Evaluation of an Extensive Greenroof

York University, Toronto, Ontario

Prepared by: The Toronto and Region Conservation Authority July 2006

Final Report

EVALUATION OF AN EXTENSIVE GREENROOF YORK UNIVERSITY, TORONTO, ONTARIO

A report prepared by:

Toronto and Region Conservation

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Sustainable Technologies Evaluation Program

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Reports conducted under STEP are available at www.sustainabletechnologies.ca. For more information about the study, please contact:

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

Tel: 416-661-6600, Ext. 5337
Fax: 416-661-6898
E-mail: Tim_Van_Seters@trca.on.ca

THE SUSTAINABLE TECHNOLOGIES EVALUATION PROGRAM

The Sustainable Technologies Evaluation Program (STEP) is a multi-agency program, led by the Toronto and Region Conservation Authority (TRCA). The program helps to provide the real world data and analytical tools necessary to support broader implementation of innovative environmental technologies within a Canadian context. The main program objectives are to:

- monitor and evaluate sustainable water, air and energy technologies
- assess potential barriers to implementing technologies
- provide recommendations for guideline and policy development
- disseminate study results and recommendations, and promote the use of effective technologies at a broader scale through education and advocacy.

Technologies evaluated under STEP are not limited to physical structures; they may also include preventative measures, alternative urban site designs, and other innovate techniques that help promote more sustainable forms of living.

For more information about STEP, please contact:

Glenn MacMillan
Manager, Water and Energy
Toronto and Region Conservation Authority
Tel: 416-661-6600 Ext. 5212
Fax: 416-661-6898
Email: gmacmillan@trca.on.ca

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EXECUTIVE SUMMARY

Background and Objectives

Rooftop gardens have been widely recognized as providing significant private and public benefits to urban environments. These benefits include improved stormwater control, better air quality, lower energy use, moderated summer air temperatures, increased biodiversity, and healthier, more beautiful cityscapes. Broader recognition and appreciation of these values has been one of the drivers behind significant growth of the greenroof industry in the Greater Toronto Area (GTA) over the past decade.

Improved control of stormwater represents one of the most important public benefits of greenroofs, and is the primary focus of this evaluation. Greenroofs provide stormwater control by temporarily retaining precipitation and returning it to the atmosphere through evapotranspiration. The resulting reduction in runoff reduces downstream peak flows, prevents channel erosion and helps protect aquatic habitat. Greenroofs also have the potential to improve the quality of receiving waters by retaining and filtering pollutants.

This study was initiated in 2002 to help address the growing need for research on the stormwater management and biodiversity benefits of greenroof technology within cold weather climates. Specific objectives of the study were to:

- evaluate the potential of rooftop gardens to reduce the quantity and improve the quality of stormwater runoff;
- quantify the stormwater management benefits of greenroofs at a watershed scale through scenario modelling;
- assess the capacity of greenroofs to improve urban biodiversity; and
- provide recommendations on the design and maintenance of greenroofs.

The chemical and leachate quality of several commercially available greenroof growing media were also analylzed. An international literature review provides a context for the study and discusses research on aspects not specifically addressed by the present study, such as the energy and air quality benefits of greenroofs, cost factors, and greenroof incentive programs offered by municipalities.

Study Site

The monitoring study was conducted on a portion of the roof on the York University Computer Science and Engineering building (Figure 1). Constructed in 2001, the building is located on the York University campus in the City of Toronto, and drains to Black Creek, a tributary of the Humber watershed.

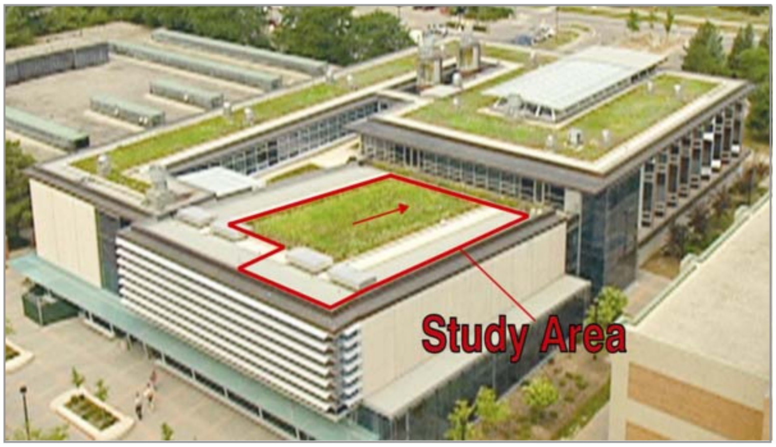

Figure 1: Study Area on the York University Computer Science Building

The portion of the roof which makes up the study area is covered by two surfaces: conventional shingles, referred to as the control roof, and the garden (Figure 1). Both roof surfaces have a 10% slope. The control roof (131 m^2) is just over half the size of the 241 m^2 garden. The garden consists of 140 mm of growing media and is vegetated with wildflowers. The growing media is composed of crushed volcanic rock, compost, blonde peat, cooked clay and washed sand. It was designed to be light weight, retain water and resist compaction.

Study Methods

Field monitoring

All climatic and hydrologic data were collected and archived in real time using a web-based monitoring system. The website provided the means to view data in real-time, while also facilitating the remote operation of equipment.

Figure 2 shows the location of monitoring instruments. Measurements included runoff, precipitation, soil moisture, relative humidity, air temperature, and growing medium temperature. Runoff flows from the garden and control roof were monitored continuously with two electromagnetic flow metres. Precipitation at the site was measured using a tipping bucket rain gauge. Nearby Atmospheric Environment Service (AES) stations provided back-up data on rain or snow conditions when site data were not available.

Garden and control roof runoff samples were collected for water quality analysis using two automated water samplers. Atmospheric deposition during wet and dry weather was monitored using an open bag lining a 48 cm diameter bucket. All samples were submitted to the Ministry of the Environment (MOE) laboratories for analysis of general chemistry (*e.g.* TSS, alkalinity), nutrients, metals, and polycyclic aromatic hydrocarbons (PAHs). Continuous water temperature data from the two roofs were collected between late July and late August, 2005.

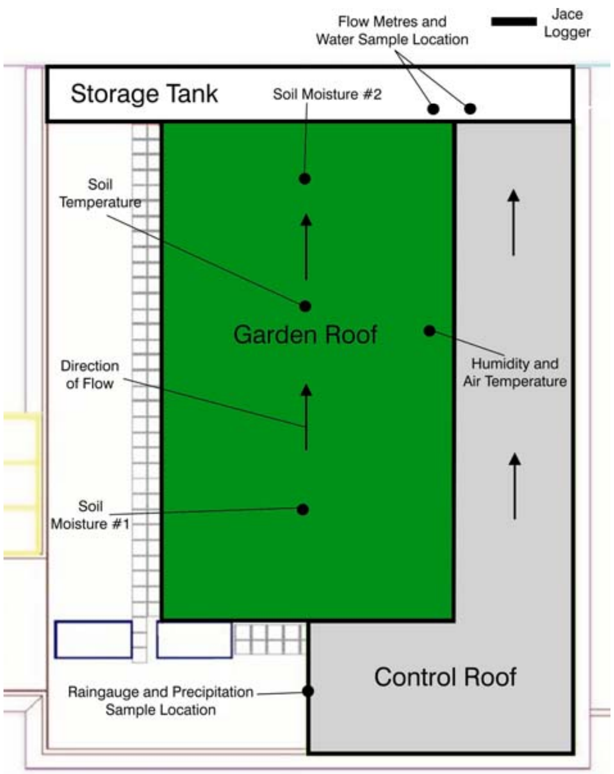

Figure 2: Schematic of Monitoring Set-up

An inventory of flora and fauna species on the greenroof was conducted during the 2004 and 2005 monitoring seasons by qualified biologists. Separate fauna surveys were conducted to evaluate the value of the greenroof as bird and bee habitat. Botanical surveys included both a comprehensive species inventory of every plant found on the greenroof and a quadrat study to analyze quantitative composition. Floristic quality of the site was determined for the greenroof using coefficients of conservatism.

Modelling

Data obtained from monitoring in 2003 and 2004 were used to model the stormwater management benefits of greenroof implementation on flat roofs within the fully developed Highland Creek watershed. Using a typical rainfall year, the Hydrological Simulation Program in Fortran (HSP-F) model was run for current conditions and two greenroof implementation scenarios.

Analyses of greenroof growing media

Chemical (soil and leachate) and physical analyses were conducted on 11 different greenroof growing media currently available commercially in order to determine the impact of growing media constituents on runoff chemistry. The bulk growing media and leachate samples were analyzed for general chemistry, nutrients, metals and particle size.

Findings

Water Quantity

Continuous runoff and precipitation data were available from May 2003 through to August 2005, excluding the winter months from January to March. Over this period, the garden retained approximately 63% of runoff (relative to the control roof). If it is assumed, based on various lines of evidence, that retention rates during the winter were between 5 and 25%, the annual retention rate for the entire study period would lie roughly between 51 and 54%.

Runoff retention rates were lower in 2003 than in later years because of greater precipitation in the fall of that year, and much more frequent irrigation, both of which had a strong influence on the garden's ability to retain water. During 2003, the garden retained only 54% of precipitation, while in 2004, approximately 75% of precipitation was retained.

Runoff retention by the garden during the warm summer months (June to August) varied little from year to year and was usually much better than in the fall and spring (Figure 3). Retention rates monitored during the summer were between 78 and 85%, compared to spring and fall retention rates of between 39 and 64%. Rainfall volumes, rainfall intensity, evapotranspiration and antecedent moisture content were the key factors explaining monthly and event-by-event variations in garden retention rates.

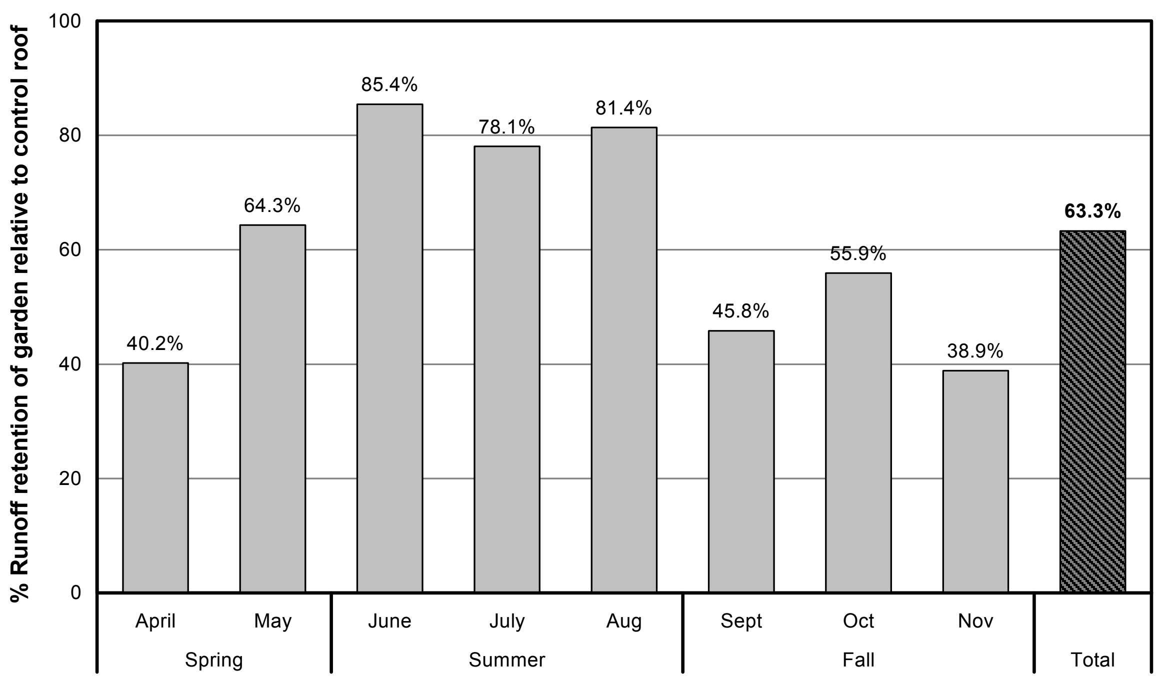

Figure 3: Average percent runoff retention of the garden relative to the control roof by month

The garden attenuated peak flows less effectively during large events. Average peak flow reductions for rainfall depths between 10 and 29 mm, 30 and 39 mm, and over 40 mm were 87, 68 and 50%, respectively.

Hydrologic simulations of greenroof implementation on 100% of available flat roofs in the fully developed Highland Creek watershed (roughly 9% of the watershed area) showed a 4% reduction in annual runoff volumes, and a 15% reduction in peak flows for events between 20 and 30 mm.

Water Quality

Water quality analysis was completed for a total of 21 events during the 2003 and 2004 monitoring seasons. Table 1 summarizes water quality results for key variables of concern. The loading 'percent difference' values shown in the far right column represent the difference in loading, expressed as a percentage, between unit area loads from the control roof and the garden. Positive values indicate higher control roof loads, while negative values indicate higher garden loads. For phosphorus and PAHs, there was a significant difference in concentrations between the two monitoring seasons; hence values for each year are shown separately.

Total loads for most pollutants of concern were lower from the garden than from the control roof, in part because, as discussed in the previous section, the garden had much smaller runoff volumes. The garden had higher loads of several chemicals that form part of the growing medium, such as potassium, magnesium, calcium and phosphorus. Most of these constituents do not pose a threat to receiving waters. Phosphorus is an exception because, at elevated concentrations in rivers and lakes, it can stimulate algal and aquatic plant growth, which deplete oxygen levels as they decompose resulting in adverse effects on aquatic organisms.

Table 1: Concentrations and the percent difference in loads for selected variables

Variable	Unit	Guideline	Volume Weighted Mean Concentrations*		Loading % Difference Control vs. Garden
			Garden	Control	
Suspended Solids	mg/L	-	2.0	6.4	88
Total Phosphorus	mg/L	0.03	0.74 / 0.30	0.09 / 0.05	-284 / -69
Total Kjeldahl Nitrogen	mg/L	-	1.69	0.68	3
Escherichia coli	c/100ml	100	807	513	39
Aluminum	µg/L	100‡	49	60	69
Copper	µg/L	5	38	111	87
Zinc	µg/L	20	9	11	69
Phenanthrene	ηg/L	30	30 / 19	178 / 34	92 / 84
Fluoranthene	ηg/L	0.8	30 / 5	265 / 44	95 / 97

Note: For PAHs, the first and second values are for the 2003 and 2004 monitoring seasons, respectively.
*Mean concentrations were weighted according to event runoff volume.
‡ Canadian Water Quality Guideline. Provincial guideline is 75 ug/L, but applies only to clay-free samples.

Phosphorus concentrations in garden runoff were in exceedence of the provincial guideline for almost all events. They were also significantly higher than observed in control roof runoff. The main source of phosphorus on the greenroof is the growing medium itself, which may have contained phosphorus rich fertilizers to help initiate plant growth. The phosphorus content of the York University greenroof growing media was the second highest of 11 other media analyzed for soil chemistry.

Garden phosphorus concentrations in 2004 were less than half of what they were in 2003 (Table 1). This decrease likely represents a process of leaching whereby soil phosphorus is gradually flushed out during the first year or two of operation. If this is the case, continued leaching over time may bring phosphorus levels from the garden down to control roof levels and/or receiving water objectives.

Compared to the garden, the control roof had higher volume weighted mean concentrations of suspended solids, several metals of concern, and all polycyclic aromatic hydrocarbons (Table 1). For most variables, concentrations were lower in precipitation than in the control and garden runoff.

Copper was the only metal which had mean concentrations significantly exceeding receiving water guidelines in both the control roof and garden runoff. Sources of copper on the greenroof may include the growing medium, atmospheric deposition and the eavestroughs used to convey runoff from the garden to the flow meters. On the conventional roof, the roofing material and flashing around the roof are probably the most significant sources of copper. The conventional roof material, which is made of shingles and tar, was also a likely source of PAHs in control roof runoff.

Runoff water temperature was measured for a total of 9 events during a particularly hot month during the summer of 2005. The maximum temperature of garden runoff (34°C) was roughly 3°C greater than that of the control roof runoff (32°C). Despite higher temperatures, the thermal impact of the garden on receiving waters is probably less than that of the control roof, simply because the garden discharges approximately 80% less runoff than the control roof during the hot summer months.

Hydrologic modelling of 100% greenroof implementation in the Highland Creek watershed (representing 9% of the watershed area) indicated that water quality loads would be reduced for almost all variables, primarily due to decreased flow volumes. The only notable exception was total phosphorus, for which levels increased moderately from baseline conditions.

Growing Media Chemical and Physical Analyses

The chemistry, grain size, and water leachate of 11 different greenroof substrates were analyzed in order to determine the impact of growing media constituents on runoff chemistry.

Chemical analyses of growing media showed that most constituents in the media were similar to or lower than typical background concentrations for agricultural soils in Ontario. Median concentrations of total Kjeldahl nitrogen (TKN) and total phosphorus in the bulk media tested were 1,860 and 540 ug/g, respectively. Although there were no published Ontario background soil concentration guidelines for nutrients (N and P), other literature suggested that the average, minimum and maximums observed in the survey of growing media concentrations was within the range of what may be expected in agricultural soils.

Grain size analyses showed that 8 of the 11 media tested consisted of more than 50% gravel, indicating that the particles in greenroof growing media tend to be relatively large (> 2 mm). These large particles in the media are usually lighter and less dense than typical gravel so that the structural load on the roof is kept to a minimum.

The leachate quality of samples from most media exceeded receiving water standards for several water quality variables, including phosphorus, aluminum, copper, iron and vanadium. Whether these same variables would be elevated in runoff under field conditions depends on a number of factors, including the type of media, storm size and age of the greenroof. This study showed that, at the very least, phosphorus may be a concern in runoff, although only long term monitoring can determine how long this issue may persist. Metals in garden runoff are generally not a concern since conventional roof runoff typically contains much higher concentrations of these constituents.

Concentrations tended to decrease from the first to the fourth leachate for nutrients and tended to increase for several metals of concern. Aluminum concentrations consistently increased from the first to fourth leachate. Copper concentrations increased from the first to the fourth leachate for more than 50% of samples, and in each instance the fourth leachate was above the receiving water quideline. While this indicates that the mobility of these metals increases with leaching it does not necessarily mean that concentrations will continue to increase in the long term. Field data from the York University greenroof show no significant upward trend in concentrations of metals over time.

Biodiversity

The greenroof was originally seeded with non-native grasses and forbs. As a result, it continues to have relatively low native biodiversity. Overall, the greenroof is a low-nutrient, low competition environment that can support conservative or rare native plants of concern. The greenroof has a relatively sparse vascular plant cover and a rather high moss cover. In 2005 the greenroof had 91 vascular plant species, of which 29 (32%) were native. From 2004 to 2005, 11 new native species were found on the garden. A list of recommended native plants for greenroofs is provided in an appendix of the report.

The fauna survey conducted in 2004 and 2005 found a total of six bird species on the greenroof. The Canada goose and house sparrow were found to be breeding. The European Starling was the most frequent species observed at the site. While there was no migrant activity recorded on the greenroof in 2005, migrant activity will likely increase over time with improved foraging and shelter prospects.

To assess the effectiveness of greenroofs as bee habitat the site was compared to other ground level habitats located nearby. The findings indicate that bee community structure on the greenroof is not significantly different than most other ground level sites surveyed. As succession occurs on the greenroof, bee nesting and foraging may occur.

Conclusions and Recommendations

Results of this study showed that greenroofs provide significant environmental benefits in terms of flow control, water quality improvement and the creation of healthy green spaces. By retaining flow, reducing peak flows, and creating habitat for plants and animals, the roof mimics many of the life sustaining features of the natural environment.

The following recommendations for greenroof design, maintenance, and research needs are based on site observations and study results.

Design

- On buildings with sufficient structural support, flow restrictors should be used in conjunction with greenroofs to help attenuate runoff peaks in the winter and early spring, when the garden is not retaining as much runoff.
- As greenroof substrates can be a significant source of phosphorus, growing media containing phosphorus-rich fertilizers or excessive nutrient levels should be avoided.
- The chemical and leachate properties of growing media should be considered in the selection of greenroof substrates. Potential constituents of concern may include phosphorus, nitrogen compounds, copper and other heavy metals.
- Construction materials surrounding the garden should be selected to minimize leaching of chemicals (e.g. metals, wood preservatives) into runoff.
- In order to maximize greenroof biodiversity, a range of different substrate types and depths as well as irrigation regimes should be used. Planting should focus on species that are less likely to arrive on their own and that are adaptable to drought, wind, low nutrients, and sometimes alkaline soils. Fertilization of greenroof soils should be avoided since the low-nutrient status on greenroofs is beneficial to biodiversity because it favours stress-tolerant, specialized native flora over aggressive opportunistic species.
- Minimizing garden runoff temperatures may require the use of more shading plants or another method that minimizes the exposure of the garden substrate to direct solar radiation.

Operations and Maintenance

- Greenroof irrigation should be minimized through appropriate plant and substrate selection. Irrigation schedules should be based on substrate moisture levels.
- Clearing of debris and bird feces from the greenroof and drainage system should be carried out as deemed necessary to prevent both clogging and the contamination of runoff.
- This study and current greenroof literature suggest that during the first season of installation plant growth and survival should be monitored carefully. Thereafter, the number of maintenance visits required will range from 3 to 10 per year.

Research Needs

- Runoff retention capacity of greenroofs during winter rainfall and snowmelt events requires further study
- Runoff water quality studies should investigate long term and seasonal trends, and focus on variables that have shown to be of concern in previous studies, such as phosphorus and copper.
- Long term monitoring of greenroof water quality is needed to determine how successive leaching of the growing media may lead to reductions in contaminant loads, and whether or not these reductions are reversed as contaminants build-up in the substrate.
- The effectiveness of various soil amendments that help reduce the release of phosphorus and other constituents of concern from greenroof substrates should be tested.
- Long term monitoring of greenroof flora and fauna populations should be conducted to determine whether flora biodiversity increases over time, and whether migrating and locally breeding birds will frequent greenroofs.

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1.0 INTRODUCTION

1.1 Background

Development in and around urban areas continues to proceed at an unprecedented pace. The urban landscape is dominated by impervious surfaces in the form of roads, sidewalks, driveways, parking lots and rooftops. Medium to high density residential subdivisions, typical of the type of development in the Greater Toronto Area (GTA), usually consist of between 50 and 75% impervious surfaces. The percent imperviousness of industrial land uses is closer to 95%.

The rapid increase in watershed impervious cover has a significant impact on the hydrologic cycle and the health of downstream aquatic biota (Ellis, 1999; Nix, 1994; and Taniguchi, 1997). Replacing natural vegetation with impervious surfaces eliminates infiltration, which in turn dramatically increases the volume of surface runoff. The larger volume of surface runoff leads to increased channel erosion and raises the potential for downstream flooding. Rooftop gardens help to mitigate some of the environmental impacts of urban stormwater runoff by temporarily retaining rainwater and returning it to the atmosphere through evapotranspiration.

In Toronto, there is an ongoing effort to quantify the runoff control benefits of greenroof infrastructure. Toronto and Region is one of 40 Areas of Concern (AOCs) bordering the shorelines of the Great Lakes in which a Remedial Action Plan (RAP) is currently being implemented. The Toronto and Region RAP was developed to restore polluted drainage networks and water bodies located in the city and along the shorelines of Lake Ontario. Greenroof technology has the potential to address several RAP goals and actions as well as the objectives of the City of Toronto Wet Weather Flow Management Master Plan (WWFMMP), which recommends greenroof infrastructure as a stormwater best management practice (BMP).

Within the City of Toronto, rooftops make up approximately 21% of the total land area (Ryerson University, 2005). Rooftop gardens reduce the total impervious cover in the Toronto and Region AOC and create vibrant new habitat for plants, animals and insects. This additional greenspace is beneficial to the urban environment not only for its stormwater management benefits, but also as a means of increasing biodiversity, reducing building energy use, minimizing the urban heat island effect, improving air quality, and enhancing the aesthetic quality of cities. For all of these reasons, the greenroof industry in the GTA has experienced significant growth over the past decade, with the encouragement of several stakeholder groups, including municipal governments, the National Research Council, Green Roofs for Healthy Cities, the TRCA, and several universities and colleges.

Since the fall of 2005, the City of Toronto has taken several steps to further encourage the widespread implementation of greenroofs through multi-stakeholder workshops and the publication of two documents discussing the benefits, costs and implementation barriers for greenroofs in Toronto. Recommendations derived from this research have been used to develop a city-wide greenroof policy, approved by city council in February 2006. The new policy includes a commitment to greening new and existing roofs on municipal buildings whenever feasible, and development of initiatives which will provide financial incentives for greenroof implementation. The policy will likely undergo significant development within the coming year.

1.2 Study Objectives

This study was initiated in 2002 in an effort to address the growing need for research on the stormwater management and biodiversity benefits of greenroof technology within cold weather climates. The specific objectives of this study were to:

- evaluate the potential of rooftop gardens to reduce the quantity and improve the quality of stormwater runoff;
- quantify the stormwater management benefits of greenroofs at a watershed scale through scenario modelling;
- assess the ability of greenroofs to improve urban biodiversity and recommend flora species for use on greenroofs in southern Ontario; and
- provide recommendations on the design and maintenance of greenroofs to maximize benefits related to stormwater management and biodiversity.

The study also includes a review of international greenroof literature as well as a chemical and leachate analysis of several commercially available greenroof growing media.

2.0 LITERATURE REVIEW

Since the 1990s, the design and construction of rooftop gardens has become increasingly popular in North America. This increased popularity parallels a growing awareness of the environmental and health impacts associated with intensified urban development and the potential that greenroof technologies offer in mitigating these impacts. A great deal of greenroof research has been undertaken in Europe and particularly in Germany since the 1960s (Carey, 2004), where intensification in urban areas has had dramatic impacts on environmental quality and the availability of greenspace (Peck et. al, 1999). This research, spurred on by the desire to improve the quality of life in urban areas, has led to a proliferation of rooftop gardens. In 2001 alone, 14% of newly constructed flat roofs in Germany were built with rooftop gardens (Keeley, 2004). The greenroof industry has also been growing in Japan and Hong Kong. The following literature review provides a summary of greenroof research from various cities around the world.

2.1 Greenroof Design Elements

2.1.1 Intensive vs. Extensive

Greenroofs are typically classified as either extensive or intensive. Extensive greenroofs, such as the York University rooftop garden, support low growing plants and have substrate depths ranging from 5 to 15 cm (Peck et. al, 1999). A greenroof with a substrate deeper than 15 cm is normally defined as intensive. Guidelines produced by the German Research Society for Landscape Development and Landscape Design (1995; hereafter referred to as the FLL[1] guidelines) specify substrate depths required for the planting of various species on a greenroof. The maximum depth specified in this document is for the planting of large trees on an intensive greenroof, which is listed as requiring a vegetation support of at least 125 cm. The deeper substrate allows intensive greenroofs to support a much wider variety of vegetation, including trees and shrubs. Because extensive greenroofs are lighter in weight, the cost of construction is generally lower than for intensive greenroofs (Peck et al., 1999). Intensive greenroofs are also associated with higher maintenance costs, as the types of vegetation used normally require a greater amount of upkeep (Peck et. al, 1999).

2.1.2 Slope

Greenroofs vary in the extent to which they are sloped. A slope of 5° is generally considered the minimum slope required for gravitational flow of stormwater towards the roof drain. Greenroofs constructed with a slope of less than 5° may require an additional layer below the substrate to drain stormwater and prevent root saturation (Scholz-Barth, 2001). The greening of a roof with a slope exceeding 20° normally requires that several soil stabilization measures be implemented, such as the use of a wooden lath grid (Auckland Regional Council, 2003). To prevent soil slippage, the German FLL guidelines (1995) do not recommend the greening of roofs with slopes exceeding 45°.

[1] FLL is the acronym for ***F****orschungsgesellschaft* ***L****andschaftsentwicklung* ***L****andschaftsbau*

2.1.3 Vegetation

The types of vegetation used in a greenroof can have a significant impact on its long-term cost, durability and potential to provide environmental benefits. Local climate is one of the key factors to consider in the selection of plants. On extensive greenroofs, plants typically need to survive in adverse conditions, including low moisture levels, temperature extremes, and shallow soil depths (Dunnett and Kingsbury, 2004). Thus, vegetation suited to dry lands, tundras, alvars, and alpine slopes are most commonly used. This may include a mixture of *sedums*, grasses, mosses, wildflowers, *festucas*, *sempervivums*, and irises (Peck and Kuhn, 2002). Sedums are a particularly popular selection for greenroofs due to their ability to survive without water for up to 80 days (Alexander, 2004). A wider range of plants are suitable for intensive greenroofs because of their deeper soils and larger load capacity. Several guidance documents on greenroof plant selection have been published both by suppliers and independent agencies such as the American Society for Testing and Materials (ASTM). The ASTM has published standards documents covering several aspects of greenroof design and construction, including guidelines for the selection, installation, and maintenance of plants on a greenroof (ASTM, 2005).

2.2 Benefits of Greenroofs

2.2.1 Water Quantity Control

A number of studies have investigated the stormwater management benefits of greenroofs. These benefits relate primarily to the ability of greenroofs to attenuate peak flows and reduce the total volume of stormwater runoff by retaining rain water in the growing media and returning a portion of it back to the atmosphere through evapotranspiration. Table 2.1 summarizes rainfall retention results from the present study and several other field monitoring studies undertaken in North America and Europe. The average percent retention rate reported in these studies was 60%, ranging from a low of 39% to a high of 72%. Most of the studies did not include winter monitoring, when evapotranspiration and water retention rates would be much lower than the summer (this study; Moran et al., 2004). Substrate thickness had a positive influence on rainfall retention in studies where more than one substrate thickness was monitored. However, the benefit of thicker substrates tended to decrease as thickness increased above approximately 5 cm (Liesecke, 1998; Dürr, 1995; Rowe et al., 2003). None of the studies explicitly evaluated the effect of roof slope on rainwater retention, but the two studies (this study; Rowe et al., 2003) with the steepest slopes also had among the highest retention rates (72 and 63%), which suggests that slope may not exert a strong influence on runoff reduction.

The ability of greenroofs to attenuate runoff peak flows has also been demonstrated in several monitoring studies. A monitoring study of a flat extensive greenroof undertaken between 2002 and 2003 in Portland, Oregon (Hutchinson et al., 2003) found that peak precipitation run-on rates ranged from 0.041 to 0.193 cubic feet per second while flow rates running off the greenroof were only 0.008 to 0.012 cubic feet per second. A study of a 35 cm intensive greenroof on the Vancouver Public Library found that peak flows were reduced by over 80% for summer events and 30% for small winter events (Johnson, 2004). Greenroofs have also been found to delay runoff peaks, as demonstrated in an extensive greenroof study conducted in Toronto by the National Research Council of Canada (NRC). Runoff flows from the greenroof investigated in this study showed an average lag of 20 to 40 minutes relative to a standard control roof for summer rainfall events (Liu and Minor, 2005).

Table 2.1: Summary of greenroof performance for water quantity control in field monitoring studies

Author(s)	Name of Periodical, Conference or Publishing Agency	Location	Monitoring Period	Slope (%)	Substrate Thickness (cm)	Vegetation Types	% Stormwater Retention
Moran et al., 2004	North Carolina State University	Kinston, NC	July-Aug & Nov-Dec '03	3	10.2	8 species of sedum and 2 of delosperma	63%
		Goldsboro, NC	April - December '03	minimal	10.2 and 5.1[1]		62%
TRCA, 2006	This study	Toronto, ON	Apr. '03 – Aug. '05 excluding winters	10	14	non-native grasses and forbs	63%
Liu and Minor, 2005	National Research Council Canada	Toronto, ON	March 2003 - November 2004 excluding winters	minimal	7.5 and 10 [2]	Mixture of sedums [3]	57% [4]
Liu, 2005	National Research Council Canada	Ottawa, ON	November 2000 - November 2001	2	15	wildflower meadow	54% [4]
Liesecke, 1998	Stadt und Grun (City and Green)	Hannover-Herrenhausen, Germany	1985 - 1994	2	2 - 4	unknown	40-45%
					6 - 8		50-55%
					10 - 12		55-60%
Dürr, 1995	Bauverlag, GmbH	Germany	Exact dates not available but numbers represent annual average	minimal	2.5 (with 5cm gravel bed)	moss and sedum	58%
				minimal	6.3	sedum and grass	67%
				minimal	10.1	grass and herbaceous plants	71%
Hutchinson et al., 2003	Greening Rooftops for Sustainable Communities Conf.: Chicago 2003	Portland, OR	May - Oct. '02	minimal	11	succulents, grasses & other herbaceous species	69%
Rowe et al., 2003	Michigan State University	East Lansing, MI	Sept 10-Oct 27, 2002 & Mar 20-28, 2003	6.5	4	seven species and cultivars of sedum	69%
					6		72%
Russell & Schickedantz, 2003	Greening Rooftops for Sustainable Communities Conf.: Chicago 2003	Dearborn, MI	Spring - Summer 2001	2	2	sedums plugs, sedum seeds & native plugs	39%
					10		58%

[1] The two different substrate depths were arranged in a checkerboard pattern.

[2] The study monitored stormwater runoff from two garden plots containing two different substrates. The plot known as "greenroof S" had a substrate thickness of 7.5 cm and plot known as "greenroof G" had a substrate thickness of 10 cm.

[3] Vegetation was not well-established during stormwater monitoring

[4] Value represents the reduction in runoff from greenroof relative to reference roof runoff, not relative to precipitation

[5] This result represents the retention value obtained from the use of XeroFlor ™ drainage system

[6] This result represents the retention value obtained from the use of Siplast ™ drainage system

2.2.2 Water Quality

The main sources of contaminants on roofs are atmospheric deposition and the roof material itself. Analysis of precipitation in a North Carolina study of highway runoff quality revealed that as much as 10-30% of total phosphorus and nitrate, 30-50% of ortho-phosphorus, and 70-90% of total Kjeldahl nitrogen and ammonia in stormwater runoff may be contributed through atmospheric deposition (Wu et al., 1998).

Greenroofs can help to reduce the overall load of contaminants to receiving water systems from roofs by soil adsorption, plant uptake, microbial activity, filtration, and evapotranspiration (*i.e.* runoff quantity reduction). The ability of vegetation and soil to attenuate contaminants through various physical, chemical and biological processes translates into lower concentrations of certain contaminants in runoff from a greenroof. Forster and Knoche (1998) found that greenroofs can act as a trap for polycyclic aromatic hydrocarbons (PAH), with larger PAH molecules being trapped to a greater extent than smaller ones. This finding agrees with the present study, which showed that greenroofs not only reduce PAH loads and concentrations, but also several other constituents, such as metals, bacteria, and suspended solids (see chapter 6).

A portion of the observed improvement in water quality is quite simply a result of the change in surface cover. When rain falls on a greenroof, the impact is absorbed by the surface soil or substrate, before it percolates slowly through the media, past a geotextile filter and into the drainage cell. On a conventional roof, the impact of rain and flow of rainwater on the hard surface leaches pollutants from the roofing material that were not deposited atmospherically. Several studies have shown that leaching of pollutants from conventional roofing materials can result in very high runoff concentrations of metals, PAHs and other pollutants (*e.g.* Clark et al., 2001).

Of course, pollutants can also be leached from greenroof materials. Forster and Knoche (1998) reported that the chemical nature of greenroof runoff is more dependent upon the nature of the materials making up the greenroof than on the extent of wet and dry deposition of contaminants. Leachate analysis conducted as part of this study indicated that heavy metal concentrations in greenroof runoff can reach toxic levels when metals leached from roof surfaces are further mobilized in the presence of dissolved organic carbon in the substrate. The authors conclude that, based on this result, metal surfaces used in greenroof construction should be appropriately weatherproofed or avoided completely.

A study conducted by the Portland Bureau of Environmental Studies reached a similar conclusion regarding the impact of roofing materials on greenroof runoff quality. Three of fourteen greenroof runoff samples analyzed were found to have copper concentrations exceeding Oregon receiving water guidelines (Hutchinson et al., 2003). Authors suggest that substrates should be carefully chosen and that treated woods should not be used in greenroof construction in order to avoid the leaching of contaminants such as heavy metals and nutrients into runoff.

The retention of runoff by greenroofs discussed earlier translates into a significant decrease in the volume of water discharged to receiving water systems. These decreased flow volumes in turn result in a reduction in the overall mass of contaminants flowing from the roof. Moran et al. (2004) found that although concentrations of total nitrogen, total phosphorus, and phosphates were generally higher in runoff from a greenroof than from a conventional reference roof, loads from the two roofs were not statistically different due to the dramatically lower greenroof flow volumes. The nutrient source causing elevated concentrations in greenroof runoff was found to be composted cow manure, which made up 15% of the substrate.

As part of the Moran et al (2004) study, leachates from several substrates were analyzed to determine if nutrient leaching from the soil would decrease over time. Results indicated that while nitrogen concentrations in the soil leachate decreased with time, phosphorus concentrations remained almost the same. The authors also concluded from this substrate analysis that the extent of phosphorus leaching was dependent upon the degree of saturation of the soil prior to the rain event. This finding suggests that phosphorus leaching into runoff increases when inter-event drying periods are short and when evapotranspiration rates are low (Moran et al., 2004)

While the aforementioned study indicated that fertilizers and high nutrient levels in greenroof substrates can lead to runoff contamination (a finding consistent with results from the present study), many research studies have also demonstrated the importance of maintaining nutrient levels. In a presentation at the Portland 2004 *Greening Rooftops for Sustainable Communities* conference, Beattie and Berghage (2004) described the importance of periodically applying small amounts of slow-release fertilizer to greenroofs to maintain plant health (Beattie et al., 2004). Experiments have shown that there is a gradual leaching of nutrients from vegetated roofs after fertilisation but that this can be kept at reasonable levels when coated slow release fertilisers are used (Fischer and Jauch, 2004).

2.2.3 Energy Efficiency

Greenroofs have the potential to reduce energy used both in the heating and cooling of buildings. In the winter, a greenroof acts as insulation on the roof and helps to maintain a comfortable ambient air temperature. Energy use for heating of the building is decreased as less heat escapes through the roof. During hot and sunny summer days, a greenroof can remain cooler than a traditional roof surface due to the effects of evapotranspiration and shading. A cooler roof results in reduced heat flow into the building, and subsequently a decreased energy demand for air conditioning. Bass and Mizra (2002) found that, in southwestern Ontario, the demand for electricity increases by 3% for every 1°C above a threshold value of 18°C, which is when people turn on their air conditioners.

Field monitoring in Osaka, Japan demonstrated that the presence of a roof lawn garden reduced summer heat flux into a building by 50% (Onmura et al., 2001). Similarly, Liesecke et al. (1989) reported that indoor temperatures in a building with a greenroof were at least 3 to 4°C lower than outside when outdoor temperatures were between 25 and 30°C.

Several research studies have attempted to quantify the potential energy savings that may be realized through the implementation of greenroofs. In Canada, the National Research Council (NRC) has led most of this research. Energy efficiency monitoring studies have been conducted by the NRC at three greenroof sites in Ontario: (i) NRC Ottawa Field Roofing Facility, (ii) Toronto City Hall, and (iii) the Eastview Community Centre in Toronto. The results from two of these sites are summarized in Table 2.2.

Table 2.2: Summary of energy efficiency results from NRC studies at Ottawa facility and Eastview C.C.

Site	Reduction in Heat Gain (%)	Reduction in Heat Loss (%)	Max. Daily Temperature Fluctuation of roof membrane (°C)		Reduction in heat flow through roof relative to reference (%)	
			Greenroof	Reference	Summer	Winter
NRC Ottawa	95	26	6	45	47 (annual)	
Eastview C.C.	95	23	10	50	70-90	10-30

Source (NRC Ottawa results): Liu and Baskaran, 2003
Source (Eastview C.C. results): Liu and Baskaran, 2005

Results from the Toronto City Hall greenroof were similar to the Eastview Community Centre greenroof in terms of reducing heat flow through the roof. During the summer, heat flow reduction relative to the reference roof ranged from 50 to 90% while winter values ranged from 10 to 40% (Liu and Baskaran, 2005). In terms of actual savings in energy use, the NRC Ottawa greenroof was found to reduce daily energy demand for space conditioning by more than 75% relative to the reference roof during the spring and summer (Liu and Baskaran, 2002).

2.2.4 Urban Heat Island Mitigation

The urban heat island (UHI) effect refers to the elevated air temperatures of urban areas relative to surrounding natural or rural areas. The UHI is caused by the low reflectivity of urban surfaces, decreased urban vegetative cover, the trapping of long wave radiation by contaminants in the air, and intensified heat releases from building heating and automobile use in urban areas. Elevated temperatures associated with the UHI can have several negative impacts on the environment and human health. Higher temperatures accelerate the chemical reactions which form smog, while also increasing energy demand for the use of air conditioning, which in turn leads to further pollutant emissions. A modeling study conducted at Lawrence Berkeley National Laboratory in California predicted that for the Los Angeles basin, a 3.3°C reduction in summer temperatures would lead to an average smog reduction of about 12 % (Rosenfeld et al., 1998).

Vegetated surfaces stay cooler and emit less heat to the atmosphere due to evapotranspiration and shading. A study conducted in Oregon showed that while a non-vegetated surface reached temperatures greater than 50°C in the month of July, a vegetated area remained significantly cooler at 25°C. (Luvall and Holbo, 1989). In middle Europe, the daytime summer temperature of a typical insulated, gravel-covered rooftop varies between 60°C and 80°C (Peck et al., 1999).

A simulation of the UHI for Toronto was conducted by Bass et al. (2003) using a mesoscale model (MC2) to predict the urban heat island for a base scenario and for a scenario in which 5% of the total area of the city was covered by greenroofs. The model predicted that the urban heat island of Toronto for the base case would be 2 to 3°C, while the greenroof coverage was predicted to cause a city-wide cooling of 0.1 to 0.8°C (Bass et al., 2003).

2.2.5 Air Pollution Reduction

Plants contribute to the removal of certain greenhouse gases and smog precursors (such as carbon dioxide and nitrogen oxides) through leaf uptake and contact removal. According to the U.S. Environmental Protection Agency (2006), atmospheric pollutants are removed by vegetation through absorption of gases or attenuation of airborne particulate matter to leaf surfaces. Pollutants absorbed may be transformed through reaction with plant materials or they may simply be stored in the plant. Particulate matter attached to leaf surfaces are eventually dislodged or washed away by rain. Trees and vegetation have the potential to remove atmospheric contaminants such as nitrogen oxides, sulphur oxides, particulates, and ground-level ozone (EPA, 2006). Additional air quality improvements result indirectly from reduced energy use and the effect of increased vegetation on summer temperatures.

A greenroof study conducted in Washington, DC used the U.S. Department of Agriculture's Urban Forest Effects (UFORE) model to predict the benefits of greenroof implementation in DC. The study found that installing greenroofs on 20% of existing greenroof-ready buildings and on 80% of new buildings (which is equivalent to 21.7 million square feet of coverage) would result in the removal of an additional 16.8 metric tonnes of air pollutants per year (Casey Trees Endowment Fund & Limno-Tech Inc., 2005). This removal rate was found to be equivalent to that which would be provided by 28,000 street trees.

2.2.6 Biodiversity

The process of urbanization is normally associated with a dramatic decrease in the connectivity, quality and quantity of natural areas which provide habitat for plants and wildlife. A greenroof has the potential to act as either a 'stepping stone habitat' which connects isolated fragments of natural habitat, or as an 'island habitat' for less mobile species, which are isolated from natural areas found at the ground level (Wieditz, 2003). Although greenroofs may not be as valuable as plant and wildlife habitat in comparison to the natural area that the building has replaced, various species of invertebrates and birds may find that greenroofs can provide food, shelter, and breeding grounds (Wieditz, 2003).

A study conducted in Basel, Switzerland compared spider species on a greenroof with those in a similar habitat located on the ground. The study reported no significant difference in the diversity of spider species at the two sites (Brenneisen, 2003a). In the same study, 254 different beetle species and 78 spider species were found on the 16 greenroofs surveyed (Brenneisen, 2003b). The survey results revealed that there are several elements of greenroof design that have a significant impact on species biodiversity. Some factors which were found to promote biodiversity include the presence of native plants which provide seeds, varying topography, the use of natural soils and the presence of large stones or pieces of wood (Brenneisen, 2003b).

2.3 Operations and Maintenance

2.3.1 Irrigation

Ensuring that plants remain healthy is one of the most important operational considerations on rooftop gardens, particularly when vegetation has not yet become well-established. A balance between the moisture needs of plants and the ability of the substrate to retain stormwater must be established in order to ensure the long-term functioning of the greenroof. While the plant species used on greenroofs are normally selected based on their tolerance to dry conditions, there may be circumstances in which some level of irrigation is required, particularly in the early stages of plant growth.

Charlie Miller of Roofscapes Inc., in a presentation to the *2003 Greening Rooftops for Sustainable Communities Conference*, indicated that eliminating the need for irrigation should be feasible in all but semi-arid climates (Miller, 2003). Researchers in Portland, Oregon, however, concluded that during the summer, greenroof plants may require periodic irrigation in order to survive. Analysis of historical climate data for Portland showed that there are frequent instances during the summer when only trace amounts of precipitation were recorded over 40-60 day spans. These conditions could lead to plant die off on the greenroof, even in highly drought-tolerant species (King, 2004).

2.3.2 Plant Management

According to the *Stormwater Management Devices Design Guidelines Manual* published by the Auckland Regional Council of New Zealand (2003), appropriate design and construction of a greenroof should minimize maintenance needs. The use of low-growing plants on a greenroof, for instance, would limit the need for pruning or trimming of plants to aesthetic preferences only. Once a greenroof has been established for one year, maintenance visits for the weeding of invasive plant species should be undertaken two to three times a year (Thompson, 1998).

2.3.3 Roofing Membrane Inspections

Preventing leakage through the roofing membrane is crucial to maintaining the long-term structural integrity of a greenroof (Eichorn, 2006). To help detect leaks, greenroof suppliers and installers often recommend the use of electric field vector mapping (EFVM) technology (Peck and Kuhn, 2002). The components of an EFVM system may be installed on a roof after the roofing membrane has been put in place and prior to the installation of the garden components (Peck and Kuhn, 2002). Using this method, inspection of membrane integrity may be carried out at any time after the garden has been established without the need for major excavation (Eichorn, 2006).

2.4 Cost Comparisons

2.4.1 Design and Installation

A Canadian greenroof design guideline document published by the Canada Mortgage and Housing Corporation and the Ontario Association of Architects provides estimates of the costs associated with the installation of greenroofs. According to these estimates, the cost of removing an existing roof and re-roofing with a root-repelling membrane should be between \$100 and \$160 per square metre. The cost of an inaccessible extensive greenroof system, its plants, and the labour for installation is estimated to be between \$98 and \$228 per square metre. This excludes the installation of an irrigation system, which costs between \$21 and \$43 per square metre (Peck and Kuhn, 2002). All estimates provided in the document are based on the assumption that the greenroof will be installed on an existing building with sufficient loading capacity. Maintenance costs are estimated to range between approximately $13 and $21 per square metre during the first two years of operation.

Researchers from the University of Singapore and the National Parks Board conducted a life-cycle cost analysis of rooftop gardens in Singapore. This study discusses the initial and long-term costs of greenroofs for new building construction. The initial structural cost of installing an extensive flat greenroof without public access was estimated to be 50% greater than the structural cost for a conventional flat roof with exposed PVC membrane. The cost for the roofing system and its installation was approximately 82% greater for the greenroof than for the conventional roof. The soil depth, the type and weight of vegetation used, and the pedestrian traffic expected on the roof were found to be the key factors affecting the initial costs of the greenroof (Wong et al., 2003).

2.4.2 Long-term costs and savings

The cost benefits of greenroofs versus conventional roofs become more palatable when the longevity and energy savings associated with the two roofs are factored into the total cost. The Singapore study cited earlier found that, without accounting for energy savings, the greenroof cost was 2.3% higher. When energy savings were considered, the greenroof life-cycle cost was 8.5% less than the cost of the conventional exposed roof (Wong et al., 2003). Most of these cost savings are attributed to the increased lifespan of the roofing membrane under a greenroof, where it may be protected from exposure to the elements and normal wear and tear. Literature from Germany indicates that a roofing membrane beneath a greenroof can last for 40-50 years while the membrane on a gravel-covered roof may require replacement after only 25 years (Krupka, 2001).

2.5 Policies and Incentives

During two greenroof technology stakeholder workshops held by the City of Toronto, 79% of workshop participants ranked cost as either the first or second most significant barrier to greenroof development (City of Toronto, 2005). While greenroofs provide various environmental benefits which can lead to significant cost savings for local government, these savings must be passed on to building owners and developers if greenroofs are to be broadly implemented across the GTA.

Recognizing that cost is a significant barrier to wider adoption of greenroofs, several incentive programs have been developed by municipalities in North America and Europe. The City of Chicago, for example, currently offers stormwater retention credits for greenroofs (City of Toronto, 2005). In Portland, Oregon stormwater fees are levied based on the amount of impervious cover on a given development, and in Munster, Germany the quantity of runoff from the site determines the stormwater fee. The municipal government of Portland is currently looking into implementing an incentive by which these stormwater fees associated with impervious cover will be decreased by 35% for greenroof sites. With the policy in Munster, stormwater fees can be up to 80% less for developments with greenroofs (City of Toronto, 2005).

Examples of other greenroof incentives that are currently in use or under consideration by municipal governments include grants, subsidies, low-interest loans, density bonuses, and various types of special consideration provided through the development application process. Experience with these incentives in Europe, and particularly in Germany, indicates that they can be effective catalysts for wider adoption of greenroof technologies. Between 1989 and 1996, greenroof coverage in Germany increased from 1 to 10 million square metres (Boivin, 1992). In 2001 alone, 14% of the country's newly constructed flat roofs were greenroofs, which translates into an increase in greenroof cover of 13.5 million square meters (Hämmerle, 2002). This success is largely attributed to the policies and incentives adopted by state and municipal governments (Boivin, 1992), although corresponding decreases in greenroof material and installation costs have also been an important factor (Keeley, 2004).

In addition to developing incentives for greenroof implementation on private buildings, several municipalities including Toronto, Portland, Basel-City (Switzerland) and Stuttgart (Germany) have implemented or are in the process of implementing policies requiring greenroofs for all new municipal buildings with flat roofs. Some of these policies also apply to roof replacements on existing municipal buildings.

3.0 STUDY SITE

The monitoring study was conducted on a portion of the roof on the York University Computer Science and Engineering building (Figure 3.1). Constructed in 2001, the building is located on the York University campus in the City of Toronto, and drains to Black Creek, a tributary of the Humber watershed (Figure 3.2).

Figure 3.1: Study Area on the York University Computer Science Building

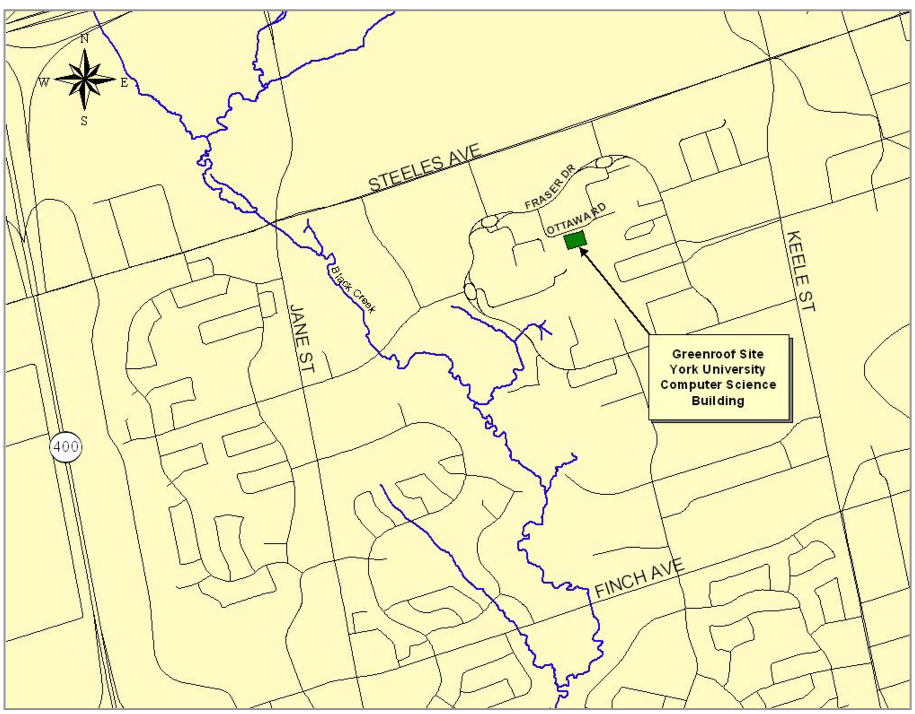


Figure 3.2: Location of York University Computer Science Building

The portion of the roof which makes up the study area is covered by two surfaces: shingles, hereafter referred to as the control roof, and the garden. Both roof surfaces have a 10% slope. The control roof, measuring 131 m^2, is almost half the size of the 241 m^2 garden (Figure 4.2). The garden consists of 140 mm of growing media and is vegetated with wildflowers. The growing media is composed of crushed volcanic rock, compost, blonde peat, cooked clay and washed sand. It was designed to be light weight, retain water and resist compaction. The greenroof has an irrigation system which came on every night during the first summer (June to October), and when soil moisture fell below a pre-established threshold value after the first year.

4.0 METHODS

This study used a web-based monitoring system for real-time collection and archiving of all climatic and hydrologic data collected at the study site (Figure 4.1). The system logged all sensor measurements in five minute intervals and the data were stored and reported through a specially designed website. The website provided the means to view data in real-time, while also facilitating the remote operation of equipment. The roof was equipped with a digital camera which could be accessed through the website, allowing users to pan and zoom in on any part of the study area.

Sensors were continuously polled by a network controller and data was archived locally at pre-programmed time intervals. Multiple trend logs were stored for each sensor on a daily, weekly and monthly basis to aid in detailed analysis. Archived logs were uploaded to a central web server at Seneca College for long term storage and automatic processing of data into user-defined report formats. Conventional browser access allows authorized users to examine pre-configured reports or perform custom queries of the archived database.

Digital instrumentation monitors for all network equipment were installed and calibrated to National Institute of Standards and Technology (NIST) traceable standards. Also, JAVA based automatic reporting software was installed for system wide access to the database for analysis and correlation.

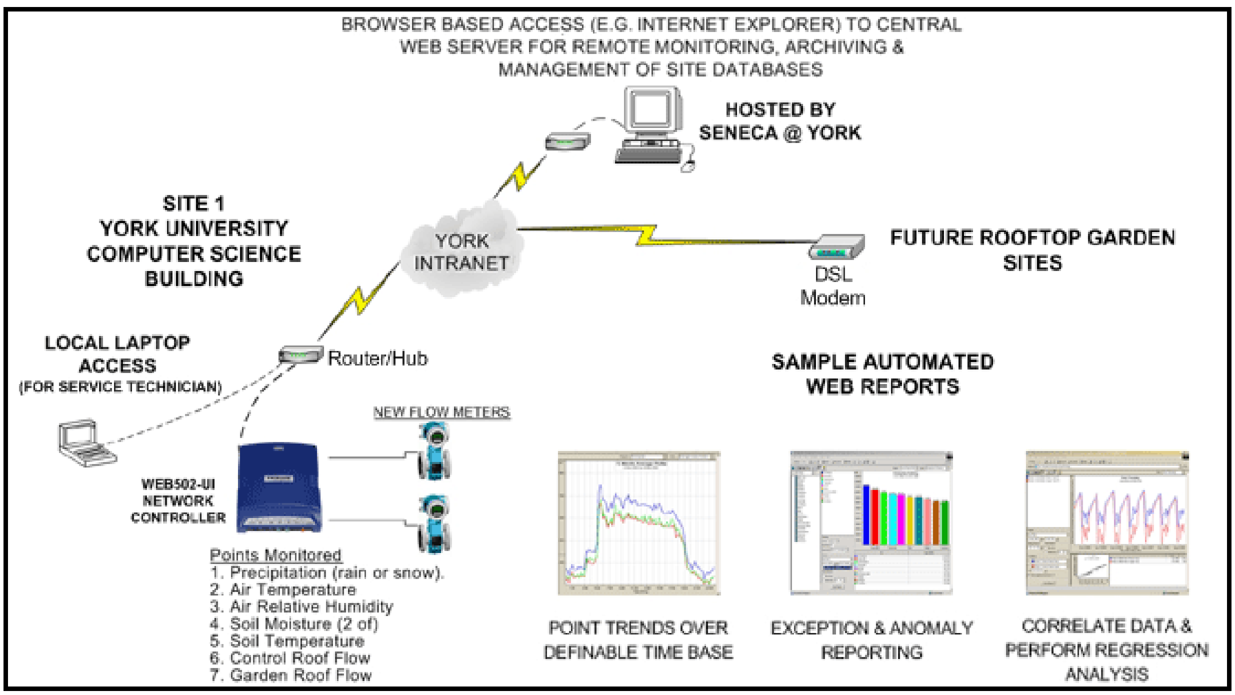


Figure 4.1: Schematic of web-based monitoring system (Facio, 2003)

The following subsections outline the methodology used to measure, collect, and interpret data collected at the York University greenroof. Figure 4.2 shows sensor and logger locations as well as flow direction.

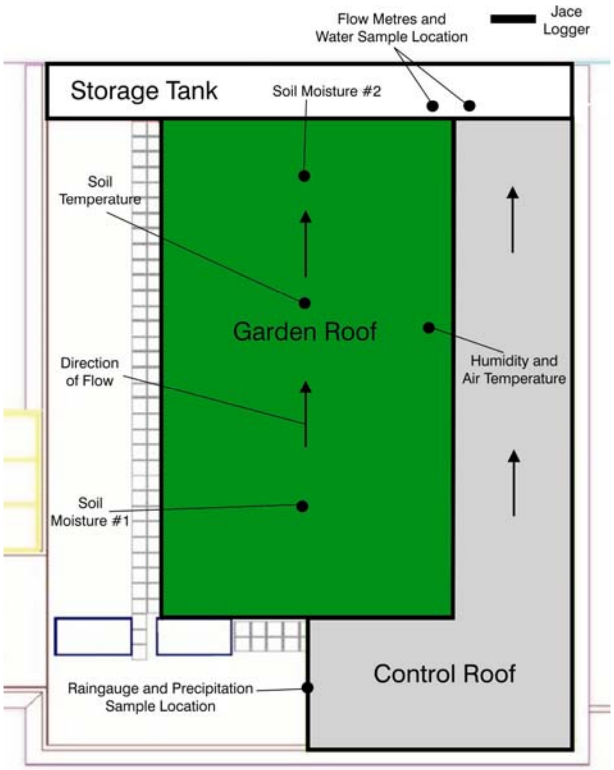


Figure 4.2: Schematic of Monitoring Set-up

4.1 Water Quantity

4.1.1 Runoff

The garden and control roof drained to separate eavestroughs at the bottom of the sloped study area. Flows conveyed to the eavestrough were piped through two 2-inch diameter Endress and Hauser Promag 50 flow metres, and ultimately to a storage tank (Figure 4.3). Flow rates were recorded at 1 minute intervals to a measurement accuracy of ± 0.5%.

Figure 4.3: Water Quantity and Water Quality sampler set-up

4.1.2 Precipitation

Precipitation at the site was measured using a Hydrological Services tipping bucket rain gauge. The rain gauge has a measuring range of 0 to 500 mm/hr with an accuracy of ± 2% at 100 mm/hr. Although the gauge was wrapped with heat tracing cable to prevent freezing during winter, it does not provide a reliable measurement of incoming precipitation in the form of snow. Precipitation must be in liquid form before it can be measured by this gauge. As snow accumulated on top of the gauge, it could be blown away and redistributed before the heat tracing cable could melt it.

4.1.3 Runoff Retention Statistics

The percent runoff retention of the garden relative to precipitation ($\%R_{GP}$) was calculated as:

$$\%R_{GP} = \frac{V_P - V_G}{V_P} \times 100 \qquad \text{(Equation 4.1)}$$

where:

V_P = Volume of precipitation falling on the garden (L)
V_G = Volume of runoff measured from the garden (L)

Similarly, the percent runoff retention of the garden relative to the control roof ($\%R_{GC}$) was calculated as:

$$\%R_{GC} = \frac{V_C - V_G}{V_C} \times 100 \qquad \text{(Equation 4.2)}$$

where:

V_C = Unit area volume of control roof runoff (L/m^2)
V_G = Unit area volume of garden runoff (L/m^2)

4.1.4 Growing Medium Moisture Content

In assessing the performance of a greenroof in terms of volume reduction, peak flow attenuation, and lag time it is important to know the amount of water in the soil immediately before a rainfall event, also referred to as the antecedent soil moisture condition. In order to collect this information, two ESI Gro-Point™ soil moisture sensors were installed within the garden substrate: one near the top (sensor #1) and the other near the bottom (sensor #2) of the slope (Figure 4.2). The sensors measured the percentage of moisture in the growing medium on a continuous basis and measurements were logged at five minute intervals.

4.2 Water Quality

4.2.1 Runoff Chemistry

Two ISCO 6700 automated water samplers were installed to collect samples of runoff from both the control roof and the garden (Figure 4.4). Samplers were programmed to initiate sampling of control roof runoff when flows exceeded 6 L/min and of garden runoff when flows exceeded 3 L/min. Samples were collected at 5 minute intervals at the control roof outlet and 10 minute intervals at the garden outlet. Sampling continued until twenty-four 1L bottles were collected. Both discrete and composite sampling was undertaken. Discrete sampling involved submitting each six litres of sample as a group. The samples could be divided into as many as four groups, depending on the amount of runoff collected. Discrete analysis allowed for more detailed analysis of contaminant concentrations over the course of an event. Composite sampling, which involved combining all 24 bottles into one sample, was undertaken for most events monitored. Composite samples were not proportioned according to flow.

Figure 4.4: ISCO 6700 Water Quality Samplers

The garden and control roof samples were submitted to the Ministry of the Environment (MOE) laboratories for analysis. Variables for which water quality analysis was conducted include the following:

- Metals
- Nutrients
- Conductivity
- Cations
- Chloride
- Turbidity
- Phenolics
- Anions
- PAHs
- Bacteria
- BODs
- CODs
- Suspended solids
- Alkalinity
- pH

4.2.2 Precipitation Chemistry

Precipitation water quality samples were collected using an open bag lining a bucket with a diameter of 48 cm. The precipitation samples were submitted to the Ministry of the Environment (MOE) laboratories for analysis. All precipitation samples were submitted to the laboratory as composites. Rainfall was submitted under the precipitation matrices because samples were considered “too clean” to be tested as surface water. Variables tested were similar to that of surface water.

4.2.3 Water Quality Analysis

The unit area loadings (UAL) for each water quality variable were calculated using Equation 4.3. This load represents the total load of a given water quality variable per square meter of roof, for all events which were sampled and submitted for water quality testing.

$$UAL = \frac{\sum_{i=1}^{i=n} (V_i \times EMC_i)}{A} \qquad \text{(Equation 4.3)}$$

where:
V_i = Total volume of runoff measured for a given event *i*
EMC_i = Event mean concentration of the variable for a given event *i* (g/m^3)
n = Number of events sampled
A = Catchment area from which the runoff was sampled (m^2)

The volume-weighted mean concentration (MC_{VW}) for each water quality variable was calculated as:

$$MC_{VW} = \frac{\sum_{i=1}^{i=n} (V_i \times EMC_i)}{\sum_{i=1}^{i=n} V_i} \qquad \text{(Equation 4.4)}$$

Total loads for each contaminant were also calculated in order to estimate loads for all events monitored for flow during the 2003 and 2004 monitoring seasons (May - November, 2003 and June - November, 2004). This value differs from the unit area load described in equation 4.3, as it includes events for which runoff was measured but no water quality sampling was done. This extrapolated unit area load was calculated as:

$$UAL_{ex} = \frac{MC_{VW} \times V_{MS}}{A} \qquad \text{(Equation 4.5)}$$

where:

UAL_{ex} = Extrapolated unit area load (g/m^2)
V_{MS} = Total volume of runoff for all events monitored during the 2003 and 2004 monitoring seasons (m^3)

The unit area loads for the control roof and garden were compared to one another by determining the percent difference between them for each water quality variable. The results of these calculations are presented in Tables 6.3, 6.5, 6.7, 6.9 and 6.11. The percent difference between the total load from the control roof and the garden was calculated in two ways: (i) using the UAL for water quality sampled events only (equation 4.3), and (ii) using the extrapolated UAL which represents the total load for all events monitored for flow over the 2003 and 2004 monitoring seasons. The general equation used to find both of these percent differences is:

$$\% \text{ Difference} = \frac{UAL_{control} - UAL_{garden}}{UAL_{control}} \times 100 \qquad \text{(Equation 4.6)}$$

where:

$UAL_{control}$ = Unit area load (g/m^2) for the control roof runoff
UAL_{garden} = Unit area load (g/m^2) for the garden runoff

4.2.4 Runoff Temperature

Between late July and late August, 2005, the temperature of runoff from both the control roof and the garden was measured using two HOBO® Water Temp Pro loggers. These sensors have a measurement accuracy of ± 0.2°C and were programmed to log measurements every five minutes. The temperature sensors were installed inside the control roof and garden pipes leading to the flow metre so that when storm runoff entered the pipe, the sensor was always submerged by runoff. Temperature measurements occurring when there was no flow (*i.e.* during dry weather) were later removed from the data set.

4.3 Micro-Climate

Continuous measurements of relative humidity, air temperature, and growing medium temperature were taken to characterize the micro-climate of the greenroof and assess storm event antecedent conditions. Veris Industries™ sensors were installed for the measurement of these three variables. The sensors' measurement accuracy for relative humidity, air temperature, and growing medium temperature were ±2%, ±0.25%, and ±0.25%, respectively. The locations of these sensors are shown in Figure 4.2. Monthly minimums, maximums, and means for air and soil temperature, soil moisture, and relative humidity are provided in Appendix A, Table A3.

