# GREEN ROOF TEST PLOT

## 2003 END OF YEAR PROJECT SUMMARY REPORT


Prepared By

MWH

for the
City of Chicago Department of Environment

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**REPORT**



**EXHIBITS**

## 1. BACKGROUND AND BENEFITS OF GREEN ROOFS

Our ancestors covered their shelters with live vegetation to keep them cool in summer and warm in winter. Today, the concept is regaining popularity. Modern vegetated or "green" roofs are an expansion of the traditional sod-covered structures found in parts of Europe and the North American plains. As the potential benefits of green roofs are more widely recognized, the interest in green roof technology has increased. Twenty-first century green roof technology employs a multilayer system, including a waterproof membrane, drainage layers, specialized soil medium, soil stabilizer, and a selection of appropriate plant species and varieties that best tolerates the often extreme environmental conditions found in a rooftop setting. The current interest in green roofs is coming to the forefront due to their potential to alleviate several environmental problems common to urban areas:

- **Storm Water Runoff:** In urbanized regions, natural areas well adapted to capturing storm water are replaced with impervious surfaces, such as roadways or buildings. Consequently, during major storm events, water quickly runs off of these impervious streets and rooftops, burdening storm sewers, treatment plants, and nearby streams and lakes. Compared to traditional roofing materials, such as tar or shingles, green roof systems detain, filter, and slowly release storm water, reducing the peak flows and overall volume of runoff. Moreover, with the implementation of Phase II of the National Pollution Discharge Elimination System (NPDES), municipalities are looking for creative and effective means to reduce storm water flows into receiving water bodies. By installing green roofs, some natural storm water control benefits are regained. If widely implemented, green rooftops have the potential to reduce storm water runoff and nonpoint source pollution problems in urban and suburban environments.

- **Urban Heat Island and Air Quality:** Most cities are largely constructed of concrete, asphalt, and brick - materials that all absorb and store heat during the day. Conventional roof surfaces also absorb heat and some have been reported to reach temperatures up to 175 ºF. The re-radiation of this heat from the building structures can cause air temperatures in large cities to be as much as 6-10° F higher than surrounding suburban and rural areas, an effect that is particularly evident at night. This phenomenon is known as the "Urban Heat Island Effect." As a result of the warmer temperatures, air conditioning use rises, putting summertime strains on local electricity distribution grids. Green roofs can help reduce the Urban Heat Island Effect, as transpiring plants lower air temperatures, soil and vegetation trap and absorb much less heat than conventional tar or shingle roofs, and retained storm water allows for the benefits of evaporative cooling.

- **Air Quality:** Warmer Urban Heat Island temperatures also exacerbate air pollution, contributing to the formation of smog and ozone. Warm air updrafts from hot surfaces can circulate fine particulates and degrade air quality. These increases in air pollution increase the risk of health complications, and reduce the quality of life for the millions of urban citizens. Green Roofs indirectly help alleviate these air pollution problems by keeping down air temperatures. Moreover, plants on rooftops could contribute directly to enhanced air quality by trapping and absorbing nitrous oxides, volatile organic compounds, and particulates.

Additional benefits of green roof technology include:

- **Energy Conservation:** By providing shading, insulation, and evaporative cooling, green roofs can lower energy use and costs, particularly on the top floor of buildings. Green roofs are most effective where the roof of the structure is flat or slightly pitched, and the roof represents a significant portion of the building surface area. Moreover, rooftop garden plants located near intakes for air conditioning systems will transpire, lowering the temperature of incoming air and reducing costs to cool the building's air supply. The additional insulation provided by the green roof materials could even cut energy use and costs during winter.

- **Urban Wildlife Attractant.** The green roof technologies promote an active growth medium to support the vegetation. In turn, this vegetation provides the habitat for additional wildlife, from pollinators to songbirds.

- **Reduced Material Use.** Green roof manufacturers/installers claim that their products will last at least forty years, versus the 10-15 year lifespan of a conventional roof. This reduces maintenance/replacement costs and the material use.

- **Public space.** With limited land space available in cities, rooftop gardens can increase public amenity space at no additional land cost.

There are two distinct types of green roof systems, extensive and intensive. Intensive green roofs have thicker soil media (minimum of 8"), are often designed to be accessible to people as an outdoor amenity, and are more traditionally landscaped, with garden-like atmospheres that include trees and shrubs. Intensive green roofs often require more elaborate drainage and irrigation systems, add a heavier load to the roof, and need regular maintenance. On the other hand, extensive green roofs have shallow, alpine-like soil layers (typically 1-4" deep), and only require minimal maintenance. Extensive green roofs are typically planted with very hardy species, such as sedums (*Sedum spp.*), that can tolerate extreme temperature and moisture conditions. While extensive roofs are typically not designed for human use, they still provide the environmental benefits. Only extensive green roof designs were tested under this program.

The benefits of green roofs have not been adequately quantified in the various climates and regions of the United States. Providing regional green roof data will allow investors to make informed decisions and local planning commissions to create financially feasible policies that enhance the urban environment. Currently, green roofs are widely used in Europe, and interest is expanding in major North American cities. As cities such as Chicago, New York, Toronto, Vancouver, and Portland move forward with green roof initiatives, projects like Chicago's Green Roof Test Plot program are evaluating the functions and mechanisms of the various green roof applications.

