Analysis of a Vegetated Roof

The Penfield Apartments
101 E. 10th Street
St, Paul MN

Prepared for: Marie Franchett, City of St. Paul

Prepared by: Angie Durhman, M.S., GRP
and John Buck, M.S., CPSS

December 4, 2015
(Revised December 23, 2015)

The authors would like to thank the City of the St Paul for considering sustainable solutions for the future development of the city, the designers and facility managers of The Penfield site, and past researchers whose work contributed to this study.

Thank You!

Angie Durhman, AD Greenroof LLC
John Buck, Civil & Environmental Consultants Inc.

AD GREENROOF
SUSTAINABLE SOLUTIONS

Abstract

We monitored the performance of the green roof in the courtyard of a newly constructed apartment complex in downtown St. Paul for two years. Weather, green roof soil characteristics (moisture, temperature, electrical conductivity), and building temperature and humidity parameters were recorded. The principal goal was to assess the hydrologic performance of the green roof for stormwater attenuation. Particular attention was given to the ability of the roof to absorb rain events that totaled up to 1.1 inches of liquid rainfall. On average, the 8" thick soil green roof microcosm retained 83.2 percent of rainfall and the 16" thick soil green roof microcosm retained 62.1 percent of rainfall. That the thinner soils had better stormwater retention than thicker soilswas unexpected, but we found there were uncontrolled variables that may explain the reversal of expectations, particularly irrigation coverage irregularities, excessive irrigation, differences in vegetation cover, and mulching. We were unable to capture the effect of snow moisture because the instruments were not heated, so these average stormwater retention figures are low estimates. There was essentially no difference in drainage rate between the 8-inch-thick and 16-inch-thick intensive green roofs; however the conventional roof drained 100%, almost immediately during the rain event. Daily temperature swings of the conventional roof membrane were extreme (as high as 75 ^{o}F), whereas the roof membrane under 8 inches of green roof soil had virtually no daily temperature swing. As a result of temperature moderation the green roof can be expected to remarkably extend the life of the plastic roof membrane over that of the conventional roof. Details of the monitoring program and access the data is presented via this URL: http://gis.cecinc.com/Penfield_weather/index.html

Introduction

Green roofs, also known as vegetative or eco-roofs, are a sought after building strategy for their many benefits. Building owners anticipate prolonged membrane longevity with these protected assemblies, where roof replacement cost is reduced. Stormwater runoff is reduced and decreased during peak flow during a storm event. Other benefits include energy savings, filtering pollutants, carbon sequestration, noise mitigation, reduction of the Urban Heat Island, increase biodiversity (habitat) where it may not otherwise be possible in urban environments, LEED credits, and designing a courtyard roof with park-like features helps psychological and health benefits, ensuring high building occupancy rates.

Traditional gravel-based roofs are designed to divert water as quickly as possible to internal drains, scuppers, or gutters. Conventional black roofs have an albedo (reflectivity of light) of 0-.1, they absorb almost all of incoming sunlight, hence capturing heat, and in urban environments, increasing the urban heat island effect (D'Orazio). In contrast, green roofs are designed to retain 45% to 85% of storm water (Speak). Because green roofs have a higher albedo, approximately 20%, and contain vegetation that evapotranspirates, and insulation during the summer, vegetative roofs add the benefit of storing heat in the winter and releasing it during the summer (Speak).

AD GREENROOF
SUSTAINABLE SOLUTIONS

While all urban environments could benefit from the use of green roof systems, the Twin Cities in particular could prosper greatly from the storm water reduction capabilities of green roofs. Our metropolitan area was formed from the economy the Mississippi River, and still today is dependent on both our rivers and many lakes to sustain drinking water and recreation to the Twin Cities' 3.5 million inhabitants.

For typical at-grade vegetated areas in this region, about 50% of surface water is naturally filtered back into the soil, 40% evaporates from plant and soil surfaces (evapotranspiration), and 10% or less is left as runoff (VanWieren). In contrast, urban areas, in which 75% to 100% of land is encompassed by hard surface, only 30% is filtered back into the ground, and 10% evaporates, leaving about 60% as runoff (VanWieren). In St. Paul, non-captured water flows directly into our watersheds, including the Mississippi River, often unfiltered.

In an effort to mitigate storm water, the Minnesota Pollution Control Agency (MPCA) created the Minimal Impact Design Standards (MIDS). MIDS states that when feasible, newly constructed infrastructure must be capable of retaining 1.1 inches of stormwater during a 24-hour period, which represents 90% of rain depth, and 75% of all pollutant discharge.

Stormwater best management practices (BMP) include bioswales, green roofs, rainwater gardens, permeable pavement, and cisterns, among others. However, because land in urban environments commands high real estate values, options such as green roofs, are favorable due to their transformation of existing roof space into park-like environments, with stormwater attenuation and energy saving benefits.

The literature review found little green roof research focused in the Twin Cities. In addition to a lack of measured green roof benefits in the region, there is no research that explores the performance of deeper soil profiles (8", 16" for example); and green roofs built over heated garage space; and in a typically managed setting with supplemental irrigation, mulch, and routine maintenance.

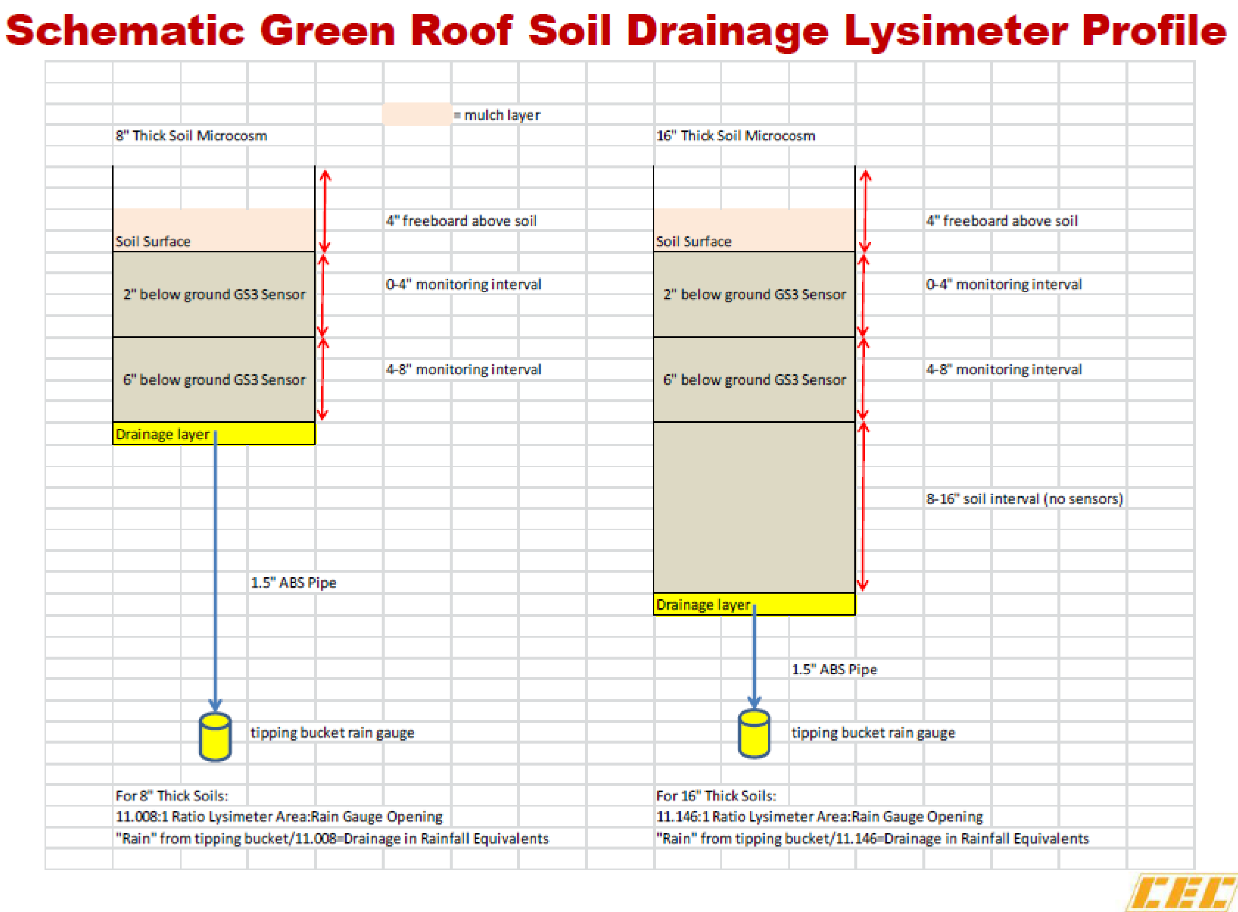
The Penfield Apartments, located in the downtown corridor of St Paul, Minnesota serves as a viable monitoring project to research storm water and temperature and possible effects on roofing type. Its green roof has a generous thickness of green roof soil - 8-inches thick or more - which is termed an "intensive" green roof. Generally, thicker green roof soils can support a more diverse range of plants and store more rainfall than thinner green roof soils, with transpiration by the green roof plants and direct evaporation from the soil drying soils down between rain events to renew soil absorption capacity.

