
Hamerschlag Hall Green Roof Storm Water Retention and Runoff Reduction Performance

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Abstract

The Hamerschlag Hall green roof at Carnegie Mellon University, Pittsburgh, Pennsylvania, was constructed in 2005, and has been monitored to evaluate its performance in reducing storm water runoff and extending the runoff duration. Green roofs can reduce the amount and rate of storm water runoff by covering the impervious roof with porous soils that can retain water and plants that evapotranspire the stored water. Storm water runoff from two hydraulically isolated areas on the Hamerschlag Hall green roofs have been monitored semi-continuously since 2008, as a control area of similar size on the adjacent flat roof which is not a green roof. From analysis of data for storms from 2009-2011, it was found that the green roof reduces the runoff volume by up to 100% compared to the control roof for small rainfall events of 0.1 inch or less. A reduction of at least 45% was found for rainfall storms between 0.1 and 0.6 inch. For events less than 0.6 inch, the reduction in the runoff peak flow rate from the green roof compared to the control roof was between 80%-100%. Runoff flow duration is extended for the green roof by at least several hours compared to the control roof. Insufficient data were obtained for large rainfall storms (rainfall depth over 1 inch), so the performance of the Hamerschlag Hall green roof is yet not to be determined under heavy rain.

Key word: storm water runoff retention, green roofs, peak flow, duration

1. Introduction

Cities which have a combined sewer systems, like Pittsburgh, Pennsylvania, often have the sewer overflow discharges which send the diluted sewage into streams. Technologies such as green roofs that can reduce sewer overflows are of interest in areas with frequent sewage overflows.

Green roofs are engineered roof systems incorporating porous soil, or a synthetic growing medium and drought-tolerant plants, installed over a conventional roof with a waterproofing membrane. The environmental advantages of green roofs are:(1) reduced heating and cooling loads on the building space beneath the green roof due to add insulation provided by the green roof; (2) increased life span for the roof due to protection from solar radiation and other weathering;(3) reduced stormwater runoff volume and runoff peak flow rate and extension of the runoff duration.

There are two kinds of green roofs, intensive and extensive (Miller, 2005). Intensive green roofs are characterized by thick soil layers (8 in-4 ft), heavy weight and elaborate planting, which requires considerable maintenance. Extensive green roofs are much lighter in weight with soil depth ranging from 3-7inches (Worden, et al,2005). Due to the relatively thin soil layers and the low maintenance requirement, plants are typically low growing ground cover that are tolerant of sunlight and drought.

The Hamerschlag Hall green roof at Carnegie Mellon University, installed in 2005, was designed as an aesthetic environment, and also to provide improved thermal insulation and storm water

retention characteristics. In addition, it was designed with monitoring systems to enable assessment of energy and storm water performance.

The objectives of this research study were to (1) investigate the effect of Hamerschlag Hall green roof on selected storm water runoff and rainfall quantity characteristics during 2009-2011; (2) evaluate quantitatively the overall performance of Hamerschlag Hall green roof for retaining stormwater, extending the duration of the flow, and reducing the peak runoff flow rate; and (3) enable prediction of the future water retention and runoff reduction performance of the green roof.

2. Hamerschlag Hall Green Roof

The Hamerschlag Hall green roof at Carnegie Mellon University is a 4500 ft² extensive green roof. The green roof was installed on top of a conventional modified bitumen flat roof. The Hamerschlag Hall green roof is shown in plan view in Figure 2.1. The adjacent control roof, also shown in Figure 2.1, has no soil or vegetation. The Hamerschlag Hall green roof has two water monitoring areas. Each monitoring area is hydraulically isolated and has one trapezoidal flume to measure outflow of water. The roof has five drains as indicated on Figure 2.1. The green roof water monitoring areas drain to two of the five drains. The other three roof drains accommodate drainage onto the roof from another roof above it, as well as runoff from the non-monitoring areas of the green roof. The two monitoring areas are hydraulically isolated from influence of the

upper roof run-on by means of a separate membrane under each of the areas.

A cross section of the Hamerschlag Hall green roof is shown in Figure 2.2. In the water monitoring areas, the thickness of synthetic soil growing medium is approximately 10 cm as indicated in Figure 2.2. In other areas of the roof, the synthetic soil is somewhat thicker.

Each monitoring area covers approximately 650 square feet of the green roof surface, making the total monitored area 1300 square feet, or about 30% of the total area of the green roof. The dimensions of each green roof water monitoring area are shown in Figure 2.3

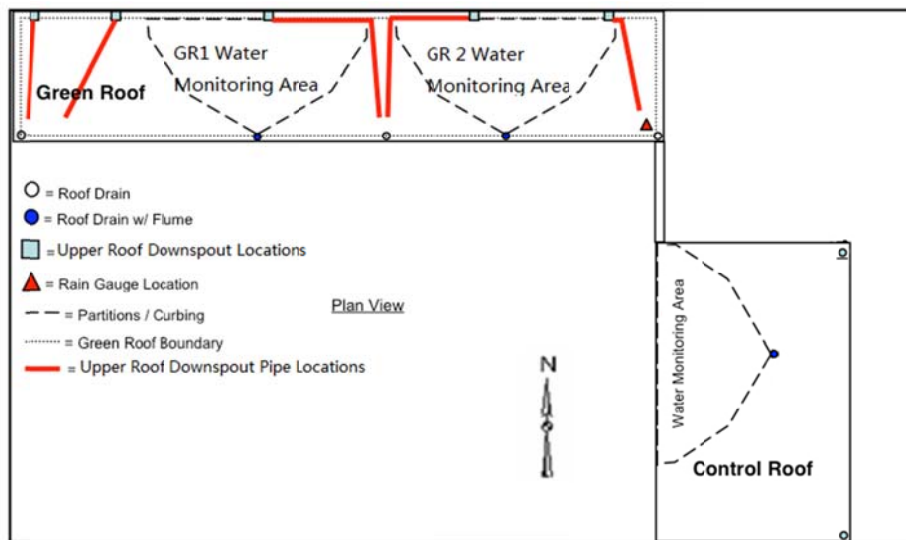


Figure 2.1 Plan view of the Hamerschlag Hall Green Roof and adjacent control roof with monitoring area locations. (Source: modified from Anumol et al., 2010)

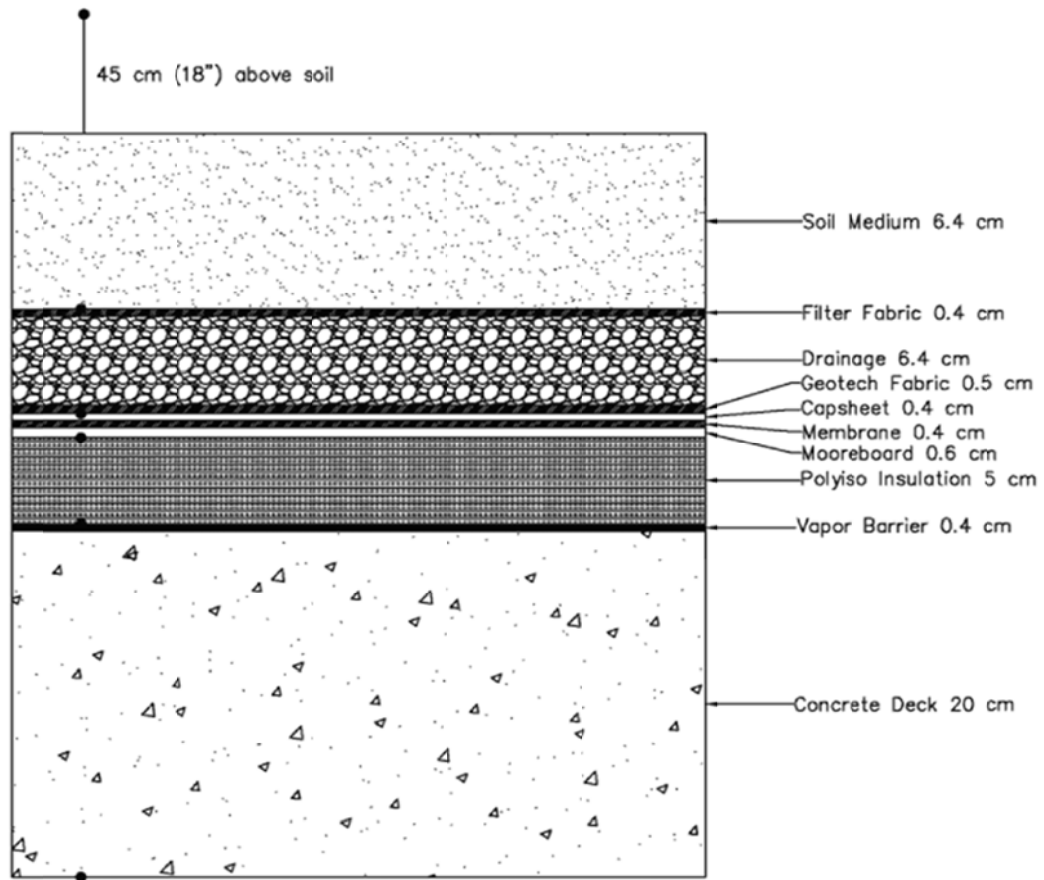


Figure 2.2 Cross section of the Hamerschlag Hall Green Roof

(Source: Becker and Wang, 2011)

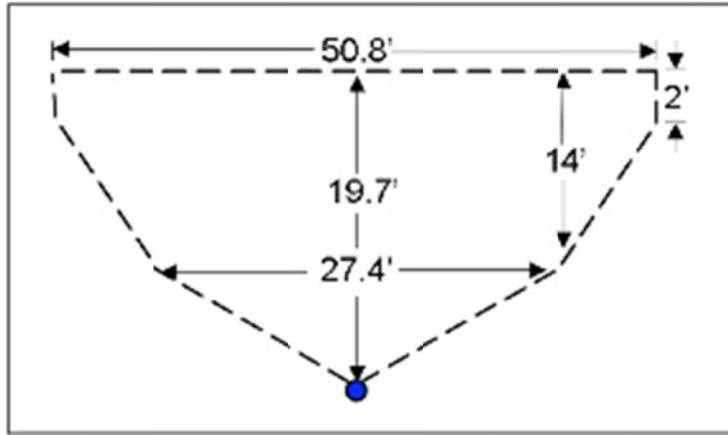


Figure 2.3 Dimensions of Hamerschlag Hall green roof water monitoring area.

(Source: Anumol et al., 2010)

3. Water Runoff Monitoring system

To measure the performance of the Hamerschlag Hall green roof on managing the storm runoff, there is flow monitoring equipment installed on both the green roofs and the control roof. A LabView and National Instruments Fieldpoint Data Logging system and a PC computer with LabView data acquisition software are also in place collect the runoff quantity data and store data in the computer.

3.1. Flumes

Flow from each water monitoring area on Hamerschlag Hall green roof is measured using 0-30 gpm trapezoidal open channel flumes(Plastifab,60° V trapezoidal flume, Tualatin, Oregon). The stormwater falling on the green roofs and control roof monitoring areas can only leave the monitoring areas through these flumes, which enables monitoring of runoff flow rate.

The trapezoidal flumes were factory calibrated and were provided with a factory calibrated empirical flume equation. This converts the height of water in the flume to the corresponding flow rate (Anumol et al., 2010).

$$Q = 1.55 \times 60 \times \left(\frac{H}{12} \right)^{2.58} \quad (3-1)$$

where H is the water height in inches, and Q is the volumetric flow rate in cfs. A photograph of the flume is shown in Figure 3.1



Figure 3.1 Trapezoidal flume, measures 0-30 gpm(Plastifab,60° V)

Source: <http://www.plasti-fab.com/wastewater-products/trapezoidal-flumes>

3.2. Ultrasonic Sensors

The water height in the trapezoidal flumes is measured semi-continuously with the use of ultrasonic sensors (Stevens Water Monitoring System, Inc, Portland, OR). The water level is sensed every minute, and the ultrasonic signals are converted to electric current (mA) pulses which are transmitted to the National Instruments data logger. A computer with Labview software is used to record the data. With defined calibration equations in this system, the electronic sensor signals can be converted into water height and flow rate automatically (Anumol et al., 2010).

3.3. Flume Calibration

The ultrasonic sensors used to measure water height in the flumes for the two green roofs and control roof are calibrated with an 8 oz. paper coffee cup, which is marked with different water weight level in advance. Water is poured into the cup filling it to the various specified levels and the ultrasonic sensor transmits a corresponding output in milliamperes to the data logger and LabView system. A point to note is that the water height is a measured distance from the horizontal plane on which the cup is placed, as shown in Figure- 3.2 (Anumol et al., 2010).

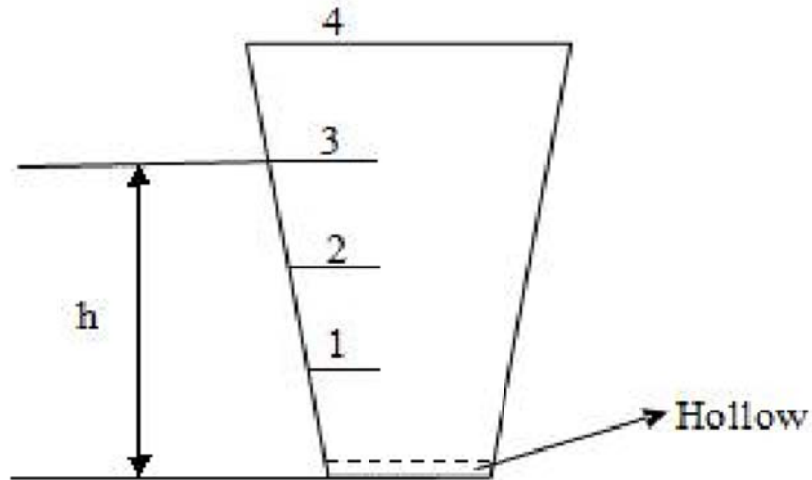


Figure 3.2 Schematic illustration of an 8 oz paper calibration cup and its placement on the flat bottom of the trapezoidal flume (Anumol et al., 2010).

Table 3.1 Cup scale depth and pouring water procedure for flume calibration (Anumol et al., 2010)

cup water level	Height H(inch)	Note
0	0	Do not put cup in the flume when calibrating for zero level
1	1	Pour water into the cup to the level 1
2	1.8	Pour water into the cup to the level 2
3	2.6	Pour water into the cup to the level 3
4	3.7	Pour water into the cup to the level full

The calibration procedure is repeated three times, with the outputted current and the corresponding water level recorded each time; water heights are converted into flow rates with Equation (3-1). The data are then analyzed with Excel to obtain a linear equation relating the water height with the electrical current. The new calibration equation is entered into the

Labview system.

3.4. Rainfall Monitoring

When monitoring green roofs for stormwater runoff it is important to know the duration and intensity of each storm event. Rain gauges typically are used to measure the amount of rainfall over a particular period of time.

There are two approaches available to monitor rainfall received by the Hamerschlag Hall green roofs: rainfall measurement with a tipping bucket rain gauge on the green roofs or runoff from the adjacent control roof. The tipping bucket rain gauge installed on the Hamerschlag Hall green roof is shown in Figure 3.3. The tipping bucket mechanism is located within the cylindrical protective shroud located on the upper part of the tripod. The rain gauge is a model RG200 6" rain gauge (Global Water, Gold River, CA). It is used to monitor rainfall amounts continuously (Anumol et al., 2010).



Figure 3.3 Tripod with Tipping Bucket Rain Gauge on the Hamerschlag Hall green roof (Anumol et al., 2010).

3.5. Data Acquisition System

The monitoring equipment on the roofs is connected to a National Instruments data logger, which is in turn connected to a computer. The water flume data are collected using the National Instruments program, LabView, and the rain gauge is controlled through the program “Global Logger II.”

