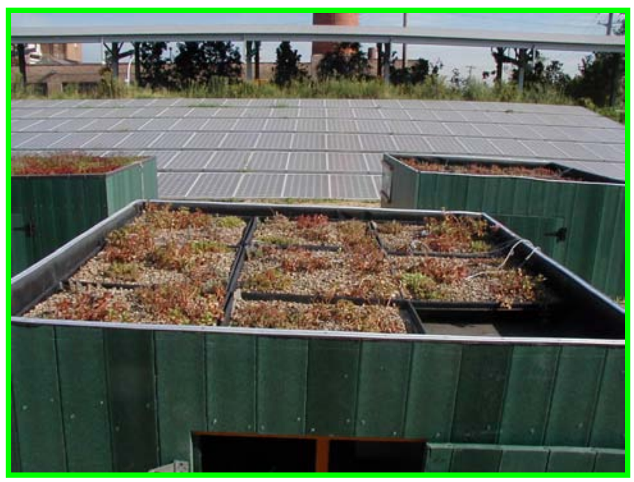
CITY OF CHICAGO
GREEN ROOF TEST PLOT PROJECT

2006 ANNUAL PROJECT SUMMARY REPORT

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for the
City of Chicago Department of Environment

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Executive Summary

The City of Chicago Department of Environment (DOE) retained MWH Americas, Inc. (MWH) to compare green roofs to conventional roofing materials under local environmental conditions. In 2003, DOE and MWH designed the Green Roof Test Plot Project and constructed nine 36-square-foot test plots at the Chicago Center for Green Technology. These test plots were outfitted with a variety of green roof and conventional roof materials and were imbedded with sensors to measure roof thermal performance and the ability to retain stormwater. Results from the project support the City's decision-making efforts regarding green roof policy and practices. Data have been collected at the test plots in 2003, 2004, and 2006; this report summarizes the results of the 2006 studies. In 2006, data were collected to again monitor test plot temperatures and stormwater runoff, but the experiments were expanded to answer the following five questions posed by DOE and MWH:

Does the size of the test plot bias results? MWH outfitted a 36-square-foot test plot and a newly constructed 96-square-foot test plot with new green roofs. Stormwater runoff results were not complete enough to compare the two test plots. Temperature results were similar at 36-square-foot and 96-square-foot test plots, although, on average, the smaller test plot reached daily peak temperatures 1.0 degree Celsius warmer than the large test plot.

Does the thickness of green roof planting media affect performance? MWH replaced two green roofs on 36-square-foot test plots, one with a new four-inch thick green roof and one with a new two-inch thick green roof. Stormwater runoff data were limited, but comparisons of runoff during three separate storm events revealed that the thicker green roof absorbed 0-20% more water than the thinner green roof. Temperature comparisons of the two test plots revealed very similar results.

How do the thermal and stormwater retention performances of newly planted green roofs compare to green roofs with well-established vegetation? Results from test plots with green roofs installed in 2003 were compared to results from new green roofs. Stormwater results from the rainmaker trials revealed that the newly installed green roof absorbed approximately 10% to 30% of storm events, compared to the mature green roofs, which absorbed approximately 40% to 50% of the storm events. Temperatures observed at the new green roofs were generally higher during the day and showed greater diurnal temperature changes than the mature green roof.

Would extensive green roofs help a development meet the new City stormwater ordinance requirement of keeping the first ½ inch of stormwater on-site? Stormwater runoff data were limited in 2006. However, past Green Roof Test Plot studies have revealed that the capacity for stormwater storage is limited and varies depending on past environmental conditions (e.g., if it rained yesterday, the green roof will retain less of today's rain). The Green Roof Test Plot Project has not revealed that four-inch thick green roofs are capable of consistently storing one-half inch of rainfall. However, green roofs can certainly contribute to part of the required storage.

How does the water quality of roof runoff compare amongst the different roof types? Water samples collected from the black tar roof and selected green roofs were analyzed in a laboratory for several compounds that could potentially run off a roof (from the roof material and from atmospheric deposition). Semivolatile Organic Compounds (SVOCs) were not found above detection limits in any of the samples. Polynuclear Aromatic Hydrocarbons (PAHs) were found in small concentrations from the test plot with the black modified-bitumen roof (Black Tar roof), but not from the other samples. Phosphorus concentrations were highest from the green roofs, while nitrogen and total suspended solids concentrations were greatest at the Black Tar roof.

1.0 INTRODUCTION

1.1 Introduction to Green Roofs in Chicago

Ask a stranger to describe Chicago and typical responses may allude to a major city in the Midwest, an economic and industrial force on the Great Lakes, or a hard-working blue-collar town. Until recently, however, the answers would not have likely described a city that is a leader in the urban environmental movement. Since the 1990s, Mayor Richard M. Daley has let the world know his dream of making Chicago "The Greenest City in America." Part of his plan has included promoting the use of vegetated roofs, or "green roofs," instead of conventional roofing materials.

Green roof efforts in Chicago began in earnest in 2000 as part of a City initiative to reduce the Urban Heat Island Effect. Urban landscapes tend to capture and store heat more than their rural or natural counterparts, leading to warmer temperatures, reduced air quality, and increased energy use to cool indoor spaces. Green roofs provide one means of lowering the urban heat signature, so the City decided to lead by example and, in 2000, installed a showcase green roof on one of its most prominent buildings, City Hall.

Figure 1 – Green Roof on CCGT

The City continued its environmental leadership in 2002 by implementing the Urban Heat Island Grant Program and by opening the Chicago Center for Green Technology (CCGT)[1], a LEED-Platinum rated green resource center open to the public (**Figure 1**). In 2003 Green Roofs for Healthy Cities held its first annual Green Roof Conference in Chicago. More recently, Chicago has built award-winning green roofs, including Millennium Park, implemented a green roof grant

[1] CCGT is located at 445 N. Sacramento Boulevard, Chicago, Illinois.

program for residential buildings and small businesses less than 10,000 square feet in size, and initiated a fast-track green permit program. As of October, 2006, the City enthusiastically claimed more than 300 public and private green roofs in the City, totaling over three million square feet.

Although the initial inspiration for green roofs focused on mitigating Chicago's Urban Heat Island Effect, City officials quickly realized that the multiple benefits of green roofs needed to be better understood under local conditions. The City of Chicago Department of Environment (DOE) retained MWH Americas, Inc. (MWH) to compare green roofs to conventional roofing materials under local environmental conditions. MWH designed the Green Roof Test Plot Project, focusing the study on temperature and storm water runoff characteristics of green roofs versus conventional roofs (**Figure 2**). Test plots were constructed at the CCGT (**Figure 3**). Results from the Green Roof Test Plot Project support the City's in decision-making efforts regarding green roof policy and practices. Data have been collected at the Green Roof Test Plot Project in 2003, 2004, and 2006. This report summarizes the results of the 2006 studies.

Figure 2 –Green Roof Test Plot Project at CCGT

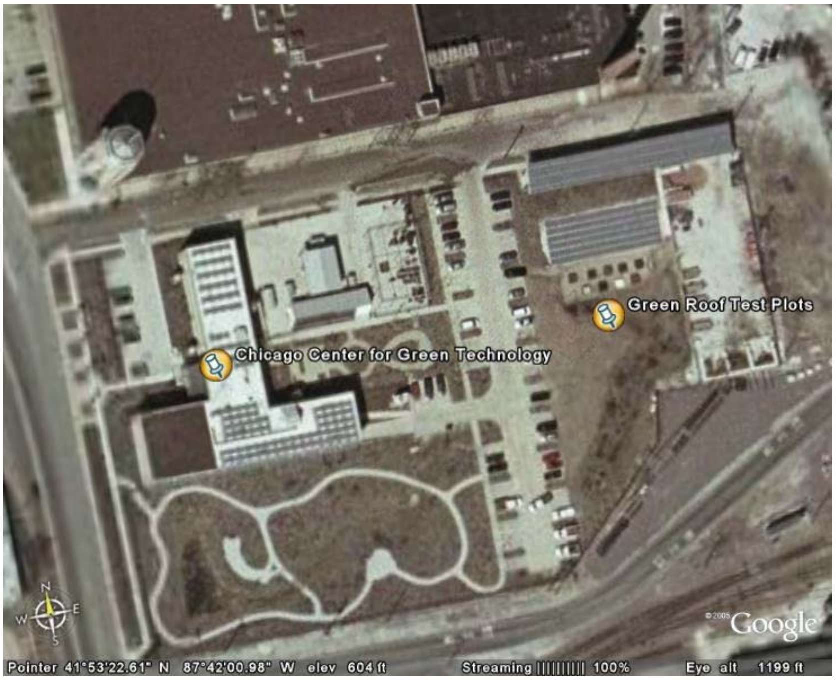


Figure 3 – Aerial Photograph of CCGT from GoogleEarth

1.2 Expansion of Studies in 2006

In 2003, nine 36-square-foot test plots were constructed and outfitted with a variety of green roof and conventional roof materials. These test plots were imbedded with sensors to measure roof thermal performance and the ability to retain stormwater. In 2006, data were collected to again monitor test plot temperatures and stormwater runoff, but the experiments were expanded to answer the following questions posed by DOE and MWH:

- Does the size of the test plot bias results? In other words, does a 36-square-foot test plot roof provide reliable results? Would the use of a larger test plot result in similar data?
- Does the thickness of green roof planting media affect performance? Studies performed in 2003 an 2004 on the Green Roof Test Plots used green roofs with approximately four inches of planting media. Would green roofs with thinner planting media provide comparable results?
- How do the thermal and stormwater retention characteristics of newly planted green roofs compare to green roofs with well-established vegetation?
- Would extensive green roofs help a development meet the new City stormwater ordinance requirement of retaining the first ½ inch of stormwater on-site?
- How does the water quality of roof runoff compare amongst the different roof types? Are common contaminants found in stormwater runoff?

2.0 EXPERIMENT

2.1 Structures and Layout

The Green Roof Test Plot experiment was designed to compare the thermal performance and stormwater retention ability of vegetated "extensive[2]" green roof and conventional roof systems. Nine test plot sheds, made of recycled plastic lumber, were constructed in 2003, each 3.5-feet tall with 36 square feet of roof surface. The test plot sheds were designed to be covered with roofing materials up to six-inches thick, and to allow for the measurement of temperature and collection of stormwater runoff. Although the test plot sheds were not designed using traditional building materials, by isolating the different roofing materials on equal shed structures subjected to similar environmental conditions, the experiment was intended to provide a reliable comparison of these roofing materials.

Six of these sheds were outfitted with extensive green roofs donated by green roof vendors and planted with sedums (*Sedum spp.*), small succulent alpine plants that thrive in shallow soils and are tolerant of extreme fluctuations in water availability and temperatures. The other three test plots were outfitted with "conventional" roofs, including a 0.25-albedo gravel-ballasted roof, a 0.65-albedo white reflective surface roof (WRS), and a black modified-bitumen system (Black Tar). These test plots were monitored during the growing seasons of 2003, 2004, and 2006 for temperature and for stormwater runoff rates. Details of the 2006 monitoring program are available in Sections 2.2 and 2.3. A conceptual representation or the original 2003 design is shown in **Figure 4**.