## 2. CHICAGO GREEN ROOF TEST PLOT PROJECT

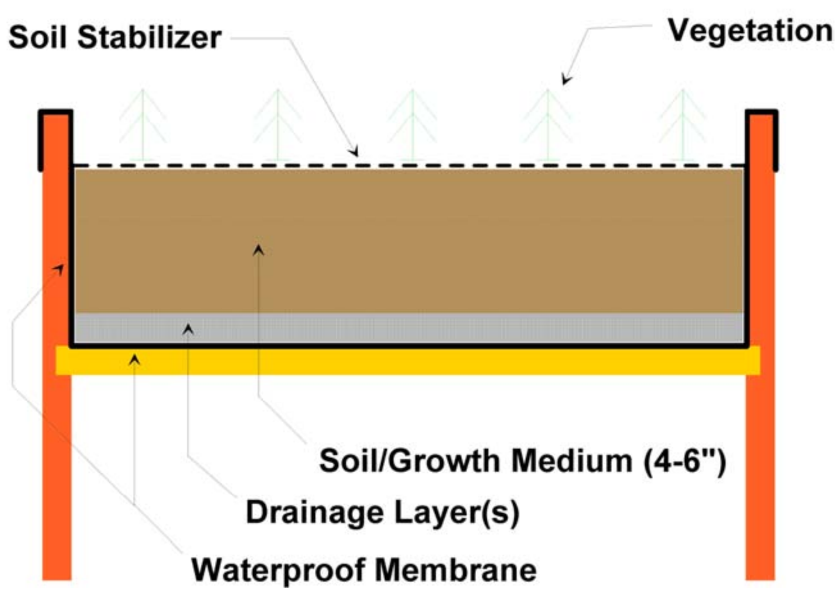
In Chicago, interest in green roofs has increased with the completion of the intensive City Hall rooftop garden. Currently, 60% of Chicago's rooftop surfaces utilize dark-colored material, and increasing use of green roofs could provide widespread environmental benefits.

As part of its ongoing commitment to, and interest in, green roof technology, the City of Chicago Department of Environment (DOE) hired MWH Americas, Inc. (MWH) to carry out an experimental program to compare temperature and runoff characteristics of experimental "green" roofs to conventional roofs. These green and conventional roof systems were installed on top of a series of 6' x 6' x 3.5' structures (sheds), which were designed and built in March and April 2003, and outfitted with data logging instrumentation. DOE invited several commercial green roof providers to install their green roof systems on individual sheds. Six unique green roof products were tested against the performance of three conventional roofing materials (stone, black tar and white reflective paint), all while monitoring baseline local weather conditions. After instruments were tested and calibrated, data collection began on May 1, 2003.

### Experimental Design

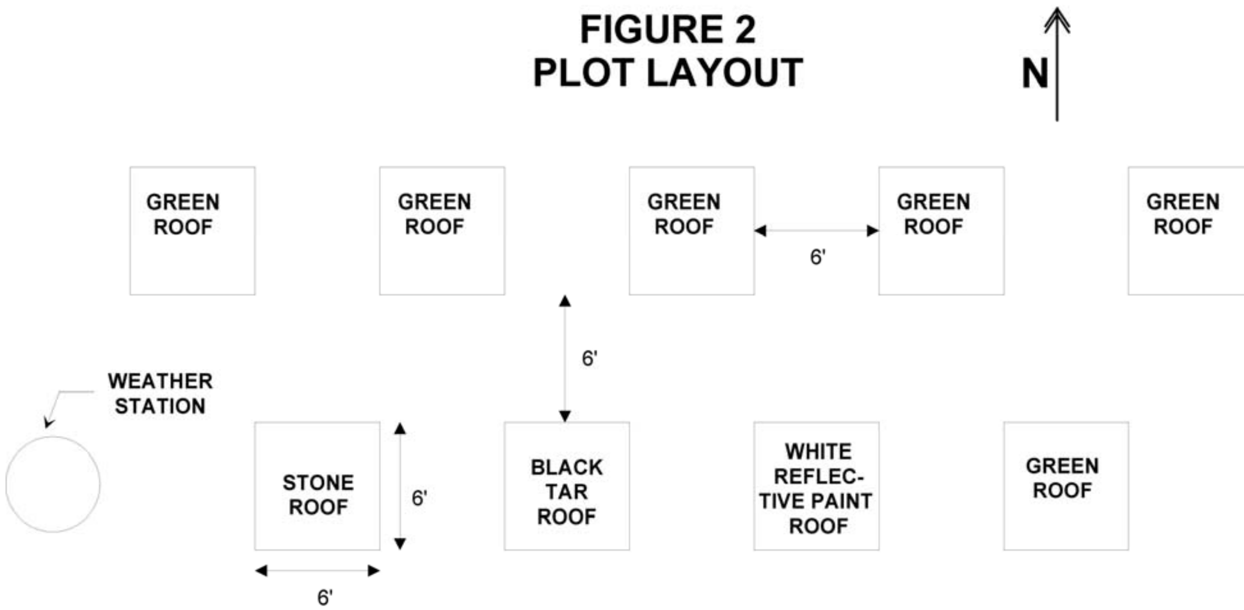
This study was designed to allow a direct comparison of various roofing applications on equivalent structures and under the same natural environmental conditions. Nine experimental rooftop units (sheds), each 3.5' high with 6' x 6' roofs, were designed and constructed for performance comparisons of planted rooftops versus conventional rooftops. Six of the sheds (the Green Roofs) were outfitted with "green" roof technology consisting of a waterproof membrane, a layer of material to facilitate drainage, a growth medium, a soil stabilizer, and vegetation (**Figure 1**). More conventional roof materials (stone, black tar, and white reflective paint) were applied to the remaining three sheds (the Conventional Roofs). All nine units were placed on a gravel pad located at the Chicago Center for Green Technology[1] (**Photos 1-3,** and **Figure 2**).

FIGURE 1
TYPICAL CROSS-SECTION
OF GREEN ROOF




[1] The Chicago Center for Green Technology is located at 445 N. Sacramento Blvd. on the west side of Chicago.