4.4 Watershed Modelling

Data obtained from the first year of monitoring was used to model the benefits of greenroof implementation within the Highland Creek Watershed. A 'Unit Response Function' (URF) was developed to characterize the greenroof response to rainfall based on monitoring data collected in 2003 and a portion of 2004. The URF was applied to areas in the watershed with flat roofs and modelled using the Hydrological Simulation Program in Fortran (HSP-F) developed for the City of Toronto as part of their Wet Weather Flow Management Master Plan (WWFMMP). Eight representative sites were selected in order to determine the percentage of roof area versus the total site area.

For modeling purposes, it was assumed that: (i) only 75% of the area of a given roof would be available for a rooftop garden and (ii) the minimum size of roof area where greenroofs were applied was $100m^2$.

The HSPF model was run for a number of different 'what if' scenarios for a typical rainfall year (1992). The objective was to assess the hydrologic benefit assuming 50% and 100% implementation of the greenroof technology for suitable land uses *(i.e.* flat roofs).

A more detailed discussion of the methods used in the URF development and HSP-F modelling exercise may be found in the report entitled *HSP-F Modelling of a Green Roof Technology – Highland Creek Watershed* (Aquafor Beech, 2005).

4.5 Survey of Growing Media Chemical Characteristics

Eleven samples of greenroof growing media that are currently available on the market were obtained from manufacturers and submitted to Entech Laboratories in Mississauga for analysis. Samples were stored at room temperature for up to three months from the time they were received to the time when they were submitted to the laboratory. Analyses were conducted to determine the chemical and physical composition of each sample of bulk growing media as well as the quality of water leachate from each of these media.

4.5.1 Bulk Media Chemical Composition

The growing media used were recommended by the manufacturers for use on a greenroof with site characteristics similar to the York University greenroof, including a 10% slope, climate conditions such as those experienced in southern Ontario, and wild flower vegetation. Variables and physical characteristics for which the bulk growing media samples were analysed include the following:

- Metals
- Nutrients
- Grain size distribution
- Total volatile matter
- Oil and grease
- Cation exchange capacity
- pH
- Sodium adsorption ratio
- Electrical conductivity

Grain size distribution was determined by passing the samples through a 2 mm screen. The material that did not pass through the screen was deemed to be gravel. The material that passed through the screen was analyzed using a hydrometer to determine the percentages of sand, silt and clay which made up the remaining portion of the sample.

4.5.2 Leachate Quality

Leachate tests were conducted in order to characterize the chemical nature of runoff that would flow from a greenroof planted with these growing media. The water leaching process was intended to simulate the effect of precipitation on the media so that the filtrate could be considered representative of runoff chemistry. Variability in runoff chemistry over time was also investigated by leaching each media sample four times and comparing the chemistry of the first leachate to that of the fourth.

As part of the laboratory leaching procedure, a minimum of 100 grams of each sample was placed in an extractor vessel made of inert material, and a quantity of water equal to 20 times the weight of the solid phase was added. The vessel was placed in a rotary agitation device at 30 ± 2 rpm for 18 ± 2 hours, with ambient temperature maintained at 23 ± 2°C. For media with particles greater than 1 cm in its narrowest dimension, particle size reduction was performed prior to agitation. Following agitation the liquid and solid phases were separated using a borosilicate glass fibre filter with a pore size of 0.6 to 0.8 µm. This process was repeated on the same sample three more times, with only the first and fourth liquid extract being collected and analyzed. These first and fourth leachates were analysed for the following variables:

▪ Trace Metals	▪ Chloride	▪ Dissolved Solids	▪ Potassium
▪ Nutrients	▪ Sodium	▪ Conductivity	▪ Sulphate
▪ Alkalinity	▪ Total solids	▪ Turbidity	▪ Bromide
▪ pH	▪ Suspended solids	▪ Hardness (CaCO3)	▪ Oil & grease

The samples tested for trace metals were acidified with nitric acid to a pH <2. All other samples were stored under refrigeration (4°C) until analysed. Maximum holding times (360 days) for all samples were not exceeded.

4.6 Fauna Inventory

An inventory of fauna species on the greenroof was conducted during the 2004 and 2005 monitoring seasons by a qualified biologist. Eight visits were made to the greenroof between May and October, 2004, and ten visits were made in 2005, between April and October. The site visits consisted of the biologist standing on the perimeter of the garden and quietly assessing the presence of birds. The biologist then walked slowly around the entire site. The duration for each visit was kept to approximately 15 minutes, as dictated by opportunity and expectation. The frequency of visits to the site was determined by the time of year. During the bird breeding season between June and July the inventory was conducted once a month. Visits to the site were more frequent in the spring and fall since the migrating birds are only present for short periods of time. Notes were taken for each visit detailing the weather conditions and time of observer arrival and departure. Any birds observed were mapped on a diagram of the project site, along with brief details of their behaviour (e.g. foraging, resting, etc.).

4.7 Flora Inventory

Botanical surveys of the greenroof were conducted during the 2004 and 2005 monitoring seasons. Surveys were completed for the entire greenroof and were not limited to the garden study area shown in Figure 3.1. Two visits were conducted in 2004 during the summer and fall, while three visits were conducted in 2005 during the spring, summer and fall. The inventory included both a comprehensive species inventory of every plant found on the greenroof and a quadrat study to analyze quantitative composition. Coefficients of conservatism, which are a measure of how much a species is restricted to high-quality natural habitats, were assigned for the native vascular plants using both the TRCA and the Ontario Natural Heritage Information Center (NHIC) versions of the coefficient of conservatism. Using both versions of this coefficient, floristic quality of the site was determined for the greenroof.

4.8 Bee Survey

The greenroof bee survey was conducted by Erin Willis, a York University undergraduate in biology, as part of a thesis project.

Pan traps were used to survey the species of bees on the greenroof. Collections took place in August and September of 2004 and from late June until early August in 2005. The pan traps were spray-painted yellow, blue and white to resemble flowers. Thirty pans (10 blue, 10 white and 10 yellow) were set up in an X-pattern on the sloped roof and the higher flat part of the roof. The pans were spaced approximately

3m apart from each other. The pans were filled with a mixture of water and odourless soap, the latter necessary to break the surface tension of the water allowing insects to fall in easier. The pans were left out from 8am until 3pm.

Additional sets of 30 pans were set up on different sites on campus in the vicinity of the Computer Science and Engineering building. The additional sites included a woodlot, a lawn and an old field. The same protocols were used to allow comparison between the greenroof site and the additional sites.

Bees collected were pinned and each specimen was labelled with location, date collected, and name of collector. Specimens were then identified to genus and species using Mitchell (1960, 1962) and other relevant taxonomic keys (Laverty 1988, McGinley 1986). Identifications were verified by comparison to a reference collection and specimens from Grixti's (2004) bee survey of an old field site in Southern Ontario. Species identifications were further confirmed, for most taxa, by Dr. Laurence Packer.

5.0 WATER QUANTITY ANALYSIS

Monitoring of control roof and garden runoff as well as rainfall was carried out on a continuous basis from May 2003 through to August 2005. All precipitation and hydrologic data for 154 rainfall events monitored during the spring, summer and fall over the study period are presented in Appendix A, Table A1. These events represent almost all events which occurred during this period. Events were omitted if they generated no runoff from the control roof, which was typically found to occur only for events with less than 1 mm of rain. Winter data were incomplete. These data are discussed separately in section 5.2.1.

5.1 Rainfall

Total monthly precipitation and average monthly temperature over the study period are compared to long term climate normals (1971-2000) in Figures 5.1 and 5.2. Due to its proximity to the greenroof site, the climate data for 2003 to 2005 were taken from the North York Atmospheric Environment Service (AES) station. Climate normals were only available from the AES station at Pearson International Airport. The comparison indicates whether or not study results are representative of normal climatic conditions.

The total precipitation for 2003, 2004 and 2005 was 964, 839 and 948 mm, respectively. All years were above the normal annual precipitation of 793 mm. The spring and fall of 2003 were wetter than normal whereas the summer of 2003 was slightly drier than normal (Figure 5.1). Both the spring and summer of 2004 were wetter than normal while the fall was much drier than normal. In 2005, the spring was slightly drier than normal despite a much wetter than normal April. The summer was drier than normal with the exception of August, during which 140.6 mm of rain was received on the 19th. This event caused the monthly rainfall to greatly exceed normal levels, even though the quantity of rainfall received during the rest of that month was close to normal. It should be noted that flow data presented in this chapter includes only rainfall received until 12:00pm on August 19th.

The average annual temperature for 2003, 2004 and 2005 was 7.7°C, 7.9°C and 8.7°C respectively. The normal average annual temperature is 7.5°C. The summer and fall of 2003 were hotter than normal and the spring of 2003 was colder than normal (Figure 5.2). In 2004 both the spring and fall were hotter than normal whereas the summer was slightly colder than normal. Temperatures were close to normal in the spring of 2005 while they were significantly higher than normal in the summer.

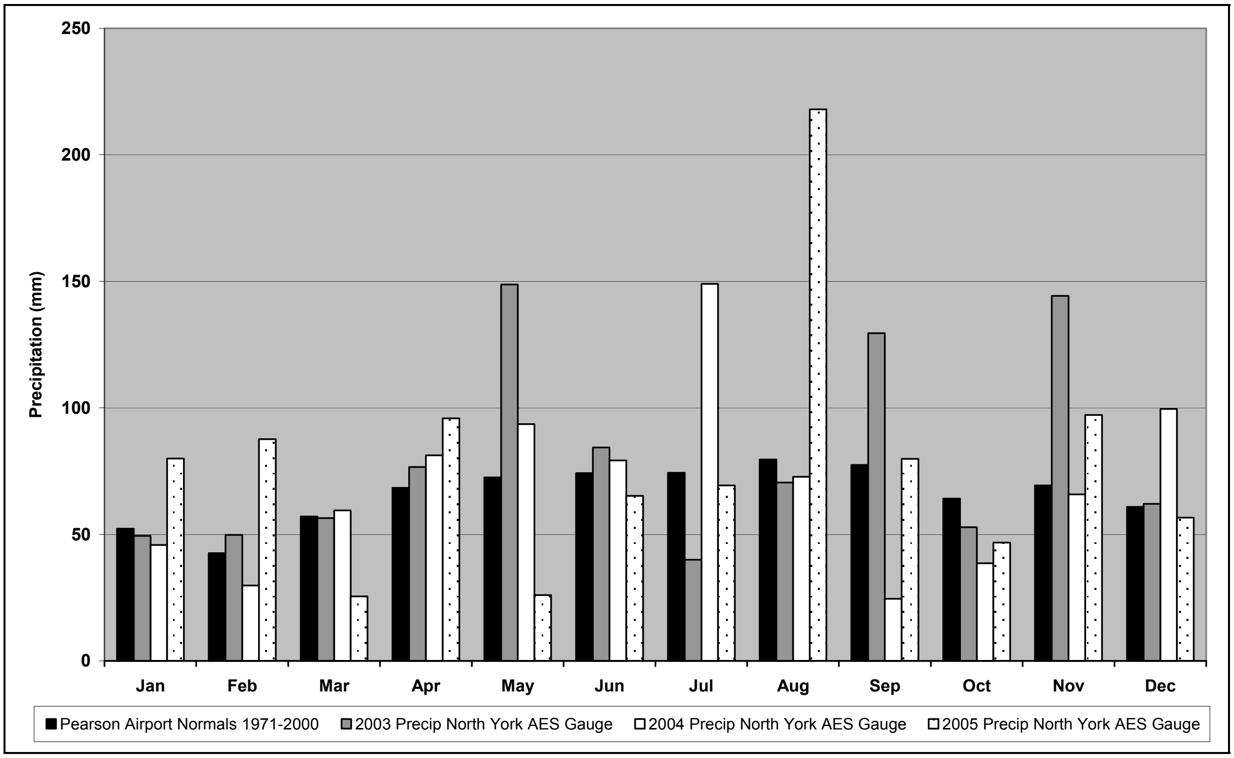


Figure 5.1: Precipitation Data Normals from Pearson International Airport and 2003-2005 Data from North York AES Gauge (Source: Environment Canada, 2006)

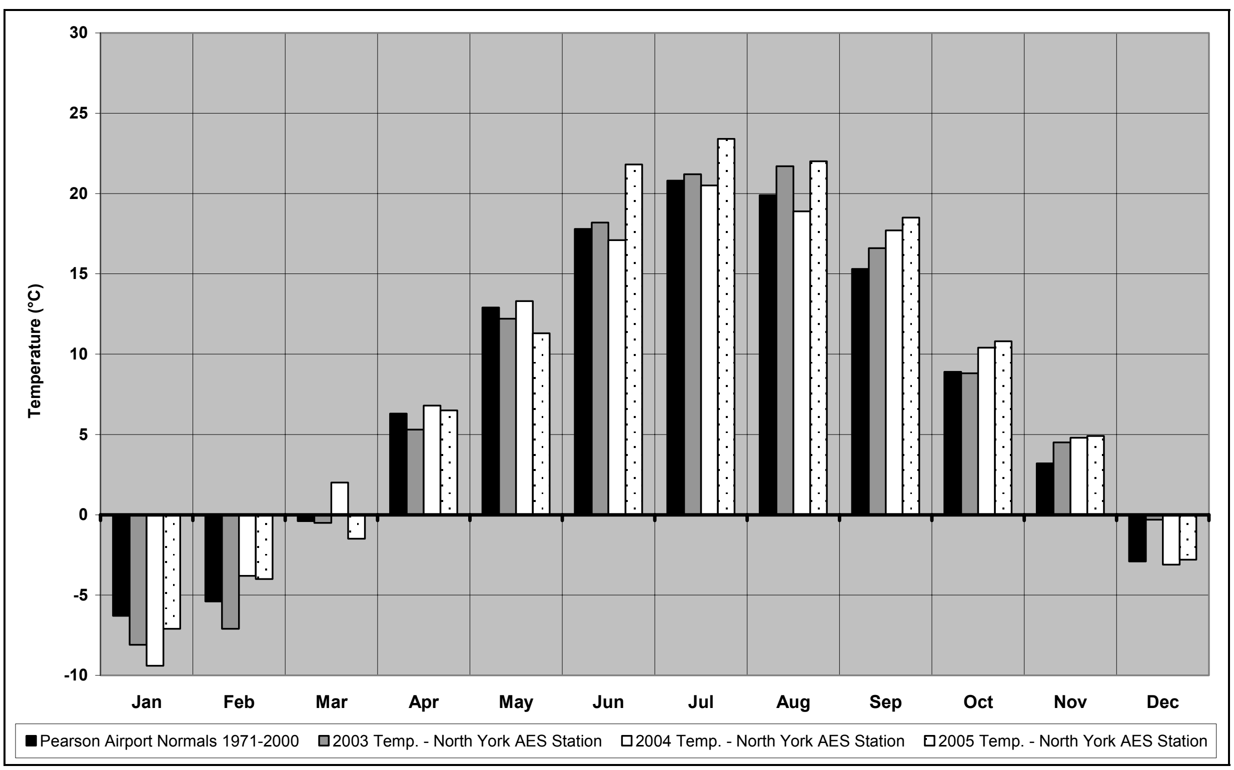


Figure 5.2: Temperature Data Normals from Pearson International Airport and 2003-2005 Data from North York AES Station (Source: Environment Canada, 2006)

5.2 Volume Reduction

The monthly performance of the garden with respect to runoff volume reduction is summarized in Table 5.1. Over the study period, the garden retained approximately 65% of precipitation. There was also a small amount of water retained on the control roof, mostly during small summer events. The discrepancy between monthly precipitation and control runoff volumes reflects this retention, as well as inherent errors in flow and rainfall measurements. These errors are minimized when the control roof and garden runoff are directly compared because both use a common rainfall measurement. Relative to the control roof, the garden retained 63% of flow volumes over the study period.

Runoff coefficients represent the proportion of total precipitation volumes that are converted to runoff. Since very little runoff is retained on the control roof, the runoff coefficient for the entire study period is close to 1.0. The garden coefficient over the same period was 0.35. As mentioned previously, monthly control roof runoff coefficients less than 0.95 and greater than 1.0 are probably a result of instrument error, which can exceed 10% when measurement errors on the raingauge and flow meter operate in the same direction.

5.2.1 Seasonal Performance

As shown in Table 5.1, the garden's capacity to retain rainfall was significantly lower in 2003 than later in the study. The garden retained only 54% of precipitation in 2003, compared to approximately 75% during the 2004 and 2005 monitoring seasons. This 20% increase in runoff retention in 2004 and 2005 is attributed to larger precipitation depths in the fall of 2003 and much larger irrigation volumes, both of which had a strong influence on the garden's ability to retain water. Note that no data were collected during the fall in 2005. The absence of fall data helps explain the high percent retention value reported for 2005, as the garden's ability to retain rainfall is typically higher in the summer than in the fall.

Table 5.2 lists monthly total runoff volumes caused by irrigation of the garden. These monthly totals do not represent the total volume of irrigation applied to the garden, but only the volume which was not retained. Each year, irrigation was initiated in June and ended in October. During the 2003 monitoring season, the garden was irrigated automatically every night regardless of weather conditions. In 2004, the irrigation system was configured to trigger based on soil moisture levels and thus irrigation only occurred when the soil conditions dropped below a threshold value. This system remained in place in 2005, however due to the malfunctioning of the soil moisture sensors, irrigation occurred far more frequently than required. In July 2005, the irrigation system was disconnected from the soil moisture sensors, so that irrigation again occurred every night regardless of precipitation. These changes are reflected in Table 5.2, which shows that flow volumes from irrigation were significantly higher in 2003 and 2005 in comparison to 2004. The 2003 total volume was approximately 4400 litres for June to October, while the 2004 total was only 795 litres over the same period of time. The 2005 volumes are approximately 40% greater than those experienced in 2003 over the June to August period.

Table 5.1: Summary of monthly rainfall, runoff volumes, percent retention, and runoff coefficients for the garden and control roof

		Month	Total Rain (mm)	Inflow (L)‡		Outflow (L)		Outflow per unit area (L/m^2)		% Runoff retention (relative to precipitation)		% Runoff retention (relative to control)	Average runoff co-efficient	
				Gdn	Ctrl	Gdn	Ctrll	Gdn	Ctrl	Gdn	Ctrl	Gdn	Gdn	Ctrl
2003	Spring / Summer	May	121.8	29354	15956	11202	14934	47	114	61.8	6.4	59.2	0.38	0.90
		June	87.8	21160	11502	3489	12175	15	93	83.5	-5.9	84.4	0.16	1.08
		July	44.2	10652	5790	749	5263	3	40	93.0	9.1	92.3	0.07	0.93
		Aug	62.6	15087	8201	2712	8192	11	63	82.0	0.1	81.9	0.18	1.01
		Total	**316.4**	**76252**	**41448**	**18152**	**40564**	**75**	**310**	**76.2**	**2.1**	**75.6**	**0.24**	**0.98**
	Fall	*Sept	143.6	34608	18812	21454	18977	89	145	38.0	-0.9	38.6	0.62	1.01
		Oct	55	13255	7205	7951	7568	33	58	40.0	-5.0	42.9	0.60	1.05
		*Nov	148.8	35861	19493	25907	21415	108	164	27.8	-9.9	34.3	0.72	1.10
		Total	**347.4**	**83723**	**45509**	**55293**	**47960**	**229**	**366**	**34.0**	**-5.4**	**37.4**	**0.66**	**1.05**
2003 Totals:			**663.8**	**159976**	**86958**	**73445**	**88524**	**305**	**676**	**54.1**	**-1.8**	**54.9**	**0.46**	**1.02**
2004	Spring / Summer	June	63.9	15400	8371	2489	7639	10	58	83.8	8.7	82.3	0.16	0.91
		July	172.2	41500	22558	10464	18780	43	143	74.8	16.7	69.7	0.25	0.83
		Aug	89.4	21545	11711	4402	10015	18	76	79.6	14.5	76.1	0.20	0.86
		Total	**325.5**	**78446**	**42641**	**17355**	**36434**	**72**	**278**	**77.9**	**14.6**	**74.1**	**0.22**	**0.85**
	Fall	*Sept	29.6	7134	3878	1350	3878	6	30	81.1	0.0	81.1	0.20	1.00
		Oct	26.6	6411	3485	613	2989	3	23	90.4	14.2	88.9	0.10	0.86
		Nov	61.4	14797	8043	6745	7614	28	58	54.4	5.3	51.8	0.46	1.00
		Total	**117.6**	**28342**	**15406**	**8708**	**14480**	**36**	**111**	**69.3**	**6.0**	**67.3**	**0.31**	**0.94**
2004 Totals:			**443.1**	**106787**	**58046**	**26063**	**50914**	**108**	**389**	**75.6**	**12.3**	**72.2**	**0.24**	**0.88**
2005	Spring / Summer	April	103.6	24968	13572	14869	13516	62	103	40.4	0.4	40.2	0.60	1.00
		May	23	5543	3013	233	2496	1	19	95.8	17.2	94.9	0.04	0.83
		June	62.5	15063	8188	949	6089	4	46	93.7	25.6	91.5	0.06	0.74
		July	50.8	12243	6655	774	5675	3	43	93.7	14.7	92.6	0.07	0.89
		†Aug	63.6	15328	8332	1671	7471	7	57	89.1	10.3	87.8	0.17	1.36
2005 Totals:			**303.5**	**73144**	**39759**	**18497**	**35247**	**77**	**269**	**74.7**	**11.3**	**71.5**	**0.25**	**0.89**
Monitoring Period Totals:			**1410.4**	**339906**	**184762**	**118005**	**174686**	**490**	**1334**	**65.3**	**5.5**	**63.3**	**0.35**	**0.95**

* Measured flow volumes were not available for some events which occurred during these months. Values are estimated based on measured flows from other similar sized events, occurring in the same season, and with similar antecedent moisture conditions.

† Results represent data collected from August 1, 2005 until 12:00 pm on August 19, 2005.

‡ Inflows were calculated based on measured precipitation and the total catchment area.

Note: Seasonal, annual, and monitoring period total percent retention values are calculated based on total inflow and outflow measurements.

Table 5.2: Monthly garden runoff volumes from irrigation

Year	Month	Total runoff from garden attributed to irrigation (Litres)
2003	June	118.5
	July	618.9
	August	915.5
	September	1494.6
	October	1317.1
	2003 Total:	**4464.6**
2004*	June	252.5
	July	96.1
	August	182.8
	September	136.9
	October	126.9
	2004 Total:	**795.2**
2005	June	648.9
	July	1038.0
	August	702.6
	2005 Total:	**2389.5**

* Irrigation was controlled by the soil moisture sensors. If the soil moisture fell below a certain threshold value in the afternoon, the sprinklers would come on overnight.

Spring/Summer

As shown in Table 5.1, runoff retention and runoff coefficients for the garden during the spring/summer season varied little from year to year and were always better than in the fall. Total spring/summer retention on the garden ranged from 74% to 78% over the study period. In general, retention is lower during the spring when monthly precipitation is higher, and evapotranspiration is lower than in the summer. May 2005 is an exception to this trend due to the unusually low quantity of rainfall (Figure 5.1). This is reflected in the results (Table 5.1), which indicate that during the month of May approximately 100 mm more precipitation was received in 2003 than in 2005, resulting in 34% more precipitation being retained in May 2005. This observation underscores the strong influence of rainfall and antecedent moisture content on the garden's ability to retain water.

Fall

During the fall the garden retained 34% of precipitation in 2003, compared to 69% in 2004. Much higher rainfall volumes and antecedent moisture conditions in 2003 largely explain this difference. The month of October in 2003 was an exception. In this month only 55 mm of precipitation was received, but retention was relatively low at 40%. The low retention value is attributed to irrigation, which was much higher in October 2003 than the same month in 2004 (Table 5.2). Overall, retention values in the fall decreased as the weather turned colder, as may be expected.

Winter

Reliable runoff data were not available for the winter months from January to March. However, measured garden retention rates in December were 30% in 2003 and 13% in 2004. Evaporation rates increase from December 21st through to March as the days become longer, but rain on snow can still result in very low retention rates during this period. The measured retention rate in April 2005, after the snow had melted was 40%.

Based on the pattern of snow and rain during the 2003 and 2004 winter months, and monitored data in December and April, retention rates were assumed to range between 5 and 25% from January to March. Accepting these values as reasonable, annual retention for the study period would range from 51 to 54% (Table 5.3). During a 'normal' year (1971-2000), assuming 63% retention from April to November (based on monitored data), and 22.5% for December, the annual retention rate would range from 49 to 53%.

Table 5.3: Runoff volumes and percent retention values for 2003, 2004, the two years together, and 'normal' (1971-2000) precipitation, assuming 5 and 25% runoff retention on the garden from January to March.

	Unit Area Runoff Volume (L/m^2)			Percent Retention of garden relative to control	
	Garden		Control		
Winter % retention[1]	5%	25%	0%	5%	25%
2003	547.8	516.7	977.1	43.9	47.1
2004	400.3	373.3	959.5	58.3	61.1
2003-04 Total	948.1	890.0	1936.6	51.0	54.0
Normals (1971 - 2000)[2]	406.1	375.7	792.8	48.8	52.6

1 % Retention for the months of Jan - Mar are assumed to be either 5% or 25%. This range is based upon available winter monitoring data.

2 Runoff volumes are calculated based on monthly precipitation normals from Environment Canada's Pearson Airport gauge. In the calculation, a garden retention rate of 63% (based on monitoring results) is assumed for the months of April to November, while 22.5% is assumed for the month of December (representing an average of December retention results in 2003 and 2004).

5.2.2 Event-based Performance

Figure 5.3 shows runoff volumes from the control roof and garden and corresponding runoff coefficients for a range of selected rainfall events monitored over the study period. Events are divided into summer/spring (a) and fall (b), and displayed in order of increasing magnitude from left to right. Table A2, Appendix A contains detailed hydrologic information for all events shown in these charts.

In general, runoff coefficients increased with event size during the growing season. In Figure 5.3a, the smallest event shown had the lowest garden runoff coefficient. This result is to be expected, as small amounts of initial rainfall are easily absorbed by the garden. For events up to the 24 mm event, runoff coefficients seem to respond only slightly to changes in storm size, while the response is more pronounced for events larger than 24 mm.

The highest garden runoff coefficient shown in Figure 5.3a occurred on April 23, 2005, during which 31 mm of rainfall was recorded. The next largest runoff coefficient occurred on July 20, 2004, during an event with even more rain (48.6 mm). Normally, larger rainfall translates into lower retention capacities and higher runoff coefficients. However, in this case, the reverse was true, probably due to higher evapotranspiration rates in July relative to April. As indicated in Table A1 in Appendix A, antecedent soil moisture levels were very similar prior to these two events.

During the fall (Figure 5.3b), the correlation between runoff coefficients and event size is less apparent than during the spring and summer (Figure 5.3a). The two largest events shown in Figure 5.3b occurred in September 2003 and had lower runoff coefficients than the smaller November events. It would appear that low intensity, long duration storms in October and November, combined with relatively low temperatures, keep the soil moist, which reduces garden retention capacities. Measurements taken at Environment Canada's North York AES station indicate that while the average monthly temperature was almost 17°C in September 2003, average monthly temperatures for November 2003 and 2004 were only 4.5°C and 4.8°C respectively. This result suggests that during the fall, ambient air temperature and antecedent moisture content may be as important as event magnitude in controlling garden runoff retention capacity.

Hydrographs and hyetographs for several events are provided in Appendix A. The hydrographs represent a range of event sizes and seasons. In general, the garden's performance with respect to volume reduction decreased when rainfall volumes and antecedent soil moisture content increased. Other important, but usually less significant factors include air temperature, soil temperature, relative humidity and various rainfall characteristics such as intensity and duration.

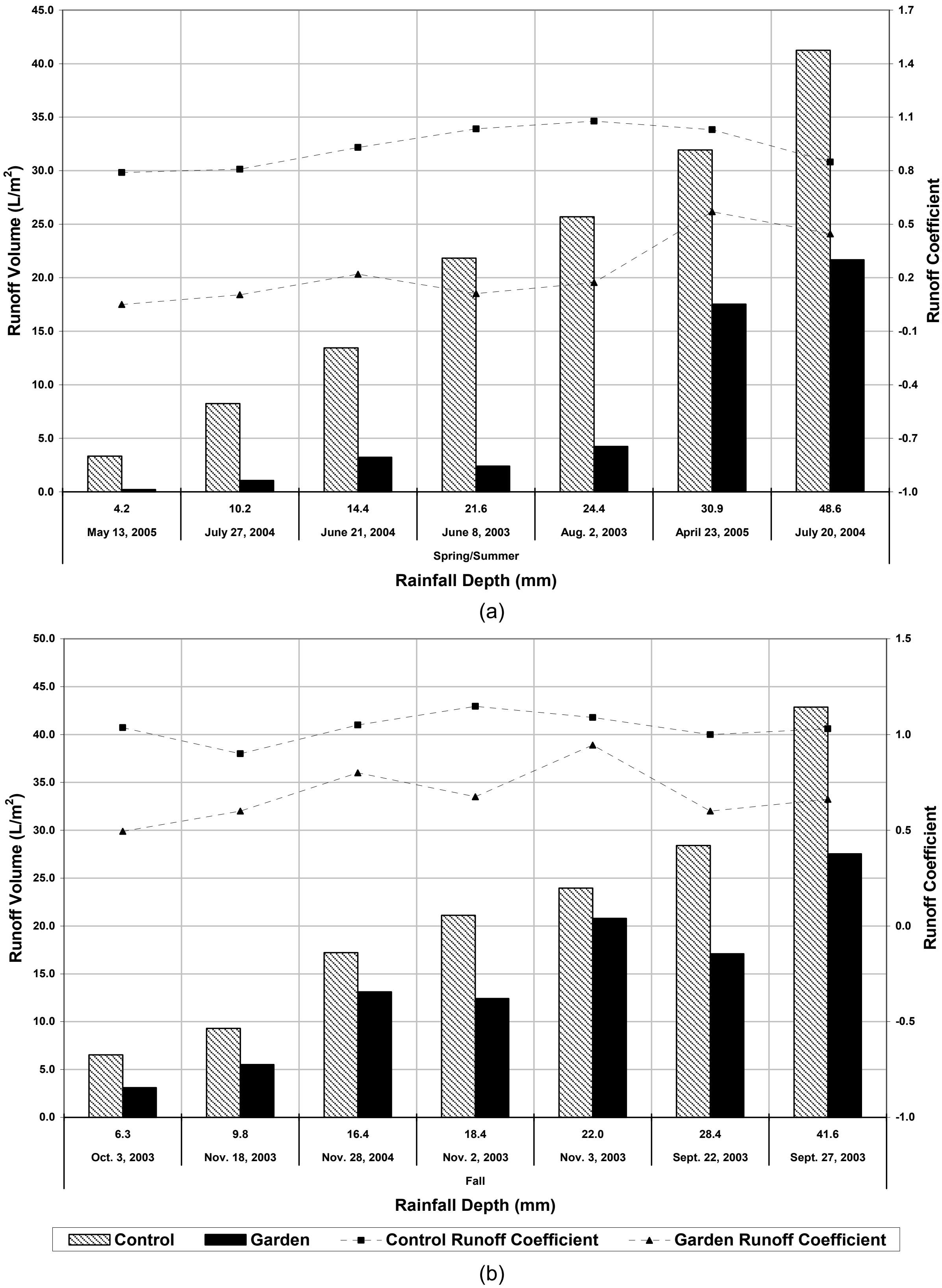


Figure 5.3: Control roof and garden runoff volumes and runoff coefficients for a range of event sizes during the spring/summer (a) and fall (b).

Event of August 28, 2004

Figure 5.4 shows precipitation and runoff flows from the control roof and garden for two consecutive events on August 28th to 29th, 2004, with an inter-event period of approximately 11 hours. The soil moisture response of the garden and air temperature measurements during the event are also shown (bottom chart). For the first event, with 8.8 mm of rain, the control roof responds immediately, while the runoff response from the garden is delayed and much smaller in magnitude, as the majority of rain is absorbed by the soil. The soil moisture content of the garden increases by just over 1% in response to this first rainfall event. Soil moisture begins to decrease slightly prior to the start of the second event.

The garden's response to the second 24.2 mm event is far more immediate due both to the higher antecedent soil moisture content and the higher rainfall intensity. During this event, soil moisture increases by approximately 2.5%. The garden response starts to mirror that of the control roof by the end of the second event. Nevertheless, volume reduction through the two events approaches 40%.

Event of May 16, 2003

Figure 5.5 depicts the runoff from a rainfall event that occurred on May 16, 2003 during which 30.6 mm of precipitation fell over a 20 hour period. At the beginning of the event, runoff from the garden is much lower than from the control roof as water is being retained within the garden substrate. The flow from the garden increases over the course of the event and ultimately exceeds the flow from the control roof during the latter part of the storm. The runoff from the garden begins to exceed that of the control at the point when the soil moisture curves begin to plateau at approximately 42.5% for the lower sensor and 33.0% for the upper sensor. Soil moisture measurements do not show any response to precipitation after this point in the event, as the substrate has become saturated. The garden provides no volume reduction benefit relative to the control roof once this saturation point has been reached.

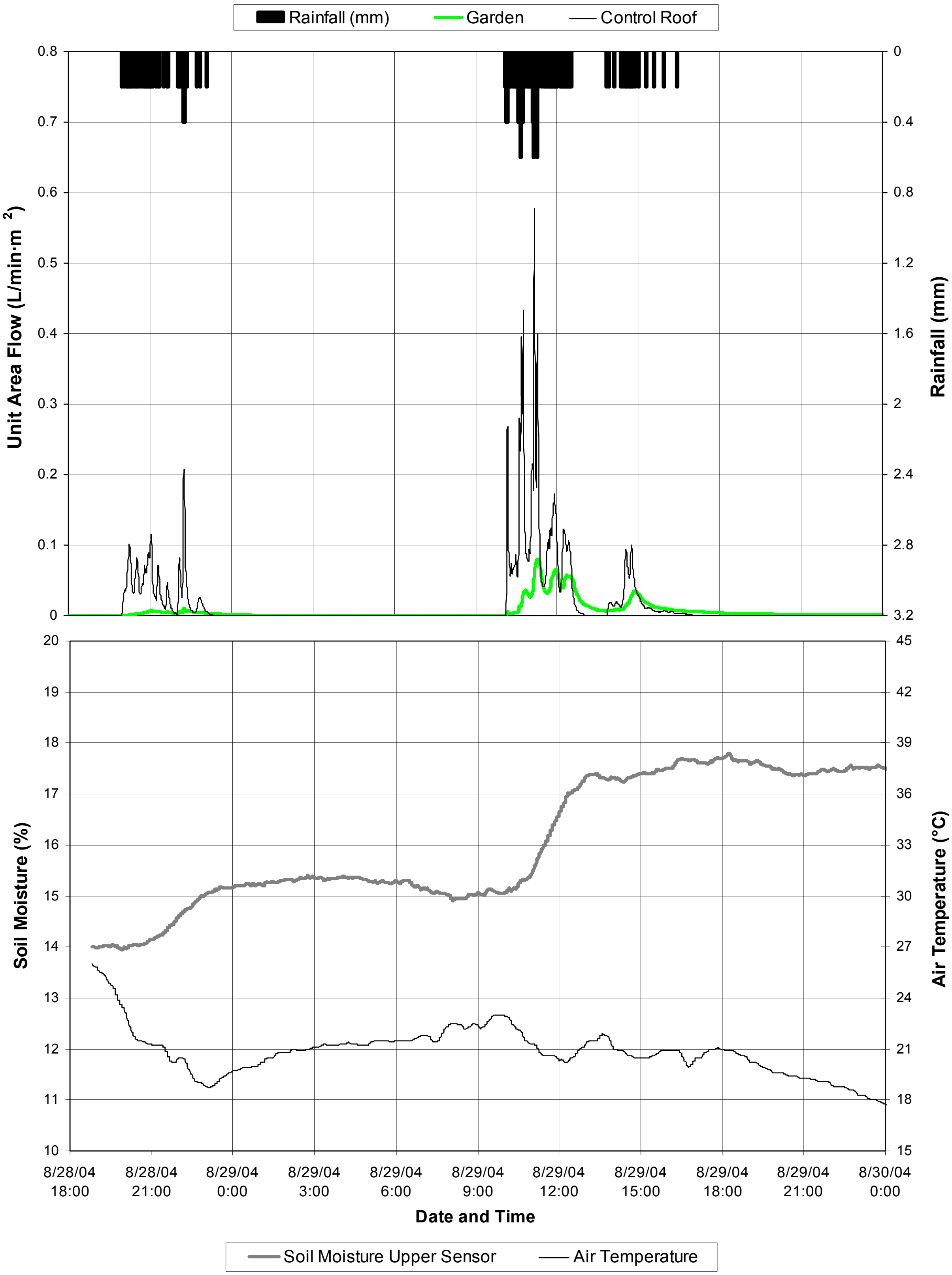


Figure 5.4*:* Top - Hydrographs and hyetograph for two events from August 28 – 29, 2004. The first is 8.8mm, the second is 24.2mm. Bottom - Soil moisture and air temperature response.

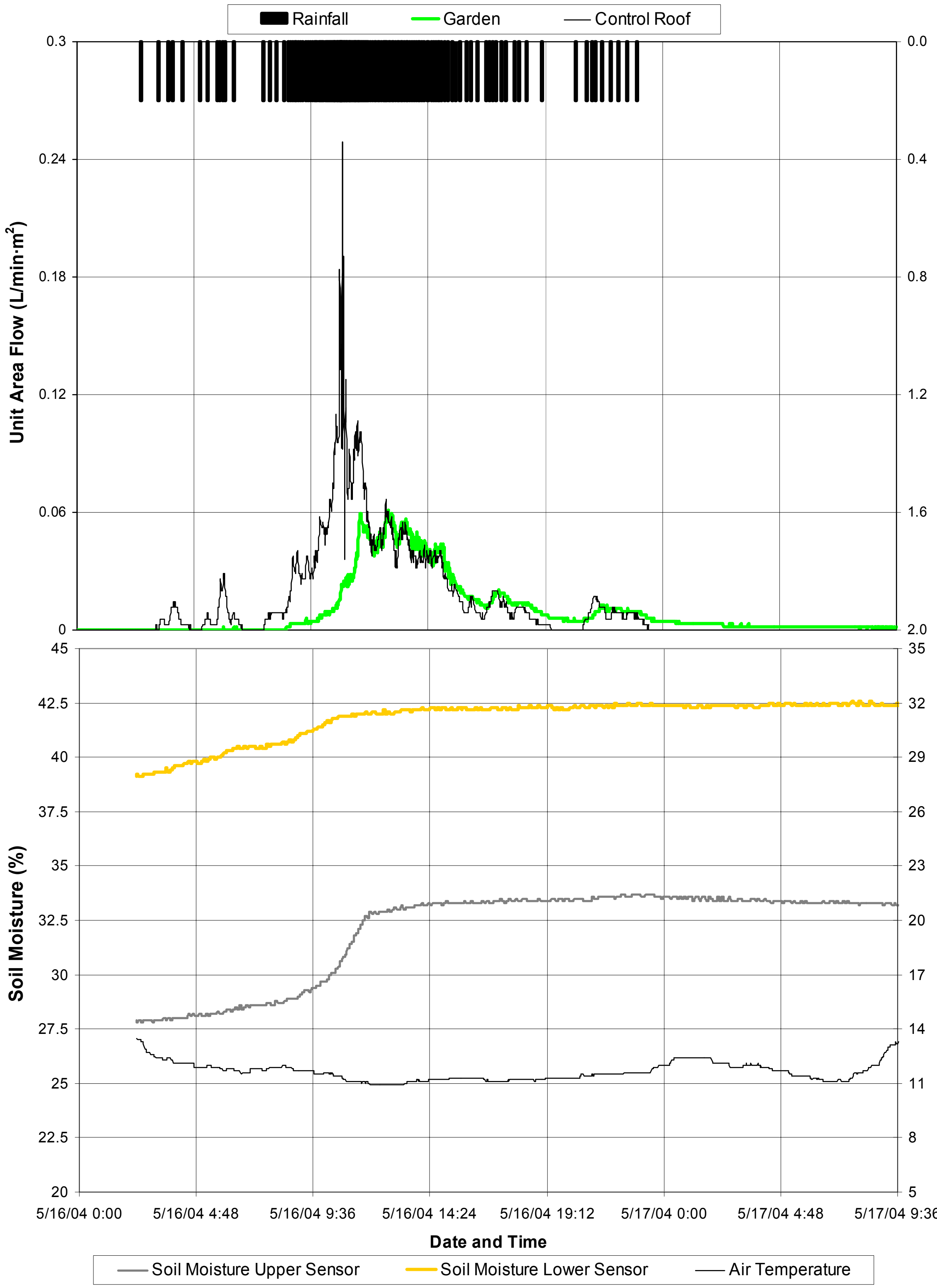


Figure 5.5*:* Top – Hydrographs and hyetograph for a 30.6 mm event on May 16, 2003.   Bottom - Soil moisture and air temperature response.

<u>Snowmelt event of December 16, 2003</u>

Figure 5.6 shows runoff from the control roof and garden during a snowmelt event on December 16, 2003. The unit area flow volume from the garden during this event was approximately 4 L/m^2, while the control roof runoff was 6.2 L/m^2. Hence, the garden retained roughly 35% of runoff relative to the control roof, which is substantial given the time of year. Other water quantity benefits during the winter include peak flow reduction and increased runoff lag times. During this event, the garden peak flows were 15% less than the control roof and there was a 5 hour lag in peaks between the two surfaces. These peak flow characteristics help to prevent stream erosion and reduce the frequency of overflows in areas where there are combined sewers.

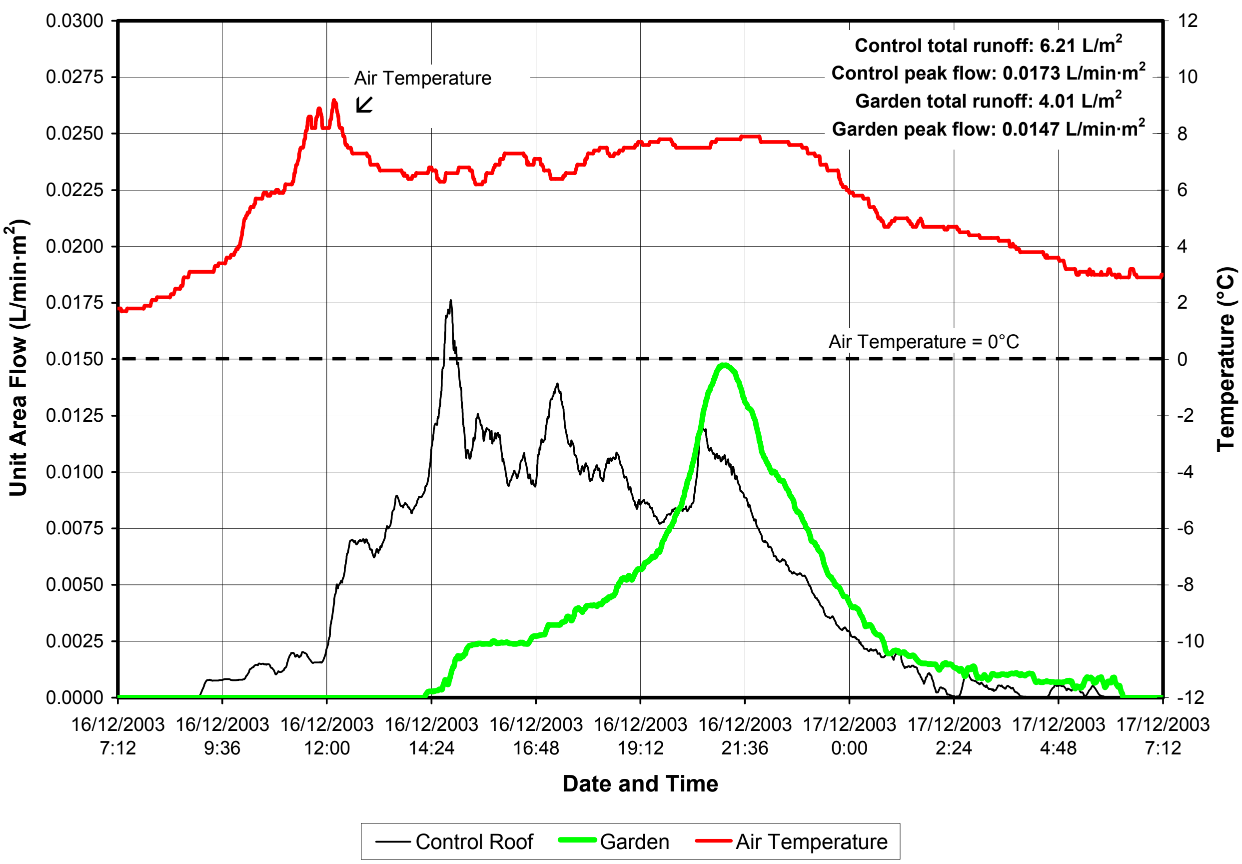


Figure 5.6: Air temperature and runoff from the control roof and garden during a snowmelt event on December 16, 2003.

5.3 Peak Flow Attenuation

Table 5.4 shows the average peak flow reduction of the garden relative to the control roof for different event size ranges. Table A4 in Appendix A lists peak flows for the control roof and garden, and the peak flow reduction of the garden, for each event in these categories. In Table A4 variations in peak flow reductions do not appear to be seasonal.

Table 5.4: Average peak flow reduction of garden relative to control roof for different event categories

Rainfall event category	Average peak flow reduction (%) (relative to control roof)
10-19 mm	87.6
20-29 mm	86.7
30-39 mm	67.8
≥ 40 mm	50.3

The garden attenuates peak flows less effectively during large events. As rainfall volumes increase above 30 mm, peak flow reductions drop from 87 to 68% for events between 30 and 39 mm, and to 50% for events larger than 40 mm. Within the City of Toronto, approximately 98% of rainfall events that occurred between 1970 and 2002 were less than 30 mm (Klassen, 2005). Assuming that peak flow reduction during events smaller than 10 mm are as high or higher than 87%, it may be concluded that the garden could provide at least an 87% reduction in peak flows for 98% of rainfall events in Toronto.

5.4 Lag Times

Lag time is a measure of the hydrologic response to rainfall. In this study, lag time is defined as the time delay between the start of rainfall and the start of runoff. Monthly average lag times as well as average lag times for the entire monitoring period are shown in Table 5.5. Individual event lag times have also been calculated and are presented in Appendix A, Table A1.

The average lag time between the start of precipitation and the start of runoff from the garden for all events monitored was 29.8 minutes, while the control roof lag was 2.9 minutes. There did not appear to be a seasonal trend in lag times. Monthly average runoff coefficients also do not seem to be strongly correlated with monthly lag times.

Event-based lag times are determined by several factors including antecedent soil moisture content, rainfall amount and intensity, air temperature and relative humidity. The relationship between these variables and the runoff lag time provided by the garden is complex, making it difficult to distinguish trends in lag time among individual events. Antecedent moisture conditions are generally drier in the summer, because of higher evapotranspiration, but at the same time, rainfall intensities are often much greater than at other times of the year. These opposing trends may explain why a clear seasonal trend cannot be discerned from the data.

Table 5.5: Average monthly runoff lag times and runoff coefficients

	Month	Total rainfall (mm)	Average runoff lag‡ (min)	
			Control	Garden
2003	May	121.8	3.4	88.7
	June	87.8	4.5	16.5
	July	44.2	4	10.8
	August	62.6	1.4	4.3
	*September	143.6	1	3
	October	55.0	-2.6	29.6
	*November	148.8	3.4	17.5
2004	June	63.9	0.9	27.3
	July	172.2	2.4	15.9
	August	89.4	-0.6	20.5
	*September	29.6	-	-
	October	26.6	7.1	108.4
	November	61.4	10.0	69.9
2005	April	103.6	4.5	21.9
	May	23	6	25.6
	June	62.5	-1.2	4.3
	July	50.8	1.5	30.6
	†August	63.6	3.6	11.3
	Monitoring Period:	**1410.4**	**2.9**	**29.8**

* Measured flow volumes were not available for some events which occurred during these months. Values are estimated based on measured flows from other similar sized events with similar antecedent moisture conditions and monitored in the same season.

†Results only represent data collected from August 1, 2005 until 12:00 pm on August 19, 2005.

‡ Runoff Lag is calculated from the start of precipitation to the start of runoff

5.5 Watershed Modelling

This section presents the water quantity modeling results for scenarios that assume 50% and 100% greenroof implementation on flat roofs in the Highland Creek Watershed. Detailed results are available in the report entitled *HSP-F Modelling of a Green Roof Technology – Highland Creek Watershed* (Aquafor Beech, 2005)

5.5.1 Land Use Analysis

The land use areas for which flat roofs could be implemented in the Highland Creek Watershed are summarized by subwatershed in Table 5.6. Roughly 9% of the total watershed area had flat roofs that could be greened.

Table 5.6: Flat roof area simulated in Highland Creek Watershed HSP-F model

Subwatershed	Subwatershed Area (ha)	Land Use with Flat Roof[1] (ha)	Flat Roof Area[2] (ha)
Dorset Park Branch	1382.5	544.4	175.5
Bendale Branch	2534.0	715.9	191.3
Markham Branch	2124.4	719.2	209.2
Malvern Branch	1411.0	618.4	227.7
Centennial Branch	519.0	41.5	9.7
Main Branch	2604.2	446.9	96.8
Whole Watershed	**10575.1**	**3086.3**	**910.1**

[1] Includes total site area
[2] Includes roof area only

The percentage of the total site area consisting of roof area was determined for eight representative sites (Table 5.7). Results indicated that roofs account for 42% of the land area at industrial sites and 10% at condominium sites.

Table 5.7: Percentage of site area as rooftop at the eight representative sites

Land use	Lot size (m^2)	Roof top (m^2)	% Roof top
Industrial 1	84522	22043	26%
Industrial 2	35548	13071	37%
Industrial 3	39595	17759	45%
Industrial 4	23394	8370	36%
Industrial 5	25039	11168	45%
Industrial 6	30711	18729	61%
		Average:	**42%**
Apartment 1	16645	1810	11%
Apartment 2	16709	1450	9%
		Average:	**10%**

5.5.2 Flow Volume Reduction

Annual runoff volumes at the mouths of the six Highland Creek subwatersheds are shown in Table 5.8. On an annual basis, the flow volume falls from 48,870,000 m^3 without greenroofs to 46,920,000 m^3 with greenroofs, assuming 100% implementation at the mouth of Highland Creek Watershed. This represents a reduction in runoff volume of approximately 4%. If 50% implementation is assumed, then the reduction will be 1.7%. Volume reductions vary from 0.9% (Centennial Branch) to 7% (Malvern Branch).

Table 5.8: Runoff volumes by subwatershed with and without greenroof implementation for the year 1992

Subwatershed	Annual Volume with no Greenroof (m^3x10^6)	Annual Volume with 100% Greenroof (m^3x10^6)	Percent Runoff Volume Reduction	Annual Volume with 50% Greenroof (m^3x10^6)	Percent Runoff Volume Reduction
Dorset Park Branch	6.69	6.33	5.3%	6.52	2.5%
Bendale Branch	12.03	11.63	3.3%	11.87	1.3%
Markham Branch	10.34	9.87	4.5%	10.16	1.7%
Malvern Branch	7.12	6.62	7.0%	6.89	3.3%
Centennial Branch	2.31	2.29	0.9%	2.30	0.4%
Highland Creek	48.87	46.92	4.0%	48.06	1.7%

5.5.3 Peak Flow Rate Reduction

Table 5.9 summarizes the dates, precipitation volumes and peak flows for the six largest events in 1992 for each subwatershed, as well as the modelled peak flows for the 50% and 100% greenroof implementation scenarios. Results indicate that effectiveness varies between subwatersheds (depending upon the percentage of land where the technology can be applied) and between events (depending upon the type of event and the seasonal effectiveness of the technology). For events between 20 and 30 mm, peak flows for the whole watershed were reduced by 12 to 19%, assuming 100% implementation of greenroofs.

Table 5.9: Rainfall and peak flow rates from each subwatershed for the six largest events in 1992

Date	Rainfall (mm)	Peak Flow - No Greenroof (m^3/sec)	Peak Flow - 100% Greenroofs (m^3/sec)	% Reduction	Peak Flow - 50% Greenroofs (m^3/sec)	% Reduction
Dorset Park Branch						
April 11-12, 1992	25.1	9.92	7.89	20%	8.89	10%
April 16-17, 1992	45.7	21.47	21.11	2%	21.36	1%
May 2-3, 1992	27.9	12.48	10.77	14%	11.58	7%
July 16-17, 1992	24.8	11.39	9.47	17%	10.44	8%
September 18-19, 1992	27.7	17.81	14.50	19%	16.03	10%
September 21-22, 1992	24.2	14.56	12.11	17%	13.33	8%
Bendale Branch						
April 11-12, 1992	25.1	11.78	10.28	13%	11.03	6%
April 16-17, 1992	45.7	40.56	40.00	1%	40.56	0%
May 2-3, 1992	27.9	18.61	16.94	9%	17.83	4%
July 16-17, 1992	24.8	15.86	14.06	11%	14.97	6%
September 18-19, 1992	27.7	27.58	23.89	13%	25.72	7%
September 21-22, 1992	24.2	21.69	18.94	13%	20.33	6%
Markham Branch						
April 11-12, 1992	25.1	15.53	12.58	19%	14.06	9%
April 16-17, 1992	45.7	36.94	36.39	2%	39.94	-8%
May 2-3, 1992	27.9	20.50	17.78	13%	19.19	6%
July 16-17, 1992	24.8	19.22	15.97	17%	17.61	8%
September 18-19, 1992	27.7	31.39	24.89	21%	28.33	10%
September 21-22, 1992	24.2	27.50	22.17	19%	24.83	10%
Malvern Branch						
April 11-12, 1992	25.1	10.75	7.94	26%	9.33	13%
April 16-17, 1992	45.7	25.61	25.11	2%	25.44	1%
May 2-3, 1992	27.9	14.33	11.86	17%	13.11	9%
July 16-17, 1992	24.8	13.11	10.25	22%	11.69	11%
September 18-19, 1992	27.7	19.28	14.58	24%	16.86	13%
September 21-22, 1992	24.2	17.50	15.44	12%	13.44	23%
Centennial Branch						
April 11-12, 1992	25.1	1.83	1.70	7%	1.77	3%
April 16-17, 1992	45.7	6.08	6.06	0%	6.08	0%
May 2-3, 1992	27.9	2.92	2.88	1%	2.86	2%
July 16-17, 1992	24.8	2.86	2.73	5%	2.77	3%
September 18-19, 1992	27.7	5.11	4.86	5%	4.97	3%
September 21-22, 1992	24.2	4.39	4.17	5%	4.28	3%
HIghland Creek Watershed						
April 11-12, 1992	25.1	46.17	40.00	13%	44.44	4%
April 16-17, 1992	45.7	155.28	153.33	1%	155.28	0%
May 2-3, 1992	27.9	79.72	70.00	12%	75.00	6%
July 16-17, 1992	24.8	70.00	59.17	15%	64.40	8%
September 18-19, 1992	27.7	113.33	92.22	19%	102.78	9%
September 21-22, 1992	24.2	95.28	78.33	18%	86.67	9%

5.5.4 Water Balance

Water balance is a tool often used in water resources management, which sums the various components of the hydrologic cycle for a watershed by balancing precipitation input, evapotranspiration output, groundwater flow input and output, and surface runoff input and output. An annual summary of the water budget components for different landuse Unit Response Functions (URFs), including the greenroof URF, indicated that the greenroof URF has the highest evapotranspiration and the lowest runoff volume among the URFs.

Tables 5.10 (a) and (b) show the annual depth of evapotranspiration and surface runoff (with and without greenroof implementation) in each subwatershed and for the entire watershed as a whole. Results indicate that evapotranspiration from all sites in the watershed with greenroofs increased by 37% and 18% for 100% and 50% implementation, respectively. Surface runoff volume from these same sites decreased by 21% and 11% for 100% and 50% implementation, respectively.

Table 5.10a: Modelled evapotranspiration by subwatershed for different levels of greenroof implementation

Subwatershed	Evapotranspiration (mm)		
	No Greenroofs	**50% Greenroofs**	**100% Greenroofs**
Dorset Park	62.1	74.5	87.0
Bendale	51.6	59.1	66.7
Markham	52.3	62.6	72.9
Malvern	64.6	80.6	96.6
Centennial	16.5	18.5	20.4
Whole Watershed	283.9	336.0	388.2

Table 5.10b: Modelled surface runoff by subwatershed for different levels of greenroof implementation

Subwatershed	Surface Runoff (mm)		
	No Greenroofs	**50% Greenroofs**	**100% Greenroofs**
Dorset Park	1524.2	1353.8	1183.4
Bendale	969.5	878.2	786.7
Markham	1240.6	1100	959.3
Malvern	2024.6	1773.3	1522.1
Centennial	250.0	227.2	204.5
Whole Watershed	6494.0	5784.7	5075.1

6.0 WATER QUALITY ANALYSIS

Runoff and precipitation water quality sampling was undertaken at the study site for a total of 21 events during the 2003 and 2004 monitoring seasons. Water quality was not monitored in 2005. Table 6.1 provides a summary of sampling dates and times for the control roof and the garden. The majority of water quality results presented in the following sections are averages and totals for the monitoring period as a whole. The percent difference in loads between the control roof and garden for individual events is provided in Appendix B, Table B12. Concentrations and loads for each individual event are also provided in Appendix B. Runoff water temperature was monitored from July 21 to August 19, 2005. These results are presented in section 6.1.6. Water quality data obtained from monitoring in 2003 were also used in a modelling exercise to predict the watershed-scale water quality benefits of greenroof implementation. These results are presented in section 6.2.

Table 6.1: Water quality sampling summary for events collected in 2003 and 2004 monitoring seasons

Sample Date	Sampler start time		Sampler end time	
	Control	Garden	Control	Garden
19-Sep-03	7:15	8:37	9:15	10:37
19-Sep-03	11:16	16:22	13:16	18:22
27-Sep-03	1:20	3:12	3:20	5:12
14-Oct-03	15:55	18:37	17:55	20:37
18-Oct-03	18:04	18:49	20:04	20:49
02-Nov-03	5:11	11:24	7:11	13:24
03-Nov-03	17:39	17:52	19:39	19:52
12-Nov-03	19:32	21:44	21:32	23:44
17-Nov-03	2:02	2:26	4:02	4:26
24-Jun-04	19:52	20:10	21:52	0:10
07-Jul-04	2:40	2:41	4:35	6:41
07-Jul-04	15:45	16:03	17:45	20:03
14-Jul-04	3:20	3:19	5:20	7:19
20-Jul-04	13:27	16:47	15:27	20:47
27-Jul-04	5:51	6:13	7:51	10:03
08-Aug-04	15:54	16:06	17:54	20:06
28-Aug-04	20:07	10:31	22:07	14:31
15-Oct-04	14:14	14:11	16:14	18:11
30-Oct-04	13:57	13:58	15:57	17:58
02-Nov-04	5:26	7:03	7:26	11:03
04-Nov-04	13:30	13:45	15:30	17:45

6.1 Field Monitoring Results

In the following subsections, water chemistry data are presented as concentrations loads. Total loads for individual events are provided in Appendix B. Water quality data are discussed in this section under the headings of general chemistry (e.g. suspended solids, chloride), nutrients (e.g. nitrogen and phosphorus compounds), bacteria, metals, and polycyclic aromatic hydrocarbons (PAHs). Observed concentrations are evaluated against the Ontario Ministry of Environment Provincial Water Quality Objectives (PWQO) for receiving waters. In cases where PWQOs were not available, other guidelines were used, such as the Canadian Water Quality Guidelines (CCME, 1999). It should be noted that roof effluent quality is not necessarily expected to meet receiving water quality guidelines - the guidelines are used here as a standard of comparison because effluent guidelines for stormwater facilities do not exist in Ontario.

Loading estimates are provided for sampled events (n=21) and for the entire monitoring period. The monitoring period load is an extrapolated load which represents the product of the total volume of runoff for all events which occurred during the 2003 and 2004 monitoring seasons (see Table 5.1) and volume weighted average concentrations for the events sampled (see section 4.2.3 for method of calculation). This extrapolated load provides an estimate of the garden's performance over the entire study period, including events for which no runoff was measured from the garden. Normally it would be expected that monitoring period loads for all variables would be less than sampling event loads because volume retention for the entire period (65%) was greater than for the sampling period only (54%).

6.1.1 General Chemistry

All median and volume weighted mean (VWM) concentrations for general chemistry variables from both the control roof and garden were less than receiving water quality guidelines (Table 6.2). The pH of precipitation samples was slightly more acidic than observed in roof runoff. The garden runoff was found to have higher VWM concentrations than the control for chloride, chemical oxygen demand, sodium, potassium, hardness, fluoride, sulphate, conductivity, solvent extractable (oil/grease) and alkalinity. The source of these is garden growing media itself. None of them represent a concern at observed concentrations. The control had higher VWM concentrations than the garden for suspended solids, turbidity, and biochemical oxygen demand. Mean concentrations of analyzed variables in precipitation were always lower than the control or garden runoff.

Table 6.3 shows percent differences between control and garden runoff loads over the monitoring period. Results reveal the same general trends present in the concentration data. The garden had lower loads of suspended solids, biochemical oxygen demand and oil/grease.

Table 6.2: Minimum, maximum, median, and VWM concentrations of general chemistry variables over the monitoring period

Variable	Units	Method Detection Limit	Guideline*	Precipitation						Control						Garden					
				# of samples	% > DL	Minimum	Maximum	Median	Volume weighted mean†	# of samples	% > DL	Minimum	Maximum	Median	Volume weighted mean†	# of samples	% > DL	Minimum	Maximum	Median	Volume weighted mean†
Chloride	mg/L	0.2	250	0						21	95	*0.10*	5.20	0.90	1.69	21	100	2.40	33.10	10.00	12.35
Mercury	ug/L	0.02	0.2	0						19	5	*0.01*	0.03	*0.01*	*0.01*	19	0	*0.01*	*0.01*	*0.01*	*0.01*
Oxygen demand; chemical	mg/L as O_2	1		0						21	100	5.0	97.0	16.0	26.0	21	100	20.3	320.3	68.0	135.7
Sodium	mg/L	0.1		17	100	*0.05*	0.57	0.18	0.16	21	100	0.62	2.14	1.03	1.18	21	100	4.24	9.04	6.12	6.47
Potassium	mg/L	0.05		17	100	*0.01*	0.46	0.07	0.08	21	100	1.22	2.73	1.88	1.93	21	100	4.24	15.30	5.48	5.79
Hardness	mg/L	1		0						21	100	8.6	35.2	15.0	17.3	21	100	53.2	147.0	87.6	101.8
Fluoride	mg/L	0.05		0						20	30	*0.03*	0.10	*0.03*	*0.05*	20	100	0.15	0.62	0.38	0.46
Sulphate	mg/L	2.5		0						21	90	*1.25*	18.50	4.20	5.49	21	100	7.90	56.50	18.40	25.08
Oxygen demand; biochemical	mg/L as O_2	0.2		0						21	100	0.60	6.40	1.90	2.13	21	100	0.47	3.70	1.60	1.41
Solids; suspended	mg/L	2.5		0						21	95	*1.25*	20.90	5.55	6.39	21	33	*1.20*	4.92	*1.25*	*1.95*
Solvent extractable	mg/L	1		0						8	13	*0.50*	2.10	*0.50*	*0.65*	8	38	*0.50*	3.00	*0.50*	*0.79*
Conductivity	uS/cm	1		20	100	7.0	36.0	17.0	16.1	21	100	30.0	105.0	45.5	49.0	21	100	155.0	329.0	205.3	224.3
pH	none	-	6.5-9.5	20	-	4.4	6.9	5.9	5.6	21	-	6.9	7.4	7.3	7.3	21	-	7.6	9.0	8.1	8.1
Alkalinity; total fixed endpoint	mg/L $CaCO_3$	2.5		20	55	*1.3*	5.1	2.7	*2.4*	21	100	7.3	20.7	14.1	14.6	21	100	42.9	85.8	65.2	63.8
Turbidity	FTU	0.01	5	0						13	100	1.60	6.19	2.21	2.66	10	100	0.61	2.96	1.24	1.43

Underscored values are in exceedence of the guideline; Italicized values are below the method detection limit

*Guidelines listed are Provincial Water Quality Objectives (OMOE, 1999) where available. For parameters with no PWQO, the Canadian Water Quality Guideline is used, with the exception of chloride (source: EC & HC, 2001)

† See section 4.2.3 for the method of calculating volume-weighted means

Table 6.3: Percent difference in loads of general chemistry variables over the monitoring period

Variable	% Difference in load from control vs. garden	
	Sampled Events only†	Monitoring Period
Chloride	-249.2	-183.1
Oxygen demand; chemical	-149.4	-102.2
Sodium	-161.6	-112.1
Potassium	-43.8	-16.6
Fluoride	-330.9	-255.9
Sulphate	-118.7	-77.3
Oxygen demand; biochemical	<u>68.3</u>	<u>74.3</u>
Solids; suspended	<u>85.4</u>	<u>88.2</u>
Solvent extractable	<u>32.5</u>	<u>53.1</u>

† Values in "sampled events only" column represent events for water quality was sampled. Values in the "Monitoring Period" column are extrapolated values for the entire monitoring period (i.e. all events in Appendix A, Table A1).

