

Green Roof Infrastructure Workshop:

Establishing Common Protocols for Building and Aggregate Level Green Roof Benefits Research

Tuesday June 13, 2000
University of Toronto, Faculty Club
41 Wilcocks St. Toronto, Canada
8:30 a.m. – 6:00 p.m.

Workshop Proceedings

Green Roofs for Healthy Cities
Environment Canada, Ontario Region
City of Toronto Public Works and Emergency Services
Toronto and Region Conservation Authority
Institute for Environmental Studies, University of Toronto



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Preface

These proceedings reflect the discussions among various experts from a cross section of disciplines that were held on June 13, 2000. They also include the expert input and advice we have gathered through a subsequent peer review process. Given the wide range of benefits that green roofs provide, the virtually infinite number of different green roof designs and contexts for implementation, there is much that still needs to be done in order to be able to adequately quantify the performance of these systems. Some areas within the document are well developed while others require additional efforts. Certain areas, such as biodiversity enhancement have not yet been addressed. Hence, these proceedings should be considered as a ‘work in progress’.

Our intent is to continue these discussions and expert reviews until we have established an effective research protocol for green roof infrastructure in North America. This will enable comparability of data between systems in different climate zones and also support a better understanding and valuation of the many public benefits of green roofs. Such a valuation is critical to the establishment of cost effective public direct and indirect investment in the establishment of a North American green roof industry.

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1.0 Introduction

The growing concern about the urban heat island, stormwater runoff, biodiversity, the effect of weather on building infrastructure and the lack of green urban amenity space has raised the awareness of the benefits of urban vegetation. The interest in urban vegetation has grown beyond urban forestry to encompass unconventional spaces. In particular, rooftops have received attention because of the large amount of available space rooftops occupy, the relative ease of using flat and moderately sloped surfaces, and the historical precedents for using rooftops to support vegetation in many cultures. In addition, a green roof infrastructure technology has been developed and used throughout Europe, a green roof infrastructure industry exists in Europe and in North America, the roofing industry is interested in marketing the technology and has developed the expertise in working with roofing materials and infrastructure.

In 1999, the Canada Mortgage and Housing Corporation issued a report, *Greenbacks from Green Roofs: Forging a New Industry in Canada* (Peck et al., 1999). This report was based on a review of the literature, an analysis of several green roof projects and an expert workshop. It provided a state-of-the-art summary of the benefits of green roofs and identified barriers to their widespread adoption in Canada. One of the critical barriers discussed in the report is the need for research to quantify the many benefits of green roofs within the Canadian context.

In reviewing the literature, it became obvious that research into the benefits of green roof infrastructure is a relatively new area, and as such there were no commonly accepted protocols for undertaking this research. Specifically, issues such as the variables, the scale of analysis, the quality of the data, the acceptable level of uncertainty, the types of models to use, and any technological assumptions had not been discussed and the research community as well as government and industry lacked a basis for evaluating research proposals. In addition, the members of the research community had not had a previous forum in which to discuss these issues and to report on the status of current research projects and research proposals.

The Green Roof Infrastructure Workshop, *Establishing Common Protocols for Building and Aggregate Level Green Roof Benefits Research* took place on Tuesday June 13, 2000 at the University of Toronto's Faculty Club. The workshop was a full-day event and hosted green roof and other researcher's in related areas from across Canada and the United States (for a list of workshop participants, please refer to Appendix 1).

The event was organized by the Adaptation and Impacts Research Group, Environment Canada and Green Roofs for Healthy Cities, a private sector consortium that is working to develop a green roof industry in North America. The event was sponsored by:

- ◆ Department of Public Works, City of Toronto,
- ◆ the Institute for Environment Studies, University of Toronto, and
- ◆ the Toronto & Region Conservation Authority.

2.0 Objectives

The objectives of the workshop were to bring together experts in a variety of fields to network and exchange views in order to:

- Share information about existing and planned green roof research.
- To share information on key ‘generic’ green roof system variables that should inform the design of site-level and aggregate or city-wide research projects.
- To begin to develop agreement on a protocol for the design of research methodologies at the site or building specific level. This will allow for comparability of data for different green roof systems in different climate zones throughout North America.
- To explore the development of a common research protocol and methodologies to calculate the aggregate or city-wide benefits that would accrue from broad green roof infrastructure implementation.
- To develop further partnerships to conduct additional research that may be needed and to share information.

Technical information about green roof performance can help to optimize public direct and indirect investment in the infrastructure and to evaluate the tangible public benefits that result from widespread green roof implementation.

3.0 Defining a Protocol

The purpose of a standard protocol is to ensure that the results from different research projects are comparable. This is particularly important in assessing the benefits of green roofs as many research studies are based on actual rooftops in specific locales, on different types of buildings and on different roof areas. Other studies are based on the use of models, yet at this point in time there are no protocols for matching model development to specific observations.

The first question to ask before taking an instrument to a site is what is to be measured? In other words, what is the phenomenon of interest? Broadly speaking there are two types of variables to describe phenomena, dependent and independent. Dependent variables describe the response of different green roof systems to the independent conditions and are directly related to the benefits. These variables also vary continuously in time. Independent variables can be further broken down into four types:

Physical properties: These are characteristics of the materials or components used in constructing a green roof system. Physical properties should be measured according to precise ‘protocols’ and should be reproducible. These are intensive properties that are not dependent on the quantity of material or geometry of a system such as the grain-size distribution and field capacity of the growing medium.

Environmental variables: These include location, roof orientation or geometry, and general climatic variables (e.g., average summer temperature, average summer rainfall).

System variables: These green roof characteristics may differ from roof to roof even if the physical properties are similar. They might include variables such as media layer thickness, roof slope, and drainage configuration.

Driving/Forcing variables: These are the imposed conditions to which the roof responds. These include external weather variables as well as interior building conditions that might affect the roof, such as indoor temperature. In general these variables are also reflective of continuously varying conditions.

The second question related to measurement or modeling a phenomenon is where is it? This is a question of scale more so than specific location. These questions are of particular importance when it is necessary to relate a set of observations or simulations a specific sites to a larger spatial domain. There are two scales of concern, space and time. Each phenomenon has a geographic address, specified by latitude, longitude and altitude and a temporal address for observations to describe some properties of the phenomenon. To account for the properties of a phenomenon, it is assumed that observations are referenced to a three-dimensional geographic space, a cube for example, that could be observed at a fixed frequency through time. A system of contiguous cubes would act as a geographic mesh permitting us to resolve the spatial and temporal extent of some phenomenon under study.

The geographic address of each cube is its centre point, and that within the geographic mesh, the cubes are grouped in degree tiles. The spatial resolution of a cube, or part of the geographic mesh, is defined by the length of one side since all sides are equal. The temporal resolution is defined by the monitoring frequency. Therefore, a reference to a geographic mesh with a 1 km resolution is a reference to cubes having dimensions of 30 arc-seconds x 30 arc-seconds x 30 arc-seconds, or approximately 1 km x 1 km x 1 km. A one-day temporal resolution is understood to have a daily monitoring frequency. From this perspective, the observations collected from an irregularly-shaped station network do not represent sampling from an evenly-spaced grid, but they do provide values for some of the volumes in the geographic mesh.

The third question relates to the quality of the data or simulation. The quality of a set of observations or model simulations is a question of uncertainty. The actual yes or no answer to the question of quality depends on the question that is being asked or the decision that has to be made. Regardless of the quality, the quantification of the uncertainty can be represented as a numerical interval, which represents the range of values within which any particular datum could fall. Every datum is expressed as a number plus or minus the maximum upper and lower values that define the uncertainty. This numerical interval includes many factors that contribute to uncertainty (U). These factors include accuracy ($X_{avg}-X_{true}$), precision (U_{prec}), deviating from observation protocol (U_{prot}) and the differences between the scale of the data and the scale at which the decision has to be made (U_{scale}). Another component that could be added in some cases to account for variations in the types of plant or surface cover on the roof (U_{cov}).

The five uncertainty terms contributing to the numerical uncertainty are shown in below.

$$\text{Numerical Interval} = (X_{avg}-X_{true}) + U_{prec} + U_{prot} + U_{cov} + U_{scale}$$

There are a few caveats to consider before tackling the derivation of a numerical interval. First, the measurement, or even the estimation, of numbers for each uncertainty beyond the environment of the instrument is very difficult because it is impossible to control the background environment while monitoring accurately small changes in a single variable at scales of 100 metres or more. Second, when a quantity is deduced for each uncertainty, it is done so with the understanding that the number represents a 95% confidence level, which represents an acceptable level of risk for variables affecting a decision. Third, the root-mean-square method is used to combine the different uncertainties, but a consensus of how each uncertainty should be weighted relative to another does not exist.

The root-mean-square method is a simple and popular method for combining different components of a larger numerical figure. Each of the smaller uncertainties due to precision, protocol, etc., is squared, the squares are summed and the square root of the sum is the total uncertainty. The final result is a value that has the same signs and units but is a smaller quantity than if all the terms were added together. A numerical interval, therefore, would be equivalent to the result of the root-mean-square calculation. Data with associated intervals are called standard data, as they can be used as a standard against which to evaluate other observations, derived data sets or forecasts.