Rain gauge data were used to measure the start time of the storm event, storm duration, and the rainfall volume. Roof runoff flume data measured by LabView system gave the runoff duration,

and runoff volume on the green roof and the adjacent control roof. Combining these two types of data together gives the overall performance of the green roof on runoff volume reduction and peak flow rate reduction.

3.5.1 Collecting the Water Flume Data

The Labview system should be open and running at all times. If the system is not running, no data will be collected. The Labview window is shown in Figure 3.4. The Labview system will save a new file for each day in the specific folder in the PC computer.

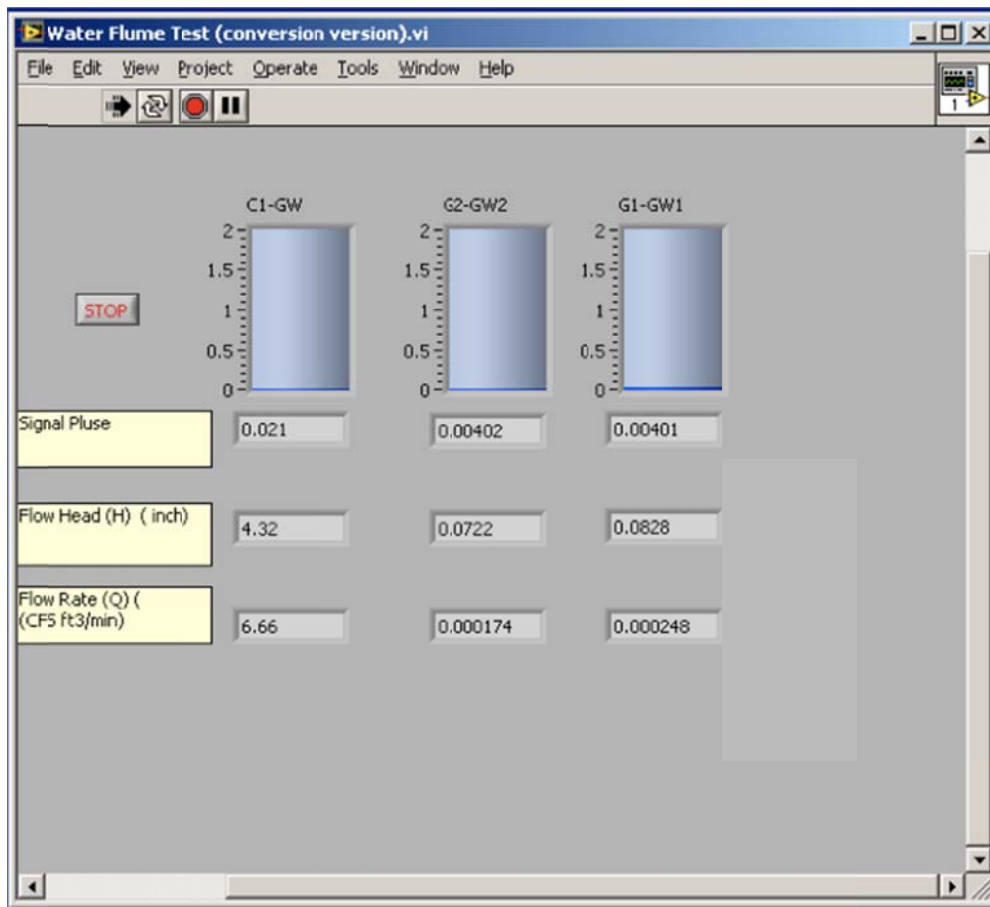


Figure 3.4 Water Flume Test (conversion version).vi running in LabView

3.5.2 Collecting the Rain Gauge Data

The data logger system doesn't need to operate at all times. It should be open whenever the rain gauge data are required. Figure 3.5 shows the interface of the Global Logger system. Connecting the "get history" icon, the system will upload the data automatically. It should be noted that the Global Logger can only store two months of rain gauge data, or it will overwrite the previous data. Any data not downloaded from Global Logger during that two month will be lost.

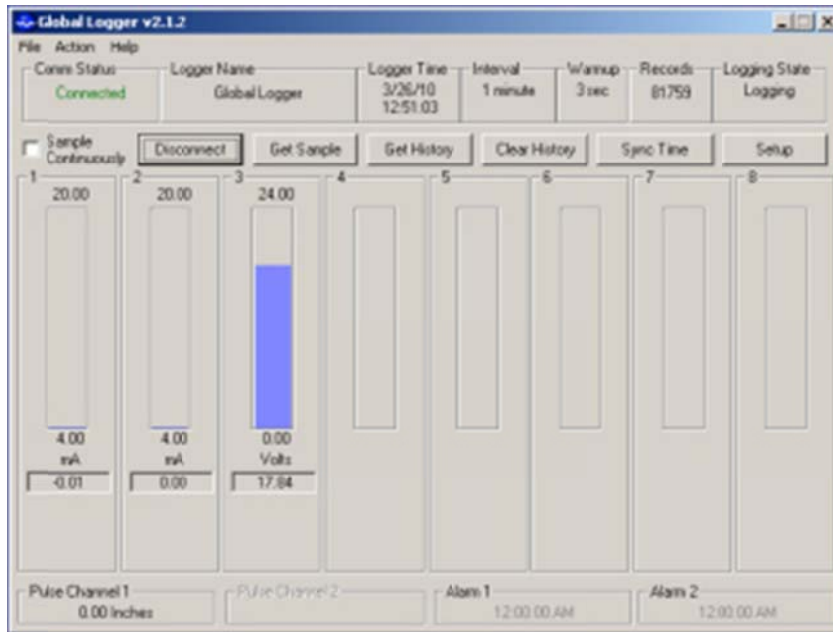


Figure 3.5 Software interface for Rain gauge monitoring program, Global Logger

4. Methods of Storm Analysis and Green Roof Performance Analysis

Analysis of the performance of the green roof is done on a storm by storm basis. A series of calculations for each storm event needs to be performed. The period of Hamerschlag Hall green roof performance analyzed in this report is from January 1, 2009 to April, 30, 2011.

4.1. Individual Storm Definition

The first step in analysis of a storm is defining a storm event. A storm must meet three criteria to be defined as an individual storm event. Table 4.1 summarizes the criterion for definition of a storm. The first criterion is the Minimum Inter-event Time (MINT). The MINT is the length of time required to be met or exceeded before and after each storm event. (Dunkerley, 2008). MINT values may range from 3 minutes to 24 hours. For the Hamerschlag Hall green roof project, MINT of 6 hours was chosen (Manfroi et al., 2004).

The second criterion is the duration of the storm event itself. For the Hamerschlag Hall green roof, a value of 30 minutes was adopted as per recommendations in the literature (Fornis, et al. 2005)

The final criterion for definition of a storm is the depth of rainfall. For the Hamerschlag Hall green roof, the minimum amount of rain that the rain gauge should register to be considered a storm event is 0.5 mm or 0.02inch.

Table 4.1 Criteria for Definition of an individual Storm

No rain for 6 hours before or after the storm event
The duration of the storm event must be at least 30 minutes
The total rainfall must be at least 0.02 inch

4.2 Measures of Green Roof Performance

After determining the storm event, the start time, end time, time of peak flow and the peak flow can be obtained directly from the hydrograph. Figure 4.1 shows visually where the characteristics are located on the hydrograph.

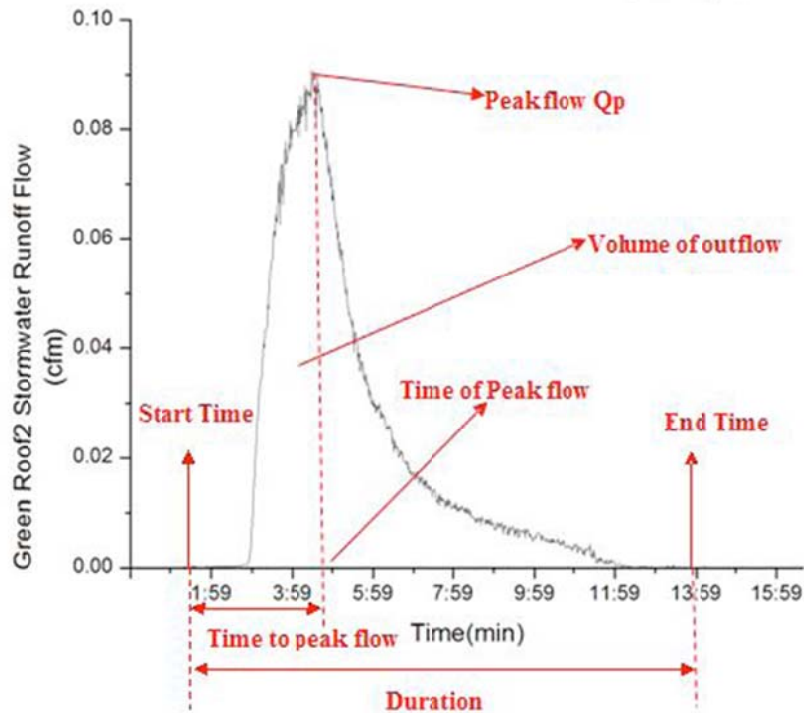


Figure 4.1 Example Hydrograph from Hamerschlag Hall Green Roof (Anumol et al., 2010).

The storm characteristics taken from the hydrograph can then be calculated to provide other useful metrics, which can be used to compare the performance of the green roofs and the control roof for different storms. Table 4.2 shows these metrics and how they be defined. The metrics were developed by Anumol et al., (2010).

Table 4.2 Storm metrics definition and calculated equations

Metric	Definition	Equation
Duration	Total length of the storm	Duration=End time-Start time
Time to Peak	The time it takes for the flow off the roof to reach its peak	Time to Peak=Time of Peak-Start time
Volume Reduction	The ratio of the volume retained by the green roof to the total volume of runoff from the control roof	$V \text{ Reduction} = \frac{V_{\text{control roof runoff}} - V_{\text{green roof runoff}}}{V_{\text{control roof runoff}}}$
Qp Reduction	The ratio of the absolute reduction of the peak flow to the peak flow on the control roof	$Q_p \text{ Reduction} = \frac{Q_{P,CR} - Q_{P,GR}}{Q_{P,CR}}$
Qp Ratio	The ratio of peak runoff rate on the Green Roof to the peak runoff rate the control roof	$Q_p \text{ Ratio} = \frac{Q_{P,GR}}{Q_{P,CR}}$
Time to Peak Extension(TPE)	Ratio of the difference in time to peak between the green roof and control roof to the time to peak on the control roof.	$TPE = \frac{t_{P,GR} - t_{P,CR}}{t_{P,CR}}$
Relative Duration(RD)	The ratio of duration of green roof runoff, DGR and control roof runoff, DCR	$RD = \frac{D_{GR}}{D_{CR}}$
Runoff Volume Ratio	Ratio of total runoff on the green roof to the runoff on the control roof	$\text{Runoff Volume Ratio} = \frac{V_{\text{green roof runoff}}}{V_{\text{control roof runoff}}}$

5. Results and Discussion

A total of 51 individual storm events during the observed period from January 2009 to April 2011 were identified by analysis of the rain gauge data. Of the total 51 events, 12 events precipitated between 0.01 inch to 0.1 inch, and there were 34 rainfall events with between 0.1 inch to 0.6

inch and only 5 events with more than 0.6 inch of precipitation. Some of the 51 storm events included days when snow occurred in winter.

5.1 Typical storm analysis

Two typical storms are analyzed below to demonstrate the performance of Hamerschlag Hall green roof. The first storm occurred on 11/27/2009, when 0.091 inch of rain landed on the roofs in approximately 7 hours (0.014 in/hr average intensity). The second storm, on 12/8/2009-12/9/2009, was much larger than the first one, yielding 1.43 inch of rain in about 10 hours (0.13 in/hr average intensity). The second storm was the heaviest one of those monitored on the roof during 2009. Figures 5.1 and 5.2 shows hydrographs for these two storms.

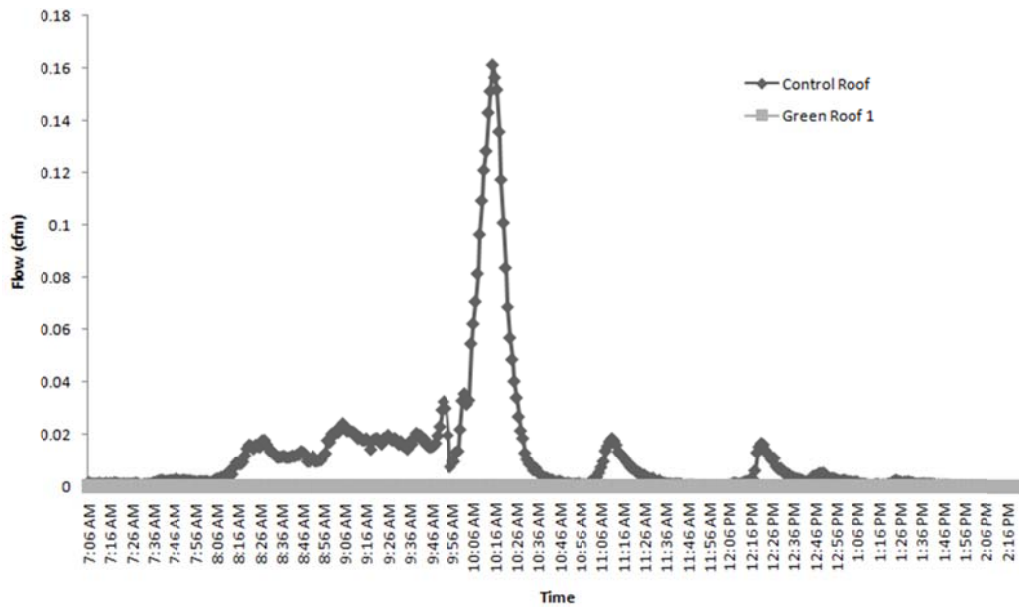


Figure 5.1 Runoff flow rates vs. time for the control roof and Green Roof 1 for the 11/27/2009 storm

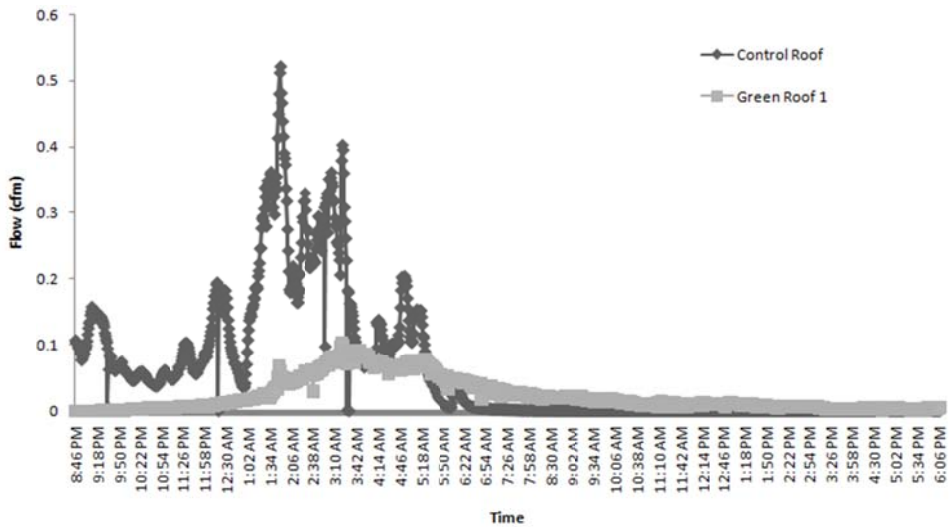


Figure 5.2 Runoff flow rates vs. time for the control roof and Green Roof 1 for the 12/8/2009-12/9/2009 storm.