**FIGURE 2**
**PLOT LAYOUT**



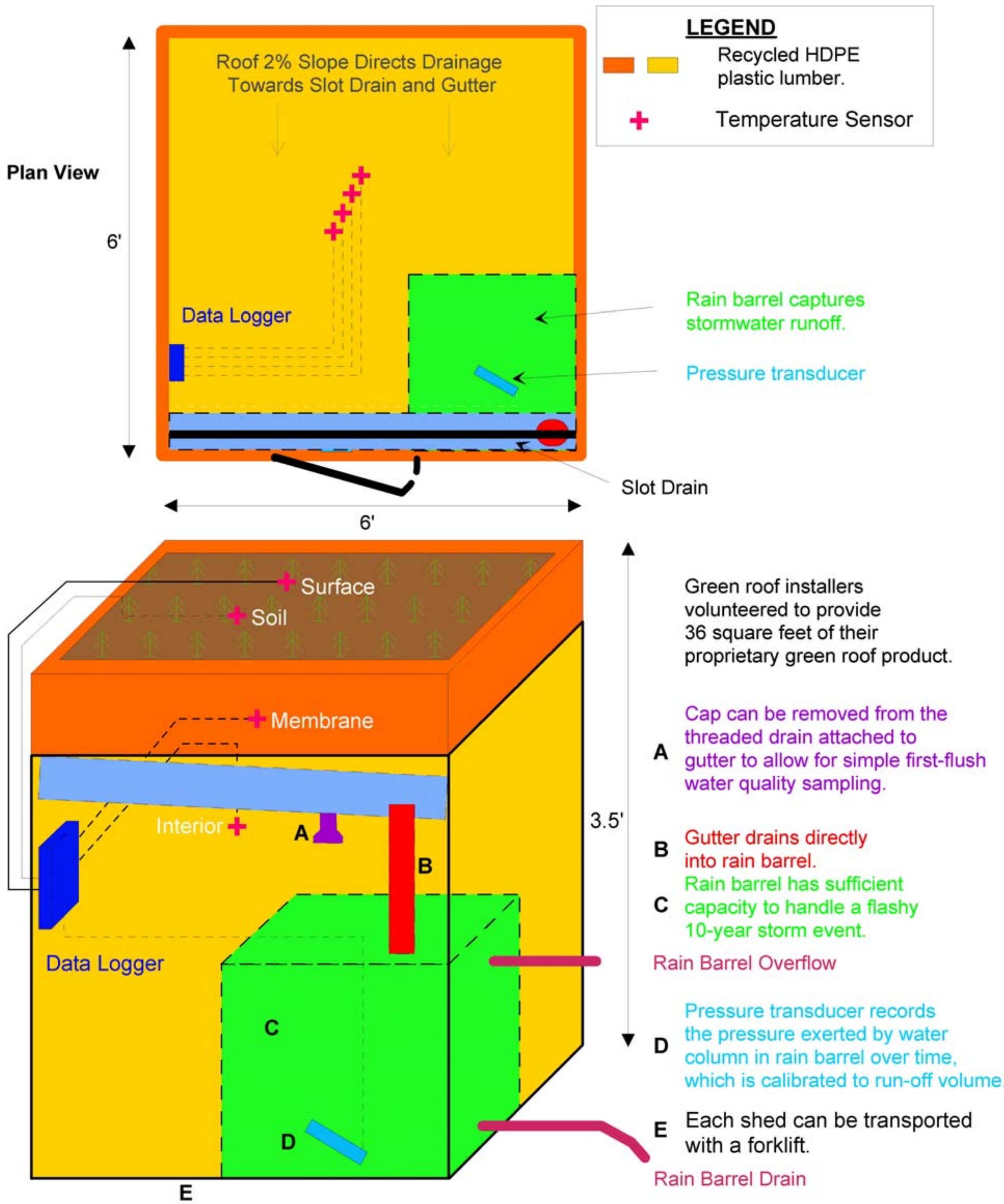

The experimental design allowed for the collection of temperature and storm water runoff data using *in situ* sensors and data logging equipment. Baseline ambient weather conditions (temperature, rainfall, wind speed and direction, and relative humidity) were recorded every 5 minutes using a weather station located on the gravel pad (**Photo 4**). Data were periodically downloaded, transferred to a database, plotted, and analyzed.

**Temperature:**
Each shed was monitored for temperature at three or four locations (**Photo 5** and **Figure 3**). Within each shed, an Onset Computer Corporation (Onset) HOBO 4-channel external temperature data logger, equipped with Onset TMC-HD and TMC-HA series temperature probes, recorded temperature readings every 15 minutes from sensors located at different horizons (**Table 1**).

**Table 1**
**Horizon Descriptions and Locations of Sensors**

| Horizon ID | Temperature Probe Location |
|---|---|
| Ambient | Attached to the weather station. |
| Surface | Located within the radiation shield, 4” above the roofing surface. |
| Soil | Buried within the planting medium (Green Roofs only). |
| Membrane | Located just below the impermeable membrane, and sealed in place with expandable foam insulation. |
| Interior/Internal | Located within the interior of the shed, 8” from the ceiling. |

# FIGURE 3
# GENERAL DESIGN OF GREEN ROOF TEST PLOTS




**NOT TO SCALE**

**Storm water Runoff:**
The volume and rate of storm water runoff was measured in the six Green Roof units and one Conventional Roof unit (white reflective paint roof). The basic system design can be seen in **Figure 3**. The roof structures were built at a two-degree pitch toward a slotted drain and an internal drainage gutter. The gutters drained to a 45-gallon rain bucket, which contained an Omega Engineering, Inc. (Omega) PX-439-002GI pressure transducer. The pressure transducer was wired to an Omega OM-42 data logger, which recorded pressure readings every 6-15 minutes, depending on conditions. The voltage readings from each pressure transducer were calibrated to rain bucket volumes before deployment so that a change in pressure exerted by the water column could be converted to a change in captured runoff volume.

**Weather Conditions:**
Site weather conditions were measured using an Omega HOBO weather station mounted on a 2-meter tripod (**Photo 4**). Temperature, relative humidity, wind speed, wind direction, and rainfall sensors were connected to the weather station and its data logger, which measured each parameter at 5-minute intervals.

**Water Quality:**
The ability to collect water quality samples from a collection system was incorporated into the design, as shown in **Photo 6** and **Figure 3**. Runoff water quality could be sampled by collecting the "first flush" of runoff in a 1-liter container connected to the internal drainage gutter. No water quality samples were taken, but future samples may be sent to a laboratory for analysis.