Underscored % difference values indicate that the garden load is less than the control roof load

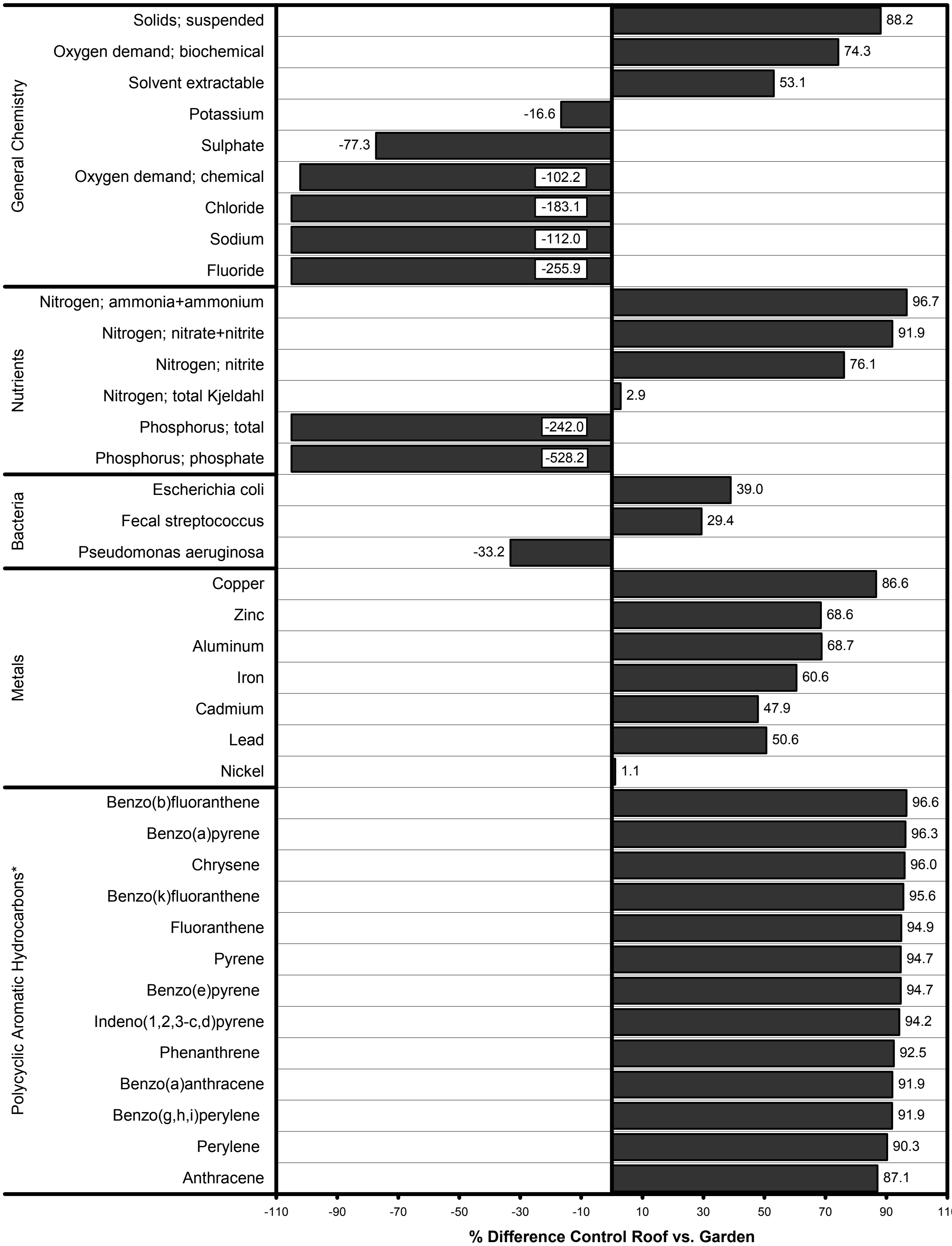


Figure 6.1: Percent differences between control roof and garden runoff loadings for select variables

Note: values shown are for the entire monitoring period (see text for discussion).
*PAH data shown is for 2003 only. For samples collected in 2004, at least 80% of samples analyzed for PAHs were below the MDL.

6.1.2 Nutrients

While maintaining soil nutrient levels is essential to the health of plants on a greenroof, high nutrient levels in runoff to receiving waters may stimulate excess algae and aquatic plant growth, which deplete oxygen as they decompose, potentially resulting in adverse effects on fish and restrictions on the recreational use of waterways. In this context, phosphorus is the most important nutrient because it is the limiting nutrient for aquatic plant growth in most inland waters.

As shown in Table 6.4, median and VWM concentrations of most nutrients in both control roof and garden runoff are typically below water quality guidelines, with the exception of total phosphorus. Phosphorus concentrations in garden runoff were in exceedence of the guideline for all events sampled, and concentrations in control roof runoff were in exceedence for all but five of the events sampled. Even when lower garden runoff is considered, phosphorus loads from the garden were 242% higher than from the control roof (Table 6.5). This result contrasts with the North Carolina greenroof study (Moran et al, 2004) discussed in the literature review chapter. In this study, phosphorus concentrations in greenroof runoff were also much higher, but phosphorus loads from the control and garden were not significantly different.

Elevated phosphorus levels in runoff from the garden are a significant water quality concern because concentrations are both well above the receiving water guideline and significantly higher than observed in control roof runoff. Sources of phosphorus on the greenroof include the growing medium, bird faeces and, to a lesser extent, dry and wet atmospheric deposition. Phosphorus-rich fertilizers may have been added to the growing medium during manufacturing in order to promote start-up plant growth. The presence of bird droppings on both the garden and control roof indicates that it may have been a significant source for runoff from both surfaces.

Figure 6.2 compares 2003 and 2004 mean concentrations and loads of total phosphorus in garden and control roof runoff. These results show a statistically significant decline in garden mean phosphorus concentrations from 0.70 mg/L in 2003 to 0.20 in 2004. Garden loads showed a similar decline. The decrease in concentration likely represents a process of leaching whereby soil phosphorus is gradually flushed out during the first year or two of operation. If this is the case, continued leaching over time may bring phosphorus levels into line with control roof levels and/or receiving water objectives. Elevated phosphorus levels may also relate to the particular substrate used on the York University garden. Chemical analyses in chapter 7.0 shows that this particular substrate (which is no longer commercially available) had higher soil phosphorus concentrations than 10 of the 11 other commercially available substrates. Further research is needed to determine whether or not other greenroof substrates perform similarly with respect to phosphorus, and if so, what amendments may be added to improve retention of this nutrient.

Table 6.4: Minimum, maximum, median, and VWM concentrations of nutrients over the monitoring period

Variable	Units	Method Detection Limit	Guideline*	Precipitation						Control						Garden					
				# of samples	% > DL	Minimum	Maximum	Median	Volume weighted mean†	# of samples	% > DL	Minimum	Maximum	Median	Volume weighted mean†	# of samples	% > DL	Minimum	Maximum	Median	Volume weighted mean†
Nitrogen; ammonia+ ammonium	mg/L	0.002	1.4	20	100	0.096	1.270	0.373	0.434	21	100	0.054	0.744	0.198	0.262	21	80	*0.001*	0.089	0.012	0.022
Nitrogen; nitrite	mg/L	0.001	0.06	20	95	*0.0005*	0.0220	0.0085	0.0084	21	100	0.0150	0.0690	0.0263	0.0294	21	100	0.0080	0.0400	0.0190	0.0181
Nitrogen; nitrate+ nitrite	mg/L	0.005		20	100	0.006	1.430	0.362	0.377	21	100	0.157	2.350	0.389	0.500	21	100	0.033	0.710	0.107	0.104
Phos.; phosphate	mg/L	0.0005		20	70	*0.0003*	0.4900	0.0018	0.0591	21	90	*0.0003*	0.1380	0.0099	0.0333	21	100	0.0459	0.8091	0.1850	0.5388
Phos.; total	mg/L	0.002	0.03	18	100	0.005	0.063	0.014	0.016	21	100	0.024	0.310	0.054	0.071	21	100	0.062	0.936	0.283	0.629
Nitrogen; total Kjeldahl	mg/L	0.02		18	100	0.260	2.280	0.600	0.685	21	100	0.230	1.680	0.565	0.675	21	100	0.310	2.420	0.960	1.689

Underscored values are in exceedence of the guideline; Italicized values are below the method detection limit

*Guidelines listed are Provincial Water Quality Objectives where available. For parameters with no PWQO, the Canadian Water Quality Guideline is used.

† See section 4.2.3 for the method of calculating volume-weighted means

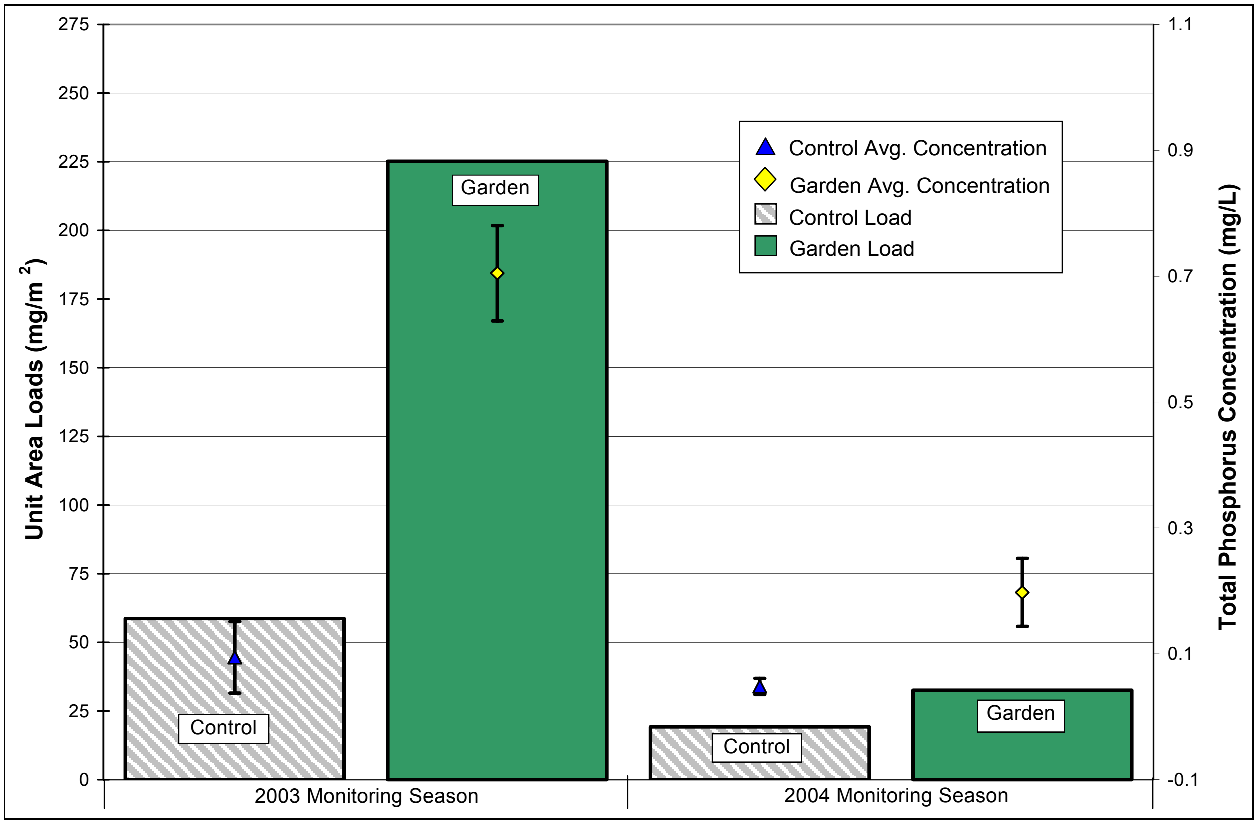


Figure 6.2: Comparison of 2003 and 2004 total phosphorus loads and concentrations

Table 6.5: Percent difference in loads of nutrients over the monitoring period

Variable	% Difference in load from control vs. garden	
	Sampled Events only†	Monitoring Period
Nitrogen; ammonia+ ammonium	<u>95.9</u>	<u>96.7</u>
Nitrogen; nitrite	<u>70.5</u>	<u>76.1</u>
Nitrogen; nitrate+nitrite	<u>90.1</u>	<u>91.9</u>
Phosphorus; phosphate	-674.8	-528.2
Phosphorus; total	-321.8	-242.0
Nitrogen; total Kjeldahl	-19.7	<u>2.9</u>

† Values in "sampled events only" column represent events for water quality was sampled. Values in the "Monitoring Period" column are extrapolated values for the entire monitoring period (i.e. all events in Appendix A, Table A1).
Underlined % difference values indicate that the garden load is less than the control roof load

6.1.3 Bacteria

Volume weighted mean concentrations of *Escherichia coli* in both control and garden runoff were above guidelines for body contact recreation (Table 6.6). Bird faeces are almost certainly the cause. Birds preferred the garden over the control roof as it offers a better environment for nesting, foraging, and resting.

Table 6.6: Minimum, maximum, median, and VWM concentrations of bacteria over the monitoring period

Variable	Units	Method Detection Limit	Guideline*	Precipitation	Control						Garden					
				Precipitation samples were not analysed for bacteria variables	# of samples	% > DL	Minimum	Maximum	Median	Volume weighted mean†	# of samples	% > DL	Minimum	Maximum	Median	Volume weighted mean†
Escherichia coli	c/100 mL	-	100		16	-	4	2800	11	513	17	-	4	5100	165	807
Fecal streptococcus	c/100 mL	-			16	-	10	7000	228	1882	17	-	40	17000	2700	3425
Pseudomonas aeruginosa	c/100 mL	-			16	-	2	3000	305	818	17	-	4	150000	600	2808

Undescored values are in exceedence of the guideline; Italicized values are below the method detection limit

*Guidelines listed are Provincial Water Quality Objectives where available. For parameters with no PWQO, the Canadian Water Quality Guideline is used.
† See section 4.2.3 for the method of calculating volume-weighted means

The total *E. coli* load from the garden was less than from the control for sampled events (by 39%) and also over the monitoring period as a whole (by 20%), as shown in Table 6.7. This positive result is entirely due to the runoff retention properties of the garden.

Table 6.7: Percent difference in loads of bacteria over the monitoring period

Variable	% Difference in load from control vs. garden	
	Sampled Events only†	Monitoring Period
Escherichia coli	20.1	39.0
Fecal streptococcus	7.6	29.4
Pseudomonas aeruginosa	-74.4	-33.2

† Values in “sampled events only” column represent events for water quality was sampled. Values in the "Monitoring Period" column are extrapolated values for the entire monitoring period (i.e. all events in Appendix A, Table A1).
Underlined % difference values indicate that the garden load is less than the control roof load

6.1.4 Metals

Table 6.8 summarizes concentration results for metals over the monitoring period. Copper was the only variable with mean concentrations that exceeded receiving water guidelines in control roof runoff, garden runoff and precipitation. The control roof runoff had the highest concentrations of copper, followed by the garden runoff and precipitation. Concentrations of cadmium, cobalt, chromium, molybdenum and lead were frequently below method detection limits and were generally not a concern.

The eavestroughs, which collect and convey runoff from the control and garden to the flow metres, may have been a source of copper and other metals. The control roofing material itself may also have been a source of metals. While precipitation samples had significantly lower copper concentrations than runoff samples, the maximum, median and VWM concentrations were all above receiving water guidelines. The source of copper in precipitation may have been wet and dry atmospheric deposition, or wind blown dust from other surfaces.

In terms of loads, the garden runoff had lower loads than the control roof for several metals of concern, including aluminum, cadmium, copper, iron, lead and zinc (Table 6.9). Percent differences in loads of nickel and vanadium were close to zero, indicating that loads were similar for the garden and control. Several metals for which the garden runoff had higher loads are naturally present in soils, such as calcium and magnesium. At observed concentrations, these chemicals do not present a threat to receiving waters.

Table 6.8: Minimum, maximum, median and VWM concentrations of metals over the monitoring period

				Precipitation						Control						Garden					
Variable	Units	Method Detection Limit	Guideline*	# of samples	% > DL	Minimum	Maximum	Median	Volume weighted mean†	# of samples	% > DL	Minimum	Maximum	Median	Volume weighted mean†	# of samples	% > DL	Minimum	Maximum	Median	Volume weighted mean†
Aluminum	ug/L	11	75‡	19	95	*5.5*	75.8	21.4	26.1	20	100	29.6	200.0	51.4	60.8	20	100	33.2	89.4	48.6	49.0
Barium	ug/L	0.2		19	100	1.0	4.8	2.5	2.3	20	100	1.46	9.17	3.36	3.74	20	100	8.65	24.60	12.65	15.73
Beryllium	ug/L	0.02	11	19	5	*0.01*	0.02	*0.01*	*0.01*	20	5	*0.01*	0.02	*0.01*	*0.01*	20	50	*0.01*	0.38	0.02	0.05
Calcium	mg/L	0.005		19	100	0.2	1.8	1.1	0.9	20	100	2.8	11.0	4.3	5.1	20	100	10.9	35.9	21.7	24.4
Cadmium	ug/L	0.6	0.1	19	11	*0.3*	1.3	*0.3*	*0.5*	20	10	*0.3*	1.1	*0.3*	*0.4*	20	25	*0.3*	0.9	*0.3*	*0.5*
Cobalt	ug/L	1.3	0.9	19	5	*0.7*	1.3	*0.7*	*0.7*	20	5	*0.7*	1.6	*0.7*	*0.7*	20	10	*0.7*	2.1	*0.7*	*0.7*
Chromium	ug/L	1.4	8.9	19	5	*0.7*	8.0	*0.7*	*1.1*	20	0	*0.7*	*0.7*	*0.7*	*0.7*	20	5	*0.7*	1.8	*0.7*	*0.7*
Copper	ug/L	1.6	5	19	100	4.0	56.4	11.6	12.3	20	100	37.8	373.0	95.8	110.8	20	100	9.5	119.0	56.3	38.2
Iron	ug/L	0.8	300	19	100	10.6	63.1	24.2	25.6	20	100	11.7	141.0	28.5	38.3	20	100	9.2	59.1	29.5	38.9
Magnesium	mg/L	0.008		19	100	0.05	0.53	0.19	0.21	20	100	0.41	2.09	0.67	0.95	20	100	1.68	9.78	4.84	6.29
Manganese	ug/L	0.2		19	100	1.2	11.2	4.9	4.4	20	100	3.2	34.4	6.5	8.9	20	100	0.6	3.0	1.5	1.5
Molybdenum	ug/L	1.6	40	19	0	*0.8*	*0.8*	*0.8*	*0.8*	20	0	*0.8*	*0.8*	*0.8*	*0.8*	20	15	*0.8*	2.8	*0.8*	*1.3*
Nickel	ug/L	1.3	25	19	16	*0.7*	17.8	*0.7*	1.6	20	15	*0.7*	2.7	*0.7*	*0.8*	20	60	*0.7*	3.7	1.5	1.9
Lead	ug/L	5	5	19	16	*2.5*	12.2	*2.5*	*3.4*	20	15	*2.5*	11.7	*2.5*	*3.7*	20	30	*2.5*	11.5	*2.5*	*4.8*
Strontium	ug/L	0.1		19	100	0.7	6.4	2.4	2.6	20	100	9.8	35.1	14.7	17.0	20	100	60.6	138.0	85.4	91.0
Titanium	ug/L	0.5		19	58	*0.3*	1.7	0.8	0.7	20	90	*0.3*	5.1	1.1	1.4	20	25	*0.3*	0.9	*0.3*	0.5
Vanadium	ug/L	1.5	6	20	0	*0.8*	*0.8*	*0.8*	*0.8*	20	25	*0.8*	2.7	*0.8*	*0.9*	20	80	*0.8*	3.4	2.1	2.1
Zinc	ug/L	0.6	20	19	100	5.4	25.6	11.6	11.8	20	100	4.4	31.3	9.1	10.8	20	100	2.1	13.7	7.8	8.7

Notes: Underscored values are in exceedence of the guideline; Italicized values are below the method detection limit

*Guidelines listed are Provincial Water Quality Objectives where available. For parameters with no PWQO, the Canadian Water Quality Guideline is used.

† See section 4.2.3 for the method of calculating volume-weighted means

‡ PWQO shown for aluminum is only considered accurate for clay-free samples

Table 6.9: Percent difference in loads of metals over the monitoring period

Variable	% Difference in load from control vs. garden	
	Sampled Events only†	Monitoring Period
Aluminum	<u>60.7</u>	<u>68.7</u>
Barium	-105.2	-63.1
Beryllium	-144.7	-94.6
Calcium	-131.2	-83.8
Cadmium	<u>34.4</u>	<u>47.9</u>
Copper	<u>83.2</u>	<u>86.6</u>
Iron	<u>50.4</u>	<u>60.6</u>
Magnesium	-223.9	-157.5
Manganese	<u>91.5</u>	<u>93.3</u>
Nickel	-24.4	<u>1.1</u>
Lead	<u>37.9</u>	<u>50.6</u>
Strontium	-160.6	-107.2
Titanium	<u>83.1</u>	<u>86.6</u>
Vanadium	-14.3	<u>9.2</u>
Zinc	<u>60.5</u>	<u>68.6</u>

† Values in “sampled events only” column represent events for water quality was sampled. Values in the "Monitoring Period" column are extrapolated values for the entire monitoring period (i.e. all events in Appendix A, Table A1).
Notes: Underlined values indicate that the garden load is less than the control roof load, Variables with greater than 80% of samples below laboratory detection limits are excluded from the table.

6.1.5 Polycyclic Aromatic Hydrocarbons

PAH concentrations over the monitoring period are presented in Table 6.10. Most PAH detection limits significantly exceed the guideline, and thus the percent of samples greater than the detection limit should always be noted when evaluating guideline exceedences. Only control roof and garden runoff samples were analysed for PAHs.

Garden runoff VWM concentrations were equal to or lower than concentrations in control roof runoff for all PAHs. Garden PAH concentrations were often below the detection limit, while control roof concentrations were considerably higher. The control roofing material (shingles with tar) was the primary source of PAHs in runoff from that surface (see for example Clark et al., 2001). Dry and wet atmospheric deposition may also have been an important source of PAHs on both the control and the garden. Both in terms of concentrations and loads, the garden performed significantly better in attenuating these contaminants as they are readily adsorbed by the growing media.

Table 6.10: Minimum, maximum, median and VWM concentrations of polycyclic aromatic hydrocarbons over the monitoring period

				Control						Garden					
Variable	Units	Method Detection Limit	Guideline*	# of samples	% > DL	Minimum	Maximum	Median	Volume weighted mean†	# of samples	% > DL	Minimum	Maximum	Median	Volume weighted mean†
Phenanthrene	ng/L	10	30	9 / 10	100 / 80	21 / 5	1100 / 160	122.5 / 23.0	178.1 / 34.4	8 / 10	28 / 20	5 / 5	70 / 30	18.6 / 5	29.8 / 19.3
Anthracene	ng/L	10	0.8	9 / 10	89 / 10	5 / 5	110 / 18	15.0 / 5.0	20.9 / 6.1	8 / 10	6 / 0	5 / 5	11 / 5	5 / 5	6.0 / 5.0
Fluoranthene	ng/L	10	0.8	9 / 10	100 / 80	30 / 5	1600 / 240	187.0 / 23.0	265.0 / 44.2	8 / 10	28 / 0	5 / 5	97 / 5	18.8 / 5	30.0 / 5.0
Pyrene	ng/L	10		9 / 10	100 / 50	22 / 5	1200 / 190	140.0 / 12.5	196.2 / 32.0	8 / 10	28 / 0	5 / 5	69 / 5	19.5 / 5	23.0 / 5.0
Benzo(a)anthracene	ng/L	20	0.4	9 / 10	89 / 20	10 / 10	460 / 68	48.3 / 10.0	70.7 / 16.3	8 / 10	6 / 0	10 / 10	26 / 10	10 / 10	12.6 / 10.0
Chrysene	ng/L	10	0.1	9 / 10	89 / 40	5 / 5	720 / 130	64.8 / 5.0	104.9 / 16.9	8 / 10	6 / 0	5 / 5	29 / 5	5 / 5	9.3 / 5.0
7,12-dimethylbenz(a) anthracene	ng/L	10		9 / 10	0 / 0	5 / 5	5 / 5	5.0 / 5.0	5.0 / 5.0	8 / 10	0 / 0	5 / 5	5 / 5	5 / 5	5.0 / 5.0
Benzo(b)fluoranthene	ng/L	10		9 / 10	100 / 50	11 / 5	690 / 140	70.0 / 8.0	108.4 / 20.2	8 / 10	6 / 0	5 / 5	23 / 5	5 / 5	8.2 / 5.0
Benzo(k)fluoranthene	ng/L	10	0.2	9 / 10	100 / 40	12 / 5	530 / 130	65.0 / 5.0	87.3 / 12.9	8 / 10	11 / 0	5 / 5	24 / 5	5 / 5	8.6 / 5.0
Benzo(e)pyrene	ng/L	10		9 / 10	89 / 40	5 / 5	440 / 84	43.3 / 5.0	67.2 / 14.8	8 / 10	6 / 0	5 / 5	21 / 5	5 / 5	7.9 / 5.0
Benzo(a)pyrene	ng/L	3		9 / 10	100 / 60	10 / 1.5	650 / 110	62.3 / 8.0	96.5 / 15.7	8 / 10	22 / 0	1.5 / 1.5	27 / 1.5	4.2 / 1.5	8.0 / 1.5
Perylene	ng/L	10	0.07	9 / 10	89 / 20	5 / 5	140 / 26	16.0 / 5.0	23.2 / 7.2	8 / 10	0 / 0	5 / 5	5 / 5	5 / 5	5.0 / 5.0
Indeno(1,2,3-c,d) pyrene	ng/L	20		9 / 10	89 / 20	10 / 10	580 / 62	71.0 / 10.0	103.0 / 15.4	8 / 10	6 / 0	10 / 10	29 / 10	10 / 10	13.1 / 10.0
Dibenzo(a,h) anthracene	ng/L	20	2	9 / 10	11 / 20	10 / 10	100 / 20	10.0 / 10.0	14.0 / 10.9	8 / 10	0 / 0	10 / 10	10 / 10	10 / 10	10.0 / 10.0
Benzo(g,h,i)perylene	ng/L	20	0.02	9 / 10	100 / 20	30 / 10	440 / 79	48.0 / 20.0	65.8 / 16.9	8 / 10	13 / 0	10 / 10	21 / 10	10 / 10	11.8 / 10.0

Notes: 1. The left and right values are 2003 and 2004 samples, respectively. 2. Underscored values are in exceedence of the guideline (Note that guideline values are often below the method detection limit); 3. Italicized values are below the method detection limit

*Guidelines listed are Provincial Water Quality Objectives where available. For parameters with no PWQO, the Canadian Water Quality Guideline is used.

† See section 4.2.3 for the method of calculating volume-weighted mean

Table 6.11: Percent difference in loads of PAHs over the monitoring period

Variable	% difference in load of control vs. garden	
	Sampled Events only†	Monitoring Period
Phenanthrene	**90.79** / 82.64	**92.45** / 84.43
Anthracene	**84.27** / 74.72	**87.10** / 77.32
Fluoranthene	**93.77** / 96.49	**94.89** / 96.85
Pyrene	**93.54** / 95.15	**94.71** / 95.65
Benzo(a)anthracene	**90.16** / 80.96	**91.93** / 82.92
Chrysene	**95.10** / 90.80	**95.98** / 91.74
Benzo(b)fluoranthene	**95.81** / 92.32	**96.57** / 93.12
Benzo(k)fluoranthene	**94.61** / 87.99	**95.58** / 89.23
Benzo(e)pyrene	**93.51** / 89.51	**94.68** / 90.59
Benzo(a)pyrene	**95.44** / 97.03	**96.26** / 97.33
Perylene	**88.14** / 78.50	**90.28** / 80.71
Indeno(1,2,3-c,d)pyrene	**92.98** / 79.83	**94.25** / 81.90
Benzo(g,h,i)perylene	**90.13** / 81.60	**91.91** / 83.50

Notes: Bolded and non-bolded values are 2003 and 2004 samples, respectively. Underlined values indicate that the garden load is less than the control roof load, Variables with greater than 80% of samples below laboratory detection limits are excluded from the table.
†Values in “sampled events only” column represent events for water quality was sampled. Values in the "Monitoring Period" column are extrapolated values for the entire monitoring period (i.e. all events in Appendix A, Table A1).

6.1.6 Runoff Water Temperature

Table 6.12 shows average and maximum runoff temperatures, and the percentage of temperature measurements above 21°C for the control roof and garden over the one month period of runoff temperature monitoring from July 21st to August 19th, 2005. Table B11 provides more detailed runoff temperature statistics for each event which occurred during this period.

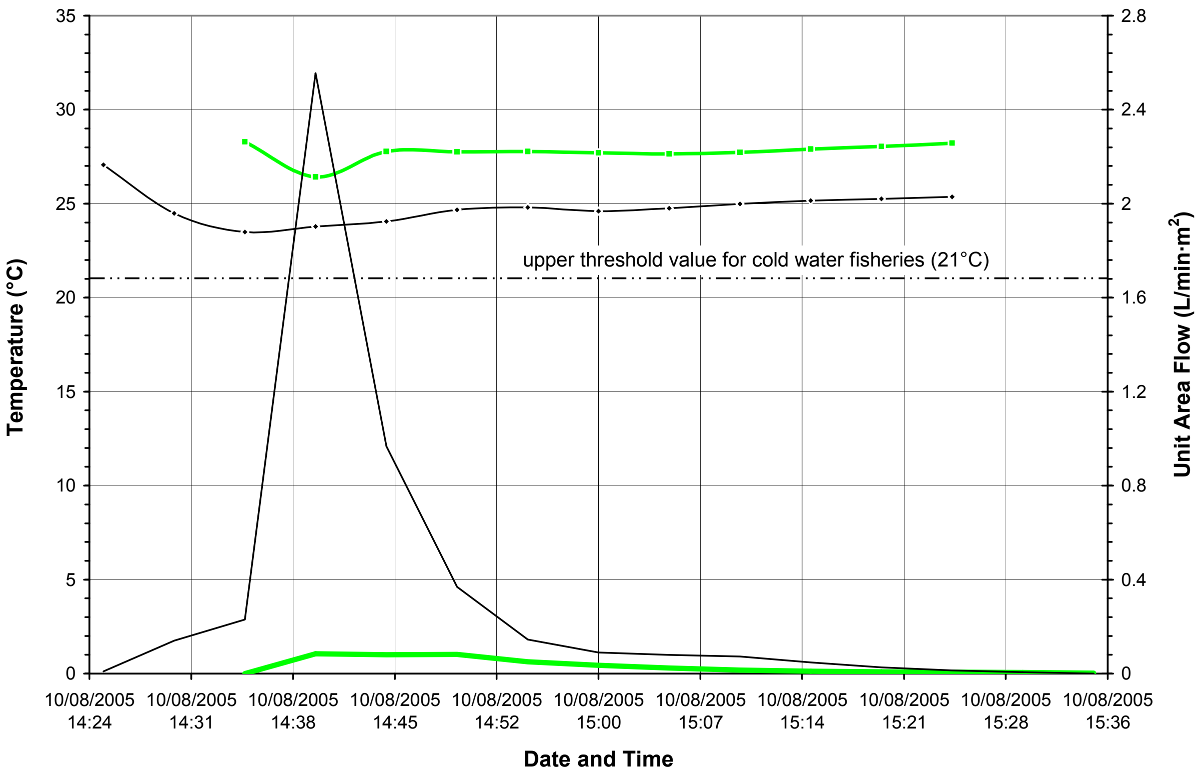
Table 6.12: Control roof and garden runoff temperature statistics

	Control Runoff	**Garden Runoff**
Average Temperature (°C)	22.1	26.7
Maximum Temperature (°C)	31.5	34.0
% Greater than 21°C	57.3	91.7

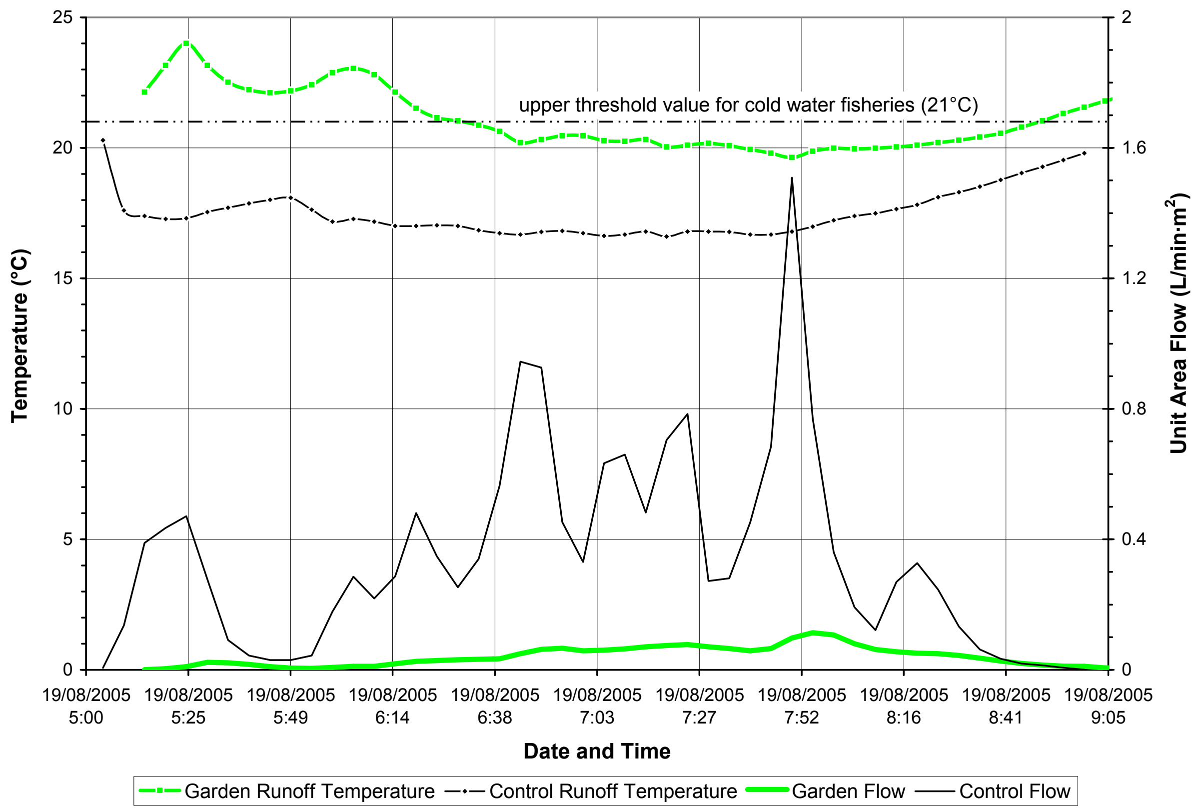
During the 9 events which occurred during the temperature monitoring period, garden runoff was significantly warmer than control roof runoff. Measurements were compared to a target temperature of 21°C, which is the commonly accepted upper threshold temperature for most cold water fish species. While measurements from both surfaces were frequently above this threshold, garden runoff exceeded this value far more frequently, as almost all measurements were greater than 21°C.

Figure 6.3 shows control roof and garden runoff flows and respective runoff temperatures during (a) a 6.4 mm event which occurred on August 10, 2005 and (b) an 18 mm event which occurred on August 19, 2005. In Figure 6.3a, garden runoff was consistently warmer than control roof runoff by approximately 3°C over the course of the event. During the larger event, shown in Figure 6.3b, garden runoff was approximately 2°C to 7°C warmer than control runoff. From a loading perspective, however, the control runoff may have no less of a thermal impact on the receiving water than the warmer garden runoff simply because there is more control roof water being discharged.

The higher garden runoff temperatures may be attributed to the ability of soil substrates to store heat and slowly release it back to the atmosphere. Moisture in the garden substrate heats up during inter-event periods. During a storm, this residual moisture mixes with rain water, and the mixed water is eventually discharged as runoff. On cloudy, rainy days, the control roof, by contrast, cools down quickly and thus runoff temperatures are more similar to the temperature of the rain falling on the roof.



(a)



(b)

Figure 6.3: Control roof and garden runoff flow volumes and temperatures for (a) a 6.4 mm event which occurred on August 10, 2005 and (b) a 18 mm event which occurred on August 19, 2005.

6.2 Watershed Modelling Results

Table 6.13 summarizes the Event Mean Concentration (EMCs) for selected water quality variables. Values are provided for a number of conditions as outlined below.

- WWFMMP: These values represent the average conditions for an industrial site as determined from the City of Toronto WWFMMP study.
- Control Roof: These values represent the average concentration as measured from the discharge location of the control roof during monitoring in 2003 only (the only data available at the time).
- Greenroof: Similar to the control roof, values shown here represent the concentrations as measured from the discharge location of the greenroof during monitoring in 2003 only.
- Precipitation: The values as shown represent the product of contaminants atmospherically deposited during dry weather and contaminants in the rain itself.

Table 6.13: Event mean concentrations for selected water quality variables

Variable	Units	Event Mean Concentration			
		WWFMMP	Control Roof	Greenroof	Precipitation
TSS	mg/L	467	6.3	2.2	6.93
Nitrate/Nitrite	mg/L	1.16	0.52	0.12	0.43
Total Phosphorus	mg/L	0.5	0.078	0.577	0.01
TKN	mg/L	1.06	0.711	1.61	0.67
Lead	ug/L	16	3.8	4.8	3.47
Zinc	ug/L	242	10.8	8.2	14.5
Benzo(g,h,i)perylene	ng/L	239	68.4	11.8	10
Escherichia Coli	c/100mL	1138	549	661	19

In order to assess the impact of implementing greenroofs on water quality within Highland Creek, the HSPF model was run for baseline conditions and for conditions where greenroofs were implemented for 100% of the eligible land uses. The comparison between baseline conditions and the greenroof implementation scenario was based on the use of 2003 control roof EMCs as the baseline and 2003 greenroof EMCs for the 100% greenroofs scenario. The precipitation quality data collected at the York University greenroof was not used as some values were high, and the concentrations represent not only contaminants in the rain itself, but also contaminants that have been atmospherically deposited during dry weather.

The WWFMMP EMC represents the average concentration from the entire site; *i.e.*: roof, parking lots, grassed area and adjacent public right of way. In order to run the model where greenroofs are implemented, adjustments were made to reflect the decrease (or increase) in the site EMC.

Table 6.14 shows the percent difference in loadings and concentrations for the baseline scenario versus the 100% greenroof implementation scenario for each of the eight parameters. Results indicate that the impact of implementing the greenroof technology is mixed. Loadings were reduced for almost all variables, primarily due to decreased flow volumes. Exceptions included total phosphorus and total Kjeldahl nitrogen, for which loadings increased moderately from the baseline. *E. coli* loads did not appear to increase or decrease from baseline conditions as a result of greenroof implementation.

Table 6.14: Percent difference in loading and concentrations between baseline and 100% greenroof implementation (based on 2003 water quality monitoring data from the York University greenroof)

Parameter	Loading		% Difference	Concentrations		% Difference
	Baseline	100% Greenroofs		Baseline	100% Greenroofs	
TSS	14669900 kg	13789100 kg	-6%	300.18 mg/L	293.89 mg/L	-2%
Nitrate/Nitrite	61020 kg	58200 kg	-5%	1.25 mg/L	1.24 mg/L	-1%
Total Phosphorus	13487 kg	15321 kg	12%	0.28 mg/L	0.33 mg/L	15%
TKN	53367 kg	56762 kg	6%	1.09 mg/L	1.21 mg/L	10%
Lead	2245 kg	2151 kg	-4%	0.05 mg/L	0.05 mg/L	0%
Zinc	51413 kg	4771 kg	-8%	0.11 mg/L	0.1 mg/L	-10%
Benzo(g,h,i)perylene	5828.2 g	5219 g	-12%	0.12 ug/L	0.11 ug/L	-9%
Escherichia Coli	60278.5 x 10^{11} counts	60270 x 10^{11} counts	0%	123.34 c/100mL	128.45 c/100mL	4%

Note: Results for TP and TKN would have been significantly better had the model simulations been based on data collected over the entire monitoring period, rather than 2003 data only. Unfortunately, these data were not available when the modeling study was conducted.

In reviewing the findings several points should be noted:

1. The results are based on a specific type of greenroof technology and may not be representative of other greenroof technologies.
2. For some variables, for example Total Suspended Solids, the primary source of the pollutant is from other sources (*eg*: roads, parking lots). Therefore, even though the difference between the EMC for the control roof and greenroof is considerable, the overall impact is not.
3. Elevated concentrations of certain parameters in the greenroof implementation scenario may be a result of sources on the greenroof itself, such as the growing media and/or faeces from birds. This may be the case for total phosphorus, TKN, and *E. coli.*
4. Results for total phosphorus and TKN concentrations and loads would have been significantly better had both years of monitoring data been used in the exercise because these constituents decreased significantly after 2003.

7.0 GROWING MEDIA QUALITY ANALYSIS

The chemistry of bulk growing media and leachate from 11 greenroof susbstrates currently available commercially were analyzed by Entech laboratories in Mississauga. The goal of this analysis was to determine the impact of growing media constituents on runoff chemistry. For each of the 11 samples, the first water leachate was compared to the fourth water leachate to determine whether leaching of contaminants decreases over time. Table 7.1 provides a general description of the composition of each substrate tested. Composition information were not available for J and K as per the manufacturers' request.

Table 7.1: Growing media composition as provided by manufacturers

Growing Media	Composition	Comments
A	5-10% organic matter and 70% porous mineral aggregate (by volume)	Crushed brick, blond peat, perlite, sand and compost from vegetable matter
B	50-60% organic matter, 30% mineral aggregate (by volume)	Bark compost, perlite, blond peat, and compost from vegetable matter
C	10-15% organic matter and 55% porous mineral aggregate (by volume)	Crushed brick, blond peat, perlite, sand and compost from vegetable matter
D	75% expanded clay and 8% organic matter (by weight)	Remaining 17% are materials balanced to the needs of the project
E	100% expanded clay	Drainage layer used under growing media
F	25% compost, 25% Solite Coarse #388, 25% perlite, 25% sand (by volume)	
G	25% fine compost, 25% Solite Fine #7, 25% perlite, 25% sand (by volume)	
H	30% slag, 10% perlite, 30% compost and 30% sand (by volume)	
I	25% coarse sand, 25% fine brick, 25% compost and 25% limestone screenings (by volume)	
J	n/a	
K	n/a	

7.1 Bulk Media

7.1.1 Chemical Composition

Table 7.2 summarizes the bulk media chemistry of the 11 products analysed, plus the product used at the York University greenroof site.[2] Substrate chemistry results are compared to typical background concentrations for agricultural land uses in Ontario (OMOE, 1998).

[2] It should be noted that the York University substrate was analyzed by a different certified laboratory (operated by the OMOE). Analytical methods were similar.

Table 7.2: Chemical composition of 11 commercially available greenroof growing media compared to chemical composition of site growing media

	Variable	Units	MDL	*GCSO Guideline	Bulk Growing Media											MOE MDL	Soil used at York U.
					A	B	C	D	E	F	G	H	I	J	K		
General Chem.	Total Volatile Matter	%	-	-	8.4	62.0	17.7	10.3	0.2	6.0	6.3	10.0	3.2	7.0	5.3	-	-
	Oil & Grease	µg/g	20	-	1248	5693	1913	537	71	1027	1128	1330	615	841	404	-	-
	CEC	Meq/100g	-	-	14.9	12.7	14.5	20.3	4.6	41.6	33.8	52.9	23.8	14.7	51	-	-
	pH	units	-	-	7.4	6.0	6.7	6.7	7.3	8.2	7.8	8.0	8.1	7.3	7.9	-	-
	SAR	-	-	1	1.41	1.46	1.59	2.95	0.67	4.79	5.37	3.33	0.51	2.88	1.88	-	-
	EC	mS/cm	-	0.47	1.40	1.75	0.72	1.18	0.21	0.72	0.93	0.40	0.30	0.54	0.03	-	0.48
Nutrients	Total Phosphorus	µg/g	1	-	489	375	565	1469	960	639	420	657	239	511	516	20	1100
	Total Organic Carbon	%	0.1	-	8.5	35.4	13.7	4.9	0.6	3.4	4.6	5.3	1.7	7.2	3.7	-	
	Total Kjeldahl Nitrogen	µg/g	5	-	1739	2986	3071	2174	3324	1984	1367	1731	191	3196	1440	10	1200
Metals	Antimony	µg/g	1	1	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	-	-
	Arsenic	µg/g	1	14	3	1	3	4	7	1	2	2	2	4	2	-	-
	Barium	µg/g	1	190	90	111	82	194	182	12	15	137	70	114	85	0	78
	Beryllium	µg/g	0.5	1.2	<DL	<DL	<DL	<DL	0.7	<DL	<DL	0.8	<DL	<DL	<DL	0	0.8
	Cadmium	µg/g	1	1	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0	0.4
	Calcium	µg/g	50	-	11323	14089	13898	13384	10516	103481	85304	84897	82727	20874	64065	0	9100
	Chromium	µg/g	1	67	10	6	9	87	29	6	6	15	8	15	11	0	31
	Cobalt	µg/g	1	19	5	2	4	14	11	2	3	4	3	7	3	0	12
	Copper	µg/g	1	56	15	17	19	49	24	6	8	26	5	26	11	0	10
	Iron	µg/g	10	-	13411	4619	11439	15178	21717	4418	4970	7755	7493	10252	8532	0	19000
	Lead	µg/g	2	55	7	8	7	<DL	26	3	4	10	<DL	20	4	0	1
	Manganese	µg/g	1	-	317	397	336	528	1182	234	202	1122	296	404	524	0	300
	Mercury	µg/g	0.05	0.16	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.01	0.0005
	Molybdenum	µg/g	2	2.5	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0	0.25
	Nickel	µg/g	2	43	10	5	9	39	30	6	10	9	6	13	5	0	37
	Selenium	µg/g	1	1.4	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	-	-
	Silver	µg/g	0.3	0.35	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	-	-
	Vanadium	µg/g	1	91	14	9	15	19	41	3	4	11	10	15	14	0	38
	Zinc	µg/g	1	150	76	100	81	75	91	25	27	133	45	68	61	0	31
	Chromium (VI)	µg/g	1	2.5	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	-	-

* MOE Guidelines for use at Contaminated Sites in Ontario - Appendix 2, Table F: Ontario typical range soil concentrations (background) for agricultural use

Underscored values are in exceedence of the guideline

Note: <DL indicates that the result was below the method detection limit

Electrical conductivity results exceeded background concentrations for almost all media, including that of the study site. Media samples were also frequently above the guideline for Sodium Adsorption Ratio, although the York University growing medium was not analysed for this variable. In general, metals concentrations rarely exceeded background levels, although concentrations of barium and chromium(III) were both above background levels for growing medium D.

The Ministry of the Environment does not publish soil background concentrations for nutrients. However, relative to one another, medium D had the highest phosphorus concentrations (1469 ug/g), followed by the York University growing medium (1100 ug/g). Medium E, which is used only as a drainage layer in conjunction with a growing medium product, was also relatively high (960 ug/g). Both media D and E consist partly of expanded clay (Table 7.1). The median phosphorus value for substrates A to K was only 516 ug/g. Total Kjeldahl nitrogen concentration was lowest for medium I at 191 ug/g, while concentrations exceeded 1000 ug/g for all other media. Media D had the highest concentrations of several metals, including barium, chromium (III), cobalt, copper, and nickel. Although there were no Ontario soil background guidelines for nutrients, soil chemistry results from samples collected in the Greater Toronto Area suggest that the minimum and maximum concentration of nutrients observed in this survey of bulk media was within the range of what may be expected in agricultural soils (MOE, 1998b).

7.1.2 Grain Size Analysis

Figure 7.1 presents grain size distributions for the 11 growing media samples. The laboratory method used to determine grain size distribution was non-destructive. As a result, the terms ‘gravel’, ‘sand’, ‘silt’, and ‘clay’ are based on size classifications, not media composition. The term ‘gravel’, for instance, is used to describe relatively solid aggregates composed of other mineral soil particles such as clay or shale.

The majority of media were more than 50% gravel, indicating that the particles in greenroof growing media tend to be relatively large (> 2 mm). These large particles in the media are typically less dense than actual gravel, and weigh significantly less so that the structural load on the roof is kept to a minimum. Media B, G and I had significantly lower proportions of gravel, as they all consist of more than 50% sand but no more than 20% gravel. Media B had the largest proportion of the finest particles (clay) at 18%. In comparing this result for medium B to the manufacturer’s composition information (Table 7.1), this product also had the highest organic content among the products with available composition information.

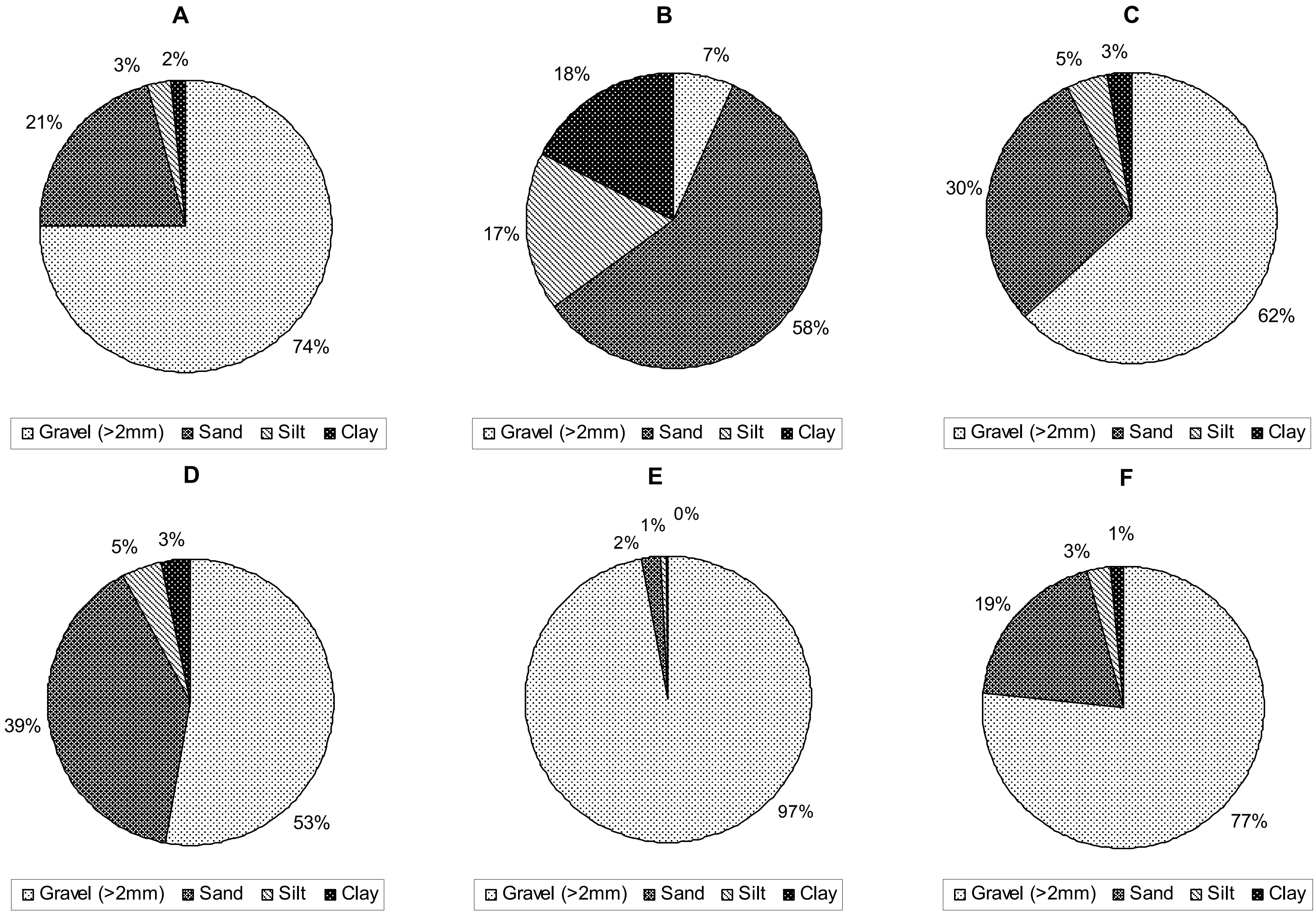


Figure 7.1: Grain size distribution of growing media products A through F

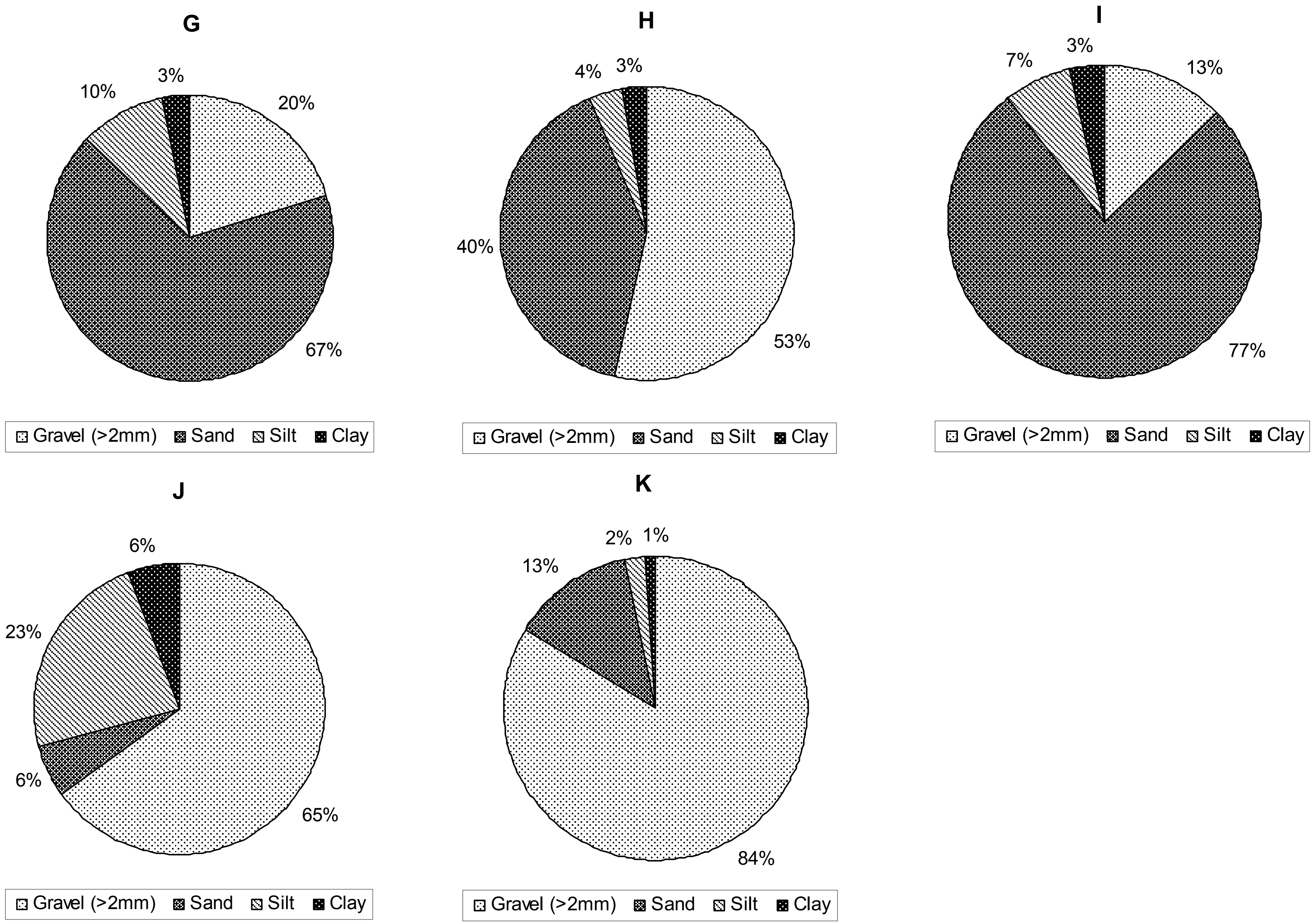


Figure 7.1 (cont'd): Grain size distribution of growing media products G through K

7.2 Leachate Quality

Leachate chemistry results for the 11 growing media products sampled are presented in Table 7.3. The York University growing medium was not tested because there was only enough undisturbed sample for chemical analysis and this product is no longer being sold.

7.2.1 General Chemistry

The pH for all media were relatively alkaline. However, combined with relatively acidic precipitation, this should not be a concern in garden runoff. TSS and turbidity leachate concentrations are influenced by the filter size used in the leachate test, and therefore may not reflect field conditions. Overall, hardness, oil and grease, and chloride concentrations always decreased from the first leachate to the fourth.

7.2.2 Nutrients

In almost all samples, concentrations of nutrient variables (phosphorus and nitrogen) decreased from the first to the fourth leachate. Nitrite-N concentrations were occasionally above the receiving water quality guideline for the first leachate, but never for the fourth leachate.

Not surprisingly, total phosphorus concentrations in leachates were significantly higher than receiving water quality guidelines for all samples. The leachates from medium B had the highest phosphorus concentration and also the highest proportion of organic matter, as indicated in Table 7.1. There was however a significant decrease in concentration from the first to the fourth leachate, suggesting that this may not be a long term concern with this growing media. Interestingly, this media had relatively low phosphorus content (Table 7.2). Medium I leachates had the lowest phosphorus concentrations, but no decrease in concentration occurred from the first to the fourth leachate. The expanded clay substrate D, which had the highest phosphorus content (Table 7.2), had the third highest phosphorus concentration in the fourth leachate. These results underscore the recommendation from the flora survey that fertilizers should not be added to greenroof growing media.

7.2.3 Metals

Relative to receiving water guidelines, several media had elevated concentrations of aluminum, copper, iron, and vanadium in the fourth leachate. Clay based soils had much higher concentrations of aluminum because this constituent forms part of the chemical composition of many types of clay. Aluminum and iron concentrations consistently increased from the first to the fourth leachates. Copper concentrations increased from the first to the fourth leachate for more than 50% of samples, and in each instance the fourth leachate was above the guideline. Lead concentrations exceeded the guideline in the fourth leachate for media E and F. For both of these media, lead concentrations were significantly higher in the fourth leachate.

Table 7.3: Greenroof growing media leachate concentrations for general chemistry and nutrients

Variable			General Chemistry														Nutrients					
Variable			Alkalinity	pH	Chloride	Sodium	Total Solids	TDS	TSS	Conductivity	Turbidity	Hardness (CaCO3)	Potassium	Total Oil & Grease	Bromide	Sulphate	(Ammonia + Ammonium)-N	Nitrate-N	Nitrite-N	TKN	Total Phosphorus	O-Phosphate (as P)
Units			mg $CaCO_3$/L	none	mg/L	mg/L	mg/L	mg/L	mg/L	mS/cm	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
MDL			2	-	0.02	0.025	3	3	3	-	0.1	1	0.1	1	0.05	0.05	0.007	0.005	0.005	0.01	0.002	0.02
Guideline*			none	6.5-9.5	250‡	none	none	none	25†	none	5	none	none	none	none	none	1.4	none	0.06	none	0.03	none
Leachate Concentration	A	1st	68	8.3	20.25	19.53	56	56	<DL	0.42	18.4	112	44.0	20	<DL	75.05	0.188	9.923	0.036	1.77	1.203	<DL
		4th	55	9.3	1.61	17.32	138	130	8	1.25	55.8	24	2.5	6	<DL	4.81	0.04	<DL	0.037	0.47	0.726	0.60
	B	1st	72	7.6	17.61	47.25	394	394	<DL	0.54	6.9	147	47.5	21	<DL	126	0.014	<DL	<DL	1.7	3.744	3.36
		4th	59	9.1	6.81	25.70	112	107	5	0.14	12.6	32	6.0	7	0.1	7.7	0.014	<DL	<DL	0.69	1.628	1.84
	C	1st	79	8.0	14.05	19.26	305	304	1	0.39	26.7	95	39.6	37	<DL	55	0.356	7.661	0.106	2.11	2.035	2.20
		4th	55	9.3	1.34	15.51	119	119	0	0.11	30.1	26	1.8	6	<DL	3.24	0.016	<DL	<DL	0.41	0.857	0.79
	D	1st	65	8.7	21.2	27.05	382	382	<DL	0.50	22.3	108	69.8	24	<DL	18.34	0.186	3.996	0.089	2.38	1.301	0.87
		4th	50	9.1	1.18	12.52	121	118	3	0.12	16.5	30	3.5	6	<DL	5.18	0.184	0.168	<DL	0.63	0.902	0.77
	E	1st	22	7.8	1.35	5.58	76	76	<DL	0.08	21.7	11	1.9	10	<DL	2.83	0.034	0.584	<DL	0.17	0.381	0.23
		4th	35	9.4	1	14.67	96	86	10	0.07	37.0	5	0.7	3	<DL	3.05	<DL	0.006	<DL	0.03	0.343	0.11
	F	1st	105	9.3	21.77	32.99	294	288	6	0.31	90.1	54	33.7	26	<DL	16.77	0.102	2.322	0.094	3.11	1.413	0.91
		4th	55	9.4	1.78	14.94	117	114	3	0.10	16.6	34	0.6	3	<DL	3.88	<DL	<DL	<DL	0.3	1.388	0.30
	G	1st	72	9.2	20.19	39.90	214	214	<DL	0.39	37.6	76	38.8	28	<DL	44.76	0.077	6.225	<DL	2.26	0.918	0.72
		4th	68	9.2	1.15	12.96	136	130	6	0.11	20.8	39	0.8	4	<DL	4.61	0.033	<DL	0.032	0.42	0.57	0.47
	H	1st	155	9.7	13.09	54.93	337	330	7	0.34	86.1	96	19.8	21	<DL	25.21	0.102	0.535	0.115	2.46	1.078	0.93
		4th	74	9.6	1.39	13.03	138	135	3	0.14	20.1	58	2.6	4	<DL	8.14	0.029	0.053	0.017	0.28	0.446	0.20
	I	1st	61	9.1	3.31	25.70	73	70	3	0.17	35.4	83	40.5	14	<DL	22.89	<DL	0.06	0.007	0.14	0.231	0.05
		4th	59	9.4	1.13	12.87	125	123	2	0.10	28.6	42	0.2	4	<DL	2.89	<DL	<DL	<DL	0.04	0.233	<DL
	J	1st	81	8.9	15.21	12.95	268	266	2	0.17	27.1	67	2.2	73	<DL	40.47	1.288	3.806	0.105	4.08	2.428	2.38
		4th	50	9.2	0.96	12.32	115	110	5	0.10	18.8	23	3.2	5	<DL	2.66	0.021	0.017	<DL	0.66	0.69	0.52
	K	1st	70	9.6	2.84	14.44	148	148	<DL	0.19	25.1	62	11.0	28	<DL	30.9	0.022	0.398	0.053	0.77	0.551	0.33
		4th	68	9.5	1.19	14.54	126	121	5	0.13	20.7	49	1.0	4	<DL	9.09	<DL	<DL	<DL	0.31	0.336	0.12

* Guidelines listed are Provincial Water Quality Objectives (OMOE, 1999) where available. For parameters with no PWQO, the Canadian Water Quality Guideline is used, with the exception of chloride‡ (source: EC & HC, 2001) and TSS† (source: (EIFAC, 1965). Leachates would not normally be expected to meet these guidelines.

Underlined values are in exceedence of the guideline

MDL: Method Detection Limit

Table 7.3 (cont'd): Greenroof growing media leachate concentrations for metals

Variable			Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese	Mercury	Molybdenum	Nickel	Silver	Vanadium	Zinc	Strontium	Titanium	Chromium (VI)
			Metals																					
Units			µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
MDL			1	1	0.10	0.02	0.1	20	0.4	0.2	0.2	5	0.6	10	0.1	0.02	0.4	0.1	0.1	0.2	0.2	0.02	0.2	1
Guideline*			75‡	100	none	11	0.1	none	8.9	0.9	5	300	5	none	none	0.2	40	25	0.1	6	20	none	none	1
Leachate Concentration	A	1st	212	<DL	20.2	0.04	<DL	30113	3.5	0.3	2.9	533	1.0	8838	8.7	<DL	5.9	1.8	<DL	13.6	3.5	80.68	9.82	<DL
		4th	1502	1.2	35.02	0.06	<DL	6755	2.2	0.7	9.6	993	1.3	1759	36.8	<DL	<DL	1.2	<DL	12.9	12.6	22.7	43.52	<DL
	B	1st	15	4.2	42.6	<DL	0.1	32863	1.3	<DL	2.6	98	0.7	15673	0.8	<DL	2.8	1.0	<DL	1.6	1.3	104	1.3	<DL
		4th	235	<DL	27.11	0.02	<DL	7313	1.5	<DL	6.0	219	<DL	3426	5.6	<DL	1.5	0.7	<DL	3.6	7.0	22.04	5.64	<DL
	C	1st	249	6.0	19.84	0.04	0.1	23043	1.4	0.3	2.4	707	<DL	9107	7.5	<DL	4.2	1.1	<DL	9.6	1.8	76.5	10.98	<DL
		4th	821	<DL	13.58	0.06	<DL	7004	2.0	0.3	1.8	599	<DL	2206	17.4	<DL	0.5	0.7	<DL	10.9	4.6	27.14	28.64	<DL
	D	1st	233	4.8	20.74	0.04	0.1	29093	2.2	0.6	13.7	369	0.9	8609	11.4	<DL	7.9	2.6	<DL	8.3	8.6	112.8	9.88	<DL
		4th	736	1.7	9.78	0.04	<DL	8885	2.5	0.4	33.3	461	1.5	2043	23.5	<DL	<DL	1.7	<DL	6.1	15.1	44.1	21	<DL
	E	1st	709	6.4	10.7	0.04	0.2	3547	1.7	0.2	1.4	549	2.1	609.1	13.4	<DL	1.5	0.6	<DL	10.6	0.9	9.56	21.14	<DL
		4th	3534	3.1	28.06	0.06	0.2	1373	4.2	0.7	118.0	1003	6.5	472.3	46.8	<DL	<DL	4.5	<DL	9.3	72.1	6.52	62.8	<DL
	F	1st	1405	4.2	17.56	0.04	0.1	13603	3.4	1.1	7.4	1110	1.5	4907	16.5	<DL	4.8	5.3	<DL	11.1	8.9	32.28	34.5	<DL
		4th	2372	1.6	7.06	0.02	0.1	9814	2.0	0.3	127.4	417	6.0	2370	13.8	<DL	<DL	3.2	<DL	3.4	92.2	22.46	19.56	<DL
	G	1st	568	4.8	14.74	0.04	0.1	18583	1.9	0.9	6.7	747	0.7	7231	8.6	<DL	4.1	4.8	<DL	9.5	19.7	51.46	14.18	<DL
		4th	612	1.8	17.98	0.02	<DL	10968	6.0	0.4	3.9	330	0.6	2920	13.4	<DL	<DL	1.6	0.1	3.9	7.6	23.8	22	<DL
	H	1st	1533	2.4	23.6	0.06	0.1	22563	4.0	1.1	11.8	1395	2.8	9569	94.3	<DL	3.4	4.3	<DL	10.1	20.6	30.14	55.28	<DL
		4th	280	1.3	8.38	0.04	<DL	14128	1.9	0.2	3.4	197	0.7	5530	35.7	<DL	<DL	0.5	0.1	4.0	9.1	11.6	18.08	<DL
	I	1st	547	3.0	18.08	0.04	<DL	19273	1.6	0.3	1.0	682	0.7	8277	12.9	<DL	3.0	0.5	<DL	15.1	2.7	240.9	12.3	<DL
		4th	458	1.4	9.26	0.02	<DL	13188	3.0	<DL	5.1	403	0.6	2235	22.6	<DL	<DL	0.3	0.1	5.3	5.9	174.2	8.84	<DL
	J	1st	730	8.9	20.76	0.04	0.3	20723	2.2	0.5	7.6	830	1.2	3738	8.3	<DL	4.7	2.0	<DL	10.1	4.9	65.54	18.68	<DL
		4th	576	2.6	10.32	0.04	<DL	5612	1.2	0.2	3.1	261	0.6	2203	15.1	<DL	0.4	0.3	0.14	8.0	3.5	20.72	13.16	<DL
	K	1st	454	2.4	10.56	0.08	<DL	20113	1.7	0.2	3.1	588	1.1	2762	11.0	<DL	3.8	3.8	<DL	23.4	4.2	47.44	14.7	<DL
		4th	776	1.3	9.34	0.04	<DL	15888	1.2	<DL	2.6	259	1.1	2220	27.1	<DL	<DL	1.9	0.14	8.2	8.3	33.64	18.6	<DL

*Guidelines listed are Provincial Water Quality Objectives where available. For variables with no PWQO, the Canadian Water Quality Guideline is used.
Underscored values are in exceedence of the guideline
MDL: Method Detection Limit
‡Guideline for aluminum is for clay-free samples. These samples are not necessarily clay-free.

