As this ratio increases, so will runoff depth due to the higher input of collected rainwater. Suitably dense, healthy lawn turf provides a useful boundary between the atmosphere and soil surface capable of retaining water and restricting overland flow velocity by increasing surface roughness, which enhances infiltration into the underlying soil and mitigates runoff discharge (Gross *et* al., 1991; Beard & Green, 1994). Additionally, interception by grass blades minimises raindrop impact and lowers the intensity at which rainwater makes contact with the soil, also acting to inhibit runoff generation (Krenitsky *et al*., 1998)

As discussed previously, the physical properties and conditions of soil have immense influence on runoff generation – this extends to lawns and the topsoil upon which they are established. Turfgrass is often laid directly on subsoil due to the complete removal of topsoil during the construction phase of housing development projects (Cogger, 2005; TRCA, 2012). This may often result in unfavourable conditions for quickflow abatement. To illustrate, Cheng *et* al. (2013) found that subsoil turfed with tall fescue (*Festuca arundinacea*) would initiate runoff in almost half the time compared to topsoil under simulated rainfall conditions and yielded approximately 440% more runoff. In addition to the clear rationale in preserving and increasing topsoil depth, there have been different approaches to improving soil and lawn health (i.e. its fertility and OM content). It has been observed that fertiliser treatment of turfgrass on sandy loam can reduce runoff velocity, where resulting increase root density augmented water uptake and lowers antecedent moisture required for runoff generation (Eston & Petovic, 2004). However, as discussed earlier, fertiliser application is not necessarily desirable due to the potential negative impacts on the aquatic ecosystems of receiving water bodies. It is noted by Law *et al*. (2004) that lawns most deficient in N content are the most likely to be treated with fertiliser, particularly in younger lawns with recently laid turf where homeowners and lawn care professionals are attempting to help the grass establish itself.

Another possibility is to use compost amendment to increase soil OM concentration and decrease bulk density. This has seen some research as a solution, although this has yet to see any widespread implementation in the GTA (TRCA, 2012). Several experiments performed as early as the late 1990s have demonstrated the plausible benefits of topsoil amendment with compost. For example, Kolsti *et al.* (1995) observed decreases in soil bulk density of up to 0.35 g cm^{-3} when integrating compost into topsoil in combination with tilling (not that heavily compacted topsoil may be in excess of 1.5 – 2 g cm^{-3}). Harrison *et al.* (1997) blended turfed topsoil with a 2:1 topsoil-compost ratio and observed increased time intervals to peak runoff flows following rainfall and a doubling of the soil's field capacity. An experiment conducted by Pitt *et al* (1999) on topsoil amendment of turf soil (mentioned in Chapter 1) also gave promising results. In addition to an un-amended topsoil control, topsoil was tilled mechanically with compost in a 2:1 soil-compost ratio in constructed plots. Aspects measured were surface runoff, subsurface discharge, infiltration rate, and nutrient loss. Their results indicated infiltration rates increased significantly and surface runoff volume decreased by factors of 5 – 10 in the compost-amended plots. However, the researchers also observed increased concentrations of macronutrients (N and P species) in surface runoff, which were being leached from the compost. Nevertheless, the researchers concluded that exported nutrient mass would be lower overall due to the increased infiltration rates observed.

Compost amendment has also been observed to decrease the rate of soil erosion. Compost increases the humus content of the soil, which binds particles together, making them more resistant to erosive forces (US Composting Council, 1997). Faucette *et al.* (2005) found that in addition to lowering total surface runoff volume by 30-60%, a 3.75cm compost blanket applied to bare soil would reduce erosion by up to 95% under simulated rainfall (intensity: 77.5 cm hr^{-1}), outperforming hydroseed and silt fence measures in comparison by as much as a factor of 3.5.

These tests were also performed in constructed plots. Compost amendment may also have the capacity to augment other restoration practices used with soil, such as chisel plowing and deep tilling. Balousek (2003) observed that these initial measures would reduce runoff from soil plots predominantly vegetated by grass and small weeds by 36 – 53% versus an unrestored control, but the additional measure of adding 15 cm of compost would decrease runoff by 74 – 91% under all the natural and simulated storm conditions (up to 130 mm hr^{-1}).

Not all strategies may necessarily involve the use of traditional compost. For example, pulp fibre, when incorporated into soil, has been found to decrease total runoff from the soil surface and reduce erosion rates due to again the effect of lowering bulk density and increasing water holding capacity (Chow *et al.*, 2003). This has an additional benefit of utilising waste from the paper industry that may otherwise be discarded. Giusquiani *et al*. (1995) experimented with the use of urban waste compost as a method of topsoil amendment. The urban organic waste, when applied to loam, significantly increased both the pore size and available water capacity of the soil, increasing overall soil quality. Although this particular experiment was conducted on farm land, it would be a viable option for increasing the quality of urban soils and improving their desirable hydrological properties.

2.8. Need for additional research

Previous studies focussed tended to focus more heavily on surface runoff mitigation rather than quickflow and moisture retention. While inhibiting surface runoff is desirable, retention of subsurface flows within the soil is also important feature, as not all quickflow exists at the surface. Examining several application configurations and using less compost (as a fraction of volume) is worth examining. Could similar results be observed using smaller fractions of compost, for example?

Prior research on topsoil compost-amendment has not measured soil moisture three dimensionally, but tends to focus primarily on quantifying stormflow output. The disadvantage here is that the dynamics of water movement below the surface are going unobserved and not being taken into account. As previously discussed, moisture conditions within soils are important when considering the hydrological behaviour of the soil under storm conditions. While it is necessary to investigate flow discharge in and out of the soil block, research should also consider where in the soil plots does moisture concentrate and linger, for how long, and how it is being distributed through the soil both spatially and temporally.

Finally, previous controlled studies examining topsoil amendment have not compared different topsoil depths. It may be that simply increasing topsoil depth is sufficient to significantly decrease quickflow discharge and bring stormwater retention to much higher levels without necessarily incurring the additional costs of compost implementation. Indeed, a larger volume of non-compacted topsoil would theoretically be able to accommodate more water and impede quickflow discharge with extended percolation time. For developers, this could be an attractive alternative and is worth being compared. The STEP experiment seeks to do this.

3. METHODS

3.1. Experiment Introduction

3.1.1 Location

The lawn soil experiment was situated at the TRCA's Kortright Centre for Conservation located in Vaughan, Ontario (see Figure 3) and falls within the Greater Toronto Area (GTA), Canada. This is an area that has undergone significant suburban expansion over the latter half of the 20th century and in recent decades and lies close to several new suburban developments. It is therefore a suitable setting for this experiment, particularly when considering the projected increases in precipitation intensity made by the PRECIS model coupled with rapid local expansion of impervious surface coverage. The local region is subject to a humid continental climate (Köppen climate classification: Dfa) typical to much of Southern Ontario. The nearest Environment Canada weather station in Woodbridge, ON (< 2 km from the Kortright Centre for Conservation), recorded a 1981 – 2010 average of ~780 mm of precipitation (~700 mm of rainfall) per year and approximately 76.3, 70.4, 80.4, and 84.6 mm of rainfall during the respective June, July, August and September summer months (Environment Canada, 2016). These months were initially selected for the field season due to their general high probability of rainfall and because the aim of the experiment was to determine soil performance under the wettest conditions expected. However, maintenance work performed on the plots during July prevented measurements from being taken for most of this month. Additional measurements were attempted in September and October to account for this and extend the field season to compensate.

At the Kortright facility, the TRCA constructed four lawn test plots that were to be monitored over the course of more than year. The plots (described in detail in section 3.1.2) were built to represent gently sloping front lawns for the proposed development of a new residential subdivision in neighbouring Newmarket, ON. The test plots were situated adjacent to a barn in the northern grounds of the conservation centre. The experiment site was fenced off, which was intended to prevent access and possible interference by the visiting public in the surrounding conservation area. The site was accessible to most local wildlife; however, this was not expected to have any significant impacts on the experiment.

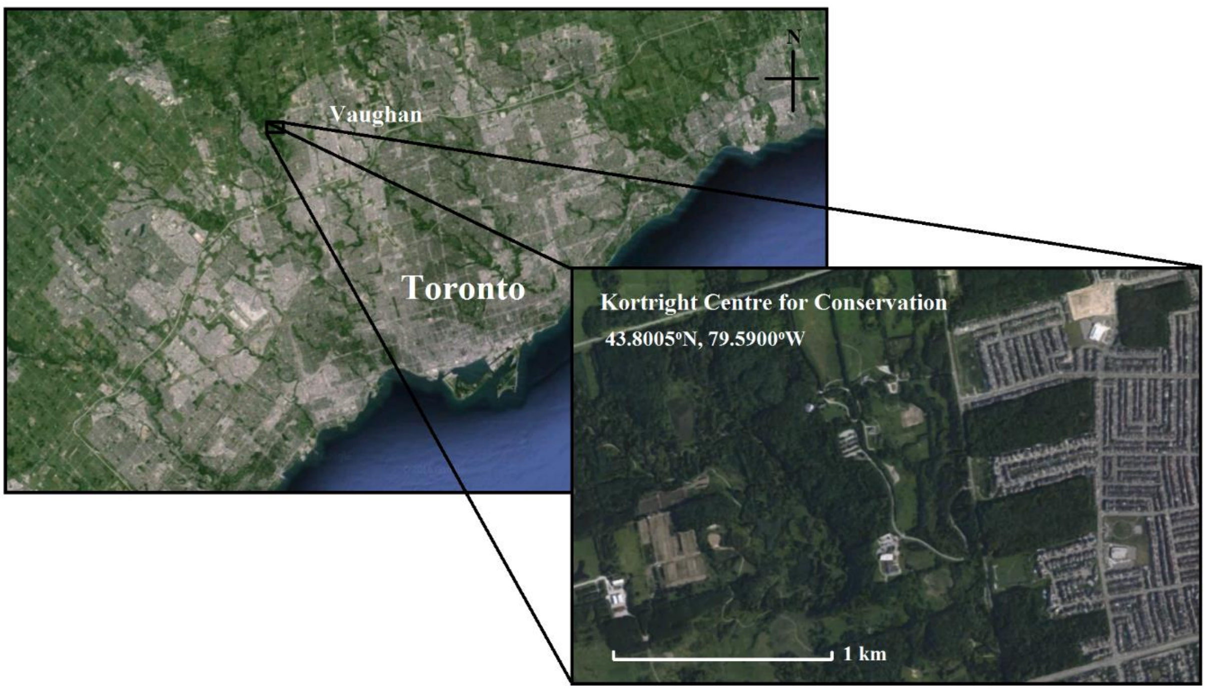


Figure 3. *Location of the Kortright Centre for Conservation, Vaughan, ON (Satellite image from Google Earth, 2016).*

3.1.2. Experiment Plan

While the TRCA were monitoring throughflow produced from the plots under unsimulated rainfall over the course of the year, several supplementary methods of analysis were included with the permission and the assistance of the authority to better understand the properties and flow of water through the plots. The physical characteristics of the soils were to be analysed (see section 3.3) and any significant statistical differences in properties between the plots identified. This was done in order to test whether the lawns and underlying soil conformed to the TRCA's recommended minimum standards for bulk density, compaction, organic matter, etc., as well as to provide supporting evidence and means of explaining the results from the flow and moisture data.

The TRCA recorded precipitation and flow data at the site throughout the year. However, for this separate analysis, several storm events were selected from the field season which were intended to represented a range of intensities and durations. This was due to the practical restraints on manually obtaining soil moisture data that corresponded to specific events, and because not all precipitation events manifested as storms capable of producing measurable flow from the plots. Storms that were <10mm in rainfall depth and <1mm hr^{-1} in mean intensity were not included in the selection, as these storm intensities had negligible impacts on soil moisture and plot flow output. A total of six rainstorms from the precipitation events occurring during the June-September summer field season were selected for analysis. Several factors were then examined, including: flow input and output (used to calculate retention), flow duration, peak flow discharge, mean flow discharge, and peak flow response time (the time between initial flow output and peak flow output). *In Situ* measurements of volumetric soil moisture were taken both before and at intervals following each event. Mean distributions and spatial changes in volumetric moisture over time were then calculated, and the antecedent conditions were used as an aid when interpreting plot flow output, as water already present in the plots would theoretically be a contributory factor that must be accounted for. Volumetric soil moisture content (% vol.) was used as it signifies how much water is effectively being held and where. The more relative degree of soil saturation can be inferred using the soil prosody values calculated for each plot (for example, volumetric soil moisture of 45% in soil of 45% porosity would represent saturated conditions).

3.2. Plot setup

The four lawn test plots were constructed by the TRCA in June, 2014 (with measurements beginning in May 2015). These plots were each 4 x 5 m in area and were constructed using ¾ inch (19 mm) plywood. Each was lawn was given a letter designation and filled with the topsoil and compost configurations described previously in Table 2 and turfed with sod. The plot interiors were lined with plastic and the base filled with a layer of clay approximately 2 cm deep to prevent leakage and percolation of moisture out of the plots (although this later failed in the control plot). The plots were connected to a 33 m^2 barn roof by drainpipe, which allowed rainwater falling on the roof to be transported to each lawn through a gutter. The purpose of this was to simulate contributions to a front lawn from a house roof, where rainwater would flow from the roof onto the lawn. These pipes were connected to a cistern which allowed the flow of water to be controlled, while also giving the option of stored water to be released onto the lawns for flow testing. While this might also serve as a potential substitute for rainfall during the absence of storm events, the water would be delivered to the lawn by gutter only, making this method less environmentally representative. The outflow valve from the cistern was left open between controlled testing to allow rainwater to flow to the lawns normally. An additional benefit of this cistern is that the water flowing from the roof could be distributed evenly to the lawns. Flow was deemed to be approximately equally distributed between the plots after testing performed by the TRCA in May, 2015. At the downslope end of each plot there was an outflow pipe which connected to a tipping bucket gauge (one per plot). These measured flows from each plot by recording each 3L bucket tip. All data were recorded by loggers housed with the gauges, with the TRCA responsible for weekly data downloads. In addition to this instrumentation, a tipping bucket rain gauge connected to a data logger was present on site, kept by the TRCA. There were no methods in place to measure any differences in precipitation falling directly onto each plot. However, considering the size and very close proximity of the plots, differences are likely to be minor. There are no large obstacles (such as trees) shadowing the plots which are likely to have intercepted rainfall (see Figure 3 and Figure 4).

Table 4. *Topsoil designations and descriptions for the four TRCA test plots constructed at the Kortright Centre for Conservation.*

Designation	**Soil description**
A	30 cm of compost-blended topsoil (increased depth and quality 1)
B	25 cm of topsoil + 5cm compost blanket (increased depth and quality 2)
C	30 cm of topsoil (increased depth)
CTL	10cm of topsoil (control)

Soil texture was analysed at the Cornell Nutrient Analysis Laboratory in Ithaca, New York. Of the three samples of topsoil analysed, the average sand, silt and clay content was 23%, 61%, and 16%, respectively. The soil was therefore categorised as silt loam under the US Department of Agriculture soil texture classification system. There was little variation between sand content in the three samples sent for analysis (22.3 – 23.6%). However, silt and clay content ranged between 56 – 65.4% and 11.1 – 21.3% respectively. Regardless, all three samples fall within the silt loam category.

In addition to the setup initially constructed by the TRCA, nine boreholes were excavated in each lawn using a 45-mm auger to create permeant measurement wells and provide an entry point for instrumentation and allow the measurement of soil moisture at different depths. These boreholes served an additional function in later hydraulic conductivity tests (as per the inversed auger-hole method). The auger-bored holes were distributed in three clusters of three holes along a downslope transect bisecting each lawn. Each cluster had holes at 6, 12 and 18 cm depths (a detailed diagram of this setup can be seen in Figure 5). Depth intervals of 6 cm were chosen as this was the length of the probe used to measure soil moisture, therefore giving an uninterrupted vertical profile. 1mm thick PVC pipes (OD = 50 mm) were inserted tightly into the holes, which prevented the lateral movement of water into the cavity. This was an important function as water from shallower depths, if allowed to flow laterally into the holes, would affect the vertical profile of soil moisture in an undesirable manner. Additionally, the pipes, which protruded 2 cm above the ground, were capped to prevent precipitation and debris from entering. Lastly, a 1 mm hole was drilled into the corner of each cap to prevent the build up of negative pressure within the pipes and allow easy removal that would neither loosen the pipe nor affect the surrounding soil.

The lawns were mowed regularly by TRCA staff using a push mower and the turf was not permitted to be extensively colonised by weeds, which were removed regularly. This simulated general lawn care practice and the physical state in which a residential lawn would normally kept. Care was taken not to tread on or knock the protruding PVC pipes as to avoid loosening them and compacting the soil around them, which would create large spaces where rainwater would infiltrate more freely.

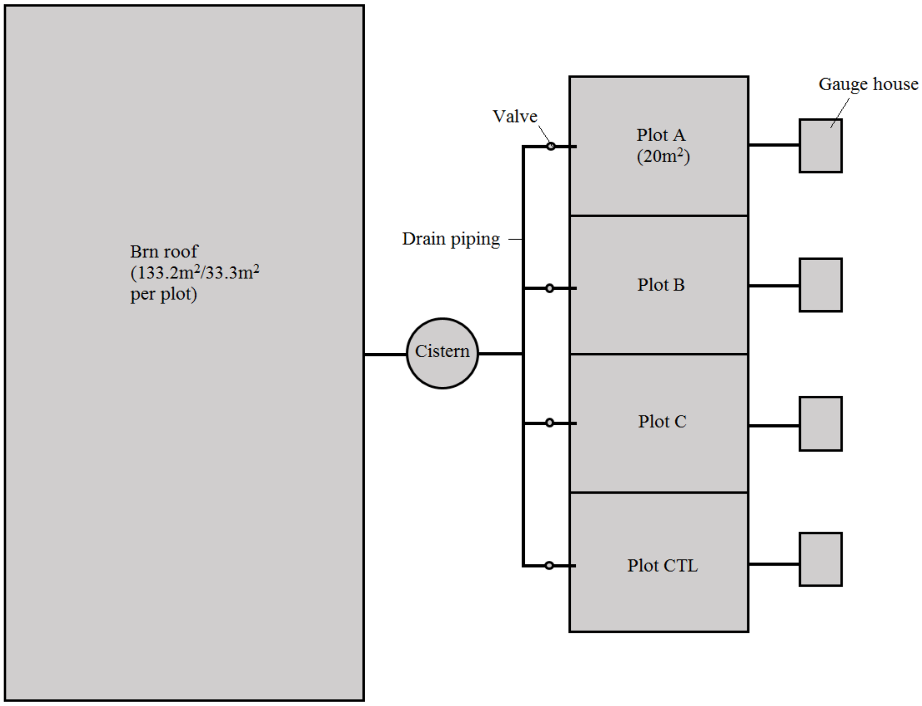


Figure 4. *Area plan of TRCA test plot and installation setup at the Kortright Centre for Conservation (not to scale).*

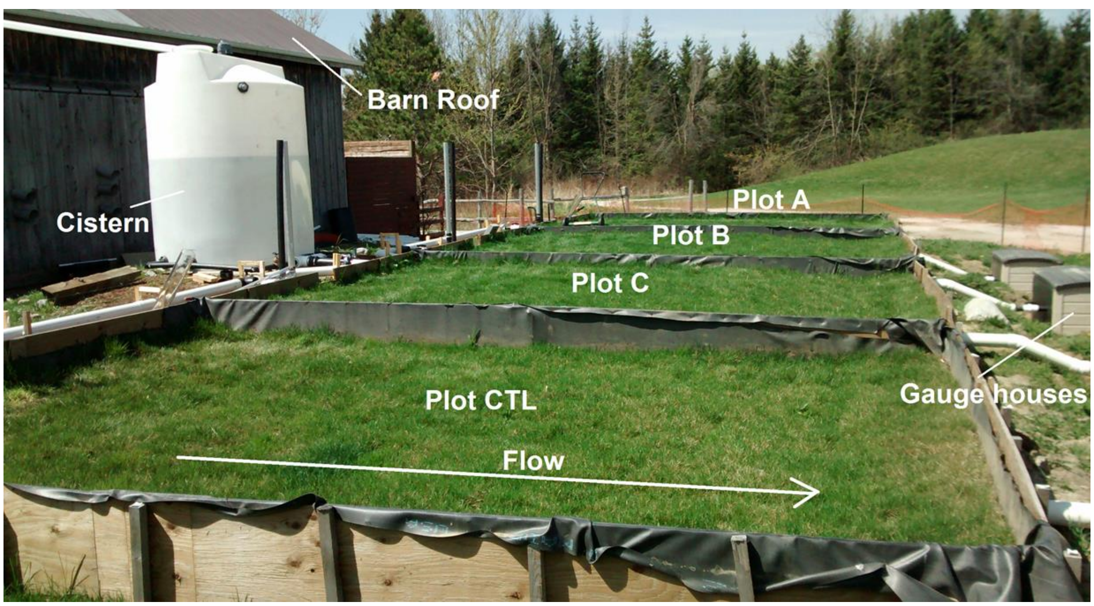


Figure 5. *Labelled photograph of the TRCA topsoil test plot setup at the Kortright Centre for Conservation, facing West (barn on left). Photograph taken on May 7, 2015.*

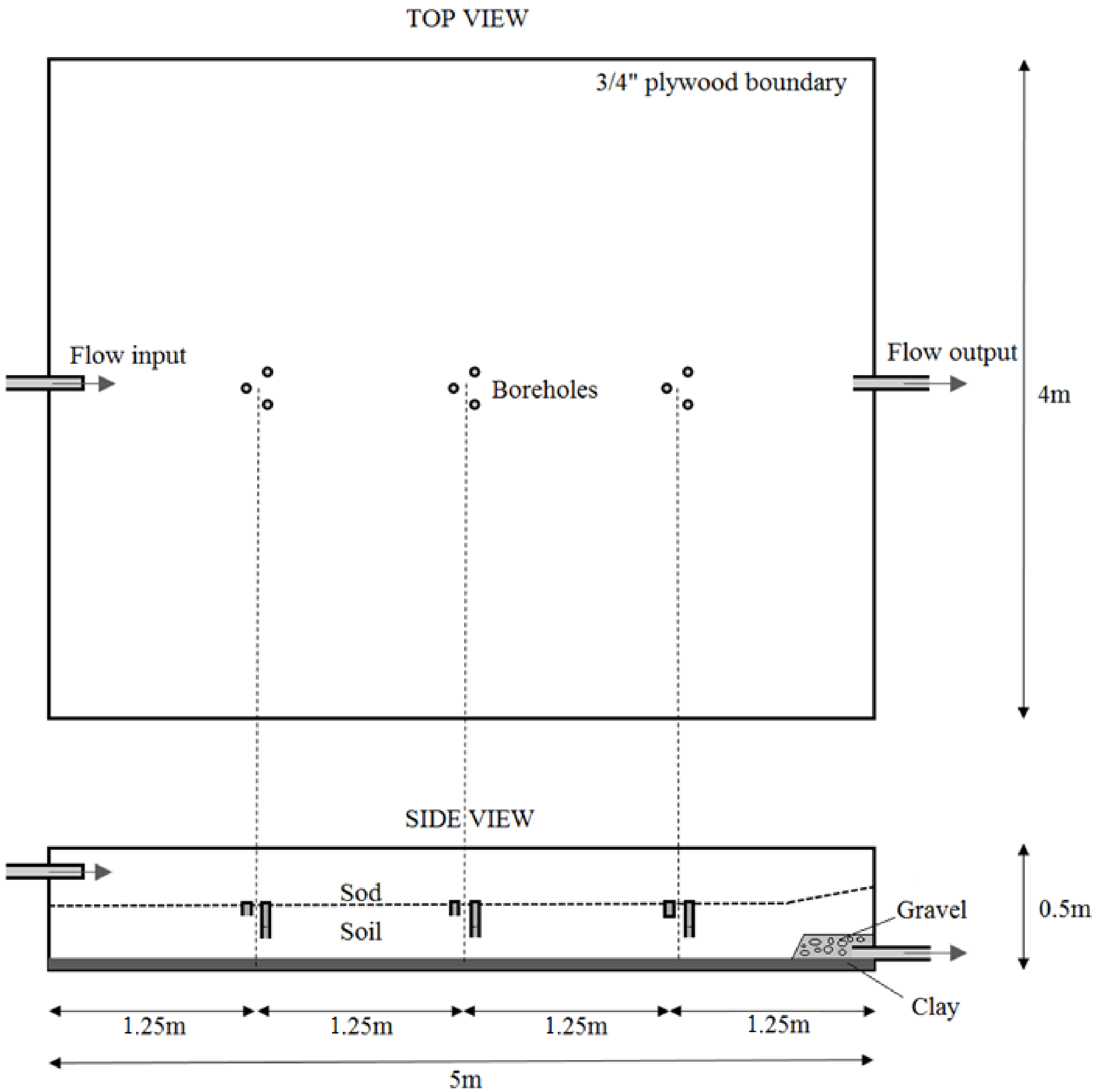


Figure 6. *Orthographic diagram of a single TRCA topsoil test plot at the Kortright Centre for Conservation, showing plot dimension and direction of water flow. Displayed are top and side views. Diagram not to scale.*

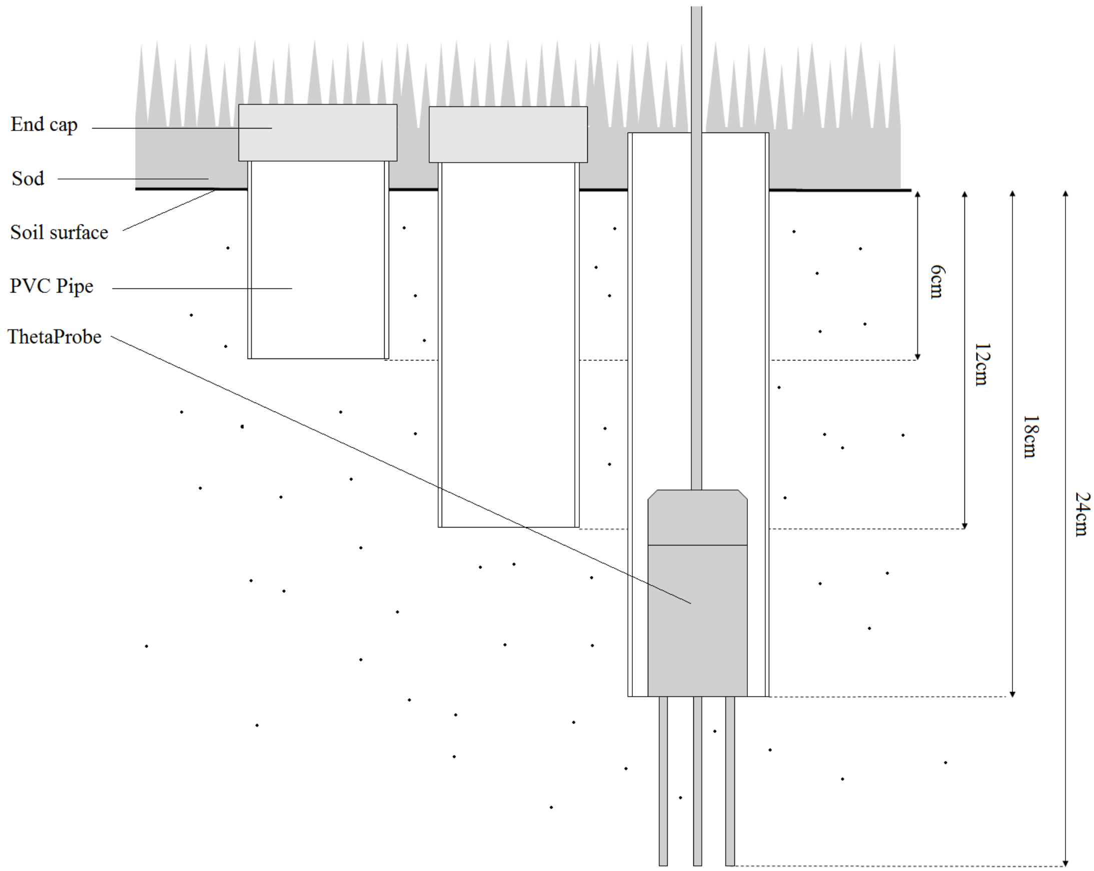


Figure 7. *Diagram of a single soil moisture monitoring well cluster installed in the TRCA topsoil test plots at the Kortright Centre for Conservation. The illustrated wells are shown side-by-side and include a ThetaProbe. Wells are approximately 5 cm apart. Diagram not to scale.*

3.3. Measurement techniques and procedure

3.3.1 Soil core properties

Additional soil physical properties were analysed in a laboratory using cores extracted from each lawn with a 20-mm soil corer. Nine cores were extracted from each lawn from evenly spaced location approximately 1 m apart. It was necessary to take multiple core samples for both statistical analyses and as soil physical properties can exhibit spatial variability even over small scales, either due to uneven compaction from grading or footfall, or the presence of stones and macropores. Care was taken not to significantly compress each core during extraction. However, a degree of compression is unavoidable and was recorded by comparing hole depth with core length. This loss of volume was accounted for when calculating the soil core volume using the core dimensions. The soil properties to analysed from the samples were: bulk density (ρ_b), porosity (*f*), field capacity (FC), particle density (ρ_p) and organic matter content by dry weight (%OM).