In principle, the first two components will shrink as the number of observations increases because the root-mean-square method requires dividing the total by the number of

observations. However, this does not eliminate other uncertainty terms. For example, if two observers are not trained in the same manner, this will increase the protocol term. Assuming that a single measurement is representative of a wider spatial domain or a larger temporal domain will increase the scale term. Applying the observations to a different vegetation canopy, or in the appropriate case to a different green roof system, will increase the surface cover term.

This workshop was the first of its type in this area, and time was insufficient for flushing out the required data and uncertainties according to these schemes. Although every attempt has been made to remain true to the discussions that occurred, changes have been made where possible for clarity and where possible to accord with this discussion. Where possible, additional material has been added at the suggestion of external reviewers.

4.0 Workshop Agenda

- 8:30-9:00 a.m. Registration
- 9:00-9:05 Welcome (Dr. Brad Bass, Environment Canada, Environmental Impacts Research Group)
- 9:05-9:30 Overview of Green Roofs and Workshop Objectives (Steven Peck, Executive Director, Green Roofs for Healthy Cities)
- 9:30-10:15 Synopsis of Current & Planned Research Projects:
- 9:30-9:35 Ted Bowering, Manager Water/Soil Quality, City of Toronto – Eastview Community Centre and City Hall Podium Roof Sites
- 9:35-9:40 Susan Motkaluk, SDM and Ed Graham, Greenland Environmental Inc. – Proposed Seneca College Site
- 9:40-9:45 Karen Liu, NRC’s Institute for Research in Construction – Ottawa Research Sites
- 9:45-9:50 John Beaudry, Environment Department, City of Chicago – City Hall Site
- 9:50-9:55 Marie-Anne Boivin, Consultant, Laval University Research Site
- 9:55-10:00 Dr. Brad Bass, Environment Canada, Urban Heat Island Modeling in Toronto
- 10:00-10:05 Darlene Conway, Toronto and Region Conservation Authority, Aggregate Stormwater Benefits in Toronto
- 10:05-10:10 Lauren Baker, FoodShare Toronto, Urban Agriculture Research
- 10:30-12:15 Breakout Groups – Site Level - Protocol Development
- A1: Site Level – Air Quality and Energy Issues. Led by Lai Wong, Energy Efficiency Office
- B1: Site Level – Stormwater Quality and Quantity Issues. Led by Ted Bowering/Gary Stinson, Toronto Works and Emergency Services Dept.
- 10:30-12:15 Breakout Groups – Aggregate Level – Developing a Baseline
- C1: Aggregate Level – Modeling the Urban Heat Island. Led by Dr. Brad Bass, Environment Canada, Environmental Impacts Research Group
- D1: Aggregate Level – Stormwater Quality and Quantity. Darlene Conway, Toronto and Region Conservation Authority
- E1: Aggregate Level – Recreation/Special Applications. Monica Kuhn

- 12:15-1:15 Networking and Buffet Lunch (at the Faculty Club)
- 1:15-2:15 Plenary Reporting on Morning Sessions (10 minutes each group)
- 2:15-2:30 Move to Afternoon Breakout Groups
- 2:30-4:30 Breakout Groups - Site Level – Protocol Development Cont’d.
- A2: Site Level – Air Quality and Energy Issues. Heinrich Feistner
B2: Site Level – Stormwater Quality and Quantity Issues. Ted Bowering
- 2:30-4:30 Breakout Groups – Aggregate Level – Specific Research Methodology Development
- C1: Aggregate Level – Modeling the Urban Heat Island. Dr. Brad Bass
D1: Aggregate Level – Stormwater Quality and Quantity. Darlene Conway
E1: Aggregate Level – Recreation/Special Applications. Monica Kuhn
- 4:00-5:15 Plenary Reporting Back (5 Minutes) and Conclusion
- 5:15-6:15 Wine and Cheese Reception (Sponsored by Institute for Environmental Studies)

5.0 Project Overviews

The first part of the morning was devoted to short presentations on current green roof research projects. For project overviews, please refer to the Appendix.

5.1 Breakout Groups

In both the morning and afternoon, workshop participants divided into breakout groups to develop a set of protocols for conducting research on site specific benefits that can be derived from a green roof or aggregate benefits from the wide-spread adoption of this infrastructure technology. Some of the groups were discussed the site-level benefits and others discussed the aggregate or citywide level benefits. The site-level benefits were divided into the categories of energy efficiency and stormwater management. The aggregate-level benefits were divided into four breakout groups: stormwater management, recreation, food production and the urban heat island.

5.1.1 Structure of Breakout Group Discussions

Each breakout group was asked to choose one or two specific research goals and complete the given template:

1. Design
 - Which ‘generic’ or other green roof design is being assumed, if any, in the research protocol for a particular benefit?
 - Are there other design issues which need to be considered to satisfy the research goal? Depending on the breakout group, they may not have addressed both of these questions.
2. Specific Data Required
 - What is the specific type of data required to address the specific research goal?
3. Method of Obtaining Data
 - What methods are available for obtaining the required data and what are the pros and cons of different methods?
4. Temporal Issues
 - Discuss issues regarding frequency and duration.
5. Scale Issues
 - What spatial scale is most appropriate to meet the specific research goal?
6. Acceptable Levels of Uncertainty
 - What are the accepted levels of uncertainty in the data, the analysis and any modeling work?
7. Relationship to Aggregate/Site Level Research

- How does the proposed research methodology impact or effect research at the other level of benefits?
8. Tools Available
 - What tools are already available or may be modified to support this research endeavour?
 9. Additional Research Needs/Opportunities
 - Are there any other research needs or opportunities that result from this discussion?
 10. Cost Benefit Analysis
 - How might this information assist in quantifying public & private benefits?

The purpose of the template was to stimulate and guide the development of a research protocol. Using the same template for each breakout group offered an opportunity to establish a common basis for communication during and after the workshop and highlights important cross-cutting concerns that can be used for synthesizing the results of different research programs.

5.2 Summary of Breakout Group Discussions

5.2.1 A1 SITE LEVEL ENERGY EFFICIENCY

Specific Research Goal:

- ◆ To define an algorithm in order to calculate energy savings from a green roof.

Summary of Discussion about 'Design':

- ◆ Considerations related to assumptions about the green roof and/or in collecting data from a green roof:
 - The moisture content of the growing medium will affect the insulation or the 'R' value of the green roof as will the depth.
 - If there is a 30-year return period, 30 years of data will be required. This must be considered in the design of the green roof.
 - Rain and snow problems should also be examined.
 - If a control building is considered, it should be similar to the building with a green roof.
 - Duration of extra loading on structural design, especially in winter, is a concern.
 - Wind is also a factor.
 - Another factor is the additional shading provided by the type of vegetation on the green roof.
- ◆ Questions that need to be answered:
 - What is the effect of evaporative cooling?
 - What is the effect of thermal mass on cooling profile?
 - What is the depth of the growing medium, and what type of medium is it?
 - What is the building's orientation?

- What types of plants are being used?
- Are there any structural changes?
- What is the building configuration?
- What about drainage?

Summary of Discussion about ‘Specific Data Required’:

- ◆ Driving Variables:
 - ◆ Meteorological data (specifically precipitation, temperature, incoming short wave radiation, outgoing long wave radiation, humidity, soil moisture & runoff¹, soil temperature, wind).
 - ◆ Building data (interior building temperature, heat flux through the roof, humidity, roof beam deflection)
- ◆ Physical Properties: heat capacity of green roof at field capacity
- ◆ Dependent Variables:
 - ◆ Building data (surface temperature of the building, as well as the roof or canopy surface temperature, the membrane temperature, building energy consumption rate, runoff).

Summary of Discussion about ‘Method of Obtaining Data’:

- ◆ Temperature data should be collected with thermocouples .
- ◆ A literature search must be conducted for other studies, e.g. in Europe.
- ◆ Rain gauges should be used.
- ◆ Weather stations and flow gauges. Automatic rain gauges are not accurate. A tipping bucket or daily reading is more accurate and recommended.

Summary of Discussion about ‘Temporal Issues’:

- ◆ Temporal rate of plant growth will affect data collected and time and frequency at which it is collected.
- ◆ There are compaction and degradation of soil issues (minimum 2 years, maximum 5 years).
- ◆ Note: The tools that are required are already there, and the building configuration and other information are known.
- ◆ Given the fluctuations that can occur throughout the day, it is necessary to have sufficient data for hourly analysis. The minimum sampling rate would be every half-hour, but 5-minute time steps would be preferable and can be accommodated with most data logging equipment.

Summary of Discussion about ‘Scale Issues’:

- ◆ A bigger roof is better for a field site as data from smaller roofs are not always applicable to larger buildings due to the potential spatial variations in the data.

Summary of Discussion about ‘Acceptable Levels of Uncertainty’:

- ◆ To estimate the levels of uncertainty, a sensitivity analysis is required.