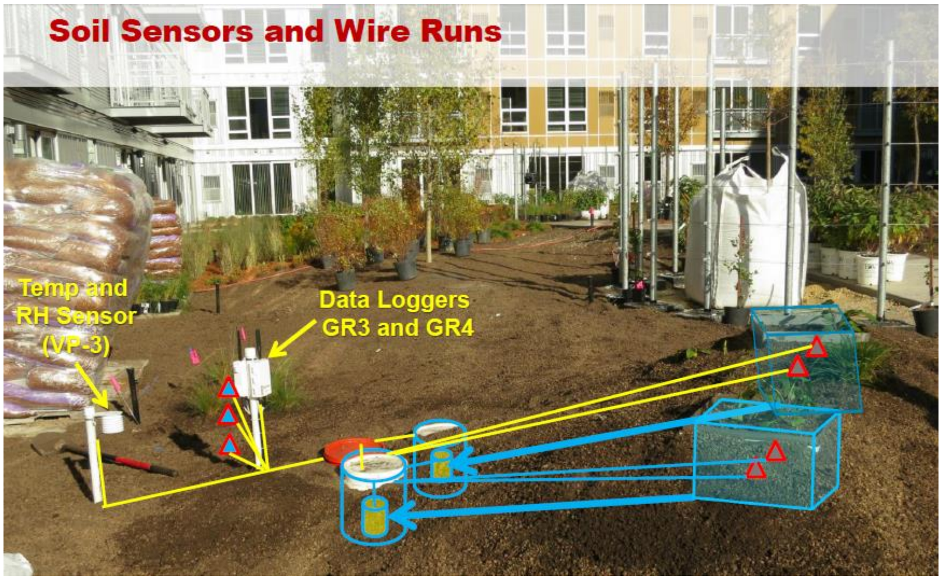
Materials and Methods

Loggers and sensors were placed throughout the green roof, on the ceilings of the garage and top floor, and the gravel-ballasted roof. This study compares the temperature flux, retained rainfall, total runoff, and intensity of rainfall to both the gravel ballasted roof, two green roof soil depths. Data was collected on 5 minute intervals, and uploaded every four hours across two consecutive years. The data was programmed into the publicly available website. http://gis.cecinc.com/Penfield_weather/index.html .

The various components of the monitoring approach are as follows:

- Weather Station (rainfall, air temperature, relative humidity, and wind speed and direction)
- Decagon Em50G Data Loggers with Cellular Telemetry
- Decagon GS3 Sensors: Soil volumetric water content/temp./EC, ceiling temperatures below control and green roof, air temperature/RH inside and outside
- Roof runoff and drainage measured in pan lysimeters at: 8” and 16” thick soil treatment
- Database Programming, Nearly-Real-Time Data Access





Results

Hydrologic Performance

Total Volume of Avoided Rainfall

For the purpose of calculations, it was assumed that under the conventional roof scenario (in this case a rubber membrane ballasted with river rock), 100 percent of rainfall reaching the roof would become runoff. The runoff reduction resulting from the green roof was measured by comparing the drainage through green roof soils in microcosms to the rainfall that fell on the microcosms. Avoided runoff was calculated as equal to: (rainfall - drainage)/rainfall.

Measurement methods resulted in an under-measurement of water inputs to the green roof, which cause estimates of green roof runoff retention to be underestimated. Data was collected with an unheated tipping bucket rain gauge and are therefore limited to liquid rainfall, so the substantial fraction of winter precipitation that came as snow has gone uncounted. In the spring, soil thawing and snow and ice melt (typically in April) results in unaccounted for “irrigation”, which may result in drainage quantities that exceed rainfall for the period.

Avoided runoff was expressed in terms of inches (Figure 1) or as percentage avoided runoff (Table 1) and are summarized on a monthly basis on the project website. Because freezing weather followed installation of the green roof monitoring system, no green roof drainage measured in the microcosms until March 29, 2014. Unexpectedly, the microcosm with 8-inch soil thickness retained more rainfall than did the 16-inch thick soil microcosm (Figure1, Table 1). There were uncontrolled variables that may explain the reversal of expectations, particularly irrigation coverage irregularities, excessive irrigation, and differences in vegetation cover and mulching.

Data from the second year of monitoring (November 2014 through October 2015) was more representative of an established intensive green roof. On average, the 8” thick soil green roof microcosm retained 83.2 percent of rainfall and the 16” thick soil green roof microcosm retained 62.1 percent of rainfall. These percentages are low estimates of the percent avoided rainfall from this roof, because uncounted snow melt and irrigation water are not in the calculations.

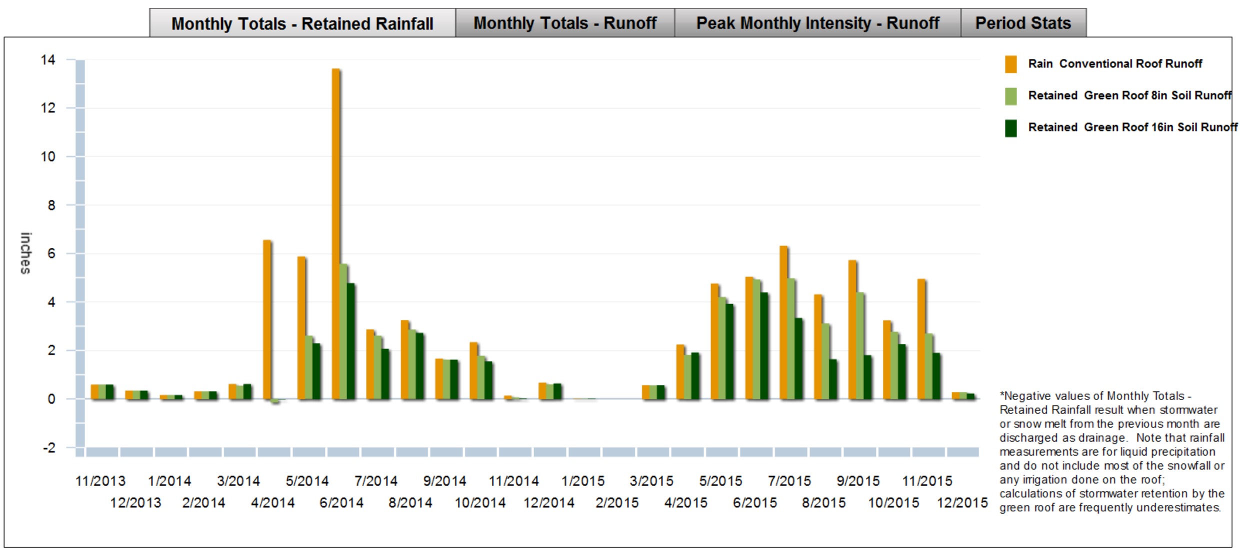


Figure 1 Rainfall monthly totals (brown bars) and retained runoff (light green = 8” thick soil microcosm, dark green = 16” thick soil microcosm) from November 2013 through October 2015. Note record breaking rainfall in June, 2014 (13.622 inches).

AD GREENROOF
SUSTAINABLE SOLUTIONS

Table 1

Summary of Green Roof Roof Rainfall Retention (Avoided Runoff)

Month	Total Rainfall and Conventional Roof Runoff (inches)	Total Runoff from 8-Inch-Thick Green Roof Soil (inches)	Retained Runoff on 8-Inch-Thick Green Roof Soil (inches)	% Retained (Avoided) Runoff on 8-Inch-Thick-Soil Green Roof	Total Runoff from 16-Inch-Thick Soil Green Roof (inches)	Retained Runoff on 16-Inch-Thick Green Roof (inches)	% Retained (Avoided) Runoff on Green Roof 16-Inch-Thick Soil
Nov-13	0.591	0.000	0.591	100.0	0.000	0.591	100.0
Dec-13	0.347	0.000	0.347	100.0	0.000	0.347	100.0
Jan-14	0.165	0.000	0.165	100.0	0.000	0.165	100.0
Feb-14	0.315	0.000	0.315	100.0	0.000	0.315	100.0
Mar-14	0.614	0.069	0.545	88.7	0.000	0.614	100.0
Apr-14	6.559	6.703	-0.144	-2.2	6.579	-0.019	-0.3
May-14	5.882	3.270	2.612	44.4	3.586	2.296	39.0
Jun-14	**13.622**	8.045	5.577	40.9	8.843	4.779	35.1
Jul-14	2.866	0.253	2.614	91.2	0.796	2.070	72.2
Aug-14	3.252	0.394	2.858	87.9	0.526	2.726	83.8
Sep-14	1.661	0.042	1.620	97.5	0.041	1.620	97.5
Oct-14	2.339	0.552	1.786	76.4	0.784	1.554	66.5
Nov-14	0.142	0.076	0.066	46.5	0.117	0.024	17.2
Dec-14	0.677	0.073	0.604	89.2	0.036	0.641	94.7
Jan-15	0.016	0.000	0.016	100.0	0.000	0.016	100.0
Feb-15	0.000	0.000	null	100.0	0.000	null	100.0
Mar-15	0.575	0.011	0.564	98.1	0.002	0.573	99.6
Apr-15	2.244	0.424	1.820	81.1	0.323	1.921	85.6
May-15	4.764	0.558	4.206	88.3	0.841	3.922	82.3
Jun-15	5.039	0.108	4.931	97.9	0.643	4.396	87.2
Jul-15	6.315	1.336	4.979	78.8	2.976	3.339	52.9
Aug-15	4.315	1.195	3.121	72.3	2.677	1.638	38.0
Sep-15	5.724	1.318	4.407	77.0	3.917	1.808	31.6
Oct-15	3.244	0.466	2.778	85.6	0.978	2.266	69.8
2-year period	**71.268**	24.892	46.377	**65.1**	33.665	37.601	**52.8**
Nov-13 to Oct-14	**38.213**	19.327	18.886	**49.4**	21.155	17.058	**44.6**
Nov-14 to Oct-15	**33.055**	5.564	27.492	**83.2**	12.511	20.544	**62.1**

To better understand the performance of the green roof, we performed more detailed follow-up analyses of aggregate storm water during individual storms. For the purpose of the analysis, we assumed that one storm event would be separated from the next by a period of at least six hours without rainfall. Soil temperatures (Figure 2) were used to determine when the green roof soil system was frozen, and when it was thawed. In general, soils were thawed from April through November. Rainfall (and conventional roof drainage) and green roof microcosm drainage hydrographs are presented over a seasonal range of dates in Figures 3-11.