Bulk density (g cm^{-3}) was calculated by measuring sample mass and diving by the dried sample volume in the standard manner. Samples were dried in an oven at a constant temperature of 40^{0}C. Additionally, porosity was calculated by subtracting the dried sample mass from the saturated sample mass. The mass of water lost determined the available pore space within the core sample (where 1 g = 1 cm^3). Samples were saturated in their containers through submersion in water. Field capacity was measured using the *European method* (see Figure 6). This is a relatively simple method of measurement that does not make use of artificially applied pressure gradients. The samples were saturated in their containers, weighed and allowed to drain vertically through a fine sieve. The change in weight was recorded until constant. From the final weight, the volume of water lost from the sample under gravity could be calculated (see equation 3). Finally, organic matter content was estimated by a loss on ignition tests. Dried samples taken from the extracted cores were ground and placed in crucibles, weighed, then re-weighed following incineration at 400°C. A sample from the upper 5 cm of compost from plot B was taken and in addition to the regular topsoil beneath and accounts of 1/6 of the core's %OM.

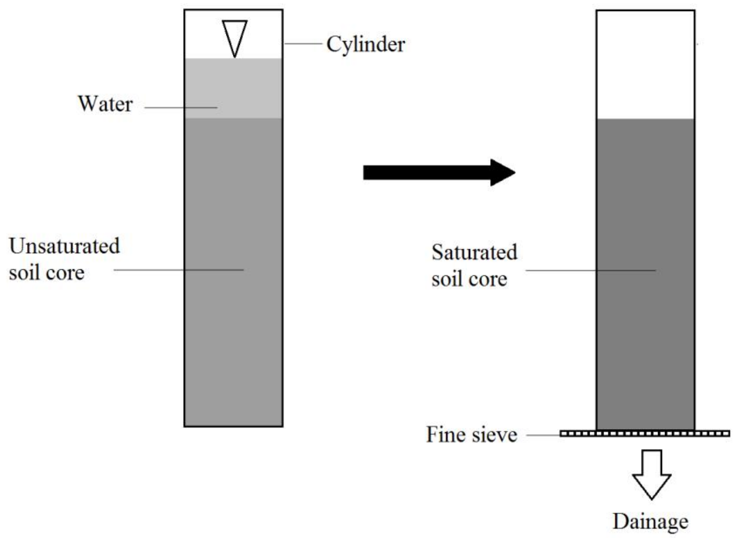


Figure 8. *Diagrammatic setup for the European method of field capacity determination of soil cores.*

<u>Formulae:</u>

Soil bulk density:

$$\rho_b = \frac{M_s}{V_s} \tag{1}$$

Where ρ_b is the soil bulk density (g cm^{-3}), M_s is the mass of the soil sample (g) and V_s is the soil sample volume (cm^3)

Porosity:

$$f = \frac{V_f}{V_t} \tag{2}$$

Where f is soil porosity (%), V_f is the pore space within the sample (cm^3) and V_t is the total sample volume (cm^3).

Field Capacity:

$$FC = \frac{V_{w2}}{V_{w1}} \tag{3}$$

Where FC is field capacity (%), V_{w1} is the initial volume of water within the saturated sample (equivalent to V_f), and V_{w2} is the remaining volume of water after drainage (cm^3).

Soil particle density (ρ_p):

$$\rho_p = \frac{\rho}{f - 1} \tag{4}$$

Where ρ_p is soil particle density (g/cm^3).

Organic Matter (OM):

$$OM = \frac{M_1 - M_2}{M_2} \tag{5}$$

Where M_1 is the initial weight of the soil and M_2 is the weight of the incinerated soil.

3.3.3. Hydraulic conductivity and infiltration rate

Hydraulic conductivity (k) was estimated using the inversed auger-hole method. While similar to the commonly used pump test, this method was chosen as the soil conditions were primarily vadose and no water table was present (meaning the conditions were unsaturated). As with the pump test, this method involves the measurement of change in hydraulic head in holes bored with an auger to determine the rate at which water moves through the surrounding soil. Each 18 cm hole was selected from the four plots for measurement (12 total). Water was poured into each auger hole and the lowering of the water head was recorded over time. As the conditions were not saturated, each hole was filled twice and allowed to drain until the drop in head was roughly at a constant rate, meaning the surrounding soil had reached a point of or close to saturation. Hydraulic conductivity (k) was then determined using the following equation (van Hoorn, 1979):

$$k = \frac{1.15r[\log\left(h_0 + \frac{r}{2}\right) - \log\left(h_t + \frac{r}{2}\right)]}{t} \tag{6}$$

Where k is hydraulic conductivity (cm s^{-1}), r is the auger hole radius (cm), h_0 is the initial height of the water surface (cm), h_t is the height of the water surface at time t (cm), and t is time (s). See Figure 9 for the experimental setup pertaining to the equation.

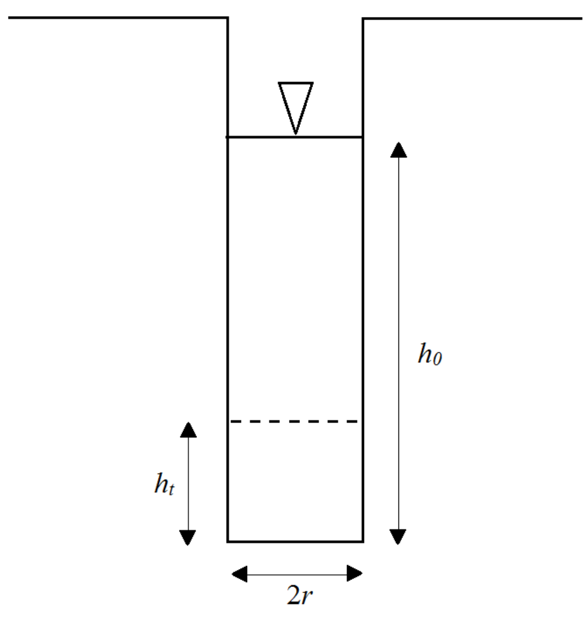


Figure 9. *Simplified diagram of the inversed auger-hole method used to calculate soil hydraulic conductivity.*

3.3.4. Infiltration

Soil infiltration rate was measured was measured using double-ring infiltrometer tests. These tests were performed on site by the TRCA staff, once per plot. The inner infiltration rings were inserted 3” (7.62 cm) and the outer rings 5.5” (13.97 cm) into the soil, which includes the overlying sod (approximately 3 cm thick). A constant head of 10 cm was maintained and the volume of water added recorded over time and recorded.

3.3.5. Surface compaction

Surface compaction was measured using an ELE International Proving Ring penetrometer, which has a 250 PSI maximum capacity and analog dial. Measurements were taken by TRCA staff at nine evenly spaced points in each plot approximately 1 m apart. An average was then calculated for each plot. Making more than nine penetrometer measurements per plot was avoided in order to negate significantly artificially enhancing the soils’ infiltration characteristics by introducing many large macropores at the surface, as the penetrometer creates a hole when inserted. These compaction measurements were performed once on June 16, 2015.

3.3.6. Flow input-output calculation

Flow input and rainfall onto the lawns was calculated by multiplying barn area (divided by four) and lawn area by rainfall depth. These two values were combined and regarded as “total input” when calculating retention, where “retention” is defined as the percentage difference between volumetric input and output over the course of the storm event and until the cessation of plot flow (deemed to end when no bucket tips were recorded for more than an hour). Flow from the gutter was not measured directly as there were no gauges permanently in place to do so. However, in May 2015, TRCA staff measured flow input from the gutter in order to test the evenness of flow distribution coming from the roof and cistern. The results would have been used to calculate an adjustment factor for each plot, as the division of flow was noticeably uneven (presumably due to differences in pipe length, slight variation in levelness, etc.). However, after adjustments made by the TRCA following the May tests, differences were deemed insignificant and flow inputs were assumed equal. The data loggers recorded the number of tips in one minute intervals, which allowed discharge to be calculated in terms of m^3 hr^{-1}. Due to the 3L capacity, of the tipping bucket, which may be too large for discharges below 0.1 m^3- hr^{-1}, intervals had to combined into 10 minutes when producing hydrographs. Finally, the antecedent soil moisture conditions prior to each storm event used to help in the analysis of flow output as ‘old water’ already present in the soil affects the timing and discharge of throughflow as it does in slopes (Mosley; 1979; McDonnell, 1990). Additionally, a drier soil block will be capable of withholding more water, resulting in lower flow outputs.

3.3.7. Soil Moisture Measurement

Measurements of soil moisture content, taken as percentage volume, were recorded using a Delta-T ML3 ThetaProbe inserted into the lawn surface and boreholes over the field season following rainfall predicted to meet the requirements for analysis. Readings were taken from both inside the boreholes and from the surface. The surface measurements were taken at each borehole cluster and approximately 1 m either side of the boreholes. This allowed changes in moisture to be observed laterally, serving as an indicator of the degree to which flow spreads across the lawn from the gutter. Therefore, there were a total of 15 soil moisture measurement locations in each plot (five each 1.75 m along the central transect). Each set of post-storm readings were taken approximately one hour, one day and one week following rainfall forecast to exceed 10 mm in total depth. Any precipitation events below this size were deemed too insignificant to noticeably affect soil moisture, either due to interception from the grass blades or evaporation. Any events below this intensity that yielded no measurable results (if readings were taken) were excluded from the study or used as antecedent measurements for following storms where necessary. The three time intervals were selected to produce both a short and longer term insight into soil moisture movement. Pre-storm measurements were taken within the 24 hours prior to the forecast storm events. Only three pre-storm surface measurements were taken in addition to the subsurface measurements, however. Surface measurements adjacent to the borehole clusters were not needed to calculate an average for the soil column. Including them would have resulted in an unrepresentative weighted bias towards the surface when calculating mean moisture volumes in each plot.

4. RESULTS

4.1. Soil properties

4.1.1. Laboratory analyses

Two soil samples taken from one core in each plot are represented in the data. One sample in the plot B series contained the pure compost component. Here results were adjusted proportionally to account for the soil-compost ratio of 1:5 in the core when calculating mean values. Soil organic matter content (Figure 10), expressed as a percentage of mass, was largest for the compost-amended soils (plots A and B), as was to be expected, averaging at approximately 14% and 16% for A and B respectively. Although the quantity of compost added to the soils in each plot was the same, a difference of approximately 3% exists between the A and B samples and 1% between the C and CTL samples. Nevertheless, %OM falls well above TRCA guidelines of 5-10% for turfed areas (outlined in Table 1, chapter 1). Soil from plot C and CTL (which were from the same source), also falls comfortably within these guidelines.

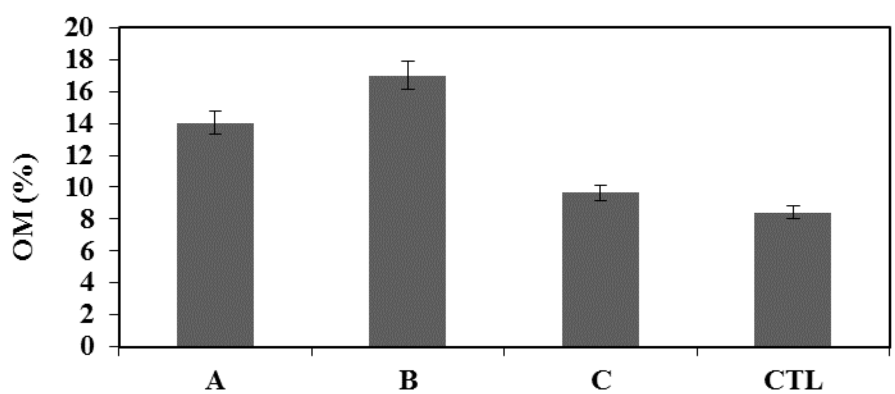


Figure 10. *Soil organic matter of TRCA topsoil test plots as % dry weight. Results derived using loss-on-ignition test performed on soil cores. n=2 (per plot).*

Figure 11 and Table 5 detail the remaining laboratory test results examining soil physical properties (note 2 cores from plots A and CTL are excluded due to damages). The samples from plots C and CTL were the densest, with samples from plot CTL being the densest overall. Welch's t-tests were used (due to unequal variances) to test plot averages against the control after the two distinct outliers in A and CTL were removed to ensure a normal distribution. Using the Bonferroni correction for the three tests to account for the possibility of type 1 error, the soils in all three amended plots were significantly denser than the control at the adjusted $\alpha = 0.016$. Regardless, the bulk density of the measured samples does not exceed the limits outlined in the TRCA recommendations, which is approximately 1.5 g cm^{-3} for silt loam textured soils (TRCA, 2012). Using the same procedure, Particle density was again significantly higher in plots C and CTL.

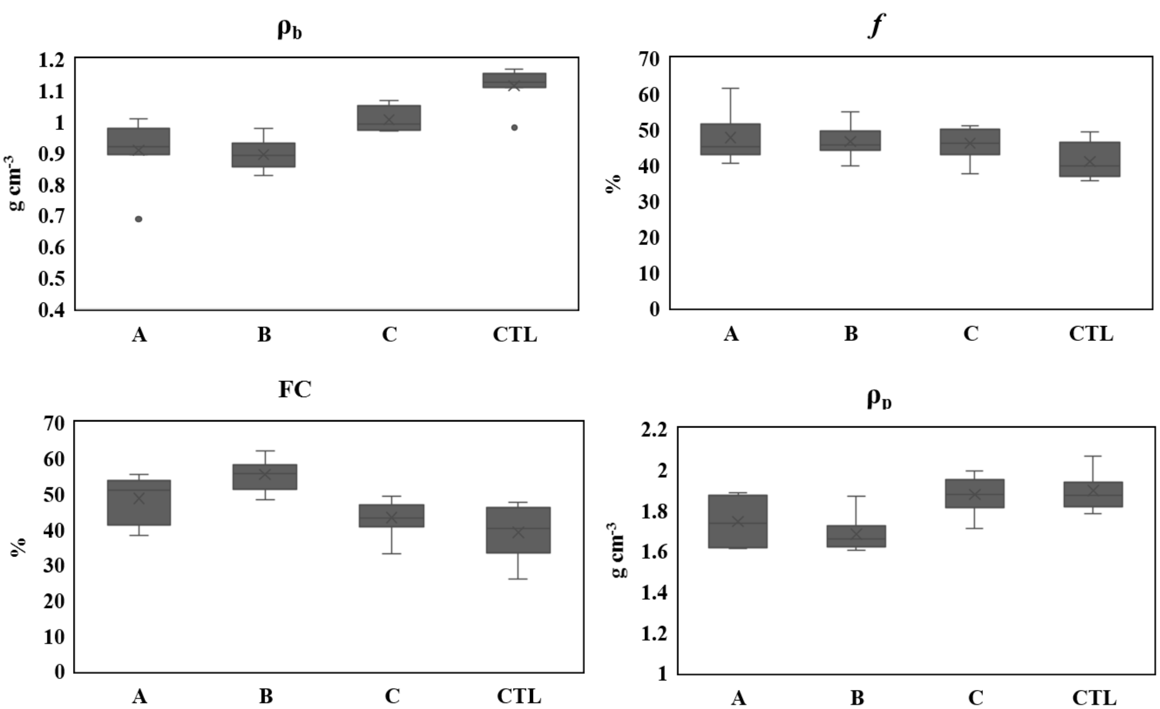


Figure 11. *Soil bulk density (ρ_b), porosity (f), field capacity (FC), and particle density (ρ_p) derived from soil cares taken from TRCA topsoil test plots at the Kortright Centre for Conservation.*

Porosity was highest in plot A and lowest in CTL. However, there were no significant differences between the compost-treated soils and non-compost-treated soils overall, taken as groups. Porosity is similar between plots A, B and C with no differences of statistical significance. However, a one-tailed t-test showed CTL to be significantly less porous than the other plots on average. A one-way ANOVA test determined the mean field capacities of each plot to be significantly different from one-another (p = 0.0005). Post hoc Welch's t-tests (1-tailed) were used to compare plots A and B to the control. Both demonstrated a significantly higher FC value vs the control (p = 0.0015 and 0.0004 for A and B respectively). Note that α = 0.025 using the Bonferroni correction for multiple comparisons.

Table 5. *Summary of soil bulk density, particle density, porosity, and field capacity from soil cores taken from TRCA topsoil test plots at the Kortright Centre for Conservation.*

Plot	A	B	C	CTL
		Bulk density (g cm^{-3})		
Mean	0.91	0.89	1.01	1.12
Median	0.92	0.89	0.99	1.13
SD	0.11	0.04	0.04	0.07
CV (%)	12	5	4	6
		Particle density (g cm^{-3})		
Mean	1.74	1.68	1.88	1.90
Median	1.74	1.66	1.88	1.87
SD	0.1	0.08	0.09	0.1
CV	0.06	0.05	0.05	0.05
		Porosity (%)		
Mean	47.74	46.62	46.17	41.03
Median	45.28	45.81	46.20	39.82
SD	7.16	46.66	4.62	4.92
CV	0.15	0.10	0.10	0.12
		Field capacity (%)		
Mean	48.7	55.36	43.21	39.03
Median	51.10	55.74	43.07	40.18
SD	6.33	4.43	4.75	8.2
CV	0.13	0.08	0.11	0.21
***n*=**	7	9	9	7

Coefficients of variation are generally within 0.1 with a small number of exceptions, suggesting a moderate-to-high degree of homogeneity between the samples, despite several outliers. Note that minor outliers in the sample groups may be due to less significant experimental error or effects caused during extraction, or the presence of physical anomalies within the soil samples, such as stones and macropores. negative correlation exists between bulk density (ρ_b) and porosity (*f*) (Figure 12a), suggesting the field capacity of the soil cores is inversely related to their particle density. Additionally, a negative correlation was found between ρ and FC (Figure12b). Linear regression analyses identified both these relationships to be significant at the 95% confidence level ($p < 0.05$). However, due to the relatively low R^2 value in the field capacity-particle density regression, the precision of this relationship is low and thus should be interpreted with a degree of caution due to the high level of variability, despite statistical significance. No correlations were significant among the other variables.

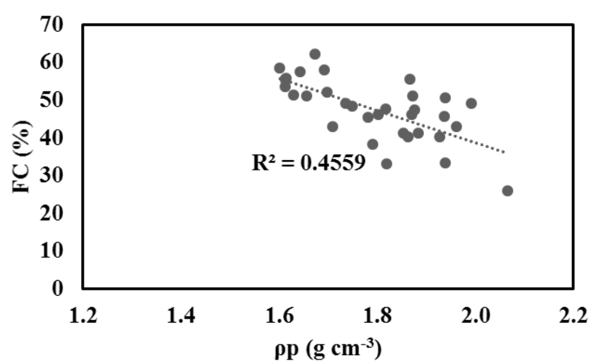


***Figure 12a**. Scatter diagram of soil particle density (ρ_p) and field capacity (FC) derived from TRCA test plot soil cores. One data point per core (n=22).*

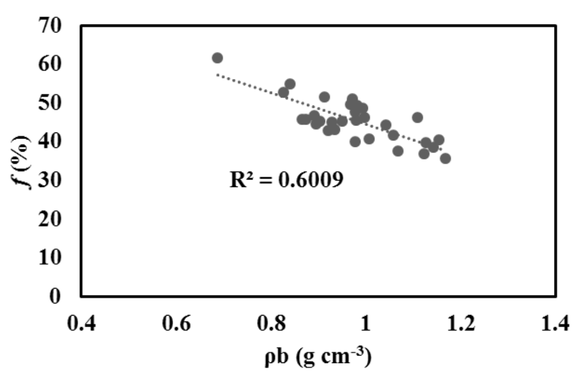


***Figure 12b**. Scatter diagram of soil porosity (f) and bulk density (ρ_b) derived from TRCA test plot soil cores. One data point per core (n=22).*

4.1.2. Field analysis - Soil compaction

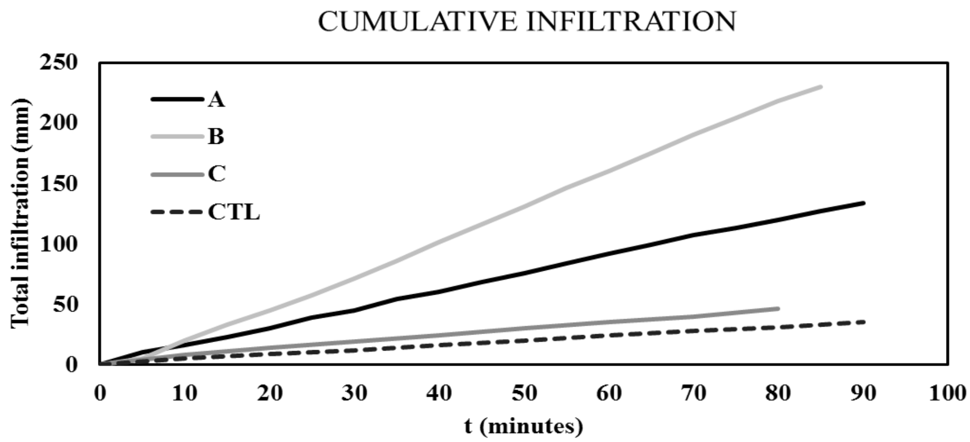
Outlined in Table 6 are the cone penetrometer results provided by the TRCA in all three units commonly used when measuring soil compaction. Each of the cone penetrometer readings placed the levels of surface compaction observed under the TRCA recommended guidelines shown in Table 3. Subsurface compaction guidelines are applied due to the 10-cm depth to which the penetrometer measures. Coefficients of variation ranged between approximately 12 – 20%, suggesting a moderate degree of variation within each plot. Plot A had the greatest mean surface compaction, the control the lowest, while B and C were similar. Note that the overlying sod will constitute 2-3 cm of depth. As the control plot is only 10 cm deep, the sod-soil ratio will be greater, making a slightly lower degree of compaction expected when compared to the other plots due to the sod's lower bulk density.

Table 6. *TRCA topsoil test plot mean surface compaction in upper 15 cm. Values in multiple units. Measured by TRCA staff at the Kortright Centre for Conservation using a cone penetrometer. n=9 (per plot).*

	Soil Plot			
	A	**B**	**C**	**CTL**
	Mean compaction in upper 15cm			
PSI	178.49	155.56	157.81	145.82
kg cm^{-2}	12.55	10.94	11.1	10.25
kPa	1230.65	1072.55	1088.06	1005.39
CV (%)	20.14	19	12.5	17.09
Within TRCA guidelines?	Yes	Yes	Yes	Yes

4.1.3. Field analysis – infiltration rates

Observable in Figure 13, infiltration rates remained relatively similar for each soil plot over the course of the infiltrometer tests. Plot B had the greatest infiltration rate overall, both on average and with the highest recorded value (see Table 7), accumulating the most water overall. Infiltration rates for A were not as high as B (which has the low-density compost blanket), but were still greater than C and the control, which had comparatively similar results (plot means were within one standard deviation from one-another). This is to be expected as plots C and CTL had the same soil, only at two different depths and with moderately different densities. When subject to Welch's t-test (assuming unequal variances) the differences observed in infiltration rate were shown to be highly significant between plots A and B ($p < 0.0001$), A and CTL ($p < 0.0001$), and B and CTL ($p < 0.0001$), also while using the Bonferroni correction for two significant test results respectively ($\alpha = 0.025$). However, there was no significant difference between C and CTL ($p > 0.05$). Additionally, coefficients of variation for plots A and C were roughly twice that of B and CTL which had infiltration rates that deviated only marginally from the mean. Note however, seen in the graphed data for the first 45 minutes, plot B stands out as being highly variable and erratic in the first 40 minutes. This irregular infiltration pattern may have been due to experimental error or anomalous behaviour of the unsaturated compost layer.



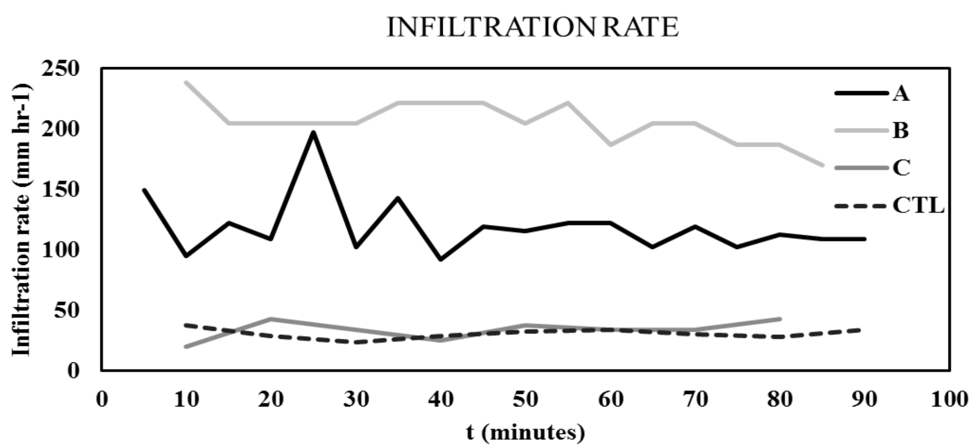


Figure 13. *Results of double ring infiltrometer tests performed by TRCA staff on the topsoil test plots at the Kortright Centre for Conservation. Shown are cumulative infiltration (above) and infiltration rate over time (below).*

Table 7. *Results of double ring infiltrometer tests performed by TRCA staff on the topsoil test plots at the Kortright Centre for Conservation: key statistical data.*

Plot	**A**	**B**	**C**	**CTL**
		Infiltration rate (mm hr^{-1})		
Mean	119.0	205.1	33.8	30.5
Maximum	149.7	238.1	42.5	37.4
Minimum	91.8	170.1	20.4	23.8
SD	23.8	16.4	7.8	3.1
CV (%)	20	8	23	10
***n*=**	18	17	8	9

4.1.4. Field analysis – hydraulic conductivity

A summary of the inversed auger-head test results is shown in Table 8 and the graphed results in Figure 14. Due to unequal variances between means, Welch's t-tests were used to test for significant differences between plot hydraulic conductivities (k). The compost-treated plots, as a group, failed to show significantly higher k versus plots C and CTL ($p = 0.03$) at the adjusted $\alpha = 0.025$ due to the Bonferroni correction for two simultaneous significant tests assuming a 95% confidence level. However, plot A, which had the highest mean k overall, was significantly greater than the other plots when subject to a t-test ($p = 0.01$). The control plot had the most variability in k between holes at a value of 29%. Plots B and C followed with 22% and 17% respectively. Variability between the holes in A was comparatively minor at 5%, with the three holes having a similar change in hydraulic head over the measurement period. Note in that in Figure 14 H did not reach 0 cm in any of the test holes. This is due to the gradual saturation of the soil after the holes were filled several times. There was approximately 1-2 cm of water present at the bottom of each borehole before filling and measurement began.

Table 8. *Summary of results for inversed auger-head tests performed on the TRCA topsoil test plots at the Kortright Centre for Conservation. Three auger holes per plot (n=3)*

	Plot			
	A	B	C	CTL
Hole	**Hydraulic conductivity k (cm s^{-1})**			
1	0.00067	0.00051	0.00034	0.00044
2	0.00072	0.0007	0.00048	0.00045
3	0.00075	0.00048	0.00045	0.00071
Mean	0.00066	0.00056	0.00042	0.00053
SD	0.00003	0.00012	0.00007	0.00015
CV (%)	5	22	17	29

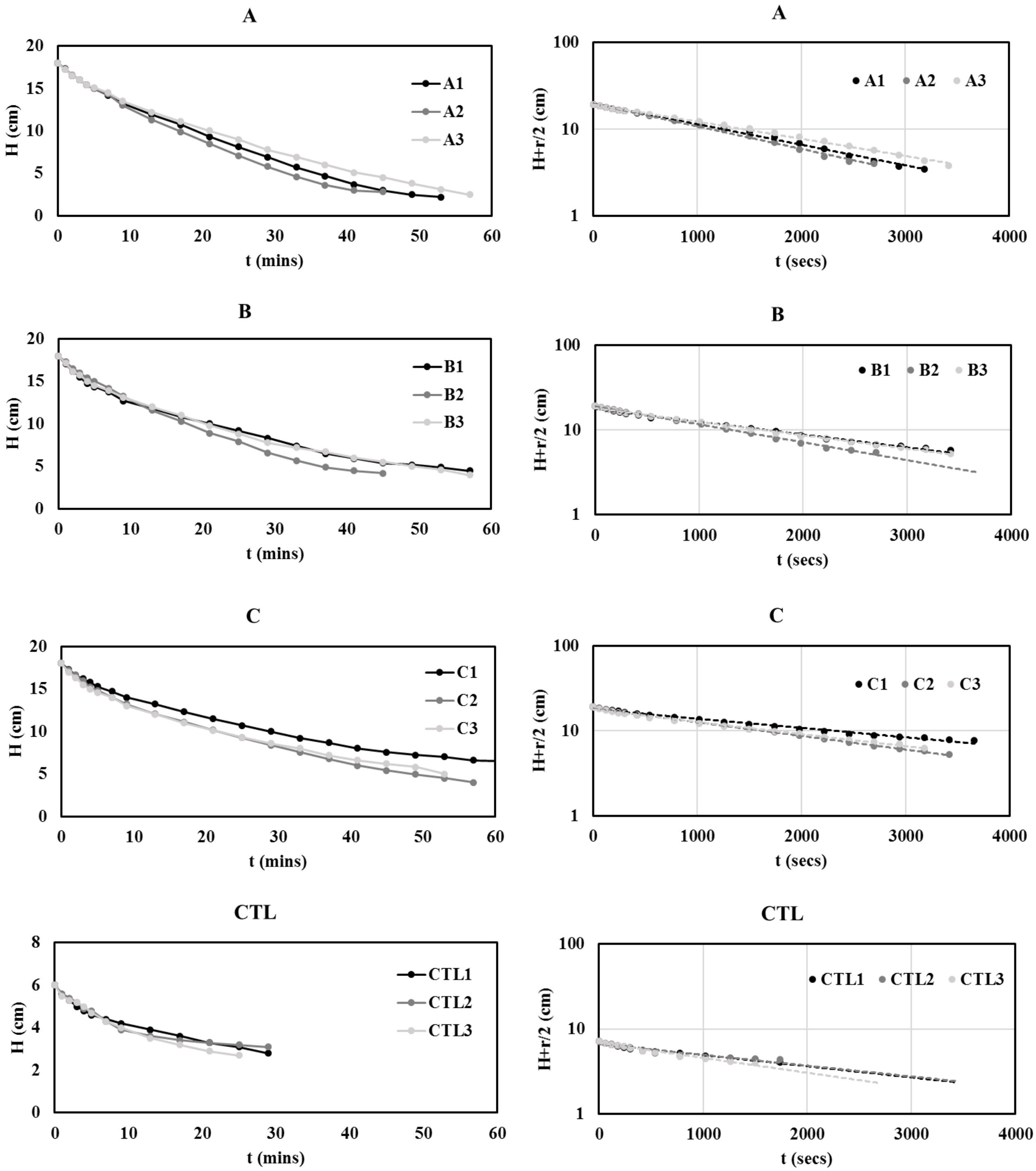


Figure 14. *Graphed results of inversed auger-head tests performed on the TRCA topsoil test plots at the Kortright Centre for Conservation. Three auger holes per plot (note 6cm holes only in the control). Change in H (cm) over time (left) and logarithmic counterpart plots (right).*

4.1. Storm and plot flow results

4.1.1. Selected precipitation events.

Six storms were selected which saw no further rainfall (or only marginal rainfall) following the event to allow changes in soil moisture to be measured without being compromised by further input. They are detailed here in Table 9.