¹ Although these variable are dependent for questions related to stormwater management, they are also drivers for energy consumption.

- ◆ Thermocouples, to accommodate for solar gains on different building components, will better reflect the levels of uncertainty due to spatial variations, and allow the derivation of U_{scale} for future studies that may only use one instrument.
- ◆ Small roof areas and side-by-side placement of the control and the green roof may create additional uncertainties due to air mixing. This would increase the protocol component of the uncertainty.

Summary of Discussion about ‘Aggregate/Site Level Relationship’:

- ◆ In most cases, the research results can be applied to other buildings to determine aggregate impacts but this will increase the uncertainty in the estimates in terms of surface cover and/or scale.

Summary of Discussion about ‘Tools Available’:

- ◆ Data on site level energy benefits of green roof infrastructure should be available from European examples.
- ◆ ASHRAE algorithms.
- ◆ Building modeling software for insulation and shading.
- ◆ National Research Council – Institute for Research in Construction: green roof field site in Ottawa.

Summary of Discussion about ‘Additional Research Needs/Opportunities’:

- ◆ There are compaction and degradation of soil issues that need to be worked out.
- ◆ Development of an evapotranspiration component that could be linked to the building modeling software for insulation and shading.
- ◆ Pilot projects that are designed to maximize energy efficiency need to be constructed.

Summary of Discussion about ‘Cost-Benefits Analysis’:

- ◆ Not available

Reviewer Comments:

- ◆ The breakout group had initially identified the need to define different R or insulation values for heating, cooling or wet, dry and windy conditions. One reviewer suggested that this is not an appropriate thermal variable to measure and suggested that shading factor, heat capacity as a function of moisture content or thermal conductivity as function of moisture content are more appropriate, but whatever variables are chosen must be quantifiable using simple laboratory tests. The purpose of these measurements is to lead to the development of predictive models, and these variables are derived from physical properties that are similar, independent of location or orientation.

5.2.2 BI SITE LEVEL STORMWATER MANAGEMENT

Specific Research Goal:

- ◆ To evaluate the impacts of green roofs on stormwater quantity.

Summary of Discussion about ‘Design’:

- ◆ The structural capacity and drainage configuration of a building is important to consider.
- ◆ Extant hydrologic and meteorological data.
- ◆ Depth of growing medium, plant types, type of drainage layer, and type of growing medium all impact stormwater retention.

Summary of Discussion about ‘Specific Data Required’:

- ◆ Driving Variables: precipitation, temperature, wind, snow accumulation and melt (for climatic studies), incoming solar radiation, wind, pan evaporation
- ◆ Physical Properties: saturated hydraulic conductivity, percolation, infiltration, air content of growing medium, grain-size distribution, maximum water capacity
- ◆ Environmental Variables: latitude, roof orientation
- ◆ System Variables: plant type, leaf area index, thickness of growing medium, roof slope, drainage configuration
- ◆ Dependent Variables: runoff, evapotranspiration outputs,

Summary of Discussion about ‘Method of Obtaining Data’:

- ◆ Methods include:
 - ◆ Flow meters,
 - ◆ Smart pipes,
 - ◆ Drain gauges,
 - ◆ Existing agronomic data for different plant types can probably be adapted for use without significant error.

Summary of Discussion about ‘Temporal Issues’:

- ◆ Enough time is required for the plant and soil community to reach “maturity”.
- ◆ What will the frequency of data collection be as there are a mix of continuously varying and discrete events?

Summary of Discussion about ‘Scale Issues’:

- ◆ If the roof is large enough, spatial scale may be an issue if maps required to display the spatial variation
- ◆ Horizontal and vertical resolution of sampling and modelling. For deterministic models, it is possible to use a very fine vertical resolution in the growing medium. Typically, many layers may be needed, even in a shallow medium, to model infiltration and percolation.

Summary of Discussion about ‘Acceptable Levels of Uncertainty’:

- ◆ The acceptable levels of uncertainty are difficult to assess without further study and actual performance measures from green roofs.

Summary of Discussion about ‘Aggregate/Site Level Relationship’:

- ◆ Aggregate/site level relationships should be derived from a number of sites.

Summary of Discussion about ‘Tools Available’:

- ◆ Available tools include:

- ◆ Simulations—computer or prototypical instrumentation,
- ◆ Already established sites.

Summary of Discussion about ‘Additional Research Needs/Opportunities’:

- ◆ The environmental characteristics must be determined, such as:
 - ◆ Plant types,
 - ◆ Soil/planting medium--geotextiles (type and depth),
 - ◆ Topography,
 - ◆ Drainage devices and drainage layer.

Summary of Discussion about ‘Cost-Benefit Analysis’:

- ◆ On site costs versus off site treatment/storage costs must be considered.
- ◆ The potential energy savings versus air quality improvement and water reuse are also important.
- ◆ Irrigation and municipal potable water for non-consumptive purposes should be avoided as much as possible.

Specific Research Goal:

- ◆ To evaluate stormwater quality benefits.

Summary of Discussion about ‘Design’:

- ◆ Design issues to consider include:
 - ◆ The influence of material choice on water quality.
 - ◆ Horticulture practices and water quality.
 - ◆ Different plants have different abilities to trap pollutants.

Summary of Discussion about ‘Specific Data Required’:

- ◆ Currently there is weak baseline data on roof water quality and soil characteristics, particularly toxicant levels and input/output chemical budgets.
- ◆ Contaminants/toxicants/nutrients/ after initial scans must be prioritized.
- ◆ Atmosphere deposition profiles are required.

Summary of Discussion about ‘Method of Obtaining Data’:

- ◆ Continue sampling for other parameters.
- ◆ Water collected to estimate runoff could be tested for water quality.

Summary of Discussion about ‘Temporal Issues’:

- ◆ How often sampling occurs and whether it’s event-specific must be considered.

Summary of Discussion about ‘Scale Issues’:

- ◆ Scale issues are less important than quantity, but location and other inputs are relevant.

Summary of Discussion about ‘Acceptable Levels of Uncertainty’:

- ◆ Acceptable levels of uncertainty are policy issues and the quantification of uncertainty will depend on specific laboratory tests.

Summary of Discussion about ‘Relationship to Aggregate/Site Level Research’:

- ◆ This depends on the number of sites and locations, as well as aggregate level and water quality data specifications.

Summary of Discussion about ‘Tools Available’:

- ◆ Simulations and instrumentation.

Summary of Discussion about ‘Additional Research Needs/Opportunities’:

- ◆ There is potential for in situ development of biohazards (bacteria, protozoa, mosquitoes), as well as increased biodiversity and ecological integrity.
- ◆ There are also opportunities for the re-use of roof water (harvest for grey water use, swimming pools).

Summary of Discussion about ‘Cost-Benefits Analysis’:

- ◆ Wherever water can be harvested, there will be avoided costs.
- ◆ Removing some pollutants from the water before it re-enters the sewage system will reduce the burden on existing municipal infrastructure.

5.2.2.3 **Proposal for the Basic Elements of a Monitoring Protocol for Hydrolic Performance**

The following is another proposal for the basic elements of a monitoring protocol for hydrologic performance (Charlie Miller, PE, Roofscapes, Inc.). As other proposals arrive, they will be included as well in order to maintain a living document and an ongoing debate. As it was received from an American participant, the units may not be metric. This goal is to spur debate and eventually gain consensus on how to conduct research.

I. DEFINE PHYSICAL PROPERTIES OF THE SYSTEM COMPONENTS:

A. MEDIA

1. Drainage media

- Moisture content at maximum water capacity (standard Forschungsgesellschaft Landschaftentwicklung Landschaftsbau e. V. procedure (**FLL**): *maximaler wasserkapazität*)
- Maximum unit weight at maximum water capacity (**FLL**)
- Porosity
- Saturated hydraulic conductivity, measured at a gradient of 0.1 at 25° F

2. Growth media

- Moisture content at maximum water capacity (**FLL**)
- Moisture content at field capacity: 0.333 bar
- Moisture content at 1.0 bar
- Maximum unit weight at maximum water capacity (**FLL**)
- Saturated hydraulic conductivity (**FLL**)
- Void ratio near saturation (air content at maximum water capacity)

(Note: The three moisture content measurements allow approximation of the soil tension vs. moisture content curve over the critical range. This can be used also to approximate the unsaturated hydraulic conductivities required in some models.)