The results in Figure 5.1 show that the Green Roof 1 significantly reduced the runoff volume for the low intensity storm of 11/27/2009 with a volume reduction of 100%. In Figure 5.2, the volume reduction for the higher intensity storm of 12/08/2009-12/09/2009 storm was of 62.7%.

The green roof also attenuated the maximum flow rate for each storm. For the 11/27/2009 storm, the maximum flow rate of the green roof was 100% lower than the control. For the 12/08-09/2009 storm, which had higher rainfall intensity, the maximum flow rate of the green roof was 80.4% lower than the control roof.

Figure 5.2 shows the delay of the runoff peak flow rate and extension of runoff duration for the 12/8/2009-12/9/2009 storm. There was a delay between the time rainfall started and runoff began to flow on the green roofs. Because of the lack of growing medium and plants, the control roof consistently exhibited runoff earlier. Figure 5.2 shows that the control roof produced runoff

approximately one hour before the green roof did. It should be noted that the rainfall start time as determined from the rain gauge should be earlier than the time the control roof produces runoff, and the start time on Green Roof 1 should lag behind the control roof. However the start time was considered always the same for these two roofs for simplicity in this project.

Generally, runoff continues to flow from the green roof after the rainfall stops and the control roof stops producing runoff. This delay was because the water entering the green roof must filter through the soil, drainage layer and filter membrane before it exits the roof and drains as runoff. During the 12/08-09/2009 storm, the runoff flow from Green Roof 1 was 3.7 hours longer than the runoff flow from the control roof.

5.2 2009-2011 Data Analysis

Tables 5-1, 5.2, 5.3 show all individual storm events identified from data obtained in 2009,2010, and 2011.

Note that monitoring was not continuous and that not all storm events each year were monitored.

Data shown for the storm events include storm duration, control roof discharge duration, rainfall volume and Green Roof 1 runoff volume reduction, peak flow rate reduction, and runoff duration extension being provided. Comprehensive data can be found in Appendixes A,B, and C. It should be noted that due to the equipment failure and maintenance shortage, the water flume data and rain gauge data from May-August were lost during 2009-2010.

Table 5.1 2009 storms and Hamerschlag Hall Green Roof 1 Performance.

STORM NUMBER	Storm Duration ^[a] [min]	CR Discharge Duration ^[b] [min]	Rainfall Volume ^[c] [ft ³]	Rain Depth ^[d] [in]	Average Rain Intensity ^[e] [in/hr]	GR1 Runoff Volume Reduction ^[f]	GR1 Qp Reduction ^[g]	GR1 Duration Extension ^[h]
2009-1	871	792	14.63	0.27	0.019	0.859	0.956	0.332
2009-2	302	212	2.17	0.04	0.008	-0.383	0.809	1.91
2009-3	542	600	6.50	0.12	0.013	0.778	0.896	0.347
2009-4	933	1017	21.67	0.4	0.026	0.698	0.93	0.588
2009-5	1560	1599	19.50	0.36	0.014	0.772	0.942	0.124
2009-6	290	363	11.92	0.22	0.046	0.778	0.964	0.218
2009-7	405	424	9.75	0.18	0.027	-0.541	0.891	1.644
2009-8	2152	2187	9.21	0.17	0.005	0.647	0.208	1.644
2009-9	1329	6231	9.21	0.17	0.008	0.603	0.847	-0.343
2009-10	711	726	20.04	0.37	0.031	0.919	0.968	0.138
2009-11	453	537	2.71	0.05	0.007	0.918	0.802	-0.479
2009-12	642	616	20.58	0.38	0.036	1	0.996	-0.45
2009-13	395	438	6.50	0.12	0.018	1	1	-1
2009-14	724	687	10.29	0.19	0.016	1	1	-1
2009-15	191	762	13.00	0.24	0.075	0.722	0.995	0.689
2009-16	648	617	74.21	1.37	0.127	0.627	0.804	1.078
2009-17	515	498	16.25	0.3	0.035	0.554	0.9	0.028
2009-18	519	1459	31.96	0.59	0.068	0.691	0.847	-0.099
2009-19	117	1122	10.29	0.19	0.097	0.342	0.721	0.186

Table 5.2 2010 storms and Hamerschlag Hall Green Roof 1 Performance.

STORM NUMBER	Storm Duration ^[a] [min]	CR Discharge Duration ^[b] [min]	Rainfall Volume ^[c] [ft ³]	Rain Depth ^[d] [in]	Average Rain Intensity ^[e] [in/hr]	GR1 Runoff Volume Reduction ^[f]	GR1 Qp Reduction ^[g]	GR1 Duration Extension ^[h]
2010-1	73	1858	4.88	0.09	0.074	0.732	0.069	0.067
2010-2	678	626	29.25	0.54	0.048	0.45	0.81	1.487
2010-3	254	311	17.33	0.32	0.076	0.944	0.965	0.878
2010-4	305	407	8.67	0.16	0.031	0.489	0.298	1.462
2010-5	51	194	7.58	0.14	0.165	1	1	-1
2010-6	164	293	3.79	0.07	0.026	1	1	-1
2010-7	197	320	2.71	0.05	0.015	1	1	-1
2010-8	269	250	8.67	0.16	0.036	1	1	-1
2010-9	298	307	16.79	0.31	0.062	1	1	-1
2010-10	121	108	1.63	0.03	0.015	1	1	-1
2010-11	297	383	16.25	0.3	0.061	NF ^[i]	NF	NF
2010-12	355	137	11.92	0.22	0.037	NF	NF	NF
2010-13	280	307	14.63	0.27	0.058	NF	NF	NF
2010-14	152	278	16.79	0.31	0.122	NF	NF	NF
*2010-15	105	149	5.42	0.10	0.057	NF	NF	NF
*2010-16	1635	1657	18.4	0.34	0.012	0.804	0.921	0.072
*2010-17	60	86	1.625	0.03	0.030	1	1	-1
*2010-18	165	210	2.17	0.04	0.015	1	1	-1
*2010-19	405	373	23.83	0.44	0.065	NF	NF	NF
*2010-20	330	353	34.7	0.64	0.116	0.717	0.9	1.207
*2010-21	270	475	1.625	0.03	0.007	1	1	-1
*2010-22	255	286	3.79	0.07	0.016	1	1	-1
2010-23	1462	1630	113.21	2.09	0.086	0.494	0.766	0.031
2010-24	1650	1308	193.38	3.57	0.130	0.037	0.697	0.401
2010-25	631	369	2.71	0.05	0.005	0.196	0.272	NF

Table 5.3 2011 storms and Hamerschlag Hall Green Roof 1 Performance

STORM NUMBER	Storm Duration ^[a] [min]	CR Discharge Duration ^[b] [min]	Rainfall Volume ^[c] [ft ³]	Rain Depth ^[d] [in]	Average Rain Intensity ^[e] [in/hr]	GR1 Runoff Volume Reduction ^[f]	GR1 Qp Reduction ^[g]	GR1 Duration Extension ^[h]
2011-1	38	75	7.58	0.14	0.221	1	1	0
2011-2	237	280	43.88	0.81	0.205	NF ^[i]	NF	NF
2011-3	556	746	12.45	0.23	0.025	NF	NF	NF
2011-4	293	746	4.56	0.08	0.016	NF	NF	NF
2011-5	808	903	12.45	0.23	0.017	0.38	0.83	0.186
2011-6	87	139	2.70	0.05	0.034	1	1	0
2011-7	85	169	7.04	0.13	0.092	1	1	0

Table 5.4 2011 storms and Hamerschlag Hall Green Roof 2 Performance

STORM NUMBER	Storm Duration ^[a] [min]	CR Discharge Duration ^[b] [min]	Rainfall Volume ^[c] [ft ³]	Rain Depth ^[d] [in]	Average Rain Intensity ^[e] [in/hr]	GR2 Runoff Volume Reduction ^[f]	GR2 Qp Reduction ^[g]	GR2 Duration Extension ^[h]
2011-1	38	75	7.58	0.14	0.221	1	1	0
2011-2	237	280	43.88	0.81	0.205	0.988	0.138	0
2011-3	556	746	12.45	0.23	0.025	0.718	-50.36	0.071
2011-4	293	746	4.56	0.08	0.016	1	1	0
2011-5	808	903	12.45	0.23	0.017	1	1	0.186
2011-6	87	139	2.70	0.05	0.034	0.991	0.996	0
2011-7	85	169	7.04	0.13	0.092	0.995	1	0

Note: [a]: Storm Duration= Storm End Time –Storm Start Time

[b]: CR Discharge Duration= CR Runoff Start Time-CR Runoff End time

[c]: Rainfall Volume measured by Rain gauge Data

[d]: Rainfall Depth= (Rainfall Volume)/Monitoring Area(650ft²)

[e]: Average Rainfall Intensity = $\frac{\text{Rainfall Depth}}{\text{Storm Duration}}$

[f]: Runoff Volume Reduction = $\frac{V_{\text{CR,Runoff}} - V_{\text{GR,Runoff}}}{V_{\text{CR,Runoff}}}$

[g]: Q_p Reduction = $\frac{Q_{\text{P,CR}} - Q_{\text{P,GR}}}{Q_{\text{P,CR}}}$

[h]: Duration Extension = $\frac{D_{\text{GR}} - D_{\text{CR}}}{D_{\text{CR}}}$

Storm Number with “*” at front in 2010 means using Three Rivers Wet Weather data due to rain gauge data missing.

Table 5.1 shows that during 2009, there were 2 storm events which were between 0.01 inch-0.1

inch, 16 events between 0.1 inch-0.6 inch, and only 1 events are over 0.6 inch. The biggest

rainfall event observed was 1.37 inch. The Hamerschlag Hall green roof performed well for in retaining runoff for the 0.01inch-0.1 inch storms, it reduced 100% of storm water runoff; provided 100% peak flow rate reduction. However its performance in retaining runoff was reduced for bigger storms, Green Roof 1 showed about 55.4%-100% runoff volume reduction and fairly stable peak flow reduction rate, between 72.1%-100% for storm greater than 0.1 inch. It is worth pointing out that due to the definition of the duration extension, there is “-1” value of duration extension when the green roof retains all the storm water runoff.

Table 5.2 shows that during 2010 there were 10 storm events whose storm depth was between 0.01 inch and 0.1 inch, 12 events between 0.1 inch-0.6 inch, and only 3 out of 24 rainfall events are over 0.6 inch. For the low rainfall amounts, the green roof still showed good performance for runoff volume reduction and peak flow reduction, as it was able to reduce 100% of storm water runoff and peak flow rate. In the middle range of rainfall (0.1 inch-0.6 inch), the runoff volume reduction was 48.9%-94.5%, and the peak flow rate was attenuated by 29.8%-97.3%.

Table 5.3 and 5.4 list 7 storm events for the first four months of 2011, with only 1 of 7 storms over 0.6 inch due to the relative short monitoring period in 2011, 2 storms between 0.01 and 0.1 inch, and 4 storms between 0.1-0.6 inch. The green roof, not surprisingly, retained almost 100% storm runoff discharge for 0.01-0.1 inch precipitation events. In addition, when the precipitation was between 0.1-0.6 inch, the green roof still provided over 90% runoff volume reduction and peak flow reduction. On the other hand, when the rain was over 0.6 inch, the green roof couldn't retain water and reduce peak flow in a more stable way.

5.3 Factors affecting Green Roof Performance

5.3.1. Rainfall amount

A total of 51 rainfall events during 2009-2011 were evaluated. Complete information is available in the appendices. For the 2009-2011 storms, there was a total of 15.32 inches of recorded precipitation, and there was a corresponding value of 13.14 inches (with a standard deviation of 0.46 inch) of control roof runoff compared to a value of 4.2 inch (with a standard deviation of 0.3 inch) of Green Roof 1 runoff. The green roof retained 72.6% of total incident precipitation, while the control roof retained 14% of the precipitation.

The water retention and peak flow reduction varied from one precipitation event to another. The runoff volume reduction on Green Roof 1 of the storms observed during 2009-2011 is plotted in Figure 5.3. From the figure, it clearly shows that there were many 100% runoff volume reduction storms during 2009-2011, when the control roof was producing runoff, while Green Roof 1 produced no runoff. There were 16 rainfall events during the observed period with no runoff on Green Roof 1, which indicates the Hamerschlag Hall green roof performed relatively well on water retention when the rainfall depth was less than 0.6 inch. Likewise, Figure 5.3 also suggests that the performance of the Green Roof 1 was similar at the same cumulative rainfall point in different storms.

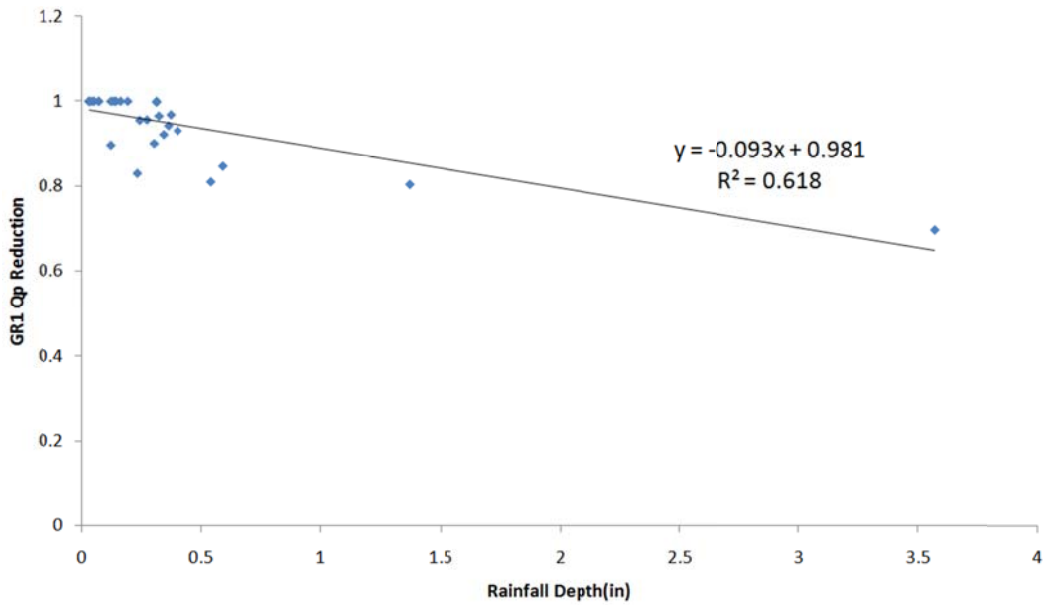


Figure 5.4 Storm depth versus storm runoff volume reduction on Green Roof 1 for all storms observed during 2009-2011 with trend line and linear regression equation

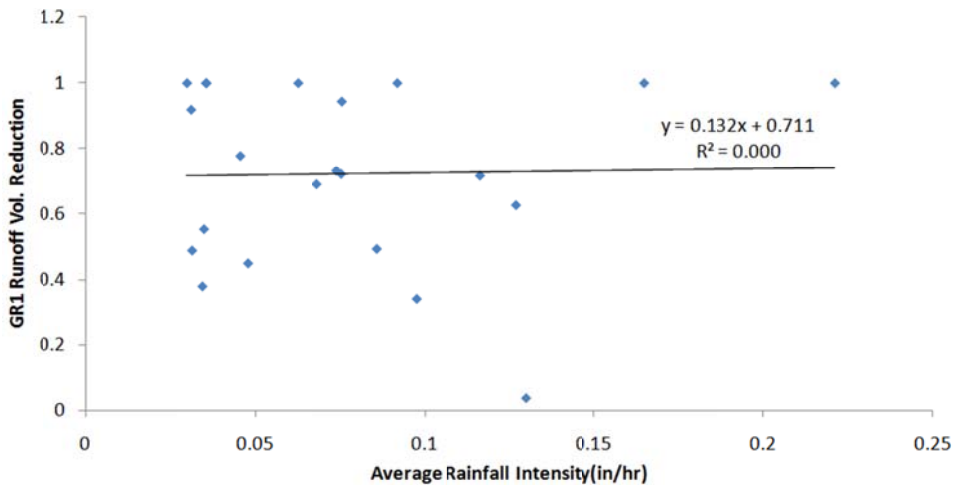


Figure 5.5 Average storm intensity versus storm water runoff peak flow reduction on Green Roof 1 for all storms observed during 2009-2011 with trend line and linear regression equation