In 2006, several modifications were made to the original experiment. The original green roofs were removed from two of the test plots (Test Plots #5 and #6, **Figure 5**) and one new larger 8-foot by 12-foot test plot (96 square feet) was constructed (Test Plot #10, **Figure 6**). Each of these three test plots were waterproofed with new Ethylene Propylene Diene Monomer (EPDM, **Figure 7**), a single-ply rubber material commonly used to waterproof roofs, and outfitted with modular green roof systems. The new modular green roof systems installed on Test Plots #5 and #6 (**Figure 8**), contained two-inches and four-inches of growth media, respectively. The new 96-square-foot test plot was also outfitted with the modular green roof system with four inches of growth media. Approximately one half of this 96-square-foot test plot was covered with newly installed green roof modules, and the other half was covered with green roof modules that had been established since 2003. The general site layout is shown in **Figure 9** along with a chart showing which parameters were monitored per test plot in 2006.

[2] Green roofs are typically described as either "extensive" or "intensive." Extensive green roofs are low-profile, lightweight, and low-maintenance green roofs that typically contain from one to six inches of lightweight, engineered soil media and are planted with low-profile herbaceous species. Intensive green roofs, in contrast, have growth media from eight inches to several feet thick and can support a wide range of herbaceous and woody vegetation.

DOE does not promote any brands of green roofs in particular. Therefore, where possible, the identities of the individual green roofs are kept anonymous when data are presented in this report.

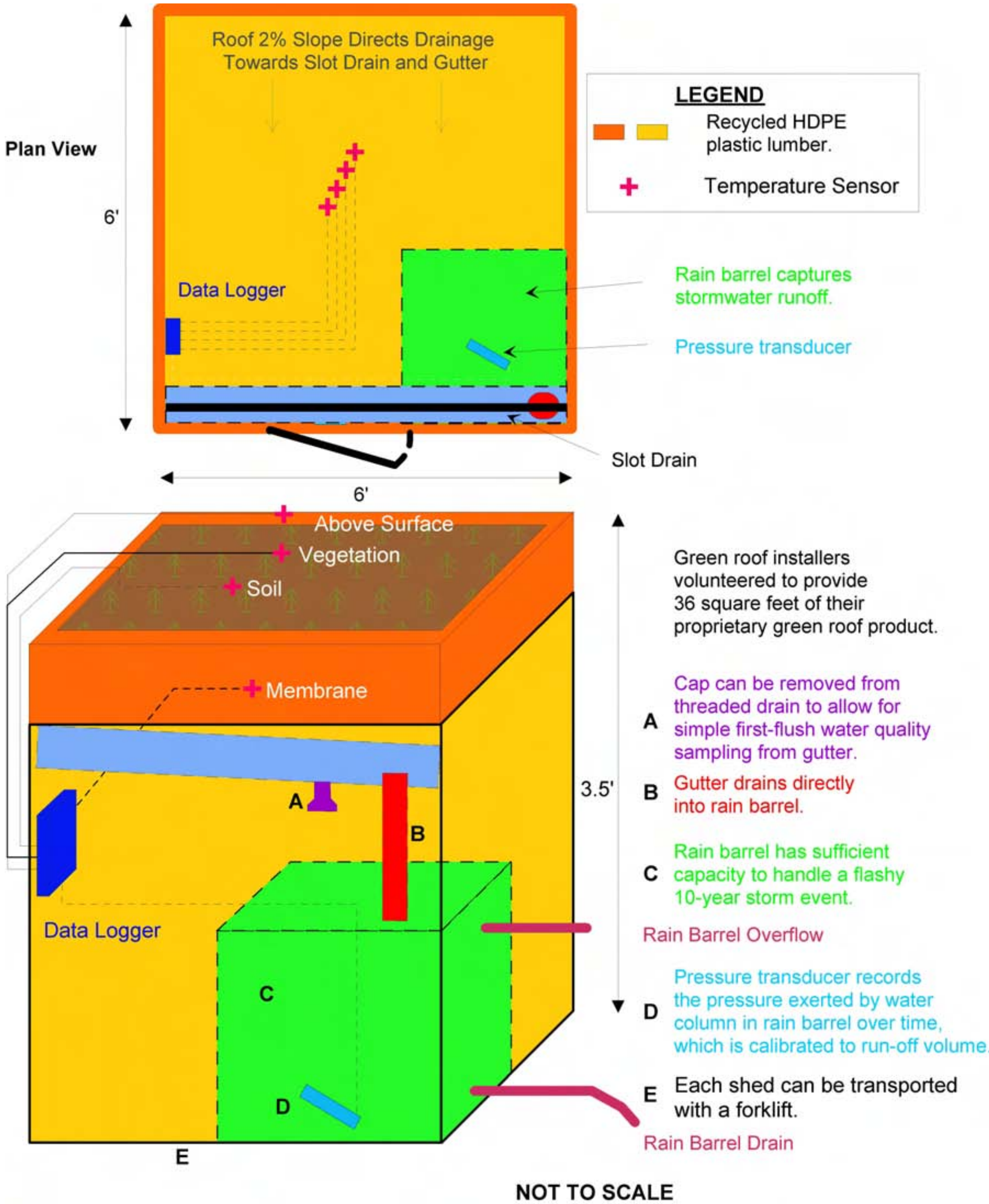


Figure 4 –2003 Conceptual Design of a Green Roof Test Plot

Figure 5 – Removing and replacing a green roof installed in 2003 (July 14, 2006)

Figure 6 – Newly constructed 8-foot by 12-foot Test Plot (August 17, 2006)

Figure 7 – EPDM membrane installation on test plot with replaced green roof (August 7, 2006)

Figure 8 – Newly installed modular green roof (August 17, 2006)

Test Plot	Temperature	Stormwater Runoff
Green Roof #1	-	-
Green Roof #2	X	-
Green Roof #3	X	X
Green Roof #4	X	X
Green Roof #5	X	X
Green Roof #6	X	X
Green Roof #10	X	X
White Reflective Surface Roof	X	X
Black Tar Roof	X	-
Gravel-Ballasted Roof	-	-

Table 1 - Parameters Measured in 2006

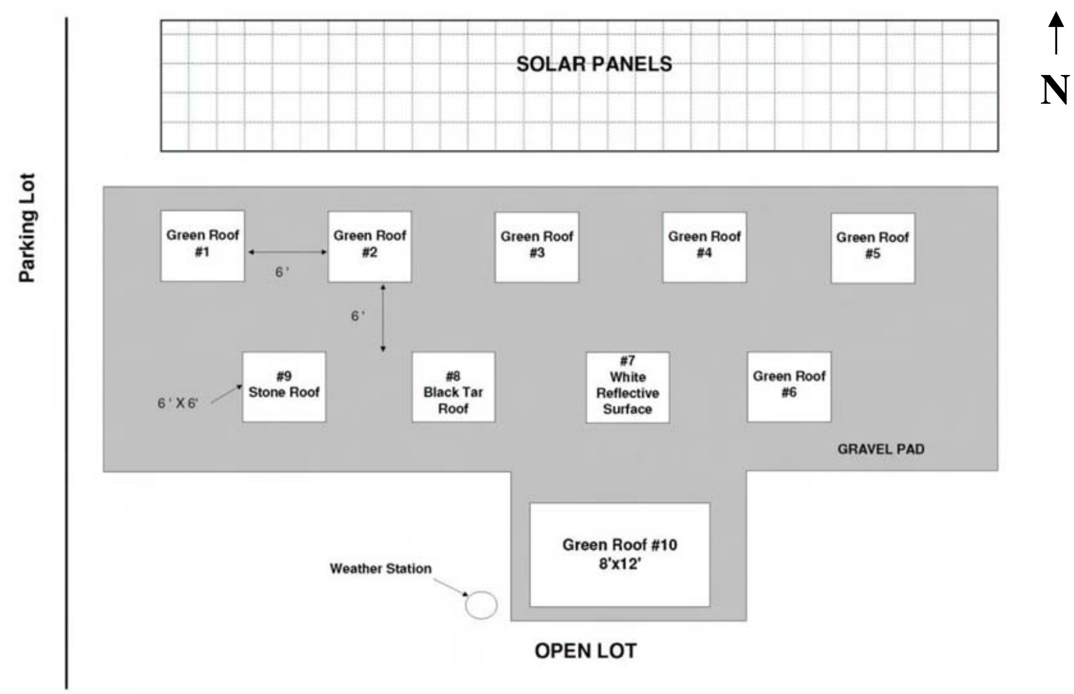


Figure 9 – Green Roof Test Plot Layout

2.2 Stormwater Collection

Two different devices were used to measure the rates of water running off the test plots. **Figure 10** shows cross sections of both measurement devices.

(1) The "Storage Tank" (or "Rain Barrel") systems were installed in 2003 and were again used for Green Roofs #3 and #4 in the 2006 study. The Storage Tank system consists of a pitched roof deck with two percent grade leading to a grated slot drain (1.5-inch by 5.5-feet) that empties into a plastic storage tank with approximately 40-gallons of functional capacity. Water falling on the 36-square-foot test plot has to filter through the green roof layers before reaching the slot drain. A six-inch parapet wall extending above the roof deck prevents surface flows from escaping the test plots. At the bottom of the plastic storage tank, a pressure transducer calibrated to storage tank volume measures the pressure of the water column in the tank (**Figure 10**). The Storage Tank systems reach their volumetric capacity and require manual draining after the equivalent of approximately 1.8 inches of rainfall runs off the 36-square-foot roof. The two Storage Tank systems used in 2006 allowed for comparisons to data collected in previous years.

(2) A new system was installed in 2006 and used on Green Roof #5, Green Roof #6, Green Roof #10, and the WRS roof. This new system utilized a flow-through orifice restriction device (ORD) that consisted of a 5-gallon bucket fitted with two vertical standpipes, one

of which contained a series of spaced holes to allow restricted outflow from the system (**Figure 10**). A pressure transducer installed in the standpipe without orifices measures the pressure of the water column in the standpipe. When runoff from the rooftop flows through the system, the orifices in the standpipe restrict outflows and cause the water column to rise in both standpipes. The rise in the water column is measured using the pressure transducer and is calibrated to flow rates. This new design was used in 2006 to alleviate problems with volumetric limitations of the Storage Tank system and to allow for the collection of large storm events up to a 24-hour, 100-year storm event. Finally, in contrast with the Storage Tank system, the ORD test plots were pitched at approximately a two percent grade towards a corner, where a drainage pipe protected by a thin metal grate was located at the roof surface, allowing excess surface flows to reach the measurement device.

The idea for using an ORD for stormwater runoff collection came from green roof studies performed by Magnusson Klemencic Associates (MKA) in Seattle, Washington. MWH communicated with Brian Taylor of MKA when setting up the ORDs.

Data loggers recorded voltage output from the pressure transducers at one minute intervals for both systems. Each pressure transducer was calibrated individually at the beginning of the 2006 experiment and the ORD systems were calibrated twice. Storage Tank systems were emptied manually once every two weeks. Data were downloaded approximately every two weeks, before being modified for transfer to a database, graphed, and analyzed.