B. DRAIN SHEETS

- Transmissivity, measured between platons at gradient of 0.1 and 0.2, a temperature of 25° F

C. FABRICS

- Moisture holding capacity

II. DEFINE SYSTEM VARIABLES

- A. LAYER THICKNESSES
 - B. ROOF SLOPE
 - C. MAXIMUM LENGTH OF DRAINAGE PATH TO DRAIN
 - D. FREE WATER IMPOUNDED OR PERMANENTLY RETAINED (e.g., water retention capacity of plastic ‘drain’ sheets, water impounding ridges, drain restrictions)
- III. INDEPENDENT VARIABLES MEASURED (all data at 10 minute intervals, or smaller)
- A. PAN EVAPORATION RATE
 - 1. Weather Service
 - B. RAINFALL
 - 1. Tipping bucket rain gauge, with digital output to data logger
 - C. HUMIDITY
 - 1. Weather Service
 - D. TEMPERATURE (optional for hydrologic monitoring)
 - 1. Sensor-Data logger measuring temperature within growth media
- IV. DEPENDENT VARIABLES MEASURED (all data at 10 minute intervals, or smaller)
- A. RUNOFF RELEASED
 - 1. Instrumented ‘Rainbarrel’ with digital output to data logger*
 - 2. Digital impeller-type in-line flow meter (submerged) with digital output to data logger
 - B. MOISTURE CONTENT OF GROWTH MEDIA
 - 1. TDT sensor with output to data logger
 - 2. Electrical resistance-type sensor with output to data logger
 - C. CAPILLARY PRESSURE IN GROWTH MEDIA (optional)
 - 1. Ceramic Tensiometer (periodic manual measurements required)

(Note: Capillary pressure can be computed from moisture content and soil tension vs. moisture content curve determined in the laboratory)

* Instructions for typical assembly required. I can provide sample designs, if desired. I favor an 8-inch diameter standpipe with one or more orifices. Water level continuously monitored with pressure transducer or bubbler device.

5.2.3. CI AGGREGATE LEVEL URBAN HEAT ISLAND

Specific Research Goal:

- ◆ To assess the impact of green roofs on aggregate cooling load.
- ◆ Ultimate goal is to assess reduction of energy load.

Summary of Discussion about 'Design Issues':

- ◆ Should initially assume homogenous vegetation cover roof to determine the range of available moisture and the range of soil depth.
- ◆ Rooftop measurements are difficult.
- ◆ What you evaluate depends on the overall impact, such as energy and health.
- ◆ Questions that need to be answered:
 - How should the roof be instrumented roof and account for the uniqueness of the urban environment?

Summary of Discussion about 'Specific Data Required':

- ◆ Drivers:
 - ◆ Remote surface temperature or in situ temperature data
 - ◆ Weather data for stimulation
- ◆ Environmental Variables for model parameters:
 - ◆ Building height and width
 - ◆ Roof top area
 - ◆ Roof top material
 - ◆ Size of urban canyons
 - ◆ Surface properties (roughness, albedo, displacement height, emissivity, skyview factor, elevation)
 - ◆ Amount of area covered with green roofs.
- ◆ System Variables:
 - ◆ Land use
 - ◆ Moisture availability
- ◆ Dependent Variables:
 - ◆ Validation data to validate spatial patterns of heat island simulation

Summary of Discussion about 'Method of Obtaining Data':

- ◆ Land use surveys of building properties.
- ◆ Thermal imagery.
- ◆ Assessment rolls to obtain properties of buildings.
- ◆ Air photographs to determine height.
- ◆ Airborne laser scanning to determine height.
- ◆ A small scale physical model should be built of the green roof, but not too small because heat properties change too much.
 - ◆ There are problems with measuring air temperature which require data collection on and around physical model.

Summary of Discussion about 'Temporal Issues':

- ◆ Times when the urban heat island (UHI) may be greatest must be specified because due to other factors, the highest UHI may not be on hot days.
- ◆ Question that needs to be answered:
 - How will transportation be affected by different weather regimes?

Summary of Discussion about 'Scale Issues':

- ◆ Roofs are not well represented in mesoscale models.
- ◆ Mesoscale models use pseudo-2D surfaces, which are okay for bulk domes but not necessarily for finer scales.
- ◆ Finer scale work is difficult.

Summary of Discussion about 'Acceptable Levels of Uncertainty':

- ◆ Roofs are not well represented.
- ◆ Aggregation of data into grids.
- ◆ Not all parameters are specified properly.

Summary of Discussion about 'Relationship to Aggregate/Site Level Research':

- ◆ Aggregating impact of different roofs is a difficult issue. It could be handled by creating a high-resolution field, and simulate each individual surface, although the model should be validated with actual data.
- ◆ To aggregate a city at a larger scale, you have to use other models to find out how those courser grids behave from above. This requires a fairly coarse pixel made up of different land uses. Green roofs must be used to move pixel to different aggregate responses.
- ◆ The real challenge is representing a single building in aggregate grid cell of the model?
 - ◆ A difficult issue is the representation of roofs in a mesoscale model. It can be handled with a very fine grid. Roofs presumably could also be represented through parameterization. This is likely to be more efficient than simply reducing the grid size. It will require site specific measurements to be linked to the inputs and outputs of the model to assess how the green roofs may be parameterized and the relative success of these measurements. For example, it may be done in terms of parameterizations of the surface turbulent fluxes as they relate to specific surface types. Some parameterizations being developed for urban areas now may lend themselves this type of application, it may be worth following this literature.
 - ◆ The storage of heat in buildings also needs to be parameterized at an aggregate level, but this requires data from specific site experiments.
- ◆ Urban surfaces could be represented in the model by thermal properties, skyview factor, water holding capacity, aerodynamic roughness and transpiration.
 - ◆ How do you accommodate smaller-scale processes in urban areas?
 - ◆ Using satellite imagery
 - Use satellites to check spatial patterns.
 - Collect air temperature data on the ground.
 - Use land use data to help calibrate satellite images.
 - ◆ Issues in the use of satellite data:
 - Infinite number of parameter combinations to create the signal

- Combination of parameters will be tied to thermal image.
- Thermal image will be used to evaluate model simulation, but how will parameter be chosen?
- What satellites provide (e.g. surface temperature) is not what models provide but the patterns might be useful.
- One must be careful as model derived surface temperature is different from what the satellites see, especially if the scales do not match.

Summary of Discussion about ‘Tools Available’:

- ◆ Mesoscale atmospheric models.
- ◆ Must understand whether fractions of vegetation and the impact of UH1 can be obtained from other modeling studies.
- ◆ Also see previous discussions.

Summary of Discussion about ‘Additional Research Needs/Opportunities’:

- ◆ The effect of lake breezes may be reduced if you reduce urban heat island.

Summary of Discussion about ‘Cost-Benefit Analysis’:

- ◆ How many days are of concern regarding high cooling loads?
- ◆ How much of an increase would we expect due to climate change?

Reviewer Comments:

How do you instrument roof and account for the uniqueness of the urban environment? Speaking from a scientific perspective, I do not believe that the urban environment is unique or that it requires any special considerations in instrumentation. The urban environment can be associated with a characteristic set of environmental and independent variables. However standardized monitoring protocols should accommodate this (and other) site conditions.

5.2.4 D1 AGGREGATE STORMWATER MANAGEMENT

Specific Research Goal:

- ◆ To evaluate stormwater quantity quality.

Summary of Discussion about ‘Design Issues’:

- ◆ Design should remain generic and flexible.
- ◆ Different types of systems and climate scenarios should be stimulated for use in existing situations and developing areas.
- ◆ Internal use of runoff water (e.g. gray water) must be accounted for.
- ◆ Continuous modeling capability is also a design issue.
- ◆ The structural capacity and drainage configuration must be identified.

Summary of Discussion about ‘Specific Data Required’:

- ◆ Drivers:
 - ◆ Weather data
- ◆ Environmental Variables;
 - ◆ Land use maps
 - ◆ Building inventory
 - ◆ Climatic averages
 - ◆ Soil and substrate depth.
 - ◆ Water and moisture storage (per unit area) capabilities.
- ◆ Dependent Variables:
 - ◆ Continuous site-specific data (e.g. flow, climate, etc).

Summary of Discussion about ‘Method of Obtaining Data’:

- ◆ GIS
- ◆ Existing hydrologic models
- ◆ Communication with site-level researchers
- ◆ Flow metres
- ◆ Smart pipes

Summary of Discussion about ‘Temporal Issues’:

- ◆ Historical climate data and forecast climate changes are both temporal issues that need to be addressed.
- ◆ The timing of roof top implementation and land use planning are important issues as well.
- ◆ The time it takes for the plants, soil and community to reach "maturity" must be considered.

Summary of Discussion about ‘Scale Issues’:

- ◆ The sub-catchment area, which is relatively small, could demonstrate dramatic benefits.
- ◆ The model will need to operate at different scales.

Summary of Discussion about ‘Acceptable Levels of Uncertainty’:

- ◆ Uncertainty can be reduced by:
 - Site calibration
 - Sub-catchment calibration
 - Sensitivity analysis

Summary of Discussion about ‘Relationship to Aggregate/Site Level Research’:

- ◆ It is necessary to identify the scale at which the highest benefits are realized.

Summary of Discussion about ‘Tools Available’:

- ◆ Several watershed models
- ◆ GIS
- ◆ Orthophotos/remote sensing

Summary of Discussion about ‘Additional Research Needs/Opportunities’:

- ◆ A detailed inventory of buildings is required, as well as information as to whether or not they can be retrofitted.
- ◆ Technology improvements to incorporate into model are necessary.
- ◆ Environmental research needs include:
 - Plant types
 - Soil/planting medium
 - topography
 - Potential energy savings
 - Potential air quality improvement
 - Water re-use
- ◆ The potential trade-off between water quality and water quantity?
- ◆ How are green roofs different from conventional on-site stormwater retention methods?