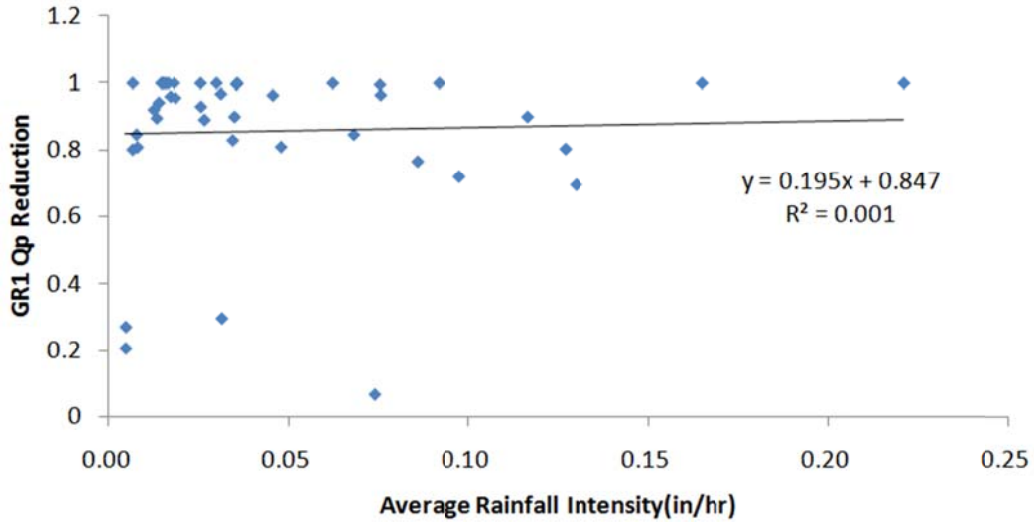


Figure 5.6 Average storm intensity versus storm water runoff peak flow reduction on Green Roof 1 for all storms observed during 2009-2011 with trend line and linear regression equation

5.3.2. Snow

During winter storms, the soil in the green roof may freeze and slowly release the water over an extended period of time, and snow landing on the green roof may accumulate and melt over an extended period. Snow may stay on the roof for several days, or even several weeks (Berghage et al, 2009). It raises difficulties for determining the end date of the snow storm events and runoff discharge flow rate. Furthermore, the rain gauge was not heated and thus was subject to snow accumulation and clogging, making it difficult to determine storm initiation times. So in this report, all the snow storms were not evaluated and the relationship between green roof performance and the snow events wasn't analyzed.

5.3.3. Seasonal Effects

In addition to the effect of rainfall depth, the storm water retention on green roof also depended

on season (Berghage et al, 2009). Water retention in warm months (April through October) was more than in the cool weather months (November through March). In the observed period, limited data were obtained during the summer months (May to August) due to lack of monitoring personnel and equipment failure. As an example of warm weather versus cold weather performance, runoff reduction on Green Roof 1 in April, 2009 was 76% of the 1.1 inches of precipitation, while in February, 2009, runoff was 86% of the 0.27 inch of precipitation on Green Roof 1. In the cool, drier months, less runoff was produced than during the warm, wetter periods. For example, in December, 2009, the runoff reduction was 44% of 2.69 inches of precipitation on Green Roof 1, while 60% of 0.59 inch of precipitation was reduced in October, 2009 on Green Roof 1.

6. Summary and Conclusions

Fifty one Storms were observed and analyzed for the Hamerschlag Hall Green Roof and control roof for the period January 2009 to April 2011. The Green Roof reduced the storm runoff volume, extended the runoff duration time, and decreased the peak flow rate of the runoff compared to the control roof.

The green roof reduced the total amount of the light storm runoff (0.01-0.1 inch) by nearly 100%. The majority of the storms during observed period were of 0.1-0.6 inch, for which the green roof lowered the runoff volume by at least 60%. Data from these 51 storms didn't show a clear relationship between the size of storms and the volume reduction on the green roof due to the

lack of the large storm occurring during the period.

During the storm, precipitation was first absorbed by soil and growing medium and then runoff was generated. It was found that the runoff start was delayed and the runoff duration was extended by the green roof compared to the control roof. The peak flow rate of the runoff from the green roof was reduced by at least 80% for light storms (0.01-0.1 inch), and for moderate storms (0.1-0.6 inch) was reduced by at least 30%.

7. References

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Appendix A 2009 Storm Summary and Individual Storm Data

Metrics used in Appendix A

Metric	Equation/definition
Vol. Reduction ^[a]	$\frac{V_{CR,RUNOFF} - V_{GR,RUNOFF}}{V_{CR,RUNOFF}}$
Relative Duration ^[b]	$\frac{D_{GR}}{D_{CR}}$
Duration Extension ^[c]	$\frac{D_{GR} - D_{CR}}{D_{CR}}$
Runoff Vol. Ratio ^[d]	$\frac{V_{GR,RUNOFF}}{V_{CR,RUNOFF}}$
Qp ^[e]	Obtained from runoff hydrograph
Time to Peak ^[f]	(Time of peak runoff rate)-(runoff start time)
Qp Reduction ^[g]	$\frac{Q_{P,CR} - Q_{P,GR}}{Q_{P,CR}}$
Time to Peak Extension ^[h]	$\frac{t_{P,GR} - t_{P,CR}}{t_{P,CR}}$
NF ^[j]	Sensor not functioning
NA ^[k]	Not Applicable

Storm 2009-1, Feb 18, 2009

Table 2009-1-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
2/18/2009	08:35:00	2/18/2009	23:06:15	871

Table 2009-1-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
2/18/2009	46	30	Rain, Snow
2/19/2009	39	17	Fog, Snow

Table 2009-1-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	2/18/2009	08:35:00	2/18/2009	21:47:00	792
Green 1	2/18/2009	08:35:00	2/19/2009	02:10:00	1055
Green 2	2/18/2009	08:35:00	NF ^[j]	NF	NF

Table 2009-1-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.27	14.63
Control Roof Flume	0.92	49.65

Table 2009-1-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	49.65
Green 1	7.02
Green 2	NF

Table 2009-1-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.58	13:25:00	290	NA ^[k]	NA
Green 1	0.025	21:15:00	760	0.96	1.62
Green 2	NF	NF	NF	NF	NF

Table 2009-1-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio[d]
Green 1	0.86	1.33	0.33	0.14
Green 2	NF	NF	NF	NF

Comments: Control Roof are abnormally high compared to the rain gauge data; sensor data are questionable; maybe the snow influenced the data.

Storm 2009-2, Feb 27, 2009

Table 2009-2-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
2/27/2009	09:55:00	2/27/2009	14:57:00	302

Table 2009-2-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
2/27/2009	57	26	Rain

Table 2009-2-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	2/27/2009	09:55:00	2/27/2009	13:27:00	212
Green 1	2/27/2009	09:55:00	2/27/2009	20:12:00	617
Green 2	2/27/2009	09:55:00	NF ^[j]	NF	NF

Table 2009-2-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.04	2.17
Control Roof Flume	0.075	4.05

Table 2009-2-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	4.05
Green 1	5.6
Green 2	NF

Table 2009-2-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.12	11:59:00	124	NA ^[k]	NA
Green 1	0.023	15:15:00	320	0.81	1.58
Green 2	NF	NF	NF	NF	NF

Table 2009-2-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	-0.383	2.91	1.91	1.38
Green 2	NF	NF	NF	NF

Comments: Runoff data possibly affected by snow on the roof.

Storm 2009-3, April 10, 2009

Table 2009-3-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
4/10/2009	06:55:00	4/10/2009	15:57:00	542

Table 2009-3-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
4/10/2009	52	43	Rain
4/11/2009	55	37	Rain

Table 2009-3-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	4/10/2009	06:55:00	4/10/2009	16:55:00	600
Green 1	4/10/2009	06:55:00	4/10/2009	20:23:00	808
Green 2	4/10/2009	06:55:00	NF ^[j]	NF	NF

Table 2009-3-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.12	6.5
Control Roof Flume	0.098	5.31

Table 2009-3-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	5.31
Green 1	1.18
Green 2	NF

Table 2009-3-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.046	08:36:00	101	NA ^[k]	NA
Green 1	0.005	13:12:00	377	0.9	2.73
Green 2	NF	NF	NF	NF	NF

Table 2009-3-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.78	1.35	0.35	0.22
Green 2	NF	NF	NF	NF

Comments:

Storm 2009-4, April 14-15, 2009

Table 2009-4-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
4/14/2009	20:34:00	4/15/2009	12:07:15	933

Table 2009-4-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
4/14/2009	57	44	Rain
4/15/2009	48	42	Fog, Rain

Table 2009-4-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	4/14/2009	20:34:00	4/15/2009	13:31:00	1017
Green 1	4/14/2009	20:34:00	4/15/2009	23:29:00	1615
Green 2	4/14/2009	20:34:00	NF ^[j]	NF	NF

Table 2009-4-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.4	21.7
Control Roof Flume	0.39	21.5

Table 2009-4-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	21.5
Green 1	6.5
Green 2	NF

Table 2009-4-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.19	00:26:00	232	NA ^[k]	NA
Green 1	0.013	17:21:00	1247	0.93	4.38
Green 2	NF	NF	NF	NF	NF

Table 2009-4-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.69	1.59	0.59	0.3
Green 2	NF	NF	NF	NF

Comments:

Storm 2009-5, April 19-20, 2009

Table 2009-5-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
4/19/2009	16:48:15	4/20/2009	18:46:00	1560

Table 2009-5-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
4/19/2009	66	55	Rain
4/20/2009	54	46	Rain

Table 2009-5-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	4/19/2009	16:46:00	4/20/2009	19:25:00	1599
Green 1	4/19/2009	16:46:00	4/20/2009	22:43:00	1797
Green 2	4/19/2009	16:46:00	NF ^[j]	NF	NF

Table 2009-5-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.36	19.5
Control Roof Flume	0.33	18.1

Table 2009-5-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	18.1
Green 1	4.1
Green 2	NF

Table 2009-5-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.14	09:47:00	1021	NA ^[k]	NA
Green 1	0.01	18:29:00	103	0.94	-0.89
Green 2	NF	NF	NF	NF	NF

Table 2009-5-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.77	1.12	0.12	0.23
Green 2	NF	NF	NF	NF

Comments:

Storm 2009-6, April 28, 2009

Table 2009-6-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
4/28/2009	16:26:00	4/28/2009	21:16:00	290

Table 2009-6-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
4/28/2009	82	53	Rain

Table 2009-6-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	4/28/2009	16:26:00	4/28/2009	22:29:00	363
Green 1	4/28/2009	16:26:00	4/28/2009	23:48:00	442
Green 2	4/28/2009	16:26:00	NF ^[j]	NF	NF

Table 2009-6-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.22	11.9
Control Roof Flume	0.21	11.7

Table 2009-6-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	11.7
Green 1	2.61
Green 2	NF

Table 2009-6-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.33	17:12:00	46	NA ^[k]	NA
Green 1	0.01	16:26:00	0	0.964	-1
Green 2	NF	NF	NF	NF	NF

Table 2009-6-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.78	1.22	0.22	0.22
Green 2	NF	NF	NF	NF

Comments:

Storm 2009-7, May 1, 2009

Table 2009-7-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
5/1/2009	04:21:00	5/1/2009	11:06:00	405

Table 2009-7-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
5/1/2009	73	51	Rain

Table 2009-7-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	5/1/2009	04:21:00	5/1/2009	11:25:00	424
Green 1	5/1/2009	04:21:00	5/1/2009	23:02:00	1121
Green 2	5/1/2009	04:21:00	NF ^[j]	NF	NF

Table 2009-7-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.18	9.75
Control Roof Flume	0.16	9.03

Table 2009-7-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	9.03
Green 1	13.9
Green 2	NF

Table 2009-7-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.334	06:40:00	139	NA ^[k]	NA
Green 1	0.036	13:28:00	547	0.89	2.94
Green 2	NF	NF	NF	NF	NF

Table 2009-7-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	-0.54	2.64	1.64	1.54
Green 2	NF	NF	NF	NF

Comments: Green roof runoff influenced by rain on previous day.

Storm 2009-8, Oct 09-10, 2009

Table 2009-8-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
10/9/2009	04:45:00	10/10/2009	16:37:00	2152

Table 2009-8-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
10/9/2009	69	52	Fog, Rain
10/10/2009	61	48	Rain

Table 2009-8-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	10/9/2009	04:45:00	10/10/2009	17:12:00	2187
Green 1	10/9/2009	04:45:00	10/10/2009	16:22:00	2137
Green 2	10/9/2009	04:45:00	NF ^[j]	NF	NF

Table 2009-8-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.17	9.21
Control Roof Flume	0.58	31.3

Table 2009-8-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	31.3
Green 1	11.04
Green 2	NF

Table 2009-8-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.28	04:56:00	11	NA ^[k]	NA
Green 1	0.22	15:55:00	2110	0.21	190.82
Green 2	NF	NF	NF	NF	NF

Table 2009-8-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.65	0.98	-0.02	0.35
Green 2	NF	NF	NF	NF

Comments: Checking the rainfall data from Three River Wet Weather, it shows the rainfall volume of the storm is 0.41 inch, close to our CR runoff data. Rain gauge data might be questionable.

Storm 2009-9, Oct 15-19, 2009

Table 2009-9-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
10/15/2009	05:53:00	10/16/2009	04:02:00	1329

Table 2009-9-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
10/15/2009	43	37	Rain
10/19/2009	55	26	Rain

Table 2009-9-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	10/15/2009	05:53:00	10/19/2009	13:44:00	6231
Green 1	10/15/2009	05:53:00	10/18/2009	02:04:00	4091
Green 2	10/15/2009	05:53:00	NF ^[j]	NF	NF

Table 2009-9-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.17	9.21
Control Roof Flume	1.1	59.4

Table 2009-9-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	59.4
Green 1	23.6
Green 2	NF

Table 2009-9-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.15	09:05:00	192	NA ^[k]	NA
Green 1	0.023	18:42:00	769	0.85	3.01
Green 2	NF	NF	NF	NF	NF

Table 2009-9-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.6	0.66	-0.34	0.4
Green 2	NF	NF	NF	NF

Comments: LabView System stopped working at 13:44:00,10/10/2009, which caused a significant difference between rain gauge data and the CR runoff flume data.

Storm 2009-10, Oct 27-28, 2009

Table 2009-10-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
10/27/2009	20:18:00	10/28/2009	08:09:00	711

Table 2009-10-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
10/27/2009	59	43	Rain
10/28/2009	57	51	Rain

Table 2009-10-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	10/27/2009	20:18:00	10/28/2009	08:24:00	726
Green 1	10/27/2009	20:18:00	10/28/2009	10:04:00	826
Green 2	10/27/2009	20:18:00	NF ^[j]	NF	NF

Table 2009-10-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.37	20
Control Roof Flume	0.32	17.6

Table 2009-10-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	17.6
Green 1	1.43
Green 2	NF

Table 2009-10-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.32	03:48:00	450	NA ^[k]	NA
Green 1	0.01	08:01:00	703	0.97	0.56
Green 2	NF	NF	NF	NF	NF

Table 2009-10-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.92	1.14	0.14	0.081
Green 2	NF	NF	NF	NF

Comments: LabView system didn't record any data after 13:50:00, 10/28/2009.