Table 9. *Summary of intensity, depth and duration of the six storm events recorded at Kortright Centre for Conservation selected for use in the topsoil test plot flow analysis.*

	Storm					
	1	**2**	**3**	**4**	**5**	**6**
Start date	Jun 8	June 16	June 27	Aug 10	Aug 20	Sep 19
Duration (hours)	8.25	5.33	28.33	7.42	4.17	1.58
Rainfall (mm)	30.8	21.2	38.8	28.8	16.8	9.6
Peak intensity (mm hr^{-1})	36.0	26.4	12.0	26.4	100.8	45.6
Mean intensity (mm hr^{-1})	3.69	3.98	1.37	3.88	4.02	6.07

The storms to be used in the analysis varied considerably between parameters. Storm duration ranged from 1.58 – 28.33 hours (CV=1.05), total rainfall from 9.6 – 38.8mm (CV=0.43), peak intensity from 12 mm hr^{-1} to 100.8 mm hr^{-1} (CV=0.76), and mean intensity 1.37 mm hr^{-1} to 6.07 mm hr^{-1} (CV=0.39). Additionally, peak intensity does not necessarily correlate with mean intensity. For example, storm 5 (August 20) had a peak intensity more than twice that of the other storms, yet its mean intensity was only 0.16 mm hr^{-1} above average and approximately 2.05 mm hr^{-1} lower than the mean intensity of storm 6, the most intense storm on average. This aptly demonstrates the uneven nature of storm intensity.

4.1.2. Plot quickflow

Hydrographs of the plot flows coupled with precipitation intensity are shown in Figures 15-20. Flow is given in units of m^3hr^{-1} and rainfall intensity in mm hr^{-1}. Each figure corresponds to a single storm event and includes the four TRCA topsoil test plots.

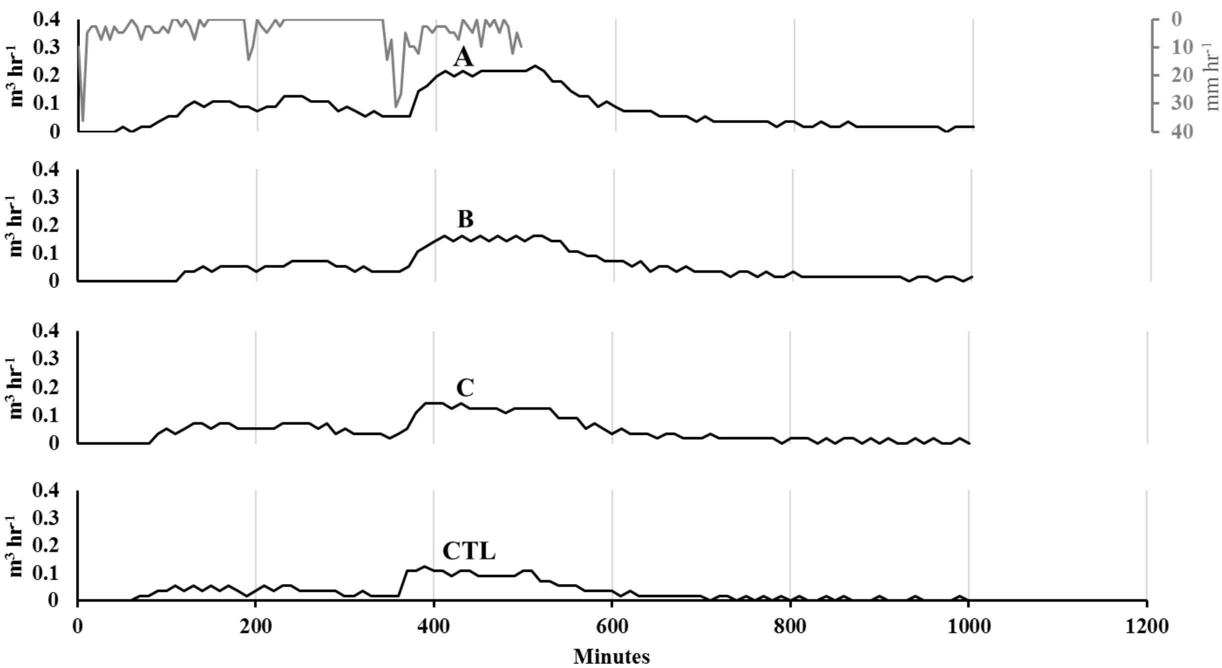


Figure 15. *Hydrograph of TRCA topsoil test plot flow discharge and rainfall intensity recorded at the Kortright Centre for Conservation. Storm 1 (June 8, 2015).*

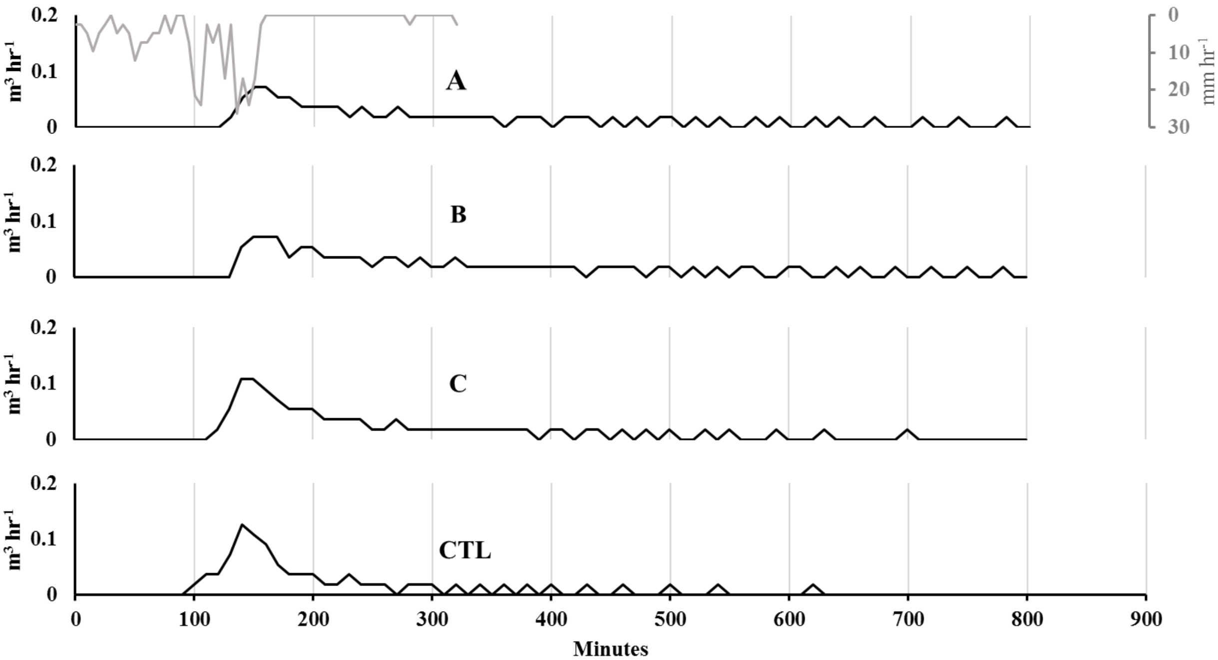


Figure 16. *Hydrograph of TRCA topsoil test plot flow discharge and rainfall intensity recorded at the Kortright Centre for Conservation. Storm 2 (June 16, 2015).*

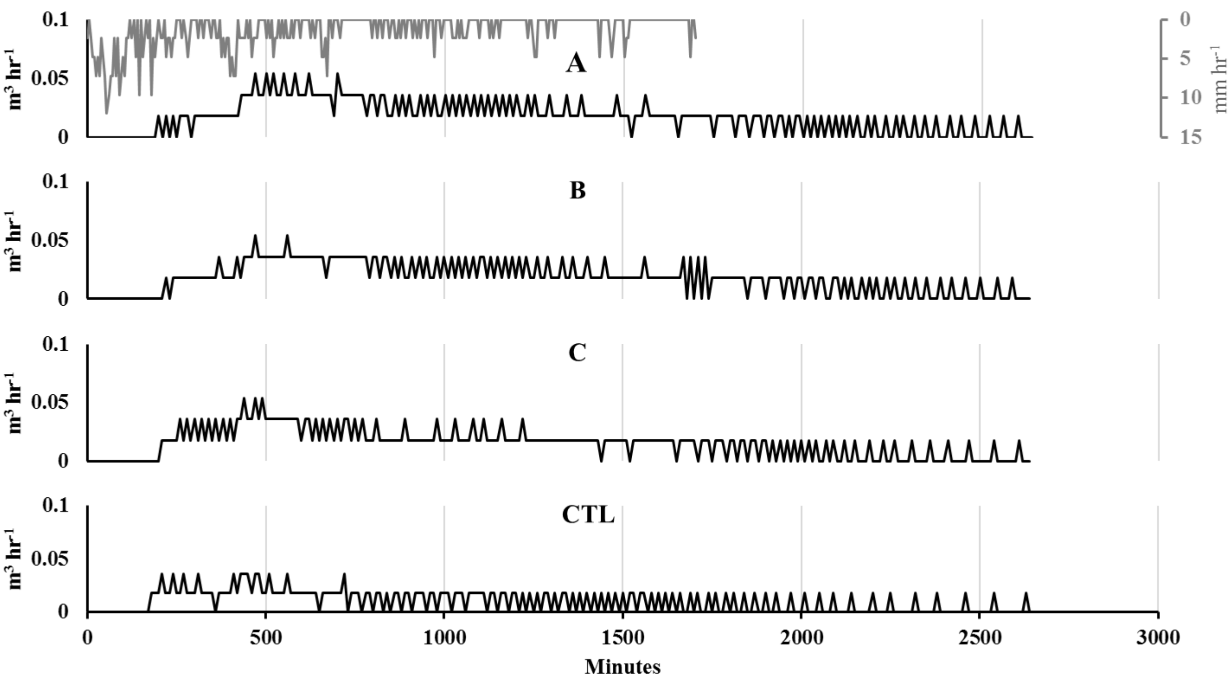


Figure 17. *Hydrograph of TRCA topsoil test plot flow discharge and rainfall intensity recorded at the Kortright Centre for Conservation. Storm 3 (June 27, 2015).*

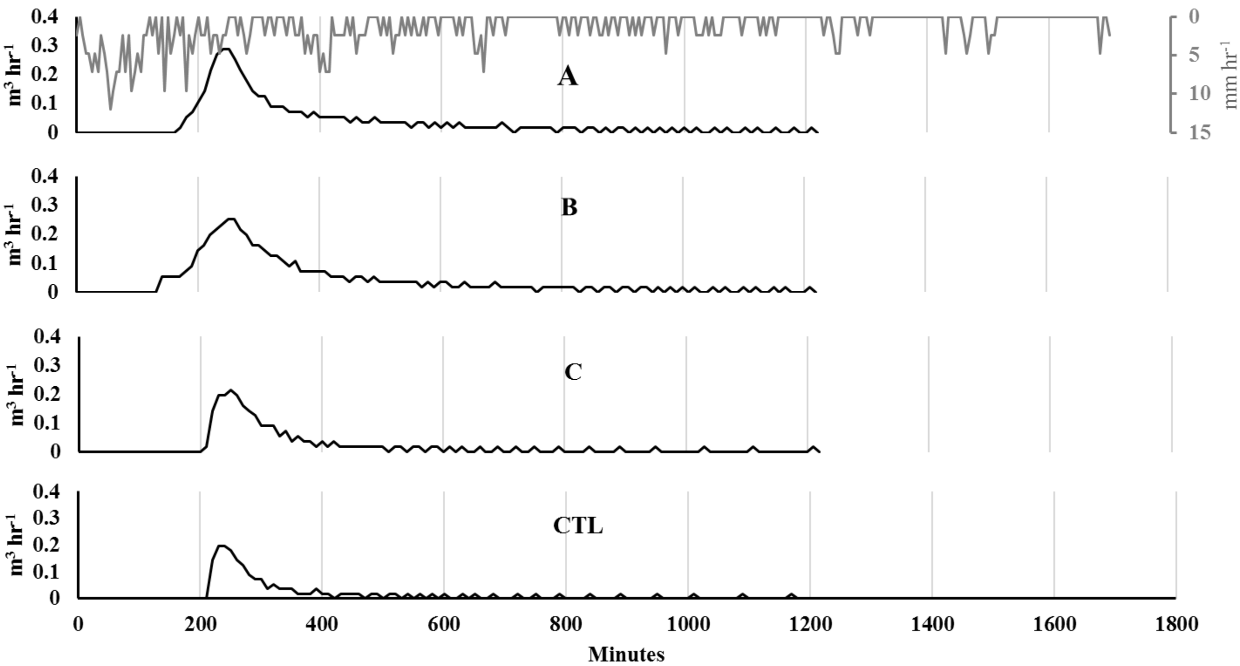


Figure 18. *Hydrograph of TRCA topsoil test plot flow discharge and rainfall intensity recorded at the Kortright Centre for Conservation. Storm 4 (August 10, 2015).*

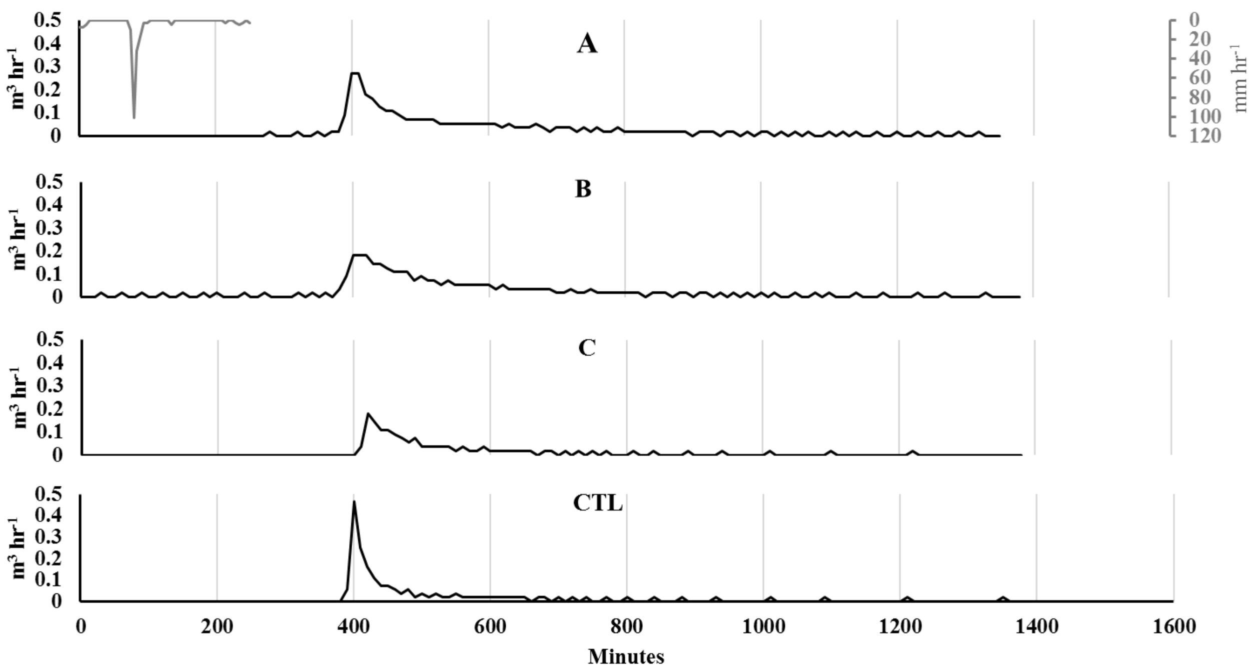


Figure 19. *Hydrograph of TRCA topsoil test plot flow discharge and rainfall intensity recorded at the Kortright Centre for Conservation. Storm 5 (August 20, 2015).*

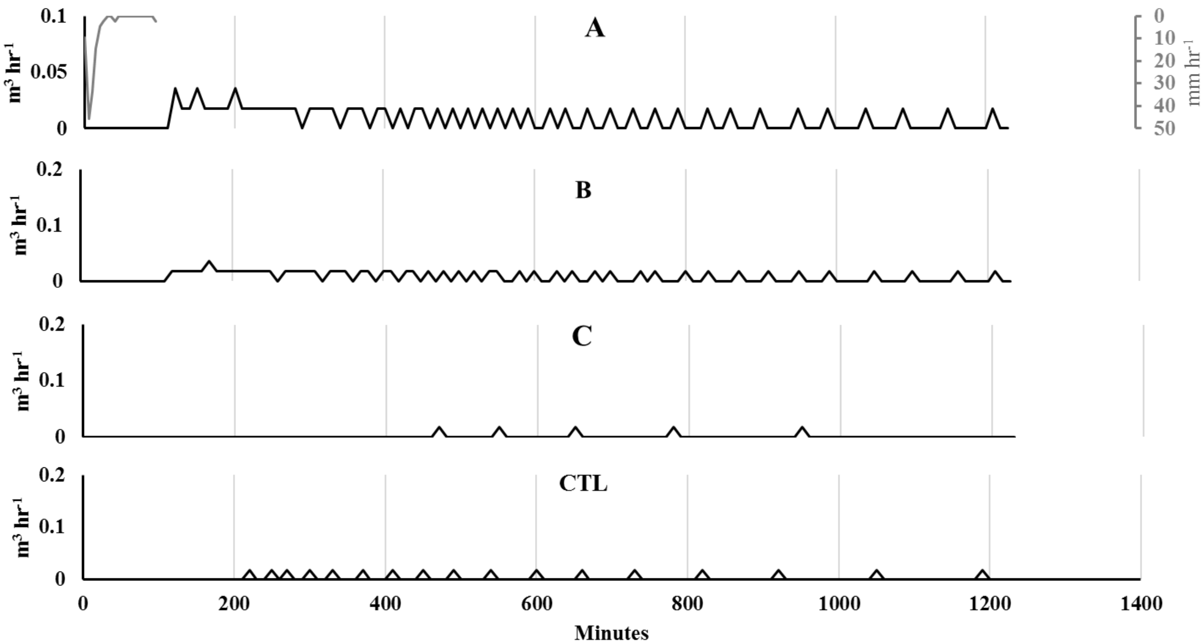


Figure 20. *Hydrograph of TRCA topsoil test plot flow discharge and rainfall intensity recorded at the Kortright Centre for Conservation. Storm 6 (September 19, 2015).*

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Only five of the 6 storms (storms 1-5) produced a flow output from the plots substantial enough to create a defined hydrograph. Storm 6, which had a total rain depth of <10mm, produced a much flatter hydrograph. 'Peak discharge' for the plots only producing one measurable discharge rate will be considered equal to this discharge rate, but the peak discharge delays for storm 6 flows have been excluded from the data as there is no way to clearly distinguish peak discharge from the initiation of measurable discharge. Also note that storm 1 produced two hydrograph peaks (one small, one large) due to two distinct periods of high-intensity rainfall during a single evet. For this study, the largest peak event is used for the comparisons. See Table 10 for more detailed results. "Retention" is defined here as the %volume of stormwater that failed to flow from the plots during the measurement period. Water "retained" either remained in the soil or was lost to the atmosphere via evapotranspiration (thus is equivalent to the percentage difference between total flow input and total flow output). Mean discharge was calculated over the same measurement period for each plot, starting with initial rainfall and ending when each plot ceased producing measurable flows for >1hr. Peak discharge delay is the time interval between the initiation of measured precipitation and the occurrence of peak flow discharge.

Table 10. *Summary of TRCA topsoil test plot flow input and output (volumetric totals), flow retention and flow discharge recorded at the Kortright centre for conservation for six storm events.*

Storm	**Plot**	**Total Input (m^3)**	**Total flow output (m^3)**	**Retention (%)**	**Peak discharge (m^3 hr^{-1})**	**Peak discharge delay (mins)**	**Mean discharge**
1	A	1.642	1.395	15.0	0.234	510	0.057
	B	1.642	0.951	42.1	0.162	410	0.039
	C	1.642	0.813	50.5	0.144	390	0.033
	CTL	1.642	0.588	64.2	0.126	390	0.024
2	A	1.130	0.183	83.8	0.072	150	0.014
	B	1.130	0.213	81.1	0.072	150	0.016
	C	1.130	0.207	81.7	0.108	140	0.015
	CTL	1.130	0.168	85.1	0.126	140	0.012
3	A	2.068	0.777	62.4	0.054	470	0.018
	B	2.068	0.795	61.6	0.054	470	0.018
	C	2.068	0.684	66.9	0.054	440	0.015
	CTL	2.068	0.441	78.7	0.036	260	0.010
4	A	1.535	0.780	49.2	0.288	240	0.038
	B	1.535	0.861	43.9	0.252	250	0.042
	C	1.535	0.426	72.2	0.216	250	0.021
	CTL	1.535	0.330	78.5	0.198	230	0.016
5	A	0.895	0.582	35.0	0.162	430	0.025
	B	0.895	0.558	37.7	0.144	430	0.024
	C	0.895	0.225	74.9	0.144	430	0.011
	CTL	0.895	0.324	63.8	0.468	400	0.014
6	A	0.512	0.165	67.8	0.036	-	0.008
	B	0.512	0.159	68.9	0.036	-	0.008
	C	0.512	0.015	97.1	0.018	-	0.001
	CTL	0.512	0.051	90.0	0.018	-	0.002
Mean	**A**		**0.647**	**52.2**	**0.141**	**360**	**0.027**
	B		**0.590**	**55.9**	**0.120**	**342**	**0.024**
	C		**0.395**	**73.9**	**0.114**	**330**	**0.016**
	CTL		**0.317**	**76.7**	**0.162**	**284**	**0.013**

SD	A	0.459	24.5	0.104	155	0.019
	B	0.342	17.3	0.082	137	0.013
	C	0.304	15.5	0.071	132	0.011
	CTL	0.190	10.7	0.164	111	0.007
CV (%)	A	71	47	74	43	69
	B	58	31	68	40	56
	C	77	21	62	40	67
	CTL	60	14	101	39	54

Storm 3 was a notable outlier when comparing total flow input with mean plot flow discharge. This was the largest storm by total depth at 38.8 mm. However, mean storm *intensity* was the lowest as the event was drawn out over more than 24 hours. This would account for the lowered mean plot flow discharge. Plot A had the longest peak discharge delays on average, followed by B, C, then the control. However, no statistically significant differences were identified when subjected to paired sample t-tests (p = >0.05). Welch's t-tests were then used in cases where variances were unequal, but again with no significant results.

There was a positive correlation ($R^2 = 0.64$) between total flow input (m^3) and flow output (m3) on average (Figure 21). As flow input increases, generally so does output. Linear regression analysis determined the relationship to be statistically significant ($p < 0.0002$), implying flow input is a reliable predictor of flow output collectively between the plots overall. The positive correlations existed for each plot individually, but with some variation between them. The correlation in plot A was comparatively weaker, whereas plot C had the highest R^2 values overall, suggesting a more defined relationship. Plots B and CTL had similar correlation coefficients. There was also positive correlation between total flow input and mean output discharge ($R^2 = 0.3$) collectively between the plots (Figure 22). The correlation becomes much stronger ($R^2 = 0.88$)

when storm 3 – the notable outlier – is excluded. Nevertheless, regression analysis indicated this to be a statistically significant relationship ($p < 0.05$) despite the presence of the outlier.

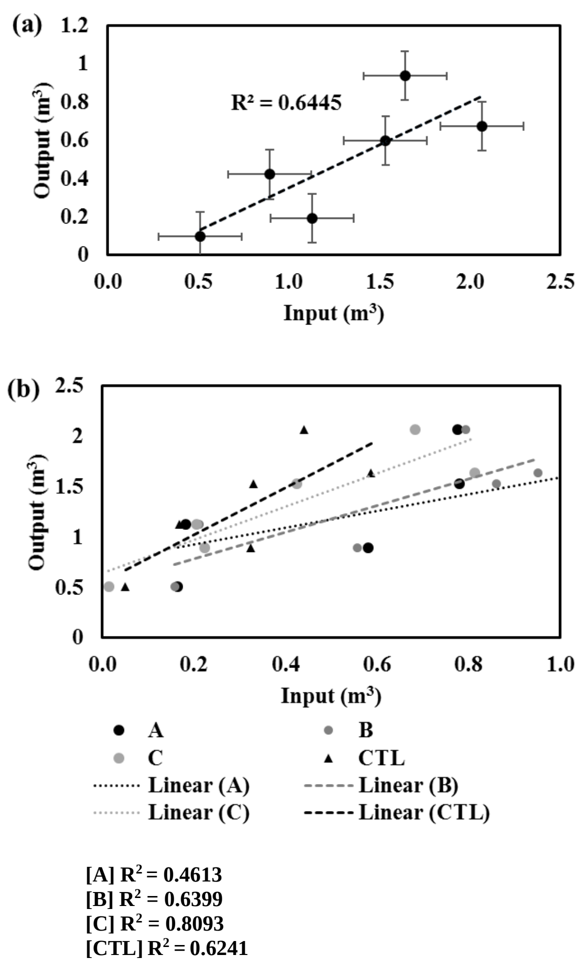

Figure 21. Regression between total topsoil test plot flow input (m^3) and output (m^3) across six storms at the Kortright Centre for Conservation. four-plot mean with standard error (a) and individual plots (b).

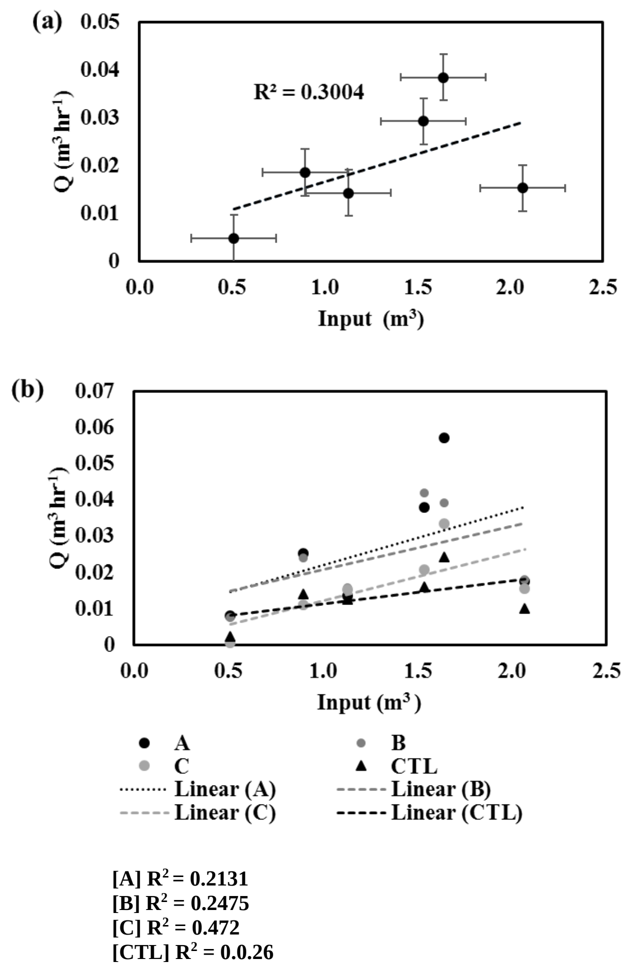

Figure 22. Regression between total test plot flow input (m^3) mean discharge ($m\ hr^{-1}$) across six storms at the Kortright Centre for Conservation. four-plot mean with standard error (a) and individual plots (b).

4.1.3. Antecedent moisture (pre-storm conditions)

Antecedent moisture conditions (Table 11) represent plot mean % vol. soil moisture within approximately 24 hours before the initiation of the corresponding storm event.