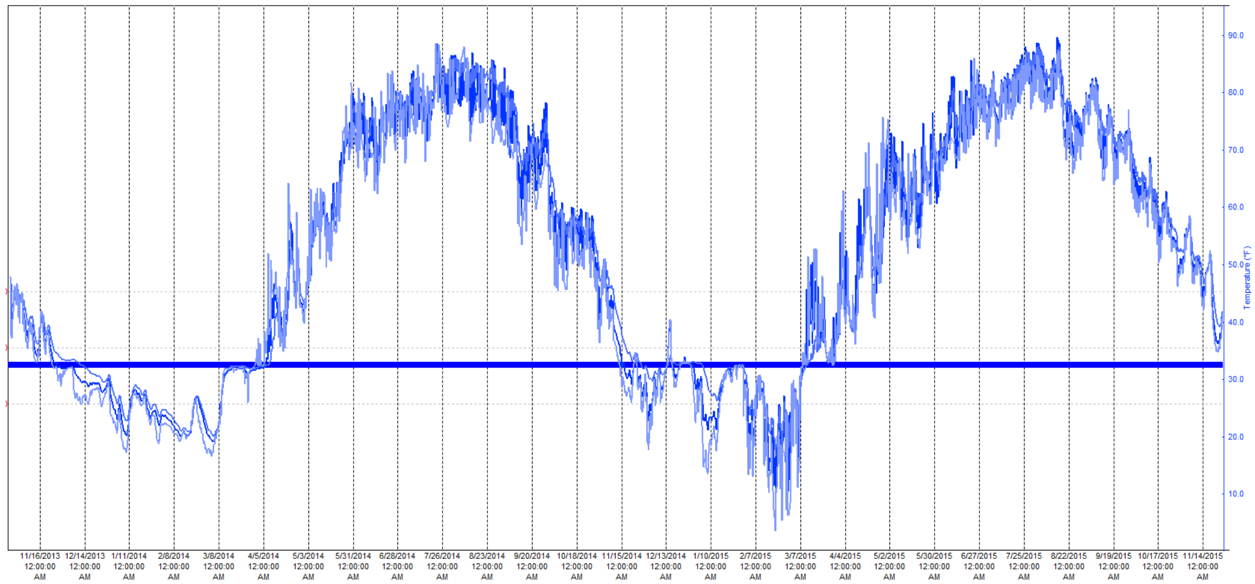


Figure 2: Soil temperature 2” and 6” below ground surface. Note that soils were frozen from 12/14/13 to 4/9/14 and from 11/28/14 to 3/9/15.

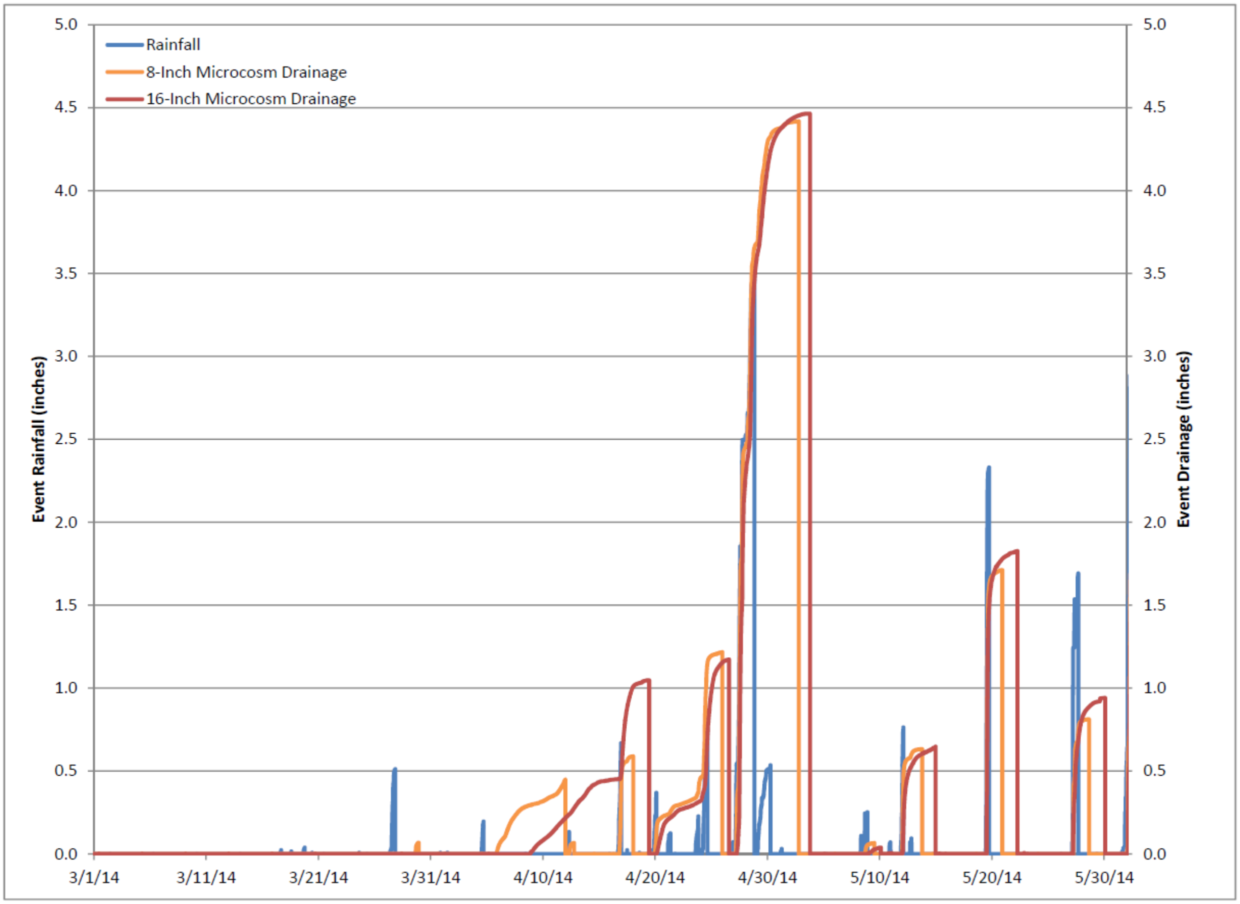


Figure 3: Hydrographs showing storm rainfall (~conventional runoff, blue trace), drainage from the 8-inch-thick-soil microcosm (orange trace), and drainage from the 16-inch-thick-soil microcosm (red trace) from March through May, 2014. Note that drainage is lower than rainfall (indicating runoff retention), except where snowmelt or excess irrigation has caused drainage without recorded rainfall. Soils were frozen from 12/14/13 to 4/9/14, so early spring drainage includes substantial snowmelt.