Storm 2009-11, Oct 31, 2009

Table 2010-11-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
10/31/2009	05:52:00	10/31/2009	13:25:00	453

Table 2009-11-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
10/31/2009	69	48	Rain

Table 2009-11-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	10/31/2009	05:52:00	10/31/2009	14:49:00	537
Green 1	10/31/2009	05:52:00	10/31/2009	10:32:00	280
Green 2	10/31/2009	05:52:00	NF ^[j]	NF	NF

Table 2009-11-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.05	2.71
Control Roof Flume	0.094	5.07

Table 2009-11-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	5.07
Green 1	0.42
Green 2	NF

Table 2009-11-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.17	09:37:00	225	NA ^[k]	NA
Green 1	0.033	10:22:00	270	0.8	0.2
Green 2	NF	NF	NF	NF	NF

Table 2009-11-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.92	0.52	-0.48	0.082
Green 2	NF	NF	NF	NF

Comments:

Storm 2009-12, Nov 19, 2009

Table 2009-12-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
11/19/2009	06:16:00	11/19/2009	16:58:00	642

Table 2009-12-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
11/19/2009	55	46	Rain

Table 2009-12-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	11/19/2009	06:16:00	11/19/2009	16:32:00	616
Green 1	11/19/2009	06:16:00	11/19/2009	11:55:00	339
Green 2	11/19/2009	06:16:00	NF ^[j]	NF	NF

Table 2009-12-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.38	20.6
Control Roof Flume	0.33	17.7

Table 2009-12-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	17.7
Green 1	0.004
Green 2	NF

Table 2009-12-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.49	11:54:00	338	NA ^[k]	NA
Green 1	0.002	11:53:00	337	0.996	-0.003
Green 2	NF	NF	NF	NF	NF

Table 2009-12-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	1	0.55	-0.45	0
Green 2	NF	NF	NF	NF

Comments:

Storm 2009-13, Nov 27, 2009

Table 2009-13-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
11/27/2009	07:06:00	11/27/2009	13:41:00	395

Table 2009-13-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
11/27/2009	37	33	Rain, Snow

Table 2009-13-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	11/27/2009	07:06:00	11/27/2009	14:24:00	438
Green 1	11/27/2009	07:06:00	11/27/2009	07:06:00	0
Green 2	11/27/2009	07:06:00	NF ^[j]	NF	NF

Table 2009-13-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.12	6.5
Control Roof Flume	0.091	4.94

Table 2009-13-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	4.94
Green 1	0
Green 2	NF

Table 2009-13-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.18	10:15:00	189	NA ^[k]	NA
Green 1	0	07:06:00	0	1	-1
Green 2	NF	NF	NF	NF	NF

Table 2009-13-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	1	0	-1	0
Green 2	NF	NF	NF	NF

Comments:

Storm 2009-14, Feb 18, 2009

Table 2009-14-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
11/29/2009	22:08:00	11/30/2009	10:12:00	724

Table 2009-14-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
11/29/2009	61	37	Rain
11/30/2009	51	30	Rain

Table 2009-14-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	11/29/2009	22:08:00	11/30/2009	09:35:00	687
Green 1	11/29/2009	22:08:00	11/29/2009	22:08:00	0
Green 2	11/29/2009	22:08:00	NF ^[j]	NF	NF

Table 2009-14-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.19	10.3
Control Roof Flume	0.23	12.5

Table 2009-14-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	12.5
Green 1	0
Green 2	NF

Table 2009-14-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.1	06:26:00	498	NA ^[k]	NA
Green 1	0	22:08:00	0	1	-1
Green 2	NF	NF	NF	NF	NF

Table 2009-14-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	1	0	-1	0
Green 2	NF	NF	NF	NF

Comments: The Green Roof 1 sensor might have some problem to record data. Normally it should have some runoff on CR based on the rainfall volume amount.

Storm 2009-15, December 02-03, 2009

Table 2009-15-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
12/2/2009	14:57:00	12/2/2009	18:08:00	191

Table 2009-15-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
12/2/2009	55	35	Rain
12/3/2009	52	39	Rain

Table 2009-15-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	12/2/2009	14:57:00	12/3/2009	04:39:00	762
Green 1	12/2/2009	14:57:00	12/3/2009	13:24:00	1287
Green 2	12/2/2009	14:57:00	NF ^[j]	NF	NF

Table 2009-15-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.24	13
Control Roof Flume	0.34	18.2

Table 2009-15-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	18.2
Green 1	5.1
Green 2	NF

Table 2009-15-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.636	01:04:00	547	NA ^[k]	NA
Green 1	0.03	01:01:00	544	0.96	-0.005
Green 2	NF	NF	NF	NF	NF

Table 2009-15-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.72	1.69	0.69	0.28
Green 2	NF	NF	NF	NF

Comments:

Storm 2009-16, December 08-09, 2009

Table 2009-16-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
12/8/2009	20:46:00	12/9/2009	07:34:00	648

Table 2009-16-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
12/8/2009	37	30	Rain
12/9/2009	57	30	Rain

Table 2009-16-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	12/8/2009	20:46:00	12/9/2009	07:03:00	617
Green 1	12/8/2009	20:46:00	12/9/2009	18:08:00	1282
Green 2	12/8/2009	20:46:00	NF ^[j]	NF	NF

Table 2009-16-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	1.37	74.2
Control Roof Flume	1.43	77.3

Table 2009-16-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	77.3
Green 1	28.9
Green 2	NF

Table 2009-16-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.522	01:49:00	303	NA ^[k]	NA
Green 1	0.102	03:21:00	395	0.8	0.3
Green 2	NF	NF	NF	NF	NF

Table 2009-16-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.63	2.08	1.08	0.37
Green 2	NF	NF	NF	NF

Comments:

Storm 2009-17, December 13, 2009

Table 2009-17-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
12/13/2009	08:41:00	12/13/2009	17:16:00	515

Table 2009-17-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
12/13/2009	46	28	Rain

Table 2009-17-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	12/13/2009	08:41:00	12/13/2009	16:59:00	498
Green 1	12/13/2009	08:41:00	12/13/2009	17:13:00	512
Green 2	12/13/2009	08:41:00	NF ^[j]	NF	NF

Table 2009-17-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.3	16.3
Control Roof Flume	0.21	11.2

Table 2009-17-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	11.2
Green 1	5
Green 2	NF

Table 2009-17-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.157	09:28:00	47	NA ^[k]	NA
Green 1	0.02	10:18:00	97	0.9	1.06
Green 2	NF	NF	NF	NF	NF

Table 2009-17-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.55	1.03	0.03	0.45
Green 2	NF	NF	NF	NF

Comments:

Storm 2009-18, Feb 25-26, 2009

Table 2009-18-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
12/25/2009	08:21:00	12/25/2009	17:00:00	519

Table 2009-18-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
12/25/2009	45	33	Rain
12/26/2009	45	30	Rain

Table 2009-18-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	12/25/2009	08:21:00	12/26/2009	08:40:00	1459
Green 1	12/25/2009	08:21:00	12/26/2009	06:15:00	1314
Green 2	12/25/2009	08:21:00	NF ^[j]	NF	NF

Table 2009-18-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.59	32
Control Roof Flume	1.23	66.8

Table 2009-18-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	66.8
Green 1	20.6
Green 2	NF

Table 2009-18-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.374	10:58:00	157	NA ^[k]	NA
Green 1	0.057	14:44:00	363	0.85	2.44
Green 2	NF	NF	NF	NF	NF

Table 2009-18-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.69	0.9	-0.099	0.309
Green 2	NF	NF	NF	NF

Comments:checking the Three River Wet Weather rainfall data on 12/25/2009, the rainfall volume is close to rain gauge data, CR runoff flume end time is early than the rain gauge end time

Storm 2009-19, December 31, 2009- Jan 1,2010

Table 2009-19-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
12/31/2009	11:52:00	12/31/2009	13:49:00	117

Table 2009-19-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
12/31/2009	36	30	Rain
1/1/2010	34	19	Rain

Table 2009-19-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	12/31/2009	11:52:00	1/1/2010	06:34:00	1122
Green 1	12/31/2009	11:52:00	1/1/2010	10:03:00	1331
Green 2	12/31/2009	11:52:00	NF ^[j]	NF	NF

Table 2009-19-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.19	10.3
Control Roof Flume	0.128	6.91

Table 2009-19-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	6.91
Green 1	4.55
Green 2	NF

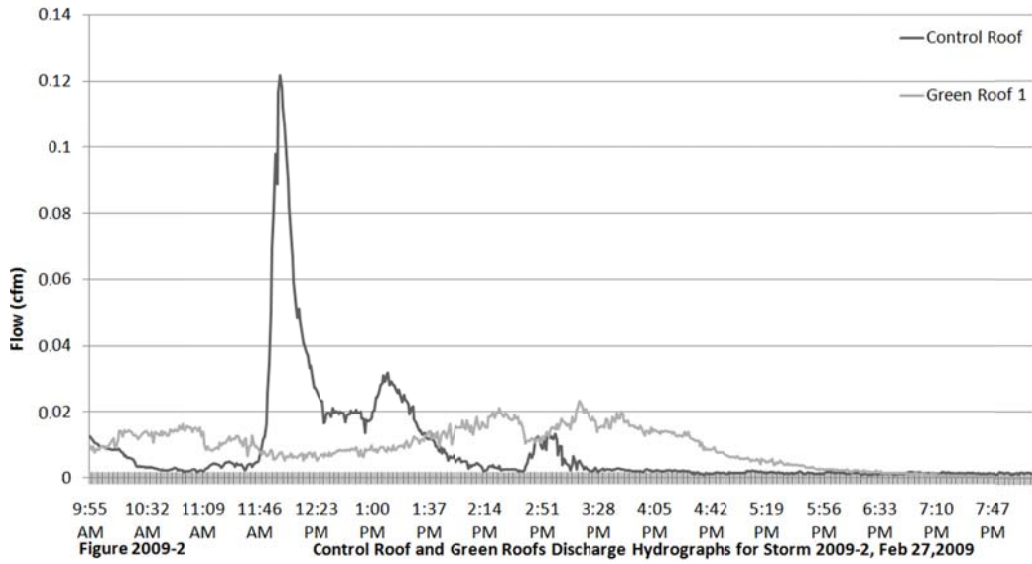
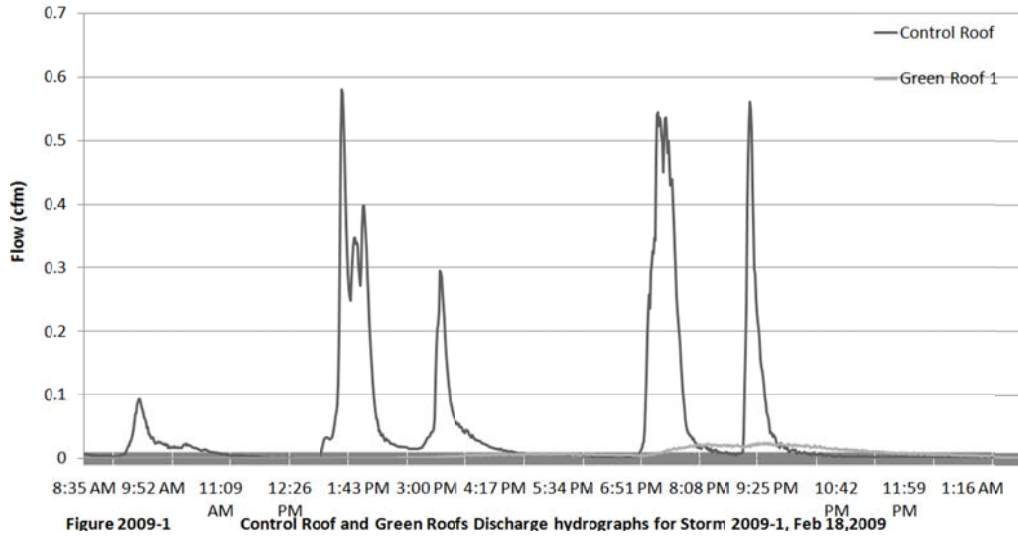
Table 2009-19-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.03	16:19:00	267	NA ^[k]	NA
Green 1	0.007	12:17:00	25	0.72	0.094
Green 2	NF	NF	NF	NF	NF

Table 2009-19-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.34	1.19	0.19	0.66
Green 2	NF	NF	NF	NF

Comments:



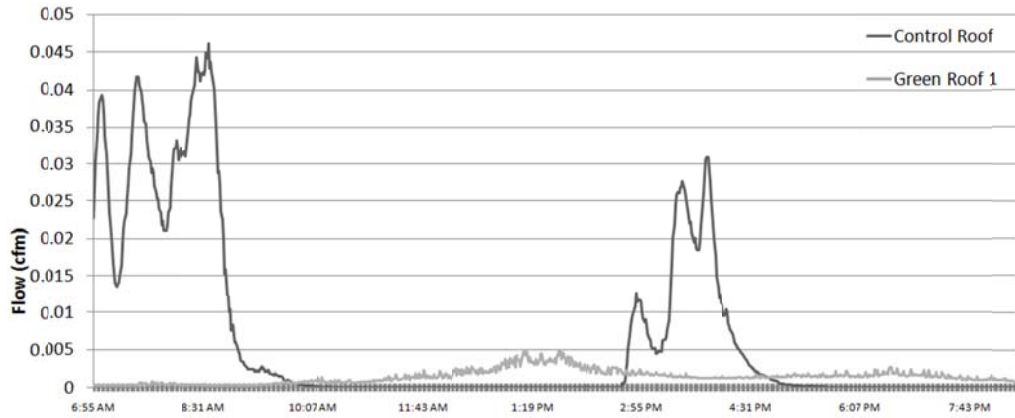


Figure 2009-3 Control Roof and Green Roofs Discharge Hydrographs for Storm 2009-3, April 10, 2009

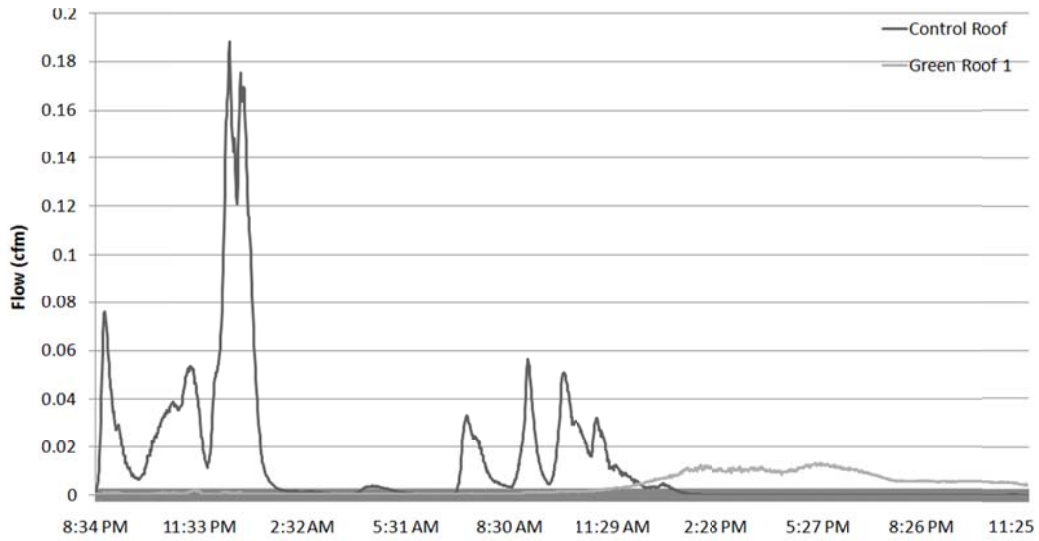


Figure 2009-4 Control Roof and Green Roofs Discharge Hydrographs for Storm 2009-4, April 14-15, 2009