Elevated leachate copper levels in several media are consistent with observed runoff quality results from the York University garden (although the York University substrate was not tested). These high copper levels do not necessarily mean that the media itself has higher copper concentrations. This is clear from Table 7.2 and 7.3, which shows no correlation between the amount of copper in the bulk media and levels of copper in the leachate.

In general, concentrations of several metals of concern were found to increase from the first to the fourth leachate. This indicates that the mobility of these metals is increasing with leaching, possibly due to changes in pH, hardness, or the availability of soluble complexes to which metals tend to bind. This does not necessarily indicate that leachate metal concentrations will continue to increase in the long-term. Field data show no significant upward trend in concentrations of metals over time.

7.3 Limitations of the Growing Media Quality Analysis

There are several factors which limit the extent to which the laboratory leachate procedure accurately simulates rainfall leaching processes occurring on an actual planted roof. The following factors may be important in evaluating growing media quality but have been omitted from this study:

- **Long-term leaching:**

  Leaching of media samples was only performed four times, which cannot compare to the extent of leaching from rainfall that occurs on a greenroof in the long term.

- **Atmospheric deposition and precipitation chemistry:**

  Because media were sampled from their original packages and not from an actual rooftop garden, contaminant inputs from atmospheric deposition and precipitation are not accounted for. The chemistry of the water used in the laboratory leaching procedure was different from that of precipitation. Also, precipitation chemistry may vary geographically and seasonally, making it difficult to simulate the in-situ leaching process during one or a series of rainfall events.

- **Influence of vegetation:**

  Plants may have a substantial impact on soil and leachate chemistry. The chemical and biological processes that occur between greenroof plants and the growing media may increase or decrease contaminant concentrations in soil or leachate.

- **Physical properties of the growing media:**

  There are several physical properties of growing media, such as moisture retention capacity, wet and dry weight, freeze-thaw resistance, and water permeability, which can have a substantial impact on a greenroof's water quantity and quality performance. The ability of a greenroof to retain water directly affects runoff volumes and, subsequently, the total load of contaminants from the greenroof. Some of the other factors mentioned may also have a direct or indirect impact on pollutant loads.

- **Influence of particulate matter on runoff chemistry:**

  Filtering of leachate samples may not mimic filtering processes occurring in the field. On field sites, rain water would be filtered by the growing media as it moves towards the outlet, and in some cases there may be another outlet filter to avoid soil loss from the roof. If this process results in greater discharge of particulate matter from the roof than occurs through simple filtering of leachate, then overall water quality in roof runoff may be worse than observed during lab leachate simulations.

8.0 BIODIVERSITY ASSESSMENT

8.1 Flora

The vegetation survey was initiated to investigate the function of greenroofs as habitat for native flora in the Toronto area. Detailed flora results are presented in Appendix D.

The greenroof was seeded in 1999 with two commercial seed mixes: non-native grasses and largely non-native forbs. Unfortunately, the company that prepared the seed mix is no longer in business and therefore the exact composition of the seed mix could not be determined. Measures of floristic quality based on the proportion of native plants, as well as the conservatism of the native species present, indicated that the greenroof flora is currently relatively low in native biodiversity and continues to be heavily influenced by original commercial seed mixes four years later. The overall condition of the greenroof indicates a relatively low-nutrient, low-competition environment that could be conducive to the establishment of conservative or rare native plants that are of local concern.

The sloped part of the greenroof still has a high complement of ornamental forbs that were probably in the original seed mix: sweet William (*Dianthus barbatus*), black-eyed Susan (*Rudbeckia hirta*), foxglove beardtongue (*Penstemon digitalis*), baby's breath (*Gypsophilia cf. paniculata*), and a few other species that are less frequent. Some of these forbs are native but the majority are not. Some of the non-native forbs are North American, but not native to the Toronto area; for example, lance-leaved coreopsis (*Coreopsis lanceolata*) and purple coneflower (*Echinacea purpurea*). In addition, the provenance of the native species in the seed mix is unknown. It is unlikely to be from within the Toronto bioregion.

The greenroof had 91 vascular plant species in 2005, of which 29 (32%) are native. This constitutes an increase of 11 native species since 2004. The overall picture of the greenroof is one of well-distributed but relatively sparse vascular plant cover, and a rather high moss cover.

Despite the influence of the original seed mixes, there have been subtle, gradual changes. Native biodiversity increased between 2004 and 2005 from 29 to 40 species. This accounted for a slight increase in floristic quality (see Appendix D). However, flora surveying must be conducted over a period longer than two years in order to clearly determine whether the net changes are towards native biodiversity or weediness. The highest proportion of native to exotic species at the York University greenroof was still found in the section that received no seed mix, but simply relied on colonization by ambient seed rain. This is not the basis for an argument against planting, however the type and timing of planting should be strategic so as to consider which plants will colonize naturally due to dispersal by wind or birds. Greenroof plant recommendations, which have been developed based on results from the York University site, are provided in section 10.2. A recommended native plant list is provided in Appendix E.

While greenroofs cannot be a substitute for conserving and restoring forested or wetland habitats on the ground, or large patches of intact landscape in the Greater Toronto Area, they can likely contribute to the conservation of some of our more sensitive flora, especially those adapted to exposed, low-nutrient habitats such as some prairie, meadow, thicket, and fen-like meadow-marsh types. The exposed environment of the greenroof would be conducive to certain habitat-specialist native plants while limiting the competitiveness of most invasive species.

8.2 Fauna

Table 8.1 summarizes the fauna observations on the greenroof during visits in 2004 and 2005. Fauna results are discussed in greater detail in Appendix F.

Table 8.1: Observed bird species and activities for all visits in 2004 and 2005

Species	6/5/04	20/5/04	31/5/04	17/6/04	6/7/04	18/8/04	10/9/04	6/10/04
Canada goose	1 Obs, 2b	2b						
mourning dove			1 Obs					
European starling	1 Obs	1 Obs					1 Obs	
savannah sparrow	1 Obs							

Species	18/4/05	25/4/05	4/5/2005	19/5/05	31/5/05	18/7/05	15/8/05	30/8/05	21/9/05	12/10/05
Canada goose	2b, 1r	2b	2b	2b						
mourning dove	1f									
European starling	1f, 5r	1s	1s, 1r	4f	2f					
chipping sparrow						1f				
house sparrow				1b	1b	1r			1r	

Note: Obs = observed. In 2005 this was refined to describe whether the bird was observed to be roosting/resting (r), foraging/feeding (f), or singing (s). In both 2004 and 2005, b = breeding. Numbers indicate the number of individual birds observed to be engaged in the activity.

A total of six bird species were found using the greenroof over the course of all visits in 2004 and 2005. The Canada goose and house sparrow were noted as breeding on the greenroof. The European starling was the most frequent species on the site, foraging for nest material early in the season. The chipping sparrow was also observed foraging on the greenroof. Notable by their absence were species such as house finch, rock pigeon, common grackle and ring-billed gull, all of which should at some time be seen foraging on such a roof top garden.

While no migrant activity was recorded on the greenroof in 2005, it is likely that migrants visited the site during the spring and fall, much as it is likely that migrants landed on many of the surrounding non-greenroofs. The chance of encountering a migrant bird will likely increase over time since the duration of each migrant visit will be prolonged as foraging and shelter prospects improve. Once the invertebrate population has been established the potential for greater use by birds - migrants and local breeders – is expected to increase.

8.3 Bees

The effectiveness of greenroofs as bee habitat was assessed by comparing the biodiversity of the greenroof to the biodiversity of various nearby sites at ground level. While the survey revealed that the bee population was lacking species that one would expect to find in similar habitats elsewhere, findings indicate that bee community structure on the greenroof is not significantly different from most sites surveyed, and is most similar to old field habitats. With succession, greenroofs may become valuable habitat for bee nesting and foraging (Willis, 2005).

9.0 OPERATIONS AND MAINTENANCE

9.1 Irrigation

The need for the irrigation of a rooftop garden is dictated by the types of plants used, local climate conditions, and the stage of plant establishment. Even in circumstances when the need for irrigation is anticipated to be low, an irrigation system should be installed unless hand watering is considered feasible. During the early stages after greenroof installation when plants are not well-established, more frequent irrigation may be required.

During the first year of monitoring at the study site, the garden was irrigated every evening between the months of June and October. This level of irrigation should not be required for a greenroof, since drought-tolerant plants are typically used. The connection of the irrigation system to garden soil moisture sensors in 2004 led to a substantial improvement in the runoff retention of the garden. In order to maximize the stormwater performance of a greenroof, irrigation schedules should be based on soil moisture. This may be accomplished by using soil moisture sensors in the same way they were used at the study site, or by having maintenance staff assess the soil moisture before irrigating. Maintenance personnel may take manual soil moisture readings or may make an assessment based on recent rainfall quantities.

9.2 Plant Management

Greenroof plants are normally selected based on their low maintenance requirements and ability to survive in adverse climate and low nutrient conditions. Similar to the need for irrigation, plant maintenance needs are greater during the period after initial planting. While maintenance requirements will vary based on the size and type of greenroof planted, maintenance is generally considered to be required more frequently during the first season. Thereafter, the number of maintenance visits required may range from 3 to 10 per year for an extensive greenroof. The need for plant maintenance on a greenroof is related to ensuring structural stability and an appropriate balance of flora species. For example, the unintended colonization by a tree or shrub species may result in stress on the roof membrane caused by roots or increased weight on the roof. In terms of managing the plant community, maintenance visits should be made to monitor plant health and prevent the establishment of invasive species. Recommendations for plant selection to maximize biodiversity are provided in Appendix E.

9.3 Substrate

As a greenroof substrate has the ability to attenuate contaminants that may be deposited onto it through wet and dry atmospheric deposition, substrate replacement may become necessary in the long term if contaminants accumulate to excessive levels and begin to leach into runoff. Samples of greenroof substrates should be collected for quality analysis every 5 years in order to monitor possible contaminant accumulation. The substrate material itself as well as the leachate of the substrate should be analysed for nutrients, metals, and PAHs. Results should be compared over time to assess whether or not contaminant levels are increasing.

The replenishment of greenroof soil loss may also be required in some circumstances. Soil loss on a greenroof may occur as a result of the breakdown of organic content in the soil and uptake by plants. Erosion caused by wind and runoff may also contribute to soil loss. Maintenance visits made for plant maintenance may incorporate measurements of soil depth at various locations in the garden. Comparison of depth measurements over time will allow maintenance staff to determine if and when soil replenishment will be needed.

Fertilizers, herbicides and pesticides should not be applied to rooftop gardens. These substances degrade runoff water quality and thereby increase contaminant loads to receiving waters. Based on runoff chemistry results from the York University garden, nutrient levels should be kept to the minimum necessary for plant survival. The presence of high nutrient levels has a negative impact on biodiversity as well as water quality, since nutrient rich conditions do not favour the establishment of stress-tolerant native flora.

9.4 Leak Detection

The presence of a greenroof is generally considered to increase the time and cost required for maintenance of the roofing membrane. Nevertheless, keeping the roofing membrane intact is vital to ensuring the structural stability of the roof, which may be an even greater concern in buildings with greenroofs. The traditional flood method used for leak detection requires the removal of the garden, which may be difficult depending on the type of greenroof system in place. Electric leak detection systems are a less invasive method of detecting and repairing membrane leaks beneath rooftop gardens. This type of system may be installed prior to greenroof installation, and subsequent leak checks may be carried out with minimal substrate removal.

9.5 Membrane Replacement

Estimates of roofing membrane lifespan vary based on several factors, such as the type of membrane used and whether or not it is exposed. The presence of a rooftop garden on top of the membrane may help to increase this lifespan by protecting it from the elements. The Canada Mortgage and Housing Corporation estimates that the membrane under a greenroof will need replacement after 30 to 50 years (Peck and Kuhn, 2002).

9.6 Other Considerations

The runoff from a rooftop garden may carry soil and plant debris and other organic matter that can deposit in the roof drainage system. The build-up of debris from the garden is significantly different from any debris accumulation that may occur on a conventional roof. To prevent clogging all components of the drainage system should be checked periodically.

Due to the potential leaching of contaminants from roofing surfaces, all materials in contact with the roof runoff should be appropriately sealed. The use of surfaces that may leach contaminants of concern, such as heavy metals, should be avoided during construction of the greenroof.

As a greenroof may provide a more desirable habitat for birds than a conventional roof, the accumulation of bird faeces may become problematic. Periodic cleaning may become necessary in order to avoid high loads of *E. coli* in garden runoff.

10.0 CONCLUSIONS AND RECOMMENDATIONS

10.1 Conclusions

Key study findings related to water quantity, water quality, and biodiversity are summarized in the following subsections.

10.1.1 Water Quantity

- Continuous runoff and precipitation data were available from May 2003 through to August 2005, excluding the winter months from January to March. Over this period, the garden retained approximately 63% of runoff volumes. If it is assumed, based on various lines of evidence, that retention rates during the winter (January to March) were between 5 and 25%, the annual retention rate for the entire study period would lie roughly between 51 and 54%.
- Irrigation frequency and quantity of precipitation received were the most important factors explaining variation in the garden's runoff retention performance from one monitoring season to another. Regular irrigation of the garden every evening in 2003 resulted in approximately 20% less retention than in 2004, when the garden was irrigated only during dry periods.
- Seasonally, the garden's retention capacity varied with evapotranspiration. The best retention rates occurred in the hot summer months, followed by the spring, fall and winter.
- During individual events in any given season, variations in garden retention capacity were influenced primarily by antecedent moisture content, rainfall size, duration and intensity. In the winter, the depth of snow accumulation during rainfall events may also have been an important factor.
- The garden ceased to retain water once the substrate was saturated. During a 31 mm event in May, 2003, this saturation point was found to be approximately 33% for the upper soil moisture sensor and 42.5% for the lower sensor.
- The garden attenuated peak flows less effectively during large events. As rainfall volumes increased above 30 mm, peak flow reductions dropped from 87 to 68% for events between 30 and 39 mm, and to 50% for events larger than 40 mm.
- The garden continued to provide stormwater management benefits during the cold season. During one snowmelt event on December 16, 2003, the garden provided 35% runoff retention and 15% peak flow reduction relative to the control roof.
- Over the study period, the average time delay between the beginning of rainfall and beginning of runoff was approximately 30 minutes on the garden.
- Hydrologic simulations of greenroof implementation on 100% of available flat roofs (representing 9% of the watershed area) in the fully developed Highland Creek watershed showed a 4% reduction in annual runoff volumes, and roughly 15% reduction in peak flows for events between 20 and 30 mm.

10.1.2 Water Quality

- Total loads for most pollutants of concern were lower from the garden than from the control roof, in part due to substantially lower runoff volumes from the garden. As expected, the garden had higher loads of several chemicals typically found in soils, such as potassium, magnesium and phosphorus.
- Most contaminants in garden runoff were observed at concentrations below receiving water quality guidelines. Notable exceptions include total phosphorus, *Escherichia Coli*, and copper. Among these, only total phosphorus had runoff loads above those of the control roof. The primary source of phosphorus on the garden is the growing medium itself.
- Phosphorus concentrations in garden runoff decreased significantly from a volume weighted mean of 0.7 in 2003 to a mean of 0.3 in 2004. Garden loads were higher than control roof loads in both years, however they were only 69% higher in 2004, while they were 284% higher in 2003. This decrease likely represents a process of leaching whereby soil phosphorus is gradually flushed out during the first year or two of operation. If this is the case, continued leaching over time may bring phosphorus levels from the garden down to control roof levels and/or receiving water objectives.
- Model simulations of water quality at a watershed scale indicated slightly improved receiving water quality for most water quality variables. Total phosphorus and total Kjeldahl nitrogen loadings increased moderately from baseline conditions. Unfortunately, the data used to calibrate the model were only from monitoring conducted in 2003. Had 2004 data been included, greenroof implementation would have resulted in lower stream concentrations of TKN and only a minor increase in total phosphorus concentrations.
- Elevated copper concentrations detected in garden and control roof runoff may be attributed to several sources, including the control roofing material, the growing medium, atmospheric deposition, and the eavestroughs which conveyed runoff to flow metres.
- Results of the water leachate chemical analysis from various growing media confirm that greenroof growing media can be a significant source of copper and phosphorus in runoff.
- The maximum temperature of garden runoff (34°C) was roughly 3°C greater than that of the control roof runoff (32°C). The mean garden runoff temperature (27°C) was approximately 5°C greater. Despite higher water temperatures, the thermal impact of the garden on receiving waters is probably less than that of the control roof, simply because the garden discharges approximately 80% less runoff during the hot summer months.

10.1.3 Biodiversity

- Greenroof flora is currently relatively low in native biodiversity and continues to be heavily influenced by original commercial seed mixes five years after initial planting.
- The overall condition of the greenroof indicates a relatively low-nutrient, low-competition environment that could be conducive to the establishment of certain habitat-specialist native plants while limiting the competitiveness of most invasive species.

- In 2005 the greenroof had 91 vascular plant species, of which 29 (32%) were native. From 2004 to 2005, 11 new native species were found on the garden. A list of recommended native plants for greenroofs is provided in an appendix of the report.
- The highest proportion of native to exotic species at the York University greenroof was found in the section that received no seed mix, but simply relied on colonization by ambient seed rain
- Flora surveying must be conducted over a longer period in order to determine whether the net changes observed thus far are towards native biodiversity or weediness.
- While greenroofs cannot be a substitute for conserving and restoring forested or wetland habitats on the ground, they may contribute to the conservation of some of our more sensitive flora, especially those adapted to exposed, low-nutrient habitats such as some prairie, meadow, thicket, and fen-like meadow-marsh types.
- The bee survey revealed that the population on the greenroof was lacking species that one would expect to find in similar habitats elsewhere, however bee community structure on the greenroof is not significantly different from most sites surveyed, and is most similar to old field habitats. With succession, greenroofs may become valuable habitat for bee nesting and foraging.
- A total of six bird species were found using the greenroof over the course of all visits in 2004 and 2005. While no migrant activity was recorded on the greenroof in 2005, it is likely that migrants visited the site during the spring and fall, much as it is likely that migrants landed on many of the surrounding non-greenroofs.
- Once the invertebrate population has been established the potential for greater use by birds - migrants and local breeders – is expected to increase.

10.2 Recommendations

The following recommendations are based on observations at the site and study findings. For detailed instructions on the design and maintenance of greenroofs, the reader should consult the German FLL guidelines (1995) or standards relating to greenroofs developed by the American Society for Testing and Materials (ASTM, 2006).

10.2.1 Design

- On buildings with sufficient structural support, flow restrictors should be used in conjunction with greenroofs to help attenuate runoff peaks in the winter and early spring, when the garden is not retaining as much runoff.
- As greenroof substrates can be a significant source of phosphorus, growing media containing phosphorus-rich fertilizers or excessive nutrient levels should be avoided.
- The chemical and leachate properties of growing media should be considered in the selection of greenroof substrates. Potential constituents of concern may include phosphorus, nitrogen compounds, copper and other heavy metals.

- Construction materials surrounding the garden should be selected to minimize leaching of chemicals (e.g. metals, wood preservatives) into runoff.
- In order to maximize greenroof biodiversity, a range of different substrate types and depths as well as irrigation regimes should be used. Planting should focus on species that are less likely to arrive on their own and that are adaptable to drought, wind, low nutrients, and sometimes alkaline soils. Fertilization of greenroof soils should be avoided since the low-nutrient status on greenroofs is beneficial to biodiversity because it favours stress-tolerant, specialized native flora over aggressive opportunistic species.
- Minimizing garden runoff temperatures may require the use of more shading plants or another method that minimizes the exposure of the garden substrate to direct solar radiation.

10.2.2 Operations and Maintenance

- Greenroof irrigation should be minimized through appropriate plant and substrate selection. Irrigation schedules should be based on substrate moisture levels.
- Clearing of debris and bird feces from the greenroof and drainage system should be carried out as deemed necessary to prevent both clogging and the contamination of runoff.
- This study and current greenroof literature suggest that during the first season of installation plant growth and survival should be monitored carefully. Thereafter, the number of maintenance visits required will range from 3 to 10 per year.

10.2.3 Research Needs

- Runoff retention capacity of greenroofs during winter rainfall and snowmelt events requires further study
- Runoff water quality studies should investigate long term and seasonal trends, and focus on variables that have shown to be of concern in previous studies, such as phosphorus and copper.
- Long term monitoring of greenroof water quality is needed to determine how successive leaching of the growing media may lead to reductions in contaminant loads, and whether or not these reductions are reversed as contaminants build-up in the substrate.
- The effectiveness of various soil amendments that help reduce the release of phosphorus and other constituents of concern from greenroof substrates should be tested.
- Long term monitoring of greenroof flora and fauna populations should be conducted to determine whether flora biodiversity increases over time, and whether migrating and locally breeding birds will frequent greenroofs.

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APPENDIX A

Detailed Results - Water Quantity

Table A1: Hydrological characteristics and greenroof performance for all events over the monitoring period

MONTH	Event start date	Time of event: Start	Time of event: End	Rainfall event characteristics: Depth (mm)	Max intensity (mm / 5 min interval)	Mean intensity (mm/hr)	Duration (hrs)	Antecedent Soil Moisture (%) upper sensor	Antecedent Soil Moisture (%) lower sensor	**Calculated Inflow (L): Control	**Calculated Inflow (L): Garden	*Measured Outflow (L): Control	*Measured Outflow (L): Garden	[+]Runoff Lag (min): Control	[+]Runoff Lag (min): Garden	Runoff Coefficient: Control	Runoff Coefficient: Garden
May	5-May-03	17:29	19:54	10.8	0.4	4.4	2.45	29.1	40.1	1414.8	2602.8	1107.9	229.0	3.0	-36.0	0.8	0.1
	5-May-03	22:14	0:49	13.8	1.6	5.4	2.55	30.4	40.2	1807.8	3325.8	2214.5	2282.9	3.0	3.0	1.2	0.7
	7-May-03	17:16	18:12	0.8	0.2	0.9	0.933	31.3	40.3	104.8	192.8	74.6	18.9	-3.0	7.0	0.7	0.1
	10-May-03	14:28	14:39	0.8	0.6	4.4	0.183	27.9	37.7	104.8	192.8	134.8	0.0	2.0	0.0	1.3	0.0
	11-May-03	4:32	13:22	9.8	1.0	1.1	8.83	27.5	38.3	1283.8	2361.8	1172.3	233.9	5.0	250.0	0.9	0.1
	12-May-03	10:06	18:13	1.6	0.2	0.2	8.12	29.9	41.1	209.6	385.6	126.4	1.5	6.0	306.0	0.6	0.0
	16-May-03	2:37	22:56	30.6	0.8	1.5	20.32	27.8	39.1	4008.6	7374.6	3503.8	4657.6	n/a	206.0	0.9	0.6
	20-May-03	12:37	17:35	12.2	1.4	2.5	4.97	27.5	37.0	1598.2	2940.2	1466.8	336.1	6.0	156.0	0.9	0.1
	23-May-03	19:29	7:18	33.6	1.0	2.8	11.82	25.7	32.1	4401.6	8097.6	4269.2	3398.9	7.0	75.0	1.0	0.4
	28-May-03	16:18	18:30	0.6	0.2	0.3	2.20	26.9	34.4	78.6	144.6	14.8	0.0	n/a	no runoff	0.2	0.0
	29-May-03	13:53	13:58	2.8	2.0	35.0	0.08	26.4	33.6	366.8	674.8	338.0	11.0	2.0	5.0	0.9	0.0
	31-May-03	3:37	4:47	0.6	0.2	0.5	1.17	25.2	32.4	78.6	144.6	29.9	0.0	n/a	no runoff	0.4	0.0
	31-May-03	13:49	18:02	3.8	0.4	0.9	4.22	25.0	32.3	497.8	915.8	480.7	32.2	n/a	181.0	1.0	0.0
	Averages:	**-**	**-**	**9.4**	**-**	**4.6**	**5.2**	**27.7**	**36.8**	**1227.4**	**2258.0**	**1148.7**	**861.7**	**3.4**	**88.7**	**0.8**	**0.2**
	Totals:	**-**	**-**	**121.8**	**-**	**-**	**-**	**-**	**-**	**15955.8**	**29353.8**	**14933.7**	**11202.1**	**-**	**-**	**0.9**	**0.4**
June	4-Jun-03	11:35	12:06	1.2	0.4	2.3	0.52	22.7	26.7	157.2	289.2	107.5	0.0	2.0	no runoff	0.7	0.0
	4-Jun-03	15:57	3:58	13.2	0.8	1.1	12.02	22.7	26.7	1729.2	3181.2	1537.3	290.7	6.0	82.0	0.9	0.1
	7-Jun-03	5:30	5:39	0.4	0.2	2.7	0.15	25.4	31.5	52.4	96.4	15.5	0.0	6.0	no runoff	0.3	0.0
	8-Jun-03	19:21	22:49	21.6	3.4	6.2	3.47	23.3	27.1	2829.6	5205.6	2861.0	579.2	2.0	28.0	1.0	0.1
	11-Jun-03	4:29	4:33	0.6	0.6	9.0	0.07	27.0	33.3	78.6	144.6	137.6	0.0	1.0	no runoff	1.8	0.0
	12-Jun-03	13:55	17:12	4.6	0.8	1.4	3.28	25.4	30.9	602.6	1108.6	534.5	73.4	5.0	26.0	0.9	0.1
	13-Jun-03	2:01	12:33	17.6	1.8	1.7	10.53	26.9	33.0	2305.6	4241.6	2172.4	1146.6	1.0	27.0	0.9	0.3
	19-Jun-03	3:02	3:10	0.4	0.2	3.0	0.13	22.8	25.2	52.4	96.4	44.3	0.0	-2.0	no runoff	0.8	0.0
	26-Jun-03	23:50	1:22	1.8	0.8	0.2	7.67	7.5	9.1	235.8	433.8	233.9	0.0	23.0	no runoff	1.0	0.0
	29-Jun-03	19:01	20:40	26.4	4.6	16.0	1.65	6.3	8.4	3458.4	6362.4	4531.1	1399.1	1.0	2.0	1.3	0.2
	Averages:	**-**	**-**	**8.8**	**-**	**4.4**	**3.9**	**21.0**	**25.19**	**1150.2**	**2116.0**	**1217.5**	**348.9**	**4.5**	**16.5**	**1.0**	**0.1**
	Totals:	**-**	**-**	**87.8**	**-**	**-**	**-**	**-**	**-**	**11501.8**	**21159.8**	**12175.1**	**3489.0**	**-**	**-**	**1.1**	**0.2**
July	7-Jul-03	5:51	7:26	9.2	3.6	1.3	7.30	8.9	18.4	1205.2	2217.2	1013.2	161.6	2.0	-9.0	0.8	0.1
	7-Jul-03	9:00	9:19	1.2	0.2	6.3	0.19	9.5	24.7	157.2	289.2	116.6	5.1	3.0	7.0	0.7	0.0
	10-Jul-03	16:06	19:17	6.2	0.6	1.9	3.18	8.8	22.1	812.2	1494.2	686.8	106.0	2.0	83.0	0.8	0.1
	11-Jul-03	14:18	14:22	0.8	0.8	12.0	0.07	9.1	27.0	104.8	192.8	88.6	0.0	1.0	no runoff	0.8	0.0
	15-Jul-03	17:38	20:10	11.6	2.0	4.6	2.53	7.2	23.6	1519.6	2795.6	1471.4	226.0	7.0	24.0	1.0	0.1
	20-Jul-03	14:31	15:24	1.4	0.2	1.6	0.88	7.9	25.3	183.4	337.4	145.7	0.0	2.0	no runoff	0.8	0.0
	21-Jul-03	21:10	22:20	1.0	0.2	0.9	1.17	7.4	26.3	131.0	241.0	63.2	0.0	14.0	no runoff	0.5	0.0
	22-Jul-03	16:30	17:01	11.2	3.0	21.7	0.52	7.3	27.4	1467.2	2699.2	1526.3	250.6	1.0	3.0	1.0	0.1
	26-Jul-03	14:56	15:23	0.8	0.2	1.8	0.45	10.9	26.9	104.8	192.8	74.6	0.0	5.0	no runoff	0.7	0.0
	27-Jul-03	7:19	7:57	0.8	0.6	1.3	0.63	10.7	27.9	104.8	192.8	76.8	0.0	3.0	no runoff	0.7	0.0
	Averages:	**-**	**-**	**4.4**	**-**	**5.3**	**1.7**	**8.77**	**25.0**	**579.0**	**1065.2**	**526.3**	**74.9**	**4.0**	**10.8**	**0.8**	**0.0**
	Totals:	**-**	**-**	**44.2**	**-**	**-**	**-**	**-**	**-**	**5790.2**	**10652.2**	**5263.2**	**749.3**	**-**	**-**	**0.9**	**0.1**

		Time of event		Rainfall event characteristics						**Calculated Inflow (L)		*Measured Outflow (L)		[+]Runoff Lag (min)		Runoff Coefficient	
MONTH	Event start date	Start	End	Depth (mm)	Max intensity (mm / 5 min interval)	Mean intensity (mm/hr)	Duration (hrs)	Antecedent Soil Moisture (%) upper sensor	Antecedent Soil Moisture (%) lower sensor	Control	Garden	Control	Garden	Control	Garden	Control	Garden
August	2-Aug-03	12:36	15:15	24.4	5.4	9.2	2.65	6.6	24.8	3196.4	5880.4	3365.6	1020.6	2.0	8.0	1.1	0.2
	6-Aug-03	5:31	6:19	1.0	0.2	1.3	0.80	17.5	33.2	131.0	241.0	96.2	40.5	3.0	6.0	0.7	0.2
	6-Aug-03	18:07	18:53	3.0	0.8	3.9	0.77	17.8	32.3	393.0	723.0	358.9	37.1	2.0	6.0	0.9	0.1
	10-Aug-03	16:03	16:17	10.6	5.2	45.4	0.23	16.3	32.1	1388.6	2554.6	1561.9	299.8	1.0	1.0	1.1	0.1
	11-Aug-03	16:36	18:23	10.6	1.6	6.0	1.78	21.3	34.3	1388.6	2554.6	1220.3	1153.6	2.0	2.0	0.9	0.5
	16-Aug-03	8:31	8:53	4.8	3.0	13.1	0.37	-	-	628.8	1156.8	655.3	124.0	0.0	3.0	1.0	0.1
	21-Aug-03	22:20	22:36	2.2	1.2	8.3	0.27	-	-	288.2	530.2	182.8	17.0	0.0	2.0	0.6	0.0
	26-Aug-03	3:34	5:30	6.0	1.6	3.1	1.93	-	-	786.0	1446.0	751.1	19.2	n/a	6.0	1.0	0.0
	There is no rainfall or flow data for the greenroof from August 26 - to September 23 and the data from Aug 22 - 26 is questionable (may be missing a storm or two)																
	Averages:	**-**	**-**	**7.8**	**-**	**11.3**	**1.1**	**-**	**-**	**1025.1**	**1885.8**	**1024.0**	**339.0**	**1.4**	**4.3**	**0.9**	**0.1**
	Totals:	**-**	**-**	**62.6**	**-**	**-**	**-**	**-**	**-**	**8200.6**	**15086.6**	**8192.0**	**2711.9**	**-**	**-**	**1.0**	**0.2**
September	2-Sep-03	1:28	2:45	1.4	0.2	1.1	1.28	-	-	183.4	337.4	183.4	203.1	n/a	n/a	1.0	0.6
	14-Sep-03	17:03	18:32	1.4	0.6	0.9	1.48	-	-	183.4	337.4	183.4	203.1	n/a	n/a	1.0	0.6
	15-Sep-03	12:02	18:34	18.8	2.0	2.9	6.53	-	-	2462.8	4530.8	2462.8	2727.5	n/a	n/a	1.0	0.6
	19-Sep-03	3:09	4:26	0.8	0.4	0.6	1.28	-	-	104.8	192.8	104.8	116.1	n/a	n/a	1.0	0.6
	19-Sep-03	6:58	18:00	51.2	1.4	4.6	11.03	-	-	6707.2	12339.2	6707.2	7428.2	n/a	n/a	1.0	0.6
	22-Sep-03	12:02	20:29	28.4	1.0	3.4	8.45	-	-	3720.4	6844.4	3720.4	4120.3	n/a	n/a	1.0	0.6
	27-Sep-03	1:19	12:15	41.6	7.6	3.8	10.93	-	-	5449.6	10025.6	5615.3	6637.2	1.0	3.0	1.0	0.7
	Averages:	**-**	**-**	**20.5**	**-**	**2.5**	**5.9**	**-**	**-**	**2687.4**	**4943.9**	**2711.0**	**3062.2**	**1.0**	**3.0**	**1.0**	**0.6**
	Totals:	**-**	**-**	**143.6**	**-**	**-**	**-**	**-**	**-**	**18811.6**	**34607.6**	**18977.3**	**21435.6**	**-**	**-**	**1.0**	**0.6**
October	3-Oct-03	22:13	5:20	6.3	0.4	0.9	7.12	-	-	825.3	1518.3	855.4	750.6	0.0	8.0	1.0	0.5
	14-Oct-03	15:35	21:31	15.7	2.0	2.6	5.93	-	-	2056.7	3783.7	2459.5	2159.3	20.0	23.0	1.2	0.6
	15-Oct-03	1:38	6:07	3.6	0.4	0.8	4.48	-	-	471.6	867.6	691.0	1221.0	-13.0	21.0	1.5	1.4
	18-Oct-03	15:01	0:12	9.4	0.6	1.0	9.18	-	-	1231.4	2265.4	1234.5	1265.2	-11.0	-17.0	1.0	0.6
	19-Oct-03	3:39	5:56	1.0	0.2	0.4	2.28	-	-	131.0	241.0	71.5	546.6	-3.0	13.0	0.5	2.3
	22-Oct-03	3:39	6:35	1.0	0.2	0.3	2.93	-	-	131.0	241.0	101.0	33.5	1.0	121.0	0.8	0.1
	26-Oct-03	0:22	11:39	15.0	0.4	1.3	11.28	-	-	1965.0	3615.0	1736.0	1595.9	-12.0	97.0	0.9	0.4
	27-Oct-03	15:31	19:24	1.6	0.2	0.4	3.88	-	-	209.6	385.6	237.1	228.3	n/a	-1.0	1.1	0.6
	29-Oct-03	2:35	4:34	1.4	0.2	0.7	1.98	-	-	183.4	337.4	182.0	150.2	n/a	1.0	1.0	0.4
	Averages:	**-**	**-**	**6.1**	**-**	**1.0**	**5.5**	**-**	**-**	**800.6**	**1472.8**	**840.9**	**883.4**	**-2.6**	**29.6**	**1.0**	**0.8**
	Totals:	**-**	**-**	**55.0**	**-**	**-**	**-**	**-**	**-**	**7205.0**	**13255.0**	**7567.9**	**7950.5**	**-**	**-**	**1.1**	**0.6**
November	2-Nov-03	3:18	18:09	18.4	0.6	1.2	14.85	-	-	2410.4	4434.4	2766.3	2992.7	1.0	58.0	1.1	0.7
	3-Nov-03	3:18	4:38	1.6	0.2	1.2	1.33	-	-	209.6	385.6	288.3	426.1	-6.0	-20.0	1.4	1.1
	3-Nov-03	13:21	22:36	22.0	0.6	2.4	9.25	-	-	2882.0	5302.0	3137.8	5010.5	4.0	-8.0	1.1	0.9
	11-Nov-03	5:54	10:23	6.8	0.4	1.5	4.48	-	-	890.8	1638.8	1110.2	155.1	2.0	51.0	1.2	0.1
	12-Nov-03	18:17	23:16	15.6	1.2	3.1	4.98	-	-	2043.6	3759.6	1967.1	2229.0	7.0	9.0	1.0	0.6
	13-Nov-03	10:25	13:54	1.8	0.2	0.5	3.48	-	-	235.8	433.8	460.3	2096.0	3.0	-3.0	2.0	4.8
	16-Nov-03	2:13	6:34	1.6	0.2	0.4	4.35	-	-	209.6	385.6	265.4	230.4	3.0	-32.0	1.3	0.6
	16-Nov-03	23:51	3:49	9.6	0.6	2.4	3.97	-	-	1257.6	2313.6	2117.2	1615.2	13.0	3.0	1.7	0.7
	18-Nov-03	19:37	0:12	9.8	1.6	2.1	4.75	-	-	1283.8	2361.8	1217.0	1332.0	n/a	120.0	0.9	0.6
	19-Nov-03	5:54	14:46	14.6	1.0	1.6	8.87	-	-	1912.6	3518.6	2013.9	3337.9	6.0	15.0	1.1	0.9
	24-Nov-03	12:09	18:47	3.2	0.2	0.5	6.63	-	-	419.2	771.2	333.6	127.0	1.0	-1.0	0.8	0.2
	27-Nov-03	12:01	21:38	15.2	0.4	1.6	9.62	-	-	1991.2	3663.2	1991.2	2205.2	n/a	n/a	n/a	n/a
	28-Nov-03	7:01	0:36	28.6	0.4	1.6	17.58	-	-	3746.6	6892.6	3746.6	4149.3	n/a	n/a	n/a	n/a
	Averages:	**-**	**-**	**11.4**	**-**	**1.6**	**7.2**	**-**	**-**	**1499.4**	**2758.5**	**1647.3**	**1992.8**	**3.4**	**17.5**	**1.2**	**1.0**
	Totals:	**-**	**-**	**148.8**	**-**	**-**	**-**	**-**	**-**	**19492.8**	**35860.8**	**21414.9**	**25906.5**	**-**	**-**	**1.1**	**0.7**

		Time of event		Rainfall event characteristics						**Calculated Inflow (L)		*Measured Outflow (L)		†Runoff Lag (min)		Runoff Coefficient	
MONTH	Event start date	Start	End	Depth (mm)	Max intensity (mm / 5 min interval)	Mean intensity (mm/hr)	Duration (hrs)	Antecedent Soil Moisture (%) upper sensor	Antecedent Soil Moisture (%) lower sensor	Control	Garden	Control	Garden	Control	Garden	Control	Garden
December* **	10-Dec-03	19:17	5:06	13	0.6	1.32	9.82	n/a	n/a	1703.0	3133.0	1252.9	937.6	-11	-12	0.74	0.30
	29-Dec-03	13:33	6:01	19.8	0.4	1.20	16.47	n/a	n/a	2593.8	4771.8	2713.0	4618.7	-1	-19	1.05	0.97
	Averages:	**-**	**-**	**16.4**	**-**	**1.26**	**13.15**	**-**	**-**	**2148.4**	**3952.4**	**1983.0**	**2778.2**	**-6.0**	**-15.5**	**0.89**	**0.63**
June	1-Jun-04	18:23	19:37	4.2	1.4	3.40	1.23	13	32.1	550.2	1012.2	547.1	87.5	2	9	0.99	0.09
	14-Jun-04	0:20	2:05	24.7	5.4	14.10	1.75	6.5	29.6	3235.7	5952.7	3235.7	855.7	n/a	n/a	1.00	0.14
	14-Jun-04	17:14	20:37	12	7.2	3.60	3.38	13.5	31.4	1572.0	2892.0	1127.3	497.3	1	2	0.72	0.17
	17-Jun-04	12:02	12:38	1.2	0.4	2.00	0.60	15	25.8	157.2	289.2	133.5	7.2	0	6	0.85	0.03
	19-Jun-04	2:18	4:00	1.6	0.2	0.94	1.70	15.1	30.8	209.6	385.6	181.2	62.3	0	31	0.86	0.16
	21-Jun-04	18:56	1:06	14.4	1.0	2.33	6.17	13.2	27.4	1886.4	3470.4	1762.8	775.8	0	89	0.93	0.22
	24-Jun-04	19:49	20:51	4.6	1.6	4.47	1.03	13.1	29	602.6	1108.6	572.3	193.1	2	10	0.95	0.17
	28-Jun-04	5:55	9:30	1.2	0.2	0.34	3.58	12.8	26.7	157.2	289.2	79.2	9.9	1	44	0.50	0.03
	Averages:	**-**	**-**	**8.0**	**-**	**3.90**	**2.43**	**12.775**	**29.1**	**1046.4**	**1925.0**	**954.9**	**311.1**	**0.9**	**27.3**	**0.85**	**0.13**
	†Totals:	**-**	**-**	**63.9**	**-**	**-**	**-**	**-**	**-**	**8370.9**	**15399.9**	**7639.1**	**2488.8**	**-**	**-**	**0.91**	**0.16**
July	4-Jul-04	17:38	18:20	18.2	8.2	26.00	0.7	8.5	14.5	2384.2	4386.2	1801.2	288.2	3	6	0.76	0.07
	7-Jul-04	1:41	3:27	9.2	4.4	5.21	1.77	10.8	33.9	1205.2	2217.2	952.9	202.8	18	63	0.79	0.09
	7-Jul-04	15:21	16:11	3.4	1.2	4.10	0.83	12.4	25.3	445.4	819.4	346.1	78.0	0	25	0.78	0.10
	7-Jul-04	19:47	20:57	18.8	3.0	16.11	1.17	12.5	n/a	2462.8	4530.8	2345.9	702.1	1	2	0.95	0.15
	14-Jul-04	3:16	4:23	25.4	7.6	22.75	1.12	11	31.6	3327.4	6121.4	2398.1	756.8	0	3	0.72	0.12
	17-Jul-04	0:27	1:00	1.4	0.4	2.55	0.55	14.8	5.1	183.4	337.4	132.9	25.9	2	4	0.72	0.08
	19-Jul-04	14:45	15:02	6	3.4	21.18	0.28	13.6	n/a	786.0	1446.0	723.5	127.0	2	3	0.92	0.09
	20-Jul-04	13:19	15:38	48.6	8.0	20.98	2.32	14.4	32.9	6366.6	11712.6	5403.6	5225.9	1	1	0.85	0.45
	20-Jul-04	19:16	20:18	6.2	3.6	6.00	1.03	19.4	n/a	812.2	1494.2	885.7	1312.2	2	0	1.09	0.88
	21-Jul-04	17:01	17:07	1	0.8	10.00	0.1	18.3	23	131.0	241.0	87.7	63.8	0	4	0.67	0.26
	22-Jul-04	20:37	20:47	3.2	2.2	19.20	0.17	17.5	30	419.2	771.2	403.4	269.6	1	1	0.96	0.35
	27-Jul-04	1:47	7:33	10.2	0.6	1.77	5.77	14.3	28.4	1336.2	2458.2	1080.0	256.4	0	58	0.81	0.10
	27-Jul-04	22:25	0:06	1	0.2	0.59	1.68	15.9	n/a	131.0	241.0	50.3	70.6	6	28	0.38	0.29
	31-Jul-04	0:46	8:12	19.6	1.6	2.64	7.43	14.2	28.8	2567.6	4723.6	2168.6	1085.0	-2	25	0.84	0.23
	Averages:	**-**	**-**	**12.3**	**-**	**11.36**	**1.78**	**14.1**	**23.9**	**1611.3**	**2964.3**	**1341.4**	**747.4**	**2.4**	**15.9**	**0.80**	**0.23**
	†Totals:	**-**	**-**	**172.2**	**-**	**-**	**-**	**-**	**-**	**22558.2**	**41500.2**	**18779.8**	**10464.3**	**-**	**-**	**0.83**	**0.25**
August	4-Aug-04	8:35	11:19	3.2	0.4	1.17	2.73	14.7	27	419.2	771.2	293.5	434.3	0	25	0.70	0.56
	8-Aug-04	15:42	16:35	7.6	2.4	8.60	0.88	11.7	30.1	995.6	1831.6	902.0	225.5	2	10	0.91	0.12
	10-Aug-04	14:01	15:31	16.4	6.8	10.93	1.5	12.5	29.5	2148.4	3952.4	1863.4	277.3	-5	8	0.87	0.07
	13-Aug-04	11:17	13:33	5.2	0.4	2.29	2.27	13.9	29.5	681.2	1253.2	547.1	60.6	2	47	0.80	0.05
	14-Aug-04	19:00	19:12	0.8	0.6	4.00	0.2	14.6	30.4	104.8	192.8	64.1	0.0	-5	no runoff	0.61	0.00
	15-Aug-04	15:27	15:38	1	0.6	5.45	0.18	13.9	29.4	131.0	241.0	84.9	0.0	-5	no runoff	0.65	0.00
	26-Aug-04	15:18	16:09	2.2	0.4	2.59	0.85	11.4	28.3	288.2	530.2	197.8	10.3	1	39	0.69	0.02
	27-Aug-04	13:35	14:13	20	9.8	31.58	0.63	10.8	30.8	2620.0	4820.0	2085.8	600.2	1	16	0.80	0.12
	28-Aug-04	19:58	23:05	8.8	1.2	2.82	3.12	14.2	31.4	1152.8	2120.8	984.0	222.9	1	16	0.85	0.11
	29-Aug-04	10:06	16:25	24.2	2.0	3.83	6.32	14.9	31.8	3170.2	5832.2	2992.2	2571.1	2	3	0.94	0.44
	Averages:	**-**	**-**	**8.9**	**-**	**7.33**	**1.87**	**13.3**	**29.8**	**1171.1**	**2154.5**	**1001.5**	**440.2**	**-0.6**	**20.5**	**0.78**	**0.15**
	†Totals:	**-**	**-**	**89.4**	**-**	**-**	**-**	**-**	**-**	**11711.4**	**21545.4**	**10014.8**	**4402.4**	**-**	**-**	**0.86**	**0.20**

		Time of event		Rainfall event characteristics						**Calculated Inflow (L)		*Measured Outflow (L)		+Runoff Lag (min)		Runoff Coefficient	
MONTH	Event start date	Start	End	Depth (mm)	Max intensity (mm / 5 min interval)	Mean intensity (mm/hr)	Duration (hrs)	Antecedent Soil Moisture (%) upper sensor	Antecedent Soil Moisture (%) lower sensor	Control	Garden	Control	Garden	Control	Garden	Control	Garden
September	7-Sep-04	8:55	11:35	3.2	0.6	1.2	2.67	n/a	n/a	419.2	771.2	419.2	77.1	n/a	n/a	1.00	0.10
	9-Sep-04	0:43	10:56	26.4	0.8	2.58	10.22	n/a	n/a	3458.4	6362.4	3458.4	1272.5	n/a	n/a	1.00	0.20
	Averages:	-	-	**14.8**	-	**1.89**	**6.45**	-	-	**1938.8**	**3566.8**	**1938.8**	**674.8**	-	-	**1.00**	**0.15**
	†Totals:	-	-	**29.6**	-	-	-	-	-	**3877.6**	**7133.6**	**3877.6**	**1349.6**	-	-	**1.00**	**0.19**
October	2-Oct-04	11:55	12:20	0.6	0.2	1.44	0.42	10.5	30.7	78.6	144.6	30.6	0.0	-5	no runoff	0.39	0.00
	9-Oct-04	7:40	7:54	1.4	1.0	6.00	0.23	9.9	30	183.4	337.4	151.1	16.4	0	4	0.82	0.05
	14-Oct-04	10:50	11:29	0.8	0.2	1.23	0.65	9.5	30.2	104.8	192.8	55.3	0.0	-2	no runoff	0.53	0.00
	15-Oct-04	11:06	14:36	10	2.2	2.86	3.50	9.4	30.1	1310.0	2410.0	1135.6	245.7	2	50	0.87	0.10
	20-Oct-04	9:12	12:01	1.4	0.2	0.50	2.82	11.8	29.1	183.4	337.4	112.9	2.5	0	178	0.62	0.01
	30-Oct-04	2:57	5:01	1.2	0.4	0.58	2.07	11.9	24.8	157.2	289.2	63.7	1.6	7	77	0.40	0.01
	30-Oct-04	10:05	15:12	11.2	4.2	2.19	5.12	12.2	26.4	1467.2	2699.2	1439.5	346.6	48	233	0.98	0.13
	Averages:	-	-	**3.8**	-	**2.11**	**2.12**	**10.7**	**28.8**	**497.8**	**915.8**	**427.0**	**87.5**	**7.1**	**108.4**	**0.66**	**0.04**
	†Totals:	-	-	**26.6**	-	-	-	-	-	**3484.6**	**6410.6**	**2988.7**	**612.8**	-	-	**0.86**	**0.10**
November	2-Nov-04	1:42	13:58	15	1.0	1.22	12.27	12.7	n/a	1965.0	3615.0	1630.0	749.1	3	118	0.83	0.21
	4-Nov-04	10:46	19:05	13.6	1.2	1.64	8.32	15	n/a	1781.6	3277.6	1674.2	1373.4	3	69	0.94	0.42
	17-Nov-04	18:33	20:33	1.4	0.2	0.70	2.00	14.5	n/a	183.4	337.4	103.1	0.0	-3	66	0.56	0.00
	20-Nov-04	11:16	12:19	1.4	0.4	1.33	1.05	14.7	n/a	183.4	337.4	144.5	22.4	3	19	0.79	0.07
	24-Nov-04	9:44	23:51	12.4	0.8	0.95	13.12	14.8	n/a	1624.4	2988.4	1750.1	1433.5	23	67	1.08	0.48
	27-Nov-04	3:41	7:00	1.2	0.2	0.36	3.32	16.7	n/a	157.2	289.2	57.8	4.9	37	139	0.37	0.02
	28-Nov-04	1:59	8:22	16.4	1.0	2.57	6.38	16.2	n/a	2148.4	3952.4	2254.4	3162.1	4	11	1.05	0.80
	Averages:	-	-	**8.8**	-	**1.25**	**6.64**	**14.9**	-	**1149.1**	**2113.9**	**1087.7**	**963.6**	**10.0**	**69.9**	**0.80**	**0.28**
	†Totals:	-	-	**61.4**	-	-	-	-	-	**8043.4**	**14797.4**	**7614.2**	**6745.4**	-	-	**0.95**	**0.46**
December***	7-Dec-04	11:57	16:18	10.6	1.2	1.67	6.35	n/a	n/a	1388.6	2554.6	1752.1	2196.0	3	55	1.26	0.86
	30-Dec-04	20:33	3:49	12.8	0.6	1.78	7.20	n/a	n/a	1676.8	3084.8	2945.3	2787.3	-153	-2	1.76	0.90
	Averages:	-	-	**11.7**	-	**1.72**	**6.78**	-	-	**2348.7**	**2491.7**	**1532.7**	**2819.7**	**-75.0**	**26.5**	**1.51**	**0.88**
March	7-Mar-05	11:06	16:03	4.5	0.6	0.90	5.0	n/a	n/a	589.5	1084.5	2269.8	2794.0	-108	-6	3.85	2.58
	31-Mar-05	11:04	15:28	2.9	0.9	0.66	4.4	n/a	n/a	379.9	698.9	243.5	301.9	2	-11	0.64	0.43
	Averages:	-	-	**3.7**	-	**0.78**	**4.7**	-	-	**484.7**	**891.7**	**1256.7**	**1548.0**	**-53.0**	**-8.5**	**2.25**	**1.50**
	†Totals:	-	-	**7.4**	-	-	-	-	-	**969.4**	**1783.4**	**2513.3**	**3095.9**	-	-	**2.59**	**1.74**
April	2-Apr-05	6:01	23:36	35	0.4	0.84	41.6	16.4	21	4585.0	8435.0	5247.0	8416.0	0	18	1.14	1.00
	7-Apr-05	10:36	13:03	4.0	0.6	1.70	2.4	16.8	23	522.7	961.6	438.9	247.4	1	0	0.84	0.26
	20-Apr-05	11:35	15:41	10.4	0.8	2.54	4.1	12.3	34.7	1362.4	2506.4	1187.7	174.2	-4	58	0.87	0.07
	22-Apr-05	20:04	4:20	8.2	0.4	0.99	8.3	13.1	35.3	1074.2	1976.2	920.9	168.4	17	69	0.86	0.09
	23-Apr-05	11:09	7:31	30.9	0.8	1.52	20.3	14.8	31.6	4047.9	7446.9	4183.6	4224.7	4	18	1.03	0.57
	24-Apr-05	21:13	5:22	3.0	0.2	0.37	8.1	17.5	26.7	391.7	720.6	216.2	263.0	13	0	0.55	0.37
	26-Apr-05	21:34	5:01	10.9	0.6	1.45	7.5	15.6	23.1	1427.9	2626.9	1240.2	1339.7	-5	0	0.87	0.51
	28-Apr-05	13:23	14:21	1.2	0.6	1.20	1.0	17.5	n/a	157.2	289.2	81.8	35.9	10	12	0.52	0.12
	Averages:	-	-	**12.9**	-	**1.33**	**11.66**	**15.5**	**27.9**	**1696.1**	**3120.3**	**1689.5**	**1858.7**	**4.5**	**21.9**	**0.84**	**0.37**
	†Totals:	-	-	**103.6**	-	-	-	-	-	**13569.0**	**24962.8**	**13516.2**	**14869.4**	-	-	**1.00**	**0.60**

		Time of event		Rainfall event characteristics						**Calculated Inflow (L)		*Measured Outflow (L)		†Runoff Lag (min)		Runoff Coefficient	
MONTH	Event start date	Start	End	Depth (mm)	Max intensity (mm / 5 min interval)	Mean intensity (mm/hr)	Duration (hrs)	Antecedent Soil Moisture (%) upper sensor	Antecedent Soil Moisture (%) lower sensor	Control	Garden	Control	Garden	Control	Garden	Control	Garden
May	13-May-05	22:17	23:40	4.2	0.9	3.00	1.4	10.9	18.9	550.2	1012.2	437.3	51.8	2	10	0.79	0.05
	14-May-05	17:27	23:11	10.4	2.0	1.82	5.7	11.9	18.2	1362.4	2506.4	1101.1	136.1	16	67	0.81	0.05
	23-May-05	20:10	20:27	2.4	1.4	8.00	0.3	7.9	16.4	314.4	578.4	247.3	9.9	2	14	0.79	0.02
	28-May-05	16:34	16:51	2.6	0.9	8.67	0.3	n/a	15.9	340.6	626.6	302.7	12.9	2	14	0.89	0.02
	29-May-05	13:04	13:59	3.4	0.6	3.78	0.9	n/a	15.7	445.4	819.4	407.5	22.4	8	23	0.91	0.03
	Averages:	**-**	**-**	**4.6**	**-**	**5.05**	**1.72**	**10.2**	**17.0**	**602.6**	**1108.6**	**499.2**	**46.6**	**6**	**25.6**	**0.84**	**0.03**
	†Totals:	**-**	**-**	**23.0**	**-**	**-**	**-**	**-**	**-**	**3013.0**	**5543.0**	**2495.9**	**233.1**	**-**	**-**	**0.83**	**0.04**
June	4-Jun-05	10:22	10:50	1.4	0.6	2.80	0.5	n/a	13.6	183.4	337.4	156.0	0.0	2	no runoff	0.85	0.00
	13-Jun-05	17:04	20:18	10.8	3.6	3.38	3.2	n/a	44.2	1414.8	2602.8	1284.9	143.3	1	8	0.91	0.06
	14-Jun-05	18:06	18:24	10.8	7.2	36.00	0.3	n/a	33.3	1414.8	2602.8	952.6	182.0	0	3	0.67	0.07
	14-Jun-05	20:10	21:28	17.4	7	13.38	1.3	n/a	33.1	2279.4	4193.4	1831.2	301.3	-3	2	0.80	0.07
	16-Jun-05	8:33	11:43	2.2	0.2	0.69	3.2	n/a	48.7	288.2	530.2	205.8	0.0	-6	no runoff	0.71	0.00
	28-Jun-05	18:57	21:00	19.9	6.2	9.71	2.1	n/a	n/a	2606.9	4795.9	1658.9	321.7	-1	4	0.64	0.07
	Averages:	**-**	**-**	**10.4**	**-**	**10.99**	**1.76**	**-**	**34.6**	**1364.6**	**2510.4**	**1014.9**	**158.2**	**-1.2**	**4.3**	**0.76**	**0.04**
	Totals:	**-**	**-**	**62.5**	**-**	**-**	**-**	**-**	**-**	**8187.5**	**15062.5**	**6089.4**	**949.4**	**-**	**-**	**0.74**	**0.06**
July	4-Jul-05	15:06	15:48	28.2	4.8	40.29	0.7	n/a	n/a	3694.2	6796.2	3162.6	476.5	1	9	0.86	0.07
	5-Jul-05	9:22	10:10	1.0	0.2	1.25	0.8	n/a	n/a	131.0	241.0	84.6	2.5	2	8	0.65	0.01
	5-Jul-05	16:24	17:38	1.8	0.6	1.50	1.2	n/a	n/a	235.8	433.8	170.3	12.3	1	58	0.72	0.03
	14-Jul-05	15:28	17:39	3.8	0.6	1.73	2.2	2.8	11.1	497.8	915.8	412.6	27.6	2	97	0.83	0.03
	16-Jul-05	17:10	19:05	1.0	0.2	0.48	2.1	n/a	10.1	131.0	241.0	48.4	0.0	8	no runoff	0.37	0.00
	17-Jul-05	4:46	5:04	8.4	3.6	28.00	0.3	2.3	n/a	1100.4	2024.4	1074.7	152.9	3	4	0.98	0.08
	26-Jul-05	8:55	10:50	4.4	0.6	2.32	1.9	n/a	6.3	576.4	1060.4	491.3	61.8	1	14	0.85	0.06
	27-Jul-05	8:08	10:26	2.2	0.2	0.96	2.3	n/a	n/a	288.2	530.2	230.9	40.4	-6	24	0.80	0.08
	Averages:	**-**	**-**	**6.4**	**-**	**9.56**	**1.44**	**2.55**	**9.2**	**909.5**	**1673.2**	**709.4**	**96.8**	**1.5**	**30.6**	**0.76**	**0.04**
	†Totals:	**-**	**-**	**50.8**	**-**	**-**	**-**	**-**	**-**	**6366.6**	**11712.6**	**5675.4**	**774.0**	**-**	**-**	**0.89**	**0.07**
August	1-Aug-05	0:56	4:27	6.2	0.6	1.77	3.5	n/a	n/a	812.2	1494.2	679.9	147.9	2	11	0.84	0.10
	2-Aug-05	15:46	16:18	11.4	2.9	22.80	0.5	0.9	n/a	1493.4	2747.4	1589.3	337.8	2	15	1.06	0.12
	10-Aug-05	14:22	15:03	6.4	4.2	9.14	0.7	0.7	4.4	838.4	1542.4	622.2	96.1	2	15	0.74	0.06
	10-Aug-05	18:58	19:53	18.0	6.2	20.00	0.9	0.8	n/a	2358.0	4338.0	2056.4	578.9	2	4	0.87	0.13
	12-Aug-05	8:17	9:11	0.9	0.2	1.00	0.9	2.4	20.6	117.9	216.9	64.9	0.0	6	no runoff	0.55	0.00
	12-Aug-05	13:06	15:25	2.8	0.9	1.22	2.3	4.6	21.2	366.8	674.8	286.2	39.3	3	11	0.78	0.06
	19-Aug-05	4:53	8:28	17.9	1.8	4.97	3.6	n/a	10.3	2344.9	4313.9	2171.6	470.8	8	21	0.93	0.11
	Averages:	**-**	**-**	**9.1**	**-**	**8.70**	**1.77**	**1.88**	**14.1**	**1375.5**	**2530.5**	**1067.2**	**238.7**	**3.6**	**11.3**	**0.82**	**0.08**
	†Totals:	**-**	**-**	**63.6**	**-**	**-**	**-**	**-**	**-**	**5502.0**	**10122.0**	**7470.5**	**1670.8**	**-**	**-**	**0.90**	**0.11**

Head Office Rainfall

Calculated Flows due to unavailability of data

Finch stn rainfall

Boyd Rainfall

Environment Canada data used for rainfall amount. Value takes into account total precipitation (rain and snow) with temperatures above zero for the time period listed.