## 3. TEST PLOT RESULTS AND DISCUSSION

### Storm Water Runoff

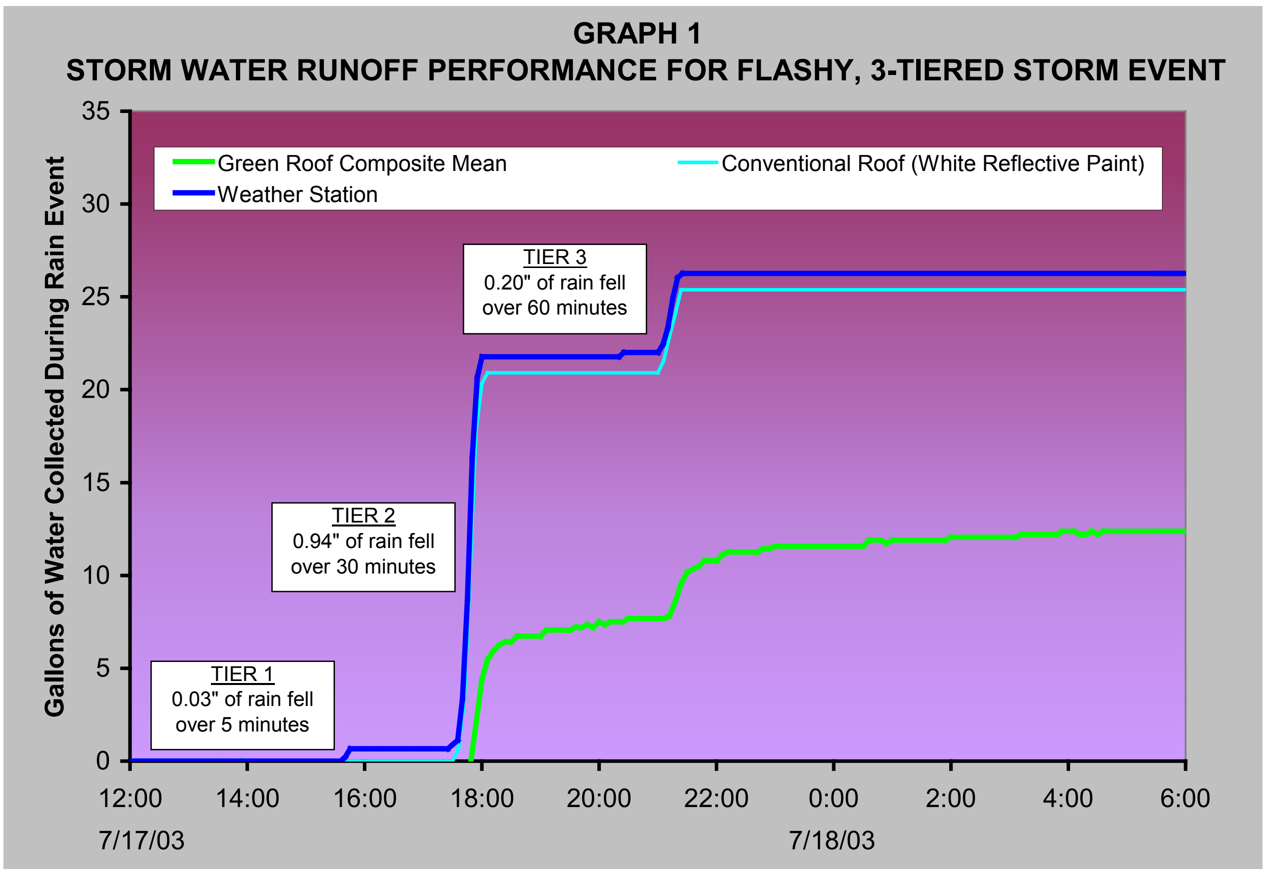
Before this project was initiated, we hypothesized that the storm water runoff volume from the Green Roofs would be less than both the Conventional Roof control and the weather station. The Green Roof materials were expected to absorb rainfall, especially at the beginning of rain events, essentially preventing runoff from reaching the rain buckets. During the larger rain events, however, we expected that the Green Roofs would absorb water until reaching saturation. Subsequent rain falling onto saturated growth medium would be collected in the Green Roof rain barrels at a rate more similar to the runoff at the control roof.

Over the course of the 2003 study period, the runoff data continually suggested that the six individual Green Roofs behaved similarly. Thus, for data analysis purposes, runoff data from the Green Roofs are presented here as a composite mean of the six sheds over time.

Our predictions were largely verified by the 2003 experimental results. Typically, the Green Roofs collected less than half of the storm water volume accumulated at the control roof during storm events. During small storm events (less than 0.5"), the Green Roofs absorbed an even greater percentage of the rainfall, keeping most of the storm water from reaching the rain collection barrels. Meanwhile, the weather station rainfall data and the control roof runoff data were similar to each other, although occasional volumetric differences occurred.

We have included data from two typical storm events, representative of the Green Roof and Conventional Roof runoff characteristics. On July 17th (**Graph 1**), a total of 1.2 inches of rain fell over a 6.1-hour period, according to the weather station. This storm event occurred in three tiers, as indicated on the graph.

> **Tier 1.** The first tier was a very minor rainfall that registered in the weather station rain gauge but not in any of the Green Roof or Conventional Roof rain barrels. This tiny (0.3") rain revealed the sensitivity differences between the weather station rain gauge and the 45-gallon rain-collection buckets with pressure transducers.




*Individual calibration curves were used to calculate rooftop runoff (in gallons) from pressure transducer output (in Volts)
**Weather station rainfall data (in mm) was extrapolated over 36 $ft^2$ to obtain gallons

> **Tier 2.** The second tier was a strong, flashy event of nearly 1" of rain falling within one-half hour. The runoff volumes in the Conventional Roof and the weather station peaked rapidly and leveled off at little over 20 gallons of water. Meanwhile, the composite mean volume in the Green Roof rain collection barrels increased quickly after a delayed response of about one-half hour – the rain had actually stopped falling before the Green Roof rain barrels began collecting water. The Green Roof volume did not level off immediately after the rainfall like the Conventional Roof, but rather continued to increase slowly over the next three hours, until the third tier of rainfall occurred. One half hour

after the Tier 2 rainfall was complete (according to the weather station), the Green Roof rain buckets had collected only 30 % of the volume found at the Conventional Roof (6.4 gallons vs. 20.9 gallons).