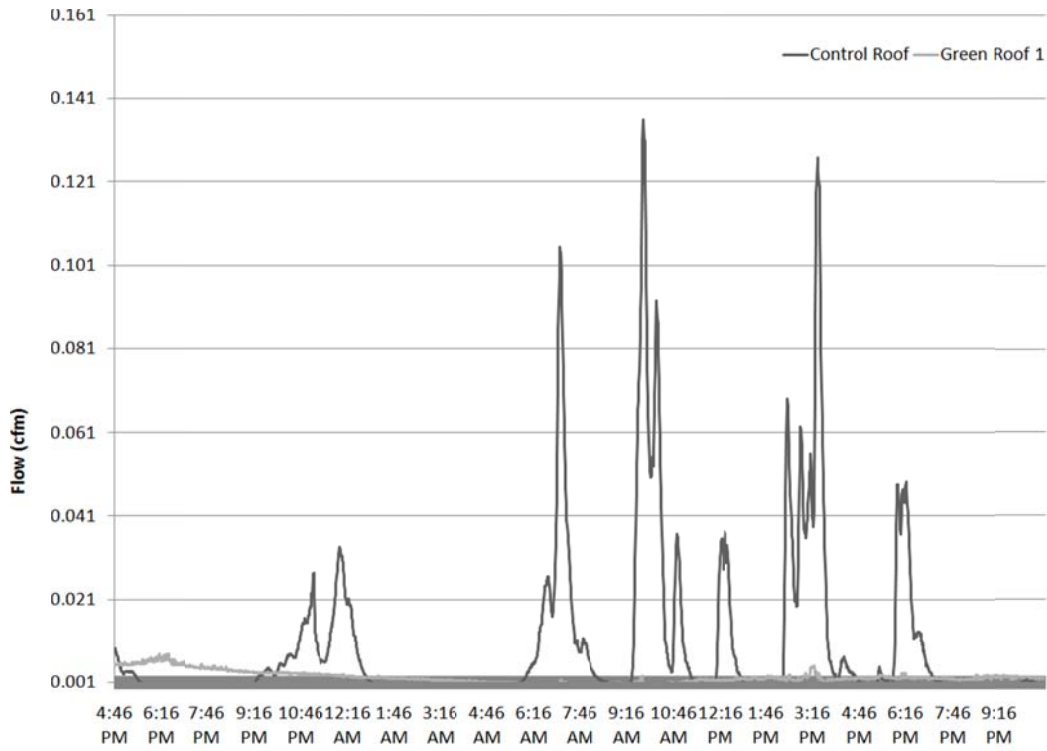


Figure 2009-5 Control Roof and Green Roofs Hydrographs for Storm 2009-5, April 19-20,2009

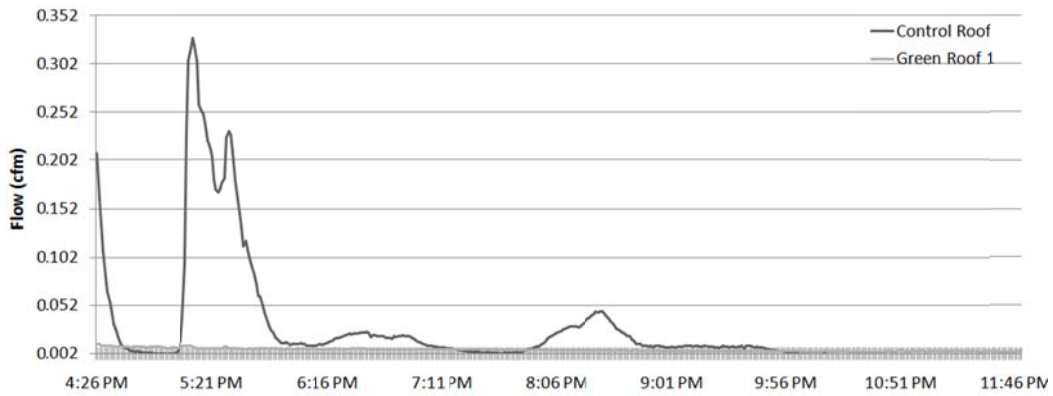


Figure 2009-6 Control Roof and Green Roofs Discharge Hydrographs for Storm 2009-6, April 28,2009

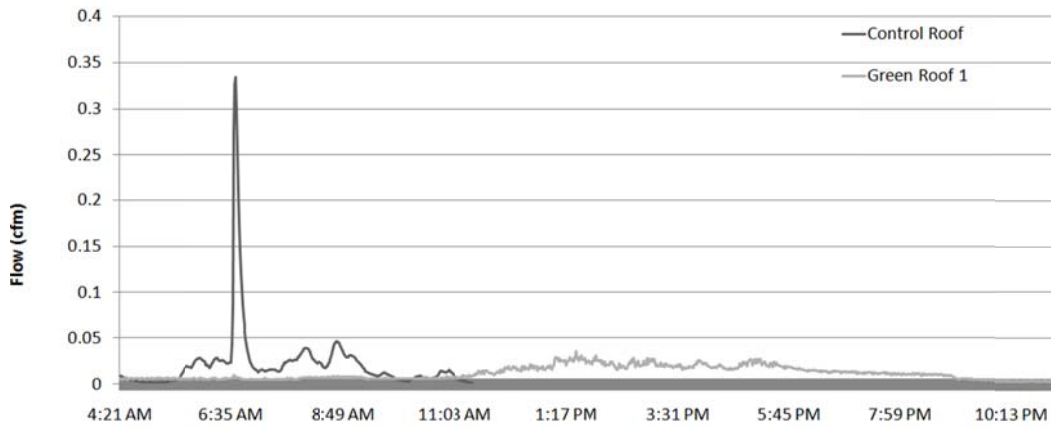


Figure 2009-7 Control Roof and GreenRoofs Discharge Hydrographs for Storm 2009-7, May 1, 2009

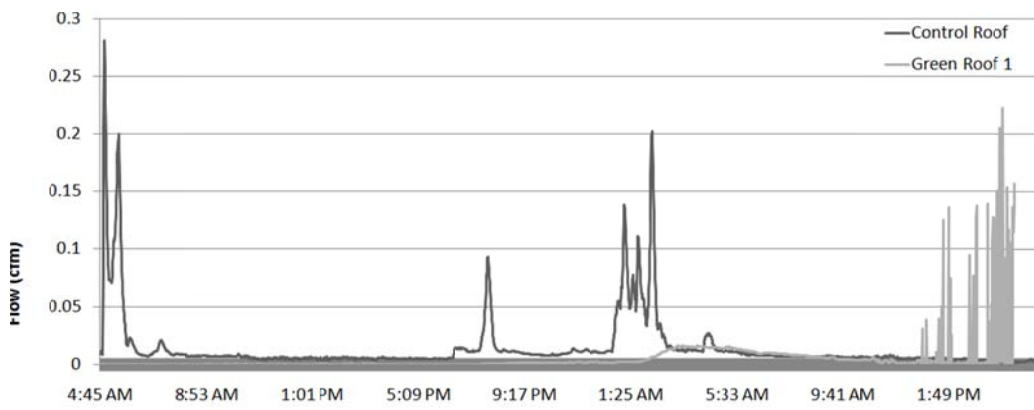


Figure 2009-8 Control Roof and GreenRoofs Discharge Hydrographs for Storm 2009-8, Oct 9-10, 2009

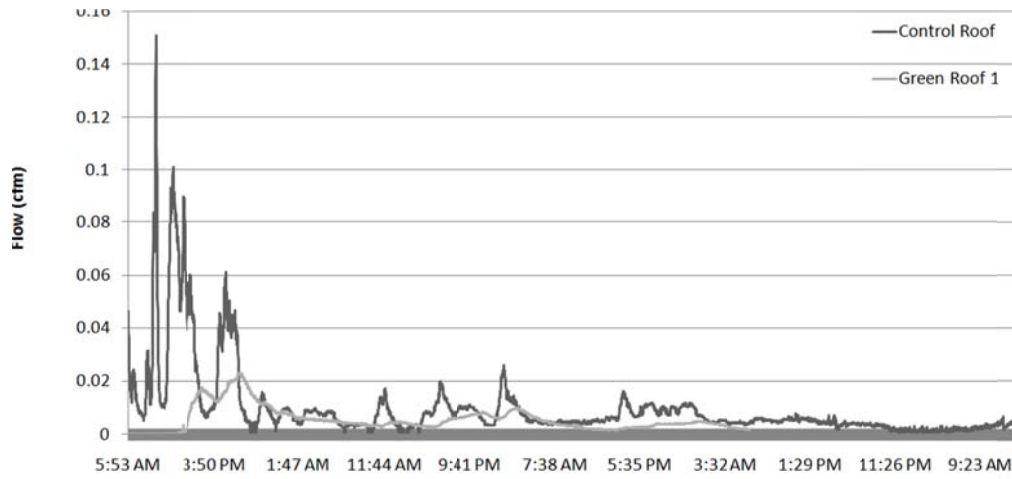


Figure 2009-9 Control Roof and Green Roofs Discharge Hydrographs for Storm 2009-9, October 15-19,2009

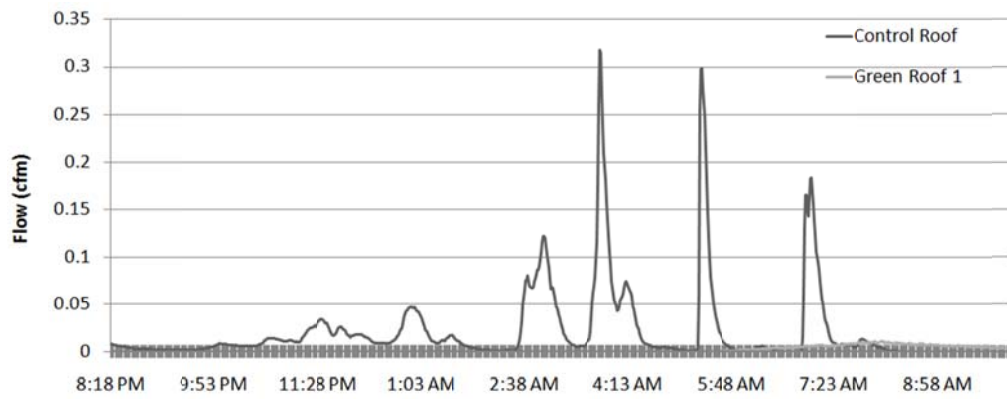


Figure 2009-10 Control Roof and Green Roofs Discharge Hydrographs for Storm 2009-10,Oct 27-28,2009

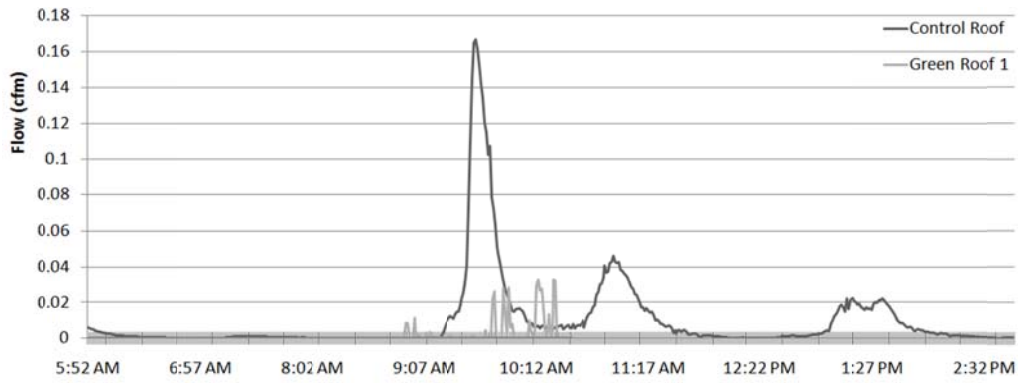


Figure 2009-11 Control roof and Green Roofs Discharge Hydrographs for Storm 2009-11, Oct 31, 2009

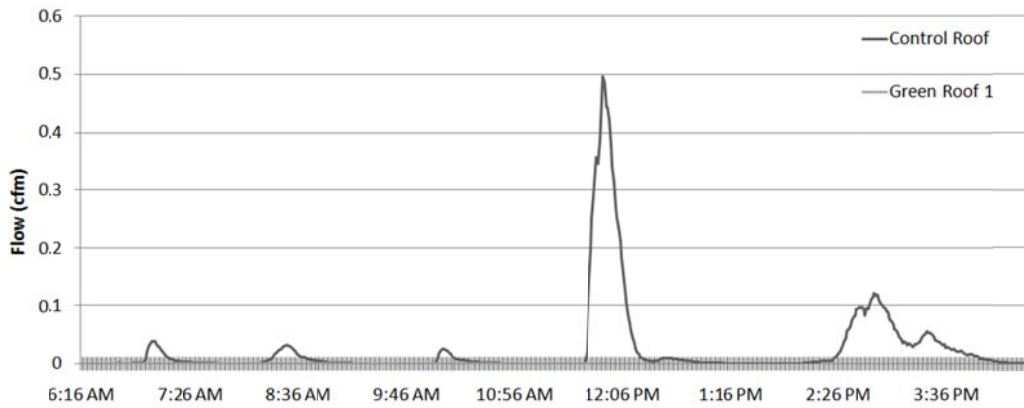


Figure 2009-12 Control Roof and Green Roofs Discharge Hydrographs for Storm 2009-12, November 19, 2009

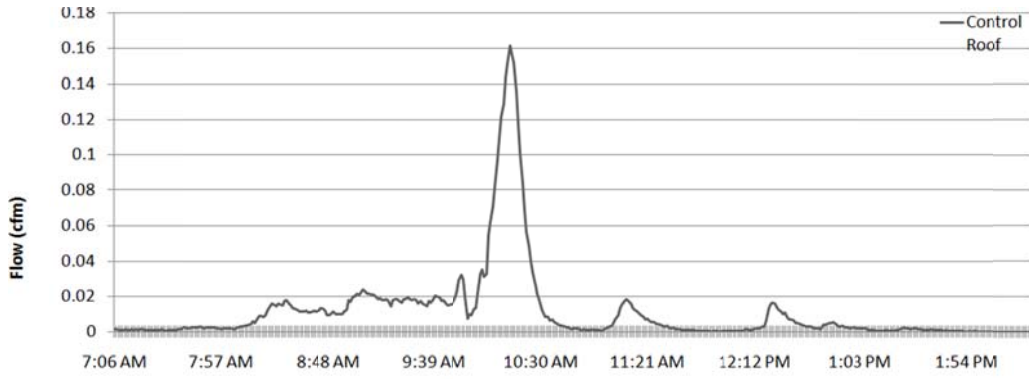


Figure 2009-13 Control Roof and Green Roofs Discharge Hydrographs for Storm 2009-13, Nov 27, 2009