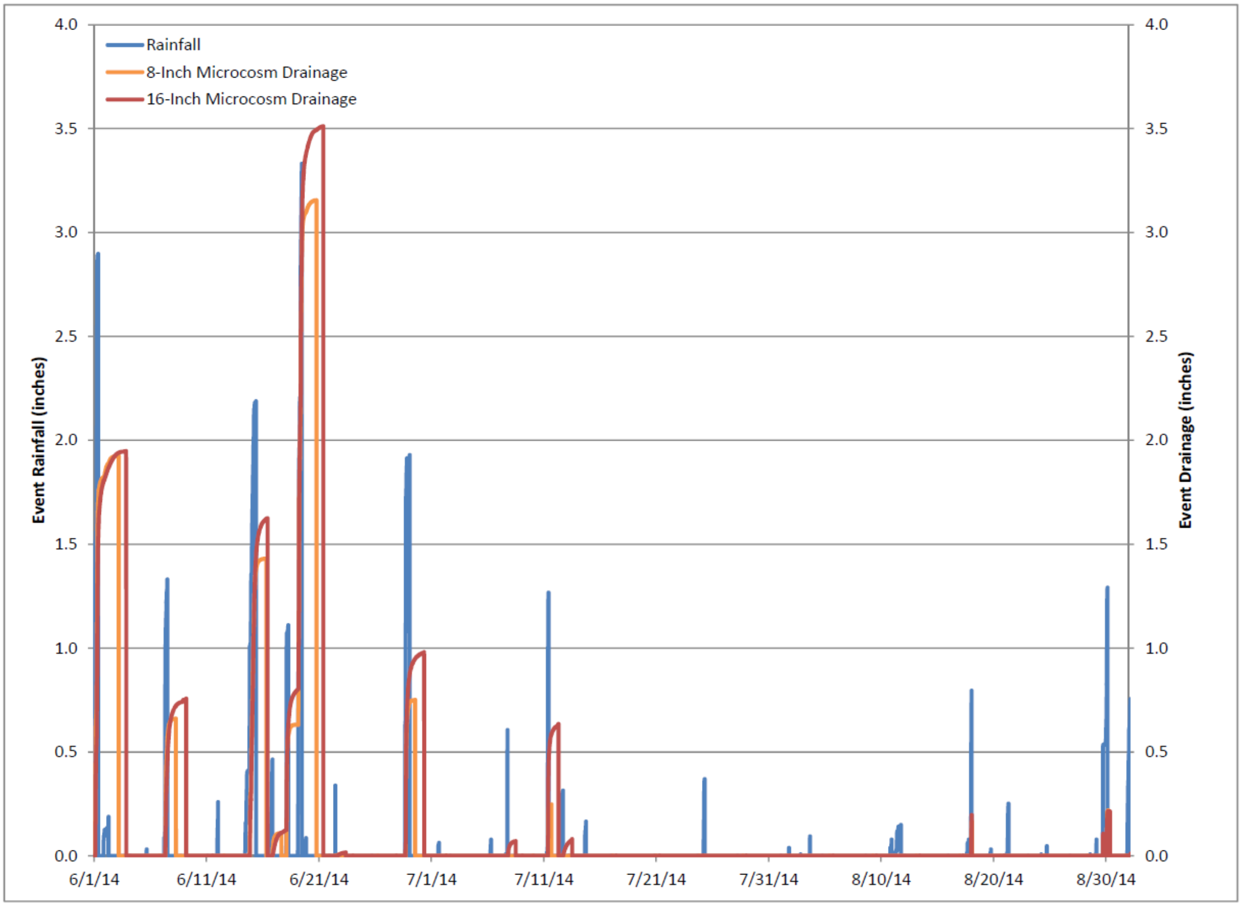


Figure 4: Hydrographs showing storm rainfall (~conventional runoff, blue trace), drainage from the 8-inch-thick-soil microcosm (orange trace), and drainage from the 16-inch-thick-soil microcosm (red trace) from June though August, 2014. Note that drainage is lower than rainfall (indicating runoff retention).

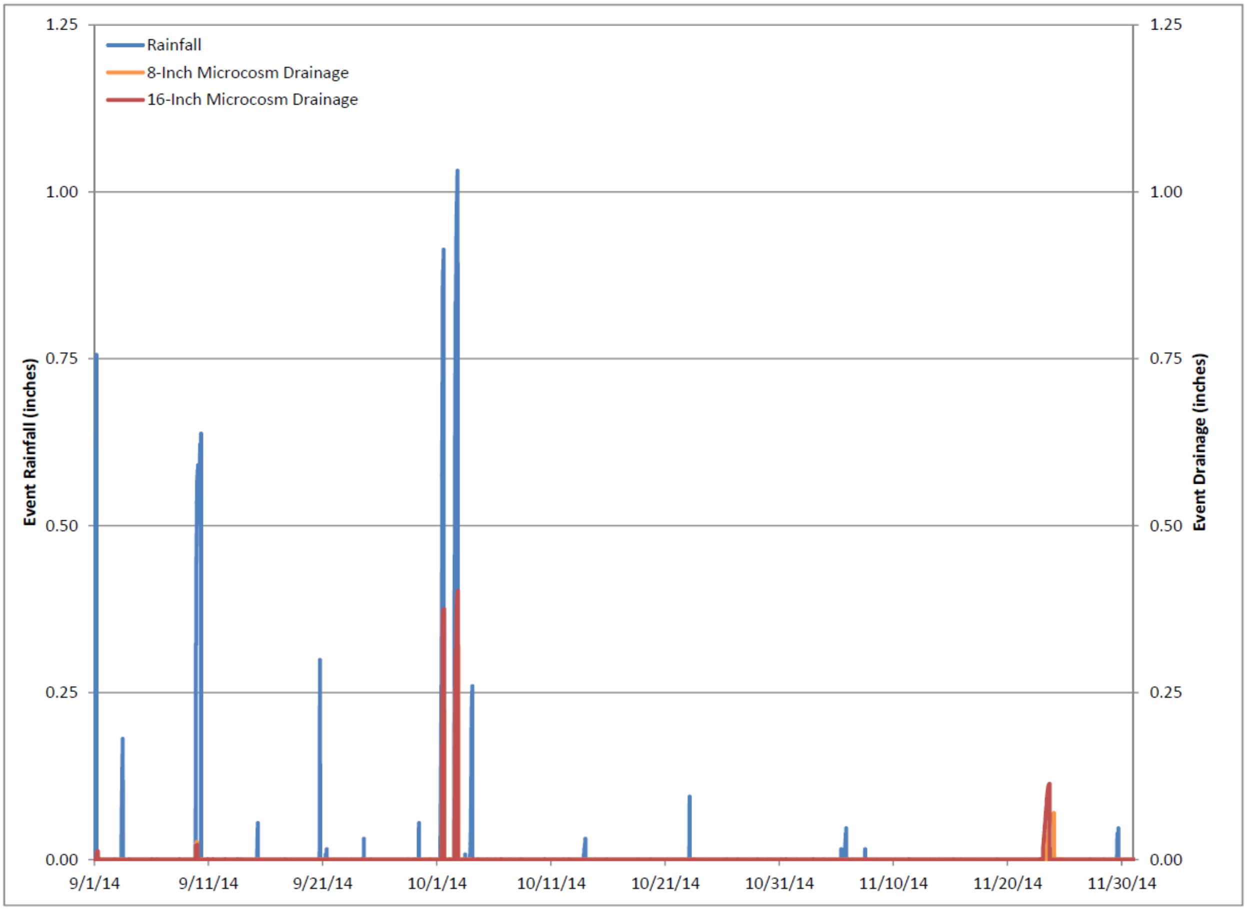


Figure 5: Hydrographs showing storm rainfall (~conventional runoff, blue trace), drainage from the 8-inch-thick-soil microcosm (orange trace), and drainage from the 16-inch-thick-soil microcosm (red trace) from September through November, 2014. Note that drainage is lower than rainfall (indicating runoff retention), except where irrigation has caused drainage without recorded rainfall.

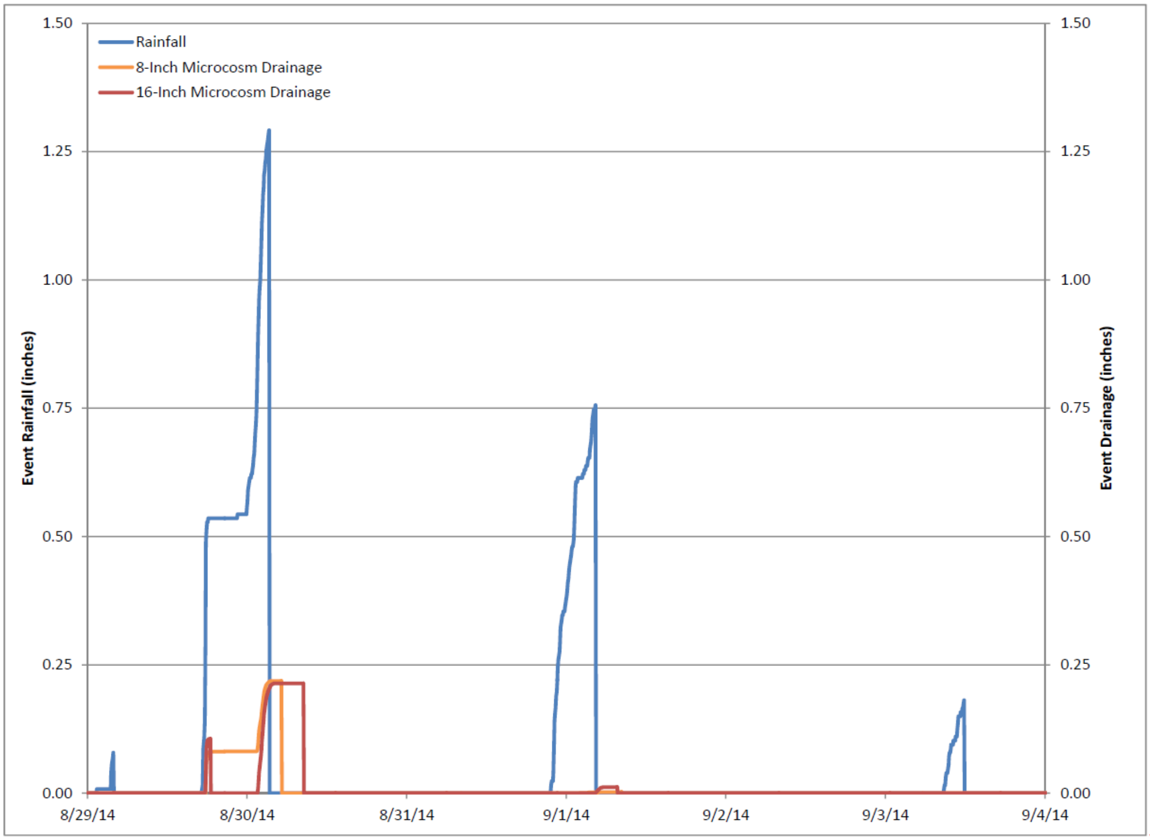


Figure 6: Close-up view of hydrographs showing storm rainfall (~conventional runoff, blue trace), drainage from the 8-inch-thick-soil microcosm (orange trace), and drainage from the 16-inch-thick-soil microcosm (red trace) from August 29 to September 4, 2014. Note that drainage is lower than rainfall (indicating runoff retention).