Summary of Discussion about 'Cost-Benefit Analysis':

- ◆ Erosion will decrease as a result of stream rehabilitation.
- ◆ Flood frequency will decrease.
- ◆ The size of ponds will be reduced.

5.2.5 EI RECREATION AND FOOD PRODUCTION

Specific Research Goal:

- ◆ To understand the role of green roofs in providing recreational space for any city.
- ◆ Possible Research Questions
 - ◆ Which is the "value added" benefit - the actual use of the green roof for recreational purposes, stormwater retention, urban heat island, energy savings, or environmental benefits?
 - ◆ Which benefit can be more easily quantified?
 - ◆ Will there be increases in property values with the introduction of green spaces?

Summary of Discussion about 'Design Issues':

- ◆ The specific type of green roof to be considered will depend on the type of building that is chosen for food production.
 - ◆ Possible public green roofs include:
 - Schools
 - Prisons
 - Multi-unit public housing
 - Government and administrative buildings
 - Hospital and other health facilities
 - Community and recreation centres
 - Parking garages
 - Works buildings
 - Water treatment facilities and reservoirs
 - Airports
 - ◆ Possible private green roofs include:

- Multi-unit residential units (e.g. co-ops, condominiums, rental/lease apartments, etc).
- Commercial office buildings
- Industrial buildings
- Retail buildings/Malls
- Parking garages
- Single-family homes
- ◆ Other design issues include safety, loading capacity, strength, material, etc.

Summary of Discussion About ‘Specific Data Required’:

- ◆ Driving Variables:
 - ◆ Weather data
- ◆ Environmental Variables:
 - ◆ Climatic averages
 - ◆ Land-use data.
 - ◆ Inventory of existing green roofs including location, description and history is necessary.
 - ◆ Public per-capita green space requirements.
 - ◆ Are there any green space deficiencies?

Summary of Discussion About ‘Method of Obtaining Data’:

- ◆ Different methods of obtaining data include:
 - Aerial photographs.
 - Land-use maps.
 - Official City plans, by-laws, and Planning Acts.
 - Government policies and studies.
 - Development approvals.
 - Real estate trends and records.
 - Weather and climate data from Environment Canada
 - Marketing studies and community interviews and studies.
 - Interviews
 - Surveys
 - Focus Groups

Summary of Discussion About ‘Temporal Issues’:

- ◆ Timing regarding the return on investment.
- ◆ Timing regarding the development and approvals process.
- ◆ Changes in "user" needs (perceived and real) over time.

Summary of Discussion About ‘Scale Issues’:

- ◆ Site Level - use depends on the size of the roof.
- ◆ Aggregate Level - aggregate level issues depend on "needs" and "perceived market niches" in the area and neighborhood.

Summary of Discussion About ‘Acceptable Levels of Uncertainty’:

- ◆ Not available

Summary of Discussion about 'Relationship to Site Level Research':

- ◆ Not available

Summary of Discussion about 'Tools Available':

- ◆ See "Method of Obtaining Data"

Summary of Discussion about 'Additional Research Needs/Opportunities':

- ◆ The compilation of all research and data relating to the health and social benefits of increased participation - active and passive - in urban green space (horticultural therapy, etc) is necessary.
- ◆ The creation of an inventory of existing green roof spaces in Toronto, including history, cost, use, etc. is required.
- ◆ The "spectrum" of different accessible roof spaces needs to be defined.
- ◆ The percentage of green space versus the percentage of hard/non planted surfacing must be understood, as well as the definition of the "threshold" at which a roof space with certain percentage of planting becomes viable as a retainer of stormwater, insulator, etc.
- ◆ At what point does a planted roof space also reap the other benefits?
- ◆ What are the marketing trends for green space users?

Summary of Discussion about 'Cost-Benefit Analysis':

- ◆ Analysis of property values with and without green space is required.
- ◆ It is easier to get data for green space at grade.
- ◆ An analysis of the returns on investment for initial capital input is needed. It could also include rental or lease income from the roof space, if the "user" is not the owner).
- ◆ Jobs will be created, and they require implementation and maintenance.
- ◆ Connections to other green roof benefits must be made.

Summary of Discussion of 'Other Issues':

- ◆ Ownership issues include a willingness to be innovative, access to funding, the payback on investments, safety requirements, insurance and liability.
- ◆ Management possibilities:
 - Publicly owned, initiated, funded, built and managed.
 - Privately owned, funded and built.
 - Required/legislated by the public.
 - Built/managed privately out of "goodwill" or for the purpose of revenue generation or in anticipation of future public requirements/legislation.
- ◆ Existing building versus new/proposed building (regarding cost of upgrading or accessing an existing roof not initially designed for recreational purposes).
- ◆ Types and Uses of Green Roofs (Active or Passive)
 - Parks/gardens
 - Sport uses
 - Educational purposes
 - Ecological spaces
 - Health uses

Specific Research Goal:

- ◆ To understand the role of green roofs in providing urban agriculture for any city.

Summary of Discussion about ‘Design Issues’:

- ◆ The wind and sun aspect of the building is important.
- ◆ A comparison of hydroponic, aeroponic and organic (soil vs. soiless) systems is important.
- ◆ Design questions that need to be answered:
 - Is the roof garden hydroponic, aeroponic or organic (soil vs., artificial growing medium)
 - The orientation to the sun is important
 - The wind regime is important
 - What are the parameters of certain crops?
 - What is the soil depth?
 - What is the load bearing capacity?
 - Are there any restrictions on new buildings?
 - What is the nutrient delivery of certain plants and what types of systems do they require?
 - What crops grow better closer to market?
 - What about seasonal crops?
 - What are the different aspects of the buildings (e.g. wind, shade, etc.) and their loading capacity?
 - Will livestock be considered in a rooftop food production system?

Summary of Discussion about ‘Specific Data Required’:

- ◆ Drivers:
 - ◆ Weather Data
- ◆ Physical Properties:
 - ◆ See B1 and D1
- ◆ System Variables:
 - ◆ A land use survey will be required as well as the documentation of available and useable space (square metres).
 - ◆ A building inventory will also need to be collected.
 - ◆ Food quality test for particulate matter will need to be conducted.
 - ◆ Waste inventory from urban areas
 - ◆ The distance and energy required per imported crop
 - Different roof systems should be compared in regards to medium and nutrient needs per crop.

Summary of Discussion about ‘Method of Obtaining Data’:

- ◆ Different methods of obtaining data include:
 - ◆ Weather and Climate data – Environment Canada
 - ◆ Other Data

- GIS
- Air photographs
- Polls
- Surveys
- Official and environmental plans.
- Collect existing database on buildings.

Summary of Discussion about ‘Temporal Issues’:

- ◆ Official plans have deadlines so any plans to conduct work must be submitted on time.
- ◆ It will take about five years to truly identify whether or not green roof infrastructure is a stable industry.
- ◆ A timeline will be required for each project.
- ◆ Successful green roof expansion could extend programs.

Summary of Discussion about ‘Scale Issues’:

- ◆ Not available

Summary of Discussion about ‘Acceptable Levels of Uncertainty’:

- ◆ Proven applications of certain technologies are unproven in this particular application.

Summary of Discussion about ‘Aggregate Site Level Relationship’:

- ◆ Not available

◆

Summary of Discussion about ‘Tools Available’:

Note, this group focused on tools to encourage rooftop food production

- ◆ Public policy for urban food production
- ◆ Corporations
- ◆ School boards
- ◆ Libraries
- ◆ All three levels of government
- ◆ Restaurant chains
- ◆ Pioneer designers
- ◆ Logo for rooftop produce branding
- ◆ Non-profit groups (e.g. FoodShare)
- ◆ Physical tools:
 - Irrigation systems
 - Tools that don't damage membrane
 - Horticulture tools

Summary of Discussion about ‘Additional Research Needs/Opportunities’:

- ◆ Research needs include:
 - ◆ The social benefits of green roof technology (such as employment).
 - New research on green roofs is required.
 - ◆ Barriers should be identified and addressed.
- ◆ Opportunities include:

Email, address, etc.
Longitude and Latitude
Average rainfall (May-October)
Average rainfall (November-April)
Area of roof
Building Characteristics
 Residential, Commercial or Industrial
 Number of Stories
 Age
 Material Composition of roof and walls
 Window Space
Summary of project (including information described above)

Metric units

Fields: Date

Time (hour:minute)
Parameter (specify units in header)
Uncertainty

7.0 CONCLUSION

This workshop was successful in bringing together a wide range of participants with varying research interests. During the workshop and the preparation of the proceedings it became obvious that the template was not fully understood by all the participants and/or it may not have been appropriate for each research theme. Thus there are some inconsistencies between the different themes, and these will have to be addressed over time. From the review process, other potential templates emerged for specific research themes, and may yet prove to be better models for what is required to establish a green roof protocol. However, this document represents the first step in that direction, and there are valuable guidelines that can be derived from the reported discussions. As the initial records of the workshop have undergone substantial revisions to improve clarity or at the suggestion of reviewers, the authors take full responsibility for any errors and for misrepresenting the views of any one particular group or individual.