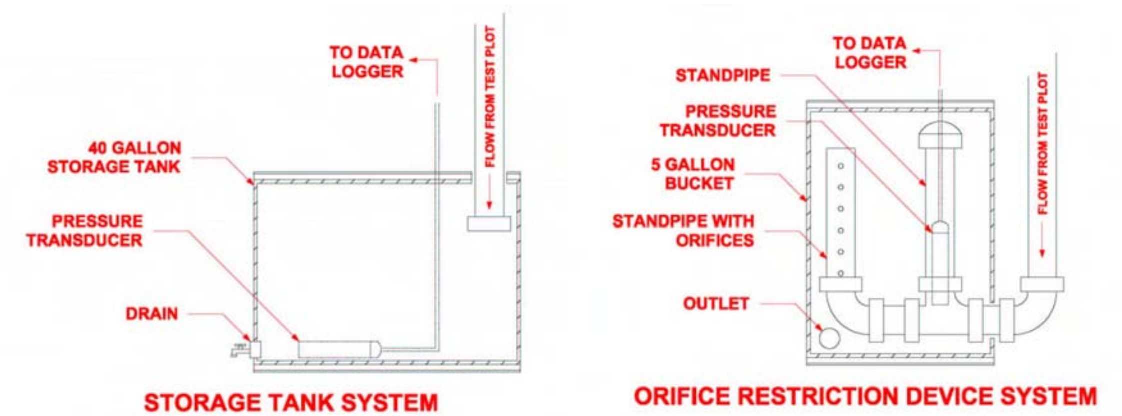


Figure 10 – Cross Sections of Two Stormwater Runoff Measurement Devices Used in 2006

2.3 Temperature Collection

Each test plot shed was monitored for temperature at two or three locations: Rooftop, Soil, and/or Membrane horizons (**Figure 11**). Up to three sensors were installed at each horizon, with a maximum of eight sensors installed per test plot shed. In 2006, multiple temperature sensors were used at each horizon to bring redundancy and more accuracy to the temperature studies. Many of the temperature sensors and data loggers originally purchased in 2003 were replaced with new equipment in 2006. Within each test plot, a data logger recorded temperature readings at 15-minute intervals. Data were downloaded approximately every two weeks, modified for transfer to a database, graphed, and analyzed.

Baseline ambient weather conditions, including temperature, rainfall, wind speed and direction, and relative humidity were recorded using an on-site weather station. Data were downloaded approximately every two weeks and transferred to a database for analysis.

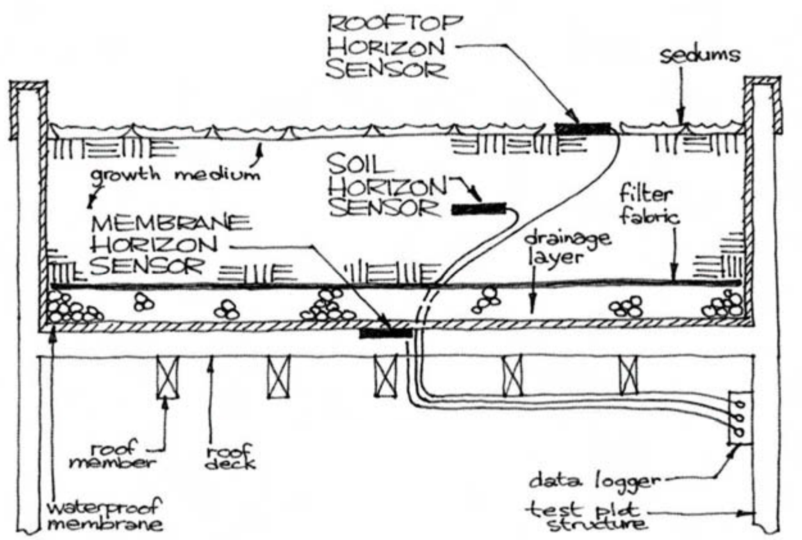


Figure 11 – Typical Green Roof Test Plot Cross-Section and Temperature Sensor Locations

2.4 Water Quality

First flush runoff samples were collected at three roofs using the rainmaker to simulate a storm event (Appendix B). Simulated rain events were used for water quality sampling instead of naturally-occurring events for several reasons: (1) the ability to monitor the collection system during the rain event, (2) to ensure adequate sample volumes were collected, and (3) to reduce the possibility of sample contamination. One duplicate sample and one sample of water directly from the rainmaker nozzles were also tested. The samples were analyzed by STAT Analysis Corporation for concentrations of 74 pollutants and nutrients, including total Kjeldahl nitrogen (TKN), nitrate-nitrite nitrogen (NO_2-NO_3), total phosphorus (TP), total suspended solids (TSS), polynuclear aromatic hydrocarbons (PAH), and semivolatile organic compounds (SVOC).

2.5 Summary of 2006 Experimental Changes

Several changes were made in the Green Roof Test Plot Project for the 2006 data collection season in response to questions posed by DOE and MWH.

#	Question	Experimental Change
1	Does the size of the test plot skew results?	Build a new 96-square foot test plot to use for comparison.
2	Does the thickness of green roof planting media affect performance?	Replace two green roofs on 36-square-foot test plots: (1) four-inch thick green roof and (2) two-inch thick green roof.
3	How do the thermal and stormwater retention performances of newly planted green roofs compare to green roofs with well-established vegetation?	Compare the data from green roofs installed in 2003 to the ones installed in 2006.
4	Would extensive green roofs help a development meet the new City stormwater ordinance requirement of keeping the first ½ inch of stormwater on-site?	Analyze data to see if extensive green roofs can hold ½ inch of water and identify limitations.
5	How does the water quality of roof runoff compare amongst the different roof types?	Collect and analyze water runoff samples for common contaminants.

Table 2 – Experimental Changes in 2006

3.0 RESULTS

3.1 Stormwater Runoff

Stormwater runoff data were collected from six test plots (**Table 1**) and baseline ambient rainfall data were collected at the weather station. The WRS test plot was used as the experimental control against which the green roofs were compared. A “storm event” was defined by cumulative precipitation recorded by the weather station, followed at least 12 hours with no precipitation. As described in Section 2.2, both traditional Storage Tank and new flow-through ORD measurement devices were deployed in 2006.

MWH also performed rainmaker tests, using a rainmaking device to simulate storm events and compare stormwater runoff characteristics of several test plots under controlled rain conditions (Appendix A). The goals of the rainmaker tests included gathering scientific data to support decisions related to the City’s stormwater ordinance and green roof policies, in addition to providing the City with a methodology for testing various roofing surfaces to verify consistency with City green roof requirements.

The data collected from the 2006 stormwater runoff studies, including both natural storm events and controlled rainmaker events, provided opportunities to analyze the characteristics of different roof materials and the two stormwater collection devices (Storage Tank versus ORD).

Storage Tank Systems. The Storage Tank collection systems, which were the systems exclusively used in 2003 and 2004, provided runoff data in 2006 that were comparable to the quality of data collected in previous years of the test plot studies. The pressure transducers in the Storage Tank systems again delivered smooth voltage curves corresponding to runoff volume over time. Short term variability in pressure transducer voltage output did not hamper data analysis. In general, the Storage Tank systems produced reasonable data that corresponded well with the graduated volumetric markings on the sides of the actual tanks. However, the major limitation of the Storage Tank collection system is the finite volumetric capacity. Approximately 1.8 inches of cumulative rainfall creates enough runoff to fill the Storage Tank on the WRS roof, which is used as the experimental control for the stormwater runoff studies. During the 2006 studies, four of the eight two-week data collection periods had greater than 1.8 inches of cumulative rainfall.

ORD Systems. In comparison, the runoff data recorded from the newly constructed ORD devices did not consistently provide the degree of accuracy expected. The zero-flow voltage output from the pressure transducers during periods of no precipitation was not consistent throughout the study period and showed diurnal variability (**Figure 12**). Calculating runoff rates was made difficult because the variability in zero flow voltages. When calculating runoff from test plots outfitted with the ORDs, we used best professional judgment to determine the zero flow voltage at the beginning of the storm event and assumed that zero-flow voltages did not vary over the course of the storm event (rainfall durations were determined from weather station data).

The voltage output from the pressure transducers is a stepped function, with each "step" equal to approximately 0.01 volts. Each "step" corresponds to approximately 0.1 gallons per minute (gpm) of runoff flow through the ORD. Therefore, even a small shift in zero-flow voltage can have a large impact over the course of a storm event. For example, if the zero-flow voltage is off by one voltage "step," over the course of a two-hour storm event the difference in runoff could be up to 12 gallons, or the equivalent of 0.53 inches of rainfall on a 36-square-foot test plot. The ORDs provided the most reliable data when runoff flows were at least 0.5 gpm. Therefore, during intense, short storm events, the data from the ORDs proved to be reliable, given the greater runoff rates and the fewer opportunities for the ORD baseline voltage to drift or fluctuate. The data collected during the short, intense rainmaker trials provided the most reliable ORD data.

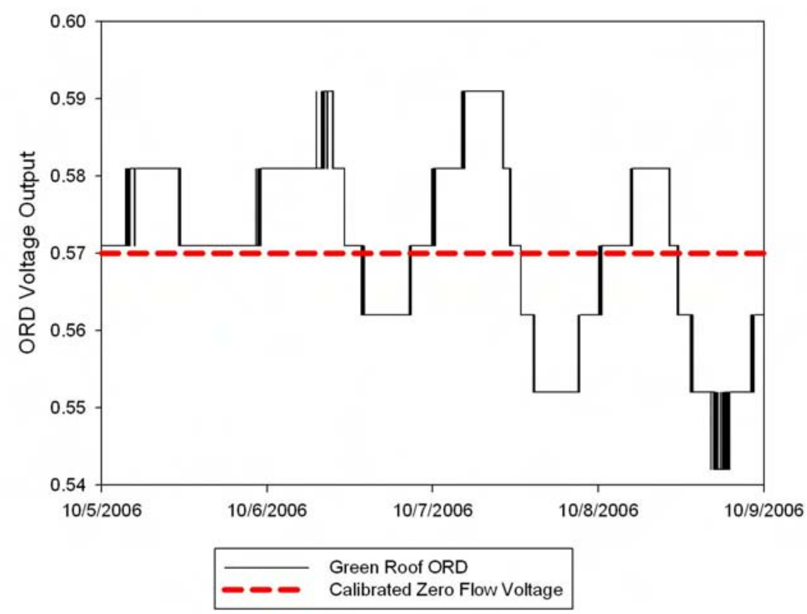


Figure 12 – Example of ORD Baseline Output Variability over Four Days with No Precipitation

Unfortunately, analyses of the pressure transducers and ORD setups have not revealed the cause(s) of the diurnal zero-flow voltage fluctuations. The two efforts to calibrate the equipment ran smoothly and did not reveal such data errors. Moreover, the pressure transducers that were used in the ORDs were previously used in the Storage Tank systems (in 2003 and 2004) and did not reveal such fluctuations in baseline output.

Over the course of the 2006 studies, the weather station recorded 34 storm events, ranging from 0.01-inches to 3.64-inches, totaling 18.43-inches of rain. Due to issues with the ORD data, it was not possible to comprehensively compare ORD data to Storage Tank data over the course of the 2006 sampling season. It was possible, however, to compare test plots for some individual storm events. Examples of two storm events of short duration, one intense (**Figure 13**) and one small (**Figure 14**), are included below.

3.1.1 Example Intense Storm Event

An example of an intense rain event is shown in **Figure 13**. This example comes from the 2006 rainmaker study (Appendix A), in which a 10-year 15-minute storm event was simulated, dropping 1.23-inches of water on each test plot over a short 15 minute period.

Runoff results from the two mature green roofs outfitted with Storage Tank collection devices showed that these green roofs retained at least 50% of the rain event. In comparison, the two new green roofs with ORD systems retained only approximately 10% of the rain event. Both the two-inch thick and four-inch thick new modular green roofs (Green Roofs C & D) revealed very similar runoff results. As expected, approximately 100% of the rain event ran off of the WRS control roof.

The runoff curves shown for Green Roofs A and B in **Figure 13** are similar to runoff curves observed in earlier Green Roof Test Plot studies (2003 and 2004), especially with regards to the lag time between rainfall and tank filling. Stormwater slowly filters through the green roofs before reaching the collection tank. In comparison, after a short lag at the initiation of the storm, the new green roofs with ORD systems showed runoff rates that were similar, but slight less, than those recorded at the WRS test plot.