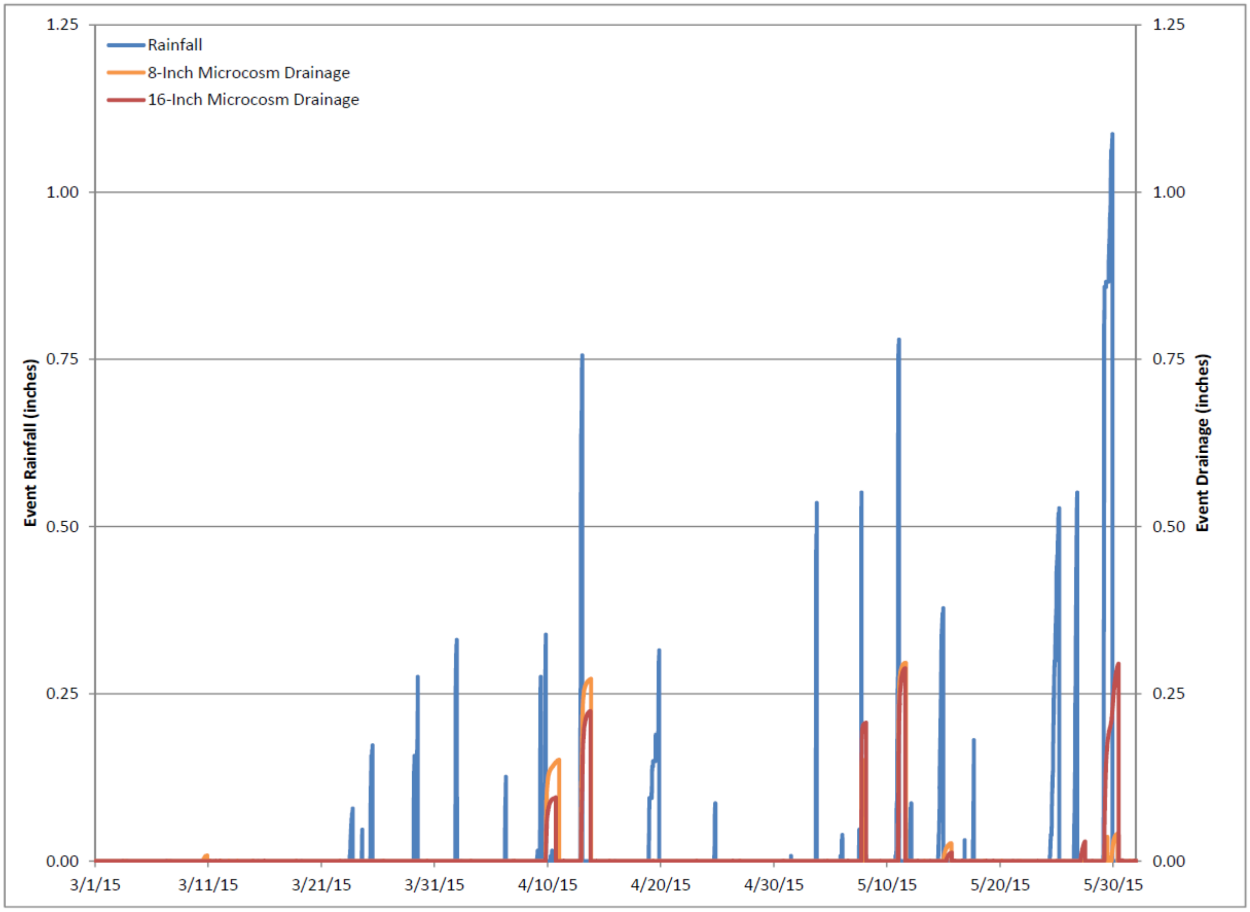


Figure 7: Hydrographs showing storm rainfall (~conventional runoff, blue trace), drainage from the 8-inch-thick-soil microcosm (orange trace), and drainage from the 16-inch-thick-soil microcosm (red trace) from March through May, 2015. Note that drainage is lower than rainfall (indicating runoff retention), except where snowmelt or excess irrigation has caused drainage without recorded rainfall. Soils were frozen 11/28/14 to 3/9/15.

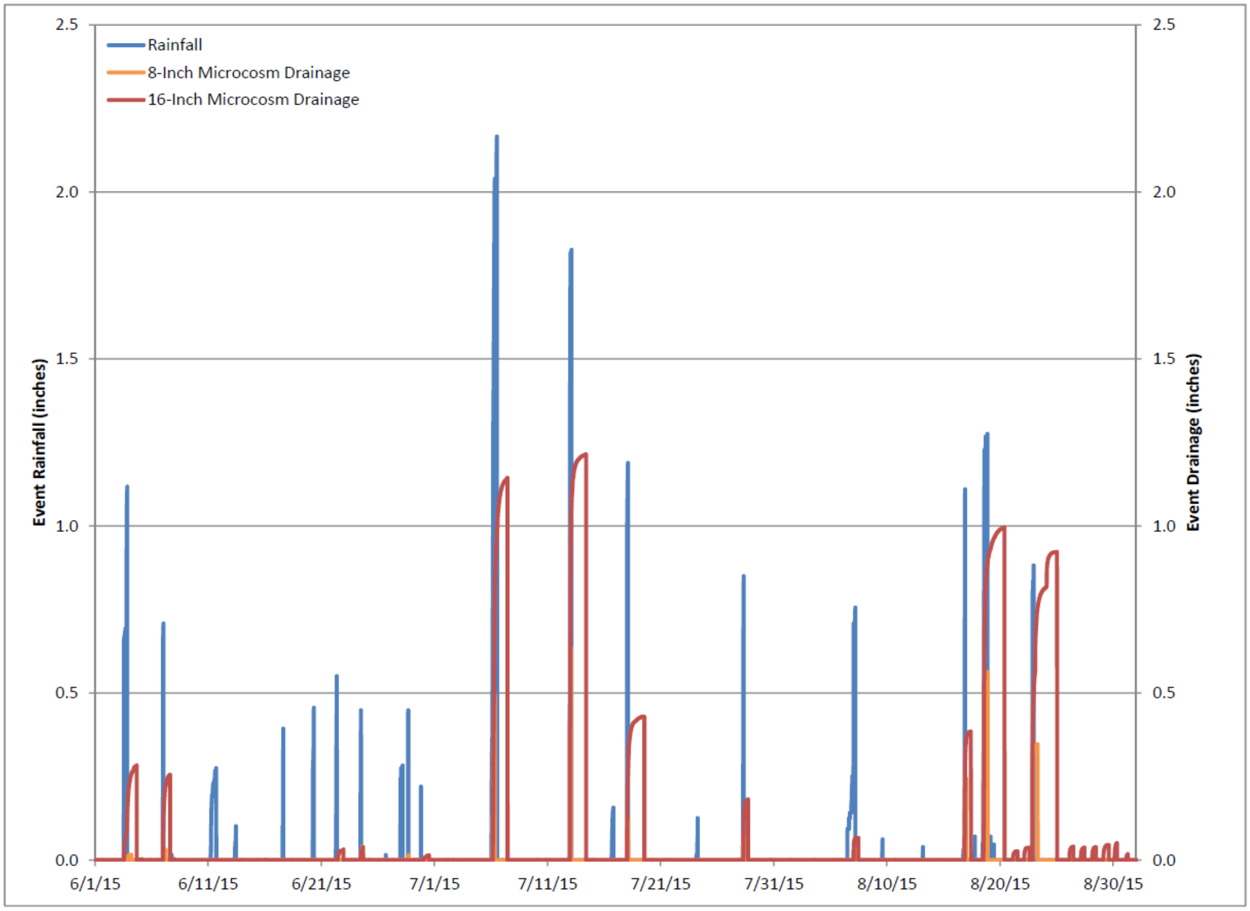


Figure 8: Hydrographs showing storm rainfall (~conventional runoff, blue trace), drainage from the 8-inch-thick-soil microcosm (orange trace), and drainage from the 16-inch-thick-soil microcosm (red trace) from June though August, 2014. Note that drainage is lower than rainfall (indicating runoff retention), except where irrigation has caused drainage without recorded rainfall (small, regularly-spaced red "bumps" in the 16-inch microcosm plots are believed to be from excess irrigation of already moist soil).