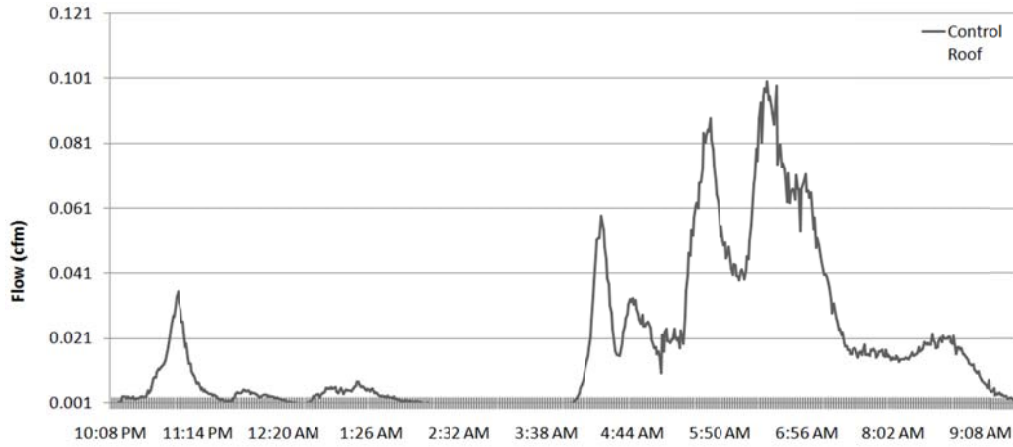


Figure 2009-14 Control Roof and Green Roofs Discharge Hydrographs for Storm 2009-14, Nov 29-30, 2009

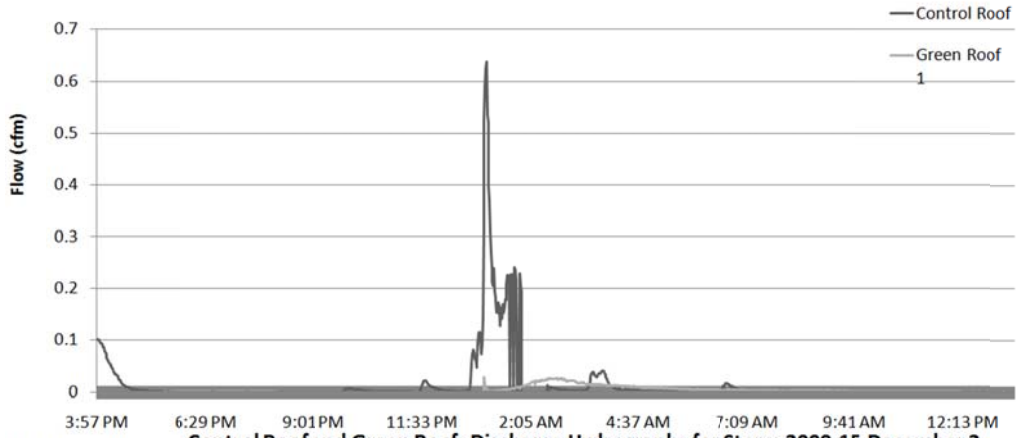


Figure 2009-15
Control Roof and Green Roofs Discharge Hydrographs for Storm 2009-15, December 2-3, 2009

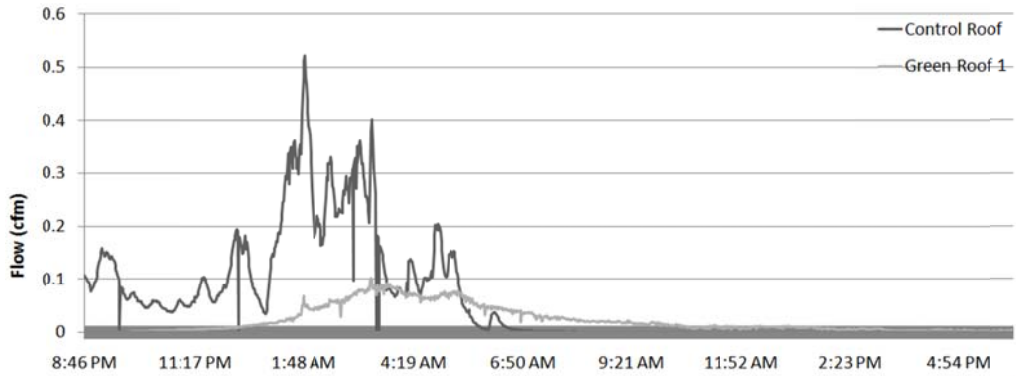


Figure 2009-16
Control Roofs and Green Roofs Discharge Hydrographs for Storm 2009-16, December 8-9, 2009

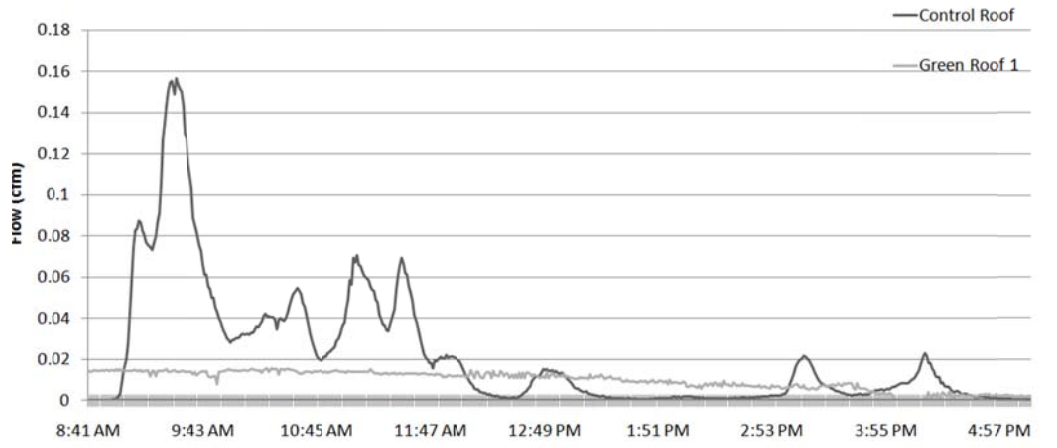


Figure 2009-17

Control Roof and Green Roofs Discharge Hydrographs for Storm 2009-17, December 13, 2009

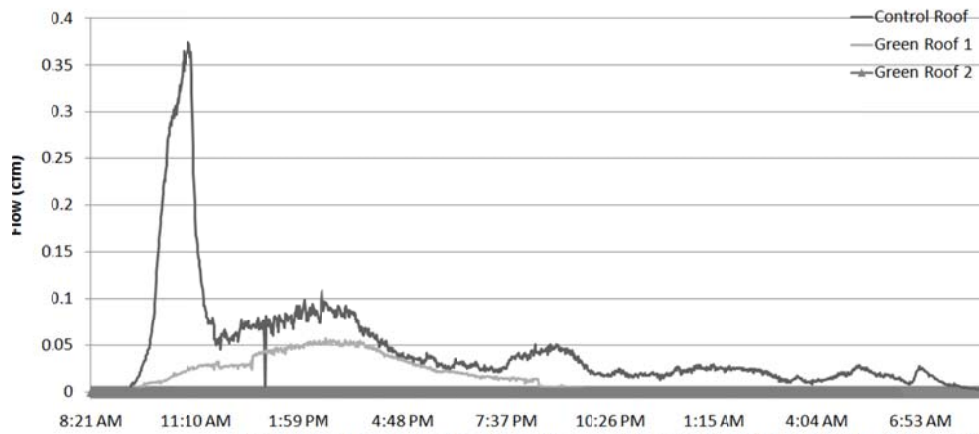


Figure 2009-18

Control Roof and Green Roofs Discharge Hydrographs for Storm 2009-18, December 25-26, 2009

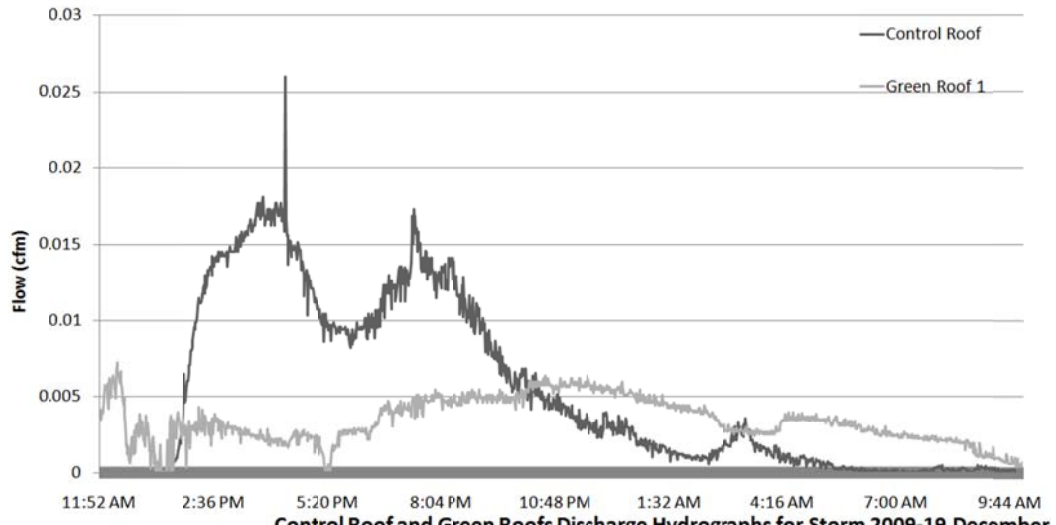


Figure 2009-19

Control Roof and Green Roofs Discharge Hydrographs for Storm 2009-19, December 31, 2009-January 1, 2010

Appendix B 2010 Storm Summary and Individual Storm Data

Metrics used in Appendix B

Metric	Equation/definition
Vol. Reduction ^[a]	$\frac{V_{CR,RUNOFF} - V_{GR,RUNOFF}}{V_{CR,RUNOFF}}$
Relative Duration ^[b]	$\frac{D_{GR}}{D_{CR}}$
Duration Extension ^[c]	$\frac{D_{GR} - D_{CR}}{D_{CR}}$
Runoff Vol. Ratio ^[d]	$\frac{V_{GR,RUNOFF}}{V_{CR,RUNOFF}}$
Qp ^[e]	Obtained from runoff hydrograph
Time to Peak ^[f]	(Time of peak runoff rate)-(runoff start time)
Qp Reduction ^[g]	$\frac{Q_{P,CR} - Q_{P,GR}}{Q_{P,CR}}$
Time to Peak Extension ^[h]	$\frac{t_{P,GR} - t_{P,CR}}{t_{P,CR}}$
NF ^[j]	Sensor not functioning
NA ^[k]	Not Applicable

Storm 2010-1, Jan 14, 2010

Table 2010-1-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
1/14/2010	12:45:00	1/14/2010	13:58:00	73

Table 2010-1-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
1/14/2010	41	23	Rain, Snow
1/15/2010	42	37	Rain, Snow

Table 2010-1-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	1/14/2010	12:45:00	1/15/2010	19:43:00	1858
Green 1	1/14/2010	12:45:00	1/15/2010	21:48:00	1983
Green 2	1/14/2010	12:45:00	NF ^[j]	NF	NF

Table 2010-1-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.09	4.88
Control Roof Flume	11.32	612.8

Table 2010-1-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	612.82
Green 1	164.32
Green 2	NF

Table 2010-1-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	1.01	13:42:00	57	NA ^[k]	NA
Green 1	0.94	12:46:00	1	0.07	-0.98
Green 2	NF	NF	NF	NF	NF

Table 2010-1-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.73	1.07	0.07	0.27
Green 2	NF	NF	NF	NF

Comments: Checking the Three River Wet Weather rain gauge data, it matched with the rain gauge data we measured. Snow may have influenced the CR runoff flume data.

Storm 2010-2, Jan 17, 2010

Table 2010-2-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
1/17/2010	11:30:00	1/17/2010	22:48:00	678

Table 2010-2-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
1/17/2010	39	35	Rain
1/18/2010	39	35	Rain

Table 2010-2-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	1/17/2010	11:30:00	1/17/2010	21:56:00	626
Green 1	1/17/2010	11:30:00	1/18/2010	13:27:00	1557
Green 2	1/17/2010	11:30:00	NF ^[j]	NF	NF

Table 2010-2-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.54	29.3
Control Roof Flume	0.42	22.7

Table 2010-2-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	22.7
Green 1	12.5
Green 2	NF

Table 2010-2-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.14	12:07:00	37	NA ^[k]	NA
Green 1	0.03	13:53:00	143	0.81	2.87
Green 2	NF	NF	NF	NF	NF

Table 2010-2-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.45	2.49	1.49	0.55
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-3, March 11-12, 2010

Table 2010-3-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
3/11/2010	23:22:00	3/12/2010	03:36:00	254

Table 2010-3-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
3/11/2010	66	44	Rain
3/12/2010	60	50	Rain

Table 2010-3-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	3/11/2010	23:22:00	3/12/2010	04:33:00	311
Green 1	3/11/2010	23:22:00	3/12/2010	09:06:00	584
Green 2	3/11/2010	23:22:00	NF ^[j]	NF	NF

Table 2010-3-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.32	17.3
Control Roof Flume	0.32	17.3

Table 2010-3-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	17.3
Green 1	0.96
Green 2	NF

Table 2010-3-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.18	03:31:00	249	NA ^[k]	NA
Green 1	0.006	04:33:00	311	0.97	0.25
Green 2	NF	NF	NF	NF	NF

Table 2010-3-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.94	1.88	0.88	0.06
Green 2	NF	NF	NF	NF

Comments: Green Roof 2 sensor had been installed back at 3/12/2010. However it still didn't work well based on the data it recorded.

Storm 2010-4, March 22, 2010(a)

Table 2010-4-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
3/22/2010	03:37:00	3/22/2010	08:42:00	305

Table 2010-4-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
3/22/2010	72	46	Rain

Table 2010-4-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	3/22/2010	03:37:00	3/22/2010	10:24:00	407
Green 1	3/22/2010	03:37:00	3/22/2010	20:19:00	1002
Green 2	3/22/2010	03:37:00	NF ^[j]	NF	NF

Table 2010-4-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.16	8.7
Control Roof Flume	0.14	7.8

Table 2010-4-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	7.8
Green 1	4
Green 2	NF

Table 2010-4-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.18	09:41:00	364	NA ^[k]	NA
Green 1	0.13	19:18:00	941	0.3	1.59
Green 2	NF	NF	NF	NF	NF

Table 2010-4-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.49	2.46	1.46	0.51
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-5, March 22, 2010(b)

Table 2010-5-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
3/22/2010	20:19:00	3/22/2010	21:10:00	51

Table 2010-5-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
3/22/2010	72	46	Rain

Table 2010-5-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	3/22/2010	20:19:00	3/22/2010	23:33:00	194
Green 1	3/22/2010	20:19:00	3/22/2010	20:19:00	0
Green 2	3/22/2010	20:19:00	NF ^[j]	NF	NF

Table 2010-5-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.14	7.6
Control Roof Flume	0.15	8.2

Table 2010-5-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	8.2
Green 1	0
Green 2	NF

Table 2010-5-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.58	21:26:00	67	NA ^[k]	NA
Green 1	0	20:19:00	0	1	-1
Green 2	NF	NF	NF	NF	NF

Table 2010-5-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	1	0	-1	0
Green 2	NF	NF	NF	NF

Comments: Green Roof 1 sensor didn't work well, it should have some runoff on the roof.