Table 11. *TRCA topsoil test plot antecedent moisture conditions (% vol.) ~24 hours prior to storms 1-6 at the Kortright Centre for Conservation (plot mean moisture values (n=12 per plot)***.***

	Plot				
	A	**B**	**C**	**CTL**	**mean**
Storm	**Mean volumetric water content (%)**				
1	42.8	42.8	41.8	44.1	**42.9**
2	37.0	35.7	37.6	39.3	**37.4**
3	38.3	38.9	40.0	41.0	**39.5**
4	40.9	40.3	41.1	42.7	**41.2**
5	42.3	42.3	42.1	45.5	**43.1**
6	30.6	31.1	32.4	31.9	**31.5**

Plot mean antecedent moisture conditions (averaged across all plots) correlate negatively with flow retention (R^2 = 0.72), and positively with maximum flow discharge (R^2 = 0.78) and mean flow discharge (R^2 = 0.68). The same correlations exist when the plots are split individually, but with greater variation between R^2 values. Linear regression analyses determined these relationships to be statistically significant when the plots are combined into single populations ($p < 0.05$) although model precision is generally low due to the high degree of variability. Due to the small sample sizes, regression analysis is not likely to yield enough statistical power if performed on the plots individually, however.

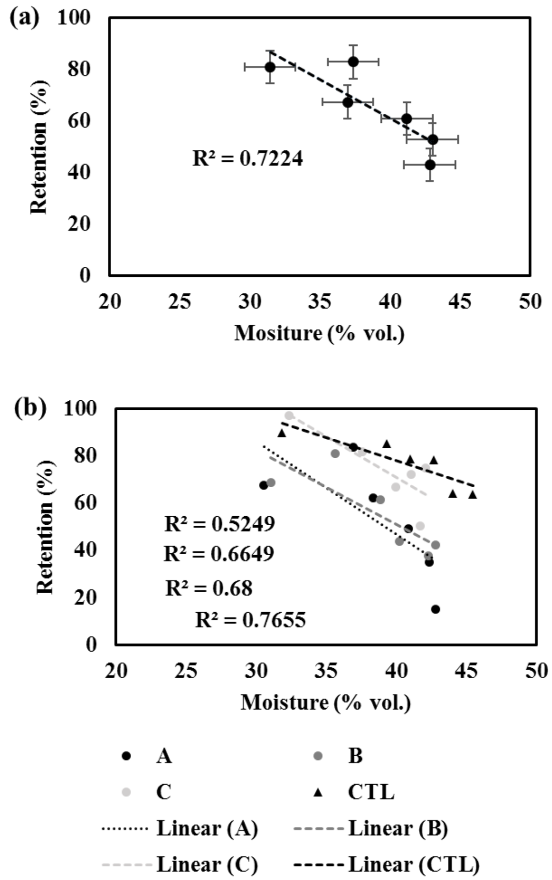

Figure 23. *Topsoil test plot mean antecedent soil moisture (% vol.) and flow retention (%) regressions. Grouped means with standard error, (a) and individual plots (b).*

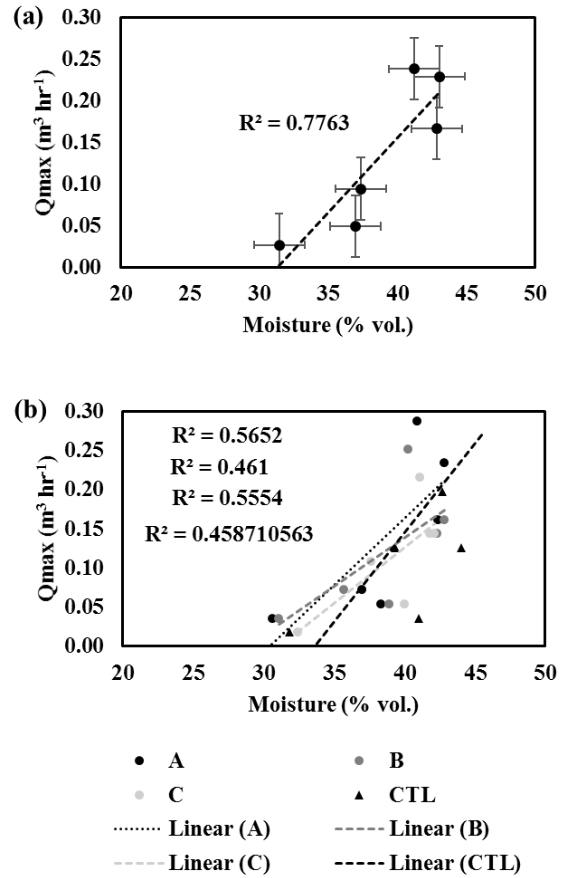

Figure 24. *Topsoil test plot mean antecedent soil moisture (% vol.) and plot peak discharge Qmax (m^3 hr^{-1}) regressions. Grouped means with standard error, (a) and individual plots (b).*

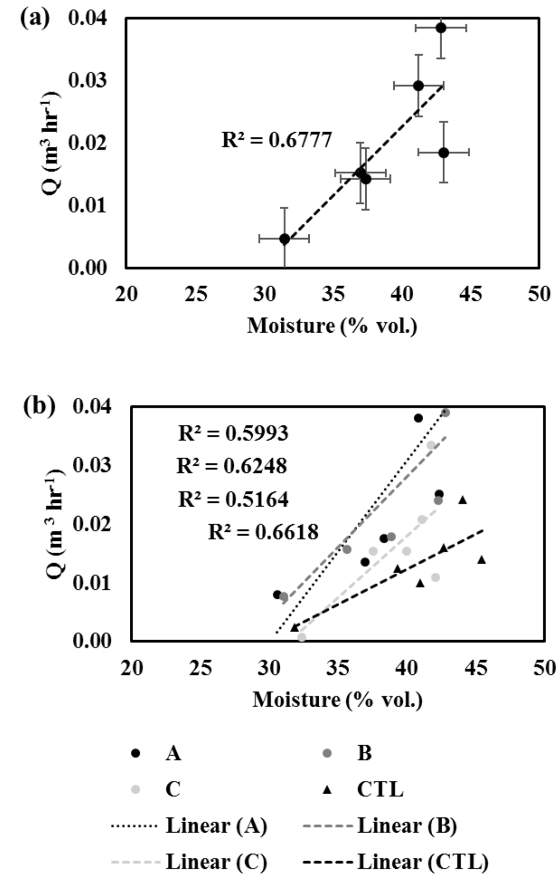

Figure 25. *Plot mean antecedent soil moisture (% vol.) and plot mean discharge Q (m^3 hr^{-1}) scatter plots. Grouped means with standard error, (a) and individual plots (b).*

4.1.4. Post-storm Soil moisture

In Figure 26 and Figure 27 it is apparent that mean moisture content increases with depth for plots A, B and C during all the post-storm measurement periods. This is not true for the control plot, however, where soil moisture as a percentage of soil volume *decreases* with depth on average. Additionally, the rate of change with depth also decreases with time, counter to the other plots. Four all four plots, the difference in volumetric soil moisture between the upper and lower measurement depths increases with time.

The vertical soil moisture gradients for plots A, B and C are similar in the <1hr measurement period and an net loss of surface moisture after one day occurs in each plot on average. However, as time progresses, plots A and B are seen to experience the greatest net loss in moisture on average over the approximate 1-week period following a storm event at -27.4% vol. Gains in moisture were only detected after one day, typically in the lower 18-24 cm. These gains were largest in plots A and B. No average gains were recorded in the upper 6cm or in plot CTL, suggesting net loss at all depths between storms. Furthermore, the averaged soil moisture profile in the control is clearly inversed during all three measurement periods. Only one of 6 storms produced a normal profile (an increase of %vol. soil moisture with depth).

Lateral surface moisture is graphed in Figure 28. Generally lateral difference in mean surface soil moisture do not exceed 5% at each point along the downslope transect. This is true for each measurement period and is evidence that the distribution of moisture at the surface is approximately even and not concentrating at specific edges or corners of the plots.

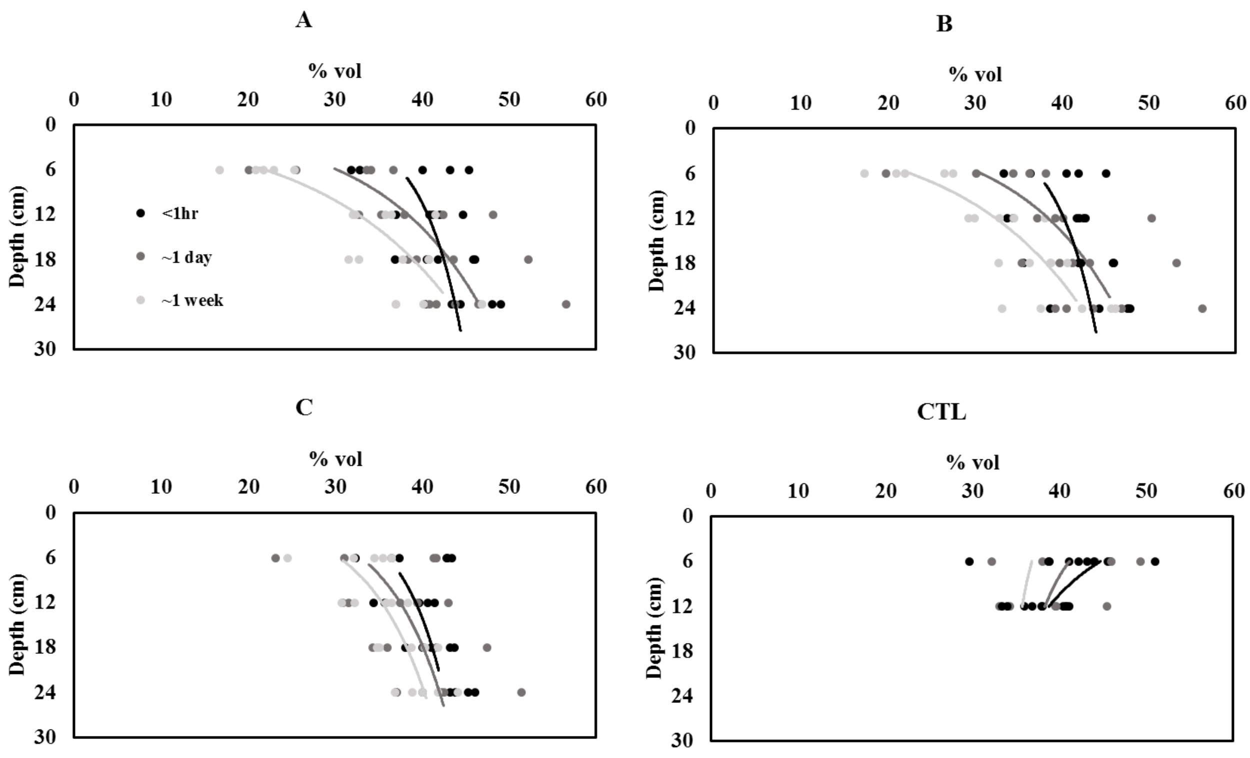

Figure 26. *TRCA topsoil test plot soil moisture (% vol.) vertical profiles. Longitudinal means by measurement depth, measured <1hr, ~ 1 day and 1 week following six storms at the Kortright Centre for Conservation.*

Table 12. *TRCA topsoil test plot change in soil moisture (%vol.) at four measurement depths averaged over six storm events at the Kortright Centre for Conservation, ~ 1 day and ~ 1 week following measurement within one hour of a storm.*

	Plot											
		A			**B**			**C**			**CTL**	
Depth		**Δ % vol.**			**Δ % vol.**			**Δ % vol.**			**Δ % vol.**	
(cm)		**1d**	**1w**		**1d**	**1w**		**1d**	**1w**		**1d**	**1w**
6	38.3	-8.4	-17.0	38.0	-7.8	-15.9	38.9	-5.0	-8.0	44.7	-3.5	-7.8
12	40.1	-0.8	-4.3	39.5	+0.3	-5.8	37.4	-1.2	-2.7	38.8	-0.4	-3.0
18	41.8	+1.2	-4.1	41.4	+1.4	-3.4	40.7	-0.8	-2.5			
24	44.4	+1.9	-2.0	43.9	+1.6	-2.3	41.9	+0.6	-1.4			
Net		**-6.1**	**-27.4**		**-4.5**	**-27.4**		**-6.4**	**-14.6**		**-4.0**	**-10.9**

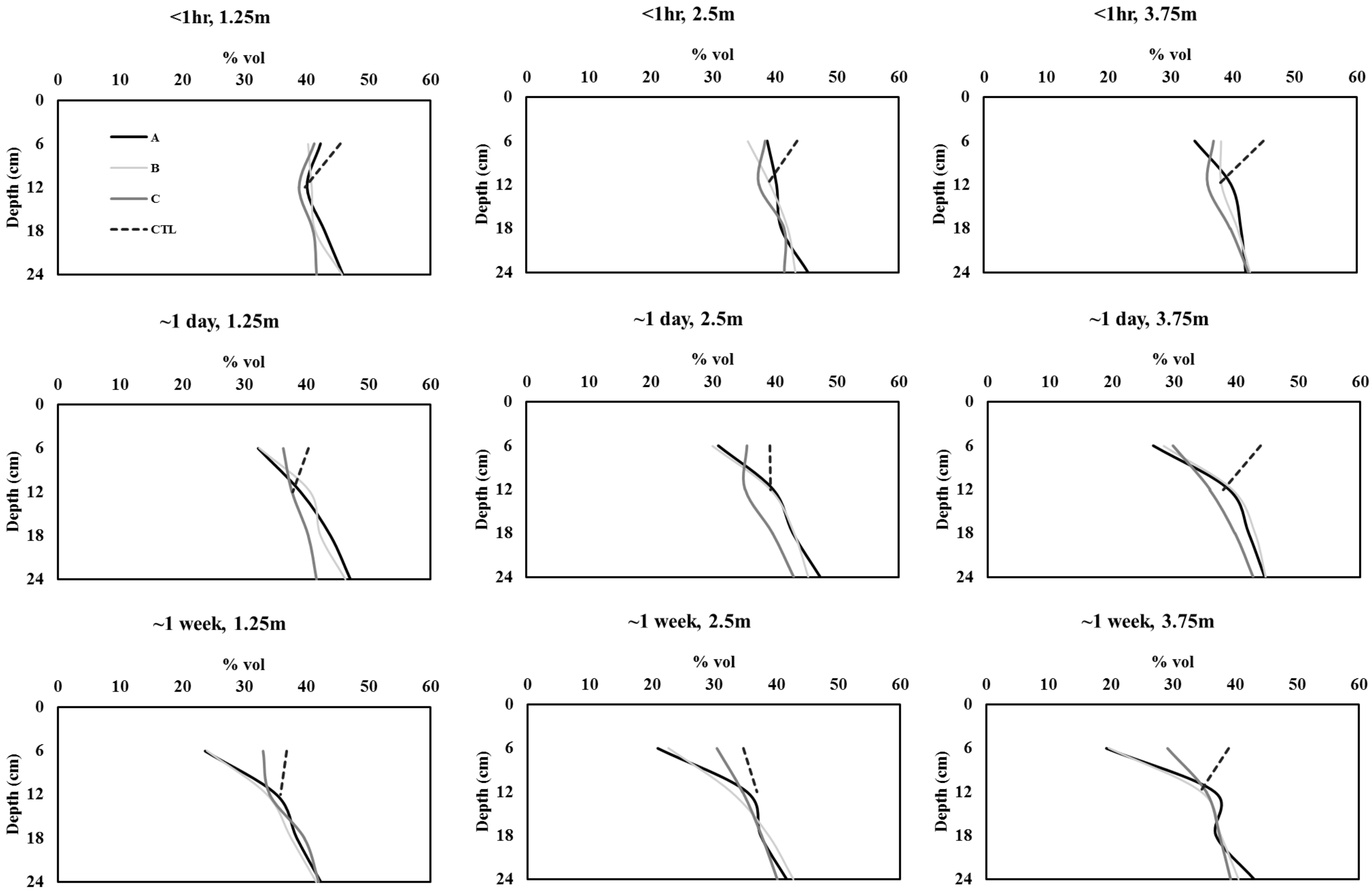

Figure 27. *TRCA topsoil test plot post-storm soil moisture (% vol.) by depth, distance from gutter, and measurement time averaged over six storms measured at the Kortright Centre for Conservation.*

Table 13. *TRCA topsoil test plot change in soil moisture (%vol.) by depth (cm), time period, and position on downslope transect (m). Changes averaged over six storm events at the Kortright Centre for Conservation, ~ 1 day and ~ 1 week following measurement within one hour of a storm.*

	Plot											
		A			B			C			D	
						1.25m						
Depth		**Δ % vol.**			**Δ % vol.**			**Δ % vol.**			**Δ % vol.**	
(cm)		**1d**	**1w**		**1d**	**1w**		**1d**	**1w**		**1d**	**1w**
6	42.3	-10.0	-18.6	40.3	-7.8	-16.3	41.3	-4.9	-8.3	45.5	-5.2	-8.6
12	40.2	-1.1	-5.0	40.8	-0.2	-7.2	38.9	-1.2	-4.8	39.8	-1.9	-3.9
18	43.0	+0.9	-4.5	41.4	+0.9	-3.9	41.1	-0.8	-1.5			
24	45.9	+1.2	-3.6	45.7	+0.6	-4.1	41.7	0.0	+0.3			
						2.5m						
		Δ % vol.			**Δ % vol.**			**Δ % vol.**			**Δ % vol.**	
		1d	**1w**		**1d**	**1w**		**1d**	**1w**		**1d**	**1w**
6	38.7	-7.8	-17.8	35.6	-5.6	-12.9	38.5	-2.9	-8.0	43.6	-4.4	-8.9
12	40.2	-0.5	-4.9	39.2	+0.1	-6.5	37.4	-2.2	-2.8	38.8	+0.5	-1.9
18	41.0	+1.9	-3.5	42.1	+1.1	-3.3	41.5	-1.8	-3.8			
24	45.4	+1.9	-3.6	43.3	+2.1	-0.5	41.5	+1.5	-1.3			
						3.75m						
		Δ % vol.			**Δ % vol.**			**Δ % vol.**			**Δ % vol.**	
		1d	**1w**		**1d**	**1w**		**1d**	**1w**		**1d**	**1w**
6	33.9	-7.2	-14.6	38.2	-9.8	-18.5	36.9	-7.1	-7.8	44.9	-1.0	-5.9
12	39.8	-0.9	-2.9	38.3	+1.2	-3.7	36.0	-0.2	-0.5	37.8	+0.1	-3.3
18	41.3	+0.7	-4.3	40.8	+2.3	-3.0	39.6	+0.2	-2.1			
24	42.1	+2.5	+1.1	42.8	+2.0	-2.2	42.5	+0.2	-3.2			

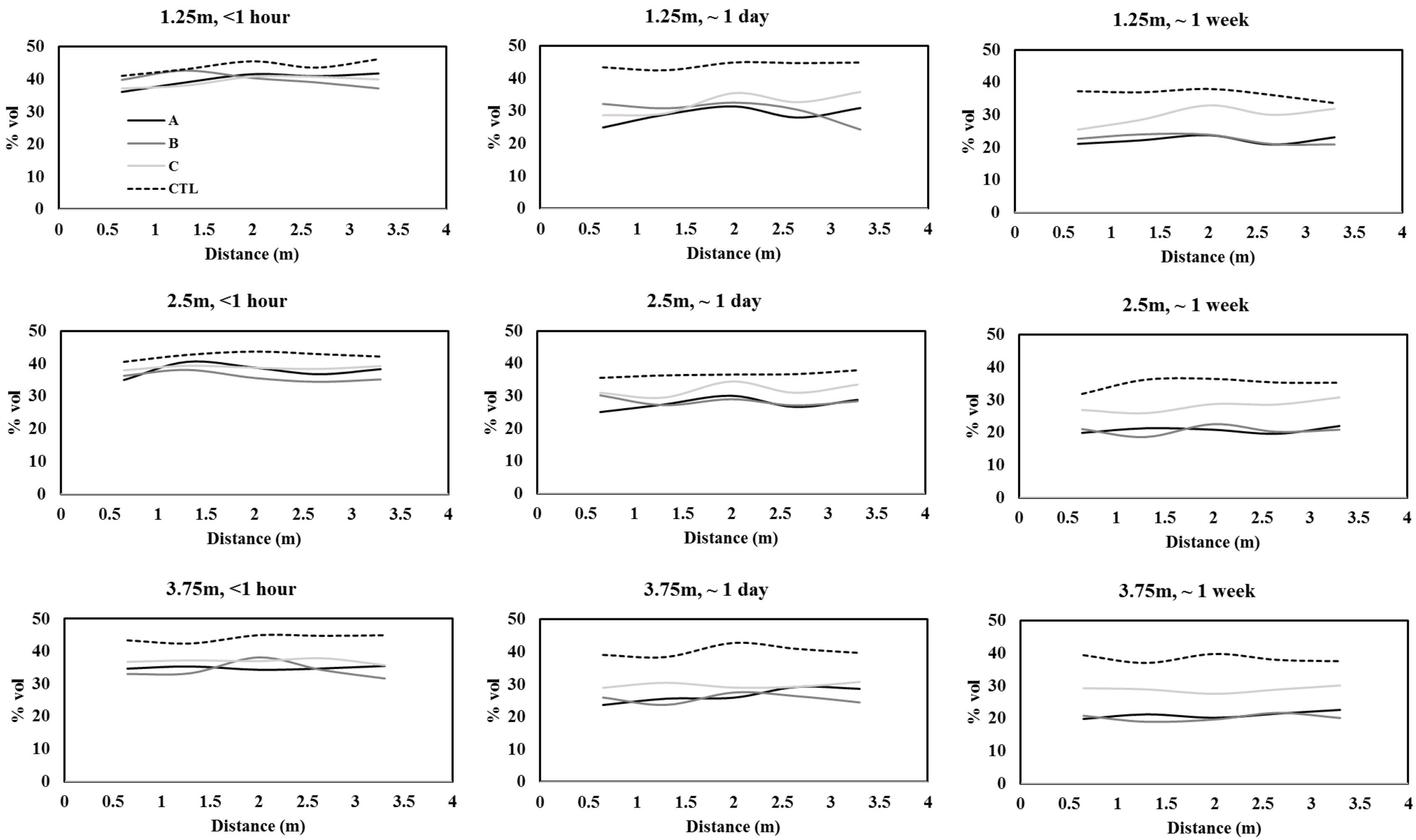

Figure 28. *TRCA Topsoil test plot post-storm soil moisture (% vol.) in upper 6cm by measurement time and distance from gutter. Mean values derived from six storm events. X-axes represent horizontal measurement distances measured from left to right (facing drain).*

5. DISCUSSION

5.1. Soil properties

5.1.1. Organic matter content

From the loss on ignition tests, it was found that soil organic matter from all four plots was well above the TRCA's recommended minimum standard of 5-10% total dry weight (outlined in Table 1). Plots A and B exceed recommendations by approximately 4% and 7% respectively and had the highest %OM overall, as was to be expected due to the additional compost component. %OM in B is somewhat larger than A. Although the same volume of compost was added to each plot, there could have been some variation in the distribution that caused this or too much compost may have been added during test plot construction. Regardless, the difference was relatively minor, falling within 3% of total dry weight. Plots C and the control (CTL) were also similar to one-another, having a difference of only 1% OM by weight. However, this should be expected as the soil came from the same source and had no changes to its composition. Only two samples were taken from each plot (one each from a core). However, there were only very small differences in %OM between each of the samples from the same plot, suggesting soil composition in each plot is likely homogenous and varies by very little. Indeed, the same soil was applied to each plot using the same grading process, notwithstanding the compost additions. The consistently small deviations between the averages of the samples would appear to corroborate these conclusions. In addition, plots A and B had the lowest particle density on average (1.74 g cm^{-3} and 1.69 g cm^{-3}, respectively, versus plots C and CTL's 1.88 g cm^{-3} and 1.9 g cm^{-3}, respectively). It would thus far be reasonable to assume that this is due to the higher OM concentration of the compost-amended plots due to the lower density of OM compared to common soil minerals such as quartz (Rawls, 1983). However, some inconsistences should be noted, which are to be discussed.

5.1.2. Soil density and porosity

Bulk density for all four plots was relatively low, considering 1.5 g cm^{-3} is the recommended limit for bulk density for silt loam (23% sand, 61% silt, 16% clay) according to guidelines by the TRCA (see Figure 29). Bulk density was typically closer to 1 g cm^{-3}, and with plots A and B averaging at <1 g cm^{-3}. This is indeed lower than most post-development urban soil bulk density (for similar soil textures) found in available literature, which typically ranges from 1.2 – 1.5 g cm^{-3}. For example, Legg *et al* found bulk densities in lawn topsoil ranging from 1.1 – 1.6 g cm^{-3} in lawns in Maddison, and Gregory *et al*., (2006) observed post-development bulk densities of approximately 1.5 g cm^{-3}. This low density may have been due to several factors. Indeed, even though the lawns were less than a year old (which would normally imply a more compacted, less porous state), bulk density was closer to that of much older lawns. This low density may have been due to how the soil was deposited into the wooden boxes without the use of vehicles or heavy machinery, which are typically responsible for much of the soil compaction at construction during property construction and development (Gregory *et al*., 2006). Lastly, plot A was tilled when mixed with the compost. Tilling is an effective way of lowering soil bulk density and increasing porosity (Lipiec *et al*., 2006), where soil peds are broken up and more air is mixed into the soil. Plot B had compost blown onto the surface, and although this was only five centimeters in depth, this would have been enough to lower the average soil bulk density below that of plots C and CTL. The higher bulk density of plot CTL soils stands out too, however. Plot C has both the shallowest and densest soil. While speculative, this may have been due to near-surface compaction (likely from footfall) affecting more of the soil column in proportional terms..

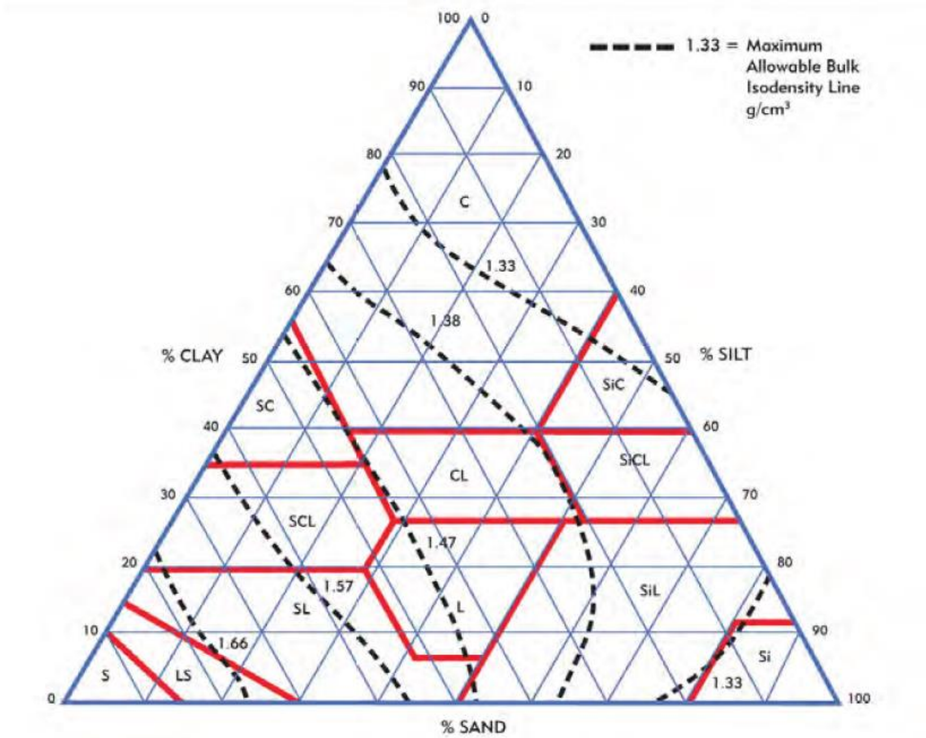

Figure 29. *Maximum allowable bulk densities by soil type. Source: The Sustainable Sites Initiative* in ***Preserving and Restoring Healthy Soil: Plans for Urban Construction*** *(TRC, (2012). Plot un-amended soil composition: 23% sand, 61% silt, 16% clay.*

Porosity was generally not significantly different between the amended plots, but they were significantly more porous than the control. Theoretically higher %OM should increase soil porosity (Boyle *et al*., 1989). It is possible that a degree of porosity in the compost-treated soils was lost due to compaction. A positive correlation between bulk density and porosity exists between the measured samples and bulk density was found to be a statistically significant predictor of porosity in the regression analysis, conforming to what is known about soils of similar texture in existing literature. Little difference existed between plots C and CTL in terms of particle density. Again, being the same soil, this was to be expected. The compost-treated soils showed significantly lower particle density, presumably due to their higher organic matter content. Interestingly, B was the lowest on average and had the least variation. As entire cores were used in the population, particles in the upper 5 cm compost blanket and the lower topsoil were combined, implying the compost blanket was influencing the cores' mean particle density.

However, the cone penetrometer tests do not corroborate the bulk density findings. Rather, plot A would appear to be the most compacted (at 12.55 kg cm^{-2}) and plot CTL the least (at 10.25 kg cm^{-2}). This is despite the control having both the lowest bulk density and porosity. It is important to consider the presence of the sod, however, which would have interfered somewhat with the penetrometer measurements. With this taken into consideration, I suggest that the penetrometer measurements should not be regarded as reliable as the bulk density measurements which included only the soil serve as a better approximation of soil compaction.

5.1.3. Field capacity

Soil from both compost-treated plots exhibited higher field capacities than the un-amended soils, suggesting the addition of the compost improved this characteristic. Particle density and field capacity were negatively correlated, albeit weakly. As low particle density is most likely caused by the presence of organic matter, it would be reasonable to assume that a positive relationship exists between soil OM and field capacity in the samples. There is already a well-established relationship between soil OM and field capacity in existing literature (Hudson, 1994, Saxton & Rawls, 2006). It is peculiar, therefore, that plot A did not demonstrate a similarly high field capacity compared to plot B, despite having a similar concentration of organic matter. It is indeed possible that the vertical distribution of organic matter from the compost affected the cores' field capacities, although this would necessitate further study.