The next steps in this process are to develop recommendations for specific procedures for data collection, specifically monitoring protocols, and model development and to look at other research themes. Other research themes might include air quality and biodiversity. This workshop was effective in establishing some principles to guide the next steps.

APPENDIX: OVERVIEW OF CURRENT AND PLANNED RESEARCH

The following provides a brief overview of various research projects either planned or underway.

Overview: Modeling the Impact of Green Roofs on Toronto's Urban Heat Island

Brad Bass, Adaptation and Impacts Research Group, Environment Canada

The Institute for Research in Construction at the National Research Council is leading a proposal to the federal government Technology Early Action Measures program to assess the potential of green roofs to reduce greenhouse gas emissions in urban areas. Part of the estimated reductions may be accounted for by the reduction of the urban heat island. In order to explore this issue, in the absence of widespread green roofs in the City of Toronto, the urban heat island will be modelled with and without green roofs. There are three methods that are being considered in this study: a mesoscale atmospheric simulation model, a one-dimensional (1-D) boundary layer model and a three-dimensional (3-D) boundary layer model.

The mesoscale model is a three-dimensional simulation of the atmosphere, both horizontally and vertically, that is used to model weather patterns at resolutions (grid cell size) ranging from 80 km to 5 km or even smaller. Typically, as the size of the region increases, so does the size of the grid cells. Thus it is possible to model a small area, such as a city, at a very high-resolution, meaning the area is divided into a fine grid. Typically each grid cell represents a 2-10 square kilometre area, allowing for the inclusion of a high degree of variation at the surface. Mesoscale models allow for the simulation of complete weather events that can influence the urban climate, and can simulate the spatial variation of urban temperatures under different weather conditions.

Although a mesoscale model can be run at a 1-km resolution, the amount of time required for this simulation is still somewhat prohibitive. An alternative is to use a resolution between 2 km and 10 km, and model specific locations with a 1-D boundary layer model. The boundary layer models include all of the major physical processes within one kilometre of the surface, and are driven by the output of the mesoscale model at an hourly time step. Important atmospheric conditions that are external to the model must either be prescribed by other data or from a larger model. The 1-D version includes only vertical motion with no variation in the land surface below, thus simulating a single atmospheric column. It is useful for assessing the impact of a specific land use on the urban climate, and then modifying that land use to account for the addition of rooftop vegetation.

The 3-D boundary-layer model allows for horizontal movements, which is important for at least parts of Toronto due to the effect of Lake Ontario on temperatures. The 3-D version can simulate the occurrence of lake breezes and their impact on the urban climate. The aspects of vegetation that are important to the climate are parameterized within the model. Although the parameters are not detailed enough for specific species, they do describe the differences between major types of vegetation cover such as grasslands or trees.

The simulation of Toronto's heat island will be based on a mesoscale model. However, this requires some observations at ground level of the urban heat island. These can be collected by vehicles fitted with externally mounted thermometers or by hand-held digital thermometers. The data will be collected in the evening, starting with sunset, and each vehicle will collect 20 observations, approximately two minutes apart. This data could also be supplemented by satellite imagery of Toronto, if it is available. In order to capture the impact of different weather events, and to adequately describe the variation of land use in Toronto, the mesoscale model will be run at three different spatial resolutions.

A 40-km resolution will describe the larger-scale weather patterns for southern Ontario. A 10-km resolution simulation will be nested in the 40-km resolution model to capture the gross spatial variation in the urban area, and a 2-km version will be nested in the 10-km simulation to capture the different land uses in pre-1998 City of Toronto. The 2-km version will be used to explore the impact of different spatial configurations and coverage of green roofs on the urban heat island. If there are features that cannot be adequately represented at the 2-km resolution, or if the 2-km resolution is too time consuming for multiple simulations, a boundary layer model will be used with the 10-km resolution output. The 2-km resolution or the boundary layer model simulation will be restricted to the old city boundaries, as the land use has been mapped out in sufficient detail from orthophotos and other data sets in a GIS format.

In addition, two other parameters must be added to the model. The first is the sky view factor, which is defined as the fraction of the sky which is visible from the surface, and in the city this has to account for the presence of buildings. In the model, this is represented by altering the surface energy budget equations, particularly the receipt and emission of longwave radiation. The sky view factor will be estimated from the GIS, as it includes details of individual buildings, by observation or from previous studies.

The second parameter involves the difference between the thermal properties of urban and rural surfaces, reflecting the capacity for buildings and roads to store and release heat. Urban surfaces are parameterized as vegetated, non-vegetated bare soil and non-vegetated cover material. The strength of the urban heat island is also very sensitive to rural surface properties, particularly the amount of soil moisture as wet soil is thermally conservative due to the capacity of water to store and release heat.

The modelling of the urban heat island could be extended to evaluate the impact of urban temperatures on the summer demand for electricity, with and without the green roofs. A similar study in the city of Rochester utilized substation level data of electricity use to derive temperature – load relationships. Temperatures in these areas were weighted by the substation's proportion of the total energy load to create a demand-weighted temperature. The demand-weighted temperatures were based on the data for one peak day, with the assumption that the spatial pattern would be similar on other peak days. These demand-weighted temperatures were aggregated into an urban-scale temperature, giving more weight to those areas with a higher energy demand. Airport temperature data from one year was regressed against temperature to create temperature-load relationships for different days of the week and for each hour of the day.

To predict the impact of the urban heat island on temperature, the simulated aggregate airport temperatures were subtracted from the demand-weighted temperatures. This

demand-weighted temperature effect was then added to the observed airport temperatures to create a temperature series that was representative of the entire area for the purpose of forecasting energy load. Depending on the availability of similar data from Toronto Hydro, it may be possible to derive similar relationships and assess the impact of green roofs on the use of air conditioning. A dominant land use category would have to be assigned to each substation in order to account for the contribution of the urban heat island to the temperature – load relationships, and to account for the impact of green roofs.

Overview: Aggregate Stormwater Research

Darlene Conway, Stormwater Management Engineer, TRCA

Project partners: Still to be confirmed (as of May 2000)

Study site: Still to be identified, but will likely be a subwatershed or subcatchment within the Don River watershed

Time frame: Probable start Fall of 2000 or early 2001.

Objective: To develop a tool to quantify the stormwater management benefits of green roofs (eg., flooding, erosion, etc.)

Outline: The proposal is to develop a simple model to determine how much volume on an annual basis can be retained by green roofs and demonstrate the resultant benefits to the receiving watercourse. A subwatershed or subcatchment within the Don watershed will be chosen for a case study. Detailed building stock information within the study area will be required to provide a realistic estimate of the potential for green roof coverage or retrofitting over a given time horizon. This data, compiled by GIS, can then be used to assess the change in rainfall-runoff response from the existing condition to the future condition with green roofs in place. This assessment of how much volume can be retained on green roofs will provide a means of quantifying the potential benefits of green roofs on a subwatershed basis. The results of detailed green roof monitoring will be incorporated when available to ensure realistic estimates of the volume retained over the subwatershed.

Overview: Food Production- Technological Challenges and Opportunities

Prepared by Lauren Baker, Urban Agriculture Coordinator, FoodShare Toronto

State of the Industry in Toronto

A rooftop food production technology has yet to emerge on the marketplace, despite growth in organic and niche food markets and increasing interest in urban agriculture. A seminar held on November 24, 1998 entitled “Greenbacks from Greenroofs: Forging a New Industry in Canada,” sponsored by Environment Canada, the Toronto Food Policy Council, Canadian Mortgage and Housing Corporation and the Rooftop Gardens Resource Group, identified a growing interest in and need for rooftop food production technologies.

The Toronto Food Policy Council, to support local food production initiatives has recently published a report entitled “Feeding the City from the Back 40: A Commercial Food Production Plan for the City of Toronto.” This report fed into the City of Toronto Environmental Task Force’s Proposed Environmental Plan. The plan recommends a strategy to encourage green roofs and rooftop gardens, as well as a broader strategy for local food production.

The Toronto Food Policy Council is submitting an implementation plan and budget requirements to City Council surrounding the Environmental Plan recommendations. A half time coordination position is being suggested. The coordinator would facilitate pilot rooftop food production projects in the City of Toronto. A budget of \$100,000 would be allocated for entrepreneurial incentives and technical design and marketing consultants.

FoodShare’s Field to Table warehouse has supported rooftop food production research for four years. The design of the systems have evolved over these years, but has primarily been based on an organic, hybrid-hydroponic technology. The objective of this activity is to design a rooftop growing system for commercial food production. After four years of experimentation we have come to the conclusion that with the appropriate technology, high quality food can be grown on the most underutilized of urban spaces, rooftops.