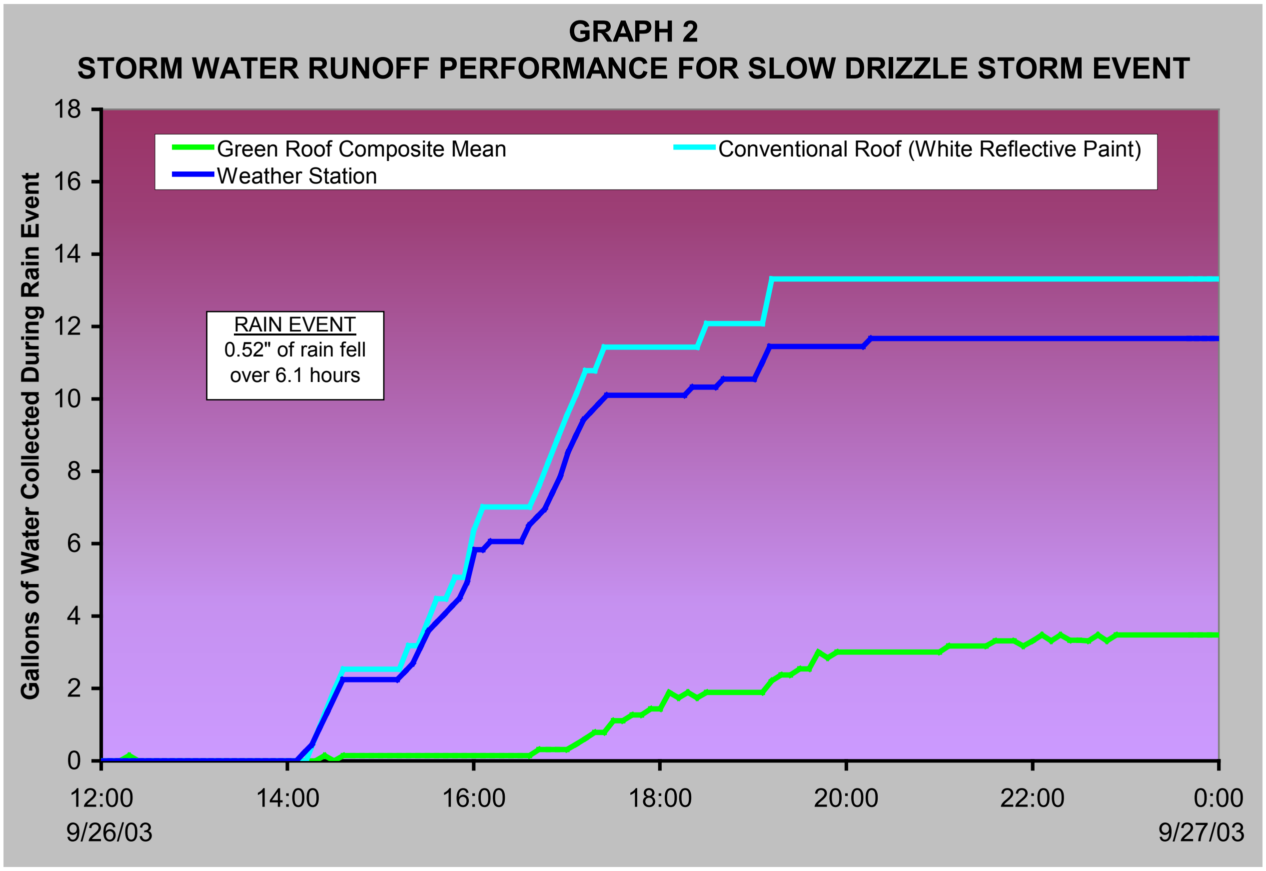
**Tier 3.** Finally, during Tier 3, about 0.2" of rain fell over an hour period. Since the previous rains saturated the Green Roof layers, a similar volume of rainfall was deposited in the Green Roof rain barrel as the Conventional Roof barrel (about 4.5 gallons in each barrel), although nearly 2.8 of the 4.5 gallons of water in the Green Roof collection barrel accumulated after the Conventional Roof barrel volume had already come to equilibrium.

**Graph 1** confirms several of our expectations. The Green Roofs significantly reduced the total volume and rate of storm water runoff, compared to the impervious control surface. By the end of the storm event, the Green Roofs had collected a mean of 12.4 gallons of water while the Conventional Roof rain barrel had more than double that volume, at 25.4 gallons. In addition, this storm demonstrates the delays in storm water runoff flows for Green Roofs. The flashiest period of the storm event was Tier 2, when the runoff from the Green Roofs was delayed 30 minutes compared to impervious Conventional Roof. However, once the Green Roof materials were saturated, the volumes of additional runoff (such as Tier 3) passing through the Green Roofs were similar to the volume at the Conventional Roofs, although the Green Roof runoff rate was lower.

By reducing the volume of storm water runoff and delaying peak storm water runoff flows, green roofs can decrease the stress on sewer systems. Green roofs retain and detain storm water in the growth medium, and return a percentage of storm water to the atmosphere via evaporation and transpiration (evapotranspiration). Storm water that does percolate through the green roofs reaches storm sewers after peak flows off impervious conventional roofs. The reduced storm water impacts on sewer systems are especially important in urban areas, such as the City of Chicago, that utilize combined sewers. Concentrating green roofs in selected Chicago areas could reduce the frequency of combined sewer overflow events.

**Graph 2** shows a low volume rain event, where approximately 0.5-inches of water fell continuously over a 6-hour period on September 26th. As expected, the Green Roofs performed even better at detaining storm water during the small, slow, drizzling rain event, than during the large, flashy event shown in Graph 1. By the end of the storm, an average of 3.5 gallons had collected in the Green Roof rain barrels, while over 13 gallons were found in the Conventional Roof barrel. That means that the Green Roofs absorbed and detained about 70% of potential roof runoff water. In addition, the Green Roofs provided an even greater time delay before beginning to collect runoff (almost 2.5 hours) than during the flashy storm event (0.5 hours).

Although the weather station and the Conventional Roof runoff volumes show very similar runoff accumulation patterns, the calculated water volumes for the Conventional Roof and weather station differ in each Graphs 1 and 2 by up to three gallons. These errors could be caused by mis-calibration, leaks in the collection systems, splashing during heavy rainfalls at the rain gauge tipping buckets, or the differences between collecting rainfall over the small rain gauge surface area versus the 36 $ft^2$ of the rooftops. Nevertheless, even taking these potential errors into account, the Conventional Roof and weather station collected significantly greater volumes of water than the Green Roofs during each storm event analyzed during 2003.