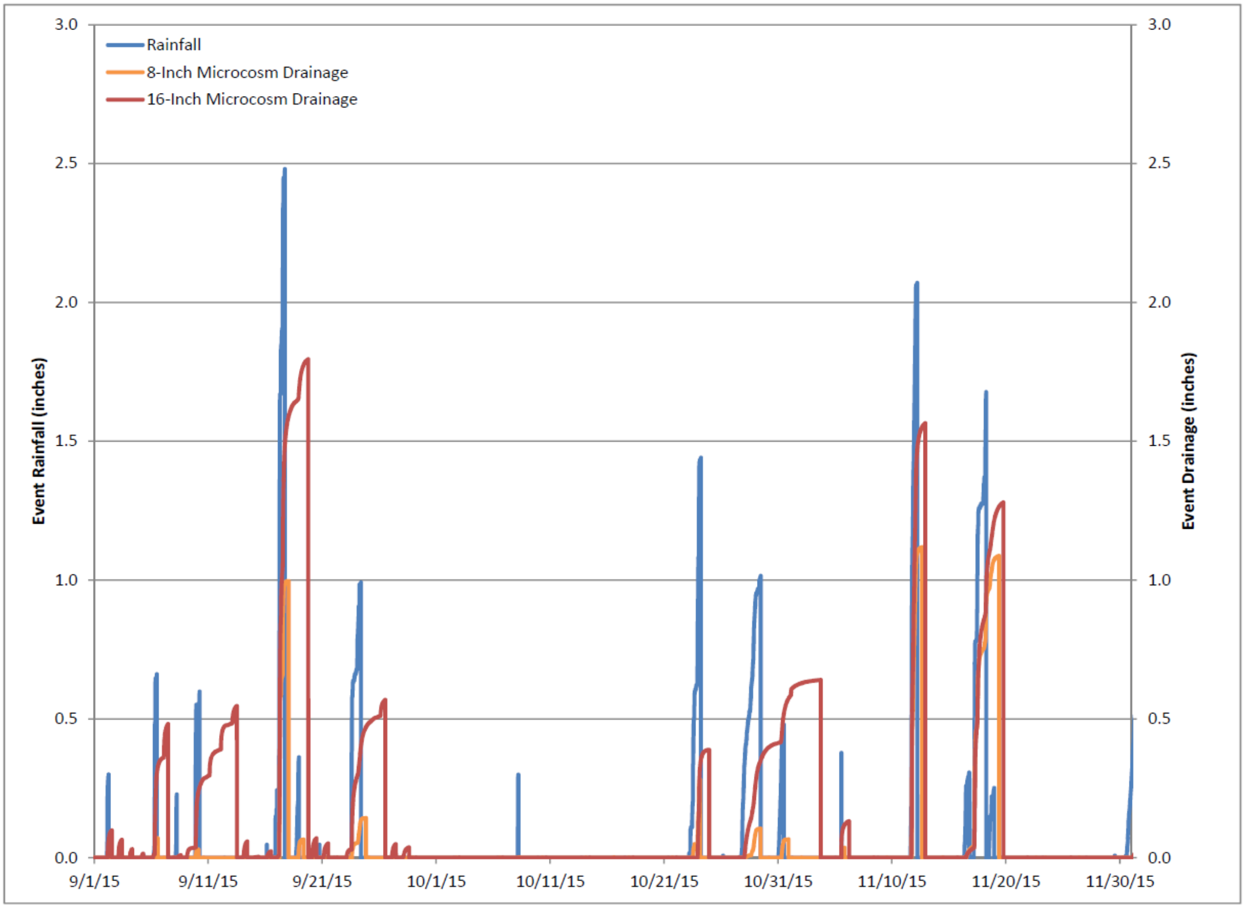


Figure 9: Hydrographs showing storm rainfall (~conventional runoff, blue trace), drainage from the 8-inch-thick-soil microcosm (orange trace), and drainage from the 16-inch-thick-soil microcosm (red trace) from September through November, 2015. Note that drainage is lower than rainfall (indicating runoff retention), except where irrigation has caused drainage without recorded rainfall (small, regularly-spaced red "bumps" in the 16-inch microcosm plots are believed to be from excess irrigation of already moist soil).

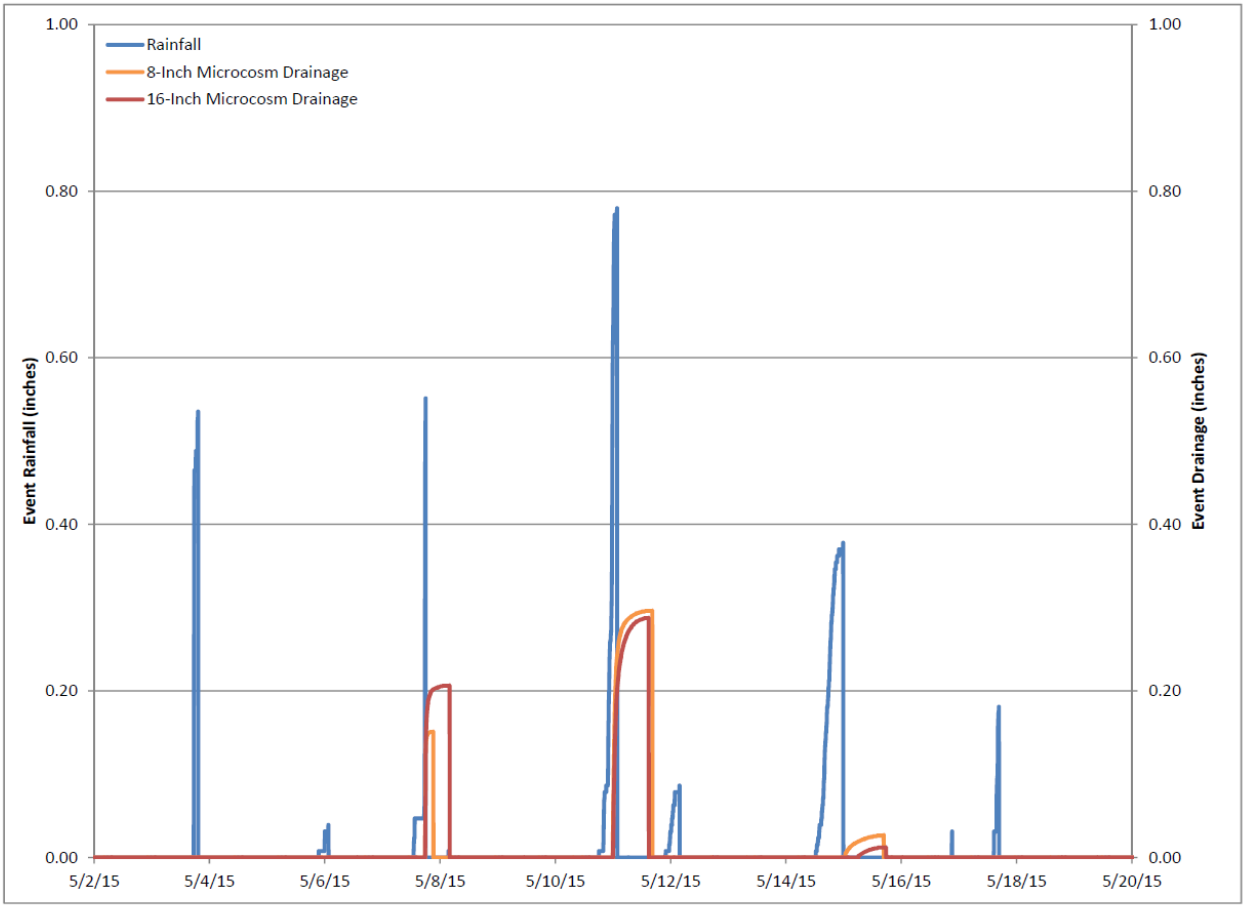


Figure 10: Close-up view of hydrographs showing storm rainfall (~conventional runoff, blue trace), drainage from the 8-inch-thick-soil microcosm (orange trace), and drainage from the 16-inch-thick-soil microcosm (red trace) from May 2-20, 2015. Note that drainage is lower than rainfall (indicating runoff retention).