Social, Environmental and Economic Opportunities

Despite projections for growth in the green roof industry, few companies are researching and developing the technology that will make urban food production possible. There are substantial opportunities in developing the rooftop food production industry. Seasonal employment on rooftop farms could provide job skills training and skill development. Green roofs improve air quality, reduce stormwater runoff and conserve energy used to heat and cool buildings.

There are several economic opportunities associated with rooftop food production. Rooftop produce can be sold to niche markets for higher prices than conventional produce. For example, organic food has a 20% greater market value than conventional produce. Rooftop farmers will be in close proximity to high-end chefs and specialty stores, and therefore are more able to respond to their produce demands than conventional farmers. Rooftop technology can be manufactured and sold to other entrepreneurs interested in

rooftop food production. Research and development of rooftop food production systems will be an ongoing economic opportunity.

Technical Challenges

What makes rooftop food production technology innovative, also makes it technically challenging. Few resources exist to guide research and development. There are several technical challenges that need to be addressed before rooftop food production is socially, environmentally and economically viable. These challenges include:

- Cost effective system design – rooftop food production systems need to be light-weight to take into consideration the structural limitations of most roofs. Light weight materials tend to be expensive, but costs could be amortized over long-term production timelines.
- Delivery of nutrient solutions to the system – research and production to date has indicated that organic produce, for environmental and economic reasons, is most appropriate for rooftop food production. Organic nutrient solutions for light weight rooftop systems need to be researched and developed for effective production.

Conclusion

Despite various technical challenges, rooftop food production has multiple social, environmental and economic opportunities. FoodShare plans to continue with rooftop food production and research through it's Urban Agriculture Program. Dedicated research and development funds are required to enable the industry to emerge.

Overview: Laval University Research Project, Quebec City

Marie-Anne Boivin, M. Sc. Agr. Rooftop Greening Consultant
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- Field Study Site: Laval University, Quebec City
- Time Frame: Winter of 1994 – Winter of 2000
- Observation part: To observe the adaptation of 125 herbaceous in the conditions of a green roof system
- Experimental part: To determine the effect of a rooftop microclimate on winter damage and growth of six perennial species grown in a green roof system
- Specific: To compare the adaptation of six perennials in three different thicknesses of growing media; to evaluate the temperature profile in different depths of growing medium; and to measure air and growing media temperature, overall solar radiation and total precipitation.
- Outline: This research work has evaluated the adaptation of herbaceous perennials to green roof conditions in a northern Canadian climate over six years.
- The Horticultural Research Center of Laval University carried out this research project under the direction of Mrs. Blanche Dansereau, professor, with the goal of adapting extensive greening systems to northern Canadian climatic conditions.
- In November 1994, a greening system was installed on two rooftops with different exposures on the services building of the Agricultural and Food Sciences Faculty. The adaptation potential of 85 plant species was studied over a total surface area of 250 square metres using different thicknesses of artificial growing substrate. A 36 square metre parcel was specifically used to study the impact of a roof microclimate on winter damage and the growth of six plant species in an extensive greening system.
- Project Status: The green roof is under evaluation since November 1994. Results will be published in 2000.

Common Research Protocol – suggested issues for discussion:

- Data collection (T, soil RH, qualitative or quantitative observations)
- Sizing of experimental units (area, number of plants/unit)
- Comparison of air temperature over a roof with or without a green roof
- Comparison of different type of plants in different climatic regions (shrubs, trees, natural grasses...)
- Determination of irrigation needs for different species

- Measurement of enhancement of air quality

Overview: Rooftop Garden Consortium, Ottawa

Karen Liu, Research Officer, Building Envelope and Structure Program, Institute for Research in Construction, National Research Council

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- Partners: Environment Canada, Public Works Government Services Canada Canadian Roofing Contractors' Association, EMCO, Garland, IKO, Monsey-Bakor, Soprema, Tremco (As of May 2000)
- Field Study Site: National Research Council, Montreal Road Campus, Ottawa
- Time Frame: summer of 2000 – winter of 2002
- General Objectives: To provide technical information on the benefits and durability of rooftop garden technology under Canadian climates and to identify its sensitivities to climate variability; and, to develop a rooftop garden computer model to predict its performance and benefits in different Canadian cities.
- Specific Objectives: To compare the following parameters between the rooftop garden and the reference roof: temperature profile, relative humidity, solar radiation, storm water runoff and the energy consumption of the building.
- Outline: This research project will evaluate the benefits of rooftop gardens using field study and computer simulation. National Research Council is setting up a Field Roofing Facility with roof area of about 800 ft² in its Ottawa campus. The roof will be divided into two thermally insulated sections. A rooftop garden system will be installed on one half and a modified bituminous roof system (reference roof) will be established on the other. The roofs will be instrumented to monitor the temperature profile, relative humidity, soil moisture content, solar radiation absorption, storm water runoff and the energy consumption. The data from the green and the reference roofs will be compared to quantify benefits of the rooftop garden.
- Under the direction of Brad Bass, Environment Canada, in parallel, is developing a computer model for the rooftop garden. They will validate the model using the field study data. The model will then be used to evaluate the benefits of rooftop gardens in different Canadian cities based on local climate conditions using the Canadian climate data archives.

Roofing Components Details - the two roofing sections will consist of the following components:

| <i>Component</i> | <i>Rooftop Garden System</i> | <i>Reference Section</i> |
|----------------------|---|--|
| structural support | Steel / wood structure, ply wood deck | Steel / wood structure, ply wood deck |
| vapour control layer | Asphalt-based membrane | Asphalt-based membrane |
| thermal insulation | 75mm (3in) thick mineral fibre board | 75mm (3in) thick mineral fibre board |
| support panel | 12.5mm (0.5in) fibreboard | 12.5mm (0.5in) fibreboard |
| Membrane | 250g polyester reinforced modified bituminous membrane formulated with root repellent agent | 250g polyester reinforced modified bituminous membrane |
| drainage layer | Polystyrene extruded panel, 0.75kg/m ² (0.15psf), 36mm (1.5in) thick | N/A |
| filter membrane | Polyethylene/polyester non-woven mat, 160g/m ² (0.032psf) | N/A |
| growing medium | 150mm (6in) light weight soil | N/A |
| Vegetation | wild flower meadow | N/A |

Project Status: NRC is completing the construction up to the deck level. In collaboration with the Rooftop Garden Consortium, the rooftop garden and the reference sections will be installed right after. Much of the instrumentation will be implemented at the same time. Debugging and fine-tuning of the instrumentation will be performed during the summer and the fall.

Common Research Protocol – suggested issues for discussion:

- Data collection (T, RH, moisture level...etc) – interval and format (max, min, avg)
- Water quality (contaminants/pollutants to be tested)
- Water consumption (frequency, definition of dryness, metering)
- Energy consumption comparison (method, accuracy)
- Leak detection (method, accuracy, inspection interval...etc)

Overview: Green Roof Systems Consortium

Ed Graham, Greenland International Consulting et al.

Ph: 905.738.18818

Participants: The Toronto and Region Conservation Authority, Seneca College, Greenland International Consulting, and SDM.

Background: Air and water are essential components for maintaining human health. Their quantity and quality are major concerns in outdoor and indoor environments. Indoor, systems for managing air, water and energy provide a safe, breathable, drinking, cleansing, disposal and overall comfortable living standards. Outdoors, legislation limits air emissions and effluent discharges. Indoors, the quality is regulated with outdoor air exchanges, even when the outdoor air is questionable. The ultimate objective of this system is to protect building occupants as well as regional and global air and water resources.

Since 1999, Greenland International Consulting Inc. (Greenland), The Toronto and Region Conservation Authority (TRCA), Seneca College (Seneca), SDM Inc. (SDM) and York University have been pursuing public and private funding for research and development initiatives to improve our environment in the area of water, air and energy. In this New Year 2000, these organizations, representing a cross section of public and private sector with excellent understanding of the policies and technical expertise, agreed to join forces to move forward this initiative as the **“GREENROOF SYSTEMS CONSORTIUM”**.

Objectives: The intent of the demonstration project is to evaluate, optimize and demonstrate the combined use of natural systems to control and recycle indoor and outdoor air quality and storm and municipal water quantity and quality. The system will combine new but proven technologies for precipitation run-off water capture, flow attenuation, storage and re-use as well as air bio-filtration mechanisms and will integrate both the internal building air/water uses. This system has immense potential to provide short and long-term benefits for indoor and outdoor air quality, storm water control and reductions in municipal potable water demand.

Seneca College has been chosen as the location for the implementation and operation of a pilot site. The site will be accurately monitored and carefully operated for at least four years to allow stabilization and performance optimisation so as to demonstrate the local, regional, and global benefits. The system will implement detailed monitoring equipment and techniques to measure the changes produced by each component of the system. Costs will be carefully documented to provide cost/benefit analysis of the system.

Specifically the system will quantify the following environmental benefits:

- Reduction in rainfall-runoff peak volume through on-site capture and on-site use.
- Corresponding reduction in municipal potable water used for sanitary disposal and for watering indoor and outdoor plants and gardens.
- Indoor air purification by air recycling through internal and rooftop vegetation systems.
- Indoor energy reduction through warm and cold air recycling and by providing natural heat insulation .
- Outdoor temperature moderation through vegetation coverage on the roof.
- Outdoor air purification through the open rooftop garden and reduction of carbon dioxide and other greenhouse gases.