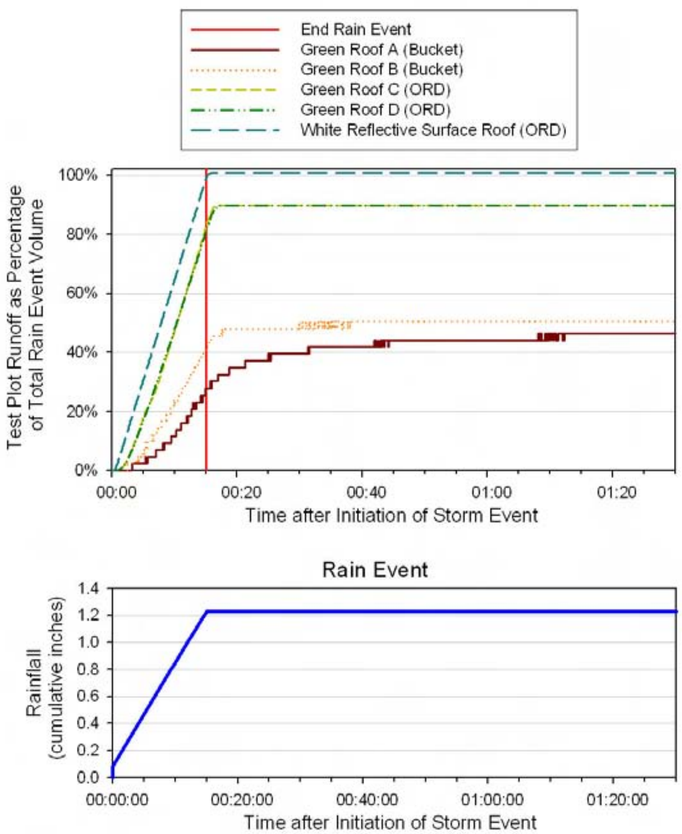


Figure 13 – Intense Storm Event Example (1.23 inches)
10-Year, 15-Minute Rainmaker Trial, September 14, 2006

3.1.2 Example Small Storm Event

An example of a small natural storm event, in which 0.31 inches of rain fell over approximately 12 hours, is shown in **Figure 14**.

Results from this small storm event reveal that the two mature green roofs (established in 2003) outfitted with Storage Tank collection devices and one of the new green roofs with an ORD system retained at least 90% of the storm event volume. Because this was a small storm event, the runoff from Green Roof B (approximately 10% of total rainfall) actually only represented one voltage "step" in pressure transducer output. The fourth green roof tested retained 70% of the storm event. However, the WRS control roof demonstrated the potential error encountered with the ORD systems for small storm events. A small error in flow measurement, compounded over the duration of a storm event, created a large error, such that the WRS revealed 40% more runoff volume than rainfall that hit the test plot. This small storm event example also shows that none of the test plots showed any runoff during the first sprinkles of rain at the initiation of the storm event (at time 0:00) and approximately time 1:30.

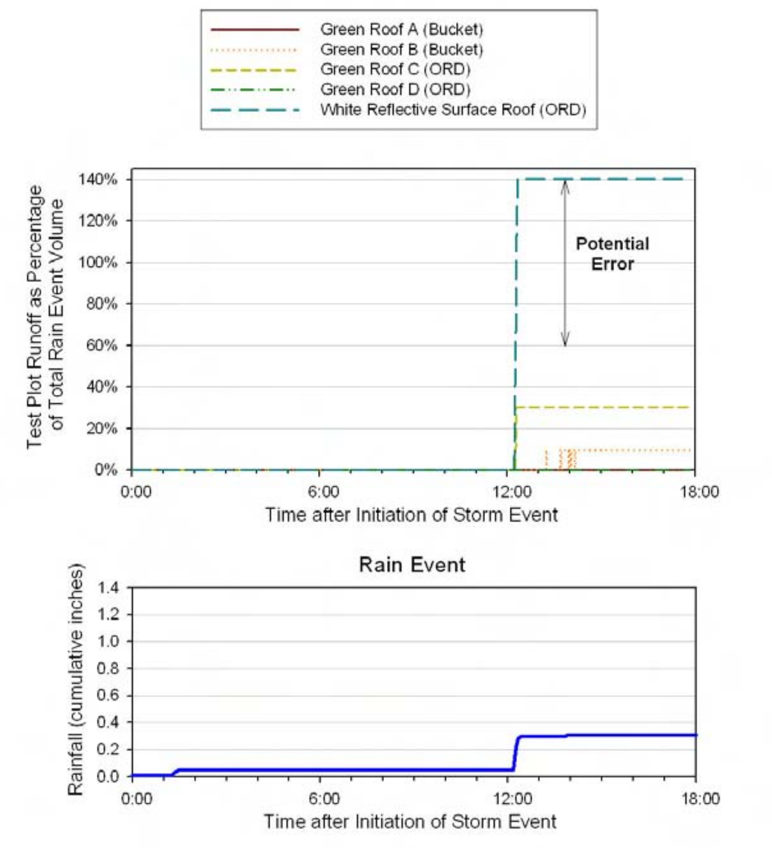


Figure 14 – Small Natural Storm Event Example (0.31 inches)
September 22, 2006

3.2 *Temperature*

Temperature data have been collected in 2003, 2004, and 2006 at the Surface, Soil, and Membrane horizons. The data collected in 2006 revealed similar temperature trends as those observed in previous years.

In 2006, multiple temperature sensors were used at each horizon to bring redundancy and more accuracy to the temperature studies. The following charts show the mean temperature at each horizon where multiple sensors were present, unless otherwise stated.

3.2.1 Example Days of Temperature Data

One reader-friendly manner of presenting the temperature data is to show temperatures over a typical day and identify trends. **Figure 15** shows temperatures at the Rooftop and Membrane horizons on typical Cool and Warm days. Data from the Black Tar and WRS test plots show the mean of the temperatures recorded at each horizon. For comparison, data from the six green roofs are included in each chart, showing the ranges of temperatures observed. Looking at the temperatures recorded on these typical days, the following trends become apparent:

- Temperature differences between roof types are greater on the Warm Day than on the Cool Day.
- On the Warm Day, the green roofs are the coolest test plots during the day, followed by the WRS and the Black Tar. Temperature patterns at the Rooftop and Membrane horizons are similar, but there is less temperature fluctuation at the Membrane horizon.
- On the Cool Day, the Rooftop temperatures were fairly similar amongst each of the three roof types.
- At nighttime in each of the charts, the WRS and Black Tar test plots show very similar temperatures, while the green roofs tend to retain heat into the nighttime and stay warmer than the other roof types.
- With the exception of the Rooftop horizon on the Cool Day, the green roofs revealed the smallest diurnal fluctuations in temperatures.

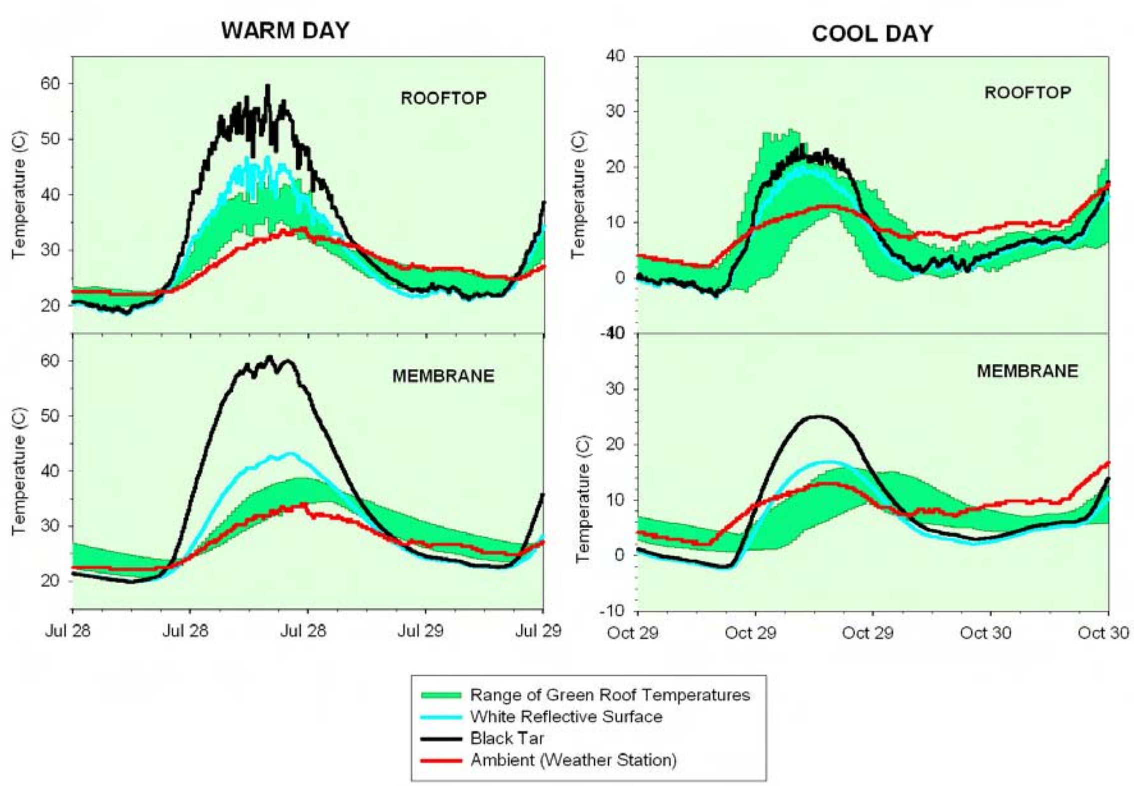


Figure 15 – Temperatures at Rooftop and Membrane Horizons, Typical Warm and Cool Days

3.2.2 Ranges of Temperatures

After analyzing typical temperature days observed in 2006, the next logical step is to analyze trends observed over the entire 2006 study. Box charts help reduce the visual clutter of large data sets (**Exhibit 16**). The top and bottom lines of the box represent the 25th and 75th percentiles of temperature data, while the center line shows the 50th percentile. The whiskers on the box represent 10th and 90th percentiles, while the dots represent the 5th and 95th percentiles. To keep the green roof vendors anonymous, the green roofs are named with letters.