Runoff coefficients are high due to snowmelt event (verified temperature through Env. Canada)

Note: For the garden, flow from the first event on July 20, 2004 was still being measured when the second event began. As a result, the garden lag = 0 while the control roof lag is 2 minutes. The flow from the control is more instantaneous and thus the

***These are only select events for which it is believed that there was little or no snow on the ground and the temperature is significantly above zero

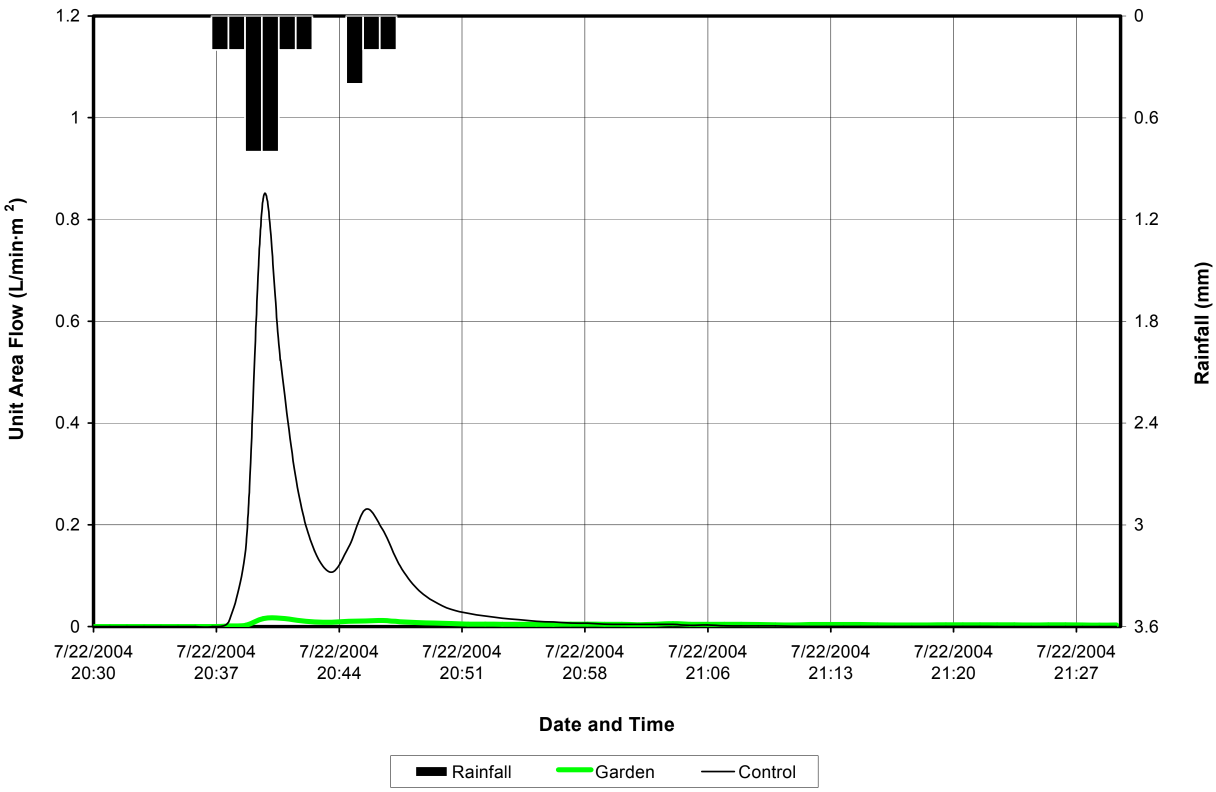
0 = no flow response to the rainfall event

† Total Runoff Co-efficients are calculated by dividing total measured monthly outflow by total calculated monthly inflow for each station (garden and control roof). The total runoff co-efficent is thus flow weighted whereas the average runoff co-efficient is not

** Calculated Inflow is defined as the volume of precipitation falling on each catchment area.

* Measured Outflow is defined as the total volume of runoff from each catchment as measured by the flow metres

† Lag time is defined here as the time between the start of precipitation and the start of runoff



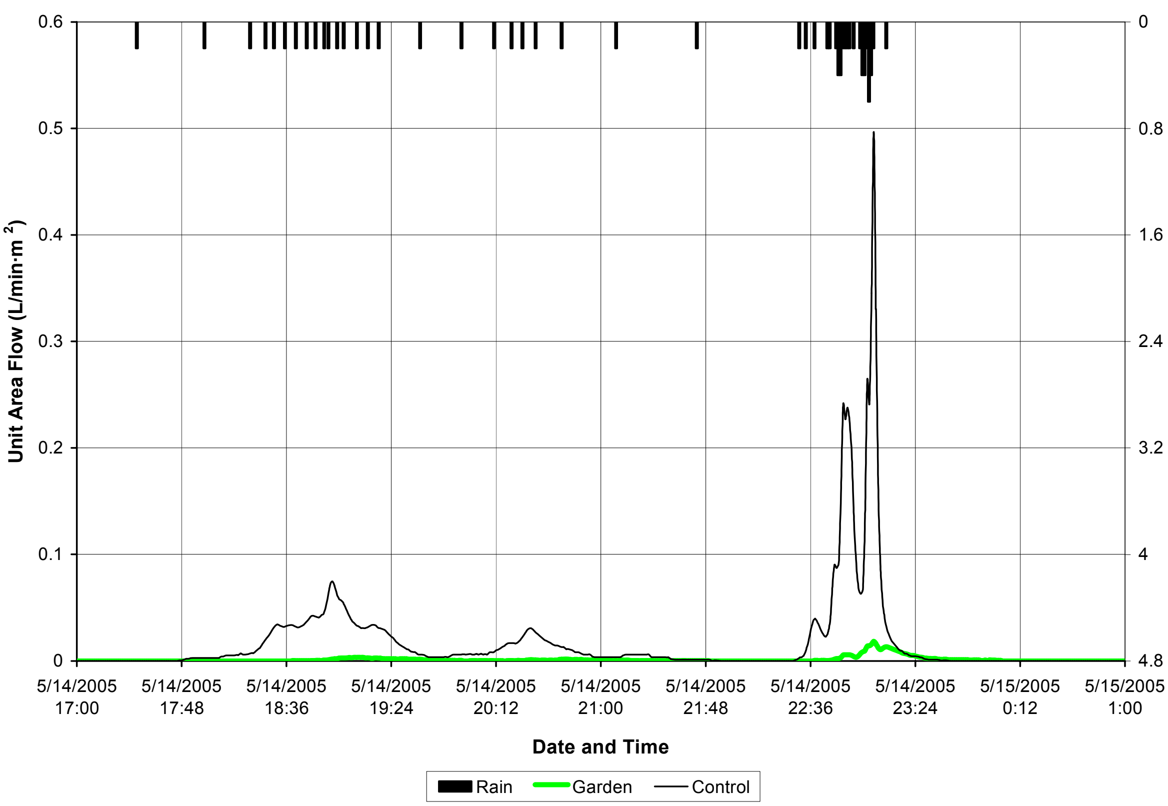
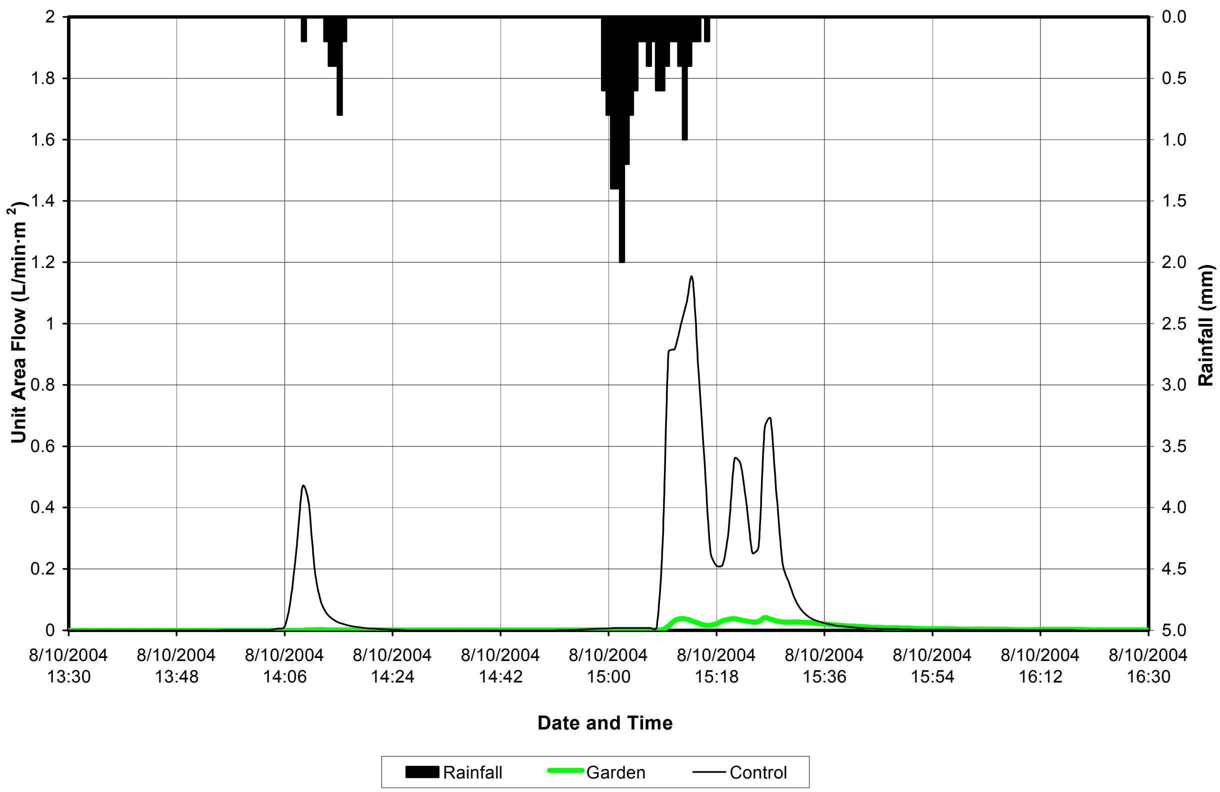


Figure A1: Hydrographs for a 3.2 mm event on July 22, 2004 (top) and a 10.4mm event on May 14, 2005 (bottom)



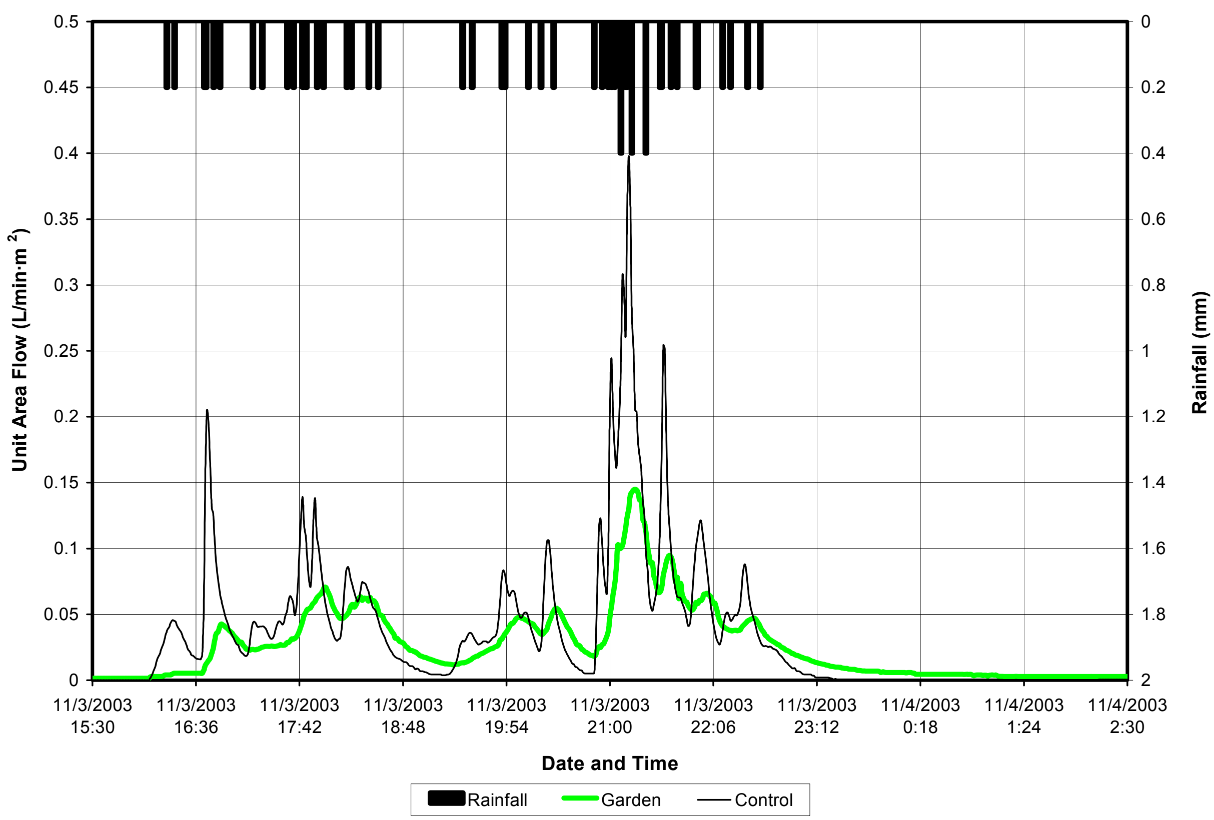


Figure A2: Hydrographs for a 16.4 mm event on August 10, 2004 (top) and a 22 mm event on November 3, 2003 (bottom)

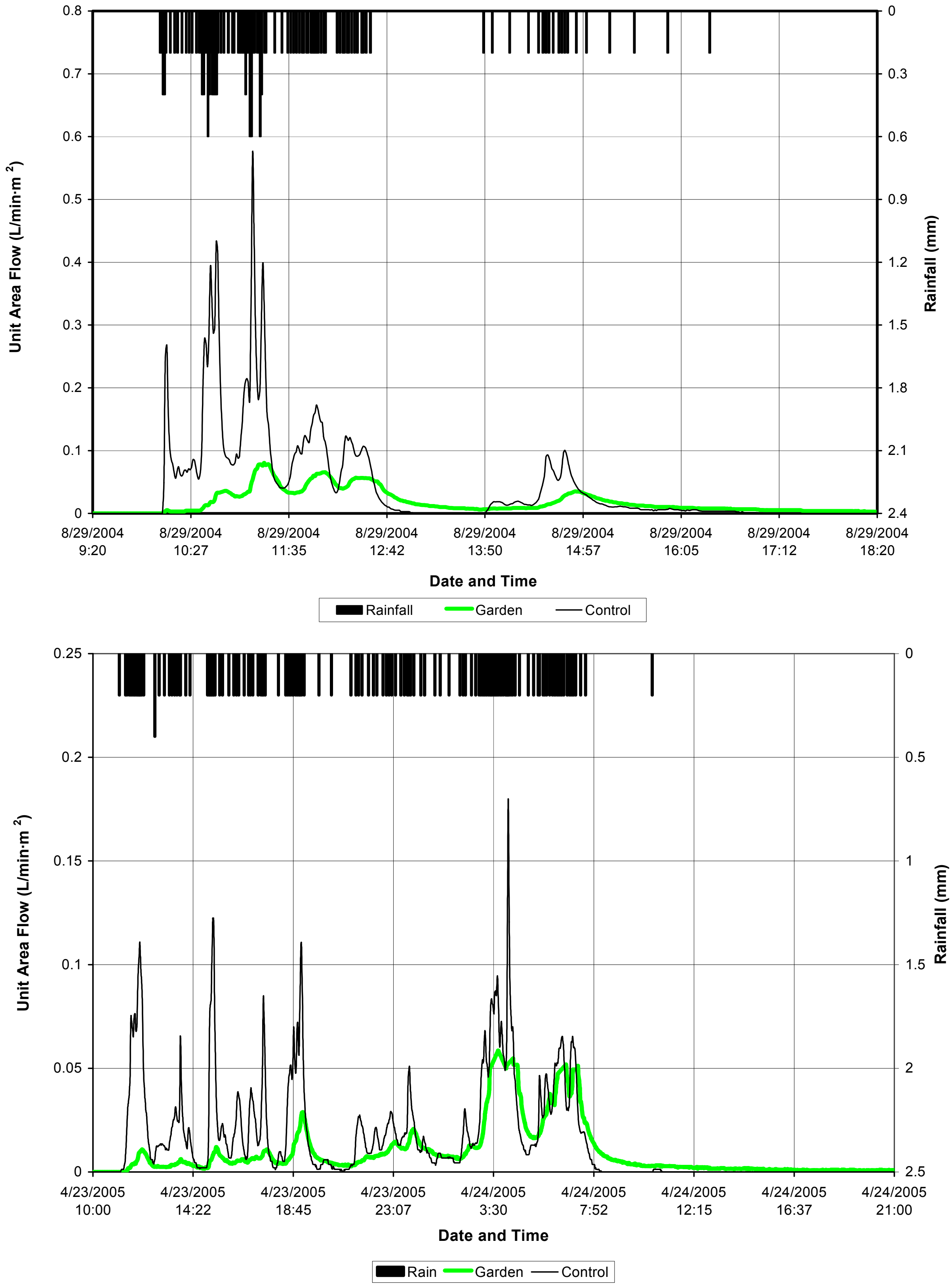
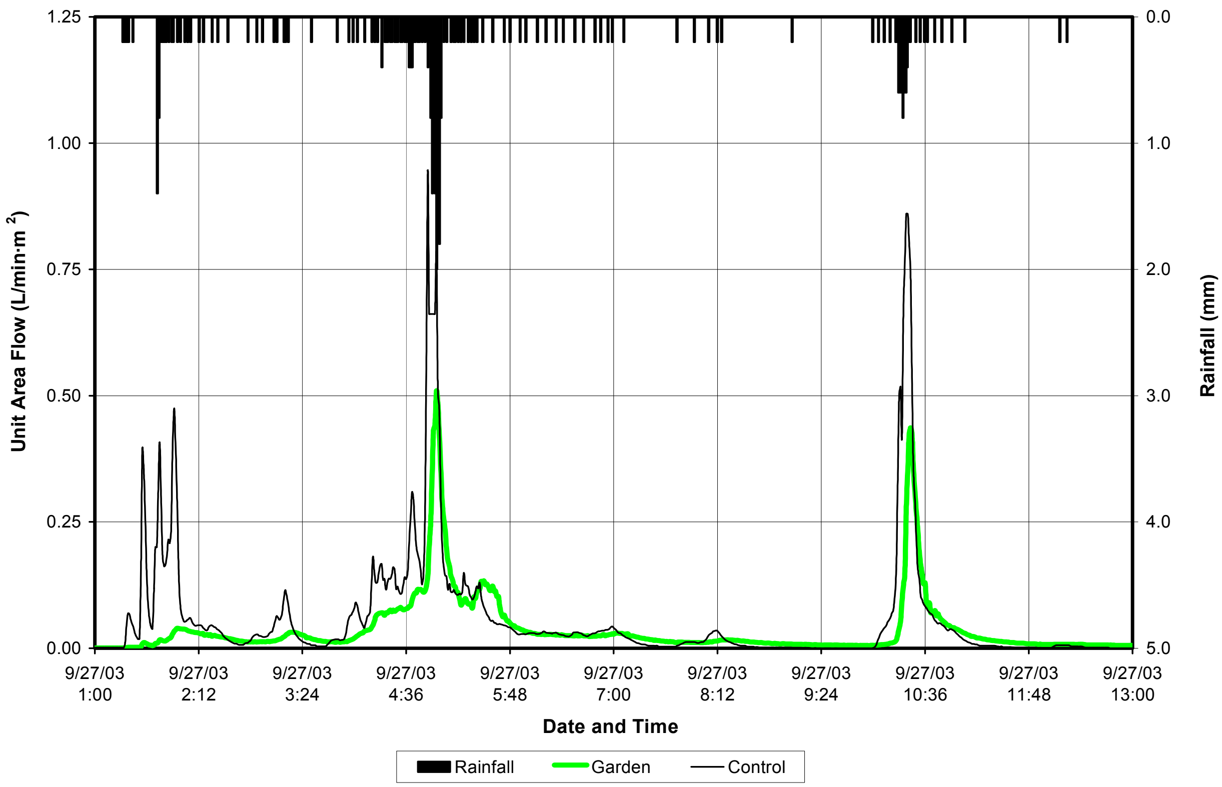


Figure A3: Hydrographs for a 24.2 mm event on August 28, 2004 (top) and a 30.9 mm event on April 23, 2005 (bottom)



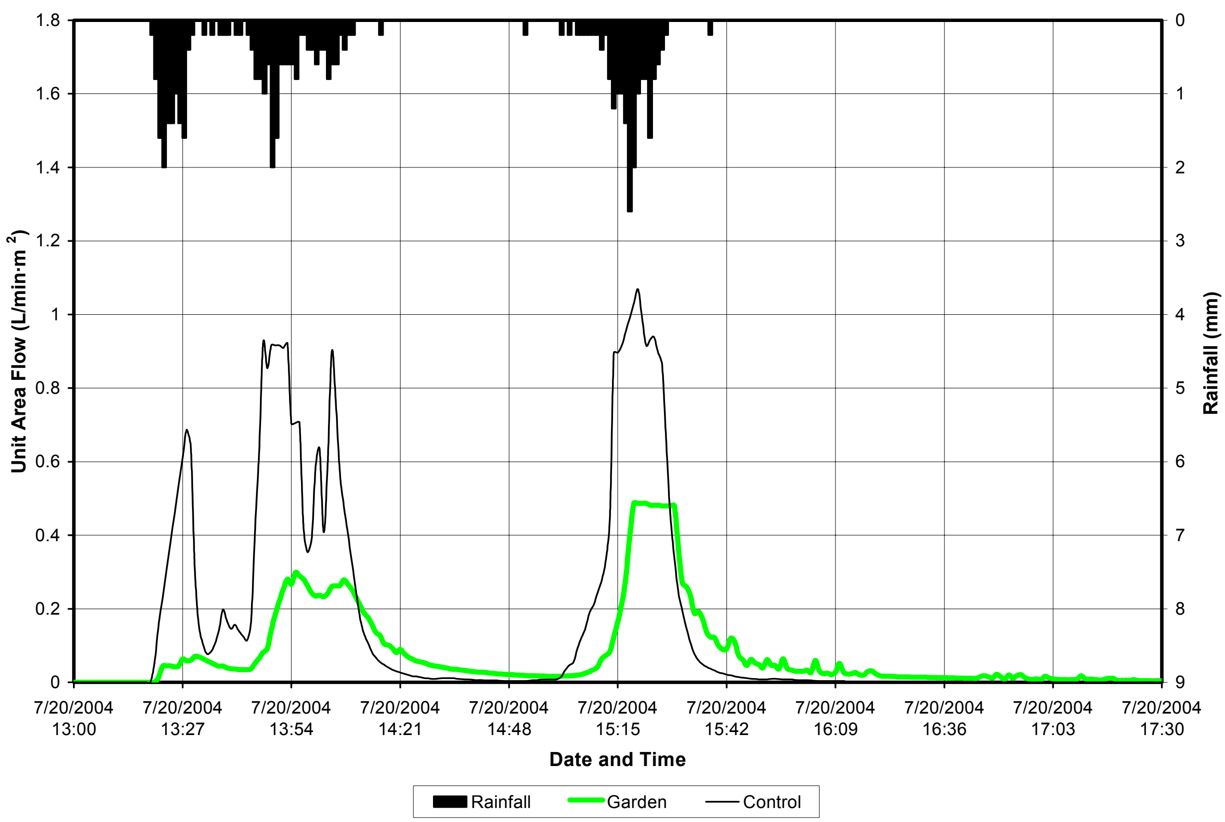


Figure A4: Hydrographs for a 41.6 mm event on September 27, 2003 (top) and a 48.6 mm event on July 20, 2004 (bottom)

Table A2: Hydrological statistics for events depicted in Figure 5.3

	Rainfall event characteristics							Calculated Inflow* per unit Area (L/m^2)		Measured Outflow† per unit Area (L/m^2)		Rain-runoff lag‡ (min)		Runoff co-efficient	
	Event start date	**Depth (mm)**	**Max intensity (mm / 5 min interval)**	**Mean Intensity (mm / hr)**	**Duration (hrs)**	**Start time**	**End time**	**Control**	**Garden**	**Control**	**Garden**	**Control**	**Garden**	**Control**	**Garden**
Spring/Summer	May 13, 2005	4.2	0.9	3.0	1.4	22:17	23:40	4.2	4.2	3.3	0.2	2.0	10.0	0.8	0.1
	July 27, 2004	10.2	0.6	1.8	5.77	1:47	7:33	8.8	10.2	8.2	1.1	0.0	58.0	0.8	0.1
	June 21, 2004	14.4	1.0	2.3	6.17	18:56	1:06	14.4	14.4	13.5	3.2	0.0	89.0	0.9	0.2
	June 8, 2003	21.6	3.4	6.2	3.47	19:21	22:49	21.6	21.6	21.8	2.4	2.0	28.0	1.0	0.1
	Aug. 2, 2003	24.4	5.4	9.2	2.65	12:36	15:15	24.4	24.4	25.7	4.2	2.0	8.0	1.1	0.2
	April 23, 2005	30.9	0.8	1.5	20.30	11:09	7:31	30.9	30.9	31.9	17.5	4.0	18.0	1.0	0.6
	July 20, 2004	48.6	8.0	20.98	2.32	13:19	15:38	48.6	48.6	41.2	21.7	1.0	1.0	0.8	0.4
Fall	**Oct. 3, 2003**	**6.3**	**0.4**	**0.9**	**7.12**	**22:13**	**5:20**	6.3	6.3	6.5	3.1	0.0	8.0	1.0	0.5
	Nov. 18, 2003	9.8	1.6	2.1	4.75	19:37	0:12	9.8	9.8	9.3	5.5	0.0	120.0	0.9	0.6
	Nov. 28, 2004	16.4	1	2.57	6.38	1:59	8:22	16.4	16.4	17.2	13.1	4.0	11.0	1.1	0.8
	Nov. 2, 2003	18.4	0.6	1.2	14.85	3:18	18:09	18.4	18.4	21.1	12.4	1.0	58.0	1.1	0.7
	Nov. 3, 2003	**22.0**	**0.6**	**2.4**	**9.25**	**13:21**	**22:36**	22.0	22.0	24.0	20.8	4.0	-8.0	1.1	0.9
	Sept. 22, 2003	**28.4**	**1.0**	**3.4**	**8.45**	**12:02**	**20:29**	28.4	28.4	28.4	17.1	0.0	0.0	1.0	0.6
	Sept. 27, 2003	**41.6**	**7.6**	**3.8**	**10.93**	**1:19**	**12:15**	41.6	41.6	42.9	27.5	1.0	3.0	1.0	0.7

0 = no flow response to the rainfall event

Finch stn rainfall

† Measured outflow is defined as the runoff from each catchment as measured by the flow meters

* Calculated inflow is the measured precipitation converted into a volume measurement for each catchment area

‡ Rain-runoff lag is the time between the start of precipitation and the start of runoff

Table A3: Monthly minimums, maximums, and means for air and soil temperature, soil moisture, and relative humidity for 2003-2005 monitoring period

	MONTH	Air Temperature(ºC)			Soil Temperature(ºC)			Upper Soil Moisture(%)			Lower Soil Moisture(%)			Relative Humidity(%)		
		MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN
2003	**May**	28.2	5.3	14.6	24.2	9.1	14.3	33.7	29.2	24.5	42.6	29.9	38.3	98.7	8.7	66.1
	June	38.6	6.3	21.1	36.3	11.2	21.2	32.4	6.2	21.6	36.7	8.4	25.8	95.7	19.2	61.6
	July	37.1	13.3	24.0	35.3	16.7	25.2	20.0	6.8	10.7	33.1	18.0	26.4	94.7	22.7	63.1
	August	36.5	12.4	24.2	30.4	15.3	23.7	23.9	6.5	16.9	41.4	21.2	32.2	98.7	20.6	68.4
	September	33.3	6.2	19.3	25.4	8.2	18.0	-	-	-	-	-	-	99.4	25.8	70.5
	October	30.6	1.5	11.3	19.0	2.4	8.7	-	-	-	-	-	-	100.3	32.4	74.6
	November	19.0	-4.2	6.7	12.7	0.2	4.4	-	-	-	-	-	-	100.4	39.0	81.7
2004	**May**	33.3	0.0	16.5	27.2	5.9	16.3	-	-	-	-	-	-	100.0	20.5	70.0
	June	34.2	9.4	20.4	29.6	13.3	20.8	17.7	5.7	12.9	-	-	-	100.0	19.2	63.6
	July	33.5	13.0	23.0	29.2	18.3	23.4	20.9	7.9	14.3	54.0	5.1	27.4	100.0	26.5	71.6
	August	33.2	11.2	21.6	28.6	14.4	21.4	19.3	9.5	13.8	34.3	24.0	29.5	100.0	32.7	70.4
	September	33.2	8.5	19.6	24.2	10.9	17.6	16.9	9.8	12.6	36.6	23.5	28.0	100.0	20.7	75.3
	October	29.8	3.8	12.8	17.1	5.6	10.8	13.4	8.3	11.2	-	-	-	100.0	24.1	74.9
	November	17.5	-2.9	7.1	11.1	0.5	4.5	18.7	11.5	15.4	17.7	12.8	15.4	100.0	27.6	75.8
2005	**April**	30.3	1.8	10.3	-	-	-	21.7	11.5	16.3	-	-	-	100.4	15.9	59.3
	May	28.8	1.9	14.7	26.7	5.9	15.8	18.7	6.2	11.6	66.3	14.4	22.3	100.3	16.8	59.4
	June	37.9	12.5	25.1	31.6	18.4	25.9	-	-	-	70.0	10.8	33.1	100.2	14.4	63.7
	July	39.6	13.3	25.9	35.9	17.2	27.8	-	-	-	27.7	5.9	12.2	100.2	20.7	62.1
	August	36.4	14.4	24.9	33.4	18.6	26.0	-	-	-	50.0	4.4	14.5	100.2	25.7	63.6

Table A4: Control and Garden peak flow volumes

Category	Event Date	Rainfall (mm)	Peak Flow (L/min·m2)		Difference (L/min·m2)	% Difference in peak flow Control vs. Garden
			Control	Garden		
10 - 19 mm	5-May-03	10.8	0.027	0.002	0.024	90.6
	5-May-03	13.8	0.235	0.031	0.204	86.9
	20-May-03	12.2	0.108	0.004	0.104	96.4
	4-Jun-03	13.2	0.050	0.002	0.047	95.0
	13-Jun-03	17.6	0.460	0.027	0.433	94.2
	15-Jul-03	11.6	1.040	0.031	1.009	97.0
	22-Jul-03	11.2	0.852	0.022	0.830	97.4
	10-Aug-03	10.6	1.494	0.060	1.434	96.0
	11-Aug-03	10.6	1.526	0.779	0.747	48.9
	14-Oct-03	15.7	0.723	0.121	0.603	83.3
	26-Oct-03	15.0	0.076	0.022	0.054	71.2
	2-Nov-03	18.4	0.205	0.036	0.169	82.6
	12-Nov-03	15.6	0.324	0.079	0.245	75.5
	19-Nov-03	14.6	0.409	0.107	0.302	73.9
	14-Jun-04	12.0	0.954	0.068	0.886	92.8
	21-Jun-04	14.4	0.222	0.011	0.211	95.0
	4-Jul-04	18.2	1.069	0.053	1.016	95.1
	7-Jul-04	18.8	0.765	0.073	0.692	90.5
	27-Jul-04	10.2	0.086	0.017	0.069	80.2
	31-Jul-04	19.6	0.401	0.052	0.349	86.9
	10-Aug-04	16.4	0.469	0.025	0.444	94.7
	15-Oct-04	10.0	0.453	0.019	0.433	95.8
	30-Oct-04	11.2	0.954	0.053	0.901	94.4
	2-Nov-04	15.0	0.176	0.021	0.155	87.9
	4-Nov-04	13.6	0.284	0.034	0.250	88.0
	24-Nov-04	12.4	0.154	0.030	0.123	80.3
	28-Nov-04	16.4	0.227	0.077	0.150	66.1
	20-Apr-05	10.4	0.185	0.010	0.174	94.4
	26-Apr-05	10.9	0.123	0.051	0.072	58.3
	14-May-05	10.4	0.075	0.003	0.071	95.6
	13-Jun-05	10.8	0.863	0.014	0.850	98.4
	14-Jun-05	10.8	0.802	0.042	0.760	94.8
	14-Jun-05	17.4	0.854	0.050	0.804	94.2
	2-Aug-05	11.4	0.705	0.057	0.648	91.9
	10-Aug-05	18.0	0.734	0.031	0.702	95.8
	19-Aug-05	17.9	0.412	0.025	0.387	94.0
	28-Jun-05	19.9	0.660	0.047	0.613	92.8
		Average:			**0.454**	**87.618**
20 - 29 mm	8-Jun-03	21.6	0.304	0.011	0.293	96.4
	29-Jun-03	26.4	1.499	0.319	1.180	78.7
	2-Aug-03	24.4	1.681	0.178	1.504	89.4
	3-Nov-03	22.0	0.398	0.142	0.256	64.3
	14-Jun-04	24.7	0.871	0.128	0.743	85.3
	14-Jul-04	25.4	0.992	0.094	0.899	90.6
	27-Aug-04	20.0	1.450	0.147	1.303	89.8
	29-Aug-04	24.2	0.574	0.081	0.494	86.0
	4-Jul-05	28.2	0.881	0.051	0.830	94.3
		Average:			**0.834**	**86.088**
30 - 39 mm	16-May-03	30.6	0.246	0.060	0.186	75.7
	23-May-03	33.6	0.260	0.102	0.158	60.7
	23-Apr-05	30.9	0.179	0.059	0.120	67.2
		Average:			**0.155**	**67.896**
≥ 40 mm	27-Sep-03	41.6	0.947	0.510	0.437	46.2
	20-Jul-04	48.6	1.069	0.486	0.582	54.5
		Average:			**0.510**	**50.3**

APPENDIX B

Detailed Results - Water Quality

Table B1: Garden water quality concentrations for all events for which composite samples were collected

Garden Concentrations			Flow volumes (L):	4077.72	3325.8	2992.7	5010.5	2229	1615.2	193.1	202.8	78	756.8	5225.9	256.4	225.5	222.9	245.7	346.6	749.057	1373.4
				2003						2004											
List ID	Parameter	Units	MDL	19-Sep-03 morning	19-Sep-03 afternoon	2-Nov-03	3-Nov-03	12-Nov-03	17-Nov-03	24-Jun-04	7-Jul-04 morning	7-Jul-04 afternoon	14-Jul-04	20-Jul-04	27-Jul-04	8-Aug-04	28-Aug-04	15-Oct-04	30-Oct-04	2-Nov-04	4-Nov-04
3016L1	Chloride	mg/L	0.2	33.1	5.2	11.6	10	5.3	4.2	5.6	3.6	9.4	8.8	11	4.9	2.4	11.9	14.9	11.1	19.1	22.3
3060L1	Mercury	ug/L	0.02			0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3170L1	Oxygen demand; chemical	mg/L as O2	1	107	33	115	142	68	41	53	39	31	74	114	46	48	138	43	42	129	250
3171L1	Calcium	mg/L	0.25	42.1	40.8	25.5	25.3	23.4	21.8	24.3	18.8	24.9	22	31.6	25.6	17.8	35.7	28.4	22	30.1	32
	Magnesium	mg/L	0.1	10.1	10.4	6.1	5.94	4.58	4.44	3.02	2.22	2.42	3.32	7.18	2.8	2.12	6.14	4.28	3.2	5.42	7.24
	Sodium	mg/L	0.1	9.04	8.76	5.9	5.94	4.84	4.66	7.38	4.86	7.02	4.24	5.84	5.56	4.74	6.12	8.22	6.06	6.76	6.56
	Potassium	mg/L	0.05	8.03	8.09	4.99	4.95	4.76	4.29	15.3	9.71	13.4	5.48	4.4	9.53	10.7	4.6	8.35	7.74	4.96	4.24
	Hardness	mg/L	1	147	144	88.8	87.4	77.4	72.6	73.2	56.2	72	68.6	108	75.4	53.2	114	88.4	68	97.4	110
3172L4	Fluoride	mg/L	0.05	0.41		0.44	0.45	0.43	0.42	0.2	0.15	0.21	0.28	0.62	0.26	0.16	0.49	0.28	0.24	0.29	0.34
	Sulphate	mg/L	2.5	56.5	46.7	18.9	16.4	10.1	7.9	17.1	12.8	18.4	19.6	24.3	12	9.3	24.4	27.2	20.6	29.4	35.7
3179L1	Phenolics; 4-AAP	ug/L	0.2	2.6																	
3182L1	Oxygen demand; biochemical	mg/L as O2	0.2	2.5	2.3	0.8	0.9	1	0.5	3.7	2.6	1.5	3.3	1.8	1.6	3.6	1.1	1.5	2.2	2.1	1.8
3188L3	Solids; suspended	mg/L	2.5	3.2	1.25	1.25	1.25	1.25	1.25	2.9	3.9	1.25	4.3	1.25	1.25	3.7	1.25	1.25	3.2	1.25	1.25
3201L1	Solvent extractable	mg/L	1		1.9	0.5	0.5		0.5		3			0.5	0.5		1.6				
3218L1	Conductivity	uS/cm	1	329	317	197	180	164	157	224	160	223	166	235	204	155	233	240	184	231	254
	pH	none		7.66	8.06	8.06	8.03	8.67	8.45	8.11	7.94	8.16	7.79	8.08	9.01	7.89	8.16	7.89	7.62	8.4	7.98
	Alkalinity; total fixed endpt	mg/L CaCO3	2.5	52.6	67.8	59.7	65.2	70.6	65.9	78.3	53.8	78.6	42.9	70.2	85.8	60.8	70.1	62.8	47	49.2	53
3311L1	Turbidity	FTU	0.01	1.34		0.61	0.78	1.18	0.67		2.96			1.77	1.28	1.9	1.19				
3364L1	Nitrogen; ammonia+ammonium	mg/L	0.002	0.089	0.048	0.006	0.001	0.012	0.003	0.026	0.039	0.001	0.052	0.014	0.001	0.001	0.015	0.005	0.019	0.001	0.007
	Nitrogen; nitrite	mg/L	0.001	0.021	0.019	0.015	0.011	0.021	0.016	0.04	0.029	0.025	0.023	0.02	0.015	0.008	0.02	0.026	0.016	0.016	0.016
	Nitrogen; nitrate+nitrite	mg/L	0.005	0.1	0.073	0.044	0.033	0.107	0.072	0.71	0.71	0.488	0.379	0.092	0.227	0.455	0.079	0.454	0.254	0.138	0.099
	Phosphorus; phosphate	mg/L	0.0005	0.564	0.752	0.557	0.569	0.567	0.559	0.175	0.139	0.0459	0.17	0.313	0.109	0.0892	0.185	0.0686	0.0844	0.0996	0.146
3367L1	Phosphorus; total	mg/L	0.002	0.618	0.848	0.637	0.674	0.621	0.643	0.276	0.196	0.062	0.279	0.401	0.145	0.157	0.283	0.105	0.141	0.135	0.191
	Nitrogen; total Kjeldahl	mg/L	0.02	2.42	2.41	1.19	1.13	0.96	0.78	0.93	0.82	0.31	1.51	2.29	0.79	0.79	2.32	0.73	0.86	0.96	1.4
3371L10	Escherichia coli	c/100mL		1900		10	20	4	4	400	5100	4	1600	1000	80	40	730			40	
	Fecal streptococcus	c/100mL		10000		500	40	70	88	600	15000	2700	17000	6700	11000	2900	4500			4400	
	Pseudomonas aeruginosa	c/100mL		8800		2500	20	120	56	300	4	4	200	600	3000	150000	6900			1100	
3386L1	Aluminum	ug/L	11	51	46.3	37.2	33.2	45.9	34.9	50.2	50.5	89.4	54.7	52.9	48.4	48.8	44.4		49.1	36.4	34.9
	Barium	ug/L	0.2	22.3	24.6	12.3	12.2	11.3	10.1	12.2	8.69	13.1	11.2	16.9	13.7	10.5	15.9		8.65	11.1	13
	Beryllium	ug/L	0.02	0.0306	0.376	0.0286	0.01	0.01	0.0233	0.01	0.01	0.01	0.01	0.0262	0.01	0.025	0.0273		0.01	0.01	0.01
	Calcium	mg/L	0.005	35.9	34.2	20.9	20	18.9	18.1	16.5	10.9	18	15.4	24	22.5	14.8	24.4		13.5	22.5	25.2
	Cadmium	ug/L	0.6	0.769	0.3	0.674	0.3	0.3	0.3	0.3	0.3	0.3	0.625	0.837	0.3	0.3	0.3		0.3	0.3	0.857
	Cobalt	ug/L	1.3	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	1.87	0.65		0.65	2.05	0.65
	Chromium	ug/L	1.4	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7		0.7	0.7	1.76
	Copper	ug/L	1.6	27.4	72.9	25.2	23.5	27.1	9.49	119	67.1	100	84.6	62.8	65	97.2	67.6		62.7	40.8	49.8
	Iron	ug/L	0.8	39.8	38.3	32.3	31	28.7	27.7	10.1	10.1	9.18	23.9	38.5	15.7	11.9	30.3		21.6	18.4	56.4
	Magnesium	mg/L	0.008	9.78	9.67	5.45	5.47	4.17	4.14	2.33	1.68	2.04	2.69	6.09	2.67	1.85	5		2.41	4.67	6.01
	Manganese	ug/L	0.2	2.56	1.56	0.859	0.719	1.41	0.615	1.94	1.86	1.23	2.36	1.65	1.17	2.24	1.07		1.61	0.992	1.1
	Molybdenum	ug/L	1.6	0.8	2.75	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.87	0.8	0.8	0.8		0.8	0.8	0.8
	Nickel	ug/L	1.3	2.29	3.68	1.59	1.99	2.4	1.6	0.65	0.65	0.65	1.47	0.65	0.65	0.65	1.57		0.65	0.65	1.77
	Lead	ug/L	5	2.5	2.5	2.5	2.5	6.92	2.5	6.37	2.5	2.5	2.5	11.5	2.5	2.5	2.5		5.94	2.5	2.5
	Strontium	ug/L	0.1	135	138	71.4	69.3	68.8	63.7	98.3	60.6	95.7	68.8	94.4	118	79.5	92.8		65.7	85.9	96.3
	Titanium	ug/L	0.5	0.875	0.693	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.508	0.25	0.25	0.25	0.25		0.25	0.25	0.25
	Vanadium	ug/L	1.5	2.73	2.14	2.76	0.75	0.75	1.95	1.7	2.25	2.1	2.17	3.44	2.39	1.8	3.39		0.75	1.73	2.26
	Zinc	ug/L	0.6	12.9	7.46	6.92	8.09	6.61	6.77	3.31	2.89	2.2	8.79	8.05	2.11	7.55	12.4		6.89	9.55	12.2
3435L2	Phenanthrene	ng/L	10	42	53		5	18	5	24	5	5	5	30	5		5		5	5	5
	Anthracene	ng/L	10	5	5		5	5	5	5	5	5	5	5	5		5		5	5	5
	Fluoranthene	ng/L	10	30	34		5	14	5	5	5	5	5	5	5		5		5	5	5
	Pyrene	ng/L	10	22	24		5	21	5	5	5	5	5	5	5		5		5	5	5
	Benzo(a)anthracene	ng/L	20	10	10		10	10	10	10	10	10	10	10	10		10		10	10	10
	Chrysene	ng/L	10	5	5		5	5	5	5	5	5	5	5	5		5		5	5	5
	7,12-dimethylbenz(a)anthracene	ng/L	10	5	5		5	5	5	5	5	5	5	5	5		5		5	5	5
	Benzo(b)fluoranthene	ng/L	10	5	5		5	5	5	5	5	5	5	5	5		5		5	5	5
	Benzo(k)fluoranthene	ng/L	10	5	5		5	5	5	5	5	5	5	5	5		5		5	5	5
	Benzo(e)pyrene	ng/L	10	5	5		5	5	5	5	5	5	5	5	5		5		5	5	5
	Benzo(a)pyrene	ng/L	3	7	8		1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5		1.5		1.5	1.5	1.5
	Perylene	ng/L	10	5	5		5	5	5	5	5	5	5	5	5		5		5	5	5
	Indeno(1,2,3-c,d)pyrene	ng/L	20	10	10		10	10	10	10	10	10	10	10	10		10		10	10	10
	Dibenzo(a,h)anthracene	ng/L	20	10	10		10	10	10	10	10	10	10	10	10		10		10	10	10
	Benzo(g,h,i)perylene	ng/L	20	10	10		10	10	10	10	10	10	10	10	10		10		10	10	10

Table B2: Garden water quality statistics for all events for which composite samples were collected

List ID	Parameter	Units	MDL	# > dl	%>dl	No. of Samples	MINIMUM	MAXIMUM	GEOMEAN	MEAN	MEDIAN	STD. DEV.	95%CI -LL	95%CI -UL
				STATISTICS										
3016L1	Chloride	mg/L	0.2	18	90.00	20	0.2	33.1	5.96	9.74	9.1	8.00	6.23	13.25
3060L1	Mercury	ug/L	0.02	0	0.00	18	0.01	0.02	0.01	0.01	0.01	0.00	0.01	0.01
3170L1	Oxygen demand; chemical	mg/L as O2	1	18	90.00	20	1	250	45.65	75.75	50.5	59.58	49.64	101.86
3171L1	Calcium	mg/L	0.25	18	90.00	20	0.25	42.1	16.67	24.63	25.1	10.59	19.99	29.27
	Magnesium	mg/L	0.1	18	90.00	20	0.1	10.4	3.08	4.56	4.36	2.82	3.32	5.79
	Sodium	mg/L	0.1	18	90.00	20	0.1	9.04	4.05	5.64	5.92	2.32	4.62	6.65
	Potassium	mg/L	0.05	18	90.00	20	0.05	15.3	4.17	6.68	5.235	3.86	4.99	8.37
	Hardness	mg/L	1	18	90.00	20	1	147	54.80	80.18	76.4	37.11	63.92	96.44
3172L4	Fluoride	mg/L	0.05	17	89.47	19	0.05	0.62	0.26	0.30	0.28	0.15	0.24	0.37
	Sulphate	mg/L	2.5	18	90.00	20	2.5	56.5	16.03	20.62	18.65	13.72	14.60	26.63
3179L1	Phenolics; 4-AAP	ug/L	0.2	1	33.33	3	0.2	2.6	0.47	1.00	0.2	1.39	-0.57	2.57
3182L1	Oxygen demand; biochemical	mg/L as O2	0.2	18	90.00	20	0.2	3.7	1.37	1.76	1.7	1.04	1.30	2.22
3188L3	Solids; suspended	mg/L	2.5	6	30.00	20	1.25	4.3	1.82	2.06	1.25	1.09	1.58	2.54
3201L1	Solvent extractable	mg/L	1	3	30.00	10	0.5	3	0.88	1.10	0.75	0.84	0.58	1.62
3218L1	Conductivity	uS/cm	1	18	90.00	20	1	329	122.37	192.75	200.5	81.43	157.06	228.44
	pH	none		n/a	n/a	18	7.62	9.01	8.10	8.11	8.06	0.35	7.95	8.27
	Alkalinity; total fixed endpt	mg/L CaCO3	2.5	18	90.00	20	2.5	85.8	44.95	56.97	61.8	21.70	47.46	66.47
3311L1	Turbidity	FTU	0.01	10	83.33	12	0.01	2.96	0.55	1.14	1.185	0.83	0.67	1.61
3364L1	Nitrogen; ammonia+ammonium	mg/L	0.002	13	65.00	20	0.001	0.089	0.01	0.02	0.0065	0.02	0.01	0.03
	Nitrogen; nitrite	mg/L	0.001	18	90.00	20	0.001	0.04	0.01	0.02	0.0175	0.01	0.01	0.02
	Nitrogen; nitrate+nitrite	mg/L	0.005	18	90.00	20	0.005	0.71	0.12	0.23	0.1035	0.23	0.13	0.33
	Phosphorus; phosphate	mg/L	0.0005	18	90.00	20	0.0005	0.752	0.11	0.26	0.158	0.24	0.16	0.36
3367L1	Phosphorus; total	mg/L	0.002	18	90.00	20	0.002	0.848	0.17	0.32	0.236	0.26	0.21	0.43
	Nitrogen; total Kjeldahl	mg/L	0.02	18	90.00	20	0.02	2.42	0.74	1.13	0.945	0.73	0.81	1.45
3371L10	Escherichia coli	c/100mL		n/a	n/a	14	4	5100	97.89	780.86	60	1396.33	49.43	1512.29
	Fecal streptococcus	c/100mL		n/a	n/a	14	40	17000	1730.16	5392.71	3650	5742.45	2384.69	8400.74
	Pseudomonas aeruginosa	c/100mL		n/a	n/a	14	4	150000	422.72	12400.29	450	39700.11	-8395.51	33196.08
3386L1	Aluminum	ug/L	11	17	89.47	19	11	89.4	39.74	43.69	46.3	16.71	36.18	51.21
	Barium	ug/L	0.2	17	89.47	19	0.2	24.6	8.29	12.01	12.2	5.86	9.37	14.64
	Beryllium	ug/L	0.02	7	36.84	19	0.01	0.376	0.02	0.04	0.01	0.08	0.00	0.07
	Calcium	mg/L	0.005	17	89.47	19	0.005	35.9	8.35	18.72	18.9	9.11	14.63	22.82
	Cadmium	ug/L	0.6	5	26.32	19	0.3	0.857	0.41	0.45	0.3	0.21	0.36	0.55
	Cobalt	ug/L	1.3	2	10.53	19	0.65	2.05	0.79	0.86	0.65	0.44	0.66	1.05
	Chromium	ug/L	1.4	1	5.26	19	0.7	1.76	0.79	0.83	0.7	0.31	0.69	0.97
	Copper	ug/L	1.6	17	89.47	19	1.6	119	34.65	52.92	62.7	34.13	37.57	68.26
	Iron	ug/L	0.8	17	89.47	19	0.8	56.4	16.10	23.45	23.9	14.60	16.88	30.01
	Magnesium	mg/L	0.008	17	89.47	19	0.008	9.78	2.03	4.01	4.14	2.73	2.78	5.24
	Manganese	ug/L	0.2	17	89.47	19	0.2	2.56	1.11	1.33	1.23	0.68	1.03	1.64
	Molybdenum	ug/L	1.6	2	10.53	19	0.8	2.75	0.96	1.04	0.8	0.53	0.80	1.28
	Nickel	ug/L	1.3	9	47.37	19	0.65	3.68	1.18	1.38	1.3	0.82	1.01	1.75
	Lead	ug/L	5	4	21.05	19	2.5	11.5	3.38	3.85	2.5	2.42	2.77	4.94
	Strontium	ug/L	0.1	17	89.47	19	0.1	138	42.04	79.07	79.5	35.84	62.96	95.19
	Titanium	ug/L	0.5	3	15.79	19	0.25	0.875	0.31	0.35	0.25	0.18	0.26	0.43
	Vanadium	ug/L	1.5	14	73.68	19	0.75	3.44	1.83	2.00	2.1	0.78	1.65	2.35
	Zinc	ug/L	0.6	17	89.47	19	0.6	12.9	5.02	6.63	6.92	3.80	4.92	8.34

Table B2 continued: Garden water quality statistics for all events for which composite samples were collected

List ID	Parameter	Units	MDL	# > dl	%>dl	No. of Samples	MINIMUM	MAXIMUM	GEOMEAN	MEAN	MEDIAN	STD. DEV.	95%CI -LL	95%CI -UL	
				STATISTICS											
3435L2	Phenanthrene	ng/L	10	2	66.67	3	10	53	28.13	35.00	42	22.34	9.72	60.28	2003 PAH Statistics
	Anthracene	ng/L	10	0	0.00	3	5	10	6.30	6.67	5	2.89	3.40	9.93	
	Fluoranthene	ng/L	10	2	66.67	3	10	34	21.69	24.67	30	12.86	10.12	39.22	
	Pyrene	ng/L	10	2	66.67	3	10	24	17.41	18.67	22	7.57	10.10	27.23	
	Benzo(a)anthracene	ng/L	20	0	0.00	3	10	20	12.60	13.33	10	5.77	6.80	19.87	
	Chrysene	ng/L	10	0	0.00	3	5	10	6.30	6.67	5	2.89	3.40	9.93	
	7,12-dimethylbenz(a)anthracene	ng/L	10	0	0.00	3	5	10	6.30	6.67	5	2.89	3.40	9.93	
	Benzo(b)fluoranthene	ng/L	10	0	0.00	3	5	10	6.30	6.67	5	2.89	3.40	9.93	
	Benzo(k)fluoranthene	ng/L	10	0	0.00	3	5	10	6.30	6.67	5	2.89	3.40	9.93	
	Benzo(e)pyrene	ng/L	10	0	0.00	3	5	10	6.30	6.67	5	2.89	3.40	9.93	
	Benzo(a)pyrene	ng/L	3	2	66.67	3	3	8	5.52	6.00	7	2.65	3.01	8.99	
	Perylene	ng/L	10	0	0.00	3	5	10	6.30	6.67	5	2.89	3.40	9.93	
	Indeno(1,2,3-c,d)pyrene	ng/L	20	0	0.00	3	10	20	12.60	13.33	10	5.77	6.80	19.87	
	Dibenzo(a,h)anthracene	ng/L	20	0	0.00	3	10	20	12.60	13.33	10	5.77	6.80	19.87	
	Benzo(g,h,i)perylene	ng/L	20	0	0.00	3	10	20	12.60	13.33	10	5.77	6.80	19.87	
3435L2	Phenanthrene	ng/L	10	3	21.43	14	5	30	7.32	9.43	5	8.35	5.06	13.80	2004 PAH Statistics
	Anthracene	ng/L	10	0	0.00	14	5	10	5.25	5.36	5	1.34	-	-	
	Fluoranthene	ng/L	10	1	7.14	14	5	14	5.65	6.00	5	2.66	4.61	7.39	
	Pyrene	ng/L	10	1	7.14	14	5	21	5.82	6.50	5	4.38	4.21	8.79	
	Benzo(a)anthracene	ng/L	20	0	0.00	14	10	20	10.51	10.71	10	2.67	-	-	
	Chrysene	ng/L	10	0	0.00	14	5	10	5.25	5.36	5	1.34	-	-	
	7,12-dimethylbenz(a)anthracene	ng/L	10	0	0.00	14	5	10	5.25	5.36	5	1.34	-	-	
	Benzo(b)fluoranthene	ng/L	10	0	0.00	14	5	10	5.25	5.36	5	1.34	-	-	
	Benzo(k)fluoranthene	ng/L	10	0	0.00	14	5	10	5.25	5.36	5	1.34	-	-	
	Benzo(e)pyrene	ng/L	10	0	0.00	14	5	10	5.25	5.36	5	1.34	-	-	
	Benzo(a)pyrene	ng/L	3	0	0.00	14	1.5	3	1.58	1.61	1.5	0.40	-	-	
	Perylene	ng/L	10	0	0.00	14	5	10	5.25	5.36	5	1.34	-	-	
	Indeno(1,2,3-c,d)pyrene	ng/L	20	0	0.00	14	10	20	10.51	10.71	10	2.67	-	-	
	Dibenzo(a,h)anthracene	ng/L	20	1	7.14	14	10	20	10.51	10.71	10	2.67	-	-	
	Benzo(g,h,i)perylene	ng/L	20	0	0.00	14	10	20	10.51	10.71	10	2.67	-	-	

Table B3: Garden runoff loading for all events for which composite samples were collected

Garden Loads

List ID	Parameter	Units	MDL	2003 LOADS						2004 LOADS											
				19-Sep-03 morning	19-Sep-03 afternoon	2-Nov-03	3-Nov-03	12-Nov-03	17-Nov-03	24-Jun-04	7-Jul-04 morning	7-Jul-04 afternoon	14-Jul-04	20-Jul-04	27-Jul-04	8-Aug-04	29-Aug-04	15-Oct-04	30-Oct-04	2-Nov-04	4-Nov-04
3016L1	Chloride	mg/L	0.2	134972.532	17294.16	34715.32	50105	11813.7	6783.84	1081.36	730.08	733.2	6659.84	57484.9	1256.36	541.2	2652.51	3660.93	3847.26	14306.9887	30626.82
3060L1	Mercury	ug/L	0.02	0	0	29.927	50.105	22.29	16.152	1.931	2.028	0.78	7.568	52.259	2.564	2.255	2.229	2.457	3.466	7.49057	13.734
3170L1	Oxygen demand; chemical	mg/L as O2	1	436316.04	109751.4	344160.5	711491	151572	66223.2	10234.3	7909.2	2418	56003.2	595752.6	11794.4	10824	30760.2	10565.1	14557.2	96628.353	343350
3171L1	Calcium	mg/L	0.25	171672.012	135692.64	76313.85	126765.65	52158.6	35211.36	4692.33	3812.64	1942.2	16649.6	165138.44	6563.84	4013.9	7957.53	6977.88	7625.2	22546.6157	43948.8
	Magnesium	mg/L	0.1	41184.972	34588.32	18255.47	29762.37	10208.82	7171.488	583.162	450.216	188.76	2512.576	37521.962	717.92	478.06	1368.606	1051.596	1109.12	4059.88894	9943.416
	Sodium	mg/L	0.1	36862.5888	29134.008	17656.93	29762.37	10788.36	7526.832	1425.078	985.608	547.56	3208.832	30519.256	1425.584	1068.87	1364.148	2019.654	2100.396	5063.62532	9009.504
	Potassium	mg/L	0.05	32744.0916	26905.722	14933.573	24801.975	10610.04	6929.208	2954.43	1969.188	1045.2	4147.264	22993.96	2443.492	2412.85	1025.34	2051.595	2682.684	3715.32272	5823.216
	Hardness	mg/L	1	599424.84	478915.2	265751.76	437917.7	172524.6	117263.52	14134.92	11397.36	5616	51916.48	564397.2	19332.56	11996.6	25410.6	21719.88	23568.8	72958.1518	151074
3172L4	Fluoride	mg/L	0.05	1671.8652	0	1316.788	2254.725	958.47	678.384	38.62	30.42	16.38	211.904	3240.058	66.664	36.08	109.221	68.796	83.184	217.22653	466.956
	Sulphate	mg/L	2.5	230391.18	155314.86	56562.03	82172.2	22512.9	12760.08	3302.01	2595.84	1435.2	14833.28	126989.37	3076.8	2097.15	5438.76	6683.04	7139.96	22022.2758	49030.38
3179L1	Phenolics; 4-AAP	ug/L	0.2	10602.072	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3182L1	Oxygen demand; biochemical	mg/L as O2	0.2	10194.3	7649.34	2394.16	4509.45	2229	807.6	714.47	527.28	117	2497.44	9406.62	410.24	811.8	245.19	368.55	762.52	1573.0197	2472.12
3188L3	Solids; suspended	mg/L	2.5	13048.704	4157.25	3740.875	6263.125	2786.25	2019	559.99	790.92	97.5	3254.24	6532.375	320.5	834.35	278.625	307.125	1109.12	936.32125	1716.75
3201L1	Solvent extractable	mg/L	1	0	6319.02	1496.35	2505.25	0	807.6	0	608.4	0	0	2612.95	128.2	0	356.64	0	0	0	0
3218L1	Conductivity	uS/cm	1	1341569.88	1054278.6	589561.9	901890	365556	253586.4	43254.4	32448	17394	125628.8	1228086.5	52305.6	34952.5	51935.7	58968	63774.4	173032.167	348843.6
	pH	none		31235.3352	26805.948	24121.162	40234.315	19325.43	13648.44	1566.041	1610.232	636.48	5895.472	42225.272	2310.164	1779.195	1818.864	1938.573	2641.092	6292.0788	10959.732
	Alkalinity; total fixed endpt	mg/L CaCO3	2.5	214488.072	225489.24	178664.19	326684.6	157367.4	106441.68	15119.73	10910.64	6130.8	32466.72	366858.18	21999.12	13710.4	15625.29	15429.96	16290.2	36853.6044	72790.2
3311L1	Turbidity	FTU	0.01	5464.1448	0	1825.547	3908.19	2630.22	1082.184	0	600.288	0	0	9249.843	328.192	428.45	265.251	0	0	0	0
3364L1	Nitrogen; ammonia+ammonium	mg/L	0.002	362.91708	159.6384	17.9562	5.0105	26.748	4.8456	5.0206	7.9092	0.078	39.3536	73.1626	0.2564	0.2255	3.3435	1.2285	6.5854	0.749057	9.6138
	Nitrogen; nitrite	mg/L	0.001	85.63212	63.1902	44.8905	55.1155	46.809	25.8432	7.724	5.8812	1.95	17.4064	104.518	3.846	1.804	4.458	6.3882	5.5456	11.984912	21.9744
	Nitrogen; nitrate+nitrite	mg/L	0.005	407.772	242.7834	131.6788	165.3465	238.503	116.2944	137.101	143.988	38.064	286.8272	480.7828	58.2028	102.6025	17.6091	111.5478	88.0364	103.369866	135.9666
	Phosphorus; phosphate	mg/L	0.0005	2299.83408	2501.0016	1666.9339	2850.9745	1263.843	902.8968	33.7925	28.1892	3.5802	128.656	1635.7067	27.9476	20.1146	41.2365	16.85502	29.25304	74.6060772	200.5164
3367L1	Phosphorus; total	mg/L	0.002	2520.03096	2820.2784	1906.3499	3377.077	1384.209	1038.5736	53.2956	39.7488	4.836	211.1472	2095.5859	37.178	35.4035	63.0807	25.7985	48.8706	101.122695	262.3194
	Nitrogen; total Kjeldahl	mg/L	0.02	9868.0824	8015.178	3561.313	5661.865	2139.84	1259.856	179.583	166.296	24.18	1142.768	11967.311	202.556	178.145	517.128	179.361	298.076	719.09472	1922.76
3371L10	Escherichia coli	c/100mL		7747668	0	29927	100210	8916	6460.8	77240	1034280	312	1210880	5225900	20512	9020	162717	0	0	29962.28	0
	Fecal streptococcus	c/100mL		40777200	0	1496350	200420	156030	142137.6	115860	3042000	210600	12865600	35013530	2820400	653950	1003050	0	0	3295850.8	0
	Pseudomonas aeruginosa	c/100mL		35883936	0	7481750	100210	267480	90451.2	57930	811.2	312	151360	3135540	769200	33825000	1538010	0	0	823962.7	0
3386L1	Aluminum	ug/L	11	207963.72	153984.54	111328.44	166348.6	102311.1	56370.48	9693.62	10241.4	6973.2	41396.96	276450.11	12409.76	11004.4	9896.76	0	17018.06	27265.6748	47931.66
	Barium	ug/L	0.2	90933.156	81814.68	36810.21	61128.1	25187.7	16313.52	2355.82	1762.332	1021.8	8476.16	88317.71	3512.68	2367.75	3544.11	0	2998.09	8314.5327	17854.2
	Beryllium	ug/L	0.02	124.778232	1250.5008	85.59122	50.105	22.29	37.63416	1.931	2.028	0.78	7.568	136.91858	2.564	5.6375	6.08517	0	3.466	7.49057	13.734
	Calcium	mg/L	0.005	146390.148	113742.36	62547.43	100210	42128.1	29235.12	3186.15	2210.52	1404	11654.72	125421.6	5769	3337.4	5438.76	0	4679.1	16853.7825	34609.68
	Cadmium	ug/L	0.6	3135.76668	997.74	2017.0798	1503.15	668.7	484.56	57.93	60.84	23.4	473	4374.0783	76.92	67.65	66.87	0	103.98	224.7171	1177.0038
	Cobalt	ug/L	1.3	2650.518	2161.77	1945.255	3256.825	1448.85	1049.88	125.515	131.82	50.7	491.92	3396.835	166.66	421.685	144.885	0	225.29	1535.56685	892.71
	Chromium	ug/L	1.4	2854.404	2328.06	2094.89	3507.35	1560.3	1130.64	135.17	141.96	54.6	529.76	3658.13	179.48	157.85	156.03	0	242.62	524.3399	2417.184
	Copper	ug/L	1.6	111729.528	242450.82	75416.04	117746.75	60405.9	15328.248	22978.9	13607.88	7800	64025.28	328186.52	16666	21918.6	15068.04	0	21731.82	30561.5256	68395.32
	Iron	ug/L	0.8	162293.256	127378.14	96664.21	155325.5	63972.3	44741.04	1950.31	2048.28	716.04	18087.52	201197.15	4025.48	2683.45	6753.87	0	7486.56	13782.6488	77459.76
	Magnesium	mg/L	0.008	39880.1016	32160.486	16310.215	27407.435	9294.93	6686.928	449.923	340.704	159.12	2035.792	31825.731	684.588	417.175	1114.5	0	835.306	3498.09619	8254.134
	Manganese	ug/L	0.2	10438.9632	5188.248	2570.7293	3602.5495	3142.89	993.348	374.614	377.208	95.94	1786.048	8622.735	299.988	505.12	238.503	0	558.026	743.064544	1510.74
	Molybdenum	ug/L	1.6	3262.176	9145.95	2394.16	4008.4	1783.2	1292.16	154.48	162.24	62.4	605.44	9772.433	205.12	180.4	178.32	0	277.28	599.2456	1098.72
	Nickel	ug/L	1.3	9337.9788	12238.944	4758.393	9970.895	5349.6	2584.32	125.515	131.82	50.7	1112.496	3396.835	166.66	146.575	349.953	0	225.29	486.88705	2430.918
	Lead	ug/L	5	10194.3	8314.5	7481.75	12526.25	15424.68	4038	1230.047	507	195	1892	60097.85	641	563.75	557.25	0	2058.804	1872.6425	3433.5
	Strontium	ug/L	0.1	550492.2	458960.4	213678.78	347227.65	153355.2	102888.24	18981.73	12289.68	7464.6	52067.84	493324.96	30255.2	17927.25	20685.12	0	22771.62	64343.9963	132258.42
	Titanium	ug/L	0.5	3568.005	2304.7794	748.175	1252.625	557.25	403.8	48.275	50.7	19.5	384.4544	1306.475	64.1	56.375	55.725	0	86.65	187.26425	343.35
	Vanadium	ug/L	1.5	11132.1756	7117.212	8259.852	3757.875	1671.75	3149.64	328.27	456.3	163.8	1642.256	17977.096	612.796	405.9	755.631	0	259.95	1295.86861	3103.884
	Zinc	ug/L	0.6	52602.588	24810.468	20709.484	40534.945	14733.69	10934.904	639.161	586.092	171.6	6652.272	42068.495	541.004	1702.525	2763.96	0	2388.074	7153.49435	16755.48
3435L2	Phenanthrene	ng/L	10	171264.24	176267.4	0	25052.5	40122	8076	4634.4	1014	390	3784	156777	1282	0	1114.5	0	1733	3745.285	6867
	Anthracene	ng/L	10	20388.6	16629	0	25052.5	11145	8076	965.5	1014	390	3784	26129.5	1282	0	1114.5	0	1733	3745.285	6867
	Fluoranthene	ng/L	10	122331.6	113077.2	0	25052.5	31206	8076	965.5	1014	390	3784	26129.5	1282	0	1114.5	0	1733	3745.285	6867
	Pyrene	ng/L	10	89709.84	79819.2	0	25052.5	46809	8076	965.5	1014	390	3784	26129.5	1282	0	1114.5	0	1733	3745.285	6867
	Benzo(a)anthracene	ng/L	20	40777.2	33258	0	50105	22290	16152	1931	2028	780	7568	52259	2564	0	2229	0	3466	7490.57	13734
	Chrysene	ng/L	10	20388.6	16629	0	25052.5	11145	8076	965.5	1014	390	3784	26129.5	1282	0	1114.5	0	1733	3745.285	6867
	7,12-dimethylbenz(a)anthracene	ng/L	10	20388.6	16629	0	25052.5	11145	8076	965.5	1014	390	3784	26129.5	1282	0	1114.5	0	1733	3745.285	6867
	Benzo(b)fluoranthene	ng/L	10	20388.6	16629	0	25052.5	11145	8076	965.5	1014	390	3784	26129.5	1282	0	1114.5	0	1733	3745.285	6867
	Benzo(k)fluoranthene	ng/L	10	20388.6	16629	0	25052.5	11145	8076	965.5	1014	390	3784	26129.5	1282	0	1114.5	0	1733	3745.285	6867
	Benzo(e)pyrene	ng/L	10	20388.6	16629	0	25052.5	11145	8076	965.5	1014	390	3784	26129.5	1282	0	1114.5	0	1733	3745.285	6867
	Benzo(a)pyrene	ng/L	3	28544.04	26606.4	0	7515.75	3343.5	2422.8	289.65	304.2	117	1135.2	7838.85	384.6	0	334.35	0	519.9	1123.5855	2060.1
	Perylene	ng/L	10	20388.6	16629	0	25052.5	11145	8076	965.5	1014	390	3784	26129.5	1282	0	1114.5	0	1733	3745.285	6867
	Indeno(1,2,3-c,d)pyrene	ng/L	20	40777.2	33258	0	50105	22290	16152	1931	2028	780	7568	52259	2564	0	2229	0	3466	7490.57	13734
	Dibenzo(a,h)anthracene	ng/L	20	40777.2	33258	0	50105	22290	16152	1931	2028	780	7568	52259	2564	0	2229	0	3466	7490.57	13734
	Benzo(g,h,i)perylene	ng/L	20	40777.2	33258	0	50105	22290	16152	1931	2028	780	7568	52259	2564	0	2229	0	3466	7490.57	13734