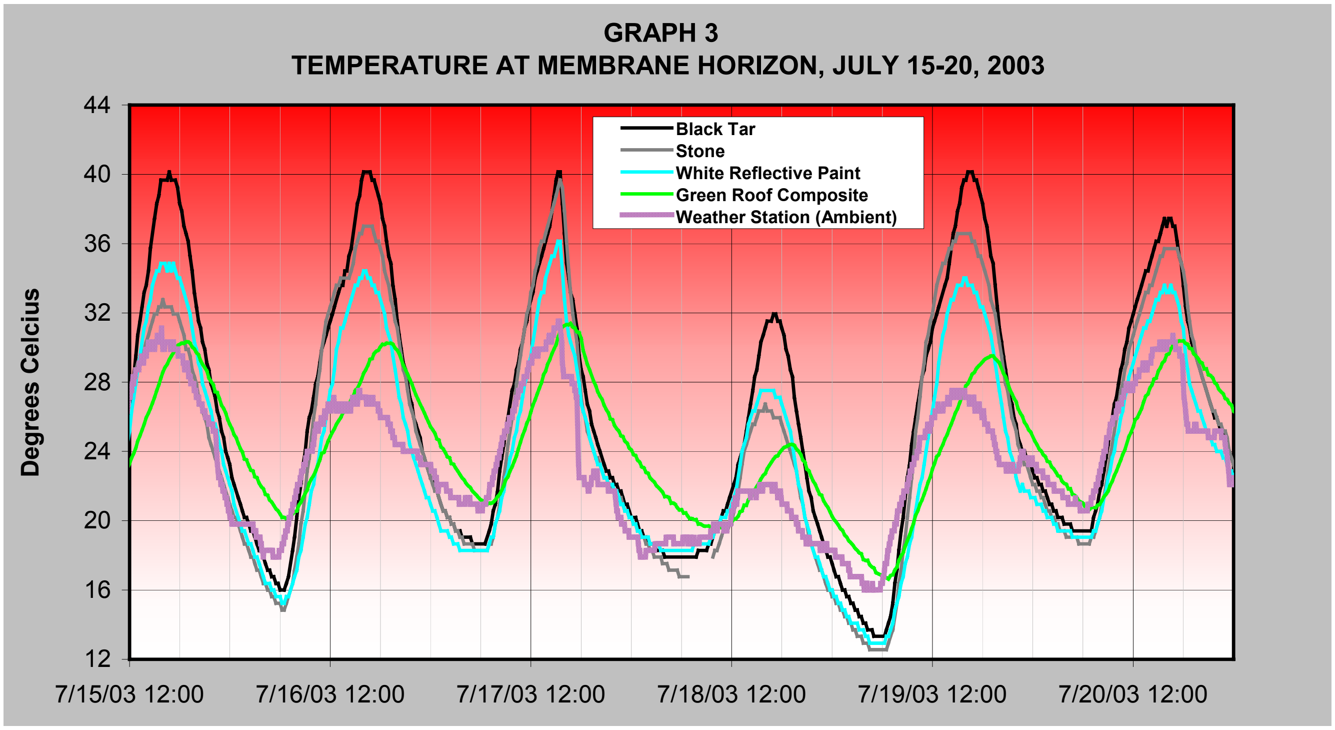



*Individual calibration curves were used to calculate rooftop runoff (in gallons) from pressure transducer output (in Volts)
**Weather station rainfall data (in mm) was extrapolated over 36 $ft^2$ to obtain gallons

## Temperature

Over the course of the 2003 study period, the plots of temperature data from individual Green Roofs consistently indicated that the six Green Roofs behaved similarly. Thus, for data analysis purposes, temperature data from the Green Roofs are presented as a composite mean of the six sheds by horizon over time.

Temperatures were taken at each of the four horizons (Interior,Soil, Surface, and Membrane; see **Figure 3** and **Photo 5**). The Interior temperature data, while interesting, were difficult to interpret. The surface areas of the sides of the shed structures were greater than the roof surface area, making it likely that the temperatures inside the sheds were more strongly influenced by the environmental forces acting on the shed sides than by the differences in heat flux through the rooftop. Soil temperature measurements were taken on the Green Roof sheds but not on Conventional Roofs as they do not have a soil layer. Therefore soil temperature comparisons to Conventional Roofs were not possible. Finally, at the Surface horizon radiation shields were used to improve the accuracy of the temperature sensors. However, it appears that the radiation shields covering the Surface temperature sensors were masking differences in Surface temperatures by creating similarly cool microclimates (we will address this problem for the 2004 study season). Thus, we present examples from the Membrane horizon, which revealed temperature differences between the different sheds directly below the roof application, emphasizing the effects of the roof type.




**Graph 3**, Temperature at Membrane Horizon, compares the Membrane temperatures of the Black Tar, Stone, White Reflective Paint, and composite Green Roof sheds for a representative warm period between July 15th and 20th. Several temperature trends that we witnessed throughout the year were also apparent during this period:

- The Black Tar Roof generally had the hottest daytime temperature peaks and the greatest daily temperature swings.
- The Stone Roof occasionally closely followed the temperature patterns of the Black Tar Roof, but showed the greatest variability when compared to the other roofs.
- The White Reflective Paint Roof daytime temperatures consistently fell in between the Black Tar and the Green Roof Composite temperatures.
- The Green Roof Composite had the lowest maximum daily temperatures, the highest daily minimums, and the narrowest range of daily temperatures.
- The diurnal patterns of the Membrane temperatures revealed a time lag for the Green Roofs relative to other roofs. The Green Roofs tended to reach their maximum afternoon temperatures about 1.5-3.0 hours after the rest of the roofs. This pattern was consistent throughout the 2003 study period, although calculations show that the time lag has generally decreased from mid-summer to fall.

Compared to the Conventional Roofs and Ambient (weather station) temperatures, the Green Roofs were cooler during the day and warmer at night. To better view these trends, **Table 2** summarizes and compares the mean temperatures at the Conventional Roofs and the Green Roofs during the average warmest and coolest 4-hour periods from July 15-20. The table reveals that during the warmest part of the day at the Membrane horizon, the Green Roofs were 19-31% cooler than the Conventional Roofs. Likewise, during the coolest part of the day, the Green Roofs were 14-19% warmer than the Conventional Roofs.