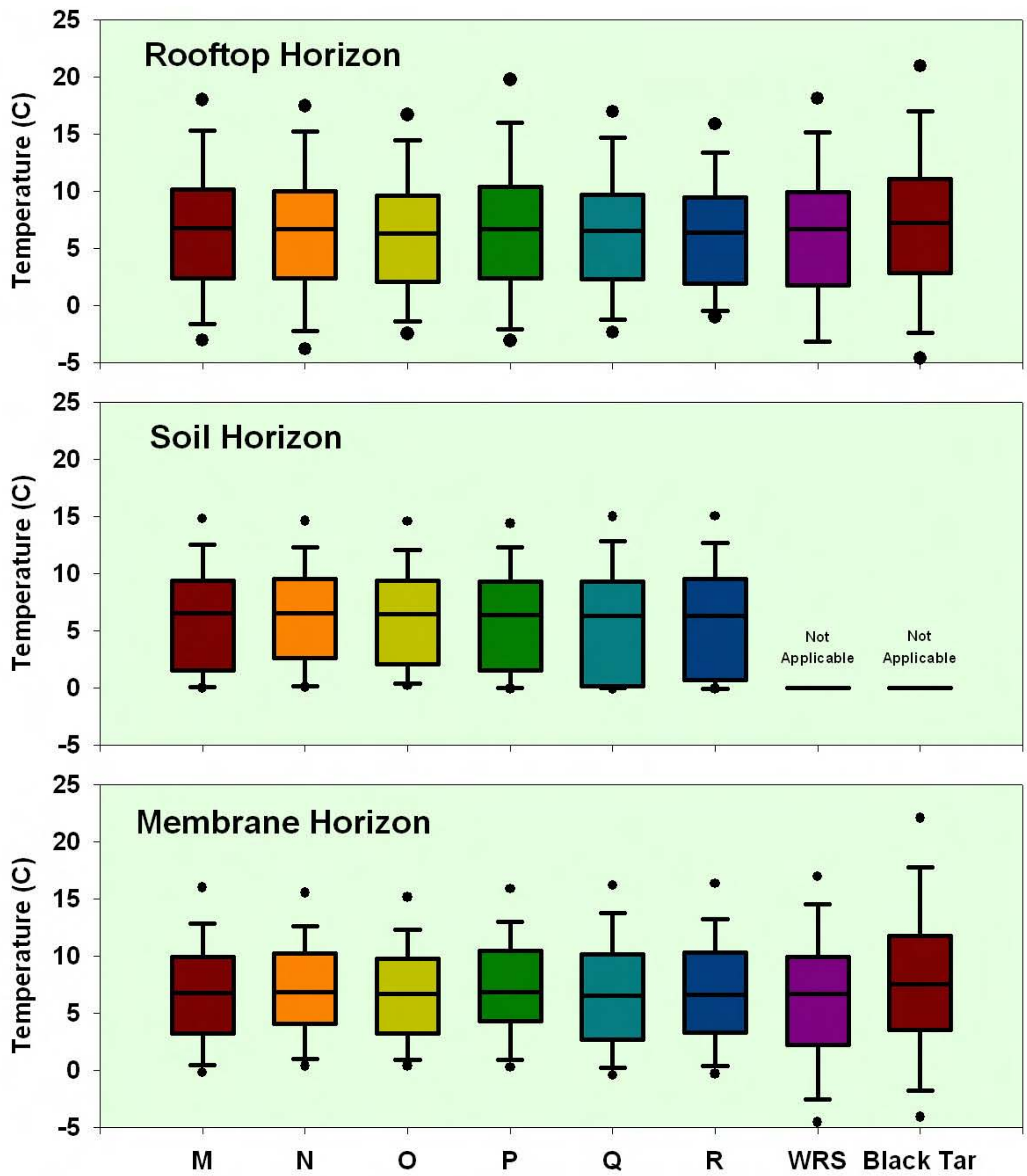


Figure 16 – Box Charts of Temperatures Recorded from July 18, 2006 – November 9, 2006

For the most part, the box charts do not reveal striking differences between test plots. The 5th and 95th percentiles of the temperature data are shown as single points on these charts, which eliminates some of the strikingly high temperatures observed at the Black Tar roof, but allows for a less biased assessment of the full year of temperature data. Temperatures at the six green roofs appeared to be fairly similar to each other at each of the three horizons, although the three green roofs with more established vegetation (Green Roofs N, O, and P) tended to show slightly less temperature variation (more compact box plots) than the other three green roofs at the Soil and

Membrane horizons. The Black Tar roof revealed the widest range of temperatures at both the Membrane and Rooftop horizons. Although differences in median temperatures may only vary by a couple degrees Celsius amongst test plots, those small temperature differences compounded over a long period of time could translate to significant energy savings for a building with a conditioned interior.

3.2.3 Daily Peak Temperature Comparisons

Daily peak temperatures were recorded at the Membrane horizon and compared amongst the test plots. Daily differences in peak temperatures were calculated and averaged over the course of the 2006 study (**Table 3**). Since similar temperature patterns were observed at each of the Rooftop, Soil, and Membrane horizons, the Membrane horizon was chosen for further analysis because its temperature results were smoother and less affected by sudden temperature spikes.

Warmer Test Plot	Cooler Test Plot	Mean Temperature Difference (ºC)
New 2-inch thick green roof (36 square feet)	New 4-inch thick green roof (36 square feet)	0.2
New 4-inch thick green roof (36 square feet)	New 4-inch thick green roof (96 square feet)	1.0
New 4-inch thick green roof (36 square feet)	Mean of three green roofs with vegetation established in 2003	1.6
Black Tar	Mean of all six green roofs	12.9
WRS	Mean of all six green roofs	3.0
Black Tar	WRS	9.8

Table 3 –Mean Differences in Daily Peak Temperatures at the Membrane Horizon, 2006

4.0 CONCLUSIONS

In analyzing the 2006 study results, efforts focused on dealing with the specific questions posed in Section 1.2 of this report.

4.1 Effect of Test Plot Size

To determine if the 36-square-foot test plots were biased due to the size of the roof surface, the results from a 36-square-foot test plot were compared with those from the 96-square-foot test plot. The two test plots were outfitted with new four-inch thick modular green roofs in 2006.

The 36-square-foot test plot was supported on an enclosed shed made of plastic lumber while the 96-square-foot test plot was open to airflow below the support platform. From the limited stormwater runoff data available, differences in stormwater absorption were not observed. However, as shown in Table 3, the daily peak temperatures at the Membrane horizon were, on average, approximately 1.0 degrees Celsius warmer at the 36 square foot test plot. It is possible that the smaller test plots create slight bias in temperature results. The data from the 96-square-foot and 36-square-foot test plots were generally similar, although either the test plot size or the structure configuration (an enclosed versus an open-air support platform) could have contributed to the slight temperature differences.

4.2 Effect of Green Roof Thickness

Intuitively, compared to a thicker green roof, a thinner green roof should provide reduced abilities to absorb stormwater and to insulate against temperature extremes. Extensive green roofs vary in thickness from approximately one to six inches. For the 2006 Green Roof Test Plot Project, the City wanted to examine whether two inch thick green roofs would provide similar temperature and stormwater benefits as four inch thick green roofs. The two inch thick green roofs inherently weigh less and are attractive to some building owners who want to retrofit green roofs on existing buildings, but have limited structural support.

Two new modular green roofs were installed on 36 square foot test plots in 2006, one with two inches of planting media and one with four inches of planting media. The amount of stormwater runoff data available to compare the two test plots in 2006 was limited. During two of the rainmaker trials, the two test plots revealed very similar runoff results, and during the third rainmaker trial – the 100-year 15-minute event – the four-inch green roof absorbed approximately 20% more rainfall than the two-inch green roof. Since the green roofs have a finite volume of water that can be retained, it is expected that the two-inch green roof would be less effective at retaining water.

Temperature comparisons of the two test plots revealed very similar results. As shown in Table 3, peak daily temperatures at the two-inch green roof were, on average, 0.2 degrees Celsius warmer than the four-inch green roof. These results fall within the range of expectations. Greater differences in temperature may be observed in the future as plant material becomes more established.

4.3 Old versus New Green Roofs

A newly installed four-inch thick green roof was compared to three four-inch thick green roofs that have been established since 2003. The comparisons seek to determine if there is an inherent bias with observations at newly installed green roofs and how the performances of the green roofs change over time.

Stormwater results from the rainmaker trials revealed that the newly installed green roof absorbed approximately 10% to 30% of storm events, compared to the mature green roofs, which absorbed approximately 40% to 50% of the storm events. These results seem reasonable. Past observations from the test plots indicate that sedums can take up to a year to become fully established. Until newly installed sedums establish more dense root systems, the benefit of having vegetation on the roof is limited. **Figure 17** shows the dense root mass of a three-year old sedum plant.

Figure 17 – Dense Root Mass of a Sedum Plant Installed in 2003 (August, 2006)

Temperatures observed at the new green roof were generally higher during the day and showed greater diurnal temperature changes than the mature green roof.

The new 96 square foot test plot was covered in two sections, one half with new four inch green roof modules and the other half with mature four inch green roof modules established in 2003. One Membrane temperature sensor was installed under the new modules and another sensor was installed under the established modules. **Figure 18** shows a few typical days of temperature data from these sensors and reveals that the established green roof modules often kept the membrane cooler during peak daytime temperatures.

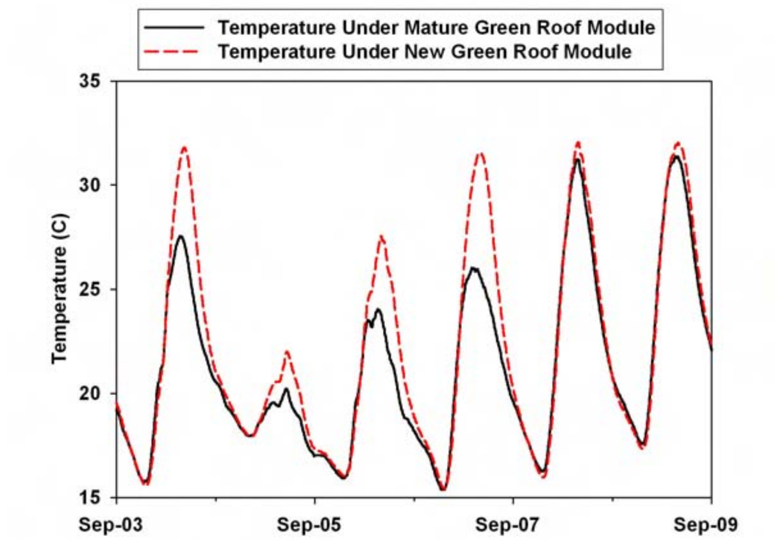


Figure 18 – Membrane Horizon Temperatures Under New and Established Green Roof Modules on the 96-Square-Foot Test Plot

4.4 Past Trends compared to 2006

Briefly, general temperature trends observed in 2006 were very similar to those observed in previous years. This consistent collection of temperature data over the course of the Green Roof Test Plot Project provides robust arguments for past and present temperature comparisons amongst roof types. Stormwater runoff trends are more difficult to compare, largely because the data collected in 2006 were limited by questionable results from the ORDs. In 2004, the Green Roof Test Plot study found that nearly 60% of the storm volume of all storm events analyzed in 2004 was absorbed by the green roofs.

4.5 City Stormwater Ordinance

The new City stormwater ordinance, which will take effect in 2008, requires that new developments and redevelopments of a certain size retain the first one-half inch of stormwater on-site. One of the goals of the 2006 Green Roof Test Plot Project was to determine whether green roofs could contribute to that stormwater retainage goal. Although the 2006 stormwater runoff data were incomplete, past Green Roof Test Plot studies (City of Chicago Green Roof Test Plot Study, 2004) have shown that extensive green roofs with three to four inches of growth media are indeed capable of retaining one-half inch of water, if the green roof is almost completely dry before the rain event. However, green roofs have finite capacity for stormwater storage that varies depending on past environmental conditions (e.g., if it rained yesterday, the green roof will retain less of today's rain event). It is possible, however that thicker green roofs or green roofs with additional water storage capacity (plastic grids with perforated cups may be installed under the filter fabric to temporarily store water) could consistently retain the first one-half inch of stormwater. While the Green Roof Test Plot Project has not revealed that four-inch thick green roofs are capable of consistently storing that much water, it certainly does not inhibit the green roofs from providing part of the required storage. Thus, green roofs may be one piece a stormwater storage plan for a development, but do not appear able to eliminate the need for other storage mechanisms.