Table B4: Control roof water quality concentrations for all events for which composite samples were collected

Control Roof Concentrations — Flow Volumes (L): 3694.2, 3013, 2766.3, 3137.8, 1967.1, 2117.2, 572.3, 952.9, 346.1, 2398.1, 5403.6, 1080, 902, 984, 1135.6, 1439.5, 1630, 1674.2

				2003						2004											
List ID	Parameter	Units	MDL	19-Sep-03 morning	19-Sep-03 afternoon	2-Nov-03	3-Nov-03	12-Nov-03	17-Nov-03	24-Jun-04	7-Jul-04 morning	7-Jul-04 afternoon	14-Jul-04	20-Jul-04	27-Jul-04	8-Aug-04	28-Aug-04	15-Oct-04	30-Oct-04	2-Nov-04	4-Nov-04
3016L1	Chloride	mg/L	0.2	2.8	5.2	0.4	1.2	0.8	0.1	0.9	0.8	0.9	0.7	3	1.3	0.3	0.7	0.9	0.8	0.4	1.8
3060L1	Mercury	ug/L	0.02			0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3170L1	Oxygen demand; chemical	mg/L as O2	1	29	33	10	14	17	13	36	21	12	11	38	9	23	10	15	32	40	5
3171L1	Calcium	mg/L	0.25	5.55	9.15	3.95	5.55	6.2	4.4	5.5	4.75	5.7	2.9	6.15	3.65	3.7	4.75	5.7	4.05	3.9	3.2
	Magnesium	mg/L	0.1	0.98	1.98	0.44	0.96	0.68	0.6	0.6	0.44	0.58	0.36	1.48	0.4	0.42	0.48	0.56	0.52	0.38	1.02
	Sodium	mg/L	0.1	1.58	2.14	0.68	1.16	1.04	0.88	0.9	0.78	1.32	0.62	1.42	0.84	0.68	1.02	1.34	1.06	0.84	1.06
	Potassium	mg/L	0.05	2.41	2.68	1.66	1.89	1.98	1.8	1.57	1.82	2.7	1.22	1.49	1.82	1.42	2.16	2.73	1.98	1.86	1.52
	Hardness	mg/L	1	17.8	31	11.6	17.8	18.2	13.4	16.2	13.8	16.6	8.6	21.6	10.8	11	13.8	16.6	12.2	11.2	12.2
3172L4	Fluoride	mg/L	0.05	0.06		0.025	0.06	0.025	0.025	0.025	0.025	0.025	0.025	0.1	0.025	0.025	0.025	0.05	0.025	0.025	0.025
	Sulphate	mg/L	2.5	4.7	9.6	3.1	4.1	6.4	2.8	5.2	6	5.6	3.6	6.5	1.25	1.25	4	4.3	4	3.8	4.3
3179L1	Phenolics; 4-AAP	ug/L	0.2	4.2																	
3182L1	Oxygen demand; biochemical	mg/L as O2	0.2	2.9	1.4	1.3	1.4	1.9	0.6	6.4	3.1	2.4	1.9	2.2	2.7	5.7	3.8	1.7	1.9	1.6	1.4
3188L3	Solids; suspended	mg/L	2.5	6.1	4.4	6.8	5	10.9	7.7	17.5	6.7	5.2	4.3	3	1.25	6.2	2.6	5.9	20.9	3	3.6
3201L1	Solvent extractable	mg/L	1		0.5	0.5	0.5		0.5		0.5			0.5	2.1		1				
3218L1	Conductivity	uS/cm	1	52	81	35	46	57	38	50	45	58	30	63	32	32	45	52	40	36	42
	pH	none		7.23	7.36	7.32	7.4	7.41	7.43	7.05	6.98	7.32	6.91	7.37	7.33	7.07	7.27	7.29	7.26	7.35	7.42
	Alkalinity; total fixed endpt	mg/L CaCO3	2.5	16	19.9	12.6	16.8	16.1	15.4	12.1	9.8	16.4	7.3	16.3	14.4	11.5	13.7	17.3	12.4	11.8	12.7
3311L1	Turbidity	FTU	0.01	1.6		2.23	2.08	6.19	3.77		2.82			2.21	1.62	4.63	1.82				
3364L1	Nitrogen; ammonia+ammonium	mg/L	0.002	0.054	0.088	0.265	0.175	0.529	0.131	0.654	0.49	0.189	0.247	0.29	0.059	0.175	0.208	0.16	0.211	0.189	0.1
	Nitrogen; nitrite	mg/L	0.001	0.04	0.033	0.027	0.015	0.063	0.021	0.026	0.033	0.054	0.021	0.024	0.022	0.029	0.052	0.032	0.023	0.018	0.017
	Nitrogen; nitrate+nitrite	mg/L	0.005	0.216	0.248	0.347	0.158	1.04	0.283	0.82	0.969	0.882	0.502	0.364	0.206	0.308	0.853	0.597	0.32	0.413	0.157
	Phosphorus; phosphate	mg/L	0.0005	0.0356	0.138	0.0102	0.0695	0.0052	0.0415	0.0011	0.0092	0.00025	0.0094	0.0403	0.0135	3E-04	0.0019	0.01	0.0042	0.0097	0.0085
3367L1	Phosphorus; total	mg/L	0.002	0.054	0.143	0.025	0.081	0.31	0.061	0.073	0.038	0.083	0.037	0.074	0.029	0.036	0.028	0.037	0.076	0.024	0.024
	Nitrogen; total Kjeldahl	mg/L	0.02	0.4	0.66	0.46	0.47	0.94	0.38	1.45	0.85	1.57	0.57	0.94	0.23	0.56	0.53	0.46	0.72	0.36	0.32
3371L10	Escherichia coli	c/100mL		610		4	12	4	8	8	8	4	32	2800	520	20				10	
	Fecal streptococcus	c/100mL		6100		32	150	84	260	240	1500	180	660	7000	1500	160				440	
	Pseudomonas aeruginosa	c/100mL		1500		2	160	2	12	220	250	360	600	3000	2000	1700				420	
3386L1	Aluminum	ug/L	11	59.8	34.5	40.7	60.3	104	50.3	122	56.1	63	51.4	39.6	29.6	94.5	34		164	29.7	42.5
	Barium	ug/L	0.2	3.87	5.53	2.32	3.43	4.83	2.2	4.47	2.78	3.38	2.11	4.17	1.46	3.36	2.55		4.99	1.57	2.65
	Beryllium	ug/L	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.022	0.01		0.01	0.01	0.01
	Calcium	mg/L	0.005	5.07	8.79	3.55	5.25	5.67	3.74	4.35	3.36	5.22	2.76	5.83	3.33	3.82	4.24		3.81	3.49	4.34
	Cadmium	ug/L	0.6	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3		0.3	0.3	1.13
	Cobalt	ug/L	1.3	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65		1.55	0.65	0.65
	Chromium	ug/L	1.4	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7		0.7	0.7	0.7
	Copper	ug/L	1.6	68.4	37.8	67.9	64.7	159	80.3	210	209	155	154	96.7	70	182	91.7		130	96.2	79.1
	Iron	ug/L	0.8	37.9	18.2	23.3	39.7	61.8	31.9	86.7	24.6	24.1	28.5	20	11.7	63.1	14.4		134	23.2	32.9
	Magnesium	mg/L	0.008	1.09	2.09	0.426	1.03	0.804	0.584	0.656	0.446	0.672	0.419	1.42	0.42	0.586	0.504		0.739	0.414	0.876
	Manganese	ug/L	0.2	7.38	5.03	6.21	6.33	12.7	6.23	16.6	11.2	9.65	9.19	5.84	3.19	15.1	6.48		13.7	4.77	4.75
	Molybdenum	ug/L	1.6	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8		0.8	0.8	0.8
	Nickel	ug/L	1.3	0.65	0.65	0.65	0.65	1.35	0.65	1.38	0.65	0.65	0.65	0.65	0.65	0.65	0.65		2.71	0.65	0.65
	Lead	ug/L	5	2.5	2.5	6.78	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5		2.5	9.25	2.5
	Strontium	ug/L	0.1	18	28.2	11.6	16.6	18.7	11.8	14.6	11.8	18.3	9.82	20.4	10.9	12.1	14.7		11.5	10.7	14.8
	Titanium	ug/L	0.5	1.47	0.71	0.96	1.82	2.96	1.49	2.18	0.978	1.18	0.95	0.604	0.25	2.1	0.25		4.37	0.67	1.14
	Vanadium	ug/L	1.5	0.75	0.75	0.75	0.75	0.75	0.75	1.74	0.75	1.78	0.75	0.75	0.75	2.39	2.66		0.75	0.75	0.75
	Zinc	ug/L	0.6	8.21	7.63	8.75	9.42	16	7.44	14.2	13.6	9.09	9.56	7.82	4.42	13.2	7.14		13.6	6.11	7.46
3435L2	Phenanthrene	ng/L	10	180	200	72	96	180	140	160	70	38	22	5	22		5		160	24	11
	Anthracene	ng/L	10	11	27	14	16	28	20	5	5	5	5	5	5		5		18	5	5
	Fluoranthene	ng/L	10	300	270	110	140	280	210	240	79	54	19	5	20		5		230	26	15
	Pyrene	ng/L	10	220	200	76	98	220	150	190	58	39	5	5	5		5		180	20	5
	Benzo(a)anthracene	ng/L	20	73	71	34	42	67	54	68	10	10	10	10	10		10		59	10	10
	Chrysene	ng/L	10	120	93	41	61	100	66	130	39	32	5	5	5		5		62	5	5
	7,12-dimethylbenz(a)anthracene	ng/L	10	5	5	5	5	5	5	5	5	5	5	5	5		5		5	5	5
	Benzo(b)fluoranthene	ng/L	10	130	100	60	74	110	66	140	27	22	5	5	5		5		100	11	5
	Benzo(k)fluoranthene	ng/L	10	98	76	39	55	83	75	130	27	19	5	5	5		5		28	5	5
	Benzo(e)pyrene	ng/L	10	76	62	32	34	71	50	84	20	16	5	5	5		5		73	5	5
	Benzo(a)pyrene	ng/L	3	110	97	39	42	90	72	110	26	19	1.5	1.5	1.5		1.5		85	9	7
	Perylene	ng/L	10	25	30	5	16	23	16	26	5	5	5	5	5		5		22	5	5
	Indeno(1,2,3-c,d)pyrene	ng/L	20	110	94	50	60	82	150	34	10	10	10	10	10		10		62	10	10
	Dibenzo(a,h)anthracene	ng/L	20	10	10	10	10	10	10	10	10	10	10	10	10		10		20	10	10
	Benzo(g,h,i)perylene	ng/L	20	71	61	30	32	70	52	34	10	10	10	10	10		10		79	10	10

Table B5: Control roof water quality statistics for all events for which composite samples were collected

				STATISTICS										
List ID	Parameter	Units	MDL	# > dl	%>dl	No. of Samples	MINIMUM	MAXIMUM	GEOMEAN	MEAN	MEDIAN	STD. DEV.	95%CI -LL	95%CI -UL
3016L1	Chloride	mg/L	**0.2**	17	94.44	18	0.1	5.2	0.88	1.28	0.85	1.25	0.70	1.86
3060L1	Mercury	ug/L	**0.02**	1	6.25	16	0.01	0.03	0.01	0.01	0.01	0.00	0.01	0.01
3170L1	Oxygen demand; chemical	mg/L as O2	**1**	18	100.00	18	5	40	17.44	20.44	16	11.35	15.20	25.69
3171L1	Calcium	mg/L	**0.25**	18	100.00	18	2.9	9.15	4.75	4.93	4.75	1.47	4.25	5.61
	Magnesium	mg/L	**0.1**	18	100.00	18	0.36	1.98	0.63	0.72	0.57	0.43	0.52	0.91
	Sodium	mg/L	**0.1**	18	100.00	18	0.62	2.14	1.02	1.08	1.03	0.38	0.90	1.25
	Potassium	mg/L	**0.05**	18	100.00	18	1.22	2.73	1.88	1.93	1.84	0.45	1.72	2.14
	Hardness	mg/L	**1**	18	100.00	18	8.6	31	14.56	15.24	13.8	5.16	12.86	17.63
3172L4	Fluoride	mg/L	**0.05**	3	17.65	17	0.025	0.1	0.03	0.04	0.025	0.02	0.03	0.04
	Sulphate	mg/L	**2.5**	16	88.89	18	1.25	9.6	4.02	4.47	4.2	1.96	3.56	5.38
3179L1	Phenolics; 4-AAP	ug/L	**0.2**	1	100.00	1	4.2	4.2	4.20	4.20	4.2	0.00	0.00	0.00
3182L1	Oxygen demand; biochemical	mg/L as O2	**0.2**	18	100.00	18	0.6	6.4	2.11	2.46	1.9	1.51	1.76	3.16
3188L3	Solids; suspended	mg/L	**2.5**	17	94.44	18	1.25	20.9	5.42	6.73	5.55	5.08	4.38	9.07
3201L1	Solvent extractable	mg/L	**1**	1	12.50	8	0.5	2.1	0.65	0.76	0.5	0.57	0.37	1.16
3218L1	Conductivity	uS/cm	**1**	18	100.00	18	30	81	44.78	46.33	45	12.95	40.35	52.32
	pH	none		n/a	n/a	18	6.91	7.43	7.26	7.27	7.32	0.16	7.19	7.34
	Alkalinity; total fixed endpt	mg/L CaCO3	**2.5**	18	100.00	18	7.3	19.9	13.68	14.03	14.05	3.05	12.62	15.44
3311L1	Turbidity	FTU	**0.01**	10	100.00	10	1.6	6.19	2.61	2.90	2.22	1.52	1.96	3.84
3364L1	Nitrogen; ammonia+ammonium	mg/L	**0.002**	18	100.00	18	0.054	0.654	0.19	0.23	0.189	0.17	0.16	0.31
	Nitrogen; nitrite	mg/L	**0.001**	18	100.00	18	0.015	0.063	0.03	0.03	0.0265	0.01	0.02	0.04
	Nitrogen; nitrate+nitrite	mg/L	**0.005**	18	100.00	18	0.157	1.04	0.40	0.48	0.3555	0.30	0.34	0.62
	Phosphorus; phosphate	mg/L	**0.0005**	16	88.89	18	0.00025	0.138	0.01	0.02	0.00955	0.03	0.01	0.04
3367L1	Phosphorus; total	mg/L	**0.002**	18	100.00	18	0.024	0.31	0.05	0.07	0.046	0.07	0.04	0.10
	Nitrogen; total Kjeldahl	mg/L	**0.02**	18	100.00	18	0.23	1.57	0.58	0.66	0.545	0.37	0.49	0.83
3371L10	Escherichia coli	c/100mL		n/a	n/a	13	4	2800	25.79	310.77	10	776.15	-111.14	732.68
	Fecal streptococcus	c/100mL		n/a	n/a	13	32	7000	435.41	1408.15	260	2341.21	135.48	2680.83
	Pseudomonas aeruginosa	c/100mL		n/a	n/a	13	2	3000	194.92	786.62	360	953.01	268.56	1304.67
3386L1	Aluminum	ug/L	**11**	17	100.00	17	29.6	164	55.56	63.29	51.4	37.13	45.64	80.94
	Barium	ug/L	**0.2**	17	100.00	17	1.46	5.53	3.05	3.27	3.36	1.22	2.69	3.86
	Beryllium	ug/L	**0.02**	1	5.88	17	0.01	0.022	0.01	0.01	0.01	0.00	0.01	0.01
	Calcium	mg/L	**0.005**	17	100.00	17	2.76	8.79	4.33	4.51	4.24	1.42	3.83	5.18
	Cadmium	ug/L	**0.6**	1	5.88	17	0.3	1.13	0.32	0.35	0.3	0.20	0.25	0.44
	Cobalt	ug/L	**1.3**	1	5.88	17	0.65	1.55	0.68	0.70	0.65	0.22	0.60	0.81
	Chromium	ug/L	**1.4**	0	0.00	17	0.7	0.7	0.70	0.70	0.7	0.00	0.70	0.70
	Copper	ug/L	**1.6**	17	100.00	17	37.8	210	103.16	114.81	96.2	53.77	89.25	140.37
	Iron	ug/L	**0.8**	17	100.00	17	11.7	134	32.07	39.76	28.5	31.29	24.89	54.64
	Magnesium	mg/L	**0.008**	17	100.00	17	0.414	2.09	0.69	0.78	0.656	0.44	0.57	0.98
	Manganese	ug/L	**0.2**	17	100.00	17	3.19	16.6	7.66	8.49	6.48	4.02	6.58	10.40
	Molybdenum	ug/L	**1.6**	0	0.00	17	0.8	0.8	0.80	0.80	0.8	0.00	-	-
	Nickel	ug/L	**1.3**	3	17.65	17	0.65	2.71	0.77	0.86	0.65	0.53	0.60	1.11
	Lead	ug/L	**5**	2	11.76	17	2.5	9.25	2.86	3.15	2.5	1.88	2.25	4.04
	Strontium	ug/L	**0.1**	17	100.00	17	9.82	28.2	14.38	14.97	14.6	4.71	12.73	17.21
	Titanium	ug/L	**0.5**	15	88.24	17	0.25	4.37	1.10	1.42	1.14	1.05	0.92	1.91
	Vanadium	ug/L	**1.5**	4	23.53	17	0.75	2.66	0.96	1.08	0.75	0.64	0.77	1.38
	Zinc	ug/L	**0.6**	17	100.00	17	4.42	16	9.12	9.63	8.75	3.27	8.07	11.18

Table B5 continued: Control roof water quality statistics for all events for which composite samples were collected

				STATISTICS											
List ID	Parameter	Units	MDL	# > dl	%>dl	No. of Samples	MINIMUM	MAXIMUM	GEOMEAN	MEAN	MEDIAN	STD. DEV.	95%CI -LL	95%CI -UL	
3435L2	**Phenanthrene**	**ng/L**	**10**	6	100.00	6	72	200	135.80	144.67	160	51.44	103.51	185.82	**2003 PAH Statistics**
	Anthracene	**ng/L**	**10**	6	100.00	6	11	28	18.28	19.33	18	6.98	13.75	24.92	
	Fluoranthene	**ng/L**	**10**	6	100.00	6	110	300	204.60	218.33	240	78.85	155.24	281.42	
	Pyrene	**ng/L**	**10**	6	100.00	6	76	220	148.71	160.67	175	62.92	110.32	211.02	
	Benzo(a)anthracene	**ng/L**	**20**	6	100.00	6	34	73	54.70	56.83	60.5	16.22	43.86	69.81	
	Chrysene	**ng/L**	**10**	6	100.00	6	41	120	75.43	80.17	79.5	29.14	56.85	103.49	
	7,12-dimethylbenz(a)anthracene	**ng/L**	**10**	0	0.00	6	5	5	5.00	5.00	5	0.00	-	-	
	Benzo(b)fluoranthene	**ng/L**	**10**	6	100.00	6	60	130	86.51	90.00	87	27.68	67.85	112.15	
	Benzo(k)fluoranthene	**ng/L**	**10**	6	100.00	6	39	98	68.07	71.00	75.5	20.95	54.24	87.76	
	Benzo(e)pyrene	**ng/L**	**10**	6	100.00	6	32	76	51.29	54.17	56	18.64	39.25	69.08	
	Benzo(a)pyrene	**ng/L**	**3**	6	100.00	6	39	110	69.56	75.00	81	29.42	51.46	98.54	
	Perylene	**ng/L**	**10**	5	83.33	6	5	30	16.75	19.17	19.5	8.80	12.13	26.20	
	Indeno(1,2,3-c,d)pyrene	**ng/L**	**20**	6	100.00	6	50	150	85.16	91.00	88	36.26	61.99	120.01	
	Dibenzo(a,h)anthracene	**ng/L**	**20**	0	0.00	6	10	10	10.00	10.00	10	0.00	-	-	
	Benzo(g,h,i)perylene	**ng/L**	**20**	6	100.00	6	30	71	49.73	52.67	56.5	18.15	38.14	67.19	
3435L2	**Phenanthrene**	**ng/L**	**10**	8	80.00	10	5	160	27.15	51.70	23	60.12	14.44	88.96	**2004 PAH Statistics**
	Anthracene	**ng/L**	**10**	1	10.00	10	5	18	5.68	6.30	5	4.11	3.75	8.85	
	Fluoranthene	**ng/L**	**10**	8	80.00	10	5	240	31.19	69.30	23	90.27	13.35	125.25	
	Pyrene	**ng/L**	**10**	5	50.00	10	5	190	18.55	51.20	12.5	72.80	6.08	96.32	
	Benzo(a)anthracene	**ng/L**	**20**	2	20.00	10	10	68	14.47	20.70	10	22.66	6.66	34.74	
	Chrysene	**ng/L**	**10**	4	40.00	10	5	130	13.17	29.30	5	40.63	4.12	54.48	
	7,12-dimethylbenz(a)anthracene	**ng/L**	**10**	0	0.00	10	5	5	5.00	5.00	5	0.00	-	-	
	Benzo(b)fluoranthene	**ng/L**	**10**	5	50.00	10	5	140	13.98	32.50	8	47.72	2.92	62.08	
	Benzo(k)fluoranthene	**ng/L**	**10**	4	40.00	10	5	130	11.13	23.40	5	38.66	-0.56	47.36	
	Benzo(e)pyrene	**ng/L**	**10**	4	40.00	10	5	84	11.19	22.30	5	30.22	3.57	41.03	
	Benzo(a)pyrene	**ng/L**	**3**	6	60.00	10	1.5	110	8.26	26.20	8	38.93	2.07	50.33	
	Perylene	**ng/L**	**10**	2	20.00	10	5	26	6.84	8.80	5	8.07	3.80	13.80	
	Indeno(1,2,3-c,d)pyrene	**ng/L**	**20**	2	20.00	10	10	62	13.56	17.60	10	17.33	6.86	28.34	
	Dibenzo(a,h)anthracene	**ng/L**	**20**	0	0.00	10	10	20	10.72	11.00	10	3.16	9.04	12.96	
	Benzo(g,h,i)perylene	**ng/L**	**20**	2	20.00	10	10	79	13.90	19.30	10	22.29	5.48	33.12	

Table B6: Control roof runoff loading for all events for which composite samples were collected

List ID	Parameter	Units	MDL	19-Sep-03 morning	19-Sep-03 afternoon	2-Nov-03	3-Nov-03	12-Nov-03	17-Nov-03	24-Jun-04	7-Jul-04 morning	7-Jul-04 afternoon	14-Jul-04	20-Jul-04	27-Jul-04	8-Aug-04	28-Aug-04	15-Oct-04	30-Oct-04	2-Nov-04	4-Nov-04
Control Roof Loads	**Flow Volumes (L):**			3694.2	3013	2766.3	3137.8	1967.1	2117.2	572.3	952.9	346.1	2398.1	5403.6	1080	902	984	1135.6	1439.5	1630	1674.2
				2 0 0 3 LOADS						2 0 0 4 LOADS											
3016L1	Chloride	mg/L	0.2	10343.76	15667.6	1106.52	3765.36	1573.68	211.72	515.07	762.32	311.49	1678.67	16210.8	1404	270.6	688.8	1022.04	1151.6	652	3013.56
3060L1	Mercury	ug/L	0.02	0	0	27.663	31.378	19.671	21.172	5.723	9.529	3.461	71.943	54.036	10.8	9.02	9.84	11.356	14.395	16.3	16.742
3170L1	Oxygen demand; chemical	mg/L as O2	1	107131.8	99429	27663	43929.2	33440.7	27523.6	20602.8	20010.9	4153.2	26379.1	205336.8	9720	20746	9840	17034	46064	65200	8371
3171L1	Calcium	mg/L	0.25	20502.81	27568.95	10926.885	17414.79	12196.02	9315.68	3147.65	4526.275	1972.77	6954.49	33232.14	3942	3337.4	4674	6472.92	5829.975	6357	5357.44
	Magnesium	mg/L	0.1	3620.316	5965.74	1217.172	3012.288	1337.628	1270.32	343.38	419.276	200.738	863.316	7997.328	432	378.84	472.32	635.936	748.54	619.4	1707.684
	Sodium	mg/L	0.1	5836.836	6447.82	1881.084	3639.848	2045.784	1863.136	515.07	743.262	456.852	1486.822	7673.112	907.2	613.36	1003.68	1521.704	1525.87	1369.2	1774.652
	Potassium	mg/L	0.05	8903.022	8074.84	4592.058	5930.442	3894.858	3810.96	898.511	1734.278	934.47	2925.682	8051.364	1965.6	1280.84	2125.44	3100.188	2850.21	3031.8	2544.784
	Hardness	mg/L	1	65756.76	93403	32089.08	55852.84	35801.22	28370.48	9271.26	13150.02	5745.26	20623.66	116717.76	11664	9922	13579.2	18850.96	17561.9	18256	20425.24
3172L4	Fluoride	mg/L	0.05	221.652	0	69.1575	188.268	49.1775	52.93	14.3075	23.8225	8.6525	59.9525	540.36	27	22.55	24.6	56.78	35.9875	40.75	41.855
	Sulphate	mg/L	2.5	17362.74	28924.8	8575.53	12864.98	12589.44	5928.16	2975.96	5717.4	1938.16	8633.16	35123.4	1350	1127.5	3936	4883.08	5758	6194	7199.06
3179L1	Phenolics; 4-AAP	ug/L	0.2	15515.64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3182L1	Oxygen demand; biochemical	mg/L as O2	0.2	10713.18	4218.2	3596.19	4392.92	3737.49	1270.32	3662.72	2953.99	830.64	4556.39	11887.92	2916	5141.4	3739.2	1930.52	2735.05	2608	2343.88
3188L3	Solids; suspended	mg/L	2.5	22534.62	13257.2	18810.84	15689	21441.39	16302.44	10015.25	6384.43	1799.72	10311.83	16210.8	1350	5592.4	2558.4	6700.04	30085.55	4890	6027.12
3201L1	Solvent extractable	mg/L	1	0	1506.5	1383.15	1568.9	0	1058.6	0	476.45	0	0	2701.8	2268	0	984	0	0	0	0
3218L1	Conductivity	uS/cm	1	192098.4	244053	96820.5	144338.8	112124.7	80453.6	28615	42880.5	20073.8	71943	340426.8	34560	28864	44280	59051.2	57580	58680	70316.4
	pH	none		26709.066	22175.68	20249.316	23219.72	14576.211	15730.796	4034.715	6651.242	2533.452	16570.871	39824.532	7916.4	6377.14	7153.68	8278.524	10450.77	11980.5	12422.564
	Alkalinity; total fixed endpt	mg/L CaCO3	2.5	59107.2	59958.7	34855.38	52715.04	31670.31	32604.88	6924.83	9338.42	5676.04	17506.13	88078.68	15552	10373	13480.8	19645.88	17849.8	19234	21262.34
3311L1	Turbidity	FTU	0.01	5910.72	0	6168.849	6526.624	12176.349	7981.844	0	2687.178	0	0	11941.956	1749.6	4176.26	1790.88	0	0	0	0
3364L1	Nitrogen; ammonia+ammonium	mg/L	0.002	199.4868	265.144	733.0695	549.115	1040.5959	277.3532	374.2842	466.921	65.4129	592.3307	1567.044	63.72	157.85	204.672	181.696	303.7345	308.07	167.42
	Nitrogen; nitrite	mg/L	0.001	147.768	99.429	74.6901	47.067	123.9273	44.4612	14.8798	31.4457	18.6894	50.3601	129.6864	23.76	26.158	51.168	36.3392	33.1085	29.34	28.4614
	Nitrogen; nitrate+nitrite	mg/L	0.005	797.9472	747.224	959.9061	495.7724	2045.784	599.1676	469.286	923.3601	305.2602	1203.8462	1966.9104	222.48	277.816	839.352	677.9532	460.64	673.19	262.8494
	Phosphorus; phosphate	mg/L	0.0005	131.51352	415.794	28.21626	218.0771	10.22892	87.8638	0.62953	8.76668	0.086525	22.54214	217.76508	14.58	0.2255	1.8696	11.356	6.0459	15.811	14.2307
3367L1	Phosphorus; total	mg/L	0.002	199.4868	430.859	69.1575	254.1618	609.801	129.1492	41.7779	36.2102	28.7263	88.7297	399.8664	31.32	32.472	27.552	42.0172	109.402	39.12	40.1808
	Nitrogen; total Kjeldahl	mg/L	0.02	1477.68	1988.58	1272.498	1474.766	1849.074	804.536	829.835	809.965	543.377	1366.917	5079.384	248.4	505.12	521.52	522.376	1036.44	586.8	535.744
3371L10	Escherichia coli	c/100mL		2253462	0	11065.2	37653.6	7868.4	16937.6	4578.4	7623.2	1384.4	76739.2	15130080	561600	18040	0	0	0	16300	0
	Fecal streptococcus	c/100mL		22534620	0	88521.6	470670	165236.4	550472	137352	1429350	62298	1582746	37825200	1620000	144320	0	0	0	717200	0
	Pseudomonas aeruginosa	c/100mL		5541300	0	5532.6	502048	3934.2	25406.4	125906	238225	124596	1438860	16210800	2160000	1533400	0	0	0	684600	0
3386L1	Aluminum	ug/L	11	220913.16	103948.5	112588.41	189209.34	204578.4	106495.16	69820.6	53457.69	21804.3	123262.34	213982.56	31968	85239	33456	0	236078	48411	71153.5
	Barium	ug/L	0.2	14296.554	16661.89	6417.816	10762.654	9501.093	4657.84	2558.181	2649.062	1169.818	5059.991	22533.012	1576.8	3030.72	2509.2	0	7183.105	2559.1	4436.63
	Beryllium	ug/L	0.02	36.942	30.13	27.663	31.378	19.671	21.172	5.723	9.529	3.461	23.981	54.036	10.8	19.844	9.84	0	14.395	16.3	16.742
	Calcium	mg/L	0.005	18729.594	26484.27	9820.365	16473.45	11153.457	7918.328	2489.505	3201.744	1806.642	6618.756	31502.988	3596.4	3445.64	4172.16	0	5484.495	5688.7	7266.028
	Cadmium	ug/L	0.6	1108.26	903.9	829.89	941.34	590.13	635.16	171.69	285.87	103.83	719.43	1621.08	324	270.6	295.2	0	431.85	489	1891.846
	Cobalt	ug/L	1.3	2401.23	1958.45	1798.095	2039.57	1278.615	1376.18	371.995	619.385	224.965	1558.765	3512.34	702	586.3	639.6	0	2231.225	1059.5	1088.23
	Chromium	ug/L	1.4	2585.94	2109.1	1936.41	2196.46	1376.97	1482.04	400.61	667.03	242.27	1678.67	3782.52	756	631.4	688.8	0	1007.65	1141	1171.94
	Copper	ug/L	1.6	252683.28	113891.4	187831.77	203015.66	312768.9	170011.16	120183	199156.1	53645.5	369307.4	522528.12	75600	164164	90232.8	0	187135	156806	132429.22
	Iron	ug/L	0.8	140010.18	54836.6	64454.79	124570.66	121566.78	67538.68	49618.41	23441.34	8341.01	68345.85	108072	12636	56916.2	14169.6	0	192893	37816	55081.18
	Magnesium	mg/L	0.008	4026.678	6297.17	1178.4438	3231.934	1581.5484	1236.4448	375.4288	424.9934	232.5792	1004.8039	7673.112	453.6	528.572	495.936	0	1063.7905	674.82	1466.5992
	Manganese	ug/L	0.2	27263.196	15155.39	17178.723	19862.274	24982.17	13190.156	9500.18	10672.48	3339.865	22038.539	31557.024	3445.2	13620.2	6376.32	0	19721.15	7775.1	7952.45
	Molybdenum	ug/L	1.6	2955.36	2410.4	2213.04	2510.24	1573.68	1693.76	457.84	762.32	276.88	1918.48	4322.88	864	721.6	787.2	0	1151.6	1304	1339.36
	Nickel	ug/L	1.3	2401.23	1958.45	1798.095	2039.57	2655.585	1376.18	789.774	619.385	224.965	1558.765	3512.34	702	586.3	639.6	0	3901.045	1059.5	1088.23
	Lead	ug/L	5	9235.5	7532.5	18755.514	7844.5	4917.75	5293	1430.75	2382.25	865.25	5995.25	13509	2700	2255	2460	0	3598.75	15077.5	4185.5
	Strontium	ug/L	0.1	66495.6	84966.6	32089.08	52087.48	36784.77	24982.96	8355.58	11244.22	6333.63	23549.342	110233.44	11772	10914.2	14464.8	0	16554.25	17441	24778.16
	Titanium	ug/L	0.5	5430.474	2139.23	2655.648	5710.796	5822.616	3154.628	1247.614	931.9362	408.398	2278.195	3263.7744	270	1894.2	246	0	6290.615	1092.1	1908.588
	Vanadium	ug/L	1.5	2770.65	2259.75	2074.725	2353.35	1475.325	1587.9	995.802	714.675	616.058	1798.575	4052.7	810	2155.78	2617.44	0	1079.625	1222.5	1255.65
	Zinc	ug/L	0.6	30329.382	22989.19	24205.125	29558.076	31473.6	15751.968	8126.66	12959.44	3146.049	22925.836	42256.152	4773.6	11906.4	7025.76	0	19577.2	9959.3	12489.532
3435L2	Phenanthrene	ng/L	10	664956	602600	199173.6	301228.8	354078	296408	91568	66703	13151.8	52758.2	27018	23760	0	4920	0	230320	39120	18416.2
	Anthracene	ng/L	10	40636.2	81351	38728.2	50204.8	55078.8	42344	2861.5	4764.5	1730.5	11990.5	27018	5400	0	4920	0	25911	8150	8371
	Fluoranthene	ng/L	10	1108260	813510	304293	439292	550788	444612	137352	75279.1	18689.4	45563.9	27018	21600	0	4920	0	331085	42380	25113
	Pyrene	ng/L	10	812724	602600	210238.8	307504.4	432762	317580	108737	55268.2	13497.9	11990.5	27018	5400	0	4920	0	259110	32600	8371
	Benzo(a)anthracene	ng/L	20	269676.6	213923	94054.2	131787.6	131795.7	114328.8	38916.4	9529	3461	23981	54036	10800	0	9840	0	84930.5	16300	16742
	Chrysene	ng/L	10	443304	280209	113418.3	191405.8	196710	139735.2	74399	37163.1	11075.2	11990.5	27018	5400	0	4920	0	89249	8150	8371
	7,12-dimethylbenz(a)anthracene	ng/L	10	18471	15065	13831.5	15689	9835.5	10586	2861.5	4764.5	1730.5	11990.5	27018	5400	0	4920	0	7197.5	8150	8371
	Benzo(b)fluoranthene	ng/L	10	480246	301300	165978	232197.2	216381	139735.2	80122	25728.3	7614.2	11990.5	27018	5400	0	4920	0	143950	17930	8371
	Benzo(k)fluoranthene	ng/L	10	362031.6	228988	107885.7	172579	163269.3	158790	74399	25728.3	6575.9	11990.5	27018	5400	0	4920	0	40306	8150	8371
	Benzo(e)pyrene	ng/L	10	280759.2	186806	88521.6	106685.2	139664.1	105860	48073.2	19058	5537.6	11990.5	27018	5400	0	4920	0	105083.5	8150	8371
	Benzo(a)pyrene	ng/L	3	406362	292261	107885.7	131787.6	177039	152438.4	62953	24775.4	6575.9	3597.15	8105.4	1620	0	1476	0	122357.5	14670	11719.4
	Perylene	ng/L	10	92355	90390	13831.5	50204.8	45243.3	33875.2	14879.8	4764.5	1730.5	11990.5	27018	5400	0	4920	0	31669	8150	8371
	Indeno(1,2,3-c,d)pyrene	ng/L	20	406362	283222	138315	188268	161302.2	317580	19458.2	9529	3461	23981	54036	10800	0	9840	0	89249	16300	16742
	Dibenzo(a,h)anthracene	ng/L	20	36942	30130	27663	31378	19671	21172	5723	9529	3461	23981	54036	10800	0	9840	0	28790	16300	16742
	Benzo(g,h,i)perylene	ng/L	20	262288.2	183793	82989	100409.6	137697	110094.4	19458.2	9529	3461	23981	54036	10800	0	9840	0	113720.5	16300	16742

Table B7: Precipitation water quality concentrations for all events for which composite samples were collected

Precipitation Concentrations

List ID	Parameter	Units	MDL	15-Sep-03	19-Sep-03 morning	19-Sep-03 afternoon	22-Sep-03	27-Sep-03	14-Oct-03	18-Oct-03	2-Nov-03	12-Nov-03	17-Nov-03	7-Jul-04 morning	7-Jul-04 afternoon	14-Jul-04	20-Jul-04	27-Jul-04	28-Aug-04	15-Oct-04
			Flow volumes (L):	6993.6	10490.4	8556	10564.8	15475.2	5840.4	3496.8	6844.8	5803.2	3571.2	3422.4	1264.8	9448.8	18079.2	3794.4	3273.6	3720
				2003										2004						
3016L1	Chloride	mg/L	0.20	0.40	0.30															
3146L1	Calcium	mg/L	0.025			0.42	0.37	0.6	0.9	1.56	1.39	1.92	0.455		1.12	1.54	0.65	1.78	0.42	1.69
	Magnesium	mg/L	0.0005			0.084	0.07	0.132	0.162	0.344	0.264	0.377	0.318		0.276	0.313	0.145	0.255	0.095	0.359
	Sodium	mg/L	0.01			0.182	0.19	0.084	0.122	0.188	0.152	0.306	0.362		0.172	0.236	0.05	0.568	0.106	0.102
	Potassium	mg/L	0.01			0.044	0.116	0.052	0.05	0.102	0.048	0.106	0.072		0.116	0.108	0.056	0.458	0.068	0.072
3170L1	Oxygen demand; chemical	mg/L as O2	1		36															
3171L1	Calcium	mg/L	0.25	0.9	0.85															
	Magnesium	mg/L	0.1	0.2	0.12															
	Sodium	mg/L	0.1	0.05	0.14															
	Potassium	mg/L	0.05	0.025	0.07															
	Hardness	mg/L	1	3.2	2.6															
3172L4	Fluoride	mg/L	0.05		0.025															
	Sulphate	mg/L	2.5		1.25															
3179L1	Phenolics; 4-AAP	ug/L	0.2	2.3	2.9															
3182L1	Oxygen demand; biochemical	mg/L as O2	0.2	1.1	1															
3188L3	Solids; suspended	mg/L	2.5	1.25	12.6															
3218L1	Conductivity	uS/cm	1	12	7	11	21	13	25	27	12	20	16	36	15	18	13	16	13	21
	pH	none		5.89	6.65	5.1	4.49	5.31	4.49	5.88	6.45	6.56	6.29	5.56	6.59	6.04	5.48	6.67	4.79	5.96
	Alkalinity; total fixed endpt	mg/L CaCO3	2.5	1.25	4.4	1.25	1.25	1.25	1.25	1.25	3.1	4	2.7	2.8	4.2	2.8	2.7	5.1	1.25	2.6
3311L1	Turbidity	FTU	0.01	0.91	1.69			0.005												
3364L1	Nitrogen; ammonia+ammonium	mg/L	0.002	0.275	0.096	0.337	0.412	0.311	0.556	1.27	0.273	0.592	0.378	0.837	0.368	0.391	0.662	0.167	0.314	0.523
	Nitrogen; nitrite	mg/L	0.001	0.014	0.01	0.011	0.004	0.0005	0.006	0.021	0.01	0.012	0.014	0.008	0.009	0.006	0.007	0.008	0.008	0.01
	Nitrogen; nitrate+nitrite	mg/L	0.005	0.333	0.143	0.296	0.242	0.006	0.587	1.43	0.312	0.633	0.592	0.903	0.408	0.482	0.344	0.329	0.294	0.807
	Phosphorus; phosphate	mg/L	0.0005	0.00025	0.0006	0.00025	0.00025	0.49	0.0056	0.0029	0.00025	0.00025	0.0019	0.0404	0.0016	0.0053	0.0053	0.0043	0.0017	0.0091
3367L1	Phosphorus; total	mg/L	0.002	0.011	0.015	0.008	0.005			0.02	0.013	0.034	0.008	0.063	0.011	0.015	0.014	0.013	0.039	0.022
	Nitrogen; total Kjeldahl	mg/L	0.02	0.44	0.26	0.56	0.64			1.52	0.43	1.03	0.49	2.28	0.54	0.65	0.79	0.93	0.41	0.69
3371L10	Escherichia coli	c/100mL		10	28															
	Fecal streptococcus	c/100mL		10	16															
	Pseudomonas aeruginosa	c/100mL		4	2															
3386L1	Aluminum	ug/L	11	17.5	30	5.5	20	15.4	18.6	39.9	41	75.8	40.7	53.3	30.7	33.9	15.5	21.4	15.5	
	Barium	ug/L	0.2	1.87	2.86	1.4	0.977	1.48	2.27	4.51	3.74	4.82	3.38	4.68	1.8	2.66	1.37	2.55	1.47	
	Beryllium	ug/L	0.02	0.01	0.01	0.01	0.023	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
	Calcium	mg/L	0.005	0.89	1.08	0.455	0.242	0.59	0.772	1.46	1.4	1.8	1.2	1.83	1.29	1.38	0.712	1.4	0.442	
	Cadmium	ug/L	0.6	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	1.3	1.03	0.3	0.3	
	Cobalt	ug/L	1.3	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	1.34	0.65	0.65	0.65	0.65	
	Chromium	ug/L	1.4	7.98	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	
	Copper	ug/L	1.6	6.57	18.9	13	6.82	12.6	11.6	6.6	7.35	15.6	7.37	56.4	16.5	19.9	5.29	16.8	10.4	
	Iron	ug/L	0.8	15.5	25.8	11.3	10.6	13.8	21.3	49.3	43.9	60.3	39.8	42	24.2	36.7	16.4	16.5	14.1	
	Magnesium	mg/L	0.008	0.192	0.176	0.0968	0.0538	0.131	0.155	0.355	0.291	0.433	0.301	0.488	0.388	0.329	0.174	0.185	0.105	
	Manganese	ug/L	0.2	4.42	5.19	2.71	1.23	2.64	3.87	11.2	7.32	8.39	5.51	9.18	4.86	5.19	3.6	4.93	2.33	
	Molybdenum	ug/L	1.6	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	
	Nickel	ug/L	1.3	17.8	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	1.58	0.65	0.65	0.65	1.79	0.65	
	Lead	ug/L	5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	12.2	2.5	2.5	5.58	2.5	6.4	2.5	2.5	2.5	
	Strontium	ug/L	0.1	2.41	2.4	1.17	0.651	1.7	2.1	4.41	3.58	5.85	4.56	6.39	3.11	4.67	1.72	5.94	1.4	
	Titanium	ug/L	0.5	0.567	1.28	0.25	0.25	0.25	0.25	0.957	1.11	1.67	0.759	1.32	1.41	1.61	0.25	1.34	0.25	
	Vanadium	ug/L	1.5	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	
	Zinc	ug/L	0.6	12.5	10.7	8.63	5.75	11	9.94	23.5	17.8	25.6	19.6	20.6	8.47	12.7	6.31	21.1	7.9	
3435L2	Phenanthrene	ng/L	10	23	14															
	Anthracene	ng/L	10	5	5															
	Fluoranthene	ng/L	10	37	17															
	Pyrene	ng/L	10	28	14															
	Benzo(a)anthracene	ng/L	20	10	10															
	Chrysene	ng/L	10	5	5															
	7,12-dimethylbenz(a)anthracene	ng/L	10	5	5															
	Benzo(b)fluoranthene	ng/L	10	12	5															
	Benzo(k)fluoranthene	ng/L	10	14	5															
	Benzo(e)pyrene	ng/L	10	15	5															
	Benzo(a)pyrene	ng/L	3	17	6															
	Perylene	ng/L	10	5	5															
	Indeno(1,2,3-c,d)pyrene	ng/L	20	10	10															
	Dibenzo(a,h)anthracene	ng/L	20	10	10															
	Benzo(g,h,i)perylene	ng/L	20	10	10															

Table B8: Precipitation water quality statistics for all events for which composite samples were collected

List ID	Parameter	Units	MDL	STATISTICS # > dl	%>dl	No. of Samples	MINIMUM	MAXIMUM	GEOMEAN	MEAN	MEDIAN	STD. DEV.	95%CI -LL	95%CI -UL
3016L1	Chloride	mg/L	0.20	2	100.00	2	0.30	0.40	0.35	0.35	0.35	0.07	0.25	0.45
3146L1	Calcium	mg/L	0.025	17	100.00	17	0.37	1.92	0.87	1.02	0.90	0.55	0.76	1.29
	Magnesium	mg/L	0.0005	17	100.00	17	0.07	0.41	0.19	0.23	0.26	0.12	0.17	0.28
	Sodium	mg/L	0.01	17	100.00	17	0.05	0.57	0.16	0.19	0.18	0.13	0.13	0.25
	Potassium	mg/L	0.01	17	100.00	17	0.01	0.46	0.08	0.10	0.07	0.10	0.05	0.15
3170L1	Oxygen demand; chemical	mg/L as O2	1	1	100.00	1	36.00	36.00	36.00	36.00	36.00	0.00	0.00	0.00
3171L1	Calcium	mg/L	0.25	2	100.00	2	0.85	0.90	0.87	0.88	0.88	0.04	0.83	0.92
	Magnesium	mg/L	0.1	2	100.00	2	0.12	0.20	0.15	0.16	0.16	0.06	0.08	0.24
	Sodium	mg/L	0.1	1	50.00	2	0.05	0.14	0.08	0.10	0.10	0.06	0.01	0.18
	Potassium	mg/L	0.05	1	50.00	2	0.03	0.07	0.04	0.05	0.05	0.03	0.00	0.09
	Hardness	mg/L	1	2	100.00	2	2.60	3.20	2.88	2.90	2.90	0.42	2.31	3.49
3172L4	Fluoride	mg/L	0.05	0	0.00	1	0.03	0.03	0.03	0.03	0.03	0.00	0.00	0.00
	Sulphate	mg/L	2.5	0	0.00	1	1.25	1.25	1.25	1.25	1.25	0.00	0.00	0.00
3179L1	Phenolics; 4-AAP	ug/L	0.2	2	100.00	2	2.30	2.90	2.58	2.60	2.60	0.42	2.01	3.19
3182L1	Oxygen demand; biochemical	mg/L as O2	0.2	2	100.00	2	1.00	1.10	1.05	1.05	1.05	0.07	0.95	1.15
3188L3	Solids; suspended	mg/L	2.5	1	50.00	2	1.25	12.60	3.97	6.93	6.93	8.03	-4.20	18.05
3218L1	Conductivity	uS/cm	1	20	100.00	20	7.00	36.00	16.62	17.70	17.00	6.56	14.82	20.58
	pH	none		20	100.00	20	4.41	6.86	5.68	5.74	5.89	0.80	5.39	6.08
	Alkalinity; total fixed endpt	mg/L CaCO3	2.5	11	55.00	20	1.25	5.10	2.19	2.53	2.65	1.38	1.92	3.13
3311L1	Turbidity	FTU	0.01	2	66.67	3	0.01	1.69	0.20	0.87	0.91	0.84	-0.09	1.82
3364L1	Nitrogen; ammonia+ammonium	mg/L	0.002	20	100.00	20	0.10	1.27	0.40	0.46	0.37	0.27	0.34	0.58
	Nitrogen; nitrite	mg/L	0.001	19	95.00	20	0.00	0.02	0.01	0.01	0.01	0.01	0.01	0.01
	Nitrogen; nitrate+nitrite	mg/L	0.005	20	100.00	20	0.01	1.43	0.35	0.47	0.36	0.31	0.33	0.61
	Phosphorus; phosphate	mg/L	0.0005	14	70.00	20	0.00	0.49	0.00	0.03	0.00	0.11	-0.02	0.08
3367L1	Phosphorus; total	mg/L	0.002	18	100.00	18	0.01	0.06	0.01	0.02	0.01	0.01	0.01	0.02
	Nitrogen; total Kjeldahl	mg/L	0.02	18	100.00	18	0.26	2.28	0.65	0.75	0.60	0.49	0.52	0.97
3371L10	Escherichia coli	c/100mL		2	100.00	2	10.00	28.00	16.73	19.00	19.00	12.73	1.36	36.64
	Fecal streptococcus	c/100mL		2	100.00	2	10.00	16.00	12.65	13.00	13.00	4.24	7.12	18.88
	Pseudomonas aeruginosa	c/100mL		2	100.00	2	2.00	4.00	2.83	3.00	3.00	1.41	1.04	4.96
3386L1	Aluminum	ug/L	11	18	94.74	19	5.50	75.80	24.97	29.59	21.40	17.59	21.68	37.50
	Barium	ug/L	0.2	19	100.00	19	0.98	4.82	2.39	2.66	2.54	1.23	2.10	3.21
	Beryllium	ug/L	0.02	1	5.26	19	0.01	0.02	0.01	0.01	0.01	0.00	0.01	0.01
	Calcium	mg/L	0.005	19	100.00	19	0.24	1.83	0.90	1.03	1.08	0.50	0.81	1.26
	Cadmium	ug/L	0.6	2	10.53	19	0.30	1.30	0.35	0.39	0.30	0.28	0.27	0.52
	Cobalt	ug/L	1.3	1	5.26	19	0.65	1.34	0.68	0.69	0.65	0.16	0.62	0.76
	Chromium	ug/L	1.4	1	5.26	19	0.70	7.98	0.80	1.08	0.70	1.67	0.33	1.83
	Copper	ug/L	1.6	19	100.00	19	4.00	56.40	11.22	13.95	11.60	11.70	8.69	19.22
	Iron	ug/L	0.8	19	100.00	19	10.60	63.10	25.06	29.12	24.20	16.48	21.71	36.53
	Magnesium	mg/L	0.008	19	100.00	19	0.05	0.53	0.20	0.24	0.19	0.14	0.18	0.31
	Manganese	ug/L	0.2	19	100.00	19	1.23	11.20	4.38	5.01	4.86	2.60	3.84	6.18
	Molybdenum	ug/L	1.6	0	0.00	19	0.80	0.80	0.80	0.80	0.80	0.00	-	-
	Nickel	ug/L	1.3	3	15.79	19	0.65	17.80	0.86	1.66	0.65	3.92	-0.10	3.42
	Lead	ug/L	5	3	15.79	19	2.50	12.20	2.98	3.38	2.50	2.41	2.30	4.46
	Strontium	ug/L	0.1	19	100.00	19	0.65	6.39	2.54	3.09	2.41	1.82	2.27	3.91
	Titanium	ug/L	0.5	11	57.89	19	0.25	1.67	0.62	0.82	0.76	0.57	0.57	1.08
	Vanadium	ug/L	1.5	0	0.00	19	0.75	0.75	0.75	0.75	0.75	0.00	-	-
	Zinc	ug/L	0.6	19	100.00	19	5.42	25.60	11.97	13.30	11.60	6.23	10.50	16.10
3435L2	Phenanthrene	ng/L	10	2	100.00	2	14.00	23.00	17.94	18.50	18.50	6.36	9.68	27.32
	Anthracene	ng/L	10	0	0.00	2	5.00	5.00	5.00	5.00	5.00	0.00	-	-
	Fluoranthene	ng/L	10	2	100.00	2	17.00	37.00	25.08	27.00	27.00	14.14	7.40	46.60
	Pyrene	ng/L	10	2	100.00	2	14.00	28.00	19.80	21.00	21.00	9.90	7.28	34.72
	Benzo(a)anthracene	ng/L	20	0	0.00	2	10.00	10.00	10.00	10.00	10.00	0.00	-	-
	Chrysene	ng/L	10	0	0.00	2	5.00	5.00	5.00	5.00	5.00	0.00	-	-
	7,12-dimethylbenz(a)anthracene	ng/L	10	0	0.00	2	5.00	5.00	5.00	5.00	5.00	0.00	-	-
	Benzo(b)fluoranthene	ng/L	10	1	50.00	2	5.00	12.00	7.75	8.50	8.50	4.95	1.64	15.36
	Benzo(k)fluoranthene	ng/L	10	1	50.00	2	5.00	14.00	8.37	9.50	9.50	6.36	0.68	18.32
	Benzo(e)pyrene	ng/L	10	1	50.00	2	5.00	15.00	8.66	10.00	10.00	7.07	0.20	19.80
	Benzo(a)pyrene	ng/L	3	2	100.00	2	6.00	17.00	10.10	11.50	11.50	7.78	0.72	22.28
	Perylene	ng/L	10	0	0.00	2	5.00	5.00	5.00	5.00	5.00	0.00	-	-
	Indeno(1,2,3-c,d)pyrene	ng/L	20	0	0.00	2	10.00	10.00	10.00	10.00	10.00	0.00	-	-
	Dibenzo(a,h)anthracene	ng/L	20	0	0.00	2	10.00	10.00	10.00	10.00	10.00	0.00	-	-
	Benzo(g,h,i)perylene	ng/L	20	0	0.00	2	10.00	10.00	10.00	10.00	10.00	0.00	-	-

Table B9: Precipitation loading for all events for which composite samples were collected

Precipitation

				2 0 0 3 L O A D S										2 0 0 4 L O A D S									
List ID	**Parameter**	**Units**	**MDL**	**15-Sep-03**	**19-Sep-03 morning**	**19-Sep-03 afternoon**	**22-Sep-03**	**27-Sep-03**	**14-Oct-03**	**18-Oct-03**	**2-Nov-03**	**12-Nov-03**	**17-Nov-03**	**7-Jul-04 morning**	**7-Jul-04 afternoon**	**14-Jul-04**	**20-Jul-04**	**27-Jul-04**	**28-Aug-04**	**15-Oct-04**	**30-Oct-04**	**2-Nov-04**	**4-Nov-04**
3016L1	Chloride	mg/L	0.20	2797.44	3147.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3146L1	Calcium	mg/L	0.025	0.00	0.00	3593.52	3908.98	9285.12	5256.36	5455.01	9514.27	11142.14	1624.90	0.00	1416.58	14551.15	11751.48	6754.03	1374.91	6286.80	3583.10	2092.50	6931.10
	Magnesium	mg/L	0.0005	0.00	0.00	718.70	739.54	2042.73	946.14	1202.90	1807.03	2187.81	1135.64	0.00	349.08	2957.47	2621.48	967.57	310.99	1335.48	845.78	373.86	2094.51
	Sodium	mg/L	0.01	0.00	0.00	1557.19	2007.31	1299.92	712.53	657.40	1040.41	1775.78	1292.77	0.00	217.55	2229.92	903.96	2155.22	347.00	379.44	766.62	290.16	1214.21
	Potassium	mg/L	0.01	0.00	0.00	376.46	1225.52	804.71	292.02	356.67	328.55	615.14	257.13	0.00	146.72	1020.47	1012.44	1737.84	222.60	267.84	233.32	78.12	688.05
3170L1	Oxygen demand; chemical	mg/L as O2	1	0.00	377654.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3171L1	Calcium	mg/L	0.25	6294.24	8916.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Magnesium	mg/L	0.1	1398.72	1258.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sodium	mg/L	0.1	349.68	1468.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Potassium	mg/L	0.05	174.84	734.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Hardness	mg/L	1	22379.52	27275.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3172L4	Fluoride	mg/L	0.05	0.00	262.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sulphate	mg/L	2.5	0.00	13113.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3179L1	Phenolics; 4-AAP	ug/L	0.2	16085.28	30422.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3182L1	Oxygen demand; biochemical	mg/L as O2	0.2	7692.96	10490.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3188L3	Solids; suspended	mg/L	2.5	8742.00	132179.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3218L1	Conductivity	uS/cm	1	83923.20	73432.80	94116.00	221860.80	201177.60	146010.00	94413.60	82137.60	116064.00	57139.20	123206.40	18972.00	170078.40	235029.60	60710.40	42556.80	78120.00	79161.60	117180.00	91065.60
	pH	none		41192.30	69761.16	43635.60	47435.95	82173.31	26223.40	20561.18	44148.96	38068.99	22462.85	19028.54	8335.03	57070.75	99074.02	25308.65	15680.54	22171.20	21790.27	24607.80	34706.11
	Alkalinity; total fixed endpt	mg/L CaCO3	2.5	8742.00	46157.76	10695.00	13206.00	19344.00	7300.50	4371.00	21218.88	23212.80	9642.24	9582.72	5312.16	26456.64	48813.84	19351.44	4092.00	9672.00	5208.00	6975.00	24790.08
3311L1	Turbidity	FTU	0.01	6364.18	17728.78	0.00	0.00	77.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3364L1	Nitrogen; ammonia+ammonium	mg/L	0.002	1923.24	1007.08	2883.37	4352.70	4812.79	3247.26	4440.94	1868.63	3435.49	1349.91	2864.55	465.45	3694.48	11968.43	633.66	1027.91	1945.56	3199.80	1785.60	1841.55
	Nitrogen; nitrite	mg/L	0.001	97.91	104.90	94.12	42.26	7.74	35.04	73.43	68.45	69.64	50.00	27.38	11.38	56.69	126.55	30.36	26.19	37.20	33.33	33.48	111.30
	Nitrogen; nitrate+nitrite	mg/L	0.005	2328.87	1500.13	2532.58	2556.68	92.85	3428.31	5000.42	2135.58	3673.43	2114.15	3090.43	516.04	4554.32	6219.24	1248.36	962.44	3002.04	2354.02	2120.40	1588.59
	Phosphorus; phosphate	mg/L	0.0005	1.75	6.29	2.14	2.64	7582.85	32.71	10.14	1.71	1.45	6.79	138.26	2.02	50.08	95.82	16.32	5.57	33.85	2.92	13.95	1.26
3367L1	Phosphorus; total	mg/L	0.002	76.93	157.36	68.45	52.82	0.00	0.00	69.94	88.98	197.31	28.57	215.61	13.91	141.73	253.11	49.33	127.67	81.84	54.16	39.06	101.18
	Nitrogen; total Kjeldahl	mg/L	0.02	3077.18	2727.50	4791.36	6761.47	0.00	0.00	5315.14	2943.26	5977.30	1749.89	7803.07	682.99	6141.72	14282.57	3528.79	1342.18	2566.80	3791.42	2008.80	2681.38
3371L10	Escherichia coli	c/100mL		69936.00	293731.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fecal streptococcus	c/100mL		69936.00	167846.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Pseudomonas aeruginosa	c/100mL		27974.40	20980.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3386L1	Aluminum	ug/L	11	122388.00	314712.00	47058.00	211296.00	238318.08	108631.44	139522.32	280636.80	439882.56	145347.84	182413.92	38829.36	320314.32	280227.60	81200.16	50740.80	0.00	87077.76	75330.00	268643.52
	Barium	ug/L	0.2	13078.03	30002.54	11978.40	10321.81	22903.30	13257.71	15770.57	25599.55	27971.42	12070.66	16016.83	2276.64	25133.81	24768.50	9675.72	4812.19	0.00	10582.66	10769.40	20995.68
	Beryllium	ug/L	0.02	69.94	104.90	85.56	242.99	154.75	58.40	34.97	68.45	58.03	35.71	34.22	12.65	94.49	180.79	37.94	32.74	0.00	41.66	55.80	50.59
	Calcium	mg/L	0.005	6224.30	11329.63	3892.98	2556.68	9130.37	4508.79	5105.33	9582.72	10445.76	4285.44	6262.99	1631.59	13039.34	12872.39	5312.16	1446.93	0.00	3003.97	2047.86	8246.50
	Cadmium	ug/L	0.6	2098.08	3147.12	2566.80	3169.44	4642.56	1752.12	1049.04	2053.44	1740.96	1071.36	1026.72	379.44	12283.44	18621.58	1138.32	982.08	0.00	1249.92	1674.00	1517.76
	Cobalt	ug/L	1.3	4545.84	6818.76	5561.40	6867.12	10058.88	3796.26	2272.92	4449.12	3772.08	2321.28	2224.56	1694.83	6141.72	11751.48	2466.36	2127.84	0.00	2708.16	3627.00	3288.48
	Chromium	ug/L	1.4	55808.93	7343.28	5989.20	7395.36	10832.64	4088.28	2447.76	4791.36	4062.24	2499.84	2395.68	885.36	6614.16	12655.44	2656.08	2291.52	0.00	2916.48	3906.00	3541.44
	Copper	ug/L	1.6	45947.95	198268.56	111228.00	72051.94	194987.52	67748.64	23078.88	50309.28	90529.92	26319.74	193023.36	20869.20	188031.12	95638.97	63745.92	34045.44	0.00	96660.48	22320.00	31367.04
	Iron	ug/L	0.8	108400.80	270652.32	96682.80	111986.88	213557.76	124400.52	172392.24	300486.72	349932.96	142133.76	143740.80	30608.16	346770.96	296498.88	62607.60	46157.76	0.00	117075.84	114948.00	319235.52
	Magnesium	mg/L	0.008	1342.77	1846.31	828.22	568.39	2027.25	905.26	1241.36	1991.84	2512.79	1074.93	1670.13	490.74	3108.66	3145.78	701.96	343.73	0.00	812.45	374.98	2691.49
	Manganese	ug/L	0.2	30911.71	54445.18	23186.76	12994.70	40854.53	22602.35	39164.16	50103.94	48688.85	19677.31	31417.63	6146.93	49039.27	65085.12	18706.39	7627.49	0.00	16498.94	11271.60	33846.05
	Molybdenum	ug/L	1.6	5594.88	8392.32	6844.80	8451.84	12380.16	4672.32	2797.44	5475.84	4642.56	2856.96	2737.92	1011.84	7559.04	14463.36	3035.52	2618.88	0.00	3333.12	4464.00	4047.36
	Nickel	ug/L	1.3	124486.08	6818.76	5561.40	6867.12	10058.88	3796.26	2272.92	4449.12	3772.08	2321.28	5407.39	822.12	6141.72	11751.48	6791.98	2127.84	0.00	2708.16	3627.00	3288.48
	Lead	ug/L	5	17484.00	26226.00	21390.00	26412.00	38688.00	14601.00	8742.00	83506.56	14508.00	8928.00	19096.99	3162.00	60472.32	45198.00	9486.00	8184.00	0.00	10416.00	13950.00	12648.00
	Strontium	ug/L	0.1	16854.58	25176.96	10010.52	6877.68	26307.84	12264.84	15420.89	24504.38	33948.72	16284.67	21869.14	3933.53	44125.90	31096.22	22538.74	4583.04	0.00	8082.82	3928.32	20337.98
	Titanium	ug/L	0.5	3965.37	13427.71	2139.00	2641.20	3868.80	1460.10	3346.44	7597.73	9691.34	2710.54	4517.57	1783.37	15212.57	4519.80	5084.50	818.40	0.00	1041.60	1395.00	8347.68
	Vanadium	ug/L	1.5	5245.20	7867.80	6417.00	7923.60	11606.40	4380.30	2622.60	5133.60	4352.40	2678.40	2566.80	948.60	7086.60	13559.40	2845.80	2455.20	0.00	3124.80	4185.00	3794.40
	Zinc	ug/L	0.6	87420.00	112247.28	73838.28	60747.60	170227.20	58053.58	82174.80	121837.44	148561.92	69995.52	70501.44	10712.86	119999.76	114079.75	80061.84	25861.44	0.00	56663.04	30243.60	58686.72
3435L2	Phenanthrene	ng/L	10	160852.80	146865.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Anthracene	ng/L	10	34968.00	52452.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluoranthene	ng/L	10	258763.20	178336.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Pyrene	ng/L	10	195820.80	146865.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Benzo(a)anthracene	ng/L	20	69936.00	104904.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Chrysene	ng/L	10	34968.00	52452.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7,12-dimethylbenz(a)anthracene	ng/L	10	34968.00	52452.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Benzo(b)fluoranthene	ng/L	10	83923.20	52452.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Benzo(k)fluoranthene	ng/L	10	97910.40	52452.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Benzo(e)pyrene	ng/L	10	104904.00	52452.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Benzo(a)pyrene	ng/L	3	118891.20	62942.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Perylene	ng/L	10	34968.00	52452.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Indeno(1,2,3-c,d)pyrene	ng/L	20	69936.00	104904.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Dibenzo(a,h)anthracene	ng/L	20	69936.00	104904.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Benzo(g,h,i)perylene	ng/L	20	69936.00	104904.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B10: Unit area loads and percent difference in loads over entire monitoring period

	Parameter	Unit Area Loading (g/m^2)						% difference control vs. garden	
		Precipitation		Control		Garden			
		Sampled Events only†	Monitoring Period	Sampled Events only†	Monitoring Period	Sampled Events only†	Monitoring Period	Sampled Events only†	Monitoring Period
General Chemistry	Chloride			0.57	1.80	2.01	5.10	-249.19	-183.09
	Oxygen demand; chemical			8.85	27.71	22.06	56.02	-149.36	-102.17
	Sodium	0.05	0.18	0.40	1.26	1.05	2.67	-161.55	-112.05
	Potassium	0.03	0.09	0.65	2.05	0.94	2.39	-43.82	-16.60
	Fluoride			0.02	0.05	0.07	0.19	-330.88	-255.91
	Sulphate			1.86	5.84	4.08	10.36	-118.73	-77.34
	Oxygen demand; biochemical			0.72	2.27	0.23	0.58	68.28	74.28
	Solids; suspended			2.17	6.80	0.32	0.81	85.40	88.16
	Solvent extractable			0.09	0.69	0.06	0.32	32.51	53.06
Nutrients	Nitrogen; ammonia+ ammonium	0.158	0.480	0.089	0.279	0.004	0.009	95.85	96.67
	Nitrogen; nitrite	0.003	0.009	0.010	0.031	0.003	0.008	70.50	76.10
	Nitrogen; nitrate+nitrite	0.137	0.417	0.170	0.532	0.017	0.043	90.10	91.90
	Phosphorus; phosphate	0.022	0.065	0.011	0.035	0.088	0.223	-674.81	-528.19
	Phosphorus; total	0.005	0.018	0.024	0.076	0.102	0.260	-321.84	-242.01
	Nitrogen; total Kjeldahl	0.210	0.758	0.229	0.718	0.275	0.697	-19.73	2.92
Bacteria*	Escherichia coli*	Precipitation samples were not analysed for bacteria variables		1420955.4	5461798.0	1135649.5	3333791.0	20.08	38.96
	Fecal streptococcus*			5212964.1	20037333.3	4816875.3	14140327.3	7.60	29.43
	Pseudomonas aeruginosa*			2264727.7	8705048.4	3950099.9	11595838.1	-74.42	-33.21
Metals	Aluminum	0.0092	0.0288	0.0201	0.0647	0.0079	0.0202	60.7	68.7
	Barium	0.00083	0.00259	0.00124	0.00398	0.00254	0.00649	-105.2	-63.1
	Beryllium	0.000004	0.000012	0.000004	0.000011	0.000009	0.000022	-144.7	-94.6
	Calcium	0.325	1.016	1.705	5.481	3.942	10.074	-131.2	-83.8
	Cadmium	0.00020	0.00050	0.00010	0.00040	0.00010	0.00020	34.4	47.9
	Copper	0.0044	0.0137	0.0367	0.1179	0.0062	0.0158	83.2	86.6
	Iron	0.0091	0.0283	0.0127	0.0407	0.0063	0.0161	50.4	60.6
	Magnesium	0.074	0.233	0.314	1.008	1.016	2.596	-223.9	-157.5
	Manganese	0.0016	0.0049	0.0030	0.0095	0.0003	0.0006	91.5	93.3
	Nickel	0.00057	0.00179	0.00025	0.00081	0.00031	0.00080	-24.4	1.1
	Lead	0.00119	0.00372	0.00124	0.00398	0.00077	0.00197	37.9	50.6
	Strontium	0.0009	0.0029	0.0056	0.0181	0.0147	0.0376	-160.6	-107.2
	Titanium	0.00030	0.00080	0.00050	0.00150	0.00010	0.00020	83.1	86.6
	Vanadium	0.00027	0.00083	0.00029	0.00094	0.00033	0.00085	-14.3	9.2
	Zinc	0.004	0.013	0.004	0.012	0.001	0.004	60.5	68.6
PAHs**	Phenanthrene	Precipitation samples were not analysed for polycyclic aromatic hydrocarbons		**0.000035** / 0.0000043	**0.00012** / 0.000013	**0.0000033** / 0.00000075	**0.0000091** / 0.0000021	**90.79 / 82.64**	**92.45 / 84.43**
	Anthracene			**0.0000042** / 0.00000077	**0.000014** / 0.0000024	**0.00000065** / 0.000020	**0.0000018** / 0.00000054	**84.27 / 74.72**	**87.10 / 77.32**
	Fluoranthene			**0.000053** / 0.0000056	**0.00018** / 0.000017	**0.0000033** / 0.00000020	**0.0000092** / 0.00000054	**93.77 / 96.49**	**94.89 / 96.85**
	Pyrene			**0.000039** / 0.0000040	**0.00013** / 0.000012	**0.0000025** / 0.00000020	**0.0000070** / 0.00000054	**93.54 / 95.15**	**94.71 / 95.65**
	Benzo(a)anthracene			**0.000014** / 0.0000021	**0.000048** / 0.0000063	**0.0000014** / 0.00000039	**0.0000039** / 0.0000011	**90.16 / 80.96**	**91.93 / 82.92**
	Chrysene			**0.000021** / 0.0000021	**0.000071** / 0.0000066	**0.0000010** / 0.00000020	**0.0000029** / 0.00000054	**95.10 / 90.80**	**95.98 / 91.74**
	Benzo(b)fluoranthene			**0.000022** / 0.0000025	**0.000073** / 0.0000079	**0.00000090** / 0.00000020	**0.0000025** / 0.00000054	**95.81 / 92.32**	**96.57 / 93.12**
	Benzo(k)fluoranthene			**0.000017** / 0.0000016	**0.000059** / 0.0000050	**0.00000093** / 0.00000020	**0.0000026** / 0.00000054	**94.61 / 87.99**	**95.58 / 89.23**
	Benzo(e)pyrene			**0.000013** / 0.0000019	**0.000045** / 0.0000057	**0.00000086** / 0.00000020	**0.0000024** / 0.00000054	**93.51 / 89.51**	**94.68 / 90.59**
	Benzo(a)pyrene			**0.000019** / 0.0000020	**0.000065** / 0.0000061	**0.00000087** / 0.00000006	**0.0000024** / 0.00000016	**95.44 / 97.03**	**96.26 / 97.33**
	Perylene			**0.0000046** / 0.00000091	**0.000016** / 0.0000028	**0.00000055** / 0.00000020	**0.0000015** / 0.00000054	**88.14 / 78.50**	**90.28 / 80.71**
	Indeno(1,2,3-c,d)pyrene			**0.000020** / 0.0000019	**0.000070** / 0.0000060	**0.00000143** / 0.00000039	**0.0000040** / 0.0000011	**92.98 / 79.83**	**94.25 / 81.90**
	Benzo(g,h,i)perylene			**0.000013** / 0.0000021	**0.000044** / 0.0000066	**0.0000013** / 0.00000039	**0.0000036** / 0.0000011	**90.13 / 81.60**	**91.91 / 83.50**

†Values in "sampled events only" column represent only events for which water quality was sampled. Values in the "Monitoring Period" column were calculated by using volume-weighted mean concentrations to extrapolate what the loading would be for the entire monitoring period (i.e. all events in Appendix A, Table A1).