Additionally, although the soil in the control plot was approximately equal to plot C's soil in %OM, and despite being from the same source, the mean FC of the samples were lower and generally more varied. However, the median FC value for plot CTL was within 3% of the plot C median. Additionally, although some prior studies would suggest that higher soil bulk density might yield higher FC (e.g. Hill & Sumner, 1967; Archer & Smith, 1972), there was no apparent correlation detected between bulk density and FC in the samples. Despite these findings, it must be stressed that a degree of experimental error will affect the accuracy of the results, particularly as the maximum sample sizes for the plots were only nine each. Despite efforts made to remove damaged samples, the compaction and alteration of samples during transport and processing may have had impacts on accuracy, as well as the experiments themselves. For example, when the samples were drained to determine FC, a small amount of soil was also lost through the sieve, which may have resulted in an underestimation of FC due to the extra loss of mass. Furthermore, a number of samples had a tendency to deform and clog the lower portions of their containers, alerting the soils' structure. Nevertheless, variation was generally low and anomalous outliers uncommon, implying the probability of a few corrupted or mishandled cores affecting group averages is likely an insignificant issue.

5.1.4 Infiltration

The infiltration tests revealed stark differences between the soil plots which, for the most part, were to be expected based on prior research. The compost blanket showed itself a superior infiltration feature, giving a mean infiltration capacity of 206.1 mm hr^{-1} over a measurement period of approximately 90 minutes. This far exceeds the storm intensities in the PRECIS model under the A1B scenario (see again Figure 1.) The soil-compost blend of plot A also revealed a high mean infiltration rate of 119 mm hr^{-1} over an equivalent measurement period. While significantly lower than plot B, this is again sufficient to accommodate most projected A1B storm intensities. These infiltration rates were also higher than many of the rates observed in previous studies. Woltemade (2010) observed mean infiltration rates of 90 mm hr^{-1} (in lawns older than 10 years), for example, and Hamilton and Waddington (1999) found infiltration rates no higher than 100 mm hr^{-1} in the Wisconsin study. The comparatively high infiltration rates seen in plot A versus plot B would seem to corroborate previous scientific findings. When organic matter (or soil organic carbon) is more concentrated near the surface, higher infiltration rates are observed despite the whole soil column having the same mean %OM content (Franzluebers, 2002). This is owed to the larger, more stable pore spaces of the overlaying compost and with its well-aggregated particles.

Conversely, infiltration rates determined for the lawns not amended with compost (C and CTL) were considerably lower (by more than 100 mm hr^{-1} in the case of plot B), as well as being very similar to one-another, even though the control plot had a significantly higher bulk density. These rates of 33.8 mm hr^{-1} and 30.5 mm hr^{-1} for C and CTL respectively were more akin to the younger lawns measured by Woltemade (2010). Taking into consideration the fact that the lawns were constructed by the TRCA within a year of the experiment, these findings conform to what is known about more recently established lawns and their typical infiltration rates (in the absence of a compost treatment). Something to take into consideration when interpreting the infiltration results however is that slope will have an impact in infiltration rate. The lawn plots were sloped at only 5%, meaning they were close to being level. Infiltration rates of grassed slopes can often decrease considerably as a slope becomes steeper (Pan & Shangguan, 2006; Joshi & Tambe, 2010). This slope effect is mitigated by the presence of denser vegetation, however. The effect slope has on the compost amendment configurations may be a pertinent factor to explore in further studies.

5.1.5. Hydraulic conductivity

The inversed-auger hole tests produce results suggesting each of the plots falls above the expected hydraulic conductivity range for silt loam and more similar to that of loam and sandy loam (~1.3 - 1.6 cm hr^{-1}) (Rawls *et al*., 1982). This may be a result of their low bulk density and %OM. Indeed, the differences observed in hydraulic conductivity would appear to reflect the organic matter content of the soil in each plot, where the compost-treated plots had the higher hydraulic conductivity values. This is consistent with what is well-established in the literature, with organic matter concentration and hydraulic conductivity generally being positively correlated (Hudson, 1994; Saxton & Rawls, 2006). It should be stated however that the organic matter in plot B is mostly concentrated near the surface. The augmented organic matter content in plot B is unlikely to have had a large impact on hydraulic conductivity due to the high-OM compost being situated in the upper 6cm only, with the majority of the soil column reflecting similar %OM to the un-amended soils in plots C and CTL. Additionally, although bulk density is typically negatively correlated with hydraulic conductivity in soils, this was not reflected in the control plot, which, while being the densest, was almost equally as hydrologically conductive as plot B. However, note that one hole in CTL is a notable outlier (hole 3 at 0.007 cm s^{-1}), which may have been due to a local anomaly such as a large macropore (or macropores) in the wall of the auger-hole. Furthermore, plot A, which had the highest hydraulic conductivity value and lowest bulk density (on average, but not significantly so) had the lowest degree of variation between the measured holes (cv=0.05). The differences between holes in the same plot may be due to a number of factors, such as different degrees of compaction of the hole walls caused by disturbances to the PVC pipes, or the uneven presence of large macropores in the soil column. This degree of variation (and some overlapping values) retrospectively justifies the measurement of multiple holes in each plot, but perhaps suggests more holes should have been bored and measured to minimise error. Regardless, doing so would have affected the wider experiment by interfering with the lawns' integrity too greatly. Therefore, these hydraulic conductivity results should be interpreted with a degree of caution.

5.2. Plot flow discharge

Higher volumes of storm input resulted in higher volumes of storm output, which was to be expected as larger volumes of water are flowing into the soils. This varied between the plots, however, due to the different retention performances (although this also varied strongly between individual storm events). Peak plot flow discharge did not correlate well with maximum precipitation intensity or mean precipitation intensity. Peak flow discharge did correlate positively with antecedent soil moisture conditions, suggesting peak discharge from the plots may be predominantly determined by moisture levels rather than the precipitation conditions. It is plausible, therefore, that higher peak discharges are being restricted by the drier soils which were retaining more flow (on average) and minimising higher flow discharge.

There were few discernable patterns between the plots and the measured storm events. The compost-treated plots did not retain more stormwater, which ran counter to expectations. In the 6 storm events used for the soil moisture analysis, the compost-treated plots actually retained *less* stormwater overall compared to the plots without compost. This would suggest that they have failed to perform as suitable amendments for this purpose. Plot A retained the least storm water on average, and the least in 4 of 6 storms.. These results did not appear to corroborate findings from prior research. For example, Harssion *et al* (1997) observed increased time intervals between rainfall and peak flows from the amended soil and a decrease in quickflow discharge. However, although plots A and B did appear to have longer time intervals between rain and peak flows, there were inadequate data to determine this to be significant. Additionally, not only were apparent decreases in flow observed, but the opposite was found – mean flow discharge and peak discharge generally saw an increase, which may have been due to antecedent conditions or unknown factors affecting soil moisture flow.

Notwithstanding plot A's higher hydraulic conductivity, it demonstrated the greatest amount of time to reach peak discharge under storm conditions on average. Only in storm 4 was it not the last to reach peak discharge (or to tie last). The laboratory tests identified mean FC to be no greater overall than the other plots, meaning this was unlikely due to a greater propensity to retain moisture. This assuming the hydraulic conductivity and field capacity analyses were accurate. Nonetheless, there were few storm events during the field season that produced flows large enough to be studied. Most precipitation events – particularly those below 10 mm – did not generate plot flow discharge of sufficient size for the 3L tipping bucket gauges to produce a useful hydrograph if practical resolution.

It must also be kept in mind, however, that the control plot was losing water due to a tear, which is likely exaggerating the 'retained' percentage, as an unknown volume of water is bleeding from the plot before reaching the outflow point. Plot CTL's quantified retention and flow results should therefore be treated with skepticism due to this tear discovered in the liner. For a plot containing a lower volume of soil, having the lowest porosity on average and significantly lower field capacity compared to the other plots, it somehow managed to retain the most stormwater. It would not unreasonable to assume that this impressive performance from a control plot intended to show the shortcomings of thin, denser urban soils was likely due to water being lost through this large tear (despite this, it was able to retain the most moisture at the surface over time, whereas the lower half of the soil column was consistently deprived in comparison – this may suggest drainage of the soil at depth due to the leak, while the moisture above remained held in the soil matrix).

5.2.1. Importance and effects of antecedent moisture

The antecedent moisture conditions measured approximately one day before each storm event appeared to have a noticeable relationship with the retention percentages shown by the plots and appear to be of high importance when predicting plot flow output in storm events. Antecedent moisture conditions were statistically tied to the retention percentages shown by the plots, in that higher mean antecedent moisture conditions yielded lower retention percentages on average – the two were negatively correlated, significantly so as indicated in the regression analysis. This is a logical result, as soil with a larger moisture deficit is capable of holding more water that enters, whereas more saturated soils are unable to accommodate this flow, and the either the moisture already in the soil is ‘pushed’ out via piston flow, or saturated overland flow initiates.

Yet the irregularity of retention performance and discharge patterns cannot be fully explained by the antecedent moisture conditions. While antecedent conditions would appear to explain *general* retention and discharge performance of the plots as together as whole, it may not account for any differences between the plots, particularly as there were too few data to explore relationships in more detail. Therefore, it would be premature to assume that antecedent conditions are unlikely to be responsible for these differences, assuming the plots averages measured are generally accurate. As moisture was only measured at depths along a single, centralised transect, it is possible that measurements failed to account for any lateral differences in the plots.

5.3. Post-storm soil moisture

Spatio-temporal soil moisture trends gave some interesting results. Firstly, plots C and CTL maintained a higher average soil moisture content nearer the surface (as percentage volume) than plots A and B, which become particularly clear the longer the later the measurement period following a storm event. In contrast, plots A and B developed a more pronounced change in soil moisture content with depth over time, having similar profiles to one-another. Both plots A and B lost more moisture at the surface on average over the approximate 1-week measurement period following the storm events. This may have been due to evapotranspiration, percolation, or a combination of the two., but this could not be determined due to a lack of instrumentation. Plot A had the highest measured hydraulic conductivity – therefore it is plausible that it was losing more water at the surface due to the more rapid movement of water through the soil column. Indeed, it withheld the least moisture overall compared to the other plots. Despite this, however, it did not appear to have low enough antecedent moisture conditions to bring its retention performance on par with plots C and CTL (as a lower %vol. of soil moisture had a negative relationship with stormwater retention). Differences in these vertical profiles with distance (1.25, 2.5 and 3.7 5 m from the gutter) were relatively minor. This may have been due to the lack of temporal resolution for the measurement taken with the ThetaProbe, as %vol. may have been equalising before variation could be detected.

On average, plots A and B saw noticeable increases in volumetric soil moisture at depths greater than 6 cm one day after storm events. This coincides with the loss of moisture near the surface, suggesting the gradual downward percolation of water. Additionally, this was less evident in plot C and did not appear to occur in the control (at least not to an extent where at resulted in average gains). This also coincides with the fact these plots maintained higher volumetric surface moisture in the upper 6 cm of the soil column. The combination of these observations between the plots would therefore strongly suggest percolation is the driving cause, although evapotranspiration cannot be discounted as a potentially significant factor. But this was not measured.

5.4 Experiment limitations

Unfortunately, this has demonstrated itself to be an experiment affected by several restrictions and problems. One of the largest limitations of this experiment is that surface runoff – perhaps the area arguable of most concern to managers due to its impacts – was not measured independently. The TRCA designed the soil plot experiment with the primary intention of measuring water *retention,* although throughflow discharge is itself a key component of quickflow, making its measurement important. The experiment also assumes that water is flowing through the soil somewhat evenly. However, given that there was noticeable variation in surface moisture, suggesting an uneven direction of flow from the gutters, it is quite plausible that any unevenness in soil density and stratification below the surface (as a result of soil grading, for example) led to a bias in certain flow pathways that were undetectable.

A further limitation of the experiment was a lack of high-resolution soil moisture data. Although the measurements obtained were useful in assessing the differences in short-term and long-term moisture profiles in the soil, they did not offer insight into the movement of moisture though the soil at shorter time intervals. One set of measurements using the ThetaProbe took approximately 45 minutes to complete. This limits the time resolution of data collection. Additionally, the delay between measurement cycles would make comparisons at specific times between the plots difficult. For example, plots A and CTL would always be at least ~45 minutes apart.

The tipping bucket gauges in the logger houses measuring soil flow discharge were only capable of measuring 3 litres per tip. This resulted in periods of unrecorded flow during times of low flow and a truncated hydrograph. High capacity buckets can be useful when measuring higher discharge as they have a smaller risk of overflowing and under-recording. However, the discharge from each of the plots was very low relative to the capacity and resolution of the equipment. Only on a few occasions was more than one tip per minute recorded in an event. Visible in each of the storm hydrographs are long, frequent periods of no flow discharge recorded at all. Time intervals, although measured every minute by the data loggers, had to be increased to ten minute intervals. However, this again sacrifices the resolution of the measurements. Although zero readings would be minimised, any changes in the rate at which the buckets fill within the extended period would be unidentified. Additionally, there were few storm events during the field season that produced flows large enough to be studied. Most precipitation events – particularly those below 10 mm – did not generate plot flow discharge of sufficient size for the 3L tipping bucket gauges to produce a useful hydrograph of practical resolution.

Perhaps the most serious setback to the experiment occurred upon the discovery of the torn liner in plot CTL. The unexpectedly low flow discharge from the plot was what led to this revelation. The plastic liner had ruptured roughly two-thirds down the left side (facing downslope). Unfortunately, this was not repaired until winter and after the field season had already concluded. The frozen ground and lack of rainfall for the next few months made additional periods of measurement impossible. Therefore, this comparison must make do in comparing the plots *without* the control in terms of flow discharge. All other data, including those concerning soil physical properties, infiltration rates and hydraulic conductivity remain valid, however, as the leak would not affect these. Soil moisture nevertheless may stand to have been affected immensely.

Another point that must be mentioned is that in real-world settings, lawns do not drain through pipes below the ground, nor or they usually sitting upon impermeable substrates. The experiment does not consider the movement of water deeper into the ground, where soil moisture not held by tensile forces percolates into the saturated zone. Therefore, this experiment likely overestimates the lateral flow of water from the bottom of the slope due to the absence of this mechanism. Additionally, stormwater could not accumulate at the foot of the lawn due to being drained by the outflow pipe. In a real-world setting, this water would have accumulated beneath the curb, with the soil become more saturated and potentially initiating saturated overland flow.

5.5. Methods of improvement

It s strongly apparent that several alterations would need to be made to this experiment in order to improve its accuracy and provide more useful information for analysis. For instance, runoff data would have allowed the parameterisation and implementation of the Green-Ampt model, which is used to predict runoff generation. As an example, Legg *et al*. (1996) used this model in their study in Madison, Wisconsin, to determine rainfall-runoff relationships in lawns of varying age. To do so, a runoff coefficient was needed to parameterise the model and create a cumulative runoff curve for statistical use. This required field observations using simulated rainfall and ponding runoff vacuumed from the lawn surface. Several methods could have been used to measure surface runoff as a distinct entity. The vacuuming method employed by Legg *et al* (1996) would be useful for collecting data for runoff coefficients, but not over extended periods of time. Alternatively, gutters installed at the ends of plot – connected to separate tipping bucket gauges and data loggers – could be used.

Installing soil moisture censors in the soil would have been a more ideal option. However, budgetary restraints and the availability of equipment made this option less feasible. Large sections of each lawn would have also required excavation in order to install the sensors, possibly disturbing the TRCA experiment and affecting the structure of the topsoil. However, if sensors were installed during plot construction, their ability to record changes in soil moisture instantaneously in real time would have made high-resolution observations possible, giving a more in-depth insight into the movement of water through the soil. Additionally, *in situ* sensors would have negated the need for access wells and made it more practical to have more measurement locations at different depths. This experiment only accounted for multiple depths along a single transect. It was deemed impractical to add additional wells at every surface measurement location due to the fact this would not only add substantially to the time it would take to measure moisture levels at a single time (which, as discussed, is preferred kept to a minimum), but also because having dozens of wells per 20 m^2 plot would become obtrusive and may adversely affect the TRCA experiment. Figure 30 offers a conceptual example of a setup using this *in situ* approach.

The unexpected behaviour of the plots when producing flow may warrant a means of investigating whether stormwater is bypassing areas of the soil matrices through certain pathways, either created through erosion or through some fault in construction. Chemical tracers such as sodium chloride (NaCl) or dyes could also be used to track the flow of water through the soil and identify preferential flow pathways through the plots. Additionally, dyes can be used to trace and map macropores and significant flow channels (Edwards *et al*., 1998)

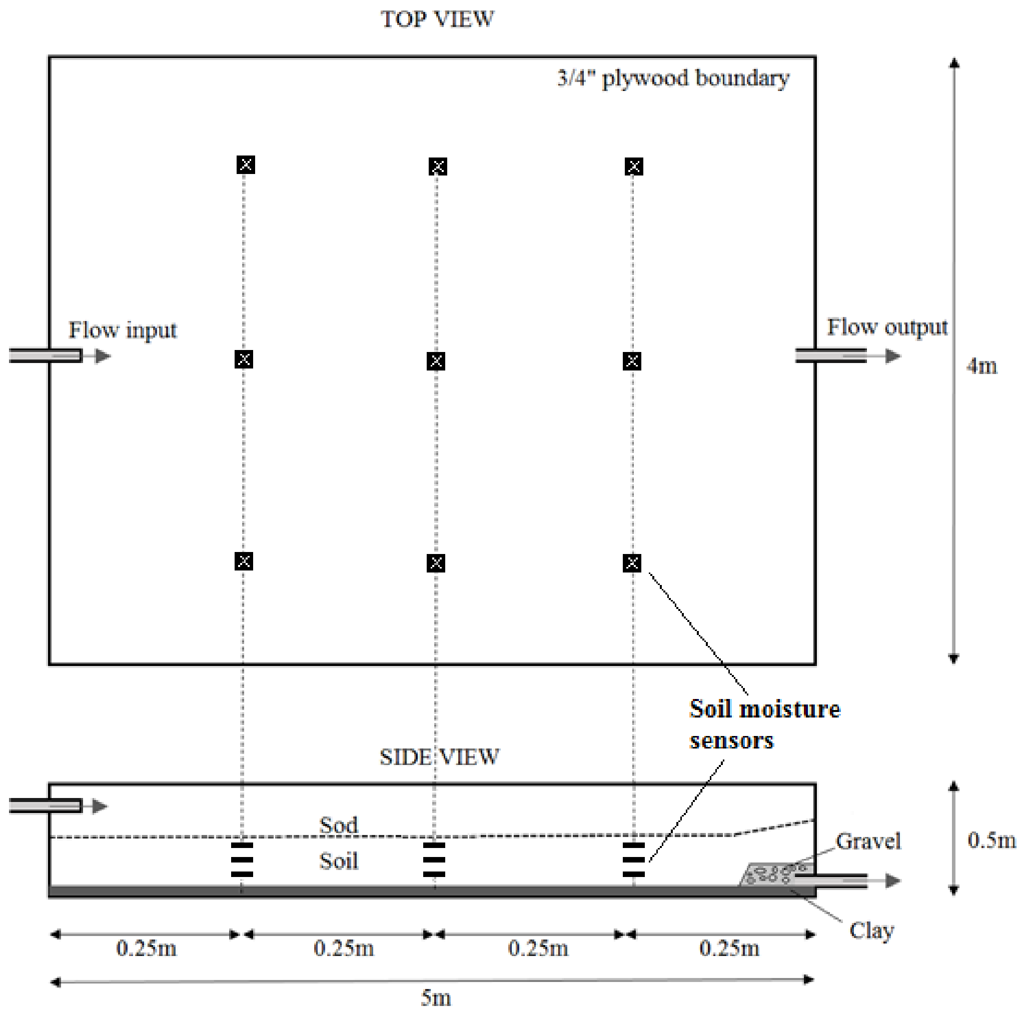

Figure 30 *Diagram of conceptual modifications of the TRCA topsoil test plots at the Kortright Centre for Conservation showing the addition of in-situ soil moisture censors. Diagram not to scale.*

Evaporation was not measured from the plots and can only be inferred through an approximated water balance using measured inputs, outputs, and changes in soil moisture. However, the spatial and temporal limitations to the measurement of moisture storage limited this approach greatly (particularly when considering some of the substantial variability in moisture between the few locations covered). Measuring evaporation from the plots could have provided additional and more accurate insight into the movement of water and would permit the calculation of an accurate water balance. A straightforward method would be using an evaporation pan, which is cheaper and simpler to construct. Nevertheless, evaporations pans will only measure potential evaporation due to the lack of soil and vegetation. They do provide an approximation, however. An installation of a small weighing lysimeter in each plot, however, would provide and accurate measure of evapotranspiration from the lawn surface. Lysimeters have been used successfully in the past to measure evapotranspiration from lawns and calculate water and energy budgets (Suckling, 1980, Feldhake *et al*., 1983), and offer a more accurate measure than evaporation pans, and generally at a lower cost than other techniques such as reverse eddy correlation.

Finally, an additional factor to be considered when interpreting the results of this experiment is that the un-amended soil was already of high quality and met TRCA standards. It must be stressed that the same cannot be said for all soils beyond this experiment, particularly those in urban environments which may often be severely deprived of organic matter (Legg *et al.*, 1996; TRCA, 2012). Should this experiment have been performed with lower quality soils with OM <5%, the two compost configurations may have fared differently. Notably, plot B would have had a more extreme OM gradient. Use of soils lower in organic matter may show the compost configurations to be more significant than they were in how they changed the soil physical characteristics and plot performances in the storm quickflow test.

5.6. Avenues for further study

Despite certain drawbacks, there is a potential for additional opportunities that could augment the TRCA experiment (or a new experiment). For example, the possibility of using forward modeling and estimating quickflow discharge in suburban-dominated sub-catchments. Data gained from this experiment (or later versions of it, with the aforementioned recommendations implemented) would be useful in model parametrisation. Mueller and Thompson (2009), for example, used infiltration data from lawns in Wisconsin in a stormwater interception model to good effect. But perhaps the most informative way to test these configurations would be to implement them in real residential developments. Measurements can than be taken from lawns under real-world conditions, and changes in quickflow discharge from entire streets or neighbourhoods could be measured. However, as it was the TRCAs intention to showcase the potential benefits of compost amendment to developers with the plot experiment, it would be more proper to continue to test compost configurations using more advanced and informative analytical methods under controlled conditions before approaching potential stakeholders.

5.6.1. Storm simulation

The TRCA did not design the experiment with the implementation of simulated rainfall. Although the gutters could supply water from the storage cistern, the results of these experiments do not reflect natural conditions. For example, water from the gutter would be flowing onto a lawn less saturated than would be expected during rainfall. Thus, the lawn would be able to accommodate more water, and discharge output would be comparatively low and unrepresentative. Additionally, antecedent moisture conditions play a crucial role in runoff generation (due to the potential generation of saturated overland flow, effects on hydraulic conductivity, etc.). If the soil moisture conditions created by rainfall, which would be expected under natural conditions, would make any runoff observations unrepresentative if rainfall was absent as a factor. However, including simulated rainfall would increase accuracy and create more representative simulated storm scenarios. Rainfall could be simulated over the plots in a number of ways. The simplest method would involve holed containers suspended above the lawns serving as crude sprinklers. This method was used by Balousek (2003), for example. Simply using larger holes would simulate more intense rainfall. A more sophisticated method would be to use a dedicated rainfall simulator system like the Norton Rainfall simulator used by Faucette *et* al. (2005). This would be less labour intensive (as containers would not need to be routinely filled) and allow more convenient timing.

5.6.2. Stable isotopes and chemical tracers

Stable isotopes have been used to track the movement of 'old water' through soils and determine the contribution of pre-event water to storm quickflow discharge (Pierce et al, 1986; Sklash *et al*., 1986; Buttle, 1994). Isotopes oxygen-18 (^{18}O) and deuterium (D) in water molecules are present in different ratios and concentrations in a sample depending on the water's source (e.g. a specific rainfall event). A delta notation (δ) is calculated by making a comparison with a universal standard (the Vienna Standard Mean Ocean Water or 'VSMOW,' for example), with the ± per-mil (‰) deviation from that standard defining the delta value of that particular sample. By measuring quantities of oxygen-18 and deuterium in water samples from throughflow or in soil moisture and making comparisons with rainwater samples, both the relative 'age' and source of this water can therefore be identified. This has been used to great effect in past hydrological research, particularly in hillslope hydrology. 'New water' – or in other words water from the most recent rainfall event – is sometimes found to be only a minor contributor to throughflow discharge and streamflow (Pierce et al, 1986; Sklash *et al*., 1986). Oftentimes much of the flow discharge from the soil is old water being forced out via piston flow and through macropores, which is usually why stream discharge appears unusually quick to respond to rainfall events in the absence of substantial rainfall intensity and surface runoff (Mosley; 1979; McDonnell, 1990). By using stable isotopes, more accurate and insightful observations about this water's origins, residence times and pathways can be made.

This would be of particular use in future experiments involving topsoil amendment, either in plot-based experiments such as the TRCA experiment, or at a greater scale, examining multiple lawns and their stormflow contributions to the catchment. In the TRCA experiment, stable isotope analysis could be used to determine the residence time of soil moisture in each plot by measuring $\delta^{18}O$ and δD in the plot outflow. Additionally, moisture samples could be taken *in situ* in different spatial configurations through autosampling to accurately measure both percolation and throughflow rates (although dyes and other chemical tracers may also be used here) while simultaneously tracing their most significant sources. The *in situ* measurements of soil moisture as a percentage of soil volume proved useful in identifying where water was more likely to remain and gave rough estimates of change in storage and residence times. Regardless, this method was not capable of distinguishing 'old' and 'new' water and was also unable to identify flow pathways. Therefore, the use of stable isotope analysis would provide an enormous advantage and improvement, but would required the use of much more specialised equipment (financial budget must again be considered)

6. CONCLUSION AND RECOMMENDATIONS

6.1. Conclusions

The results of the experiments indicate that each lawn's soil configuration meets TRCA-recommended guidelines. Surface compaction, bulk density, and organic matter content were all within those standards outlined in the TRCA's 2012 *Preserving and Restoring Healthy Soil: Plans for Urban Construction* publication. It may therefore be concluded that either lawn topsoil configurations A, B or C would be sufficient for implementation in future developments based on TRCA criteria alone. The control (CTL) would not, however, as it does not meet minimum depth standards by design. This is despite the fact it managed to meet all other TRCA standards. This thesis has reached the following conclusions based on the hypotheses outlined in chapter 1:

1. *"Compost-amended lawn topsoil will have significantly higher infiltration capacities versus the un-amended topsoil."* This hypothesis is <u>supported.</u> The compost amended lawns demonstrated surface infiltration rates several times higher than the soils not treated with compost, and was statistically significant. Additionally, plot B (with the 5 cm compost blanket) was the highest overall, surpassing the other compost-treated runner-up, plot A.

2. *"Topsoil blended with compost will have higher hydraulic conductivity than the un-amended plots."* This hypothesis is <u>supported</u>. The hydraulic conductivity of plot A (topsoil blended with compost) demonstrated significantly higher hydraulic conductivity than the other plots on average. Indeed, k values obtained from plot A were closer to those that would be expected of loam or sandy loam (the soil prior to treatment was classified as silt loam).

3. *"Compost-amended plots will have higher field capacities versus the control plot."* This hypothesis is supported. In the laboratory tests of extracted soil cores, soil from both plot A and plot B demonstrated field capacities significantly greater than the control, which had the lowest of the plots. Plot B had the highest mean FC overall, and was significantly greater than A.

4. *"Compost-amended plots will retain significantly more stormwater than the un-amended plots."* This hypothesis is rejected. Plots not amended with compost retained more stormwater on average and in most of the measured storm events.

5. *"Compost-amended plots will have lower mean flow discharge versus un-amended plots."* This hypothesis is rejected. The compost-treated plots did not produce significantly lower flows. However, it must be remembered that the control plot was leaking during the experiment. The extent of the water lost to leakage is unknown.

6. "*Compost-amended plots will have significantly higher volumetric moisture contents compared to the un-amended plots 24 hours after a storm event."* This hypothesis is rejected. Plots A and B did not have significantly higher volumetric moisture contents when measured approximately one day and one week following an event. In fact, they had marginally lower volumetric water content on average compared to the plots without compost, which maintained higher moisture levels over time, suggesting greater long-term retention, particularly nearer the surface. However, this may have implications concerning surface runoff generation (which was not measured).

Unfortunately, the rupture discovered in the liner of plot CTL by TRCA staff has rendered it unreliable for accurate comparison due to high uncertainty concerning the volume of water that was potentially lost. Results seemed to suggest that the control was producing the lowest flows and retaining the most stormwater. Considering the volume of soil and its physical characteristics, however, it is unlikely its deceptively strong performance did not go unaided by a leak. Regardless, a slightly more reliable comparison could still be made available between the amended plots. Additionally, other soil attributes measured in this study, such as bulk density, hydraulic conductivity and infiltration rate, would not have been affected.