The lower daytime temperatures at the Green Roofs demonstrate the ability of vegetated surfaces to resist heat absorption compared to the conventional roofing materials when the sun is out. Nevertheless, the Green Roofs did absorb some heat during the day and reradiated that heat energy to the cooler nighttime air. Actually, as shown in Table 2, the Green Roofs were warmer than the Conventional Roofs at night. While the Green Roofs heated up less and more slowly than the Conventional Roofs during the day, the Green Roofs were likewise slow to reradiate that absorbed heat. However, the Green Roofs have more roofing material mass (e.g. drainage layer, growing medium) than the Conventional Roofs. This additional material mass could slow down the absorption and reradiation of heat compared to the Conventional Roofs. In comparison, the lower mass of the Conventional Roof roofing materials heated up rapidly during the warm daytime, and that lost heat energy quickly at nighttime.

**Table 2**
**Comparison of Green Roof Composite to Conventional Roof Mean Temperatures at Membrane During the Average Warmest and Coolest Four-Hour Periods, July 15-20, 2003**

| Rooftop | Warm Period (12:30-16:30) | | Cool Period (3:00-7:00) | |
|---|---|---|---|---|
| | Mean Temperature (ºC) | Mean % Warmer Than Green Roof Mean Temperature | Mean Temperature (ºC) | Mean % Cooler Than Green Roof Mean Temperature |
| White Reflective Paint | 31.38 | 18.8 | 17.88 | 15.9 |
| Stone | 32.92 | 24.3 | 16.72 | 19.0 |
| Black Tar | 34.56 | 30.6 | 18.29 | 13.9 |
| Green Roof Composite | 26.44 | - | 21.16 | - |

Overall, the data suggest that the Green Roof applications have measurable impacts on the temperature at the Membrane horizon. The range of daily temperatures at the Green Roofs was consistently much smaller than the range at the Conventional Roofs. The Green Roofs helped moderate temperature highs and lows compared to the Conventional Roofs. Part of this effect may have been due to the insulation value of the Green Roof materials (the growth medium and drainage layer act as additional insulation that the Conventional Roofs do not have). However, the remainder of the temperature moderation effect could be attributed to the advertised values of the planted Green Roofs: (1) evapotranspiration, sunlight absorption/reflection, and water retention keep the roofs cooler during the day and (2) the earthen material mass acts as insulation, which limits the heat transfer in or out of the interior space.

## Plant Growth

All green roof sheds were planted with the same number of individual species. Plant cover was measured in each plot using cover classes (1-5), which corresponded to estimated coverage of each shed (1 = <5% cover; 2 = 5-25% cover; 3 = 25-50% cover; 4 = 50-75% cover; 5 = 75-100% cover); this system helps reduce observer bias. Cover is the preferable measure of plant abundance or productivity than the number of individuals because of difficulties in determining the number of individuals or total plant biomass.

**Table 3**
**Estimated Plant Coverage on Green Roofs on October 17, 2003**

| **Green Roof #** | 1* | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| **Cover Class** | 4 | 3 | 3 | 3 | 5 | 3 |

* Green Roof Shed #1 has reduced surface area, approximately 26 sq feet.

With the exception of Green Roof #5 the estimated plant densities did not change since the middle part of July, when plant coverage was initially recorded. On Green Roof #5, the plant growth spread to colonize almost the entire rooftop surface area (**Table 3**). No significant plant mortality was observed during 2003.

## Weather Station

We tracked local temperature, relative humidity, rainfall, wind speed, and wind direction at the study site using a weather station. These data were used to help interpret the temperature and runoff data collected from the test plots.

## 4. CONCLUSION

To evaluate the use of green development policies, including incentives for installing green roofs, the City of Chicago DOE has taken the innovative and forward-thinking step of collecting quantitative data on which to base their policies. In response to their request, MWH designed a system to compare green roofs with some more traditional roofing materials. After controlling several variables, we placed the sheds out in the elements and, using *in situ* sensors, recorded temperatures and storm water runoff characteristics. Hopefully, the data gathered during this project will allow the DOE to better implement future greening initiatives related to green roofs.

Although this study has the potential to be a multi-year data collection project, we have already made several key observations:

- The six green roof products that were installed on our experimental sheds all tended to act similarly with regards to temperature profiles and storm water runoff characteristics.

- The green roofs reduced total storm water runoff and decreased peak runoff flows compared to the conventional roofing materials.
- The green roofs moderated temperatures just below the waterproof membrane compared to the conventional rooftops. Daytime temperature peaks at the green roofs were often 5-10 ºC cooler than the conventional roofs.

If installed within the Chicagoland area, green roofs could reduce the Urban Heat Island effect, reduce storm water runoff, and enhance air quality. The vegetation could also create wildlife habitat, which is aligned with Chicago's commitment to create and improve bird habitat. MWH looks forward to future involvement in this exciting greening initiative.

## 5. FUTURE EFFORT AND FOCUS

To enhance this program in 2004, and potentially for years to come, the following improvements and additional tasks have been suggested:

- We will collect temperature and runoff data during 2004. However, the Interior temperature sensors will be transferred to locations just above the rooftop surface, and the radiation shields covering the Surface sensors will be exchanged for much smaller shields.
- As part of the City's future green roof policy, the DOE would like to have a method for testing new green roof products to make sure that they meet storm water runoff standards. MWH will build a rainmaker with rainfall gauges and help to create a protocol for testing green roof products in the future.
- To create a better understanding of the thermal dynamics of our plastic lumber green roof sheds, we will record the sheds for several days using an infrared camera. Hopefully, this will allow us to have a better understanding of how the data from these sheds may relate to buildings.
- Finally, we will monitor temperatures at the existing green roof and white reflective paint roof on top of the Chicago Center for Green Technology (CCGT) building. The data collected at the CCGT will be compared to the test plot data.