AD GREENROOF
SUSTAINABLE SOLUTIONS

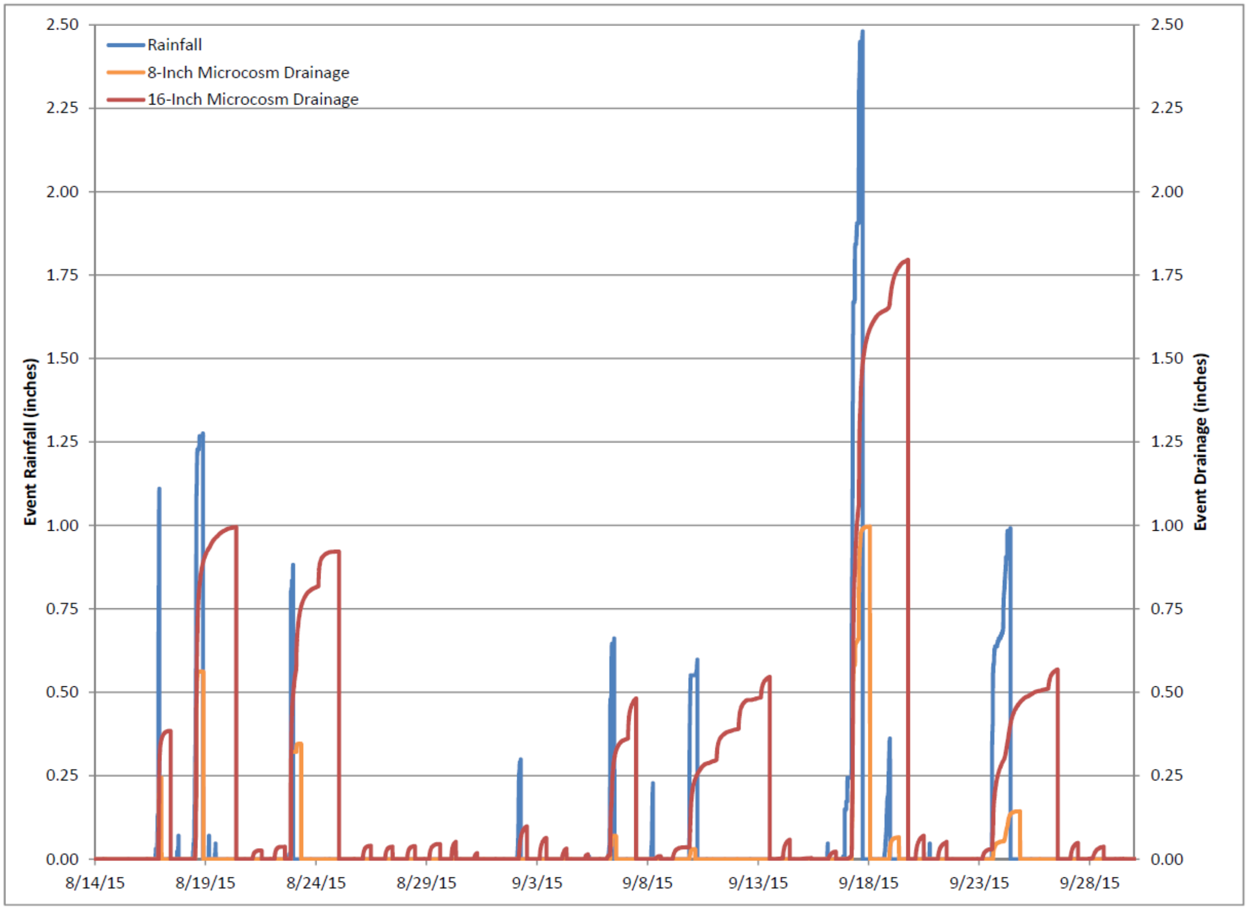


Figure 11: Close-up view of hydrographs showing storm rainfall (~conventional runoff, blue trace), drainage from the 8-inch-thick-soil microcosm (orange trace), and drainage from the 16-inch-thick-soil microcosm (red trace) from August 14 to September 30, 2015. Note that drainage is lower than rainfall (indicating runoff retention), except where irrigation has caused drainage without recorded rainfall (small, regularly-spaced red "bumps" in the 16-inch microcosm plots are believed to be from excess irrigation of already moist soil).

Examination of hydrographs indicated that there were instances of soil drainage that were isolated from rainfall or snow/ice melt that indicate that the unmeasured irrigation system was applying more water than the soils can absorb. Over-irrigation was particularly evident in data from the 16" microcosm – see plot of data in Figure 11 from the August 14 to September 30, 2015 timeframe. The fact that drainage events isolated from rainfall show regularity in timing and magnitude suggests a regular irrigation cycle, with water applied to soils already too wet to absorb any more. Excessive irrigation reduced the stormwater absorption capacity of the green roof soils, and may also damage the health of plants by presenting a root environment where disease and root rot are more likely.

Rainfall and Runoff Intensity Moderation

Green roof soils are required by industry standards to have high soil infiltration rates - at least 0.7 inches per hour, and often higher. At this high infiltration rate, green roof soils can absorb most rain storms without any runoff, but the water that can't be absorbed by the green roof leaves the soil as drainage. The maximum soil drainage rate is expected to be controlled by the drainage rate of the soil and underlying geocomposite drainage layer.

The microcosms have stainless steel borders that project above the soil surface, so surface runoff out of the microcosms is impossible. Over the 2 year monitoring period (Figure 2), the maximum green roof drainage rate was 1.5 inches per hour (August, 2015) compared with the maximum rainfall rate (akin to conventional roof runoff) of 4.4 inches per hour (July 2015). To date at Penfield, green roof drainage are significantly less than the drainage rates of a conventional roof surface (Figure 11). No substantial differences were found in the drainage rate between the 8-inch and 16-inch-thick intensive green roofs – they were both moderated by the soil water absorption and drainage properties.

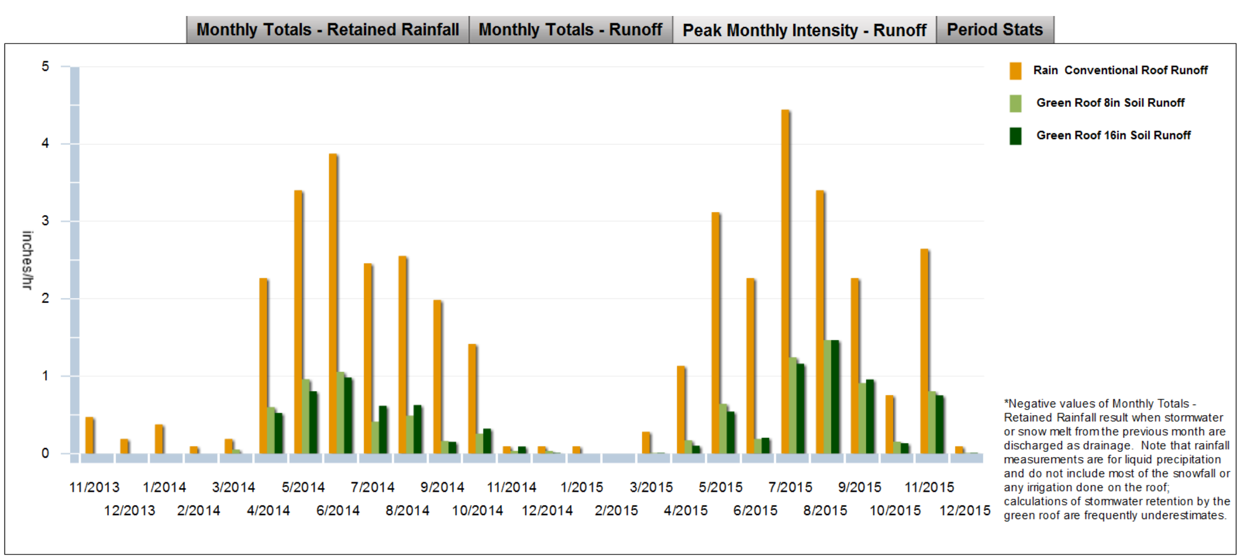


Figure 12 Rainfall maximum intensity (inches/hour, brown bars) and green roof microcosm drainage rates (light green = 8” thick soil microcosm, dark green = 16” thick soil microcosm) from November 2013 through October 2015.

Green Roof Temperature and Relative Humidity

On 5-minute intervals throughout the project we measured the temperature of the conventional roof membrane under gravel ballast, as well as the roof membrane under the green roof. Temperature data are summarized in Figures 3 and 4 as well as Table 2. Daily temperature swings of the conventional roof membrane were extreme (as high as 75.1 °F), whereas the roof membrane under 8 inches of green roof soil showed negligible (2.4 °F) daily temperature swing (Figures 13 and 14).

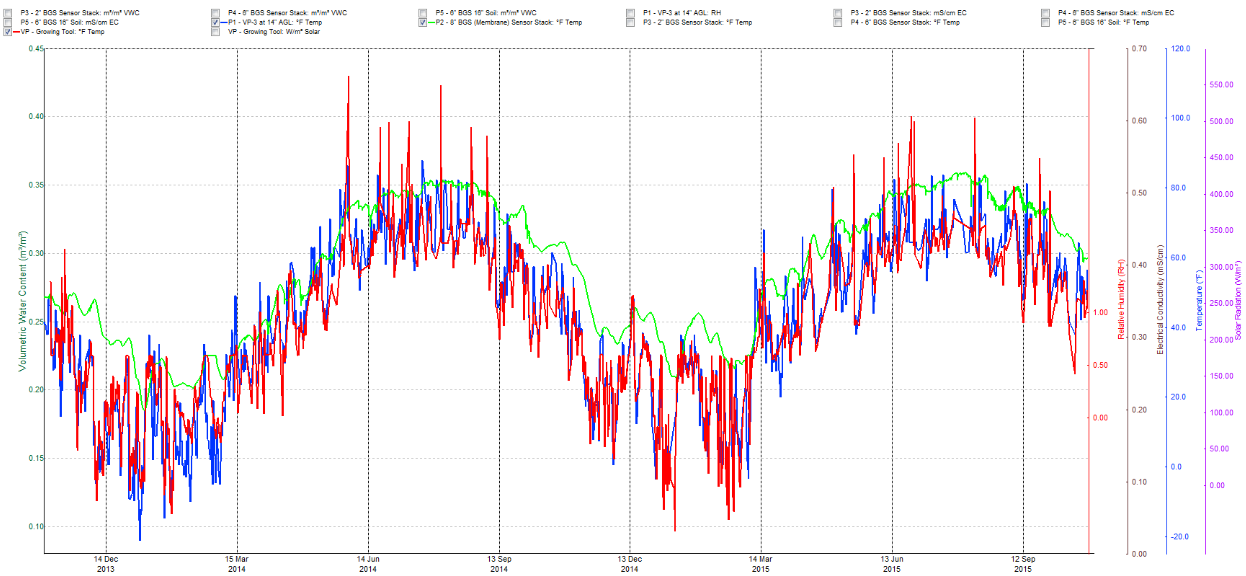


Figure 13: Air over green roof (blue trace), green roof membrane (green trace) and conventional roof membrane (red trace) temperatures from November 2013 through October 2015. Note extreme daily conventional roof membrane temperature swings compared to temperature changes on roof membrane under green roof.