Despite the resolution of data leaving more to be desired, there was a demonstration of the potential benefit in measurement of soil moisture within each plot. Antecedent moisture conditions were shown to be a significant factor when predicating plot flow discharge and moisture retention. Indeed, this appeared to play a more deterministic role in these areas than precipitation. Even so, the extent to which antecedent moisture conditions correlated with these factors varied largely between the plots, therefore it must be assumed that other, undetermined factors were influencing the results, such as macropores and preferential flow channels, uneven substrates, etc. Additionally, the compost-amended plots were found to lose more surface moisture over time. These soil moisture findings permitted a supplemented interpretation of the studied storms, and gave some useful insight into where moisture was concentrating with time. It was clear that plots C and control maintained relatively high volumes of moisture near the surface over time compared to the compost-treated plots. However, few trends were observed horizontally and longitudinally. Nevertheless, it should not be assumed that the spatio-temporal progression of moisture through the plots was similar. This may necessitate the use of more sophisticated techniques to measure moisture over space and time, as the manual method of moisture measurement limited temporal and spatial resolution.

There were indeed a number of drawbacks to this experiment that limited the extent to which the results can be relied upon. The lack of large storms over the field season posed a challenge, as there were fewer than a dozen events large enough to produce flows from the plots which the 3L tipping bucket gauges could precisely register. Other apparent methodological limitations of the experiment included the spatial and temporal resolution of the soil moisture measurements which prevented a potentially more in-depth analysis of plot flows, no means of measuring evapotranspiration, and no means of disguising surface runoff from through flow in the plot flow outputs. Additionally, it would be beneficial to measure hydraulic conductivity and field capacity using more sophisticated methods in order to improve accuracy.

6.2. Recommendations

Thee following methods should be used to improve accuracy and permit more detailed comparison:

1. Include a means of measuring surface runoff as a distinct component of quickflow.
2. Use automated soil moisture censors to record data instantaneously at higher temporal and spatial resolutions.
3. Implement a means of measuring evapotranspiration from the plots.

It would also be pertinent to explore other factors such as slope, and whether conditions change with the use of seeded grass instead of sod. The use of smaller-capacity tipping bucket gauges would permit the measurement of low flows with greater precision. Additionally, it would be more useful to conduct the experiment using soils which *do not* meet recommended guidelines. While this experiment was useful in identifying changes the addition of compost can have, there would be more justification in using poor quality soil in the increased depth and control plots. This would better illustrate the potential drawbacks of soil falling below %OM and bulk density requirements and properly gauge if the compost application can make beneficial differences under the scenario originally intended. Lastly, a greater number of storm events need to be analysed in order to increase the statistical power of the results and provide a larger database to make multiple comparisons. This may take several years, however.

Despite failing to demonstrate the retention and quickflow inhibition capabilities desired, the B configuration has an advantage in that it is the simplest to apply and maintain. Compost degrades with time and %OM gradually decreases as it is metabolised. This means compost will need to be added to the soil again after several years to maintain the desired OM levels and keep to standards. The A configuration would require the entire 30c m topsoil column be tilled for additional compost to be tilled in, which requires more labour, more equipment (such as rototillers), and therefore increases the costs. Macropores that have established themselves in the soil over the years (see Legg *ett al*., 1996 and Woltemade, 2000) would be lost when the soil is disturbed and regraded. However, the B configuration would require only an additional layer of compost be applied to the surface after stripping the turf, which may then be re-lain. This saves the property owner both time and money. Additionally, the underlying 25 cm of topsoil would go undisturbed. Coupled with the impressive infiltration rates observed, it is this authors opinion that, despite limited performances in the plot flow experiment and the need for more data, the method of applying compost directly to the surface may have the greatest potential as method of increasing surface permeability within increasingly urbanised catchments.

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APPENDIX

***A1.** Storm intensity-duration-frequency (IDF) curves for: [43.9059, -79.3672] 1960 – 1990, 2015 – 2045, 2035 – 2065, and 2065 – 2095 using the PRECIS model under the IPCC A1B emission scenario, P50. University of Regina, 2014.*

Time period	**Freq. (Years)**	**Duration (mins)**								
		5	10	15	30	60	120	360	720	1440
		Intensity (mm hr-1)								
1960-1990	2	60.29	47.65	40.05	28.22	18.93	12.32	6.05	3.82	2.41
	5	86.4	68.98	58.18	41.01	27.32	17.55	8.37	5.19	3.21
	10	105.02	83.81	70.55	49.51	32.89	21.02	9.91	6.09	3.73
2015-2045	2	71.25	56.81	47.82	33.59	22.58	14.75	7.17	4.5	2.81
	5	109.8	87.99	74.06	51.51	33.96	21.66	10.23	6.25	3.79
	10	136.39	108.91	91.44	63.36	41.47	26.19	12.16	7.41	4.47
2035-2065	2	69.91	55.45	46.78	33.26	22.59	14.91	7.5	4.57	2.77
	5	109.18	87.98	74.66	53.18	35.77	23.19	10.95	6.58	3.94
	10	135.88	109.66	93.07	66.19	44.34	28.58	13.22	7.91	4.71
2065-2095	2	81.37	63.64	53.22	37.32	25.02	16.33	8.07	5.13	3.26
	5	130.84	103.65	87.08	61.07	40.58	26.06	12.47	7.71	4.7
	10	163.44	130.1	109.5	76.84	50.91	32.52	15.32	9.22	5.52

***A2.** Soil sample raw data with sample bulk density, porosity, field capacity, and particle density individual calculated values. Derived from cores taken from TRCA topsoil test plots at the Kortright Centre for Conservation*

Plot	**Sample**	**Vol (cm^3)**	**M_{sat} (g)**	**$M_{drained}$ (g)**	**M_{dried} (g)**	**ρ_B (g cm^{-3})**	***f* (%)**	**FC (%0**	**ρ_P (g cm^{-3})**
A	A1	-	-	-	-	-	-	-	-
A	A2	55.99	73.02	51.70	38.54	0.69	61.58	38.17	1.79
A	A3	-	-	-	-	-	-	-	-
A	A4	77.80	113.26	95.08	76.08	0.98	47.79	51.10	1.87
A	A5	76.93	103.82	89.11	70.82	0.92	42.90	55.42	1.61
A	A6	64.53	91.30	78.72	65.08	1.01	40.63	52.04	1.70
A	A7	57.89	82.69	65.18	52.89	0.91	51.49	41.23	1.88
A	A8	76.08	101.97	86.28	68.10	0.90	44.52	53.67	1.61
A	A9	72.21	101.32	84.72	68.62	0.95	45.28	49.24	1.74
B	B1	57.08	79.40	65.47	48.05	0.84	54.92	55.57	1.87
B	B2	80.98	111.80	96.43	75.28	0.93	45.10	57.91	1.69
B	B3	77.59	106.90	91.85	75.92	0.98	39.93	51.42	1.63
B	B4	72.93	99.10	86.21	65.04	0.89	46.70	62.16	1.67
B	B5	84.87	113.10	95.89	74.22	0.87	45.81	55.74	1.61
B	B6	85.84	117.20	101.50	80.18	0.93	43.13	57.59	1.64
B	B7	77.61	102.90	88.09	67.30	0.87	45.87	58.40	1.60
B	B8	75.38	102.10	81.55	62.36	0.83	52.72	48.29	1.75
B	B9	74.22	100.80	84.34	67.10	0.90	45.41	51.16	1.66

C	C1	64.62	96.12	81.01	67.43	1.04	44.40	47.34	1.88
C	C2	73.78	108.98	88.33	78.15	1.06	41.78	33.02	1.82
C	C3	66.30	98.40	81.16	64.47	0.97	51.18	49.19	1.99
C	C4	61.65	90.40	72.08	59.75	0.97	49.72	40.23	1.93
C	C5	84.37	121.13	100.40	82.63	0.98	45.63	46.16	1.80
C	C6	70.61	103.05	83.90	70.43	1.00	46.20	41.28	1.85
C	C7	59.69	88.13	71.00	58.04	0.97	50.41	43.07	1.96
C	C8	69.47	102.85	84.44	69.00	0.99	48.73	45.61	1.94
C	C9	70.03	101.10	86.11	74.82	1.07	37.53	42.96	1.71
CTL	CTL1	34.09	51.99	45.60	39.81	1.17	35.73	47.54	1.82
CTL	CTL2	36.64	54.71	47.32	41.18	1.12	36.93	45.38	1.78
CTL	CTL3	35.89	55.94	46.46	41.41	1.15	40.48	34.76	1.94
CTL	CTL4	40.78	64.10	50.10	45.22	1.11	46.30	25.86	2.07
CTL	CTL5	39.50	60.22	51.74	44.49	1.13	39.82	46.07	1.87
CTL	CTL6	35.75	54.69	46.44	40.89	1.14	38.60	40.18	1.86
CTL	CTL7	-	-	-	-	-	-	-	-
CTL	CTL8	36.36	53.63	41.68	35.68	0.98	49.37	33.41	1.94
CTL	CTL9	-	-	-	-	-	-	-	-

A3. *Soil sample data obtained from the loss on ignition test. Derived from cores taken from TRCA topsoil test plots at the Kortright Centre for Conservation*

Sample	Crucible (g)	Unburned total (g)	Burned total (g)	Unburned soil (g)	Burned soil (g)	Loss (g)	OM (%)
A2	27.7391	48.2093	46.5501	20.4702	17.7713	2.6990	13.18
A7	26.3967	50.2935	48.5791	23.8968	20.3353	3.5615	14.90
B2	28.7047	48.619	47.2205	19.9143	17.8900	2.0243	10.17
B2T	26.6167	38.3878	36.7674	11.7711	8.1522	3.6189	30.74
C1	27.4735	48.7269	47.3628	21.2534	19.2148	2.0386	9.59
C5	27.3724	49.8616	48.422	22.4892	20.2971	2.1921	9.75
CTL4	28.099	49.068	47.7386	20.969	19.1576	1.8114	8.64
CTL5	28.1447	48.4141	47.6557	20.2694	18.6055	1.6640	8.21
B9	26.9637	49.216	47.728	22.2523	20.1861	2.0662	9.29

A4. *TRCA topsoil test plot double-ring infiltration test results. Inner ring ID = 21.2mm. Tests performed and raw data provided by TRCA staff.*

Plot	t (mins)	t interval (min)	Inner H(cm)	Inner Water Added (cm)	Volume of Inner Water Added (cm3)	Incremental Infiltration Velocity (mm/hr)	Cumulative infiltration (mm)
A	0		10	0			0
	5	5	9	1	440	149.7	10
	10	5	9.4	0.6	280	95.2	16
	15	5	9.3	0.7	360	122.4	23
	20	5	9.3	0.7	320	108.8	30
	25	5	9.1	0.9	580	197.3	39
	30	5	9.4	0.6	300	102.0	45
	35	5	9.1	0.9	420	142.9	54
	40	5	9.4	0.6	270	91.8	60
	45	5	9.2	0.8	350	119.0	68

	50	5	9.2	0.8	340	115.6	76
	55	5	9.2	0.8	360	122.4	84
	60	5	9.2	0.8	360	122.4	92
	65	5	9.3	0.7	300	102.0	99
	70	5	9.2	0.8	350	119.0	107
	75	5	9.4	0.6	300	102.0	113
	80	5	9.3	0.7	330	112.2	120
	85	5	9.3	0.7	320	108.8	127
	90	5	9.3	0.7	320	108.8	134
B	0		10	0			0
	5	5	9.5	0.5	250		5
	10	5	8.5	1.5	700	238.1	20
	15	5	8.7	1.3	600	204.1	33
	20	5	8.8	1.2	600	204.1	45
	25	5	8.8	1.2	600	204.1	57
	30	5	8.6	1.4	600	204.1	71
	35	5	8.5	1.5	650	221.1	86
	40	5	8.5	1.5	650	221.1	101
	45	5	8.5	1.5	650	221.1	116
	50	5	8.5	1.5	600	204.1	131
	55	5	8.5	1.5	650	221.1	146
	60	5	8.6	1.4	550	187.1	160
	65	5	8.5	1.5	600	204.1	175
	70	5	8.5	1.5	600	204.1	190
	75	5	8.6	1.4	550	187.1	204
	80	5	8.6	1.4	550	187.1	218
	85	5	8.8	1.2	500	170.1	230
C	0	10	10	0			0
	10	10	9.2	0.8	120	20.4	8
	20	10	9.4	0.6	250	42.5	14
	30	10	9.5	0.5	200	34.0	19
	40	10	9.5	0.5	150	25.5	24
	50	10	9.4	0.6	220	37.4	30
	60	10	9.5	0.5	200	34.0	35
	70	10	9.5	0.5	200	34.0	40
	80	10	9.4	0.6	250	42.5	46
CTL	0		10	0	0		0
	10	10	9.5	0.5	220	37.4	5
	20	10	9.6	0.4	170	28.9	9
	30	10	9.7	0.3	140	23.8	12
	40	10	9.6	0.4	170	28.9	16
	50	10	9.6	0.4	190	32.3	20
	60	10	9.6	0.4	200	34.0	24
	70	10	9.6	0.4	180	30.6	28
	80	10	9.7	0.3	165	28.1	31
	90	10	9.6	0.4	200	34.0	35

A5. *Raw data from reverse Auger Method tests performed on TRCA topsoil test plots at the Kortright Centre for Conservation*

	A						B					
t	**Hole 1**		**Hole 2**		**Hole 3**		**Hole 1**		**Hole 2**		**Hole 3**	
(mins)	**Ht**	**Ht+r/2**	**Ht**	**Ht+r/2**	**Ht**	**Ht+r/2**	**Ht**	**Ht+r/2**	**Ht**	**Ht+r/2**	**Ht**	**Ht+r/2**
0	18	19.3	18	19.25	18	19.25	18.0	19.25	18	19.25	18	19.25
1	17.3	18.6	17.2	18.45	17.2	18.45	17.0	18.28	17.3	18.55	17.1	18.35
2	16.5	17.8	16.6	17.85	16.5	17.75	16.2	17.42	16.5	17.75	16.2	17.45
3	16	17.3	16	17.25	16	17.25	15.5	16.77	16	17.25	15.7	16.95
4	15.4	16.7	15.4	16.65	15.4	16.65	14.7	15.98	15.4	16.65	15	16.25
5	15	16.3	15	16.25	15.1	16.35	14.3	15.60	15	16.25	14.5	15.75
7	14.2	15.5	14.3	15.55	14.5	15.75	13.7	14.97	14.2	15.45	13.9	15.15
9	13.2	14.5	13	14.25	13.5	14.75	12.7	13.94	13.2	14.45	13.1	14.35
13	11.9	13.2	11.3	12.55	12.2	13.45	11.8	13.04	11.6	12.85	12	13.25
17	10.7	12.0	9.9	11.15	11.1	12.35	10.8	12.09	10.3	11.55	11	12.25
21	9.3	10.6	8.5	9.75	10	11.25	10.0	11.25	8.9	10.15	9.8	11.05
25	8.1	9.4	7.1	8.35	9	10.25	9.2	10.43	7.9	9.15	8.8	10.05
29	6.9	8.2	5.8	7.05	7.8	9.05	8.3	9.57	6.6	7.85	7.8	9.05
33	5.7	7.0	4.6	5.85	6.9	8.15	7.4	8.65	5.7	6.95	7.2	8.45
37	4.7	6.0	3.6	4.85	6	7.25	6.5	7.75	4.9	6.15	6.7	7.95
41	3.7	5.0	3	4.25	5.1	6.35	5.9	7.17	4.5	5.75	6	7.25
45	3	4.3	2.8	4.05	4.5	5.75	5.4	6.65	4.2	5.45	5.5	6.75
49	2.5	3.8			3.8	5.05	5.2	6.42			5	6.25
53	2.2	3.5			3.1	4.35	4.9	6.15			4.6	5.85
57					2.5	3.75	4.5	5.75			4	5.25
61	18	19.3	18	19.25	18	19.25						

	C							CTL					
t (mins)	**Hole 1**		**Hole 2**		**Hole 3**		**t (mins)**	**Hole 1**		**Hole 2**		**Hole 3**	
	Ht	**Ht+r/2**	**Ht**	**Ht+r/2**	**Ht**	**Ht+r/2**		**Ht**	**Ht+r/2**	**Ht**	**Ht+r/2**	**Ht**	**Ht+r/2**
0	18	19.25	18	19.25	18	19.25	0	6	7.25	6	7.25	6	7.25
1	17.3	18.55	17.2	18.45	17	18.25	1	5.6	6.85	5.5	6.75	5.5	6.75
2	16.6	17.85	16.6	17.85	16.3	17.55	2	5.4	6.65	5.4	6.65	5.3	6.55
3	16.2	17.45	16	17.25	15.5	16.75	3	5.2	6.45	5.2	6.45	5.2	6.45
4	15.8	17.05	15.2	16.45	15	16.25	4	4.9	6.15	4.9	6.15	5	6.25
5	15.3	16.55	14.8	16.05	14.6	15.85	5	4.7	5.95	4.8	6.05	4.7	5.95
7	14.7	15.95	14	15.25	14	15.25	7	4.5	5.75	4.6	5.85	4.3	5.55
9	14	15.25	13.2	14.45	13	14.25	9	4.3	5.55	4.3	5.55	4	5.25
13	13.2	14.45	12.1	13.35	12	13.25	11	4	5.25	3.9	5.15	3.5	4.75
17	12.3	13.55	11.1	12.35	11	12.25	13	3.8	5.05	3.7	4.95	3.2	4.45
21	11.5	12.75	10.2	11.45	10.1	11.35	15	3.7	4.95	3.5	4.75	2.9	4.15
25	10.7	11.95	9.7	10.95	9.3	10.55	17	3.6	4.85	3.3	4.55	2.8	4.05
29	10	11.25	8.4	9.65	8.6	9.85	19	3.5	4.75	3.2	4.45		
33	9.2	10.45	7.6	8.85	8	9.25	21	3.4	4.65	3.1	4.35		
37	8.7	9.95	6.8	8.05	7.2	8.45	23			3	4.25		
41	8	9.25	6	7.25	6.6	7.85	25			2.9	4.15		
45	7.5	8.75	5.4	6.65	6.2	7.45	27			2.8	4.05		
49	7.2	8.45	4.9	6.15	5.8	7.05							
53	7	8.25	4.5	5.75	5	6.25							
57	6.6	7.85	4	5.25	5.6								
61	6.5	7.75											

A6. *Cone penetrometer test results from the TRCA topsoil test plots at the Kortright Centre for Conservation.*

	Plot		
A	**B**	**C**	**CTL**
	Lbs		
208.3753	192.869	131.79319	102.9958
209.95758	169.7678	138.43875	154.578
211.2234	130.8438	160.27414	151.4134
180.84372	155.5273	179.5779	130.5274
174.51462	119.7679	144.45139	153.3121
206.79303	125.7805	185.907	167.8691
156.47668	132.4261	179.5779	140.3375
104.57806	195.7171	153.62859	187.4893
153.62859	177.3627	146.66658	123.8818

A7. *Precipitation data form the Kortright Centre for Conservation for storms 1-6*

Time	**Storm 1 08-Jun 1:45:00 AM**		**Storm 2 16-Jun 3:40:00 AM**		**Storm 3 27-Jun 2:55:00 PM**		**Storm 4 10-Aug 1:25:00 PM**		**Storm 5 20-Aug 3:55:00 AM**		**Storm 6 19-Sep 2:40:00 PM**	
(mins)	**mm**	**mm hr^{-1}**	**mm**	**mm hr^{-1}**	**mm**	**mm hr^{-1}**	**mm**	**mm hr^{-1}**	**mm**	**mm hr^{-1}**	**mm**	**mm hr^{-1}**
0	-	-	-	-	-	-	-	-	-	-	-	-
5	0.8	9.6	0.2	2.4	0.2	2.4	0.6	7.2	0.6	7.2	0.8	9.6
10	3.0	36.0	0.2	2.4	0.0	0.0	0.6	7.2	0.6	7.2	3.8	45.6
15	0.4	4.8	0.4	4.8	0.2	2.4	0.6	7.2	0.4	4.8	2.8	33.6
20	0.2	2.4	0.8	9.6	0.4	4.8	0.8	9.6	0.0	0.0	1.2	14.4
25	0.2	2.4	0.4	4.8	0.4	4.8	0.2	2.4	0.0	0.0	0.4	4.8
30	0.6	7.2	0.2	2.4	0.6	7.2	0.4	4.8	0.0	0.0	0.2	2.4
35	0.2	2.4	0.0	0.0	0.4	4.8	0.4	4.8	0.0	0.0	0.0	0.0
40	0.6	7.2	0.4	4.8	0.6	7.2	0.4	4.8	0.0	0.0	0.0	0.0
45	0.2	2.4	0.2	2.4	0.2	2.4	0.6	7.2	0.0	0.0	0.2	2.4
50	0.4	4.8	0.4	4.8	0.4	4.8	0.4	4.8	0.0	0.0	0.0	0.0
55	0.4	4.8	1.0	12.0	0.6	7.2	0.4	4.8	0.0	0.0	0.0	0.0
60	0.2	2.4	0.6	7.2	1.0	12.0	1.0	12.0	0.0	0.0	0.0	0.0
65	0.0	0.0	0.6	7.2	0.8	9.6	0.8	9.6	0.0	0.0	0.0	0.0
70	0.2	2.4	0.4	4.8	0.6	7.2	0.2	2.4	0.0	0.0	0.0	0.0
75	0.6	7.2	0.4	4.8	0.6	7.2	0.6	7.2	0.0	0.0	0.0	0.0
80	0.2	2.4	0.0	0.0	0.2	2.4	0.6	7.2	0.8	9.6	0.0	0.0
85	0.2	2.4	0.4	4.8	0.6	7.2	0.6	7.2	8.4	100.8	0.0	0.0
90	0.4	4.8	0.0	0.0	0.2	2.4	0.8	9.6	2.6	31.2	0.0	0.0
95	0.4	4.8	0.0	0.0	0.8	9.6	0.8	9.6	1.4	16.8	0.0	0.0
100	0.2	2.4	0.6	7.2	0.6	7.2	0.4	4.8	0.2	2.4	0.2	2.4
105	0.4	4.8	1.8	21.6	0.4	4.8	0.6	7.2	0.2	2.4		
110	0.0	0.0	2.0	24.0	0.6	7.2	0.0	0.0	0.0	0.0		
115	0.0	0.0	0.2	2.4	0.2	2.4	0.2	2.4	0.0	0.0		
120	0.2	2.4	0.6	7.2	0.2	2.4	0.0	0.0	0.0	0.0		
125	0.0	0.0	0.2	2.4	0.0	0.0	0.0	0.0	0.0	0.0		
130	0.2	2.4	1.4	16.8	0.2	2.4	0.0	0.0	0.0	0.0		
135	0.6	7.2	0.2	2.4	0.0	0.0	0.0	0.0	0.0	0.0		
140	0.0	0.0	2.2	26.4	0.4	4.8	0.0	0.0	0.4	4.8		
145	0.2	2.4	1.4	16.8	0.0	0.0	0.0	0.0	0.0	0.0		
150	0.0	0.0	2.0	24.0	0.8	9.6	0.4	4.8	0.0	0.0		
155	0.0	0.0	1.4	16.8	0.0	0.0	0.2	2.4	0.0	0.0		
160	0.0	0.0	0.2	2.4	0.4	4.8	0.0	0.0	0.0	0.0		
165	0.0	0.0	0.0	0.0	0.2	2.4	0.0	0.0	0.0	0.0		
170	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
175	0.0	0.0	0.0	0.0	0.2	2.4	0.4	4.8	0.0	0.0		
180	0.0	0.0	0.0	0.0	0.0	0.0	0.6	7.2	0.0	0.0		
185	0.0	0.0	0.0	0.0	0.8	9.6	2.2	26.4	0.0	0.0		
190	0.0	0.0	0.0	0.0	0.2	2.4	1.0	12.0	0.0	0.0		
195	1.2	14.4	0.0	0.0	0.4	4.8	0.8	9.6	0.0	0.0		
200	0.8	9.6	0.0	0.0	0.2	2.4	0.6	7.2	0.0	0.0		
205	0.0	0.0	0.0	0.0	0.0	0.0	1.4	16.8	0.0	0.0		

210	0.2	2.4	0.0	0.0	0.2	2.4	0.6	7.2	0.0	0.0
215	0.4	4.8	0.0	0.0	0.2	2.4	0.8	9.6	0.0	0.0
220	0.2	2.4	0.0	0.0	0.0	0.0	0.8	9.6	0.2	2.4
225	0.0	0.0	0.0	0.0	0.4	4.8	1.2	14.4	0.0	0.0
230	0.2	2.4	0.0	0.0	0.2	2.4	0.8	9.6	0.0	0.0
235	0.0	0.0	0.0	0.0	0.2	2.4	0.6	7.2	0.2	2.4
240	0.0	0.0	0.0	0.0	0.4	4.8	0.8	9.6	0.4	4.8
245	0.0	0.0	0.0	0.0	0.2	2.4	0.8	9.6	0.2	2.4
250	0.0	0.0	0.0	0.0	0.2	2.4	0.4	4.8	0.0	0.0
255	0.0	0.0	0.0	0.0	0.0	0.0	0.4	4.8	0.2	2.4
260	0.0	0.0	0.0	0.0	0.0	0.0	0.4	4.8		
265	0.0	0.0	0.0	0.0	0.0	0.0	0.4	4.8		
270	0.0	0.0	0.0	0.0	0.2	2.4	0.2	2.4		
275	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
280	0.0	0.0	0.0	0.0	0.2	2.4	0.2	2.4		
285	0.0	0.0	0.2	2.4	0.4	4.8	0.0	0.0		
290	0.0	0.0	0.0	0.0	0.2	2.4	0.0	0.0		
295	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
300	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
305	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
310	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
315	0.0	0.0	0.0	0.0	0.2	2.4	0.0	0.0		
320	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
325	0.0	0.0	0.2	2.4	0.0	0.0	0.0	0.0		
330	0.0	0.0			0.2	2.4	0.0	0.0		
335	0.0	0.0			0.0	0.0	0.0	0.0		
340	0.0	0.0			0.0	0.0	0.0	0.0		
345	0.0	0.0			0.0	0.0	0.0	0.0		
350	1.2	14.4			0.2	2.4	0.0	0.0		
355	0.6	7.2			0.0	0.0	0.0	0.0		
360	2.6	31.2			0.0	0.0	0.0	0.0		
365	2.2	26.4			0.2	2.4	0.2	2.4		
370	0.4	4.8			0.2	2.4	0.0	0.0		
375	0.8	9.6			0.0	0.0	0.0	0.0		
380	0.8	9.6			0.4	4.8	0.0	0.0		
385	1.0	12.0			0.2	2.4	0.0	0.0		
390	0.2	2.4			0.4	4.8	0.0	0.0		
395	0.2	2.4			0.2	2.4	0.0	0.0		
400	0.4	4.8			0.2	2.4	0.2	2.4		
405	0.2	2.4			0.6	7.2	0.0	0.0		
410	0.2	2.4			0.4	4.8	0.0	0.0		
415	0.2	2.4			0.6	7.2	0.0	0.0		
420	0.4	4.8			0.6	7.2	0.2	2.4		
425	0.4	4.8			0.0	0.0	0.0	0.0		
430	0.6	7.2			0.2	2.4	0.0	0.0		
435	0.0	0.0			0.2	2.4	0.0	0.0		
440	0.2	2.4			0.2	2.4	0.0	0.0		
445	0.4	4.8			0.2	2.4	0.0	0.0		
450	0.0	0.0			0.0	0.0	0.2	2.4		
455	0.8	9.6			0.2	2.4				
460	0.0	0.0			0.0	0.0				
465	0.2	2.4			0.4	4.8				
470	0.0	0.0			0.2	2.4				
475	0.4	4.8			0.2	2.4				
480	0.0	0.0			0.2	2.4				
485	0.2	2.4			0.0	0.0				
490	1.0	12.0			0.0	0.0				
495	0.4	4.8			0.0	0.0				
500	0.8	9.6			0.0	0				
505					0.2	2.4				
510					0.0	0				
515					0.2	2.4				
520					0.0	0				
525					0.4	4.8				
530					0.2	2.4				
535					0.2	2.4				
540					0.0	0				
545					0.2	2.4				
550					0.0	0				
555					0.2	2.4				
560					0.0	0				
565					0.2	2.4				
570					0.2	2.4				
575					0.0	0				
580					0.2	2.4				
585					0.0	0				

590	0.0	0
595	0.0	0
600	0.2	2.4
605	0.0	0
610	0.0	0
615	0.0	0
620	0.0	0
625	0.0	0
630	0.2	2.4
635	0.0	0
640	0.2	2.4
645	0.0	0
650	0.0	0
655	0.0	0
660	0.4	4.8
665	0.4	4.8
670	0.2	2.4
675	0.6	7.2
680	0.0	0
685	0.0	0
690	0.2	2.4
695	0.0	0
700	0.0	0
705	0.0	0
710	0.2	2.4
715	0.0	0
720	0.0	0
725	0.0	0
730	0.0	0
735	0.0	0
740	0.0	0
745	0.0	0
750	0.0	0
755	0.0	0
760	0.0	0
765	0.0	0
770	0.0	0
775	0.0	0
780	0.0	0
785	0.0	0
790	0.0	0
795	0.0	0
800	0.2	2.4
805	0.0	0
810	0.0	0
815	0.2	2.4
820	0.0	0
825	0.0	0
830	0.2	2.4
835	0.0	0
840	0.0	0
845	0.0	0
850	0.2	2.4
855	0.0	0
860	0.0	0
865	0.2	2.4
870	0.2	2.4
875	0.0	0
880	0.2	2.4
885	0.0	0
890	0.0	0
895	0.2	2.4
900	0.0	0
905	0.0	0
910	0.0	0
915	0.2	2.4
920	0.0	0
925	0.2	2.4
930	0.0	0
935	0.2	2.4
940	0.0	0
945	0.0	0
950	0.0	0
955	0.2	2.4
960	0.0	0
965	0.0	0