4.6 Water Quality

Results of the water quality study are in Appendix B. Samples were taken from two green roofs, the Black Tar roof, and the water source (the rainmaker). SVOCs were not found above detection limits in any of the samples. PAHs were found in small concentrations from the Black Tar roof runoff, but not from the other samples. Phosphorus concentrations were highest from the green roofs, while nitrogen and total suspended solids concentrations were greatest at the Black Tar Roof. Further discussion of the water quality results are available in Appendix B.

APPENDIX A

Rainmaker and Runoff Coefficient Report, 2006

INTRODUCTION

The City of Chicago (City) Department of Environment (DOE) retained the services of MWH Americas, Inc. (MWH) to perform a second year of controlled, simulated storm event testing, comparing stormwater runoff characteristics of several vegetated roofing systems (green roofs). The goals of the project included gathering scientific data to support decisions related to the City's stormwater ordinance and green roof policies, in addition to providing the City with a methodology for testing various roofing surfaces to verify consistency with City green roof requirements.

Two types of green roof systems were tested in this phase of rainmaker and runoff coefficient field testing. The first type, installed on Green Roofs #3 and #4 in 2003, generally consisted of a uniform, approximately four-inch-deep layer of growth media sandwiched on top of a geotextile fabric and a drainage layer – these green roof systems were also studied in MWH's 2004 Rainmaker and Runoff Coefficient Study (2004 Study). Stormwater from this roof type filtered through the green roof toward a slot drain, and was directed to a collection bucket via a gutter system. The second type, installed on Green Roofs #5 and #6 in July of 2006, consisted of eight two by two foot plastic trays, each filled with approximately two or four inches of growth media on top of geotextile fabric. This second type of green roof system, hereinafter referred to as the "modular" system, covered 89% of the test plot surface. One-ninth of the test plot was left unimproved to allow for installation of a surface drain with a mesh cover, a more accurate representation of an actual roof installation. Finally, a test plot outfitted with a 0.65-albedo white reflective surface (WRS) roof was used as the experimental control.

RAINMAKER AND TEST PLOT DESIGN

Rainmaker Device. The revised rainmaker design consisted of a closed loop of four-inch diameter PVC pipe outfitted with a low-pressure gage[1], an external hose connection, and four spray nozzles[2] designed to release a uniform square spray pattern over each test plot. Two sets of interchangeable spray nozzles were used to more accurately represent high intensity and low intensity storm events. The rainmaker was suspended from adjustable chains from the top of

Exhibit 1
2006 Rainmaker Device

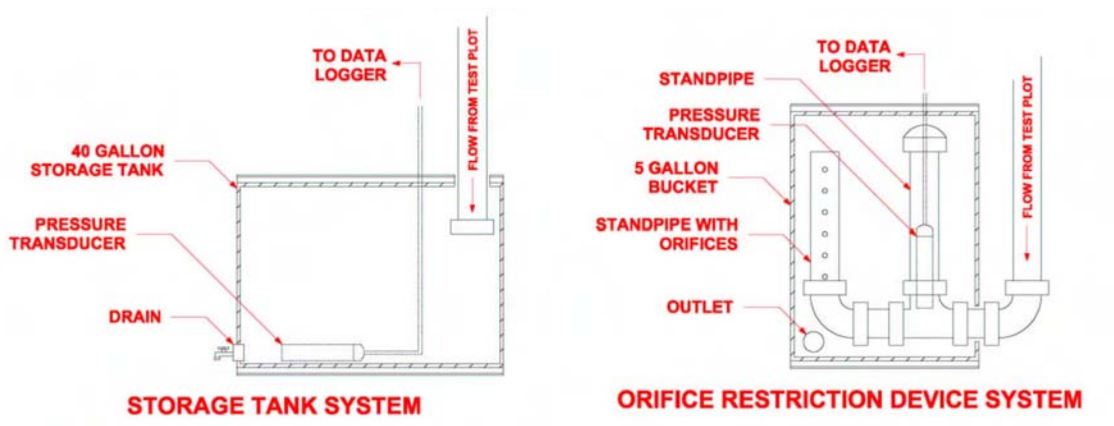
[1] Palmer Wahl Instrumentation Group, 0-15 psi, stainless steel low pressure gage
[2] PNR America LLC, Models BDQ1270SN and BDQ1740SN, stainless steel spray nozzles

eleven-foot mobile scaffolding and connected to a heavy-duty construction hose using a standard ball valve. Two 5-foot sections of standard roof gutters were also attached below the PVC loop to help divert water emitted from the nozzles away from the test plots while the rainmaker operator stabilized rainmaker pressures prior to conducting field tests. **Exhibit 1** shows the configuration of the revised rainmaker device.

To pressurize the rainmaker, the hose was connected to an outdoor spigot and the PVC loop was allowed to fill with water with the ball valve completely open. When the system was pressurized, the ball valve was then used to manually adjust the pressure in the rainmaker.

Runoff Measuring Devices. Two devices were used to measure the volume of water passing through the test plots during field testing. The Storage Tank device consisted of a 40-gallon plastic storage tank with a pressure transducer placed at the bottom of the tank. This design, which was used in the 2004 Study, was used for Green Roofs #3 and #4 in this study. The second method, used on the remaining three test plots tested in 2006, utilized new flow-through orifice restriction devices (ORD) that consisted of a 5-gallon bucket fitted with two vertical standpipes. This design was implemented to address problems with the Storage Tank system capacity encountered during the 2004 field testing. Exhibit 2 shows cross sections of both measurement devices.

Exhibit 2
Runoff Volume Measurement Devices



GREEN ROOF EXPERIMENTAL METHODOLOGY

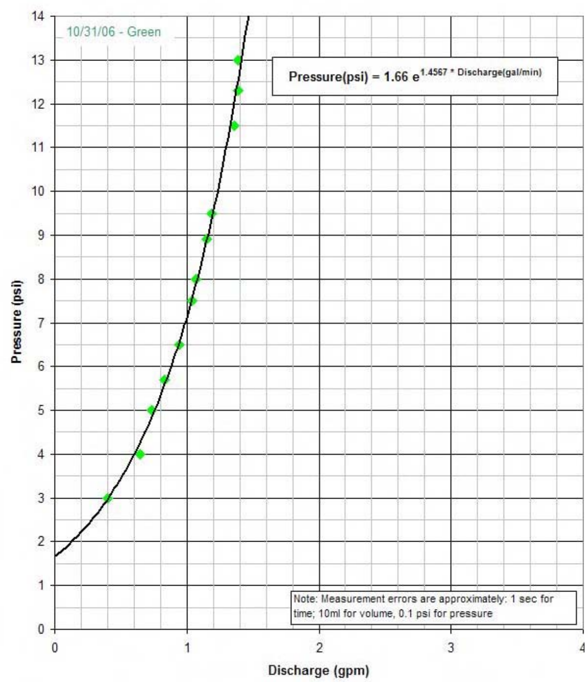
The three storm events analyzed in this report included the 2-, 10- and 100-year, 15-minute storm events. The recurrence intervals were selected to cover a wide range of rainfall intensities. The 15-minute storm duration was chosen to provide an adequate volume of water to be released and captured over the test plots during each rain trial. Rainfall intensities for each event were taken directly from the City of Chicago's Stormwater Ordinance. Table 1 shows a summary of the design rainfall intensity values used in the analysis.

Table 1
Design Rainfall Intensities – 15-minute Storm Duration

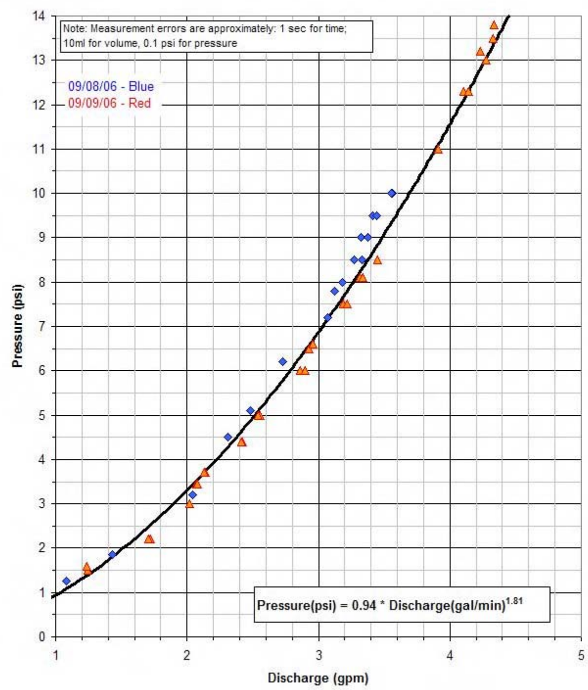
Storm Event	Design Rainfall Intensity (in/hr)
2	3.28
10	4.84
100	8.20

Rainmaker Calibration. Before the rain trials were performed, the rainmaker was calibrated for each set of nozzles. Calibration curves were created to correlate rainmaker pressure and outflow. These curves were later used during rain trial testing to match the rainmaker pressure to the corresponding design rainfall intensity. **Exhibit 3** shows the results of the model calibration for both sets of spray nozzles.

Exhibit 3
Rainmaker Calibration Results



LOW FLOW NOZZLES



HIGH FLOW NOZZLES

Soil Moisture. The soil moisture content for each green roof test plot was tracked over the duration of the simulated rain events. These data were collected to help adjust for the potential impacts soil moisture had on the retention capacity of the green roofs during each field test.

Experimental Methodology. The following methodology was adhered to for each trial:

1. Prepare the test plot for the simulated rain event by testing batteries, re-setting the data loggers, testing the initial soil moisture content and, when applicable, draining the Storage Tank.
2. Adjust the rainmaker scaffolding to center the rainmaker over the test plot.
3. Pressurize the rainmaker while diverting spray emitted from the four spray nozzles away from the test plot using the movable gutter system.
4. Adjust the rainmaker to the desired system pressure.
5. Begin testing, recording rainmaker pressure and soil moisture content each minute.
6. Turn off rainmaker, and repeat steps 1-5 for each test plot.
7. Allow at least one hour for water to percolate through the test plot growth media before uploading data from the data loggers.
8. Calculate the simulated volume of water emitted by the rainmaker using the recorded pressure readings and calibration curve.
9. Estimate a C-value correction factor for the amount of rain that did not actually hit the roof.
10. Calculate C-value.

RESULTS

Following model calibration, the 2-, 10- and 100-year, 15-minute simulated storm events were conducted on three separate days between September 14 and October 31, 2006. Table 2 shows a comparison of the design and calculated rainfall intensity values used in the analysis.

Table 2
Calculated vs. Predicted Rainfall Intensities

Storm Event	Date Simulated	Design Rainfall Intensity (in/hr)	Calculated Rainfall Intensity (in/hr)
2	October 31, 2006	3.28	3.55
10	September 14, 2006	4.84	4.59
100	September 29, 2006	8.20	8.11

Stormwater runoff for each rain trial was measured from the four green roof test plots and the WRS roof. Stormwater runoff results are based upon the assumption that each green roof was installed properly by the green roof vendor and was functioning properly at the time of field testing. After the data were collected and analyzed, the C-value, or ratio of the stormwater runoff volume collected from each test plot to the total volume emitted from the rainmaker, was calculated for each storm event and each test plot using the following equation:

C = (Total Runoff Volume Collected from Test Plot) / (Total Rainfall Volume Emitted from Rainmaker)

The simulated test results are shown in **Tables 3** and **4** and illustrated in **Exhibits 4** through **6**.