# PHOTOPLATE

**PHOTO PLATE**

Green Roof Test Plot Project

**Photo 1**

**Unit Construction**

- All units are constructed of nearly 100% recycled plastic
- Roof surface is 6’ x 6’
- Total External Height is 3’ 6”
- Roof is pitched at 2% to a slot drain
- Internal gutter system
- 45-gallon tank collects rainwater
- Internal volume is 3’ x 6’ x 6’ ($108ft^3$)
- Roof surface area: siding surface area is approximately 1:2
- Designed to withstand $65lbs/ft^2$


**Photo 2**

**Site Preparation**

- Photo taken april 14, 2003
- Plot area is graded
- Gravel is being placed
- A layer of course sand will finish plot

**PHOTO PLATE**
Green Roof Test Plot Project

**Photo 3**

**First 5 Units Delivered to Site**

- Photo taken April 16, 2003
- Gravel pad is leveled and covered with course sand
- Chicago Center for Green Technology (CCGT) is seen in background

**Photo 4**

**Weather Station**

- MWH employees Ken Bagstad and Rick Bolliger fine-tune the weather station.
- Weather station is grounded to prevent lightning damage
- Weather station has identical temperature sensor as test units.
- Records temperature, relative humidity, rainfall, wind speed, and wind direction every five minutes.

**PHOTO PLATE**
Green Roof Test Plot Project

**Photo 5**

**Locations of Temperature Sensor**

A. SURFACE: Sensor is located within the radiation shield, four inches above the surface.
B. SOIL: Sensor is buried within the planting medium
C. MEMBRANE: Sensor is located just below the impermeable membrane
D. INTERNAL: Sensor located in the unit interior, 8 inches from ceiling.

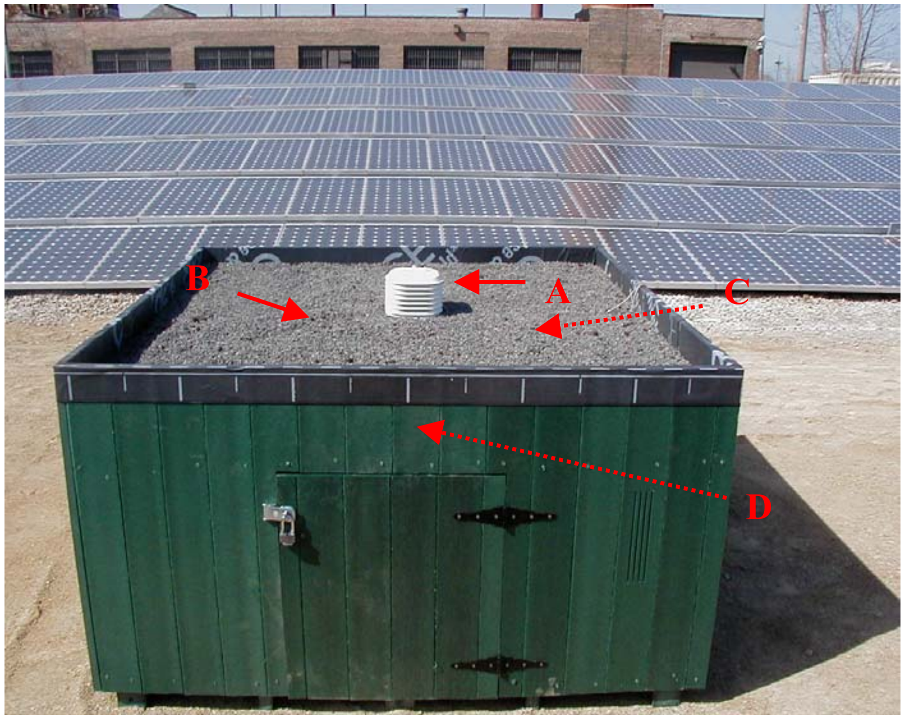
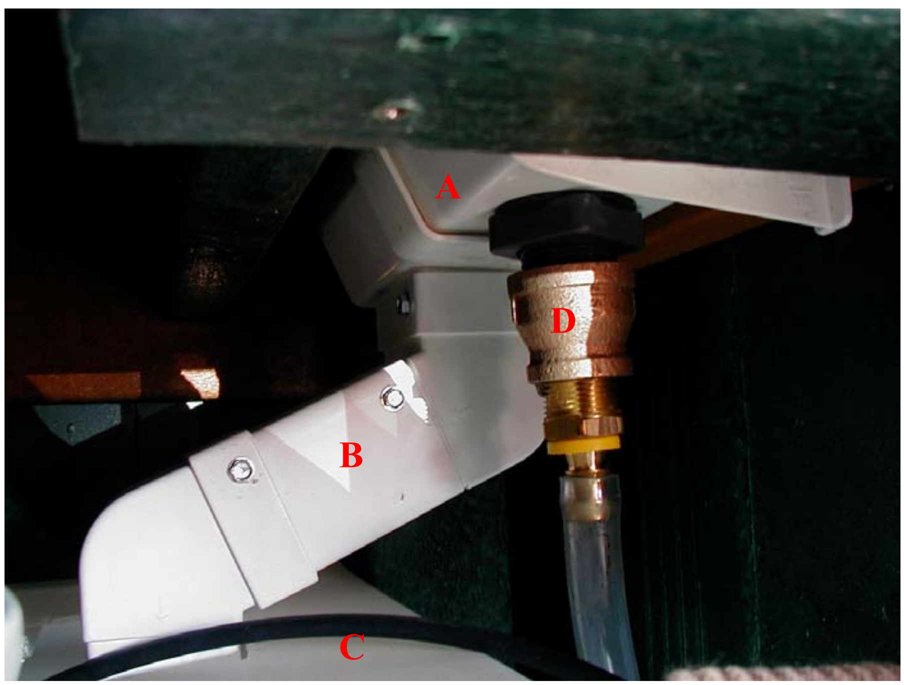



**Photo 6**

**Internal Drainage**

Internal drainage consists of:

A. Gutter
B. Downspout
C. Rain Bucket
D. First Flush Collection



# PHOTO PLATE

Green Roof Test Plot Project

**Photo 7**

**Green Roof #5**

Green Roof #5 had the thickest vegetative coverage of the six green roofs. This photograph was taken on September 2nd, 2003.

**Photo 8**

**Green Roof Vegetation**

This Green Roof had less plant coverage than Green Roof #5. The sedums did not expand much from their original planting locations during the first year of growth. This photograph was also taken on September 2nd, 2003.