970	0.0	0
975	0.4	4.8
980	0.0	0
985	0.0	0
990	0.0	0
995	0.2	2.4
1,000	0.0	0
1,005	0.0	0
1,010	0.0	0
1,015	0.0	0
1,020	0.0	0
1,025	0.2	2.4
1,030	0.2	2.4
1,035	0.2	2.4
1,040	0.0	0
1,045	0.2	2.4
1,050	0.0	0
1,055	0.2	2.4
1,060	0.2	2.4
1,065	0.2	2.4
1,070	0.0	0
1,075	0.0	0
1,080	0.0	0
1,085	0.0	0
1,090	0.0	0
1,095	0.0	0
1,100	0.2	2.4
1,105	0.0	0
1,110	0.0	0
1,115	0.0	0
1,120	0.0	0
1,125	0.0	0
1,130	0.2	2.4
1,135	0.0	0
1,140	0.2	2.4
1,145	0.0	0
1,150	0.0	0
1,155	0.2	2.4
1,160	0.0	0
1,165	0.0	0
1,170	0.0	0
1,175	0.0	0
1,180	0.0	0
1,185	0.0	0
1,190	0.0	0
1,195	0.0	0
1,200	0.0	0
1,205	0.0	0
1,210	0.0	0
1,215	0.0	0
1,220	0.0	0
1,225	0.0	0
1,230	0.0	0
1,235	0.2	2.4
1,240	0.0	0
1,245	0.0	0
1,250	0.2	2.4
1,255	0.4	4.8
1,260	0.4	4.8
1,265	0.0	0
1,270	0.0	0
1,275	0.0	0
1,280	0.0	0
1,285	0.0	0
1,290	0.2	2.4
1,295	0.0	0
1,300	0.0	0
1,305	0.0	0
1,310	0.2	2.4
1,315	0.0	0
1,320	0.0	0
1,325	0.0	0
1,330	0.0	0
1,335	0.0	0
1,340	0.0	0
1,345	0.0	0

1,350	0.0	0
1,355	0.0	0
1,360	0.0	0
1,365	0.0	0
1,370	0.0	0
1,375	0.0	0
1,380	0.0	0
1,385	0.0	0
1,390	0.0	0
1,395	0.0	0
1,400	0.0	0
1,405	0.0	0
1,410	0.0	0
1,415	0.0	0
1,420	0.0	0
1,425	0.0	0
1,430	0.0	0
1,435	0.4	4.8
1,440	0.0	0
1,445	0.0	0
1,450	0.0	0
1,455	0.0	0
1,460	0.0	0
1,465	0.2	2.4
1,470	0.4	4.8
1,475	0.2	2.4
1,480	0.0	0
1,485	0.0	0
1,490	0.0	0
1,495	0.0	0
1,500	0.0	0
1,505	0.4	4.8
1,510	0.2	2.4
1,515	0.2	2.4
1,520	0.0	0
1,525	0.0	0
1,530	0.0	0
1,535	0.0	0
1,540	0.0	0
1,545	0.0	0
1,550	0.0	0
1,555	0.0	0
1,560	0.0	0
1,565	0.0	0
1,570	0.0	0
1,575	0.0	0
1,580	0.0	0
1,585	0.0	0
1,590	0.0	0
1,595	0.0	0
1,600	0.0	0
1,605	0.0	0
1,610	0.0	0
1,615	0.0	0
1,620	0.0	0
1,625	0.0	0
1,630	0.0	0
1,635	0.0	0
1,640	0.0	0
1,645	0.0	0
1,650	0.0	0
1,655	0.0	0
1,660	0.0	0
1,665	0.0	0
1,670	0.0	0
1,675	0.0	0
1,680	0.0	0
1,685	0.0	0
1,690	0.4	4.8
1,695	0.0	0
1,700	0.0	0
1,705	0.2	2.4

A8.1. *Flow data from the TRCA topsoil test plots at the Kortright Centre for Conservation, storms 1-3.*

		Storm 1					Storm 2					Storm 3		
Time (24hr)	**A**	**B** $m^3 s^{-1}$	**C**	**CTL**	**Time (24 hr)**	**A**	**B** $m^3 s^{-1}$	**C**	**CTL**	**Time (24hr)**	**A**	**B** $m^3 s^{-1}$	**C**	**CTL**
2:35	0.018	0	0	0	5:20	0	0	0	0.018	17:55	0	0	0	0.018
2:45	0	0	0	0	5:30	0	0	0	0.036	18:05	0	0	0	0.018
2:55	0.018	0	0	0.018	5:40	0	0	0.018	0.036	18:15	0.018	0	0	0.018
3:05	0.018	0	0	0.018	5:50	0.018	0	0.054	0.072	18:25	0	0	0.018	0.036
3:15	0.036	0	0.036	0.036	6:00	0.054	0.054	0.108	0.126	18:35	0.018	0.018	0.018	0.018
3:25	0.054	0	0.054	0.036	6:10	0.072	0.072	0.108	0.108	18:45	0	0	0.018	0.018
3:35	0.054	0	0.036	0.054	6:20	0.072	0.072	0.09	0.09	18:55	0.018	0.018	0.018	0.036
3:45	0.09	0.036	0.054	0.036	6:30	0.054	0.072	0.072	0.054	19:05	0	0.018	0.018	0.018
3:55	0.108	0.036	0.072	0.054	6:40	0.054	0.036	0.054	0.036	19:15	0.018	0.018	0.036	0.018
4:05	0.09	0.054	0.072	0.036	6:50	0.036	0.054	0.054	0.036	19:25	0.018	0.018	0.018	0.036
4:15	0.108	0.036	0.054	0.054	7:00	0.036	0.054	0.054	0.036	19:35	0.018	0.018	0.036	0.018
4:25	0.108	0.054	0.072	0.036	7:10	0.036	0.036	0.036	0.018	19:45	0	0.018	0.018	0.018
4:35	0.108	0.054	0.072	0.054	7:20	0.036	0.036	0.036	0.018	19:55	0.018	0.018	0.036	0.018
4:45	0.09	0.054	0.054	0.036	7:30	0.018	0.036	0.036	0.036	20:05	0.018	0.018	0.018	0.036
4:55	0.09	0.054	0.054	0.018	7:40	0.036	0.036	0.036	0.018	20:15	0.018	0.018	0.036	0.018
5:05	0.072	0.036	0.054	0.036	7:50	0.018	0.018	0.018	0.018	20:25	0.018	0.018	0.018	0.018
5:15	0.09	0.054	0.054	0.054	8:00	0.018	0.036	0.018	0.018	20:35	0.018	0.018	0.036	0.018
5:25	0.09	0.054	0.054	0.036	8:10	0.036	0.036	0.036	0	20:45	0.018	0.018	0.018	0.018
5:35	0.126	0.054	0.072	0.054	8:20	0.018	0.018	0.018	0.018	20:55	0.018	0.018	0.036	0
5:45	0.126	0.072	0.072	0.054	8:30	0.018	0.036	0.018	0.018	21:05	0.018	0.036	0.018	0.018
5:55	0.126	0.072	0.072	0.036	8:40	0.018	0.018	0.018	0.018	21:15	0.018	0.018	0.036	0.018
6:05	0.108	0.072	0.072	0.036	8:50	0.018	0.018	0.018	0	21:25	0.018	0.018	0.018	0.018
6:15	0.108	0.072	0.054	0.036	9:00	0.018	0.036	0.018	0.018	21:35	0.018	0.018	0.036	0.018
6:25	0.108	0.072	0.072	0.036	9:10	0.018	0.018	0.018	0	21:45	0.018	0.018	0.018	0.036
6:35	0.072	0.054	0.036	0.036	9:20	0.018	0.018	0.018	0.018	21:55	0.018	0.036	0.036	0.018
6:45	0.09	0.054	0.054	0.018	9:30	0.018	0.018	0.018	0	22:05	0.036	0.018	0.036	0.036
6:55	0.072	0.036	0.036	0.018	9:40	0	0.018	0.018	0.018	22:15	0.036	0.036	0.054	0.036
7:05	0.054	0.054	0.036	0.036	9:50	0.018	0.018	0.018	0	22:25	0.036	0.036	0.036	0.036
7:15	0.072	0.036	0.036	0.018	10:00	0.018	0.018	0.018	0.018	22:35	0.036	0.036	0.036	0.018
7:25	0.054	0.036	0.036	0.018	10:10	0.018	0.018	0	0	22:45	0.054	0.054	0.054	0.036
7:35	0.054	0.036	0.018	0.018	10:20	0	0.018	0.018	0.018	22:55	0.036	0.036	0.036	0.036
7:45	0.054	0.036	0.036	0.018	10:30	0.018	0.018	0.018	0	23:05	0.036	0.036	0.054	0.018
7:55	0.054	0.054	0.054	0.108	10:40	0.018	0.018	0	0	23:15	0.054	0.036	0.036	0.018
8:05	0.144	0.108	0.108	0.108	10:50	0.018	0	0.018	0.018	23:25	0.036	0.036	0.036	0.036
8:15	0.162	0.126	0.144	0.126	11:00	0	0.018	0.018	0	23:35	0.054	0.036	0.036	0.018
8:25	0.198	0.144	0.144	0.108	11:10	0.018	0.018	0	0	23:45	0.036	0.036	0.036	0.018
8:35	0.216	0.162	0.144	0.108	11:20	0	0.018	0.018	0.018	23:55	0.036	0.036	0.036	0.018
8:45	0.198	0.144	0.126	0.09	11:30	0.018	0.018	0	0	0:05	0.054	0.036	0.036	0.018
8:55	0.216	0.162	0.144	0.108	11:40	0	0	0.018	0	0:15	0.036	0.054	0.036	0.036
9:05	0.198	0.144	0.126	0.108	11:50	0.018	0.018	0	0	0:25	0.036	0.036	0.036	0.018
9:15	0.216	0.162	0.126	0.09	12:00	0.018	0.018	0.018	0.018	0:35	0.054	0.036	0.036	0.018
9:25	0.216	0.144	0.126	0.09	12:10	0	0	0	0	0:45	0.036	0.036	0.036	0.018
9:35	0.216	0.162	0.126	0.09	12:20	0.018	0.018	0	0	0:55	0.036	0.036	0.018	0.018
9:45	0.216	0.144	0.108	0.09	12:30	0	0	0.018	0	1:05	0.036	0.036	0.036	0.018
9:55	0.216	0.162	0.126	0.09	12:40	0.018	0.018	0	0.018	1:15	0.054	0.036	0.036	0.018
10:05	0.216	0.144	0.126	0.108	12:50	0	0	0.018	0	1:25	0.036	0.036	0.018	0.018
10:15	0.234	0.162	0.126	0.108	13:00	0	0.018	0	0	1:35	0.036	0.036	0.036	0.018
10:25	0.216	0.162	0.126	0.072	13:10	0.018	0.018	0	0	1:45	0.036	0.036	0.018	0
10:35	0.18	0.144	0.126	0.072	13:20	0	0	0	0	1:55	0.036	0.036	0.036	0.018
10:45	0.18	0.144	0.09	0.054	13:30	0.018	0	0.018	0	2:05	0.036	0.018	0.018	0.018
10:55	0.144	0.108	0.09	0.054	13:40	0	0.018	0	0	2:15	0.036	0.036	0.036	0.018
11:05	0.126	0.108	0.09	0.054	13:50	0	0.018	0	0	2:25	0.018	0.036	0.018	0.018
11:15	0.126	0.09	0.054	0.036	14:00	0.018	0	0	0.018	2:35	0.054	0.036	0.036	0.018
11:25	0.09	0.09	0.072	0.036	14:10	0	0	0.018	0	2:45	0.036	0.036	0.018	0.018
11:35	0.108	0.072	0.054	0.036	14:20	0.018	0.018	0	0	2:55	0.036	0.036	0.036	0.036
11:45	0.09	0.072	0.036	0.036	14:30	0	0	0	0	3:05	0.036	0.036	0.036	0
11:55	0.072	0.072	0.054	0.018	14:40	0	0.018	0	0	3:15	0.036	0.036	0.018	0.018
12:05	0.072	0.054	0.036	0.036	14:50	0.018	0	0	0	3:25	0.036	0.036	0.036	0.018
12:15	0.072	0.072	0.036	0.018	15:00	0	0	0	0	3:35	0.036	0.036	0.018	0.018
12:25	0.072	0.036	0.036	0.018	15:10	0	0.018	0	0	3:45	0.036	0.036	0.036	0
12:35	0.054	0.054	0.018	0.018	15:20	0	0	0.018	0	3:55	0.018	0.036	0.018	0.018
12:45	0.054	0.054	0.036	0.018	15:30	0.018	0	0	0	4:05	0.036	0.018	0.018	0.018
12:55	0.054	0.036	0.036	0.018	15:40	0	0.018	0	0	4:15	0.036	0.036	0.018	0
13:05	0.054	0.054	0.018	0.018	15:50	0	0	0	0	4:25	0.018	0.036	0.036	0.018
13:15	0.036	0.036	0.018	0.018	16:00	0.018	0	0	0	4:35	0.036	0.018	0.018	0.018

13:25	0.054	0.036	0.018	0.018
13:35	0.036	0.036	0.036	0
13:45	0.036	0.036	0.018	0.018
13:55	0.036	0.018	0.018	0.018
14:05	0.036	0.036	0.018	0
14:15	0.036	0.036	0.018	0.018
14:25	0.036	0.018	0.018	0
14:35	0.036	0.036	0.018	0.018
14:45	0.018	0.018	0.018	0
14:55	0.036	0.018	0	0.018
15:05	0.036	0.036	0.018	0
15:15	0.018	0.018	0.018	0.018
15:25	0.018	0.018	0.018	0
15:35	0.036	0.018	0	0
15:45	0.018	0.018	0.018	0.018
15:55	0.018	0.018	0	0
16:05	0.036	0.018	0.018	0.018
16:15	0.018	0.018	0.018	0
16:25	0.018	0.018	0	0
16:35	0.018	0.018	0.018	0
16:45	0.018	0.018	0	0.018
16:55	0.018	0.018	0.018	0
17:05	0.018	0.018	0	0
17:15	0.018	0	0	0
17:25	0.018	0.018	0.018	0.018
17:35	0.018	0.018	0	0
17:45	0.018	0	0.018	0
17:55	0	0.018	0	0
18:05	0.018	0.018	0	0
18:15	0.018	0	0.018	0.018
18:25	0.018	0.018	0	0

16:10	0	0.018	0	0
16:20	0	0	0	0
16:30	0	0	0	0
16:40	0.018	0.018	0	0
16:50	0	0	0	0
17:00	0	0	0	0
17:10	0	0	0	0

4:45	0.036	0.036	0.018	0
4:55	0.018	0.036	0.018	0.018
5:05	0.018	0.018	0.018	0
5:15	0.036	0.036	0.018	0.018
5:25	0.018	0.018	0.018	0.018
5:35	0.036	0.036	0.018	0
5:45	0.018	0.018	0.036	0.018
5:55	0.036	0.018	0.018	0.018
6:05	0.018	0.036	0.018	0
6:15	0.018	0.018	0.018	0.018
6:25	0.036	0.036	0.018	0.018
6:35	0.018	0.018	0.018	0.018
6:45	0.036	0.036	0.018	0
6:55	0.018	0.018	0.018	0.018
7:05	0.036	0.018	0.018	0.018
7:15	0.018	0.036	0.036	0
7:25	0.018	0.018	0.018	0.018
7:35	0.036	0.036	0.018	0.018
7:45	0.018	0.018	0.018	0.018
7:55	0.036	0.036	0.018	0
8:05	0.018	0.018	0.036	0.018
8:15	0.036	0.036	0.018	0.018
8:25	0.018	0.018	0.018	0.018
8:35	0.036	0.036	0.018	0
8:45	0.018	0.018	0.018	0.018
8:55	0.036	0.036	0.036	0.018
9:05	0.018	0.018	0.018	0.018
9:15	0.036	0.036	0.018	0.018
9:25	0.018	0.036	0.036	0.018
9:35	0.036	0.018	0.018	0
9:45	0.018	0.036	0.018	0.018
9:55	0.036	0.018	0.018	0.018
10:05	0.018	0.036	0.018	0
10:15	0.036	0.018	0.036	0.018
10:25	0.018	0.036	0.018	0.018
10:35	0.036	0.018	0.018	0
10:45	0.018	0.036	0.018	0.018
10:55	0.036	0.018	0.018	0.018
11:05	0.018	0.036	0.018	0
11:15	0.018	0.018	0.036	0.018
11:25	0.036	0.036	0.018	0
11:35	0.018	0.018	0.018	0.018
11:45	0.036	0.018	0.018	0
11:55	0.018	0.036	0.018	0.018
12:05	0.018	0.018	0.018	0
12:15	0.018	0.018	0.018	0.018
12:25	0.036	0.036	0.018	0.018
12:35	0.018	0.018	0.018	0
12:45	0.018	0.018	0.018	0.018
12:55	0.018	0.018	0.018	0
13:05	0.018	0.036	0.018	0.018
13:15	0.036	0.018	0.018	0.018
13:25	0.018	0.018	0.018	0
13:35	0.018	0.036	0.018	0.018
13:45	0.018	0.018	0.018	0
13:55	0.036	0.018	0.018	0.018
14:05	0.018	0.018	0.018	0
14:15	0.018	0.036	0.018	0.018
14:25	0.018	0.018	0.018	0
14:35	0.018	0.018	0.018	0.018
14:45	0.018	0.018	0.018	0
14:55	0.018	0.018	0	0.018
15:05	0.018	0.036	0.018	0
15:15	0.018	0.018	0.018	0.018
15:25	0.018	0.018	0.018	0
15:35	0.036	0.018	0.018	0.018
15:45	0.018	0.018	0.018	0
15:55	0.018	0.018	0.018	0.018
16:05	0.018	0.018	0.018	0
16:15	0	0.018	0	0.018
16:25	0.018	0.018	0.018	0.018
16:35	0.018	0.018	0.018	0
16:45	0.018	0.018	0.018	0.018
16:55	0.036	0.036	0.018	0.018
17:05	0.018	0.018	0.018	0
17:15	0.018	0.018	0.018	0.018

17:25	0.018	0.018	0.018	0
17:35	0.018	0.018	0.018	0.018
17:45	0.018	0.018	0.018	0
17:55	0.018	0.018	0.018	0.018
18:05	0.018	0.018	0.018	0
18:15	0.018	0.018	0.018	0.018
18:25	0	0.018	0	0
18:35	0.018	0.018	0.018	0.018
18:45	0.018	0.036	0.018	0
18:55	0.018	0	0.018	0
19:05	0.018	0.036	0.018	0.018
19:15	0.018	0	0.018	0
19:25	0.018	0.036	0	0.018
19:35	0.018	0	0.018	0
19:45	0.018	0.036	0.018	0
19:55	0.018	0	0.018	0.018
20:05	0	0.018	0	0
20:15	0.018	0.018	0.018	0.018
20:25	0.018	0.018	0.018	0
20:35	0.018	0.018	0.018	0
20:45	0.018	0.018	0	0.018
20:55	0.018	0.018	0.018	0
21:05	0	0.018	0.018	0.018
21:15	0.018	0.018	0	0
21:25	0.018	0.018	0.018	0
21:35	0.018	0.018	0.018	0.018
21:45	0	0	0	0
21:55	0.018	0.018	0.018	0
22:05	0.018	0.018	0.018	0.018
22:15	0.018	0.018	0	0
22:25	0	0.018	0.018	0
22:35	0.018	0	0.018	0.018
22:45	0.018	0.018	0	0
22:55	0	0.018	0.018	0
23:05	0.018	0.018	0	0.018
23:15	0.018	0.018	0.018	0
23:25	0	0	0	0
23:35	0.018	0.018	0.018	0
23:45	0	0.018	0	0.018
23:55	0.018	0	0.018	0
0:05	0.018	0.018	0	0
0:15	0	0.018	0.018	0
0:25	0.018	0	0	0.018
0:35	0	0.018	0.018	0
0:45	0.018	0.018	0	0
0:55	0	0	0.018	0
1:05	0.018	0.018	0	0.018
1:15	0	0.018	0	0
1:25	0.018	0	0.018	0
1:35	0	0	0	0
1:45	0.018	0.018	0.018	0.018
1:55	0	0.018	0	0
2:05	0.018	0	0	0
2:15	0	0.018	0.018	0
2:25	0.018	0	0	0
2:35	0	0.018	0	0.018
2:45	0.018	0	0.018	0
2:55	0	0	0	0
3:05	0	0.018	0	0
3:15	0.018	0	0	0
3:25	0	0.018	0.018	0
3:35	0.018	0	0	0.018
3:45	0	0.018	0	0
3:55	0	0	0	0
4:05	0.018	0	0.018	0
4:15	0	0.018	0	0
4:25	0	0	0	0.018
4:35	0.018	0.018	0.018	0
4:45	0	0	0	0
4:55	0.018	0	0	0
5:05	0	0.018	0	0
5:15	0	0	0	0
5:25	0.018	0	0.018	0
5:35	0	0.018	0	0.018
5:45	0	0	0	0
5:55	0.018	0	0	0

6:05	0	0.018	0	0
6:15	0	0	0.018	0
6:25	0.018	0	0	0
6:35	0	0	0	0.018
6:45	0	0.018	0	0
6:55	0	0	0	0
7:05	0.018	0	0.018	0
7:15	0	0.018	0	0
7:25	0	0	0	0
7:35	0.018	0	0	0
7:45	0	0	0	0
7:55	0	0.018	0	0.018
8:05	0	0	0.018	0
8:15	0.018	0	0	0
8:25	0	0	0	0
8:35	0	0.018	0	0
8:45	0	0	0	0
8:55	0.018	0	0	0
9:05	0	0	0	0
9:15	0	0	0.018	0.018
9:25	0	0.018	0	0
9:35	0.018	0	0	0
9:45	0	0	0	0
9:55	0	0	0	0
10:05	0	0.018	0	0
10:15	0.018	0	0	0
10:25	0	0	0.018	0
10:35	0	0	0	0
10:45	0	0	0	0.018
10:55	0	0	0	0

A8.2. *Flow data from the TRCA topsoil test plots at the Kortright Centre for Conservation, storms 4-6.*

		Storm 4					**Storm 5**					**Storm 6**		
Time (24hr)	**A**	**B** m^3 s^{-1}	**C**	**CTL**	**Time (24hr)**	**A**	**B** m^3 s^{-1}	**C**	**CTL**	**Time (24hr)**	**A**	**B** m^3 s^{-1}	**C**	**CTL**
15:45	0	0.054	0	0	4:25	0	0.018	0	0	16:40	0.036	0.018	0	0
15:55	0	0.054	0	0	4:35	0	0	0	0	16:50	0.018	0.018	0	0
16:05	0	0.054	0	0	4:45	0	0	0	0	17:00	0.018	0.018	0	0
16:15	0.018	0.054	0	0	4:55	0	0.018	0	0	17:10	0.036	0.018	0	0
16:25	0.054	0.072	0	0	5:05	0	0	0	0	17:20	0.018	0.018	0	0
16:35	0.072	0.09	0	0	5:15	0	0	0	0	17:30	0.018	0.036	0	0
16:45	0.108	0.144	0	0	5:25	0	0.018	0	0	17:40	0.018	0.018	0	0
16:55	0.144	0.162	0.018	0	5:35	0	0	0	0	17:50	0.018	0.018	0	0
17:05	0.216	0.198	0.144	0.144	5:45	0	0	0	0	18:00	0.036	0.018	0	0
17:15	0.27	0.216	0.198	0.198	5:55	0	0.018	0	0	18:10	0.018	0.018	0	0
17:25	0.288	0.234	0.198	0.198	6:05	0	0	0	0	18:20	0.018	0.018	0	0.018
17:35	0.288	0.252	0.216	0.18	6:15	0	0	0	0	18:30	0.018	0.018	0	0
17:45	0.252	0.252	0.198	0.144	6:25	0	0.018	0	0	18:40	0.018	0.018	0	0
17:55	0.216	0.216	0.162	0.126	6:35	0	0	0	0	18:50	0.018	0.018	0	0.018
18:05	0.18	0.198	0.144	0.09	6:45	0	0	0	0	19:00	0.018	0	0	0
18:15	0.144	0.162	0.126	0.072	6:55	0	0.018	0	0	19:10	0.018	0.018	0	0.018
18:25	0.126	0.162	0.09	0.072	7:05	0	0	0	0	19:20	0.018	0.018	0	0
18:35	0.126	0.144	0.09	0.036	7:15	0	0.018	0	0	19:30	0	0.018	0	0
18:45	0.09	0.126	0.09	0.054	7:25	0	0	0	0	19:40	0.018	0.018	0	0.018
18:55	0.09	0.126	0.054	0.036	7:35	0	0	0	0	19:50	0.018	0.018	0	0
19:05	0.09	0.108	0.072	0.036	7:45	0	0	0	0	20:00	0.018	0	0	0
19:15	0.072	0.09	0.036	0.036	7:55	0	0.018	0	0	20:10	0.018	0.018	0	0.018
19:25	0.072	0.108	0.054	0.018	8:05	0	0	0	0	20:20	0	0.018	0	0
19:35	0.072	0.072	0.036	0.018	8:15	0	0	0	0	20:30	0.018	0.018	0	0
19:45	0.054	0.072	0.036	0.018	8:25	0	0.018	0	0	20:40	0.018	0	0	0
19:55	0.072	0.072	0.018	0.036	8:35	0.018	0	0	0	20:50	0.018	0.018	0	0.018
20:05	0.054	0.072	0.036	0.018	8:45	0	0	0	0	21:00	0	0.018	0	0
20:15	0.054	0.072	0.018	0.018	8:55	0	0	0	0	21:10	0.018	0	0	0
20:25	0.054	0.054	0.036	0	9:05	0	0	0	0	21:20	0.018	0.018	0	0
20:35	0.054	0.054	0.018	0.018	9:15	0.018	0.018	0	0	21:30	0	0.018	0	0.018
20:45	0.054	0.054	0.018	0.018	9:25	0	0	0	0	21:40	0.018	0	0	0
20:55	0.036	0.036	0.018	0.018	9:35	0	0.018	0	0	21:50	0	0.018	0	0
21:05	0.054	0.054	0.018	0.018	9:45	0.018	0	0	0	22:00	0.018	0.018	0	0