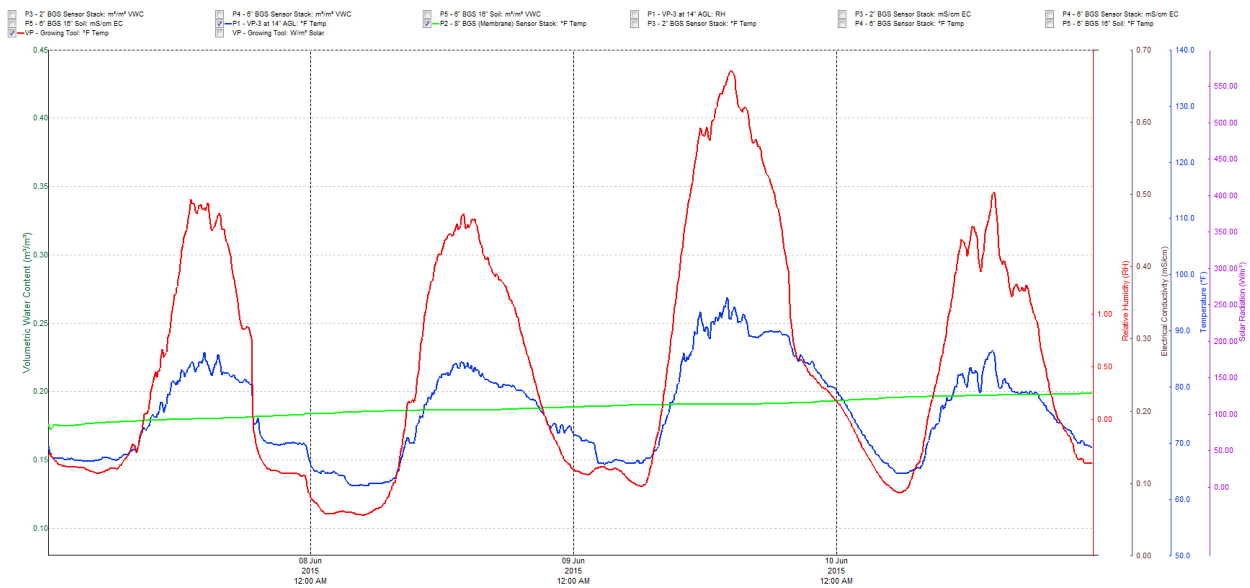


Figure 14: Air over green roof (blue trace), green roof membrane (green trace) and conventional roof membrane (red trace) temperatures from June 7-11, 2015. Note extreme (75.1 ^{o}F) conventional roof membrane temperature fluctuation compared to insignificant (2.4 ^{o}F) temperature changes on the roof membrane under the green roof soil.

Table 2

Summary of Temperature and Humidity Monitoring of Air and Roof Membranes

	Air Over Ballasted Roof	Balasted Roof Membrane Temperature	Air Over Green Roof	Green Roof Membrane Temperature		Air Over Ballasted Roof	Air Over Green Roof
Measurement (5 minute sampling interval)	Temp	Temp	Temp	Temp		Relative Humidity	Relative Humidity
Minimum	-21.1 (1/6/2014 2:15:00 AM)	-18.84 (1/13/2015 3:30:00 AM)	-21.46 (1/6/2014 5:15:00 AM)	16.16 (1/9/2014 10:30:00 AM)		10.99 (4/23/2015 5:55:00 PM)	12.98 (4/23/2015 3:55:00 PM)
Maximum	95.9 (6/9/2015 6:00:00 PM)	136.26824 (6/9/2015 2:25:00 PM)	99.14 (8/14/2015 2:20:00 PM)	84.51446 (7/28/2015 2:15:00 AM)		103.79 (12/4/2013 5:55:00 PM)	104.99 (2/16/2014 11:30:00 AM)
Average	45.92	48.89	46.09	57.22		68.90	70.67
Mode (Freq)	68.72 (1091)	31.9372 (2616)	68 (1379)	31.9372 (2549)		80.53 (115)	75.12 (127)
99th Percentile	87.08	116.20	87.80	83.93		100.23	100.04
90th Percentile	76.82	88.58	77.90	80.73		92.28	92.99
10th Percentile	9.14	12.32	8.96	29.80		42.13	44.83
1st Percentile	-7.60	-5.72	-7.78	22.53		24.33	26.68

Relative humidity (RH) levels over the green roof are, on average, about 3 percent higher than over the conventional roof, presumably a result of evapotranspiration from plants and soils. Considering the 90th percentile RH levels, which would correspond closely with humid days without rain, there is virtually no difference in humidity between the green roof and conventional roof.

Discussion

Considering the additional cost of soil and roof structure required to increase green roof intensity from an 8-inch to 16-inch soil thickness, and that stormwater was no better with the extra-thick soils, there does not appear to be an advantage to using soil thickness greater than 8 inches, except that thicker soils may be able to support a variety of plant species, including trees.

Green roof growing media and plants moderate surface temperatures of the roof assembly below. Temperature moderation by green roofs is most dramatic in summer months when the combination of soil insulation and, more importantly, evaporative cooling reduce high temperature extremes. In winter months, temperature moderation is less dramatic, and is due more to insulation effects of soil. Because roof temperatures do not fluctuate greatly, green roofs have the benefit of prolonging the life of the protected roof, keeping the building inhabitants and neighborhood cooler in the summer, and saves energy in both warm and cool months. Roof membranes of conventional roofs are put under great strain by wide temperature swings and associated expansion and contraction, plus ultraviolet light degradation when exposed directly to the sun.

Heat enters and leaves buildings through the roof in hot and cold months, respectively. As noted above, green roofs add insulation, and evapotranspiration from soil and plant surfaces in the summer can be a significant heat sink. We did not calculate heat flows through the roof assemblies because of substantial differences in roof assembly and air conditioning regimes under the green roof and conventional roof areas.

We believe that there are substantial, but unquantified energy savings from the green roof based on extensive monitoring of a green roof and adjacent, otherwise identical roof in Pittsburgh, PA. Becker and Wang considered insulation components and temperature gradients across green roof and control roof layers to calculated heat flux. They found greatest energy benefits took place in warm weather – cooler roof temperatures reduced heat gain to the building by 75.3% in the June-August air conditioning season. Becker and Wang found a modest, 8.2%, energy benefit in the November 2010-April 2011 heating season.

Conclusion

- In situ monitoring of an establishing green roof can cause unexpected results if irrigation is applied in an excessive and/or non-uniform manner. The effect of maintenance (irrigation, plant replacement, mulching, use as an amenity) likely distorted results. Excessive irrigation is believed to have caused the deeper (16") soil profile to report lower than expected stormwater retention percentages relative to the thinner (8") soil profile. Regardless, both soil profiles showed significant retention compared to the conventional roof, but stormwater retention would have been higher in a non-irrigated roof landscape where soils can dry down more extensively between rain events.
- Excessive irrigation, in addition to reducing the stormwater absorption capacity of the green roof soils, may also damage the health of plants by presenting a root environment where disease and root rot are more likely.
- For green roof BMP on a budget, it is likely that no more than 8-inch depth of green roof media is needed to manage a 1.1 inch rainfall event. Based on team experience at other sites, an 8-inch-thick green roof soil thickness can provide sufficient plant-available water storage to establish a diverse and robust plant community.
- Where roof loading capacities and/or budgets are lighter, the combination of a thin profile green roof (extensive) and use of a cistern may be sufficient to manage CSO.
- The green roof showed little temperature fluctuation compared to the conventional roof, and this will prolong the life of the protected assembly below.
- Design and manage green roofs using Certified Green Roof Professionals. Not all landscape management techniques translate well to roof gardens, and high-performance green roof soils (high infiltration and drainage rate, lightweight, high plant-available water storage) differ radically from typical landscape soils.

References

Becker, D. and D. Wang. Allegheny County Office Building by CEC. http://www.cmu.edu/environment/campus-green-design/green-roofs/documents/heat-transfer-and-thermal-performance-analysis.pdf

Buck, John K. Green Roof Monitoring Depth Profile. Digital image. Civil & Environmental Consultants Inc., 2013. http://gis.cecinc.com/Penfield_weather/index.html

Buck, John K. Plan View: Green Roof Layout. Digital image. Civil & Environmental Consultants Inc., 2013. Web. Apr. 2014.

D'Orazio, M., C. Di Perna, and E. Di Giuseppe. "Green Roof Yearly Performance: A Case Study in a Highly Insulated Building under Temperate Climate." Energy and Buildings 55 (2012): 439+.ScienceDirect. Web. Mar. 2014.

Minnesota Stormwater Manual. "Introduction to Stormwater Modeling." Minnesota Pollution Control Agency, 01 Aug. 2013. Web. Mar. 2014.

Oquist, K., Udai Singh, Jen Keville, Brian Jastram, and Nick Klein. "Annual Monitoring Report 2013." Annual Monitoring Report 2013 (2014).

Speak, A.f., J.j. Rothwell, S.j. Lindley, and C.l. Smith. "Rainwater Runoff. Retention on an Aged Intensive Green Roof." Science of The Total Environment 461-462 (2013): 28-38. Online.

VanWieren, Rebekah, and Janette Monear. "Landscaping Ideas That Improve Water Quality Along the Mississippi River." Green Spaces, Clean Water (2005) Mississippi Watershed Management Organization. Web. Mar. 2014.