Table 3
Calculated C-Values for Test Plots Outfitted With Four-Inch Extensive Green Roofs Installed in 2003 and Storage Tank Collection Systems

	C-value		
Roof[1]	**Rain Event #1 2-yr, 15-min**	**Rain Event #2 10-yr, 15-min**	**Rain Event #3 100-yr, 15-min**
Green Roof 3	0.68	0.46	0.51
Green Roof 4	0.72	0.53	0.58
Green Roofs Mean (standard deviation)	0.70 (+/- 0.03)	0.50 (+/- 0.05)	0.55 (+/- 0.05)
WRS[3]	[2]	1.01	0.91

[1] To keep each green roof vendor anonymous, each test plot is identified with a number.
[2] Results were not obtained due to meter malfunction and/or battery failure.
[3] The results of the WRS test plot were used to calculate the correction factors for the green roof rainfall volumes.

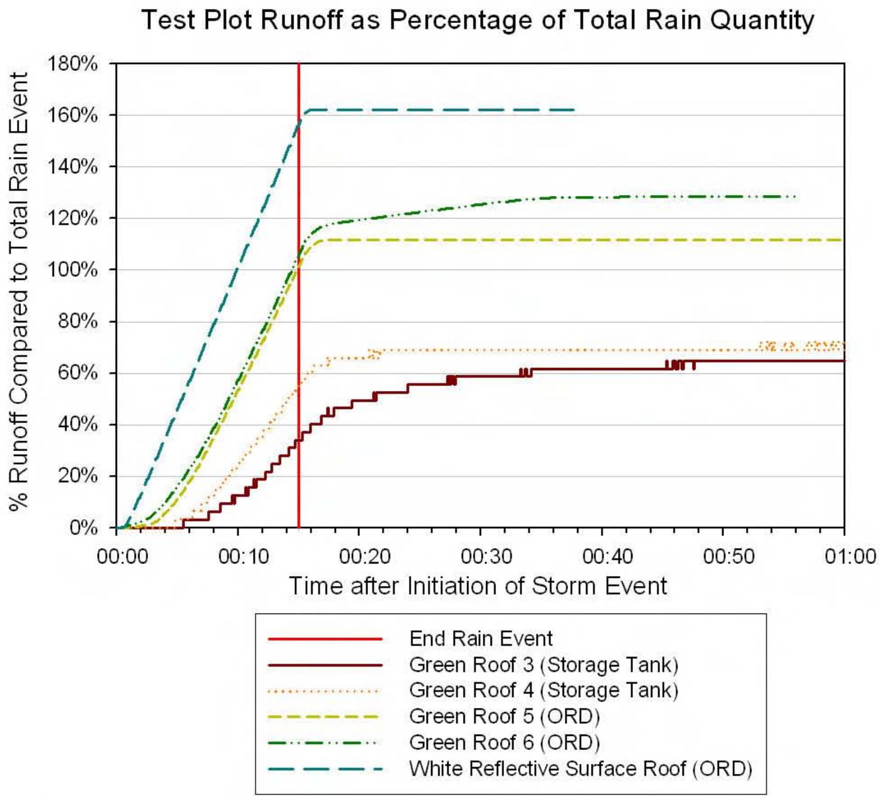
Table 4
Calculated C-Values for Test Plots Oufitted With "Modular" Green Roofs Installed in 2006 and Orifice Restriction Device Collection Systems

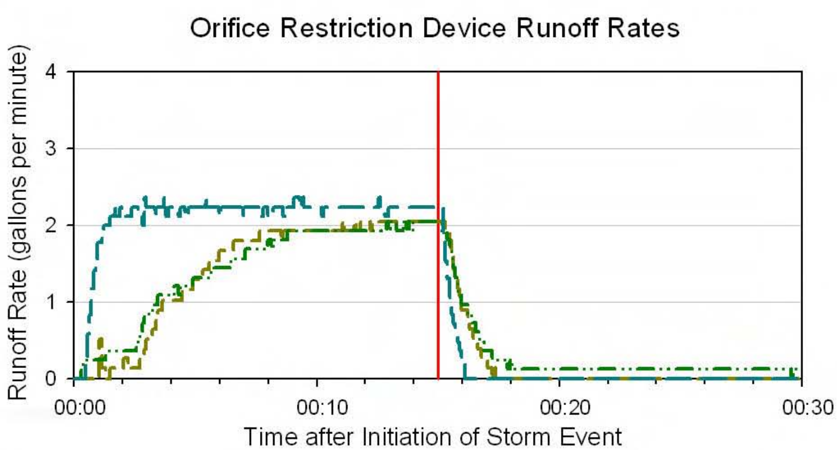
	C-value		
Roof[1]	**Rain Event #1 2-yr, 15-min**	**Rain Event #2 10-yr, 15-min**	**Rain Event #3 100-yr, 15-min**
Green Roof 5	[2]	0.90	0.89
Green Roof 6	[2]	0.90	0.73
Green Roofs Mean (standard deviation)	N/A	0.90 (+/- 0.00)	0.81 (+/- 0.11)
WRS[3]	[2]	1.01	0.91

[1] To keep each green roof vendor anonymous, each test plot is identified with a number.
[2] Results were not obtained due to meter malfunction and/or battery failure.
[3] The results of the WRS test plot were used to calculate the correction factors for the green roof rainfall volumes.

Exhibit 4*

2-YEAR, 15-MINUTE STORM EVENT
October 31, 2006





* Erroneous results were obtained from the 2-year, 15-minute rainmaker storm event. The runoff rates recorded from the ORDs resulted in more runoff volume than rainfall. Therefore, these ORD results were not included in further analyses.

Exhibit 5

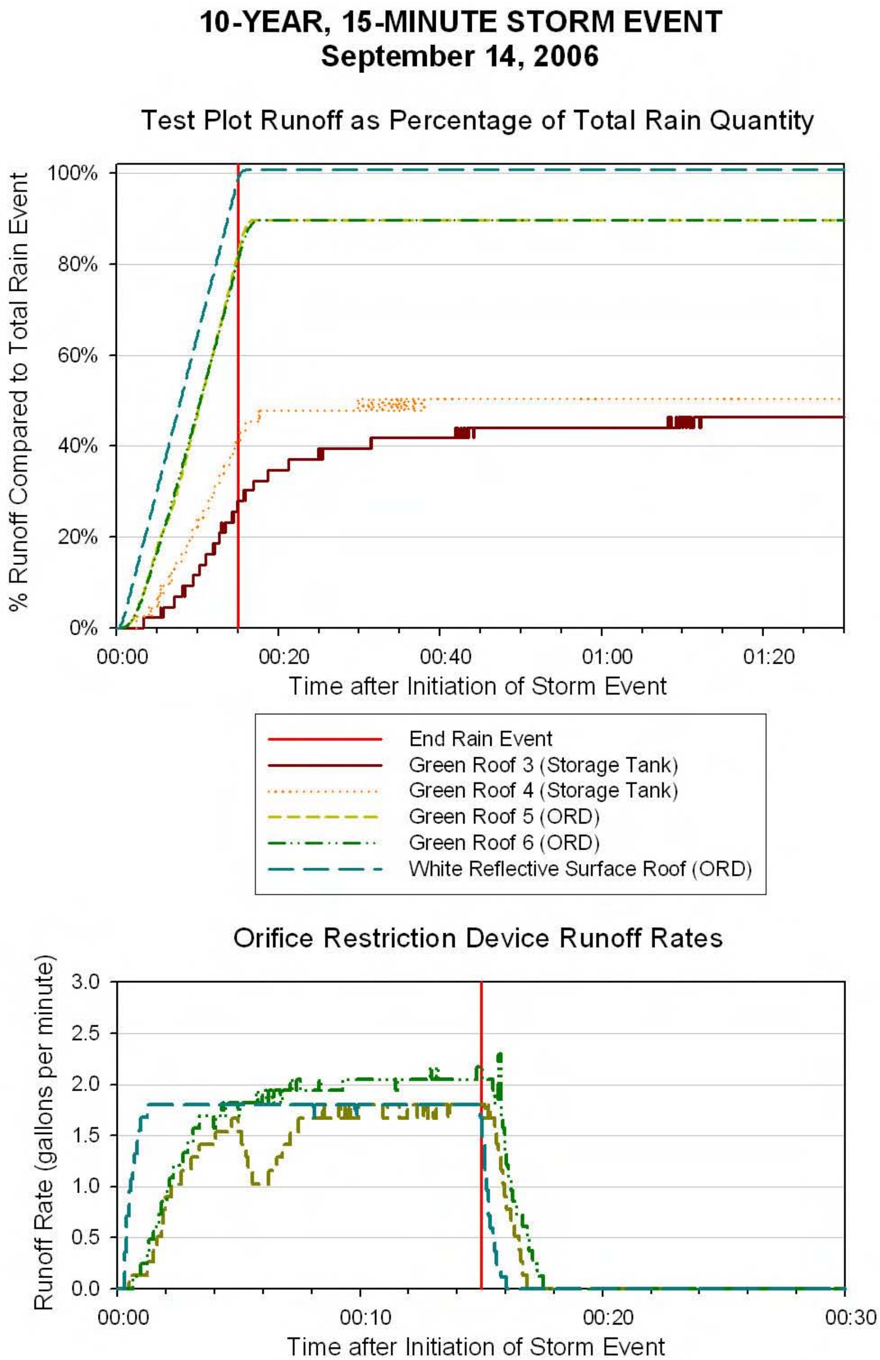
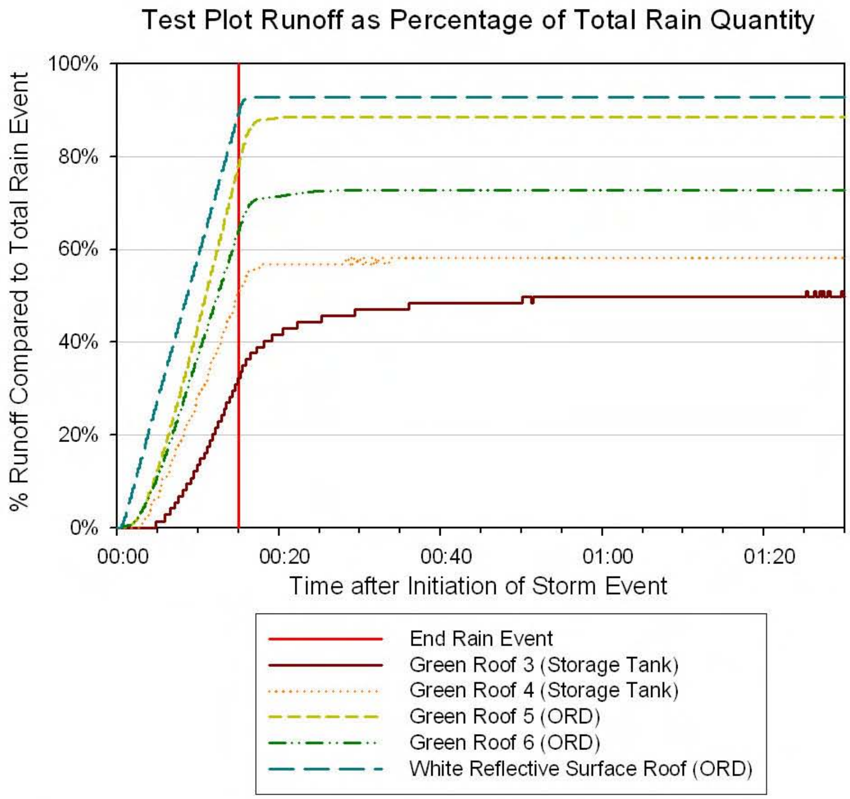
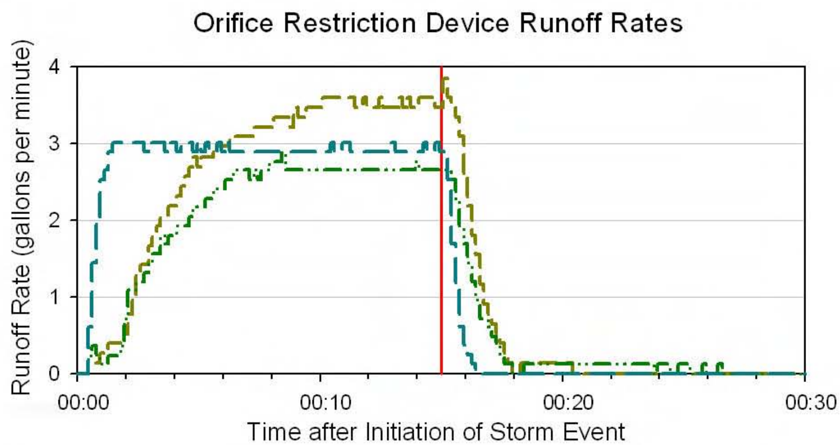