The system design incorporates a system of ‘**QUADRANTS**’ to quantify relative changes and variations of the system components. The roof will be divided into four quadrants: 1) A closed greenhouse/indoor air filtration quadrant; 2) An open roof garden quadrant; 3) A precipitation capture and evaporation quadrant; and 4) A control quadrant. The closed greenhouse quadrant will house a closed greenhouse designed to circulate and filter indoor air prior to sending it back into the building. Air ducts will direct indoor air in at one end of the sealed rooftop greenhouse. Rainfall/snowmelt from this quadrant will be stored and distributed to users in the system. The design will provide the vegetation, configuration, and airflow rates to maximize filtering. The open-air roof garden quadrant will provide a function similar to other naturally vegetated areas. Natural water budget will be replicated (infiltration/evapotranspiration) and outdoor air filtration mechanisms will be provided through plantings. Rainfall/snowmelt runoff from this quadrant will also be stored and recycled to other water users in the system. The precipitation capture and evaporation quadrant will capture and hold rain and snowmelt water. On the average, potential evaporation is greater than the precipitation depth and if sufficient storage is provided, and the size of the evaporative surface is maintained, excess water would be returned back to the atmosphere. During extremely large events, the evaporation quadrant will overflow into the separate roof drain and the overflow volume will be measured prior to reaching storage. The fourth quadrant is the ‘control’ quadrant. The control is required to compare the performance of each of the other quadrants with current practices, thus providing the measured evidence of performance.

Overview: Eastview and City Hall Stormwater Monitoring

Ted Bowering/Gary Stinson: City of Toronto's Works and Emergency Services Department, Soil/Water Quality Improvement

Partners: Environment Canada, Impacts and Adaptation Research Group, National Research Council's Institute for Research in Construction, City of Toronto, Toronto Atmospheric Fund and Green Roofs for Healthy Cities, whose members include Flynn Canada Inc., IRC Building Sciences Group, De Boers Landscaping and Maintenance, Soprema Inc, Garland Inc. and Sheridan Nurseries.

Study Site: Eastview Community Centre, 86 Blake Street, Toronto

- \$285,000 in Capital Budget 2000 for roof replacement
- Total roof area 20,000ft²
- Support from Centre and Community for garden
- High density neighbourhood (Pape/Danforth area)
- Mixed residential and commercial

Outline: The City of Toronto's Environmental Task Force identified green roofs as a method of promoting sustainability. The Works and Emergency Services Department have partnered with Green Roofs for Healthy Cities to contribute in the development of a working protocol. The Soil/Water Quality Improvement Branch of the Environmental Services Section has particular interest in the ability of storm gardens to mitigate the impacts of urban runoff.

A second site, Toronto's City Hall podium is proposed as demonstration site and may include research elements related to plant survivability and stormwater. The 5,000 square foot site will be divided into 8 separate plots to illustrate different green roof applications. The focus of the remainder of this overview is on Eastview, which is approved.

General Objectives: To study the effectiveness of Green Roof technology and discuss implementation opportunities.

As recommended in the Environmental Task Force's proposed Environmental Plan to promote sustainability, evaluate what potential benefits Green Roof technology could bring to the City of Toronto.

Specific Objectives:

To sample and analyse storm water runoff, observing the positive effect green roofs may have both qualitatively and quantitatively.

Contribute to the development of Eastview Community Centre as a test site and model for green roof development citywide.

| Issues | Comments | Item for Discussion |
|---|---|--|
| <ul style="list-style-type: none"> • Sample type - Grab - Composite - Flow Weighted | <p>Eastview CC lends itself well to sample collection with several roof leader clean outs located in the building. The use of automatic samplers is possible.</p> | <p>Pros and cons of sample methodology.</p> |
| <ul style="list-style-type: none"> • Sample Parameters - Sewer Use By-Law - Recreational Quality - Site Improvement | <p>Various measuring sticks of storm water quality exist, the need for a site-specific study may rule out the development of standard parameters.</p> | <p>Develop protocol on quality parameters. Site specific or broad based.</p> |
| <ul style="list-style-type: none"> • Storm Water Management - Storm Intensity - Storm Duration | <p>If possible the overall performance of the Eastview CC storm garden facility should be studied in relation to the intensity and duration of storm events.</p> | <p>Discuss overall importance of storm frequency in design of facility.</p> |

Additional research on the Eastview Site is being planned by Karen Liu , National Research Council’s Institute for Research in Construction. This will involve establishing a variety of sensors to monitor benefits associated with factors such as:

- Roof membrane durability.
- Energy efficiency.
- Micro-climate impacts.

NRC is awaiting final funding approval from the Technology for Early Action Measures in order to implement this research.

City of Portland Orgeon

Tom Lipton, Environment Specialist, Bureau of Environmental Services

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Portland is in the process of developing a program to provide financial incentives for ‘eco-roofs’ and green roofs. It will be based on giving new and existing buildings reduced lot

level fees for stormwater management. Portland considers green roofs to be a legitimate stormwater management technique.

Portland is involved in two green roof demonstration projects. One site is 6,000 square feet in size and divided into two parts. One section has 10 lbs/square inch (3 inch thick) growing medium and the other section is 25 lbs/square inch (5 inches thick) growing medium. Portland has installed flow meters and is looking at monitoring energy benefits.

The second site is 1,200 square feet in size and features a variety of plants native to the west coast. The site will not be irrigated in order to determine which plants are most suitable for green roof applications.

Overview: Chicago Green Roof

John Beaudry, Project Coordinator, Environment Department, City of Chicago

In Chicago, Mayor Daley's plan to put a garden on the City Hall rooftop is now a reality. Construction began April, 2000. The initial planning for this 38,800 square foot project began in January, 1999. During initial feasibility studies it was determined that the roof is a clay tile/concrete structural slab with sloping cinder concrete fill, pitched to drain areas.

It was thought that some of the cinder concrete fill could be removed to allow more weight to be allotted to the garden, however, due to the enormous cost of removing it, it was decided that it would have to remain. This meant that the existing roof would, at best, support only an extensive planting system. However, portions of the roof that once contained large skylights and have since been replaced by solid roofing, could be reinforced to allow a greater load capacity. In those areas and where support columns lie beneath the roof, it would be possible to have intensive planting systems. Based on this information, and the original concept of this being a demonstration project, it was decided that the garden would demonstrate a variety of design concepts.

The current design, one that has evolved out of a naturalistic scheme, is a formal one that is symmetrical in its overall appearance and contains both extensive and intensive systems, as well as vertical gardens on the walls of the existing penthouse. The design was guided by the location of the old skylights and support posts. Because the soil could be up to 18" deep in those locations, it was possible to create a slight topography which includes two main hills. These hills will be constructed using a base of 14,500 cubic feet of extruded polystyrene to help lighten the load. At the top of these, a Cockspur Hawthorn and Prairie Crabapple will be planted. In large starbursts, rays of alternating colored plants will radiate out from the peaks of the hills. Concentric paths that encircle and weave between the two sides will provide access for maintenance. The rooftop will not be open to the public, but because building is surrounded by taller buildings, the garden will be viewed from all sides.

The Plant matrix involves a large variety of plant types due to the multiple types of systems involved. 11,800 square feet of the roof will contain extensive plantings with sedum and forbes in four inches of soil weighing 20-34 pounds per square foot. Another 9,800 square feet will be semi-intensive with a forbes/graminoides mix and will weigh 50-90 pounds per square foot. And, finally, approximately 100 square feet will support intensive plantings over the structural columns and will weigh 80-150 pounds per square foot. This area will provide the soil base needed for trees and shrubs. Rainwater will be collected on the 7,700 square foot penthouse and stored for periods without rain. A supplementary irrigation system will assure establishment of the plants and provide supplemental water in periods of extreme drought.

In all, 20,000 herbaceous plants consisting of 156 varieties, 112 shrubs in seven varieties and 37 vines of American Bittersweet and Boston Ivy will be planted. Herbaceous plants will be installed as plugs grown in the specified growing media. Herbaceous plants and shrubs will be brought up by freight elevator. The trees will be balled and burlapped and brought up by crane. 12,700 cubic feet of growing media will also be brought up by crane. Plants will be installed at horticulturally proper times on a staggered schedule.

In keeping with the concept of creating a demonstration project, the rooftop is being monitored for air quality. Because City Hall occupies only half of the building, (the other half is occupied by Cook County's administrative offices) weather stations have been set up on both halves, one green and one tar. These weather stations will monitor temperature, rainfall, wind speed and direction. Additionally, plans are underway to monitor both butterfly and bird populations to identify the impact green roofs have on them.

Roofscapes, Inc., a sister company to Optigrun in Germany, has been awarded the contract for design of the roofing systems and will work under Bennett and Brosseau Roofing, Inc. who will serve as general contractor. Chicago area based Church Landscape, Inc. will provide plant material.