Shaded % difference values indicate that the garden load is less than the control roof load

*Unit area loading in coliforms/m^2

**For all PAHs, the value on the left in bold is for the 2003 samples while the value on the right is for 2004 samples. A significant difference in concentration magnitudes between 2003 and 2004 was noted, thus the two years were analysed separately. This difference is coincident with a change in laboratory analytical method for PAHs, although it is not clear that the method change was the cause of the difference in reported values.

Note: Variables have been excluded from this table if more than 80% of samples submitted were observed to be below the method detection limit.

Table B11: Control roof and garden runoff water temperature

Event Date	Start Time	Rainfall (mm)	Average Temperature (°C)		Maximum Temperature (°C)		% Greater than 21°C	
			Garden	Control	Garden	Control	Garden	Control
August 12, 2005	8:20	1.0	-	21.2	-	22.5	-	50
July 27, 2005	8:10	2.2	25.7	20.1	32.6	23.9	100	15.6
August 12, 2005	13:10	2.8	28.1	24.9	30.1	27	100	100
July 26, 2005	8:55	4.4	27.9	23.8	30.7	25.8	100	100
August 1, 2005	1:05	6.2	26.1	19.8	28.9	22	100	2.1
August 10, 2005	14:25	6.4	27.8	24.9	28.5	27.1	100	100
August 2, 2005	12:30	13.6	28.6	26.3	34	31.5	100	100
August 10, 2005	19:00	18.0	26.6	22.7	27.7	23.8	100	100
August 19, 2005	4:55	18.0	21.2	17.5	24	20.3	49.1	0

Table B12: Percent difference in control roof runoff loads vs. garden runoff loads of select water quality variables for all events sampled

	Event Date	Event size (mm)	% Difference in loading from control vs. garden																	
			Chloride	Suspended Solids	Nitrogen; ammonia+ ammonium	Nitrite	Nitate+Nitrite	Phosphate	Phosphorus	TKN	E. Coli	Aluminum	Cadmium	Copper	Iron	Nickel	Lead	Zinc	Phenanthrene	Fluoranthene
Summer	6/24/04	4.6	-14	97	99	72	84	-2818	31	88	-817	92	82	90	98	91	53	96	97	100
	7/7/04 PM	3.4	-28	97	100	94	93	-2149	91	98	88	83	88	92	95	88	88	97	98	99
	8/8/04	7.6	-9	92	100	96	80	-4749	41	81	73	93	86	93	97	86	86	92	n/a	n/a
	8/28/04	8.8	-109	94	99	95	99	-1099	-24	46	n/a	84	88	91	74	70	88	79	88	88
	7/7/04 AM	9.2	48	93	99	90	92	-75	40	89	-7275	90	88	96	95	88	88	98	99	99
	7/27/04	10.2	51	87	100	91	86	-4	35	56	98	79	87	88	83	87	87	94	97	97
	9/19/03 PM	23	40	83	67	65	82	-227	-256	-119	n/a	19	40	-16	-26	-240	40	41	84	92
	7/14/04	25.4	-116	83	96	81	87	-210	-29	55	-758	82	64	91	86	61	83	84	96	95
	9/19/03 AM	28.2	-609	69	1	69	72	-851	-587	-263	-87	49	-54	76	37	-111	40	6	86	94
	7/20/04	48.6	-93	78	97	56	87	-308	-185	-28	81	30	-47	66	-1	47	-142	46	-215	47
Fall	10/18/03*	9.4	-224	91	99	62	88	-776	-520	60	-499	64	44	84	55	-69	44	46	97	98
	11/17/03	9.6	-1642	93	99	68	89	-459	-337	15	79	71	59	95	64	-2	59	62	99	99
	10/15/04	10	-95	98	100	90	91	19	67	81	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	10/30/04	11.2	-82	98	99	91	90	-163	76	84	n/a	96	87	94	98	97	69	93	100	100
	11/4/04	13.6	-452	85	97	58	72	-666	-255	-95	n/a	63	66	72	24	-21	55	27	80	85
	11/2/04	15	-1093	90	100	78	92	-156	-41	33	0	69	75	89	80	75	93	61	95	95
	11/12/03	15.6	-308	93	99	79	94	-6616	-23	37	38	73	38	90	71	-10	-70	75	94	97
	10/14/03*	15.7	-127	79	99	85	97	-1802	-509	48	-1156	74	67	96	70	-9	-34	74	98	99
	11/2/03	18.4	-1605	89	99	67	93	-3111	-1398	-52	-47	46	-32	78	18	-44	78	53	n/a	n/a
	11/3/03	22	-623	78	100	36	82	-611	-622	-109	-45	52	13	68	32	-166	13	25	95	97
	9/27/03*	41.6	-420	78	97	41	89	-1397	-860	-80	-1289	23	47	86	-11	-151	57	66	74	75

*These events were sampled discretely and later volume weighted to calculate the mean concentration for the event.

APPENDIX C

Water Quality Guidelines and Method Detection Limits

Table C1: List of parameter reporting method detection limits and guidelines*

Parameter			units	RMDL	Guideline*
General Chemistry	3016L1	Chloride	mg/L	0.2	250‡
	3060L1	Mercury	ug/L	0.02	0.2
	3170L1	Oxygen demand; chemical	mg/L as O2	1	
		Sodium	mg/L	0.1	
		Potassium	mg/L	0.05	
		Hardness	mg/L	1	
	3172L4	Fluoride	mg/L	0.05	
		Sulphate	mg/L	2.5	
	3179L1	Phenolics; 4-AAP	ug/L	0.2	
	3179L1	Oxygen demand; biochemical	mg/L as O2	0.2	
	3182L1	Solids; suspended	mg/L	2.5	25†
	3188L3	Solvent extractable	mg/L	1	
	3201L1	Conductivity	uS/cm	1	
	3218L1	pH	none	-	6.5-9.5
		Alkalinity; total fixed endpt	mg/L CaCO3	2.5	
	3311L1	Turbidity	FTU	0.01	5
Nutrients	3364L1	Nitrogen; ammonia+ammonium	mg/L	0.002	1.4
		Nitrogen; nitrite	mg/L	0.001	0.06
		Nitrogen; nitrate+nitrite	mg/L	0.005	
		Phosphorus; phosphate	mg/L	0.0005	
	3367L1	Phosphorus; total	mg/L	0.002	0.03
		Nitrogen; total Kjeldahl	mg/L	0.02	3.2
Bacteria	3371L10	Escherichia coli	c/100mL	-	100
		Fecal streptococcus	c/100mL	-	
		Pseudomonas aeruginosa	c/100mL	-	
Metals	3386L1	Aluminum	ug/L	11	75∞
		Barium	ug/L	0.2	
		Beryllium	ug/L	0.02	11
		Calcium	mg/L	0.005	
		Cadmium	ug/L	0.6	0.1
		Cobalt	ug/L	1.3	0.9
		Chromium	ug/L	1.4	8.9
		Copper	ug/L	1.6	5
		Iron	ug/L	0.8	300
		Magnesium	mg/L	0.008	
		Manganese	ug/L	0.2	
		Molybdenum	ug/L	1.6	10
		Nickel	ug/L	1.3	25
		Lead	ug/L	5	5
		Strontium	ug/L	0.1	
		Titanium	ug/L	0.5	
		Vanadium	ug/L	1.5	7
		Zinc	ug/L	0.6	20
Polycylic Aromatic Hydrocarbons	3435L2	Phenanthrene	ng/L	10	30
		Anthracene	ng/L	10	0.8
		Fluoranthene	ng/L	10	0.8
		Pyrene	ng/L	10	
		Benzo(a)anthracene	ng/L	20	0.4
		Chrysene	ng/L	10	0.1
		7,12-dimethylbenz(a)anthracene	ng/L	10	
		Benzo(b)fluoranthene	ng/L	10	
		Benzo(k)fluoranthene	ng/L	10	0.2
		Benzo(e)pyrene	ng/L	10	
		Benzo(a)pyrene	ng/L	3	
		Perylene	ng/L	10	0.07
		Indeno(1,2,3-c,d)pyrene	ng/L	20	
		Dibenzo(a,h)anthracene	ng/L	20	2
		Benzo(g,h,i)perylene	ng/L	20	0.02

* Guidelines listed are Provincial Water Quality Objectives (OMOE, 1999) where available. For parameters with no PWQO, the Canadian Water Quality Guideline is used, with the exception of chloride‡ (source: EC & HC, 2001) and TSS† (source: (EIFAC, 1965).

∞Guideline for aluminum is for clay-free samples. These samples are not necessarily clay-free.

APPENDIX D

Flora Inventory

THE GREEN ROOF AT YORK UNIVERSITY, TORONTO, CANADA: BASELINE FLORISTIC STUDY ONE-YEAR FOLLOW-UP

ABSTRACT

The York University Computer Science Building, built in 2001, incorporated a green roof into its design. Green roofs are a mostly new technology that promises greater urban sustainability. Most of the attention has been directed to improvements in water quality and quantity, energy efficiency, and urban agriculture.

This study was initiated to investigate the function of green roofs as habitat for native flora in the Toronto area. The roof at the Computer Science Building at York University had been covered with a volcanic-based substrate and seeded with two commercial seed mixes (non-native grasses and largely non-native forbs). A smaller area was left unseeded. Three years later, in 2004, a systematic inventory of vascular plants was undertaken on the roof, and covered the growing seasons of 2004 and 2005. In addition, permanent quadrats were set up and cover estimates of vascular plant species, as well as mosses, liverworts, and exposed soil, were taken in the summer and fall of 2004 and spring, summer and fall of 2005. Measures of floristic quality based on the proportion of native plants as well as the conservatism of the native species present indicated that the flora is currently relatively low in native biodiversity and still heavily influenced by the original commercial seed mixes. However, the overall condition of the roof does indicate a relatively low-nutrient, low-competition environment that could be conducive to the establishment of conservative or rare native plants that are of local concern. The closeness of the situation to primary rather than secondary succession, as well as the role of mosses in habitat creation, is briefly discussed. Further monitoring, as well as trials of seeding suitable native species, is recommended.

The two-year period was not sufficient to track significant changes over time in the floristic composition. However, there was an increase in the total number of species recorded (from 91 to 110), including a ladies’ tresses orchid.

1. INTRODUCTION

Green roofs have been instituted in recent years as part of the overall movement to improve sustainable land use and ecological health in cities. The main thrust has been towards improving hydrology (reduced storm water runoff, improved water quality), improving energy efficiency and reducing urban heat island effects, and providing benefits to the community (e.g. recreation, food production)(City of Portland & Green Roofs for Healthy Cities, 2004). However, the benefits of green roofs to biodiversity and to the health of the natural system have had much less attention. Most of the work in this regard has been in Europe (Brenneisen, 2004). It can be anticipated that green roofs, once they cover a significant amount of the built surface of the city, could provide substantial ***indirect*** benefits to the surrounding natural system. Improvements to the local hydrology and climate are bound to provide some support to adjacent and nearby natural habitats by reducing stress on them. Green roofs that are also used for recreation could also reduce the pressure for recreation on remnant natural areas. We will not know the extent of these benefits until a significant proportion of the roofs in our cities is green.

While such roofs will not support forest or most wetland habitats due to structural feasibility issues, nor provide large contiguous habitat patches, their potential role in ***directly*** providing habitat needs to be investigated. Can a green roof support a healthy, native-dominated habitat? Within the parameters of structural considerations, roofs could support open habitat types: meadow, prairie, meadow-marsh, and some shrub thicket. They could even function in some way as synthetic alvars with the flat surface, shallow soils, and high exposure to the elements of such habitats.

This botanical survey of the green roof at the Computer Science Building at York University in Toronto commenced in the summer of 2004 and continued to the fall of 2005. The intention is to follow up in subsequent years to track biodiversity trends, depending upon funding availability. We want to assess the floristic character of the green roof at York University, with attention to the following questions:

1. What is getting established on the roof? Is it from the original seed mix or has it volunteered from the surroundings?
2. Is biodiversity increasing or decreasing?
3. Perhaps more important than simple biodiversity, is ***floristic quality*** increasing or decreasing? What is the proportion of natives to exotics? Floristic quality, based on the prevalence of sensitive native species, can be quantitatively calculated using our TRCA flora species scores (see below).
4. Further experiments with different substrate types on the green roof may be added in the future.
5. Removal of invasive exotic species and seeding with various native species may also be undertaken in the future. Will this activity further the improvement of floristic quality?

2. METHODS

2.1 THE ROOF

The green sections of the roof of the York University Computer Science Building were covered with a light substrate of volcanic origin and seeded in 2001. The roof is divided into a number of sections as follows:

- The main section, gently sloping, from which all the storm water runoff information is gathered. This was seeded with a "wildflower" (i.e. forb-dominated) seed mix in 2001. It is 241 m^2 in size.
- The upper section, which is larger than the main section, forms a long and winding stretch of roof to the north and west of the main section. This section of the roof is flat. It was seeded with a grass mix (mainly *Festuca* spp.) in 2001.
- The containers, 7 in total, located at the base of the main sloping roof. These were treated the same as the main section, but the long-term objective is to replace the volcanic substrate with a number of other types to test their suitability for supporting a healthy plant community.
- The lower beds. Two small beds are also at the base of the sloping roof - one storey below the upper roof. These were seeded with the forb mix in 2001.
- A bed on the lower level that never was seeded. It is separated from the main entrance area by an enclosed passageway. All plants in it are derived from natural seed dispersal from the other sections of the roof or the surrounding environment. This section of roof is surrounded by one storey of the building and so also receives some shade and shelter.

It should be noted that the roof receives supplemental watering during dry spells.

<u>Substrate</u>

The substrate is a light-weight, porous material of volcanic origin. It was chosen to reduce the load on the roof. The texture is relatively loose and gravely, but its porosity helps it to retain moisture. The chemical characteristics of the substrate and its leachate are discussed in greater detail in sections 6.0 and 7.0 in the main report.

The Seed Mixes

As the company that provided the seed no longer exists, no certain composition of the seed mixes is available. However, the current vegetation seems to still reflect the seed mix very strongly. The "wildflower" component consists of a number of ornamental perennials, a minority of which are native. Many of these are showy and do not commonly occur even as adventives in the surrounding area (e.g. *Dianthus*, *Gypsophila*, *Rudbeckia hirta*, *Penstemon digitalis*). The grassed roof is heavily dominated by three commonly-seeded (non-native) fescue species, and so it can be deduced that the seed mix was largely composed of *Festuca rubra*, *F. trachyphylla*, and *F. ovina*. Other grasses or forbs that have failed to persist over the four years since seeding may have been present in these seed mixes.

2.2 INVENTORY METHODOLOGY

The survey began in July, 2004, with a second observation in October. In 2005, three visits were made during the growing season: May, July, and October. This ensured that flora were observed over the course of the year in order to get a comprehensive picture.

The survey has two parts: an inventory of all the species found on each section of the roof (as described above) and a quantitative quadrat study.

2.2.1 Inventory

An inventory of all the species found on each section of the roof included every plant that was found over the various visits during the growing season. Thus, each roof section has one list of flora species per year. In 2005, visits occurred on 25 May, 20 July, and 12 October.

The inventory yields the following:

- A species list for each of the five sections of the roof, as well as a complete list for the whole roof.
- Coefficients of conservatism (CC) for the native vascular plants that were encountered (using two versions of the coefficient of conservatism provided by the Toronto Region Conservation Authority (TRCA) and the Ontario Natural Heritage Information Centre (NHIC) respectively). These were averaged for each roof section as well as the roof as a whole.
- Site Floristic Quality Index (FQI), again in two versions based upon the two measures of Coefficient of Conservatism. These are provided for each roof section and the roof as a whole.

The coefficient of conservatism (CC) is a measure of a plant's fidelity to high-quality remnant natural habitats (Masters, 1997). It ranges from 0 to 10. A high score indicates that the species in question is restricted to such habitats, while a low score indicates a disturbance-tolerant habitat generalist. It must be noted that a given species of plant may behave differently in different parts of its range. Thus, the CC for the same species may vary considerably between say, Ontario and Missouri.

Conventionally, the CC is assigned by means of a considered judgment by local botanists. It is thus that the NHIC CC scores are assigned for southern Ontario species, for example (NHIC, 2004). On the other hand, the TRCA scores are based upon its more detailed scoring and ranking protocol (TRCA, 2003). These values are the sum of scores for habitat dependence (0-5) and sensitivity to development (0-5)[1]. The NHIC and TRCA CC scores are often discordant and both

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[1] TRCA L-ranks are derived from these two scores, together with a score for distribution and local population trend. Ranks range from L1-L5, corresponding to the provincial (or state) system of S1-S5 and the global system of G1-G5. Exotics are identified as L+. Species ranked

will probably receive more fine-tuning. At present, both measures of CC were used for this survey.

The Floristic Quality Index (FQI) is a measure that takes into account both species richness and conservatism (Masters, 1997). It is obtained by the following formula:

FQI = average CC * $\sqrt{n}$, where n = number of native species.

2.2.2 Quadrat Study

Quantitative sampling was undertaken for the “wildflower” and grassed roof sections. For this purpose, each of these two roof sections was set up with twenty permanent, staked quadrats that were measured to be evenly distributed across each surface. (Because of structural elements such as ventilation shafts, the quadrats could not be perfectly evenly spaced). The quadrats were 0.25 m^2 in size (squares measuring 0.5 m per side). In 2004, the summer sampling occurred on 23 July and 5 August, and the fall visit was on 4 October. In 2005, the visits occurred on 25 May, 20 July, and 12 October.

Within each quadrat, all the vascular plants were identified and percentage covers for each estimated to increments of 5%. When a species was only present in traces, it was automatically assigned a cover value of 1%. In addition to vascular plants, cover estimates were provided for mosses and liverworts (not distinguished beyond the category of “moss” or “liverwort” with the exception of *Polytrichum* moss), and for a bird’s nest fungus that appeared in a couple of quadrats. The amount of visible bare soil was also estimated.

One important difference from the inventory methodology is that the three fescue species were lumped together in the quadrat survey and treated as one taxon, *Festuca* spp. This is because the fescues can be difficult to tell apart. While distinct examples of each species can be found on the roof as a whole, individuals within the quadrats are often ambiguous: they may be young or they may not be readily distinguishable as cespitose or turf-forming. The three fescues are all non-native and so it makes little difference to the results that they are amalgamated.

When a species could not be identified with certainty, it was identified to the lowest taxonomic level possible. In general, if its provenance was uncertain, it was considered exotic.

The quadrat study yielded separate seasonal estimates in 2004 and 2005 for the “wildflower” and grassed roof sections, including:

- Frequency of occurrence for each element (vascular plant taxa, mosses, liverworts, bird’s nest fungus, bare soil)
- Average and relative percent covers for each element
- Relative frequency for each element
- Importance value for each element (the average of relative frequency and relative cover)

Relative frequency and cover are standardized measures whereby the frequency (or cover) for each element is divided by the sum of all the frequency (or cover) values of all the elements, multiplied by 100.

Relative frequency, relative cover, and relative importance values were also calculated for the following broad groupings of elements:

- Native vascular plants

L1 – L3 are considered of concern across the region, while those ranked L4 are generally secure, but of concern in the urban environment with its disturbances. Hence the L-rank is a composite of conservatism and rarity. L-ranks are included in the species table (Table D1).

- Non-native vascular plants
- Non-vascular plants (mosses, liverworts, fungi)
- Bare soil

Average coefficients of conservatism (CC) by both TRCA and NHIC protocol and floristic quality indices (FQI) were calculated for each quadrat. Thus, we were able to obtain the following measures for the "wildflower" and grassed roof habitats:

- Mean CC per 0.25 m^2
- Mean FQI per 0.25 m^2

Statistical tests to determine the significance of trends (over time and between seed or substrate treatments) would require a longer time series of data than two years. However, measures of mean quadrat CC and FQI include standard deviations.

3. RESULTS

3.1 SPECIES RICHNESS

A total of 110 vascular plant species was found over the 2005 season when all sections of the green roof are included together (Table D1). Of this total, 40 (37%) are native, and 70 (63%) are exotic or probably exotic. This represents a slight increase in overall diversity both native and exotic over the previous year. The figures for 2004 are 91 vascular plant taxa, 29 of them native, and 62 exotic.

The "wildflower" roof had 62 vascular plant species (increased from 43), of which 18 (29%) are native, while the grassed roof also had a total of 62 species (increased from 51), of which 26 (42%) are native.

The smaller sections of roof include the containers (26 species, 8 of them native); the lower plots seeded a year after the main roof sections (32 species, 8 of them native), and the non-seeded roof colonized strictly by volunteer propagules (36 species, 18 of them native).

One of the mosses on the grassed roof could be identified as belonging to the genus *Polytrichum* (haircap mosses), and a fungus belonging to the bird's nest group (possibly genus *Cyathus* or *Crucibulum*) (Barron, 1999) was noted on the "wildflower" roof. These were present in both 2004 and 2005.

3.2 SPECIES COMPOSITION

3.2.1 "Wildflower" Roof

When relative frequency and cover values were taken into account, the composition of the "wildflower" roof showed a relative frequency of 18-19% for native vascular plants as a group over the 2005 season (Tables D3e, D3g, D3i; Figure D1a), and a relative cover of 5-10% (Tables D3e, D3g, D3i; Figure D2a). That is, native species tended to occur frequently but occupy little space. The importance value for natives as a group was in the order of 12-15 (Tables D3e, D3g, D3i; Figure D3a). These figures show a slight (not significant) decline from 2004 (Tables D3a, D3c). Exotic species had the highest relative frequency value: 60-62%, but (as with 2004) they also occupied proportionately little space; the relative cover for this group was 38-48%. Mosses actually covered a large portion of the surface: over half of the total quadrat area (yielding a relative cover of 34-40%) (Tables D2a - D2f; Figure D2a). The overall picture of the "wildflower" roof is one of well-distributed but relatively sparse vascular plant cover, and a rather high moss cover.

Individual species that were relatively prominent included horseweed (*Conyza canadensis*), lance-leaved coreopsis (*Coreopsis lanceolatus*), sweet William (*Dianthus barbatus*), foxglove beardtongue (*Penstemon digitalis*), dandelion (*Taraxacum officinale*), and fescue (*Festuca* spp.) (Tables D2a-D2c). Each of these had importance values of over 4 during at least part of 2005.

Bare soil was visible over a total of 18-19% of the quadrat surface.

3.2.2 Grassed Roof

Native species occurred more frequently, but even more thinly, on the grassed roof than on the "wildflower" roof. As a group, native vascular plants had a relative frequency value of 28-31 (Tables D3f, D3h, D3j; Figure D1b), but a relative cover of only 6-9 (Figure D2b for summer). The importance value ranged from 18-20 (Figure D3b for summer). Exotic species were dominant, with a relative frequency of 49-55 and relative cover of 56-62. Importance value for exotics was 55-57. Non-vascular plants, mostly mosses, had fairly high representation with a relative frequency of 13-18, relative cover of 29-36, and importance values of 23-27. Mosses were found in every sampling save one quadrat each season, and covered 42-55% of the surface over the three visits.

The fescues (*Festuca* spp.) were dominant overall, covering an average of over 70% of the quadrats (Tables D2d, D2e, D2f). Fescue relative frequency was 16-17, relative cover 40-53, and importance value 28-35. Thus, the exotic component was mostly fescue.

A small share of the native species on the grassed roof was seedlings of various poplars (*Populus* spp.) and willows (*Salix* spp.)(Tables D1, D2d, D2e, D2f). The overall picture of the grassed roof includes a high but not constant cover of fescue, a fairly high prominence of mosses, and a sparse cover of native vascular plants.

There was very little bare soil on the grassed roof.

3.3 CONSERVATISM AND FLORISTIC QUALITY

3.3.1 Site Values

If the green roof at York University is taken as a single site or one habitat patch, the average coefficient of conservatism (CC) for its 40 native plant species is 4.5 according to the TRCA reckoning and 2.8 according to the NHIC reckoning (Table D4b; Figure D4). These values yield a site TRCA-FQI of 28.3 and NHIC-FQI of 17.9 (Table D4b; Figure D5).

In 2005, each of the subsections of the roof had a mean TRCA-CC ranging from 3.1 to 4.6 and NHIC-CC ranging from 1.3 to 2.8. TRCA-FQI's ranged from 10.6 for the small lower plots up to 23.3 for the larger grassed roof. NHIC-FQI's ranged from 4.2 for the lower plots to 13.7 for the grassed roof.

A few fairly conservative species were found on the roof (Table D1). According to the generally more strict NHIC reckoning, the most conservative species was slender willow-herb (*Epilobium leptophyllum*) with a CC of 7. (Sky-blue aster (*Aster oolentangiensis*) was only found in 2004). A total of 8 species on the roof as a whole have a NHIC-CC of 5 or higher, while 20 species have a TRCA-CC of 5 or higher (Table D1).

Six species found in 2005 (three in 2004) were considered to be of regional concern, with TRCA ranks of L3 (or L3L4): *Agrostis* cf. *scabra*, *Aster* cf. *urophyllus*, *Heliopsis helianthoides* and *Penstemon digitalis* on the "wildflower" roof; and *Epilobium leptophyllum* and *Spiranthes cernua* on the grassed roof. An additional seven species ranked L4 are considered of concern in the urban environment (*Acer saccharinum*, *Amelanchier* sp., *Betula papyrifera*, *Populus grandidentata*, *Rudbeckia hirta*, *Salix bebbiana*, and *Salix discolor*).

3.3.2 Mean Quadrat Values

The quadrats set up on the "wildflower" and grassed sections of the roof enabled the calculation of average CC and FQI values per 0.25m^2 (Table D5b, with 2004 data in Table D5a for comparison).

For the "wildflower" roof, mean TRCA-CC per quadrat ranged from 2.5 to 3.4 and NHIC-CC per quadrat was between 1.9 and 2.5 (Figures D6a, D6b). The quadrat TRCA-FQI was between 3.9 and 4.7 and NHIC-FQI ranges from 2.8 to 3.4 (Figures D7a, D7b).

The grassed roof mean TRCA-CC per quadrat ranged from 1.4 to 1.6 and NHIC-CC per quadrat was 1.2 to1.3 (Figures D6a, D6b). The quadrat TRCA-FQI was 2.5 to 2.7, while the NHIC-FQI was betweem 1.9 and 2.1 (Figures D7a, D7b). Variability was high, as shown by standard deviations (Figures D6-D7).

4. CONCLUSIONS

4.1 VASCULAR PLANT BIODIVERSITY

Overall, the study shows low floristic diversity if the York University green roof is compared with natural prairie habitats. Packard and Ross (1997) describe high-quality prairie and savannah remnants has having a site FQI as high as 50 or even greater, with 20 or more native species per 0.25 m^2. On good sites generally, the mean CC per quadrat is over 4, while the average quadrat FQI is over 15 (it can exceed 20 in pristine prairie).

By contrast, the York green roof has, depending on the CC methodology, a site FQI of 16 to 24 and generally fewer than 5 native species per 0.25 m^2 quadrat (Table D4, Figure D5, Tables D2a-D2d). The mean CC per quadrat was 1.4 to 2.7 in 2004 and 1.2 to 3.4 in 2005 (again, depending on whether the TRCA or NHIC methodology is used), while the average quadrat FQI ranged from 1.9 to 3.5 in 2004 and 1.9 to 4.7 in 2005 (Table D5; Figures D6-D7). These values are comparable to the lower quality sites described by Packard and Ross (1997).

The total number of species on the green roof was 110 in 2005 (91 in 2004), just 40 (29 in 2004) of which are native (Table D1). These numbers are low, but the site is very small and relatively new. Natural areas surveyed by the TRCA over the past four years usually have a few hundred vascular plant species. However, these sites are usually over 100 hectares and the green roof occupies less than 1 hectare. Most urban natural areas within the Toronto area have a close to 50-50 proportion of native and exotic plants, while higher quality natural areas in our area have about 75% of the species total being native.

The original seed mixes from 1999 still exert a strong influence on the floristic composition of the green roof (Tables D1 and D2a-D2d). While the exact composition of the seed mixes is unknown, the fescue dominance on the grassed roof is very noticeable. The "wildflower" roof still has a high complement of ornamental forbs that were probably in the seed mix: sweet William (*Dianthus barbatus*), black-eyed Susan (*Rudbeckia hirta*), foxglove beardtongue (*Penstemon digitalis*), lance-leaved coreopsis (*Coreopsis lanceolata*), and a few other species that are less frequent. Some of these forbs are native, but not the majority. Some of the non-native forbs are North American, but not native to the Toronto area; for example, lance-leaved coreopsis (*Coreopsis lanceolata*) and purple coneflower (*Echinacea purpurea*). In addition, the provenance of the native species in the seed mix is unknown. It is unlikely to be from within the Toronto bioregion.

In this respect, the small section of roof that was ***not*** seeded has a relatively high proportion of native species: 18 out of the total of 36 (15 out of 33 in 2004) (Tables D1 and D4). The floristic quality measures, however, are comparable to the other roof sections.

One would have to conclude that the use of the commercial seed mixes was a mistake from a perspective of maximizing native biodiversity.

Attempts to compare the York University green roof with other natural areas such as prairie remnants or Toronto area habitats need to take into account the serious differences between the roof and surface landscapes. The rooftop situation is not only much smaller than a typical landscape habitat patch, it is also fundamentally different from most urban sites in that the situation is more analogous to ***primary*** succession (i.e. colonization of an entirely new, bare, mineral substrate such as exposed rock) rather than ***secondary*** succession (colonization of disturbed, nutrient-rich soils as in old field succession) (Chiaffredo & Denayer, 2004). Perhaps the most similar situations in the Toronto area are gravel pits. The roof top is also subject to extremes of temperature, high winds, and sunlight. A closer look at the results is definitely warranted.

4.2 FURTHER OBSERVATIONS

The high proportion of mosses and discontinuous cover of vascular plants after four to five years of growth fits the picture of primary succession. Mosses, together with other non-vascular plants, lichens, fungi, and microbes often form a crust on exposed rock or gravel (Chiaffredo & Denayer, 2004). This crust improves water retention, builds up a new soil, and provides a favourable habitat for colonization by native plants.

The prominence of mosses, together with the leachate monitoring also suggests that the green roof has a relatively low nutrient status which discourages the growth of aggressive monocultures of weedy species that often prevail in secondary succession in the Toronto area[2]. For example, buckthorn (*Rhamnus cathartica*) and creeping thistle (*Cirsium arvense*) are abundant in the surrounding landscape. They are also present on the roof, but in low numbers and the individuals tend to be stunted. The non-native fescues, on the other hand, do have some tolerance for poorer soils. Likewise, non-native legumes such as sweet clover (*Melilotus* spp.) and black medick (*Medicago lupulina*) are nitrogen fixers and can readily exploit the roof conditions. A patch of yellow sweet clover on the “wildflower” roof expanded from July to October 2004, but then seemed to decline, although it is too early to tell if there is any statistically significant. Russian-olive (*Elaeagnus angustifolia*), a non-leguminous nitrogen-fixer, grew rapidly in a few places in 2005.

A few species are worth noting individually or collectively. Those that were clearly not in the seed mix tend to be dispersed by wind, for example, poplars (*Populus* spp.), goldenrods (*Solidago* spp.), and horseweed (*Conyza canadensis*). The poplars and a few other tree species are unlikely to persist due to the shallow substrate and probable low nutrient status. If they do persist beyond the seedling stage, they are liable to be removed for hazard reasons.

The sky-blue aster, *Aster* cf. *oolentangiensis*, was an unusual find. This is a conservative plant usually found in prairie and savannah remnants, such as High Park. Sky-blue aster is ranked L3 in the TRCA system. It was an isolated occurrence on the grassed roof, so was not an obvious member of the seed mix, although it could have been a minor, inadvertent component. Ticklegrass (*Agrostis* cf. *scabra*) was another unusual adventive, also ranked L3, found in one of the containers at the base of the “wildflower” roof.

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[2] One of the containers at the base of the “wildflower” roof had a nesting pair of Canada geese in it. Their fæces contributed to local nutrient loading and the vegetation there was noticeably thicker and taller.

The orchid nodding ladies' tresses (*Spiranthes cernua*) was found in 2005 on the grassed roof. This species often appears in abandoned gravel pits and similar environments, and the TRCA was looking for it in 2004. Orchids have been found on European green roofs.

The other species of regional concern – foxglove beardtongue (*Penstemon digitalis*) and ox-eye (*Heliopsis helianthoides*) are showy forbs that were found on the "wildflower" roof. They were almost certainly introduced with the original seed mix.

The low nutrient status and stressful environment (shallow substrate, exposure to weather extremes) of the green roof could actually favour biodiversity in the long term, as more conservative, less competitive species might be able to find a foothold. Some green roofs in Europe have actually become refuges for endangered plants (Brenneisen, 2004).

The margin of error for the measurements is large enough, and the time series short enough, that we cannot make clear conclusions about any trends in floristic biodiversity on the green roof.

There are a few things to note for 2005 in addition to what has been discussed for 2004.

- A slight but fairly consistent increase in biodiversity overall, from a total of 91 to 110 vascular plant taxa. Both native and exotic species increased in richness. Although the average coefficients of conservatism remained about the same, the increase in biodiversity caused a slight increase in overall floristic quality indices. The significance of the site FQI increase could not be assessed.
- The prominence of mosses and the early-successional character of the green roof were still evident.
- While the sky-blue aster was not found in 2005, the orchid nodding ladies'-tresses (*Spiranthes cernua*) put in an appearance. Orchids have been found on European green roofs, and in 2004, the York University green roof was deemed to be possibly suitable for *Spiranthes*.
- The status of invasive alien nitrogen-fixers on the roof such as the clovers as well as Russian-olive (*Elaeagnus angustifolia*) should be further investigated. Large shrubs of the latter appeared in 2005.
- Other changes could be random: for example, the decline of a few species and the increase of others such as dandelion; the possible decline in the proportion of native species offset by increase in biodiversity, etc. A longer study would be needed to assess these possible changes.
- Seeds of slender gerardia (*Agalinis tenuifolia*) and blue-eyed grass (*Sisyrinchium montanum*) from GTA populations were sown onto the "lower" roof section in the winter of 2005-2006. These were deemed to be suitable species based on the 2004 observations of site conditions. It would be interesting to see if these establish themselves.

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Table D1: Green Roof species list May to October 2005

Species	Total Roof	Wildflower	Grass	Containers	Lower plots	Lower unseeded	CC TRCA	CC NHIC	L-Rank TRCA
Acer ginnala	X		x						L+
Acer negundo	X		x		x	x			L+?
Acer saccharinum	X		x				7	5	L4
Agrostis gigantea	X	x		x					
Agrostis scabra	X	x					8	6	L3
Amaranthus cf. retroflexus	X	x			x				L+
Ambrosia artemisiifolia	X	x	x				4	0	L5
Amelanchier sp.	X		x				7	5	L4
Asclepias syriaca	X		x			x	1	0	L5
Aster cf. urophyllus	X	x					7	6	L3
Aster ericoides	X	x		x		x	3	4	L5
Aster lanceolatus	X	x	x		x	x	3	3	L5
Aster novae-angliae	X	x		x		x	3	2	L5
Aster sp.	X	x					3	2	L5?
Betula papyrifera	X		x		x	x	6	2	L4
bird's nest fungus	X	x	x						
Bromus cf. japonicus	X	x		x	x				L+
Capsella bursa-pastoris	X	x	x		x				L+
Catalpa speciosa	X					x			L+
Centaurea cyanus	X	x		x	x				L+
Cerastium fontanum	X		x			x			L+
Chaenorrhinum minus	X					x			L+
Chenopodium album	X	x			x				L+
Chrysanthemum leucanthemum	X	x							L+
Chrysanthemum x maximum	X	x		x	x	x			L+
Cichorium intybus	X	x							L+
Cirsium arvense	X		x		x	x			L+
Cirsium vulgare	X	x							L+
Conyza canadensis	X	x	x		x	x	2	0	L5
Coreopsis lanceolata	X	x		x	x				L+
Crepis cf. tectorum	X	x	x		x				L+
Dalea purpurea	X	x							L+
Daucus carota	X	x	x	x					L+
Dianthus armeria	X	x							L+
Dianthus barbatus	X	x							L+
Draba sp.	X	x							L+
Echinacea purpurea	X	x		x	x				L+
Echinochloa cf. crus-galli	X				x				L+
Elaeagnus angustifolia	X	x	x	x					L+
Epilobium ciliatum	X	x	x		x	x	3	3	L5
Epilobium hirsutum	X		x						L+
Epilobium leptophyllum	X		x				8	7	L3
Epilobium parviflorum	X		x						L+
Erigeron annuus	X	x	x	x	x	x	1	0	L5
Erigeron philadelphicus	X	x					1	1	L5
Erysimum capitatum	X	x							L+
Euthamia graminifolia	X		x				5	2	L5
Festuca ovina	X	x		x					L+
Festuca pratensis	X					x			L+
Festuca rubra	X	x	x	x	x	x			L+
Festuca trachyphylla	X	x	x	x	x				L+
Fragaria virginiana	X	x					2	2	L5
Fraxinus pennsylvanica var. sub	X		x				5	3	L5
Gypsophila muralis	X	x							L+
Heliopsis helianthoides	X	x			x	x	8	3	L2
Hieracium aurantiacum	X		x						L+
Hieracium cf. piloselloides	X	x	x						L+
Kochia scoparius	X	x							L+
Lactuca serriola	X	x	x	x					L+

Linaria vulgaris	X		x						L+
liverwort	X	x	x			x			
Lotus corniculatus	X		x						L+
Lythrum salicaria	X		x						L+
Malus sp.	X		x						L+
Medicago lupulina	X	x	x	x	x				L+
Melilotus alba	X		x	x	x	x			L+
Melilotus officinalis	X	x							L+
moss, haircap (Polytrichum sp.)	X	x	x			x			
mosses, other	X	x	x	x	x	x			
Oenothera biennis?	X	x				x	2	0	L5
Oxalis stricta	X				x				L+
Parthenocissus sp.	X	x	x	x		x			L+?
Penstemon digitalis	X	x					6	6	L3L4
Pinus nigra (seedling)	X			x					L+
Plantago major	X		x			x			L+
Poa pratensis	X	x	x		x				L+
Polygonum aviculare	X	x							L+
Populus balsamifera	X		x				5	4	L5
Populus deltoides	X		x			x	5	4	L5
Populus grandidentata	X		x				7	5	L4
Populus tremuloides	X	x	x	x		x	4	2	L5
Populus x jackii	X					x	5	4	LHL5
Portulaca oleracea	X	x							L+
Potentilla norvegica	X	x	x		x				L+?
Ratibida columnifera	X	x							L+
Rhamnus cathartica	X		x						L+
Rhus typhina	X		x				4	1	L5
Rudbeckia hirta	X	x	x	x	x	x	7	0	L4
Sagina subulata	X		x						L+
Salix bebbiana	X		x				8	4	L4
Salix discolor	X			x		x	7	3	L4
Salix eriocephala	X		x			x	4	4	L5
Salix exigua	X		x				7	3	L5
Salix x rubens	X		x						L+
Salsola tragus	X	x							L+
Senecio viscosus	X	x							L+
Senecio vulgaris	X	x	x			x			L+
Setaria viridis	X	x							L+
Silene armeria	X			x	x				L+
Silene vulgaris	X	x	x		x	x			L+
Solanum dulcamara	X		x			x			L+
Solidago altissima	X	x	x	x	x		0	1	L5
Solidago canadensis	X		x				1	1	L5
Solidago gigantea	X		x			x	2	4	L5
Solidago nemoralis	X		x				4	2	L5
Sonchus cf. arvensis	X		x		x	x			L+
Sonchus oleraceus	X	x				x			L+
Spiranthes cernua	X		x				9	5	L3
Taraxacum officinale	X	x	x	x	x	x			L+
Thlaspi arvense	X		x						L+
Tilia americana	X					x	5	4	L5
Trifolium repens	X	x	x		x	x			L+
Vicia cracca	X	x	x						L+
Vitis riparia	X			x			0	0	L5
# vascular plant species	110	62	62	26	32	36			
# native species	40	18	26	8	8	18			
# exotic species	70	44	36	18	24	18			
# non-vascular plant taxa	4	4	4	1	1	3			
mean CC TRCA	4	4	5	3	4	4			
mean CC NHIC	3	2	3	1	2	2			
site FQI TRCA	28	16	23	9	11	17			
site FQI NHIC	18	10	14	4	4	10			

Table D2a: Green roof species cover estimates – sloping Wildflower section – May 25, 2005

Species	Quadrat #																				Frequency	Average % cover	Relative Frequency	Relative % cover	Importance value	Conservatism TRCA	Weighted Conservatism TRCA	Conservatism NHIC	Weighted Conservatism NHIC
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	D1	D2	D3	D4	D5									
Acer ginnala																					0	0	0.00	0.00	0.00				
Acer negundo																					0	0	0.00	0.00	0.00				
Agrostis gigantea								1			5		5								3	0.55	1.58	0.44	1.01				
Amaranthus cf. retroflexus																					0	0	0.00	0.00	0.00				
Ambrosia artemisiifolia																					0	0	0.00	0.00	0.00	4	0.00	0	0.00
Amelanchier sp.																					0	0	0.00	0.00	0.00	7	0.00	5	0.00
Arenaria serpyllifolia																					0	0	0.00	0.00	0.00				
Asclepias syriaca																					0	0	0.00	0.00	0.00	1	0.00	0	0.00
Aster ericoides											1			1							2	0.1	1.05	0.08	0.57	3	1.70	4	2.26
Aster lanceolatus	5																				1	0.25	0.53	0.20	0.36	3	1.09	3	1.09
Aster sp.																					0	0	0.00	0.00	0.00	3	0.00	2	0.00
bare soil	1	50	10	10	20	20	70	5			5	5	20	30	20	20	5	20	50	1	18	18.1	9.47	14.34	11.91				
Betula papyrifera																					0	0	0.00	0.00	0.00	6	0.00	2	0.00
bird's nest fungus																					0	0	0.00	0.00	0.00				
Bromus cf. japonicus					5	10				5	1	10		1	1		1		1	10	10	2.25	5.26	1.78	3.52				
Capsella bursa-pastoris																					0	0	0.00	0.00	0.00				
Catalpa speciosa																					0	0	0.00	0.00	0.00				
Centaurea cyanus																					0	0	0.00	0.00	0.00				
Cerastium fontanum																					0	0	0.00	0.00	0.00				
Chaenorrhinum minus																					0	0	0.00	0.00	0.00				
Chenopodium album																					0	0	0.00	0.00	0.00				
Chrysanthemum x maximum												10									1	0.5	0.53	0.40	0.46				
Cichorium intybus																					0	0	0.00	0.00	0.00				
Cirsium arvense																					0	0	0.00	0.00	0.00				
conifer seedling (Pinus nigra?)																					0	0	0.00	0.00	0.00				
Conyza canadensis		5	1			1				5	1										5	0.65	2.63	0.51	1.57	2	3.15	0	0.00
Coreopsis lanceolata	5	1	15	15	5	10	5	5		1		10	25		5		1	1		1	15	5.25	7.89	4.16	6.03				
Crepis cf. tectorum			1	5	1		1	5	1	5						5					8	1.2	4.21	0.95	2.58				
Daucus carota		1																			1	0.05	0.53	0.04	0.28				
Dianthus barbatus		5				20	5			1	50	30				5	15	5	5	20	11	8.05	5.79	6.38	6.08				
Draba sp.																					0	0	0.00	0.00	0.00				
Echinacea purpurea			5	10						1			1	1							5	0.9	2.63	0.71	1.67				
Elaeagnus angustifolia																					0	0	0.00	0.00	0.00				
Epilobium ciliatum					1			3		1				1	1	1					6	0.4	3.16	0.32	1.74	3	5.21	3	5.21
Epilobium hirsutum																					0	0	0.00	0.00	0.00				
Epilobium parviflorum																					0	0	0.00	0.00	0.00				
Erigeron annuus					1					1				1		15			1		5	0.95	2.63	0.75	1.69	1	1.69	0	0.00
Erigeron philadelphicus											5										1	0.25	0.53	0.20	0.36	1	0.36	1	0.36
Euthamia graminifolia																					0	0	0.00	0.00	0.00	5	0.00	2	0.00
Festuca spp.	80	30	10				1			25	10					1	1		30		9	9.4	4.74	7.45	6.09				
Fragaria virginiana																					0	0	0.00	0.00	0.00	2		2	
Fraxinus pennsylvanica																					0	0	0.00	0.00	0.00	5	0.00	3	0.00
grass sp. (slender?)																					0	0	0.00	0.00	0.00				
Gypsophila muralis		5					5	1			10	5	5	1	5		10	5			10	2.6	5.26	2.06	3.66				
Hieracium aurantiacum																					0	0	0.00	0.00	0.00				
Hieracium cf. piloselloides		1				1	1	1			5	5				1	1				8	0.8	4.21	0.63	2.42				
Kochia scoparia																					0	0	0.00	0.00	0.00				
Lactuca serriola																					0	0	0.00	0.00	0.00				
liverwort		1														1	1				3	0.15	1.58	0.12	0.85				
Malus sp.																					0	0	0.00	0.00	0.00				
Medicago lupulina															1						1	0.05	0.53	0.04	0.28				
Melilotus alba																					0	0	0.00	0.00	0.00				
Melilotus officinalis		1		20					95					20							4	6.8	2.11	5.39	3.75				
mosses	65		90	40	90	60	20	90	5	60	40	80	75	30	70	75	90	80	20	5	19	54.25	10.00	42.97	26.49				
mustard sp. (perennial)																					0	0	0.00	0.00	0.00				
Oenothera biennis?																					0	0	0.00	0.00	0.00	2	0.00	0	0.00
Parthenocissus sp.																					0	0	0.00	0.00	0.00				
Penstemon digitalis			1	1		1				1					1	15	10	1	20		9	2.55	4.74	2.02	3.38	6	20.27	6	20.27
Plantago major																					0	0	0.00	0.00	0.00				
Poa pratensis				10	1		1					1				5					5	0.9	2.63	0.71	1.67				
Polygonum aviculare																					0	0	0.00	0.00	0.00				
Polytrichum sp. (haircap moss)																					0	0	0.00	0.00	0.00				
Populus deltoides																					0	0	0.00	0.00	0.00	5	0.00	4	0.00
Populus grandidentata																					0	0	0.00	0.00	0.00	7	0.00	5	0.00
Populus tremuloides																					0	0	0.00	0.00	0.00	4	0.00	2	0.00
Ratibida columnifera											1					5					2	0.3	1.05	0.24	0.65				
Rhamnus cathartica																					0	0	0.00	0.00	0.00				
Rudbeckia hirta										1		5			1						3	0.35	1.58	0.28	0.93	7	6.50	0	
Salix bebbiana																					0	0	0.00	0.00	0.00	8	0.00	4	0.00
Salix x rubens																					0	0	0.00	0.00	0.00				
Salsola tragus																					0	0	0.00	0.00	0.00				
Setaria viridis																					0	0	0.00	0.00	0.00				
Silene armeria																					0	0	0.00	0.00	0.00				
Silene vulgaris									5					15				5	1		4	1.3	2.11	1.03	1.57				
Solanum dulcamara																					0	0	0.00	0.00	0.00				
Solidago altissima	1							15							1						3	0.85	1.58	0.67	1.13	0	0.00	1	1.13
Solidago gigantea																					0	0	0.00	0.00	0.00	2	0.00	4	0.00
Sonchus cf. arvensis																					0	0	0.00	0.00	0.00				
Taraxacum officinale	1	1	1	5	3	5		5	5	5	1	5	5	1	5	5			1		16	2.7	8.42	2.14	5.28				
Tragopogon dubium																					0	0	0.00	0.00	0.00				
Trifolium repens																					0	0	0.00	0.00	0.00				
Vicia cracca															1					75	2	3.8	1.05	3.01	2.03				

Table D2b: Green roof species cover estimates – sloping Wildflower section – July 20, 2005

Species	Quadrat #																				Frequency	Average % cover	Relative Frequency	Relative % cover	Importance value	Conservatism TRCA	Weighted conservatism TRCA	Conservatism NHIC	Weighted conservatism NHIC
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	D1	D2	D3	D4	D5									
Acer ginnala																					0	0	0.00	0.00	0.00				
Acer negundo																					0	0	0.00	0.00	0.00				
Agrostis gigantea								15					20								2	1.75	1.00	1.10	1.05				
Amaranthus cf. retroflexus							1		5			1									3	0.35	1.49	0.22	0.86				
Ambrosia artemisiifolia																					0	0	0.00	0.00	0.00	4	0.00	0	0.00
Amelanchier sp.																					0	0	0.00	0.00	0.00	7	0.00	5	0.00
Arenaria serpyllifolia																					0	0	0.00	0.00	0.00				
Asclepias syriaca																					0	0	0.00	0.00	0.00	1	0.00	0	0.00
Aster ericoides	5										10			5							3	1	1.49	0.63	1.06	3	3.18	4	4.24
Aster lanceolatus	30																				1	1.5	0.50	0.94	0.72	3	2.16	3	2.16
Aster sp.																					0	0	0.00	0.00	0.00	3	0.00	2	0.00
bare soil		40	1	10	10	15	55	10	20	40	5	5	20	30	20	20	5	15	50	1	19	18.6	9.45	11.65	10.55				
Betula papyrifera																					0	0	0.00	0.00	0.00	6	0.00	2	0.00
bird's nest fungus																					0	0	0.00	0.00	0.00				
Bromus cf. japonicus					1	1															2	0.1	1.00	0.06	0.53				
Capsella bursa-pastoris					1																1	0.05	0.50	0.03	0.26				
Catalpa speciosa																					0	0	0.00	0.00	0.00				
Centaurea cyanus					15		1														2	0.8	1.00	0.50	0.75				
Cerastium fontanum																					0	0	0.00	0.00	0.00				
Chaenorrhinum minus																					0	0	0.00	0.00	0.00				
Chenopodium album		1					1		5							1		1		5	6	0.7	2.99	0.44	1.71				
Chrysanthemum x maximum												10									1	0.5	0.50	0.31	0.41				
Cichorium intybus						5															1	0.25	0.50	0.16	0.33				
Cirsium arvense																					0	0	0.00	0.00	0.00				
conifer seedling (Pinus nigra?)																					0	0	0.00	0.00	0.00				
Conyza canadensis					15		5	1							25		5	10			6	3.05	2.99	1.91	2.45	2	4.89	0	0.00
Coreopsis lanceolata	15	1	20	30	40	55	20	20		20	1	50	55	20	15	20	15	30	5	5	19	21.85	9.45	13.68	11.57				
Crepis cf. tectorum			1	1	1										1						4	0.2	1.99	0.13	1.06				
Daucus carota																					0	0	0.00	0.00	0.00				
Dianthus barbatus		5				20	15		5		40	20					15	1	5	30	10	7.8	4.98	4.88	4.93				
Draba sp.					1																1	0.05	0.50	0.03	0.26				
Echinacea purpurea			5	5	5								1	10							5	1.3	2.49	0.81	1.65				
Elaeagnus angustifolia																					0	0	0.00	0.00	0.00				
Epilobium ciliatum							5														1	0.25	0.50	0.16	0.33	3	0.98	3	0.98
Epilobium hirsutum																					0	0	0.00	0.00	0.00				
Epilobium parviflorum																					0	0	0.00	0.00	0.00				
Erigeron annuus					30					10				1		25			5		5	3.55	2.49	2.22	2.36	1	2.36	0	0.00
Erigeron philadelphicus																					0	0	0.00	0.00	0.00	1	0.00	1	0.00
Euthamia graminifolia																					0	0	0.00	0.00	0.00	5	0.00	2	0.00
Festuca spp.	60	25	20		1		1			35	10			1			1		40		10	9.7	4.98	6.07	5.52				
Fragaria virginiana																					0	0	0.00	0.00	0.00	2		2	
Fraxinus pennsylvanica																					0	0	0.00	0.00	0.00	5	0.00	3	0.00
grass sp. (slender?)																					0	0	0.00	0.00	0.00				
Gypsophila muralis					1			1				1			1						4	0.2	1.99	0.13	1.06				
Hieracium aurantiacum																					0	0	0.00	0.00	0.00				
Hieracium cf. piloselloides		5	1			5	15				1	10				15	5	1			9	2.9	4.48	1.82	3.15				
Kochia scoparius		1			15					1								1			4	0.9	1.99	0.56	1.28				
Lactuca serriola																					0	0	0.00	0.00	0.00				
liverwort																					0	0	0.00	0.00	0.00				
Malus sp.																					0	0	0.00	0.00	0.00				
Medicago lupulina					1										5						2	0.3	1.00	0.19	0.59				
Melilotus alba																					0	0	0.00	0.00	0.00				
Melilotus officinalis		10							50					30							3	4.5	1.49	2.82	2.16				
mosses	50	15	85	40	80	55	25	80	5	60	70	80	65	30	70	75	80	80	25	5	20	53.75	9.95	33.66	21.80				
mustard sp. (perennial)																					0	0	0.00	0.00	0.00				
Oenothera biennis?							1														1	0.05	0.50	0.03	0.26	2	0.53	0	0.00
Parthenocissus sp.																					0	0	0.00	0.00	0.00				
Penstemon digitalis		1	1	1		1	1			1	1			1	5	25	35	5	20		13	4.9	6.47	3.07	4.77	6	28.61	6	28.61
Plantago major																					0	0	0.00	0.00	0.00				
Poa pratensis				25	5		1			1	1	20			1						7	2.7	3.48	1.69	2.59				
Polygonum aviculare				5																	1	0.25	0.50	0.16	0.33				
Polytrichum sp. (haircap moss)																					0	0	0.00	0.00	0.00				
Populus deltoides																					0	0	0.00	0.00	0.00	5	0.00	4	0.00
Populus grandidentata																					0	0	0.00	0.00	0.00	7	0.00	5	0.00
Populus tremuloides																					0	0	0.00	0.00	0.00	4	0.00	2	0.00
Ratibida columnifera											5			1							2	0.3	1.00	0.19	0.59				
Rhamnus cathartica																					0	0	0.00	0.00	0.00				
Rudbeckia hirta										1		10			1	10					4	1.1	1.99	0.69	1.34	7	9.38	0	
Salix bebbiana																					0	0	0.00	0.00	0.00	8	0.00	4	0.00
Salix x rubens																					0	0	0.00	0.00	0.00				
Salsola tragus																					0	0	0.00	0.00	0.00				
Setaria viridis			1																		1	0.05	0.50	0.03	0.26				
Silene armeria																					0	0	0.00	0.00	0.00				
Silene vulgaris									15				1	60				20	10		5	5.3	2.49	3.32	2.90				
Solanum dulcamara																					0	0	0.00	0.00	0.00				
Solidago altissima	1	1						15							1						4	0.9	1.99	0.56	1.28	0	0.00	1	1.28
Solidago gigantea																					0	0	0.00	0.00	0.00	2	0.00	4	0.00
Sonchus cf. arvensis																					0	0	0.00	0.00	0.00				
Taraxacum officinale	1	5	5	1	10	5	1	5	15	5		1	5	5	5	5			1	5	17	4	8.46	2.50	5.48				
Tragopogon dubium																					0	0	0.00	0.00	0.00				
Trifolium repens																					0	0	0.00	0.00	0.00				
Vicia cracca															5					80	2	4.25	1.00	2.66	1.83				

Table D2c: Green roof species cover estimates – sloping Wildflower section – October 12, 2005

	Quadrat #																												
Species	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	D1	D2	D3	D4	D5	Frequency	Average % cover	Relative Frequency	Relative % cover	Importance value	Conservatism TRCA	Weighted conservatism TRCA	Conservatism NHIC	Weighted conservatism NHIC
Acer ginnala																					0	0	0.00	0.00	0.00				
Acer negundo																					0	0	0.00	0.00	0.00				
Agrostis gigantea								5	15				40							1	4	3.05	2.04	1.78	1.91				
Amaranthus cf. retroflexus									10			1									2	0.55	1.02	0.32	0.67				
Ambrosia artemisiifolia																					0	0	0.00	0.00	0.00	4	0.00	0	0.00
Amelanchier sp.																					0	0	0.00	0.00	0.00	7	0.00	5	0.00
Arenaria serpyllifolia																					0	0	0.00	0.00	0.00				
Asclepias syriaca																					0	0	0.00	0.00	0.00	1	0.00	0	0.00
Aster ericoides	8										10			5							3	1.15	1.53	0.67	1.10	3	3.30	4	4.41
Aster lanceolatus	40																				1	2	0.51	1.17	0.84	3	2.52	3	2.52
Aster sp.		1																			1	0.05	0.51	0.03	0.27	3	0.81	2	0.54
bare soil	5	30	5	10	10	15	55	10	10	30	1	5	5	20	20	15	10	5	20		19	14.05	9.69	8.21	8.95	0	0.00		
Betula papyrifera																					0	0	0.00	0.00	0.00	6	0.00	2	0.00
bird's nest fungus							1		1								1	1			4	0.2	2.04	0.12	1.08	5	5.39		
Bromus cf. japonicus						1															1	0.05	0.51	0.03	0.27				
Capsella bursa-pastoris																					0	0	0.00	0.00	0.00				
Catalpa speciosa																					0	0	0.00	0.00	0.00				
Centaurea cyanus																					0	0	0.00	0.00	0.00				
Cerastium fontanum																					0	0	0.00	0.00	0.00				
Chaenorrhinum minus																					0	0	0.00	0.00	0.00				
Chenopodium album		1		30			1		5						1			1		5	7	2.2	3.57	1.29	2.43				
Chrysanthemum x maximum												10									1	0.5	0.51	0.29	0.40				
Cichorium intybus																					0	0	0.00	0.00	0.00				
Cirsium arvense																					0	0	0.00	0.00	0.00				
conifer seedling (Pinus nigra?)																					0	0	0.00	0.00	0.00				
Conyza canadensis					20		10								20		5	5			5	3	2.55	1.75	2.15	2	4.30	0	0.00
Coreopsis lanceolata	18	40	40	50	40	70	20	30		15	5	20	60	30	20	20	15	40	5	30	19	28.4	9.69	16.60	13.15				
Crepis cf. tectorum																					0	0	0.00	0.00	0.00				
Daucus carota																					0	0	0.00	0.00	0.00				
Dianthus barbatus						10	15				50	15	1		1	5	15	5	5	30	11	7.6	5.61	4.44	5.03				
Draba sp.																					0	0	0.00	0.00	0.00				
Echinacea purpurea			15	20	5									15							4	2.75	2.04	1.61	1.82				
Elaeagnus angustifolia																					0	0	0.00	0.00	0.00				
Epilobium ciliatum																					0	0	0.00	0.00	0.00	3	0.00	3	0.00
Epilobium hirsutum																					0	0	0.00	0.00	0.00				
Epilobium parviflorum																					0	0	0.00	0.00	0.00				
Erigeron annuus					10					10				5	1	20			5	5	7	2.8	3.57	1.64	2.60	1	2.60	0	0.00
Erigeron philadelphicus																					0	0	0.00	0.00	0.00	1	0.00	1	0.00
Euthamia graminifolia																					0	0	0.00	0.00	0.00	5	0.00	2	0.00
Festuca spp.	50	40	40				1			40	5			1	1		1		40		10	10.95	5.10	6.40	5.75				
Fragaria virginiana											5										1	0.25	0.51	0.15	0.33	2		2	
Fraxinus pennsylvanica																					0	0	0.00	0.00	0.00	5	0.00	3	0.00
grass sp. (slender?)																					0	0	0.00	0.00	0.00				
Gypsophila muralis								1													1	0.05	0.51	0.03	0.27				
Hieracium aurantiacum																					0	0	0.00	0.00	0.00				
Hieracium cf. piloselloides		5	1			5	10				15	1				15	10	1			9	3.15	4.59	1.84	3.22				
Kochia scoparia					10					1											2	0.55	1.02	0.32	0.67				
Lactuca serriola																					0	0	0.00	0.00	0.00				
liverwort																					0	0	0.00	0.00	0.00				
Malus sp.																					0	0	0.00	0.00	0.00				
Medicago lupulina			5		10										40						3	2.75	1.53	1.61	1.57				
Melilotus alba																					0	0	0.00	0.00	0.00				
Melilotus officinalis		10							10												2	1	1.02	0.58	0.80				
mosses	70	20	80	40	80	80	20	80	5	70	80	80	70	40	70	75	80	90	25	1	20	57.8	10.20	33.79	22.00				
mustard sp. (perennial)																					0	0	0.00	0.00	0.00				
Oenothera biennis?							1														1	0.05	0.51	0.03	0.27	2	0.54	0	0.00
Parthenocissus sp.																					0	0	0.00	0.00	0.00				
Penstemon digitalis		1				1	1			1	1				1	40	40	5	20		10	5.55	5.10	3.24	4.17	6	25.04	6	25.04
Plantago major																					0	0	0.00	0.00	0.00				
Poa pratensis				40			1		5	1	1	10			1						7	2.95	3.57	1.72	2.65				
Polygonum aviculare				5											1						2	0.3	1.02	0.18	0.60				
Polytrichum sp. (haircap moss)																1					1	0.05	0.51	0.03	0.27				
Populus deltoides																					0	0	0.00	0.00	0.00	5	0.00	4	0.00
Populus grandidentata																					0	0	0.00	0.00	0.00	7	0.00	5	0.00
Populus tremuloides																					0	0	0.00	0.00	0.00	4	0.00	2	0.00
Ratibida columnifera											5			1						10	3	0.8	1.53	0.47	1.00				
Rhamnus cathartica																					0	0	0.00	0.00	0.00				
Rudbeckia hirta										1					1	10					3	0.6	1.53	0.35	0.94	7	6.58	0	
Salix bebbiana																					0	0	0.00	0.00	0.00	8	0.00	4	0.00
Salix x rubens																					0	0	0.00	0.00	0.00				
Salsola tragus		1																			1	0.05	0.51	0.03	0.27				
Setaria viridis			1																		1	0.05	0.51	0.03	0.27				
Silene armeria																					0	0	0.00	0.00	0.00				
Silene vulgaris									35			1	5	40				15	5		6	5.05	3.06	2.95	3.01				
Solanum dulcamara																					0	0	0.00	0.00	0.00				
Solidago altissima		1						15						1	1						4	0.9	2.04	0.53	1.28	0	0.00	1	1.28
Solidago gigantea																					0	0	0.00	0.00	0.00	2	0.00	4	0.00
Sonchus cf. arvensis																					0	0	0.00	0.00	0.00				
Taraxacum officinale	1	10	5	1	10	5	5	15	25	1		1	10	15	1	1		1	5		17	5.6	8.67	3.27	5.97				
Tragopogon dubium																					0	0	0.00	0.00	0.00				
Trifolium repens										5											1	0.25	0.51	0.15	0.33				
Vicia cracca															10					70	2	4	1.02	2.34	1.68				