21:15	0.036	0.054	0.018	0	9:55	0	0.018	0	0	22:10	0.018	0	0	0.018
21:25	0.036	0.036	0.018	0.018	10:05	0.018	0	0	0	22:20	0	0.018	0	0
21:35	0.054	0.054	0.018	0.018	10:15	0.018	0.036	0	0	22:30	0.018	0	0.018	0
21:45	0.036	0.036	0.018	0	10:25	0.09	0.09	0	0.054	22:40	0	0.018	0	0
21:55	0.036	0.036	0	0.018	10:35	0.27	0.18	0	0.468	22:50	0.018	0	0	0.018
22:05	0.036	0.036	0.018	0.018	10:45	0.27	0.18	0.036	0.252	23:00	0	0.018	0	0
22:15	0.036	0.036	0.018	0	10:55	0.18	0.18	0.18	0.162	23:10	0.018	0	0	0
22:25	0.036	0.036	0	0.018	11:05	0.162	0.144	0.144	0.108	23:20	0	0.018	0	0
22:35	0.018	0.036	0.018	0	11:15	0.126	0.144	0.108	0.072	23:30	0.018	0	0	0
22:45	0.036	0.036	0.018	0.018	11:25	0.108	0.126	0.108	0.072	23:40	0	0.018	0	0.018
22:55	0.036	0.018	0	0	11:35	0.108	0.108	0.09	0.054	23:50	0.018	0.018	0.018	0
23:05	0.018	0.036	0.018	0.018	11:45	0.09	0.108	0.072	0.036	0:00	0	0	0	0
23:15	0.036	0.018	0.018	0	11:55	0.072	0.108	0.054	0.054	0:10	0.018	0	0	0
23:25	0.018	0.036	0	0.018	12:05	0.072	0.072	0.072	0.018	0:20	0	0.018	0	0
23:35	0.036	0.036	0.018	0	12:15	0.072	0.09	0.036	0.036	0:30	0.018	0	0	0
23:45	0.018	0.018	0	0	12:25	0.072	0.072	0.036	0.018	0:40	0	0.018	0	0.018
23:55	0.036	0.018	0.018	0.018	12:35	0.072	0.072	0.036	0.036	0:50	0	0	0	0
0:05	0.018	0.036	0	0	12:45	0.054	0.054	0.036	0.018	1:00	0.018	0	0	0
0:15	0.018	0.018	0	0.018	12:55	0.054	0.072	0.036	0.018	1:10	0	0.018	0	0
0:25	0.018	0.018	0.018	0	13:05	0.054	0.054	0.018	0.036	1:20	0.018	0	0	0
0:35	0.018	0.018	0	0	13:15	0.054	0.054	0.036	0.018	1:30	0	0.018	0.018	0
0:45	0.018	0.018	0	0.018	13:25	0.054	0.054	0.018	0.018	1:40	0	0	0	0.018
0:55	0.018	0.036	0.018	0	13:35	0.054	0.054	0.018	0.018	1:50	0.018	0	0	0
1:05	0.036	0.018	0	0	13:45	0.054	0.054	0.036	0.018	2:00	0	0.018	0	0
1:15	0.018	0.018	0	0	13:55	0.054	0.054	0.018	0.018	2:10	0	0	0	0
1:25	0	0.018	0.018	0.018	14:05	0.054	0.036	0.018	0.018	2:20	0.018	0.018	0	0
1:35	0.018	0.018	0	0	14:15	0.036	0.054	0.018	0.018	2:30	0	0	0	0
1:45	0.018	0.018	0	0	14:25	0.054	0.036	0.018	0.018	2:40	0	0	0	0
1:55	0.018	0.018	0.018	0.018	14:35	0.036	0.036	0.018	0.018	2:50	0.018	0	0	0.018
2:05	0.018	0	0	0	14:45	0.036	0.036	0.018	0.018	3:00	0	0.018	0	0
2:15	0.018	0.018	0	0	14:55	0.036	0.036	0.018	0	3:10	0	0	0	0
2:25	0.018	0.018	0	0	15:05	0.054	0.036	0	0.018	3:20	0.018	0.018	0	0
2:35	0	0.018	0.018	0.018	15:15	0.036	0.036	0.018	0.018	3:30	0	0	0	0
2:45	0.018	0.018	0	0	15:25	0.018	0.036	0.018	0	3:40	0	0	0.018	0
2:55	0.018	0.018	0	0	15:35	0.036	0.018	0	0.018	3:50	0.018	0	0	0
3:05	0.018	0.018	0	0	15:45	0.036	0.018	0.018	0	4:00	0	0.018	0	0
3:15	0	0	0	0	15:55	0.036	0.036	0	0.018	4:10	0	0	0	0
3:25	0.018	0.018	0.018	0.018	16:05	0.018	0.018	0.018	0	4:20	0	0	0	0.018
3:35	0.018	0.018	0	0	16:15	0.036	0.018	0	0.018	4:30	0.018	0.018	0	0
3:45	0	0	0	0	16:25	0.018	0.036	0.018	0	4:40	0	0	0	0
3:55	0.018	0.018	0	0	16:35	0.036	0.018	0	0	4:50	0	0	0	0
4:05	0	0.018	0	0	16:45	0.018	0.018	0.018	0.018	5:00	0.018	0	0	0
4:15	0.018	0	0.018	0.018	16:55	0.018	0.018	0	0	5:10	0	0.018	0	0
4:25	0.018	0.018	0	0	17:05	0.036	0.018	0	0	5:20	0	0	0	0
4:35	0	0.018	0	0	17:15	0.018	0.018	0	0.018	5:30	0	0	0	0
4:45	0.018	0	0	0	17:25	0.018	0.018	0.018	0	5:40	0.018	0	0	0
4:55	0	0.018	0	0	17:35	0.018	0.018	0	0	5:50	0	0.018	0	0
5:05	0.018	0.018	0	0	17:45	0.018	0	0	0	6:00	0	0	0	0.018
5:15	0	0	0.018	0.018	17:55	0.018	0.018	0.018	0.018	6:10	0	0	0	0
5:25	0.018	0.018	0	0	18:05	0.018	0.018	0	0	6:20	0	0	0	0
5:35	0	0	0	0	18:15	0.018	0.018	0	0	6:30	0.018	0.018	0.018	0
5:45	0.018	0.018	0	0	18:25	0.018	0	0	0	6:40	0	0	0	0
5:55	0	0	0	0	18:35	0.018	0.018	0	0.018	6:50	0	0	0	0
6:05	0.018	0.018	0	0	18:45	0.018	0.018	0.018	0	7:00	0	0	0	0
6:15	0	0	0	0.018	18:55	0	0	0	0	7:10	0.018	0.018	0	0
6:25	0.018	0.018	0	0	19:05	0.018	0.018	0	0	7:20	0	0	0	0
6:35	0	0	0.018	0	19:15	0.018	0.018	0	0	7:30	0	0	0	0
6:45	0	0	0	0	19:25	0.018	0	0	0.018	7:40	0	0	0	0
6:55	0.018	0.018	0	0	19:35	0	0.018	0.018	0	7:50	0	0	0	0
7:05	0	0	0	0	19:45	0.018	0	0	0	8:00	0.018	0	0	0
7:15	0.018	0.018	0	0	19:55	0.018	0.018	0	0	8:10	0	0.018	0	0.018
7:25	0	0	0	0	20:05	0	0	0	0	8:20	0	0	0	0
7:35	0	0	0	0.018	20:15	0.018	0.018	0	0	8:30	0	0	0	0
7:45	0.018	0.018	0	0	20:25	0	0	0	0	8:40	0	0	0	0
7:55	0	0	0.018	0	20:35	0.018	0.018	0	0	8:50	0.018	0	0	0
8:05	0.018	0.018	0	0	20:45	0.018	0	0.018	0.018	9:00	0	0.018	0	0
8:15	0	0	0	0	20:55	0	0.018	0	0	9:10	0	0	0	0
8:25	0	0	0	0	21:05	0.018	0	0	0	9:20	0	0	0	0
8:35	0.018	0.018	0	0	21:15	0	0	0	0	9:30	0	0	0	0
8:45	0	0	0	0	21:25	0.018	0.018	0	0	9:40	0	0	0	0
8:55	0	0.018	0	0.018	21:35	0	0	0	0	9:50	0.018	0	0	0
9:05	0.018	0	0	0	21:45	0.018	0	0	0	10:00	0	0.018	0	0
9:15	0	0	0	0	21:55	0	0.018	0	0	10:10	0	0	0	0
9:25	0	0	0	0	22:05	0	0	0	0.018	10:20	0	0	0	0
9:35	0.018	0.018	0.018	0	22:15	0.018	0.018	0.018	0	10:30	0	0	0	0.018
9:45	0	0	0	0	22:25	0	0	0	0	10:40	0	0	0	0

22:35	0.018	0	0	0	10:50	0.018	0.018	0	0
22:45	0	0	0	0	11:00	0	0	0	0
22:55	0.018	0.018	0	0	11:10	0	0	0	0
23:05	0	0	0	0					
23:15	0	0	0	0					
23:25	0.018	0	0	0					
23:35	0	0.018	0	0					
23:45	0	0	0	0					
23:55	0.018	0	0	0					
0:05	0	0	0	0.018					
0:15	0	0	0.018	0					
0:25	0.018	0.018	0	0					
0:35	0	0	0	0					
0:45	0	0	0	0					
0:55	0.018	0	0	0					
1:05	0	0.018	0	0					
1:15	0	0	0	0					
1:25	0.018	0	0	0					
1:35	0	0	0	0					
1:45	0	0	0	0					
1:55	0.018	0	0	0					
2:05	0	0.018	0	0					
2:15	0	0	0	0					
2:25	0	0	0	0.018					
2:35	0.018	0	0	0					
2:45	0	0	0	0					
2:55	0	0	0	0					

A9. *Antecedent soil moisture data from the TRCA topsoil test plots at the Kortright Centre for Conservation, storms 1 – 6.*

			A			**B**			**B**			**CTL**	
Storm	**Depth (cm)**					**Soil moisture (% vo.)**							
1	6	43.1	45.8	42.4	40.1	41.0	41.7	42.4	44.1	41.3	50.7	44.5	50.1
	12	43.7	40.5	41.3	41.9	42.2	40.6	40.8	40.8	40.2	42.2	40.2	36.7
	18	43.9	41.1	40.0	43.3	41.1	41.3	40.0	40.0	42.7			
	24	44.0	46.3	41.7	46.7	47.7	46.4	42.2	42.3	44.1			
2	6	30.4	24.2	19.6	27.0	22.4	21.8	38.8	39.1	27.6	42.3	41.7	44.0
	12	38.0	37.2	33.5	36.2	36.9	32.2	38.0	38.0	33.0	36.5	36.2	35.3
	18	41.8	40.2	40.3	36.7	40.1	39.6	40.9	40.9	34.7			
	24	45.9	45.8	46.8	45.6	47.9	41.6	40.3	40.3	39.5			
3	6	33.0	34.1	36.9	36.7	39.1	39.3	40.2	41.1	39.0	40.9	41.5	44.7
	12	37.5	36.6	38.9	37.5	35.1	38.0	37.9	36.4	38.7	41.2	39.8	37.9
	18	39.8	39.3	39.6	38.1	39.6	41.6	40.5	38.1	41.8			
	24	41.8	41.4	41.2	42.7	39.0	39.8	40.8	42.3	43.0			
4	6	33.2	39.6	38.4	33.7	37.8	38.4	41.2	41.3	41.0	46.0	45.3	44.2
	12	41.9	42.4	42.5	41.4	39.1	39.8	38.3	38.4	41.8	40.7	41.2	38.7
	18	42.4	39.6	40.0	41.9	42.1	39.2	40.9	39.3	44.3			
	24	44.0	43.6	42.9	44.3	44.0	41.3	43.3	42.2	41.3			
5	6	46.7	41.8	46.1	38.9	45.4	40.8	43.4	42.0	42.2	51.7	48.0	50.4
	12	39.2	41.2	42.1	41.5	45.0	38.9	38.3	40.9	39.9	41.9	41.3	39.6
	18	40.2	40.9	40.5	40.9	43.0	41.5	42.8	42.6	43.4			
	24	44.7	43.9	40.7	49.2	43.0	39.5	44.3	43.3	42.6			
6	6	19.4	18.7	19.2	18.5	20.8	19.6	28.0	24.5	25.7	29.4	29.1	30.2
	12	31.5	30.2	35.4	28.1	28.9	33.5	29.4	31.5	31.1	32.3	34.6	35.5
	18	32.2	33.4	35.0	36.7	36.9	36.5	34.7	32.9	39.3			
	24	35.6	37.0	39.3	36.4	39.0	38.1	36.9	36.5	38.0			

A10. *Post-storm vertical soil moisture data, from the TRCA topsoil test plots at the Kortright Centre for Conservation, storms 1 – 6.*

Storm	**Depth (cm)**	**0.25 A**	**0.25 B**	**0.25 C**	**0.25 CTL**	**0.5 A**	**0.5 B**	**0.5 C**	**0.5 CTL**	**0.75 A**	**0.75 B**	**0.75 C**	**0.75 CTL**
								% vol.					
								<1hr					
1	6	40.7	38.6	42.7	52.6	46.4	41.1	44.5	48.9	42.7	41.9	41.5	51.6
	12	44.1	42.1	40.9	42.6	40.8	42.4	40.9	41.4	41.4	40.7	40.2	39.5
	18	44.4	43.7	40.1		41.2	41.2	40.1		40.0	41.7	43.0	
	24	44.5	47.4	42.6		46.8	48.5	42.6		41.9	46.9	44.6	
2	6	47.4	38.8	43.7	46.7	42.0	46.0	42.2	46.3	46.8	40.9	42.4	44.6
	12	39.2	41.7	38.1	41.3	41.3	45.5	41.0	41.3	42.3	38.8	39.9	38.6
	18	40.2	41.0	43.1		41.0	43.3	42.8		40.6	41.7	43.8	
	24	45.3	50.2	44.8		44.3	43.4	43.7		40.8	39.4	42.8	
3	6	42.0	43.7	35.3	44.1	32.0	26.5	35.3	42.1	24.6	38.9	26.4	43.5
	12	41.7	44.2	37.2	39.4	43.6	41.9	37.2	37.5	38.6	42.1	28.7	37.1
	18	46.8	43.8	43.5		44.5	45.6	43.5		47.0	48.5	33.1	
	24	46.9	47.3	43.7		50.0	47.0	43.7		47.3	48.4	48.4	
4	6	28.7	36.1	39.9	41.6	34.4	30.9	34.7	42.6	32.6	33.1	37.5	42.4
	12	35.4	34.0	36.6	41.7	37.8	33.1	36.1	40.4	37.8	34.2	34.3	40.1
	18	37.0	37.0	37.4		35.5	36.2	37.5		38.3	33.7	39.3	
	24	40.0	39.3	36.2		42.0	38.3	34.8		39.3	38.5	40.0	
5	6	45.2	45.2	44.4	47.9	38.8	42.4	43.9	45.0	36.4	47.5	41.8	43.9
	12	43.7	44.8	42.8	41.8	45.0	40.4	42.8	40.4	45.5	42.4	38.8	40.2
	18	46.5	44.8	45.1		46.4	49.7	44.4		44.8	43.1	41.7	
	24	51.0	49.8	45.5		50.6	46.6	46.4		45.7	47.3	46.5	
6	6	49.7	39.1	41.7	40.3	38.8	26.6	30.2	37.0	20.3	27.1	32.0	43.6
	12	36.9	38.3	37.6	31.9	33.0	32.1	26.6	32.0	33.0	31.6	34.1	31.3
	18	42.9	38.3	37.6		37.3	36.4	40.6		37.3	36.1	37.0	
	24	47.5	40.3	37.1		38.5	35.9	38.1		37.7	36.4	32.9	
								~ 1 day					
1	6	32.4	33.0	41.3	51.8	39.6	37.5	41.5	45.0	38.3	38.3	41.1	51.2
	12	42.1	41.6	38.1	42.4	42.7	39.0	38.8	40.2	42.8	39.8	41.5	36.4
	18	42.7	42.1	41.0		39.5	42.3	39.2		40.1	39.2	44.8	
	24	44.5	44.7	43.7		44.0	44.5	42.4		43.2	41.5	41.4	
2	6	32.7	36.4	40.2	41.0	33.4	39.0	44.6	41.7	36.5	39.2	40.1	49.6
	12	37.3	37.2	37.7	41.3	38.0	40.0	36.0	39.8	38.8	40.6	38.6	37.6
	18	39.8	37.9	40.5		38.8	39.6	37.9		39.5	41.8	42.0	
	24	42.0	43.0	40.9		41.6	38.9	42.6		41.3	39.8	43.3	
3	6	39.0	36.2	36.7	42.7	33.7	35.8	40.1	46.6	28.4	31.3	32.8	48.5
	12	45.4	51.6	44.6	42.1	49.0	48.7	43.6	46.8	50.3	50.7	40.7	47.6
	18	53.1	51.5	46.7		53.6	54.3	47.3		50.0	53.8	48.5	
	24	54.7	56.7	50.4		60.0	56.8	54.0		55.2	55.0	49.7	
4	6	20.6	22.1	24.1	32.0	19.3	16.9	27.5	29.2	20.5	20.3	17.9	35.5
	12	34.6	35.6	34.9	32.5	35.7	37.3	30.5	36.4	35.8	38.6	29.4	34.2
	18	42.7	42.8	36.6		43.6	41.0	36.8		44.6	45.7	34.8	
	24	47.6	47.5	37.2		46.1	46.8	41.0		45.9	46.4	41.8	
5	6	38.8	38.8	39.5	38.4	20.4	25.9	28.3	35.9	17.3	25.7	25.3	39.8
	12	36.2	39.1	34.3	33.1	32.0	34.1	28.6	33.2	30.2	30.2	29.8	33.1
	18	41.5	37.0	35.2		38.8	37.3	35.5		34.9	31.8	32.2	
	24	45.1	39.3	36.4		44.4	39.4	39.0		33.1	39.1	35.8	
6	6	30.1	28.0	36.2	35.8	39.2	24.7	31.3	36.7	18.9	15.6	21.7	39.2
	12	39.0	38.5	36.8	35.8	41.2	36.9	33.8	39.4	35.4	36.9	34.9	38.5
	18	43.6	42.3	42.0		43.1	44.3	41.1		43.3	46.3	36.7	
	24	48.5	46.5	41.3		47.8	46.1	39.2		49.2	47.0	44.5	

							~ 1 week						
1	6	22.8	26.5	35.1	42.1	25.7	28.9	32.9	39.2	27.5	27.1	35.4	42.1
	12	32.0	27.1	29.3	36.8	31.8	30.9	31.7	38.1	33.4	29.8	35.7	27.1
	18	34.7	32.2	36.0		31.0	35.8	34.1		29.1	30.2	34.2	
	24	36.5	33.5	44.6		37.2	34.1	36.8		37.4	31.8	35.2	
2	6	26.6	20.6	32.5	40.2	18.1	22.9	31.0	34.7	20.8	19.5	33.1	41.6
	12	35.5	32.3	34.4	40.6	36.3	31.7	35.7	39.1	37.9	34.4	39.4	34.5
	18	38.2	36.3	42.0		38.6	41.0	35.9		36.8	39.1	43.0	
	24	41.2	42.8	41.6		41.2	43.3	42.0		38.2	41.0	41.9	
3	6	17.1	16.1	26.7	28.2	16.5	18.6	22.8	28.1	16.8	17.3	24.1	32.8
	12	30.6	29.6	28.2	31.5	30.9	27.7	30.4	34.0	34.9	32.7	33.7	34.9
	18	31.4	36.3	34.1		32.6	36.6	32.1		34.4	36.1	39.2	
	24	35.1	36.0	36.6		36.6	38.8	36.1		39.3	37.9	37.9	
4	6	22.2	33.3	36.7	42.5	23.4	25.5	34.3	41.9	17.1	20.6	38.4	47.7
	12	40.3	40.4	39.4	36.1	40.5	35.0	39.5	35.8	43.9	38.9	36.2	36.1
	18	43.4	44.3	43.2		43.2	36.6	43.1		41.7	41.1	39.4	
	24	46.7	45.1	46.7		45.2	46.5	45.6		49.0	47.1	40.0	
5	6	29.3	25.5	40.2	40.4	22.4	20.5	40.2	34.9	17.3	19.8	26.2	41.1
	12	37.8	35.8	37.7	35.5	36.9	36.4	37.7	37.7	32.8	31.4	32.2	37.3
	18	41.7	36.4	41.1		40.5	40.1	41.1		40.3	39.6	34.1	
	24	46.6	46.4	40.3		46.4	48.8	40.3		47.6	41.7	39.4	
6	6	24.4	21.7	26.9	27.8	19.5	19.6	21.8	29.6	16.2	14.0	17.6	28.9
	12	34.9	36.6	35.6	34.8	35.8	34.8	32.5	36.9	38.0	40.5	35.3	37.0
	18	41.2	39.8	41.4		39.4	42.7	39.7		39.8	40.8	35.6	
	24	47.7	45.9	41.8		43.8	45.1	40.2		47.9	44.4	41.8	

A11. *Post-storm surface moisture data, from the TRCA topsoil test plots at the Kortright Centre for Conservation, storms 1 – 6.*

				A					**B**					**C**					**CTL**		
	L (m)	**0.65**	**1.3**	**2**	**2.65**	**3.3**	**0.65**	**1.3**	**2**	**2.65**	**3.3**	**0.65**	**1.3**	**2**	**2.65**	**3.3**	**0.65**	**1.3**	**2**	**2.65**	**3.3**
											% vol.										
											<1hr										
1	**1.25**	45.3	45.2	40.7	37.1	44.1	37.8	43.2	38.6	43.7	46.6	44.2	41.8	42.7	42.2	49.1	46.2	45.2	52.6	49.1	52.7
2	**1.25**	44.3	40.2	47.4	45.6	46.3	41.6	47.6	38.8	42.8	38.0	43.4	40.4	43.7	39.3	43.0	46.8	47.7	46.7	46.9	58.2
3	**1.25**	36.1	37.2	37.7	37.8	41.0	41.1	35.7	43.7	29.2	39.7	34.9	36.3	35.3	43.5	39.7	39.3	42.2	44.1	42.7	43.4
4	**1.25**	30.2	28.1	28.7	42.2	39.2	37.1	36.0	36.1	35.2	33.3	35.9	36.7	39.9	37.7	34.6	37.4	39.3	41.6	38.8	36.6
5	**1.25**	39.1	44.0	45.2	45.6	44.2	43.4	51.3	45.1	47.1	38.1	40.3	41.1	46.9	46.4	44.5	42.5	43.6	47.9	47.9	47.9
6	**1.25**	21.1	39.0	49.7	37.3	36.1	37.7	42.0	39.6	36.1	26.9	25.2	32.6	36.6	35.6	29.2	34.3	40.5	40.3	36.2	38.0
1	**2.5**	52.1	44.6	46.4	45.5	49.1	48.2	49.4	41.1	42.7	47.3	45.7	41.4	44.2	42.8	47.9	44.7	49.1	48.9	50.9	47.0
2	**2.5**	42.7	44.5	42.0	41.1	45.1	46.1	44.6	46.0	42.5	42.8	45.0	44.6	42.2	43.1	46.8	43.7	49.1	46.3	53.6	52.3
3	**2.5**	25.6	31.5	32.0	34.9	25.8	24.5	33.8	26.5	31.2	29.8	35.3	45.6	38.8	31.8	30.4	36.2	37.7	42.1	37.2	36.3
4	**2.5**	30.4	31.8	34.4	27.6	32.6	29.7	34.0	30.9	34.1	32.6	34.0	35.6	34.7	35.9	32.3	39.8	39.0	42.6	39.3	34.3
5	**2.5**	39.0	49.5	38.8	43.9	42.8	41.4	35.8	42.4	36.6	36.9	36.6	43.4	43.9	43.4	43.9	45.2	46.0	45.0	43.1	47.9
6	**2.5**	19.9	41.2	38.8	27.3	34.0	28.0	31.5	26.6	19.3	21.3	30.9	25.8	28.5	33.0	34.3	33.8	34.9	37.0	33.1	35.2
1	**3.75**	43.3	45.1	42.7	41.5	48.2	44.3	42.4	41.9	44.2	39.4	49.1	43.8	41.5	47.2	40.8	51.8	49.1	51.6	52.7	52.7
2	**3.75**	48.1	43.1	46.8	45.9	45.5	44.0	45.0	40.9	44.9	42.3	44.6	48.2	42.4	47.1	45.2	48.2	45.5	44.6	46.8	50.3
3	**3.75**	28.1	27.5	24.6	27.1	24.0	25.0	25.4	38.9	25.3	27.6	28.4	29.2	26.4	26.9	27.7	37.8	39.5	43.5	42.3	41.9
4	**3.75**	30.8	34.0	32.6	32.6	30.5	28.7	32.2	33.1	33.1	31.0	35.2	33.8	37.5	37.0	34.1	36.6	38.3	42.4	40.5	34.9
5	**3.75**	34.8	42.0	36.4	35.4	42.2	39.2	31.0	47.5	38.8	26.6	34.3	38.2	41.8	37.2	38.3	46.8	46.2	43.8	47.6	47.3
6	**3.75**	23.8	21.0	23.7	26.4	23.3	16.9	23.6	27.1	19.6	22.7	28.8	29.7	32.0	31.6	27.9	38.9	36.0	43.6	38.3	42.2

~1 day

1	**1.25**	34.7	34.6	32.4	33.3	35.6	35.1	37.9	33.0	38.3	39.2	37.4	36.8	41.3	39.0	43.0	46.1	46.0	51.8	47.0	47.9
2	**1.25**	36.7	30.8	32.7	36.5	35.1	37.1	35.2	33.7	36.5	36.5	40.1	39.0	40.2	38.2	41.3	43.9	38.2	41.0	43.4	46.7
3	**1.25**	25.6	30.3	33.2	26.5	33.4	38.8	30.5	39.3	28.4	19.4	30.8	29.1	31.2	31.6	37.1	32.6	42.2	36.3	40.9	43.8
4	**1.25**	16.2	16.8	20.6	20.0	20.6	21.4	22.8	22.2	21.4	14.0	19.7	20.9	24.1	23.2	30.7	27.0	30.9	32.0	29.6	29.5
5	**1.25**	17.3	31.4	38.8	32.7	30.2	30.3	33.6	38.8	30.3	16.1	22.2	26.5	39.5	33.0	31.0	35.9	37.7	38.4	30.0	34.7
6	**1.25**	18.4	29.2	30.1	18.3	29.9	29.8	24.5	28.0	27.2	20.3	22.5	23.8	36.2	31.2	31.6	32.5	33.8	35.8	36.0	34.4
1	**2.5**	41.0	36.0	39.6	36.1	43.2	34.8	36.2	37.5	39.5	41.0	37.4	38.5	41.5	40.1	44.7	47.0	45.0	45.0	46.9	45.3
2	**2.5**	38.3	34.6	33.4	36.7	35.5	34.5	36.5	39.0	37.9	38.4	37.9	39.2	44.6	40.2	39.2	43.3	42.8	41.7	42.0	44.7
3	**2.5**	24.6	25.3	28.6	24.7	28.9	35.3	27.9	29.8	26.2	26.8	29.7	26.2	34.1	29.9	33.2	37.3	35.7	31.1	39.7	39.4
4	**2.5**	16.4	15.0	19.3	18.7	19.2	21.0	18.4	16.9	15.5	16.9	25.8	21.9	27.5	20.7	26.9	24.2	27.2	29.2	29.8	31.3
5	**2.5**	13.3	29.9	20.4	24.2	28.6	29.0	24.0	25.9	21.8	25.4	30.9	25.6	28.3	28.8	26.2	29.4	31.6	35.9	28.8	30.7
6	**2.5**	16.1	23.1	39.2	19.0	17.6	26.2	20.2	24.7	21.9	21.7	24.7	25.9	31.3	26.5	31.3	32.4	35.7	36.7	33.1	36.0
1	**3.75**	39.8	38.3	38.3	39.5	38.0	32.2	37.5	38.3	39.6	42.5	43.9	39.2	41.1	35.9	42.4	45.9	45.1	51.2	51.3	44.6
2	**3.75**	34.9	36.2	36.5	37.2	35.2	36.2	35.6	39.2	37.9	37.6	39.3	40.4	40.1	40.7	37.7	41.5	42.1	49.6	46.0	48.2
3	**3.75**	22.2	21.4	24.1	25.8	28.8	27.2	28.6	26.6	26.4	20.8	27.7	31.8	27.9	27.5	27.7	43.4	42.0	41.2	40.5	40.6
4	**3.75**	12.6	22.1	20.5	25.5	22.1	18.5	13.1	20.3	13.9	12.1	18.8	22.6	17.9	19.1	21.0	33.2	30.9	35.5	35.4	33.1
5	**3.75**	15.8	15.4	17.3	23.5	16.7	19.7	14.8	25.7	23.4	19.8	21.7	24.1	25.3	24.6	30.0	32.6	31.4	39.8	34.2	32.4
6	**3.75**	16.5	20.2	18.9	24.3	31.4	22.3	12.6	15.6	17.6	14.1	22.4	25.1	21.7	27.8	26.0	37.6	38.8	39.2	37.9	38.9

~1 week

1	**1.25**	31.2	20.1	22.8	25.6	21.5	21.1	29.8	26.5	22.6	31.2	33.8	35.6	35.1	31.0	34.1	52.1	40.1	42.1	40.1	39.0
2	**1.25**	20.1	22.5	26.6	22.0	19.9	23.4	21.4	20.6	23.5	26.3	28.0	30.9	32.5	30.5	26.2	35.1	40.3	41.3	39.8	37.8
3	**1.25**	19.2	17.3	17.1	16.7	14.7	14.7	15.7	16.1	15.1	17.2	24.6	25.9	26.7	25.1	25.6	29.0	31.3	28.2	29.3	22.9
4	**1.25**	20.1	21.6	22.2	21.5	31.6	24.8	25.5	33.3	23.6	20.2	25.2	30.3	36.7	35.3	41.7	47.1	45.4	48.3	47.3	43.6
5	**1.25**	21.2	32.1	29.3	23.9	29.1	30.3	35.5	25.5	18.9	13.9	21.7	30.7	40.2	33.0	30.6	34.3	36.6	40.4	40.0	31.7
6	**1.25**	15.1	19.7	24.4	16.0	21.8	21.8	16.2	21.7	22.4	16.5	19.2	17.4	26.9	25.4	33.4	26.3	28.2	27.8	20.4	26.6
1	**2.5**	27.8	26.8	25.7	24.8	27.7	30.9	22.4	28.9	22.7	22.9	35.4	26.6	32.9	33.8	36.4	37.0	41.6	39.2	38.5	34.3
2	**2.5**	19.8	23.5	18.1	17.6	18.5	21.2	18.8	22.9	24.4	22.1	31.5	28.9	31.0	33.5	33.1	35.3	37.2	41.3	38.9	36.0
3	**2.5**	17.5	18.0	16.5	15.2	17.1	16.5	17.7	18.6	16.6	15.6	20.9	24.9	22.8	22.2	24.0	27.3	25.2	31.5	28.1	27.4
4	**2.5**	21.4	21.6	23.4	22.8	31.5	18.5	19.1	25.5	22.8	29.2	28.7	27.5	34.3	27.1	38.4	36.0	43.8	42.7	46.9	48.0
5	**2.5**	17.5	17.3	22.4	20.9	21.3	21.8	16.4	20.5	17.3	18.8	24.4	26.2	29.9	33.2	29.8	31.3	40.3	34.9	34.1	34.9
6	**2.5**	15.6	21.0	19.5	16.5	16.3	17.5	16.5	19.6	17.4	16.6	20.8	21.4	21.8	21.9	23.6	24.7	29.5	29.6	25.9	31.4
1	**3.75**	26.3	33.1	27.5	21.7	22.2	27.8	27.6	27.1	27.5	25.7	33.3	42.2	35.4	36.1	35.8	43.4	38.9	42.1	41.2	37.7
2	**3.75**	17.1	18.5	20.8	17.0	19.8	22.6	20.6	19.5	20.4	21.6	33.0	31.3	33.1	30.6	29.9	44.6	43.4	47.6	43.1	40.4
3	**3.75**	16.0	16.7	16.8	19.7	17.6	16.7	15.5	17.3	16.8	17.1	29.9	25.6	24.1	24.6	30.6	31.7	30.1	32.8	30.8	28.6
4	**3.75**	21.3	21.1	22.2	28.1	32.0	18.6	19.0	20.6	28.4	24.8	36.5	31.7	30.9	36.2	37.7	44.8	38.6	46.8	45.6	48.0
5	**3.75**	20.5	20.3	17.3	21.4	21.9	21.3	16.5	19.8	21.8	18.8	25.6	25.0	24.7	25.7	25.8	42.0	37.8	41.1	37.3	38.4
6	**3.75**	17.5	17.7	16.2	20.8	22.3	17.7	15.1	14.0	14.8	13.0	17.3	17.7	17.6	20.1	20.6	30.5	34.0	28.9	30.4	32.7