10-YEAR, 15-MINUTE STORM EVENT
September 14, 2006
Test Plot Runoff as Percentage of Total Rain Quantity
% Runoff Compared to Total Rain Event
100%
80%
60%
40%
20%
0%
00:00
00:20
00:40
01:00
01:20
Time after Initiation of Storm Event
End Rain Event
Green Roof 3 (Storage Tank)
Green Roof 4 (Storage Tank)
Green Roof 5 (ORD)
Green Roof 6 (ORD)
White Reflective Surface Roof (ORD)
Orifice Restriction Device Runoff Rates
Runoff Rate (gallons per minute)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
00:00
00:10
00:20
00:30
Time after Initiation of Storm Event

Exhibit 6

100-YEAR, 15-MINUTE STORM EVENT
September 29, 2006





The 2004 rainmaker system design was revised in 2006 in an attempt to try and improve the spray pattern over each test plot by allowing the rainmaker device to be lowered to within 2-3 feet above the growth media[3]. However, wind and other factors still resulted in small losses of spray that extended beyond the surface of the test plots. To correct for these losses, the pressure readings taken during the 2006 simulated storm events and the associated rainmaker calibration curves were used to calculate the total volume of water produced by the rainmaker over each rain trial. A correction factor was then calculated based on the actual amount of water collected at the WRS test plot compared to the calculated output from the rainmaker device while assuming that up to one gallon of water remained on the roof surface after testing[4] and that no water was lost from runoff collection system. The resulting C-value correction factors calculated for each rain trial ranged from 0.46 to 1.29.

The C-value study revealed that the mature green roof systems (installed in 2003) produced average C-values ranging between 0.50 and 0.70. Results for the modular roofing systems (installed in 2006) produced average C-values on the order of 0.81 and 0.90. The relative differences between these C-value calculations is attributed to the type of roof installation, green roof manufacturer, wind conditions, and weather and soil moisture conditions of the test plots leading up to time of the rain trials.

Further analysis of the results for the green roof test plots installed with the ORDs showed a lag in the time required to achieve maximum discharge to be on the order of 8 to 10 minutes from that of the WRS roofing system.

CONCLUSIONS

The green roof systems used in this study were found to provide stormwater retention benefits, although the capacity of each system is limited. Compared to the newly installed modular roofing systems, the mature green roofs with well-established vegetation yielded much lower C-values. Green roofs installed with a thicker, uniform growth media and/or imbedded with additional stormwater storage devices such as eggshell retention/drainage boards should provide lower C-values.

[3] The 2004 rainmaker design required the rainmaker device to be suspended 11 feet above the growth media.

[4] Experimental testing in 2004 revealed that the WRS test plot can retain up to 1.0 gallon of water on its surface due to the presence of small, buckled areas located along its surface that developed after roof installation.

APPENDIX B

Water Quality Study, 2006

Introduction

This letter report summarizes the Chicago Green Roof Test Plot Project water quality analysis conducted on October 31, 2006. The objective of this study is to compare water quality in stormwater runoff from the various types of roofs present at the Green Roof Test Plot Project site.

Project Background

The Chicago Green Roof Test Plot Project was initiated to determine the effects of green roofs on temperature and stormwater in comparison to conventional roof materials. A total of ten test plots have been constructed at the Chicago Center for Green Technology: seven outfitted with green roofs and three with unvegetated roofs (stone ballast, black tar, and high-albedo white reflective surface). All of the unvegetated roofs and six of the green roofs measure 36 square feet (six by six feet), while the seventh green roof, built in 2006, is 96 square feet (eight by twelve feet).

Approximately one half of the green roofs were planted in 2003, while the others, including the eight by twelve foot roof, were planted in 2006. Each of the green roofs and the black tar roof were constructed with a downspout, through which stormwater runoff was collected. This letter report focuses on comparisons of stormwater runoff from several types of roofs present at the test plot. Of specific interest was the ability of green roofs to remove substances from stormwater that would simply flow off of conventional roof materials.

Collection Methods

Two green roofs and the black tar roof were used to analyze rainwater runoff. Green Roof #4 was randomly selected from the three green roof test plots constructed and planted in 2003, and the eight by twelve foot roof (Green Roof #10) was used as the second test roof. This combination of green roofs allowed for the collection of stormwater from one green roof with well-established three-year-old vegetation and one with vegetation installed in July of 2006. Rain was produced from an artificial rain maker, which was suspended over the roofs and connected to an outdoor spigot of municipal tap water for a water source. Artificial rainfall rates were maintained at similar intensities for each collection test. First flush stormwater runoff (the initial release from the test plot downspouts) was collected from each of the three roofs by placing bottles under the drain in each roof. Green Roof #10 was chosen at random for collection of a duplicate set of rainwater samples. Water was also collected directly from the artificial rain maker by placing bottles directly under the rainmaker nozzles. Collected water samples were immediately placed on ice and transported to STAT Analysis Corporation (STAT) located in Chicago.

STAT analyzed each sample for concentrations of 74 pollutants and nutrients, including total Kjeldahl nitrogen (TKN), nitrate-nitrite nitrogen (NO_2-NO_3), total phosphorus (TP), total suspended solids (TSS), polynuclear aromatic hydrocarbons (PAH), and semivolatile organic compounds (SVOC).

Analytical Results

Water quality analytical data are attached to this letter. Most pollutants were below the detection limits for all tested roofs. The following chemicals and tests were found to exceed the analytical detection limit in at least one sample: benz(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, chrysene, fluoranthene, dibenz(a,h)anthracene, indeno(1,2,3-cd)pyrene, phenanthrene, pyrene, NO_2-NO_3, TKN, TP, and TSS. Each substance and its source are briefly described below.

<u>Pollutants Detected Above Reporting Limits</u>

Benzo(a)anthracene: A PAH formed during combustion of carbon materials. This suspected carcinogen is present in tar and oil products. Industrial emissions release benzo(a)anthracene into the air where it can travel large distances before deposition occurs.

Benzo(a)pyrene: This PAH is produced during incomplete combustion and is recognized by the Environmental Protection Agency (EPA) as a hazardous substance. Known health affects include cancer, immunosuppression, genetic damage, and reproductive problems. Benzo(a)pyrene is present in oil, asphalt, tar, and gasoline and is produced by industrial and transportation emissions.

Benzo(g,h,i)perylene: A PAH found in tar and oils and is produced during incomplete combustion. The capacity of this substance as a carcinogen is unknown, although it is regulated by the Clean Water Act and is included as a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) hazardous substance. Benzo(g,h,i)perylene has been detected in automobile exhaust, and in releases during coal and wood combustion.

Chrysene: Classified as a PAH, this potential carcinogen is produced during incomplete combustion. Chrysene has been detected in automobile exhaust, industrial smoke, and tar.

Flouranthene: A PAH that is classified as an irritant and a co-carcinogen (amplifies affects of a carcinogen, but does not cause cancer itself). This substance is found in automobile exhaust, oil, tar, and other sources where combustion occurs.

Dibenz(a,h)anthracene: Although its affects on human health is unknown, this PAH is known to cause cancer in animals and can cause mutations. It is formed during incomplete combustion of fossil fuels and is found in cigarette smoke and tar.

Indeno(1,2,3-cd)pyrene: A PAH formed during incomplete combustion which also can be found in tar and oil. It is a potential carcinogen and a known mutagen.

Phenanthrene: A known PAH mutagen that is regulated by the Clean Water Act. It is a product of incomplete combustion of fossil fuels and can be found in oil and tar.

Pyrene: The carcinogenic effects of this PAH are unknown, although it is regulated by the Clean Water Act. It is produced during incomplete combustion and can travel long distances in the atmosphere. It is also found tobacco smoke, oil, and tar.

Nutrients and Total Suspended Solids

NO_2-NO_3 nitrogen, TKN, TP, TSS: These nutrients are found in the atmosphere, soils and rocks, and organic materials. NO_2-NO_3 are inorganic forms of nitrogen, while TKN includes both inorganic and organic forms of nitrogen. Nitrogen occurs naturally in soils, groundwater, and the atmosphere. TP includes inorganic and organic forms of phosphorus, which can be found in soils and rocks, and within organic materials. TSS includes dirt, detritus, and other undissolvable materials.

Water Quality Conclusions

SVOCs were not found above detection limits in any of the samples. PAH pollutants were found at concentrations above detection limits only in water runoff samples taken from the black tar roof. Pollutants detected on the black tar roof ranged from 0.0001 mg/L to 0.001 mg/L. PAHs detected on the black tar roof test plot could originate within the tar itself or from atmospheric deposition. A Metra rail yard located approximately 300 feet south of the site could provide a nearby source of pollutants arising from incomplete combustion. The absence of PAHs from the rainmaker and Green Roof water sample suggests that the Green Roofs remove and/or bind atmospheric deposition of PAHs, or the black tar is the source of the PAHs detected. Neither the atmosphere nor the various roof materials appeared to contribute SVOCs to stormwater runoff.

Nutrient concentrations in stormwater runoff samples varied between the black tar roof and the green roofs and also varied between the two green roofs sampled. NO_2-NO_3 nitrogen and TKN concentrations were highest on the black tar roof. TKN varied little among the green roofs. NO_2-NO_3 nitrogen was lowest at Green Roof #4 (the green roof established in 2003), where concentrations of NO_2-NO_3 nitrogen were lower than concentrations detected in samples taken directly from the artificial rain maker. The patterns of nitrogen concentrations among roofs suggest that atmospheric deposition of nitrogen may occur. Furthermore, Green Roof #4 revealed lower concentrations of NO_2-NO_3 nitrogen than Green Roof #10, suggesting that establishment of vegetation may increase nitrogen uptake or that newly placed soils may leach nitrogen. TP concentrations were lowest at the black tar roof and highest at Green Roof #4. This pattern suggests phosphorus may leach from the vegetation and soils on the green roofs; concentrations of TP were higher in the samples of test plot stormwater runoff than in samples taken directly from the artificial rainmaker or from the black tar roof. The water from the rainmaker, however, did appear to contribute low concentrations of both nitrogen and phosphorus. TSS concentrations were higher from the black tar roof than from any other source. Atmospheric deposition is the likely source of TSS. The green roofs appear to filter TSS, as concentrations were below detection limits. This ability to filter TSS may be assisted by the filter fabric layer of the green roof sandwich. The Black Tar roof, in comparison, does not have a filter fabric, so atmospheric dust and debris deposited on the black tar roof may be collected by stormwater and flow directly off the rooftop.