Table D2d: Green roof species cover estimates – grass section – May 25, 2005

	Quadrat #																				Frequency	Average % cover	Relative Frequency	Relative % cover	Importance value	Conservatism TRCA	Weighted conservatism TRCA	Conservatism NHIC	Weighted conservatism NHIC
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20									
Acer ginnala															1						1	0.05	0.87	0.03	0.45				
Acer negundo																					0	0	0.00	0.00	0.00				
Agrostis gigantea																					0	0	0.00	0.00	0.00				
Amaranthus cf. retroflexus																					0	0	0.00	0.00	0.00				
Ambrosia artemisiifolia																					0	0	0.00	0.00	0.00	4	0.00	0	0.00
Amelanchier sp.							1														1	0.05	0.87	0.03	0.45	7	3.16	5	2.26
Arenaria serpyllifolia																					0	0	0.00	0.00	0.00				
Asclepias syriaca																1					1	0.05	0.87	0.03	0.45	1	0.45	0	0.00
Aster ericoides																					0	0	0.00	0.00	0.00	3	0.00	4	0.00
Aster lanceolatus			5																		1	0.25	0.87	0.17	0.52	3	1.56	3	1.56
Aster sp.																					0	0	0.00	0.00	0.00	3	0.00	2	0.00
bare soil											5					5					2	0.5	1.74	0.34	1.04				
Betula papyrifera								1													1	0.05	0.87	0.03	0.45	6	2.71	2	0.90
bird's nest fungus																					0	0	0.00	0.00	0.00				
Bromus cf. japonicus																					0	0	0.00	0.00	0.00				
Capsella bursa-pastoris																					0	0	0.00	0.00	0.00				
Catalpa speciosa																					0	0	0.00	0.00	0.00				
Centaurea cyanus																					0	0	0.00	0.00	0.00				
Cerastium fontanum				5				1													2	0.3	1.74	0.21	0.97				
Chaenorrhinum minus																					0	0	0.00	0.00	0.00				
Chenopodium album																					0	0	0.00	0.00	0.00				
Chrysanthemum x maximum																					0	0	0.00	0.00	0.00				
Cichorium intybus																					0	0	0.00	0.00	0.00				
Cirsium arvense																					0	0	0.00	0.00	0.00				
conifer seedling (Pinus nigra?)																					0	0	0.00	0.00	0.00				
Conyza canadensis																					0	0	0.00	0.00	0.00	2	0.00	0	0.00
Coreopsis lanceolata																					0	0	0.00	0.00	0.00				
Crepis cf. tectorum											15			1							2	0.8	1.74	0.55	1.14				
Daucus carota										1						1					2	0.1	1.74	0.07	0.90				
Dianthus barbatus																					0	0	0.00	0.00	0.00				
Draba sp.																					0	0	0.00	0.00	0.00				
Echinacea purpurea																					0	0	0.00	0.00	0.00				
Elaeagnus angustifolia																					0	0	0.00	0.00	0.00				
Epilobium ciliatum																					0	0	0.00	0.00	0.00	3	0.00	3	0.00
Epilobium hirsutum					1																1	0.05	0.87	0.03	0.45				
Epilobium parviflorum						1															1	0.05	0.87	0.03	0.45				
Erigeron annuus	1				1		5														3	0.35	2.61	0.24	1.42	1	1.42	0	0.00
Erigeron philadelphicus																					0	0	0.00	0.00	0.00	1	0.00	1	0.00
Euthamia graminifolia																					0	0	0.00	0.00	0.00	5	0.00	2	0.00
Festuca spp.	80	95	100	100	5	70	90	15	100	95	10	100	100	90	100	15	80	85	100	100	20	76.5	17.39	52.67	35.03				
Fragaria virginiana																					0	0	0.00	0.00	0.00	2		2	
Fraxinus pennsylvanica							1			1				1	1	1					5	0.25	4.35	0.17	2.26	5	11.30	3	6.78
grass sp. (slender?)																					0	0	0.00	0.00	0.00				
Gypsophila cf. paniculata																					0	0	0.00	0.00	0.00				
Hieracium aurantiacum															5						1	0.25	0.87	0.17	0.52				
Hieracium cf. piloselloides						1										1					2	0.1	1.74	0.07	0.90				
Kochia scoparia																					0	0	0.00	0.00	0.00				
Lactuca serriola																					0	0	0.00	0.00	0.00				
liverwort					10																1	0.5	0.87	0.34	0.61				
Malus sp.		1																			1	0.05	0.87	0.03	0.45				
Medicago lupulina												1									1	0.05	0.87	0.03	0.45				
Melilotus alba	1															1					2	0.1	1.74	0.07	0.90				
Melilotus officinalis																					0	0	0.00	0.00	0.00				
mosses	65	20	10		90	70	65	95	25	50	95	30	20	80	30	95	65	70	30	40	19	52.25	16.52	35.97	26.25				
mustard sp. (perennial)																					0	0	0.00	0.00	0.00				
Oenothera biennis?																					0	0	0.00	0.00	0.00	2	0.00	0	0.00
Parthenocissus sp.																					0	0	0.00	0.00	0.00				
Penstemon digitalis																					0	0	0.00	0.00	0.00	6	0.00	6	0.00
Plantago major				1																	1	0.05	0.87	0.03	0.45				
Poa pratensis	1																				1	0.05	0.87	0.03	0.45				
Polygonum aviculare																					0	0	0.00	0.00	0.00				
Polytrichum sp. (haircap moss)																					0	0	0.00	0.00	0.00				
Populus deltoides										1											1	0.05	0.87	0.03	0.45	5	2.26	4	1.81
Populus grandidentata										5											1	0.25	0.87	0.17	0.52	7	3.65	5	2.60
Populus tremuloides			1			5		10		1											4	0.85	3.48	0.59	2.03	4	8.13	2	4.06
Ratibida columnifera																					0	0	0.00	0.00	0.00				
Rhamnus cathartica																		1			1	0.05	0.87	0.03	0.45				
Rudbeckia hirta																					0	0	0.00	0.00	0.00	7	0.00	0	
Salix bebbiana						1				1											2	0.1	1.74	0.07	0.90	8	7.23	4	3.62
Salix x rubens	1							1													2	0.1	1.74	0.07	0.90				
Salsola tragus																					0	0	0.00	0.00	0.00				
Setaria viridis																					0	0	0.00	0.00	0.00				
Silene armeria																					0	0	0.00	0.00	0.00				
Silene vulgaris																	20				1	1	0.87	0.69	0.78				
Solanum dulcamara								1													1	0.05	0.87	0.03	0.45				
Solidago altissima	5	10	15		30	5		20		1	1	30		1		20			1		12	6.95	10.43	4.78	7.61	0	0.00	1	7.61
Solidago gigantea						5															1	0.25	0.87	0.17	0.52	2	1.04	4	2.08
Sonchus cf. arvensis		1	1					1		1											4	0.2	3.48	0.14	1.81				
Taraxacum officinale	1		1	1	10	10	5	5			5	5				3		1	1		12	2.4	10.43	1.65	6.04				
Tragopogon dubium																					0	0	0.00	0.00	0.00				
Trifolium repens		5																			1	0.25	0.87	0.17	0.52				
Vicia cracca																					0	0	0.00	0.00	0.00				

Table D2e: Green roof species cover estimates – grass section – July 20, 2005

Species	Quadrat #																				Frequency	Average % cover	Relative Frequency	Relative % cover	Importance value	Conservatism TRCA	Weighted conservatism TRCA	Conservatism NHIC	Weighted conservatism NHIC
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20									
Acer ginnala															1						1	0.05	0.82	0.03	0.43				
Acer negundo																					0	0	0.00	0.00	0.00				
Agrostis gigantea																					0	0	0.00	0.00	0.00				
Amaranthus cf. retroflexus																					0	0	0.00	0.00	0.00				
Ambrosia artemisiifolia																					0	0	0.00	0.00	0.00	4	0.00	0	0.00
Amelanchier sp.							1														1	0.05	0.82	0.03	0.43	7	2.99	5	2.13
Arenaria serpyllifolia																					0	0	0.00	0.00	0.00				
Asclepias syriaca																1					1	0.05	0.82	0.03	0.43	1	0.43	0	0.00
Aster ericoides																					0	0	0.00	0.00	0.00	3	0.00	4	0.00
Aster lanceolatus		5	5		1																3	0.55	2.46	0.38	1.42	3	4.25	3	4.25
Aster sp.																					0	0	0.00	0.00	0.00	3	0.00	2	0.00
bare soil					5						5					1					3	0.55	2.46	0.38	1.42				
Betula papyrifera								1													1	0.05	0.82	0.03	0.43	6	2.56	2	0.85
bird's nest fungus										1										1	2	0.1	1.64	0.07	0.85				
Bromus cf. japonicus																					0	0	0.00	0.00	0.00				
Capsella bursa-pastoris																					0	0	0.00	0.00	0.00				
Catalpa speciosa																					0	0	0.00	0.00	0.00				
Centaurea cyanus																					0	0	0.00	0.00	0.00				
Cerastium fontanum				5																	1	0.25	0.82	0.17	0.50				
Chaenorrhinum minus																					0	0	0.00	0.00	0.00				
Chenopodium album																					0	0	0.00	0.00	0.00				
Chrysanthemum x maximum																					0	0	0.00	0.00	0.00				
Cichorium intybus																					0	0	0.00	0.00	0.00				
Cirsium arvense																					0	0	0.00	0.00	0.00				
conifer seedling (Pinus nigra?)																					0	0	0.00	0.00	0.00				
Conyza canadensis								1													1	0.05	0.82	0.03	0.43	2	0.85	0	0.00
Coreopsis lanceolata																					0	0	0.00	0.00	0.00				
Crepis cf. tectorum											10										1	0.5	0.82	0.34	0.58				
Daucus carota										5											1	0.25	0.82	0.17	0.50				
Dianthus barbatus																					0	0	0.00	0.00	0.00				
Draba sp.																					0	0	0.00	0.00	0.00				
Echinacea purpurea																					0	0	0.00	0.00	0.00				
Elaeagnus angustifolia																				15	1	0.75	0.82	0.51	0.67				
Epilobium ciliatum																			1		1	0.05	0.82	0.03	0.43	3	1.28	3	1.28
Epilobium hirsutum																					0	0	0.00	0.00	0.00				
Epilobium parviflorum						1															1	0.05	0.82	0.03	0.43				
Erigeron annuus					1		5														2	0.3	1.64	0.21	0.92	1	0.92	0	0.00
Erigeron philadelphicus																					0	0	0.00	0.00	0.00	1	0.00	1	0.00
Euthamia graminifolia			1																		1	0.05	0.82	0.03	0.43	5	2.13	2	0.85
Festuca spp.	40	50	100	100		80	95	15	90	90	20	100	100	90	100	1	90	80	100	100	19	72.05	15.57	49.30	32.44				
Fragaria virginiana																					0	0	0.00	0.00	0.00	2		2	
Fraxinus pennsylvanica							1			1					1				1		4	0.2	3.28	0.14	1.71	5	8.54	3	5.12
grass sp. (slender?)																					0	0	0.00	0.00	0.00				
Gypsophila muralis																					0	0	0.00	0.00	0.00				
Hieracium aurantiacum															1						1	0.05	0.82	0.03	0.43				
Hieracium cf. piloselloides						1					5					1					3	0.35	2.46	0.24	1.35				
Kochia scoparius																					0	0	0.00	0.00	0.00				
Lactuca serriola																					0	0	0.00	0.00	0.00				
liverwort																					0	0	0.00	0.00	0.00				
Malus sp.																					0	0	0.00	0.00	0.00				
Medicago lupulina	50	30							20						1						4	5.05	3.28	3.46	3.37				
Melilotus alba	30	5											5			20	10				5	3.5	4.10	2.39	3.25				
Melilotus officinalis																					0	0	0.00	0.00	0.00				
mosses	50	5	40		90	70	10	95	20	20	95	20	10	50	30	90	50	60	20	20	19	42.25	15.57	28.91	22.24				
mustard sp. (perennial)																					0	0	0.00	0.00	0.00				
Oenothera biennis?																					0	0	0.00	0.00	0.00	2	0.00	0	0.00
Parthenocissus sp.														1			1			1	3	0.15	2.46	0.10	1.28				
Penstemon digitalis																					0	0	0.00	0.00	0.00	6	0.00	6	0.00
Plantago major																					0	0	0.00	0.00	0.00				
Poa pratensis																					0	0	0.00	0.00	0.00				
Polygonum aviculare																					0	0	0.00	0.00	0.00				
Polytrichum sp. (haircap moss)								1													1	0.05	0.82	0.03	0.43				
Populus deltoides										1											1	0.05	0.82	0.03	0.43	5	2.13	4	1.71
Populus grandidentata										5											1	0.25	0.82	0.17	0.50	7	3.47	5	2.48
Populus tremuloides			1			1		10		5									1		5	0.9	4.10	0.62	2.36	4	9.43	2	4.71
Ratibida columnifera																					0	0	0.00	0.00	0.00				
Rhamnus cathartica																					0	0	0.00	0.00	0.00				
Rudbeckia hirta																					0	0	0.00	0.00	0.00	7	0.00	0	
Salix bebbiana						5															1	0.25	0.82	0.17	0.50	8	3.96	4	1.98
Salix x rubens																					0	0	0.00	0.00	0.00				
Salsola tragus																					0	0	0.00	0.00	0.00				
Setaria viridis																					0	0	0.00	0.00	0.00				
Silene armeria																					0	0	0.00	0.00	0.00				
Silene vulgaris																	20				1	1	0.82	0.68	0.75				
Solanum dulcamara																					0	0	0.00	0.00	0.00				
Solidago altissima	10	10	20	1	50	5	15	30		1	5	5				30		1	1		14	9.2	11.48	6.29	8.89	0	0.00	1	8.89
Solidago gigantea						5															1	0.25	0.82	0.17	0.50	2	0.99	4	1.98
Sonchus cf. arvensis		15	1			5		10		5											5	1.8	4.10	1.23	2.66				
Taraxacum officinale		1	1	1	15	5	5	1				1	1					1	1		11	1.65	9.02	1.13	5.07				
Tragopogon dubium																					0	0	0.00	0.00	0.00				
Trifolium repens		70																			1	3.5	0.82	2.39	1.61				
Vicia cracca																					0	0	0.00	0.00	0.00				

Table D2f: Green roof species cover estimates – grass section – October 12, 2005

Species	Quadrat #																				Frequency	Average % cover	Relative Frequency	Relative % cover	Importance value	Conservatism TRCA	Weighted conservatism TRCA	Conservatism NHIC	Weighted conservatism NHIC
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20									
Acer ginnala															1						1	0.05	0.79	0.03	0.41				
Acer negundo																					0	0	0.00	0.00	0.00				
Agrostis gigantea																					0	0	0.00	0.00	0.00				
Amaranthus cf. retroflexus																					0	0	0.00	0.00	0.00				
Ambrosia artemisiifolia																					0	0	0.00	0.00	0.00	4	0.00	0	0.00
Amelanchier sp.							1														1	0.05	0.79	0.03	0.41	7	2.88	5	2.05
Arenaria serpyllifolia																					0	0	0.00	0.00	0.00				
Asclepias syriaca																					0	0	0.00	0.00	0.00	1	0.00	0	0.00
Aster ericoides																					0	0	0.00	0.00	0.00	3	0.00	4	0.00
Aster lanceolatus		40	10		5																3	2.75	2.38	1.55	1.96	3	5.89	3	5.89
Aster sp.																					0	0	0.00	0.00	0.00	3	0.00	2	0.00
bare soil					5						1										2	0.3	1.59	0.17	0.88				
Betula papyrifera								1													1	0.05	0.79	0.03	0.41	6	2.47	2	0.82
bird's nest fungus																					0	0	0.00	0.00	0.00				
Bromus cf. japonicus																					0	0	0.00	0.00	0.00				
Capsella bursa-pastoris																					0	0	0.00	0.00	0.00				
Catalpa speciosa																					0	0	0.00	0.00	0.00				
Centaurea cyanus																					0	0	0.00	0.00	0.00				
Cerastium fontanum				10																	1	0.5	0.79	0.28	0.54				
Chaenorrhinum minus																					0	0	0.00	0.00	0.00				
Chenopodium album																					0	0	0.00	0.00	0.00				
Chrysanthemum x maximum																					0	0	0.00	0.00	0.00				
Cichorium intybus																					0	0	0.00	0.00	0.00				
Cirsium arvense																					0	0	0.00	0.00	0.00				
conifer seedling (Pinus nigra?)																					0	0	0.00	0.00	0.00				
Conyza canadensis																					0	0	0.00	0.00	0.00	2	0.00	0	0.00
Coreopsis lanceolata																					0	0	0.00	0.00	0.00				
Crepis cf. tectorum											15			1							2	0.8	1.59	0.45	1.02				
Daucus carota										1										1	2	0.1	1.59	0.06	0.82				
Dianthus barbatus																					0	0	0.00	0.00	0.00				
Draba sp.																					0	0	0.00	0.00	0.00				
Echinacea purpurea																					0	0	0.00	0.00	0.00				
Elaeagnus angustifolia			20																	60	2	4	1.59	2.25	1.92				
Epilobium ciliatum																					0	0	0.00	0.00	0.00	3	0.00	3	0.00
Epilobium hirsutum																					0	0	0.00	0.00	0.00				
Epilobium parviflorum						1															1	0.05	0.79	0.03	0.41				
Erigeron annuus					1		10														2	0.55	1.59	0.31	0.95	1	0.95	0	0.00
Erigeron philadelphicus																					0	0	0.00	0.00	0.00	1	0.00	1	0.00
Euthamia graminifolia			1																		1	0.05	0.79	0.03	0.41	5	2.05	2	0.82
Festuca spp.	70	50	100	90	1	70	90	15	90	90	20	95	100	90	100	1	70	90	100	100	20	71.6	15.87	40.28	28.08				
Fragaria virginiana																					0	0	0.00	0.00	0.00				
Fraxinus pennsylvanica							1			1									1		3	0.15	2.38	0.08	1.23	5	6.16	3	3.70
grass sp. (slender?)																					0	0	0.00	0.00	0.00				
Gypsophila muralis																					0	0	0.00	0.00	0.00				
Hieracium aurantiacum															1						1	0.05	0.79	0.03	0.41				
Hieracium cf. piloselloides						1					5					1					3	0.35	2.38	0.20	1.29				
Kochia scoparius																					0	0	0.00	0.00	0.00				
Lactuca serriola																					0	0	0.00	0.00	0.00				
liverwort																					0	0	0.00	0.00	0.00				
Malus sp.																					0	0	0.00	0.00	0.00				
Medicago lupulina	15								50						15						3	4	2.38	2.25	2.32				
Melilotus alba	50	50	20										10			80	90				6	15	4.76	8.44	6.60				
Melilotus officinalis																					0	0	0.00	0.00	0.00				
mosses	60		50	20	90	80	60	95	40	70	95	40	30	80	30	95	40	80	40	20	19	55.75	15.08	31.36	23.22				
mustard sp. (perennial)																					0	0	0.00	0.00	0.00				
Oenothera biennis?																					0	0	0.00	0.00	0.00	2	0.00	0	0.00
Parthenocissus sp.														1			1			1	3	0.15	2.38	0.08	1.23				
Penstemon digitalis																					0	0	0.00	0.00	0.00	6	0.00	6	0.00
Plantago major				1																	1	0.05	0.79	0.03	0.41				
Poa pratensis	1																				1	0.05	0.79	0.03	0.41				
Polygonum aviculare																					0	0	0.00	0.00	0.00				
Polytrichum sp. (haircap moss)								1													1	0.05	0.79	0.03	0.41				
Populus deltoides										1											1	0.05	0.79	0.03	0.41	5	2.05	4	1.64
Populus grandidentata										5											1	0.25	0.79	0.14	0.47	7	3.27	5	2.34
Populus tremuloides			1			1		10		5									1		5	0.9	3.97	0.51	2.24	4	8.95	2	4.47
Ratibida columnifera																					0	0	0.00	0.00	0.00				
Rhamnus cathartica																					0	0	0.00	0.00	0.00				
Rudbeckia hirta														1							1	0.05	0.79	0.03	0.41	7	2.88	0	
Salix bebbiana						1															1	0.05	0.79	0.03	0.41	8	3.29	4	1.64
Salix x rubens																					0	0	0.00	0.00	0.00				
Salsola tragus																					0	0	0.00	0.00	0.00				
Setaria viridis																					0	0	0.00	0.00	0.00				
Silene armeria																					0	0	0.00	0.00	0.00				
Silene vulgaris																	10				1	0.5	0.79	0.28	0.54				
Solanum dulcamara																					0	0	0.00	0.00	0.00				
Solidago altissima	10	20	25	1	50	5	15	20		1	5	5				50		1	1		14	10.45	11.11	5.88	8.50	0	0.00	1	8.50
Solidago gigantea						5															1	0.25	0.79	0.14	0.47	2	0.93	4	1.87
Sonchus cf. arvensis		10	1			5		10		15											5	2.05	3.97	1.15	2.56				
Taraxacum officinale	1	1	1	1	5	5	5				1	5	1	1		1		1	1		14	1.5	11.11	0.84	5.98				
Tragopogon dubium																					0	0	0.00	0.00	0.00				
Trifolium repens		90																			1	4.5	0.79	2.53	1.66				
Vicia cracca															15						1	0.75	0.79	0.42	0.61				

Table D3a: "Wildflower" Roof Plant Groupings: summer 2004

	relative frequency	relative cover	importance value
native species	20.86	11.67	16.26
exotic species	57.75	38.01	47.88
non-vascular plants	11.76	43.14	27.45
bare soil	9.63	7.18	8.40

Table D3b: Grassed Roof Plant Groupings: summer 2004

	relative frequency	relative cover	importance value
native species	33.56	9.22	21.39
exotic species	47.65	56.99	52.32
non-vascular plants	13.42	31.74	22.58
bare soil	5.37	2.05	3.71

Table D3c: "Wildflower" Roof Plant Groupings: fall 2004

	relative frequency	relative cover	importance value
native species	24.42	12.23	18.32
exotic species	52.91	42.73	47.82
non-vascular plants	12.79	34.09	23.44
bare soil	9.88	10.95	10.42

Table D3d: Grassed Roof Plant Groupings: fall 2004

	relative frequency	relative cover	importance value
native species	33.08	5.86	19.47
exotic species	50.38	63.21	56.79
non-vascular plants	15.79	30.73	23.26
bare soil	0.75	0.20	0.48

Table D3e: "Wildflower" Roof Plant Groupings: spring 2005

	relative frequency	relative cover	importance value
native species	18.42	5.03	11.73
exotic species	60.53	37.54	49.04
non-vascular plants	11.58	43.09	27.33
bare soil	9.47	14.34	11.91

Table D3f: Grassed Roof Plant Groupings: spring 2005

	relative frequency	relative cover	importance value
native species	28.70	6.51	17.60
exotic species	52.17	56.83	54.50
non-vascular plants	17.39	36.32	26.85
bare soil	1.74	0.34	1.04

Table D3g: "Wildflower" Roof Plant Groupings: summer 2005

	relative frequency	relative cover	importance value
native species	18.91	10.21	14.56
exotic species	61.69	44.49	53.09
non-vascular plants	9.95	33.66	21.80
bare soil	9.45	11.65	10.55

Table D3h: Grassed Roof Plant Groupings: summer 2005

	relative frequency	relative cover	importance value
native species	31.15	8.38	19.76
exotic species	48.36	62.23	55.30
non-vascular plants	18.03	29.01	23.52
bare soil	2.46	0.38	1.42

Table D3i: "Wildflower" Roof Plant Groupings: fall 2005

	relative frequency	relative cover	importance value
native species	18.37	9.56	13.96
exotic species	59.18	48.29	53.74
non-vascular plants	12.76	33.94	23.35
bare soil	9.69	8.21	8.95

Table D3j: Grassed Roof Plant Groupings: fall 2005

	relative frequency	relative cover	importance value
native species	27.78	8.78	18.28
exotic species	54.76	59.66	57.21
non-vascular plants	15.87	31.39	23.63
bare soil	1.59	0.17	0.88

Table D4a: York University Green Roof - Floristic Composition; Site Coefficients of Conservatism (CC) and Floristic Quality Indices (FQI) 2004

	Whole Roof	Sections of Roof				
		"Wildflower"	Grassed	Containers	Lower	Unseeded
# vascular plant species	**91**	43	51	32	26	33
# native species	**29**	11	21	9	8	15
# exotic species	**62**	32	30	23	18	18
# non-vascular plant taxa	**4**	3	3			
mean CC TRCA	**4.48**	3.64	4.05	4.44	3.63	3.87
mean CC NHIC	**2.90**	2.09	2.81	2.67	2.00	2.07
site FQI TRCA	**24.14**	12.06	18.55	13.33	10.25	14.98
site FQI NHIC	**15.60**	6.93	12.87	8.00	5.66	8.00

Table D4b: York University Green Roof - Floristic Composition; Site Coefficients of Conservatism (CC) and Floristic Quality Indices (FQI) 2005

	Whole Roof	Sections of Roof				
		"Wildflower"	Grassed	Containers	Lower	Unseeded
# vascular plant species	**110**	62	62	26	32	36
# native species	**40**	18	26	8	8	18
# exotic species	**70**	44	36	18	24	18
# non-vascular plant taxa	**4**	4	4	1	1	3
mean CC TRCA	**4.48**	3.72	4.58	3.13	3.75	3.94
mean CC NHIC	**2.83**	2.28	2.69	1.33	1.50	2.33
site FQI TRCA	**28.30**	15.79	23.34	8.84	10.61	16.73
site FQI NHIC	**17.87**	9.66	13.73	3.77	4.24	9.90

Table D5a: Mean Quadrat Coefficients of Conservatism (CC) and Floristic Quality Indices (FQI) 2004

	"Wildflower" Roof				Grassed Roof			
	summer		fall 2004		summer		fall 2004	
CC - TRCA *(stand. deviation)*	2.67	*1.19*	2.67	*1.40*	2.20	*0.91*	1.60	*1.30*
CC - NHIC *(stand. deviation)*	1.35	*1.35*	1.61	*1.64*	1.47	*0.94*	1.19	*0.90*
FQI - TRCA *(stand. deviation)*	3.78	*1.80*	3.77	*1.93*	3.49	*2.00*	2.76	*2.56*
FQI - NHIC *(stand. deviation)*	1.86	*1.49*	2.21	*1.69*	2.29	*1.38*	1.96	*1.57*

Table D5b: Mean Quadrat Coefficients of Conservatism (CC) and Floristic Quality Indices (FQI) 2005

	"Wildflower" Roof						Grassed Roof					
	spring		summer		fall		spring		summer		fall	
CC - TRCA *(stand. deviation)*	2.95	*2.19*	3.41	*2.11*	2.47	*2.12*	1.44	*1.85*	1.41	*1.73*	1.55	*2.08*
CC - NHIC *(stand. deviation)*	2.19	*2.00*	2.50	*2.08*	1.88	*1.74*	1.18	*1.10*	1.27	*1.03*	1.17	*1.01*
FQI - TRCA *(stand. deviation)*	4.01	*2.75*	4.74	*2.67*	3.85	*3.37*	2.48	*3.42*	2.55	*3.18*	2.65	*3.48*
FQI - NHIC *(stand. deviation)*	2.98	*2.26*	3.44	*2.42*	2.83	*2.45*	1.89	*2.15*	2.08	*2.05*	1.95	*2.15*

Figure D1a: Relative Frequency: "w ildflow er" roof, summer 2005

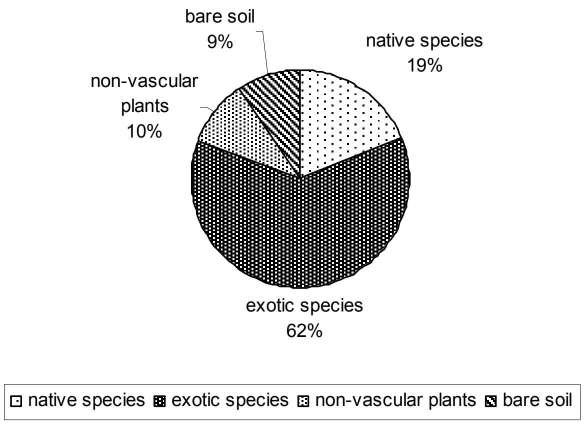


Figure D1b: Relative Frequency: grassed roof, summer 2005

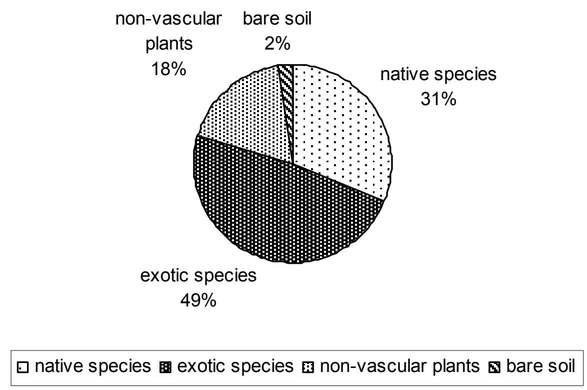


Figure D2a: Relative Cover: "w ildflow er" roof, summer 2005

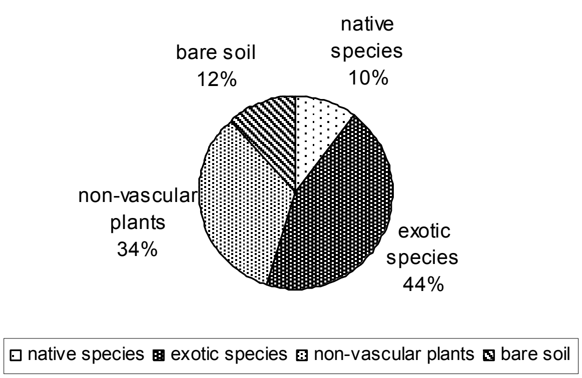


Figure D2b: Relative Cover: grassed roof, summer 2005

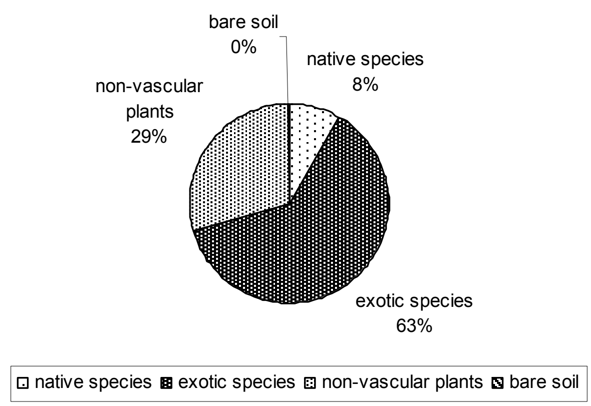


Figure D3a: Relative Importance Value: "w ildflow er" roof, summer 2005

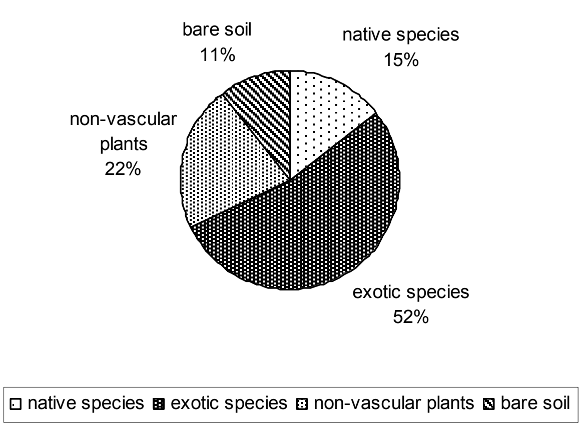


Figure D3b: Relative Importance Value: grassed roof, summer 2005

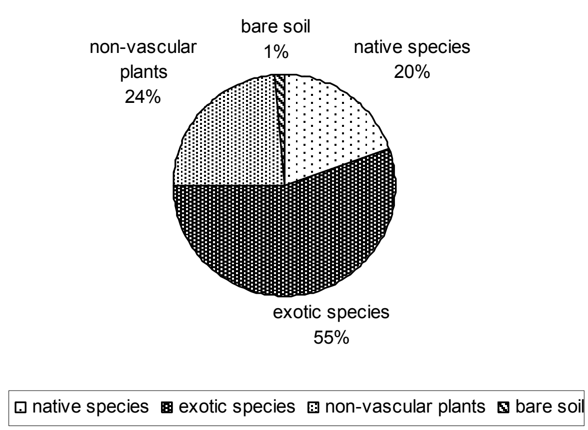


Figure D4: **Roof & Section Mean Coefficients of Conservatism**

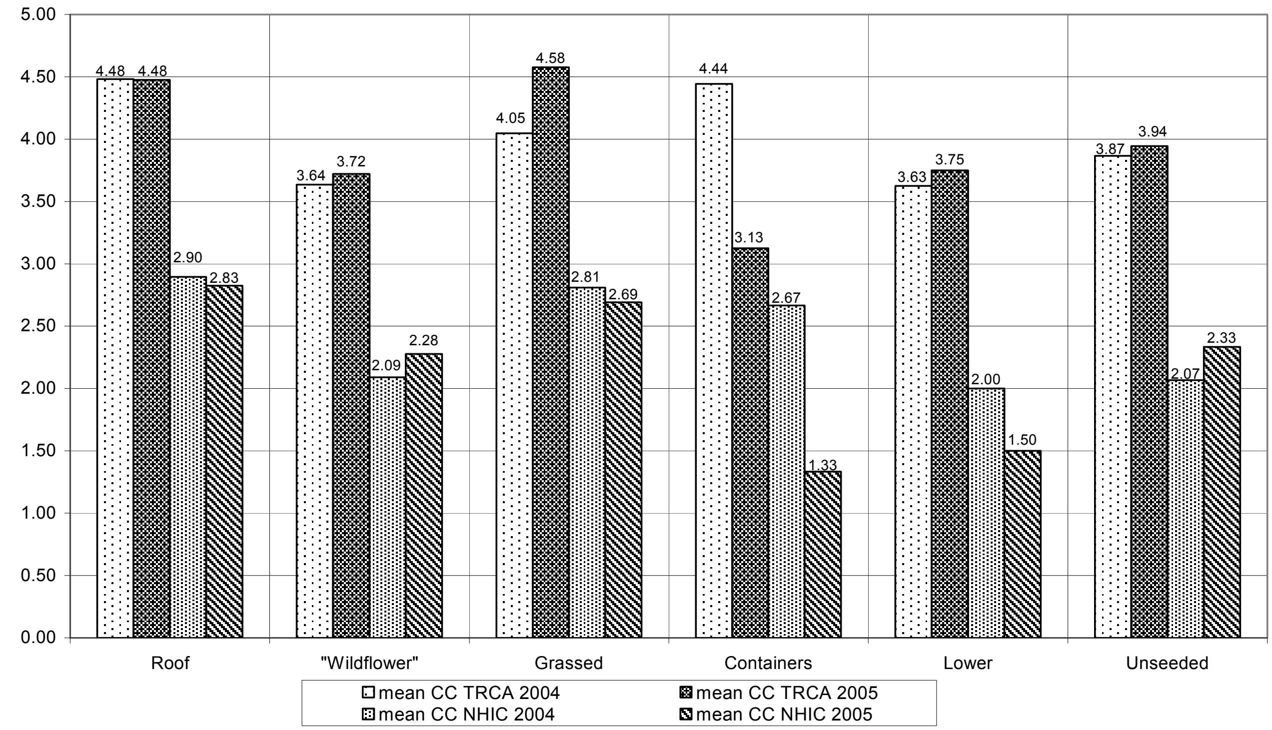


Figure D5: **Roof & Section Mean Floristic Quality Indices**

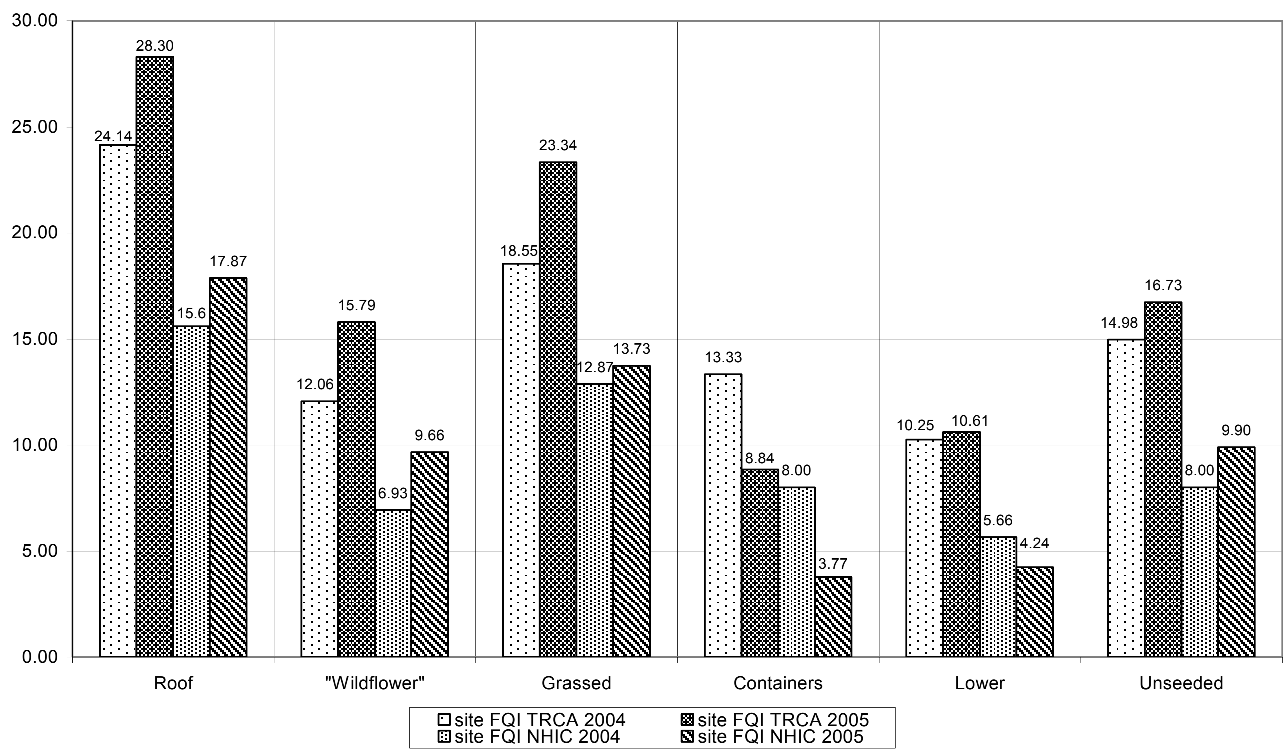


Figure D6a: **Mean Quadrat TRCA Coefficients of Conservatism**

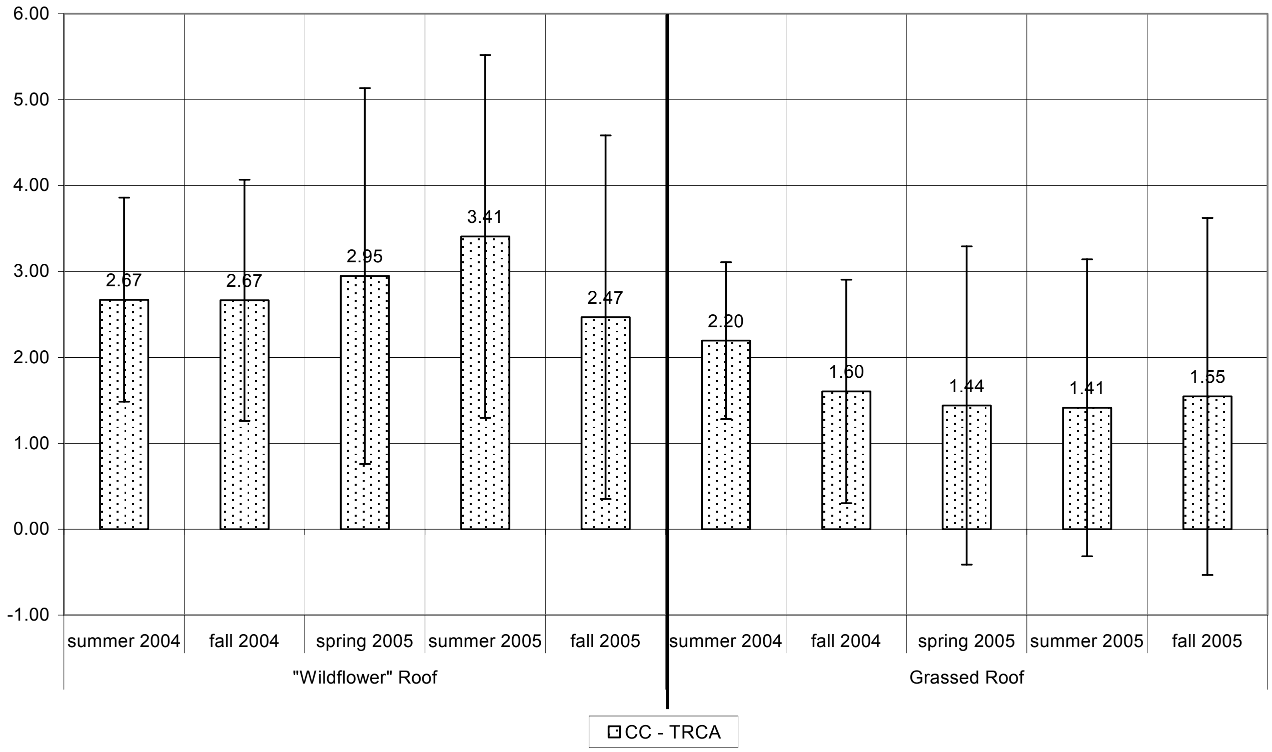


Figure D6b: **Mean Quadrat NHIC Coefficients of Conservatism**

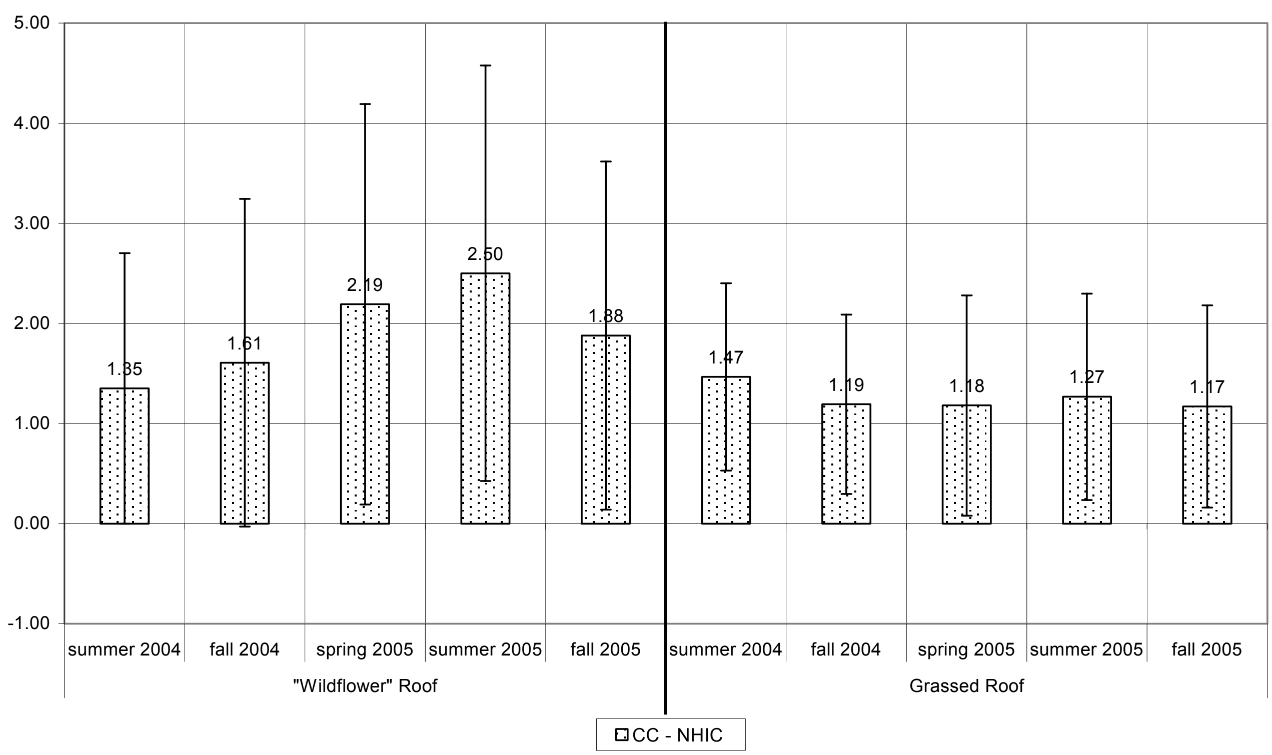


Figure D7a: **Mean Quadrat TRCA Floristic Quality Index**

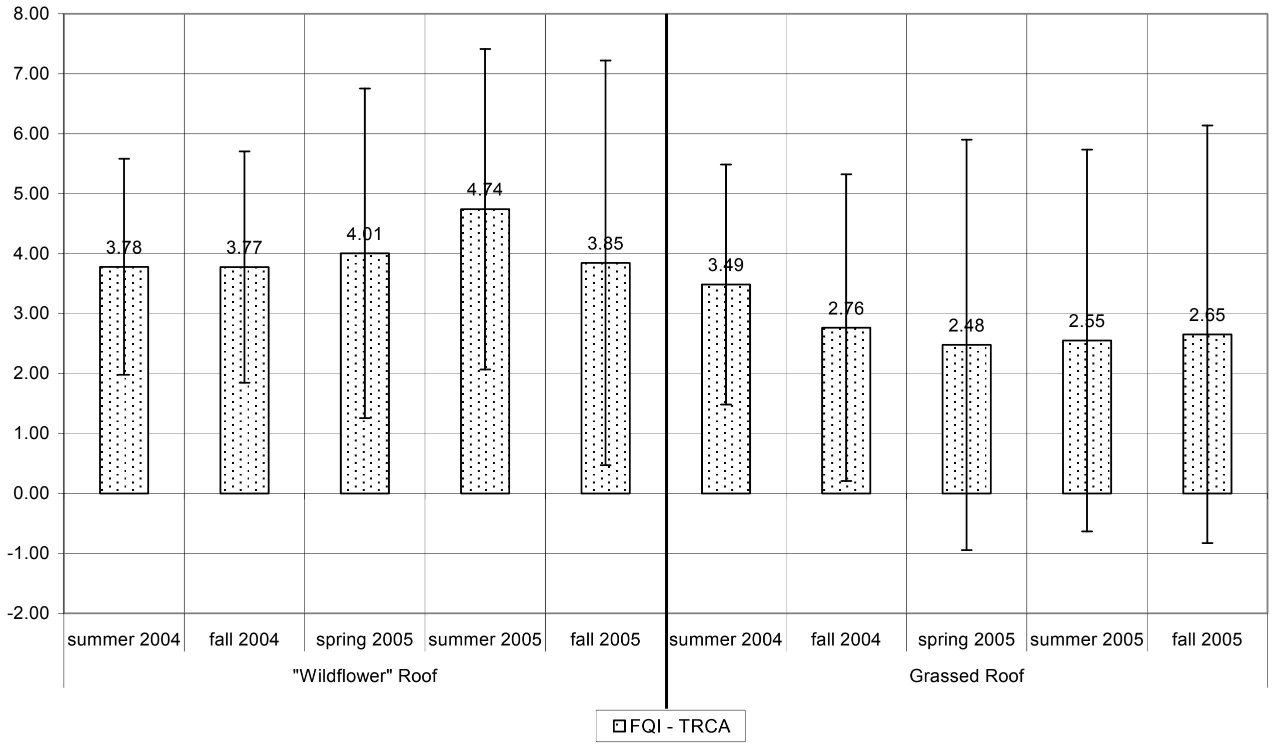
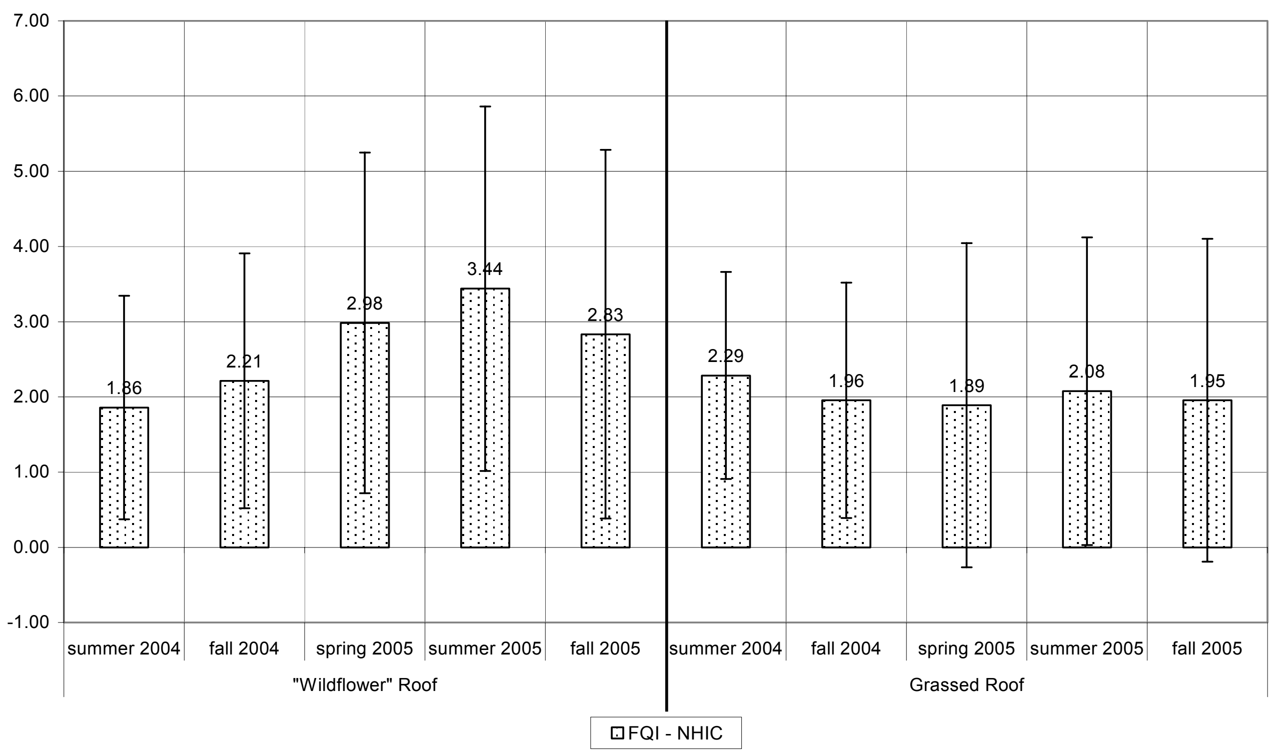


Figure D7b: **Mean Quadrat NHIC Floristic Quality Index**



APPENDIX E

Greenroof Plant Recommendations

PLANTING FOR BIODIVERSITY ON GREENROOFS – RECOMMENDATIONS

The following recommendations are based upon flora data collected at the York University Greenroof during 2004 and 2005, as well as general restoration principles. These recommendations may evolve over time as we expand our knowledge of how greenroofs perform in the GTA.

1. The key to improving biodiversity for greenroofs is to provide the habitat and allow nature to do most of the work.

2. The exotic-dominated seed mixes used at the York University Greenroof continue to exert a strong effect on the species composition five years later, although there are subtle, gradual changes. Flora surveying must be conducted over a period longer than two years in order to determine whether the net changes are towards native biodiversity or weediness, and whether trends are statistically significant. Native plants of conservation concern are appearing, but there also increases in weedy nitrogen-fixing species (*i.e.* alien legumes and Russian-olive). The legumes were probably present in the seed mix; the Russian-olive was probably introduced by birds.

3. The highest proportion of native to exotic species at the York University Greenroof is found in the section that received no seed mix, but simply relied on colonization by ambient seed rain. This is not the basis for an argument against planting, however the type and timing of planting should be strategic and take into consideration which plants will colonize naturally due to dispersal by wind or birds.

4. In order to maximize biodiversity on a greenroof, habitat diversity must be incorporated. This may be accomplished by using a range of different substrate types, substrate depths, and irrigation regimes. Some areas should receive no irrigation, while others could have water features or wetlands.

5. The generally low-nutrient status on green rooftops is actually beneficial to biodiversity. It favours stress-tolerant, specialized native flora over aggressive opportunistic species that benefit competitively from high nutrient levels. In general, there should be no fertilization on greenroofs where biodiversity is the aim.

6. Plants that naturally colonize greenroofs easily are dispersed either by wind or by birds. For example, asters have a pappus on the seed that facilitates wind dispersal, while ladies' tresses orchids are minute and dust-like. The invasive Russian-olive has small fruit that are consumed by birds. Therefore, plantings should emphasize species that are not readily dispersed by wind or birds. These are less likely to arrive on their own.

7. Greenroof environments are suitable for certain meadow, prairie, alvar, and meadow-marsh plants that include many species of conservation concern. Species chosen should be adaptable to drought, wind, low nutrients, and (usually) alkaline soils, as building materials, artificial substrates, and irrigation water in the Toronto area tend to be alkaline.

8. Shrub species can also be suitable. Trees would require special structural reinforcement in the building during construction.

9. Plants should be from locally-collected seed.

10. Local native seed and plants tend to be considerably more expensive than commercial seed mixes. Use a "nucleus approach" where quantities can be small rather than broadcasting over the whole roof.

The following is a plant list for greenroofs taking into account the above factors. The list only includes native plants, which are encouraged to promote habitat and native biodiversity. Common species likely to arrive in significant numbers on their own are omitted.

SHRUBS

Species	**Common name**	**Notes**
Arctostaphylos urva-ursi	bearberry	Extirpated from the wild in the TRCA jurisdiction.
Juniperus communis	common juniper	Exposure-tolerant native evergreen. Good for shelter / habitat.
Juniperus virginiana	red cedar	Can become a tree
Prunus pumila var. susquehanae	sand cherry	Extirpated from the wild in the TRCA jurisdiction
Rosa blanda	smooth wild rose	
Rubus flagellaris	dewberry	An uncommon dwarf blackberry
Shepherdia canadensis	buffaloberry	
Spiraea alba	meadowsweet	Moist places

GRAMINOIDS

Species	**Common name**	**Notes**
Agrostis scabra	ticklegrass	Appeared spontaneously at York University
Andropogon gerardii	big bluestem	Tallgrass prairie species
Bromus kalmii	Kalm's brome	Extirpated from TRCA jurisdiction
Calamagrostis canadensis	Canada bluejoint	Moist to wet areas
Carex aurea	gold-fruited sedge	
Carex flava	yellow sedge	Moist alkaline areas
Carex granularis	meadow sedge	
Carex molesta	troublesome sedge	Moist alkaline areas
Carex muhlenbergii	muhly sedge	Dry sandy or gravelly substrates
Carex siccata	sandbank sedge	Dry sandy or gravelly substrates
Danthonia spicata	poverty oat grass	
Juncus dudleyi	Dudley's rush	
Muhlenbergia mexicana	common muhly grass	
Panicum acuminatum	hairy panic grass	
Panicum virgatum	switch grass	Tallgrass prairie species
Schizachyrium scoparium	little bluestem	Tallgrass prairie species
Scirpus pendulus	nodding bulrush	Moist alkaline areas
Sorghastrum nutans	Indian grass	Tallgrass prairie species
Sphenopholis intermedia	slender wedge grass	
Sporobolus cryptandrus	sand dropseed	Sandy or gravelly substrates

FORBS

Species	Common name	Notes
Agalinis tenuifolia	slender gerardia	Sown on one section of York University 03 Feb 06
Anaphalis margaritacea	pearly everlasting	
Anemone cylindrical	long-headed thimbleweed	
Antennaria spp.	pussytoes	
Aster oolentangiensis	sky-blue aster	Spontaneously appeared at York University in low numbers
Aster urophyllus	arrow-leaved aster	Spontaneously appeared at York University in low numbers
Campanula rotundifolia	harebell	
Cirsium discolor	pasture thistle	Rare thistle for recovery plan (Species At Risk Act)
Desmodium canadense	showy tick-trefoil	Native legume
Epilobium angustifolium	fire-weed	
Equisetum variegatum	variegated scouring-rush	
Fragaria virginiana	wild strawberry	Spontaneously appeared at York University 2005
Gentiana andrewsii, Gentianopsis crinita, Gentianella quinquefolia	gentians (bottle, fringed, stiff)	All are species of concern. Greenroofs could provide very suitable habitat (moist, exposed, alkaline). They could be part of a local recovery plan for these species. Irrigation probably needed.
Gnaphalium obtusifolium	fragrant everlasting	
Liatris spicata	spike blazing-star	Recovery plan (Species At Risk Act)
Monarda fistulosa	wild bergamot	
Penstemon digitalis	foxglove beard-tongue	In York seed mix
Penstemon hirsutus	hairy beard-tongue	
Physostegia virginiana	obedient plant	
Potentilla simplex	old-field cinquefoil	
Rudbeckia hirta	black-eyed Susan	In York seed mix
Rumex acetosella	sheep sorrel	
Silene antirrhina	sleepy catchfly	Exotic Silene spp. are abundant at York.
Sisyrinchium montanum	common blue-eyed grass	Sown on one section of York University 03 Feb 06
Verbena simplex	slender vervain	
Verbena stricta	hoary vervain	

APPENDIX F

Fauna Inventory

Monitoring Vertebrate Fauna Use of a Green Roof Site at York University

Based on results of the monitoring of fauna on the York University green roof in 2004 it was decided that the methodology should remain unchanged but to attempt more visits through the season. The intention was to maintain the same degree of coverage through the main breeding season months (June and July) but then to increase the number of visits through the spring and fall migration periods, thereby increasing the chances of encountering visiting migrants (this was suggested due to time constraints during the TRCA fauna-survey field-work season, June/July).

Inventory Method

Visits to the green roof site were made as opportunities arose for the period April through to October. The duration for each visit was kept to approximately 15 minutes, as dictated by opportunity and expectation. For the bird breeding season period (June and July) it is sufficient to make only one visit per month since if a species is breeding on the site it should be present every day and the choice of visit date should not influence the chance of encountering that individual. Ideally these breeding season visits should be made in mid to late June and early July. For the migrant period, spring and fall, the visits need to be more frequent since migrants will potentially be present for only hours (or minutes) at a time; increasing the frequency of visits increases the chance of encountering such transients.

In 2005 the green roof site was visited a total of ten times between early mid-April and mid-October. The June visit was missed but results from the visit made on 31/05/05 are probably a fair indication of what was present in June. Each visit began with the biologist standing quietly for about 5 minutes, assessing the presence of any birds on the site. The biologist then walked slowly around the entire site, usually taking approximately 10 minutes. Where necessary (e.g. over larger patches of vegetation) the biologist walked across sections of the vegetation, but otherwise kept to the perimeter of the garden. Notes were taken for each visit detailing the weather conditions and time of observer arrival and departure; any fauna (birds) observed were mapped on a rough diagram of the project site together with brief details of their behaviour (e.g. foraging, resting, singing, breeding). Essentially, the biologist was required to do as much as necessary to determine whether any birds were present on the green roof during the visit.

Results

Species	6/5/04	20/5/04	31/5/04	17/6/04	6/7/04	18/8/04	10/9/04	6/10/04
Canada goose	1 Obs, 2b	2b						
mourning dove			1 Obs					
European starling	1 Obs	1 Obs					1 Obs	
savannah sparrow	1 Obs							

Species	18/4/05	25/4/05	4/5/2005	19/5/05	31/5/05	18/7/05	15/8/05	30/8/05	21/9/05	12/10/05
Canada goose	2b, 1r	2b	2b	2b						
mourning dove	1f									
European starling	1f, 5r	1s	1s, 1r	4f	2f					
chipping sparrow						1f				
house sparrow				1b	1b	1r			1r	

Note: Obs = observed. In 2005 this was refined to describe whether the bird was observed to be roosting/resting (r), foraging/feeding (f), or singing (s). In both 2004 and 2005, b = breeding. Numbers indicate the number of individual birds observed to be engaged in the activity.

Discussion of Results

A total of six bird species were found using the greenroof over the course of all visits in 2004 and 2005. The intention at the beginning of the season was to visit the site twice in each migration-season month from April to November with one visit in each of the two breeding season months (June and July). Such an itinerary would have resulted in a total of 14 visits. In 2005, only 10 visits were made but it is doubtful that any real change in observations would have resulted had the full quota of visits been conducted. As in the 2004 results, species such as house finch, rock pigeon, common grackle and ring-billed gull, all of which should at some time be seen foraging on such a roof top garden, were notable by their absence.

Two species – Canada goose and house sparrow – were noted as breeding on the green roof. The Canada goose pair nested very close to last year's site but failed at the egg stage; the nest was unattended on 19th May, and crushed egg-shell was found in the abandoned nest. There was no indication as to the cause of the failure. The house sparrows were observed carrying food into a nest below the eaves of the upper level of the green roof.

European starlings breed on nearby buildings (as do house sparrows) so it was no surprise that this was the most frequent species on the site; foraging for nest material was observed by this species early in the season. An addition to the small list of species observed using the green roof is chipping sparrow. This species was seen foraging successfully on the 18th July when an adult bird was observed to catch a large orthopterid and then fly west to a nearby mature tree where the food was given to waiting juveniles. As predicted in last year's report, as the invertebrate population associated with the green roof increases it is likely that more of such foraging behaviour will be observed.

On the three earlier dates (April 18th and 25th, May 4th) migrant (and non-migrant) bird activity was noted in ground level vegetation on the approach to the building. On these dates, species such as white-throated sparrow, hermit thrush, slate-coloured junco, American robin and northern cardinal were seen foraging on lawns and among other garden vegetation within 100 m of the building.

At the beginning of the 2004 season there was some hope that the rooftop would be used by passing migrants. In 2005 there was no migrant activity recorded despite the presence of migrant species at ground level within the vicinity of the building. It is highly likely that migrants visited the site during the spring and fall, much as it is likely that migrants landed on many of the surrounding non-green roofs. The hope however is that the green roof will provide foraging and shelter for migrants, such that the presence of the green roof is actually benefiting those migrants. This being the case the chances of encountering a migrant bird on the green roof should become higher since the duration of each migrant visit will be prolonged as foraging and shelter prospects improve over time.

General Discussion

There are two quite different questions that can be asked with regards to fauna use of the green roof site and the direction of future monitoring depends on which of these two questions the project is hoping to address.

1) Does the fauna use (where "use" includes breeding, foraging and resting) of the green roof increase as the vegetation establishes itself over the course of time?
2) How does fauna use of the green roof site compare to use of other sites in the vicinity, either natural cover at ground level or non-green roof sites (controls)?

Since the answer to the former question is partly dependent on the establishment of a healthy invertebrate population on the roof such a question will be unanswerable for the first few years of the life of the green roof. The latter question would require a much larger input of time and effort and it is possible, given the limited expectations for benefit of this site from a fauna perspective, that such an input is deemed excessive. Anecdotally, however, the observations made in the vicinity of the building in spring, 2005, suggest that at this juncture there are many more migrants (particularly early-season, temperate migrant species) using ground-level vegetation in the vicinity of the building.

At this early stage in the development of the green roof site it is more important to closely monitor changes in invertebrate fauna. Once the invertebrate population has been established the potential for greater use by birds - migrants and local breeders - will increase.

Attempts should be made - again - in 2006 to increase the number of visits through spring and fall, commencing in April and ending in November. No change to the actual protocol during those visits is necessary.