Storm 2010-6, March 23, 2010

Table 2010-6-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
3/23/2010	09:30:00	3/23/2010	12:14:00	164

Table 2010-6-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
3/23/2010	46	37	Rain

Table 2010-6-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	3/23/2010	09:30:00	3/23/2010	14:23:00	293
Green 1	3/23/2010	09:30:00	3/23/2010	09:30:00	0
Green 2	3/23/2010	09:30:00	NF ^[j]	NF	NF

Table 2010-6-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.07	3.8
Control Roof Flume	0.1	5.2

Table 2010-6-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	5.2
Green 1	0
Green 2	NF

Table 2010-6-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.098	10:49:00	79	NA ^[k]	NA
Green 1	0	09:30:00	0	1	-1
Green 2	NF	NF	NF	NF	NF

Table 2010-6-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	1	0	-1	0
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-7, April 8, 2010

Table 2010-7-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
4/8/2010	15:09:00	4/8/2010	18:26:00	197

Table 2010-7-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
4/8/2010	75	43	Rain

Table 2010-7-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	4/8/2010	15:09:00	4/8/2010	20:29:00	295
Green 1	4/8/2010	15:09:00	4/8/2010	15:09:00	0
Green 2	4/8/2010	15:09:00	NF ^[j]	NF	NF

Table 2010-7-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.05	2.71
Control Roof Flume	0.12	6.28

Table 2010-7-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	6.28
Green 1	0
Green 2	NF

Table 2010-7-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.19	15:54:00	45	NA ^[k]	NA
Green 1	0	15:09:00	0	1	-1
Green 2	NF	NF	NF	NF	NF

Table 2010-7-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	1	0	-1	0
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-8, April 13, 2010

Table 2010-8-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
4/13/2010	07:37:00	4/13/2010	12:06:00	269

Table 2010-8-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
4/13/2010	53	42	Rain

Table 2010-8-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	4/13/2010	07:37:00	4/13/2010	11:47:00	250
Green 1	4/13/2010	07:37:00	4/13/2010	07:37:00	0
Green 2	4/13/2010	07:37:00	NF ^[j]	NF	NF

Table 2010-8-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.16	8.67
Control Roof Flume	0.2	11.07

Table 2010-8-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	11.07
Green 1	0
Green 2	NF

Table 2010-8-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.13	08:34:00	57	NA ^[k]	NA
Green 1	0	07:37:00	0	1	-1
Green 2	NF	NF	NF	NF	NF

Table 2010-8-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	1	0	-1	0
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-9, April 16, 2010

Table 2010-9-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
4/16/2010	15:43:00	4/16/2010	20:41:00	298

Table 2010-9-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
4/16/2010	80	54	Rain

Table 2010-9-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	4/16/2010	15:43:00	4/16/2010	20:50:00	307
Green 1	4/16/2010	15:43:00	4/16/2010	15:43:00	0
Green 2	4/16/2010	15:43:00	NF ^[j]	NF	NF

Table 2010-9-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.31	16.79
Control Roof Flume	0.51	27.56

Table 2010-9-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	27.58
Green 1	0
Green 2	NF

Table 2010-9-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.6	15:52:00	9	NA ^[k]	NA
Green 1	0	15:43:00	0	1	-1
Green 2	NF	NF	NF	NF	NF

Table 2010-9-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	1	0	-1	0
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-10, April 24, 2010

Table 2010-10-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
4/24/2010	10:09:00	4/24/2010	12:10:00	121

Table 2010-10-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
4/24/2010	66	50	Rain

Table 2010-10-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	4/24/2010	10:09:00	4/24/2010	11:57:00	108
Green 1	4/24/2010	10:09:00	4/24/2010	10:09:00	0
Green 2	4/24/2010	10:09:00	NF ^[j]	NF	NF

Table 2010-10-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.03	1.63
Control Roof Flume	0.041	2.23

Table 2010-10-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	2.23
Green 1	0
Green 2	NF

Table 2010-10-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.6	15:52:00	9	NA ^[k]	NA
Green 1	0	10:09:00	0	1	-1
Green 2	NF	NF	NF	NF	NF

Table 2010-10-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	1	0	-1	0
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-11, April 24-25, 2010

Table 2010-11-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
4/24/2010	23:03:00	4/25/2010	04:00:00	297

Table 2010-11-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
4/24/2010	66	50	Rain
4/25/2010	75	53	Rain

Table 2010-11-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	4/24/2010	23:03:00	4/25/2010	05:26:00	383
Green 1	4/24/2010	23:03:00	NF ^[j]	::00	NF
Green 2	4/24/2010	23:03:00	NF	NF	NF

Table 2010-11-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.3	16.25
Control Roof Flume	0.38	20.52

Table 2010-11-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	20.52
Green 1	NF
Green 2	NF

Table 2010-11-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.203	02:36:00	213	NA ^[k]	NA
Green 1	NF	NF	NF	NF	NF
Green 2	NF	NF	NF	NF	NF

Table 2010-11-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	NF	NF	NF	NF
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-12, April 25, 2010

Table 2010-12-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
4/25/2010	15:47:00	4/25/2010	21:38:00	355

Table 2010-12-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
4/25/2010	75	53	Rain

Table 2010-12-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	4/25/2010	15:47:00	4/25/2010	18:04:00	137
Green 1	4/25/2010	15:47:00	NF ^[j]	NF	NF
Green 2	4/25/2010	15:47:00	NF ^[j]	NF	NF

Table 2010-12-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.22	11.92
Control Roof Flume	0.203	11

Table 2010-12-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	11
Green 1	NF
Green 2	NF

Table 2010-12-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	1.02	15:47:00	0	NA ^[k]	NA
Green 1	NF	NF	NF	NF	NF
Green 2	NF	NF	NF	NF	NF

Table 2010-12-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	NF	NF	NF	NF
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-13, April 26, 2010(a)

Table 2010-13-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
4/26/2010	02:51:00	4/26/2010	07:31:00	280

Table 2010-13-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
4/26/2010	60	48	Rain

Table 2010-13-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	4/26/2010	02:51:00	4/26/2010	07:58:00	307
Green 1	4/26/2010	02:51:00	NF ^[j]	NF	NF
Green 2	4/26/2010	02:51:00	NF ^[j]	NF	NF

Table 2010-13-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.27	14.63
Control Roof Flume	0.32	17.11

Table 2010-13-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	17.11
Green 1	NF
Green 2	NF

Table 2010-13-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.68	02:51:00	0	NA ^[k]	NA
Green 1	NF	NF	NF	NF	NF
Green 2	NF	NF	NF	NF	NF

Table 2010-13-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	NF	NF	NF	NF
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-14, April 26, 2010(b)

Table 2010-14-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
4/26/2010	17:12:00	4/26/2010	19:44:00	152

Table 2010-14-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
4/26/2010	60	46	

Table 2010-14-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	4/26/2010	17:12:00	4/26/2010	19:41:00	149
Green 1	4/26/2010	17:12:00	4/26/2010	11:59:00	407
Green 2	4/26/2010	17:12:00	NF ^[j]	NF	NF

Table 2010-14-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.31	16.79
Control Roof Flume	0.44	23.72

Table 2010-14-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	23.72
Green 1	0.28
Green 2	NF

Table 2010-14-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.8	17:12:00	0	NA ^[k]	NA
Green 1	0.002	:::00	86	0.99	NA
Green 2	NF	NF	NF	NF	NF

Table 2010-14-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.99	2.73	1.73	0.012
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-15, October 3, 2010

Table 2010-15-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
10/3/2010	17:00:00	10/3/2010	18:45:00	105

Table 2010-15-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
10/3/2010	57	46	Rain

Table 2010-15-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	10/3/2010	17:00:00	10/3/2010	19:29:00	149
Green 1	10/3/2010	17:00:00	NF ^[j]	NF	NF
Green 2	10/3/2010	17:00:00	NF	NF	NF

Table 2010-15-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.1	5.42
Control Roof Flume	0.094	5.1

Table 2010-15-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	5.1
Green 1	NF
Green 2	NF

Table 2010-15-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.084	18:00:00	60	NA ^[k]	NA
Green 1	NF	NF	NF	NF	NF
Green 2	NF	NF	NF	NF	NF

Table 2010-15-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	NF	NF	NF	NF
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-16, October 5-6, 2010

Table 2010-16-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
10/5/2010	16:45:00	10/6/2010	20:00:00	1635

Table 2010-16-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
10/5/2010	50	44	Rain
10/6/2010	51	44	Rain

Table 2010-16-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	10/5/2010	16:45:00	10/6/2010	20:22:00	1657
Green 1	10/5/2010	16:45:00	10/6/2010	22:22:00	1777
Green 2	10/5/2010	16:45:00	NF ^[j]	NF	NF

Table 2010-16-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.34	18.4
Control Roof Flume	0.3	16.1

Table 2010-16-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	16.1
Green 1	3.16
Green 2	NF

Table 2010-16-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.074	16:19:00	1414	NA ^[k]	NA
Green 1	0.006	18:08:00	1523	0.92	0.077
Green 2	NF	NF	NF	NF	NF

Table 2010-16-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.8	1.07	0.072	0.2
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-17, October 11, 2010

Table 2010-17-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
10/11/2010	22:30:00	10/11/2010	23:30:00	60

Table 2010-17-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
10/11/2010	80	55	Rain

Table 2010-17-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	10/11/2010	22:30:00	10/11/2010	23:56:00	86
Green 1	10/11/2010	22:30:00	10/11/2010	22:30:00	0
Green 2	10/11/2010	22:30:00	NF ^[j]	NF	NF

Table 2010-17-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.03	1.63
Control Roof Flume	0.019	1.04

Table 2010-17-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	1.04
Green 1	0
Green 2	NF

Table 2010-17-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.076	22:30:00	0	NA ^[k]	NA
Green 1	0	22:30:00	0	1	NA
Green 2	NF	NF	NF	NF	NF

Table 2010-17-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	1	0	-1	0
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-18, October 14, 2010

Table 2010-18-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
10/14/2010	13:30:00	10/14/2010	16:15:00	165

Table 2010-18-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
10/14/2010	59	48	Rain

Table 2010-18-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	10/14/2010	13:30:00	10/14/2010	17:00:00	210
Green 1	10/14/2010	13:30:00	10/14/2010	13:30:00	0
Green 2	10/14/2010	13:30:00	NF ^[j]	NF	NF

Table 2010-18-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.04	2.17
Control Roof Flume	0.023	1.24

Table 2010-18-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	1.24
Green 1	0
Green 2	NF

Table 2010-18-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.067	16:03:00	153	NA ^[k]	NA
Green 1	0	13:30:00	0	1	-1
Green 2	NF	NF	NF	NF	NF

Table 2010-18-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	1	0	-1	0
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-19, October 25, 2010

Table 2010-19-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
10/25/2010	11:15:00	10/25/2010	18:00:00	405

Table 2010-19-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
10/25/2010	63	57	Rain

Table 2010-19-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	10/25/2010	11:15:00	10/25/2010	17:28:00	373
Green 1	10/25/2010	11:15:00	NF ^[j]	NF	NF
Green 2	10/25/2010	11:15:00	NF	NF	NF

Table 2010-19-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.44	23.83
Control Roof Flume	0.34	18.36

Table 2010-19-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	18.36
Green 1	NF
Green 2	NF

Table 2010-19-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.36	14:48:00	213	NA ^[k]	NA
Green 1	NF	NF	NF	NF	NF
Green 2	NF	NF	NF	NF	NF

Table 2010-19-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	NF	NF	NF	NF
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-20, October 26, 2010

Table 2010-20-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
10/26/2010	17:30:00	10/26/2010	23:00:00	330

Table 2010-20-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
10/26/2010	79	55	Rain
10/27/2010	74	53	Rain

Table 2010-20-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	10/26/2010	17:30:00	10/26/2010	23:23:00	353
Green 1	10/26/2010	17:30:00	10/27/2010	06:29:00	779
Green 2	10/26/2010	17:30:00	NF ^[j]	NF	NF

Table 2010-20-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.64	34.7
Control Roof Flume	0.42	22.49

Table 2010-20-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	22.49
Green 1	6.37
Green 2	NF

Table 2010-20-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.35	20:16:00	166	NA ^[k]	NA
Green 1	0.035	21:41:00	251	0.9	0.512
Green 2	NF	NF	NF	NF	NF

Table 2010-20-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.72	2.21	0.21	0.28
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-21, Nov 4, 2010

Table 2010-21-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
11/4/2010	13:15:00	11/4/2010	17:45:00	270

Table 2010-21-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
11/4/2010	48	39	Rain

Table 2010-21-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	11/4/2010	13:15:00	11/4/2010	21:10:00	475
Green 1	11/4/2010	13:15:00	11/4/2010	13:15:00	0
Green 2	11/4/2010	13:15:00	NF ^[j]	NF	NF

Table 2010-21-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.03	1.63
Control Roof Flume	0.037	2

Table 2010-21-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	2
Green 1	0
Green 2	NF

Table 2010-21-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.017	17:36:00	261	NA ^[k]	NA
Green 1	0	13:15:00	0	1	-1
Green 2	NF	NF	NF	NF	NF

Table 2010-21-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	1	0	-1	0
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-22, Nov 5, 2010

Table 2010-22-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
11/5/2010	04:15:00	11/5/2010	08:30:00	255

Table 2010-22-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
11/5/2010	44	37	Rain

Table 2010-22-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	11/5/2010	04:15:00	11/5/2010	09:01:00	286
Green 1	11/5/2010	04:15:00	11/5/2010	04:15:00	0
Green 2	11/5/2010	04:15:00	NF ^[j]	NF	NF

Table 2010-22-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.07	3.79
Control Roof Flume	0.038	2.05

Table 2010-22-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	2.05
Green 1	0
Green 2	NF

Table 2010-22-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.071	07:56:00	221	NA ^[k]	NA
Green 1	0	04:15:00	0	1	-1
Green 2	NF	NF	NF	NF	NF

Table 2010-22-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	1	0	-1	0
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-23, Nov 25-26, 2010

Table 2010-23-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
11/25/2010	04:17:00	11/26/2010	04:39:00	1462

Table 2010-23-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
11/25/2010	51	43	Rain
11/26/2010	51	43	Rain

Table 2010-23-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	11/25/2010	04:17:00	11/26/2010	07:27:00	1630
Green 1	11/25/2010	04:17:00	11/26/2010	08:17:00	1680
Green 2	11/25/2010	04:17:00	NF ^[j]	NF	NF

Table 2010-23-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	2.09	113.21
Control Roof Flume	1.33	71.78

Table 2010-23-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	71.78
Green 1	36.36
Green 2	NF

Table 2010-23-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.439	06:31:00	134	NA ^[k]	NA
Green 1	0.1	08:46:00	269	0.77	2.01
Green 2	NF	NF	NF	NF	NF

Table 2010-23-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.49	1.03	0.031	0.51
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-24, Nov 30- Dec 1, 2010

Table 2010-24-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
11/30/2010	03:17:00	12/1/2010	06:47:00	1650

Table 2010-24-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
11/30/2010	55	44	Rain
12/1/2010	59	41	Rain

Table 2010-24-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	11/30/2010	03:17:00	12/1/2010	07:27:00	1630
Green 1	11/30/2010	03:17:00	12/1/2010	08:17:00	1680
Green 2	11/30/2010	03:17:00	NF ^[j]	NF	NF

Table 2010-24-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	3.57	193.38
Control Roof Flume	1.78	96.63

Table 2010-24-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	96.63
Green 1	93.02
Green 2	NF

Table 2010-24-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.6	22:08:00	1131	NA ^[k]	NA
Green 1	0.18	22:09:00	1132	0.697	1.001
Green 2	NF	NF	NF	NF	NF

Table 2010-24-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.037	1.4	0.4	0.96
Green 2	NF	NF	NF	NF

Comments:

Storm 2010-25, Dec 30, 2010

Table 2010-25-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
12/30/2010	00:36:00	12/30/2010	11:07:00	631

Table 2010-25-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
12/30/2010	36	29	Rain

Table 2010-25-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	12/30/2010	00:36:00	12/30/2010	06:45:00	369
Green 1	12/30/2010	00:36:00	12/30/2010	06:45:00	369
Green 2	12/30/2010	00:36:00	NF ^[j]	NF	NF

Table 2010-25-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.05	2.71
Control Roof Flume	0.04	2.41

Table 2010-25-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	2.41
Green 1	1.93
Green 2	NF

Table 2010-25-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.01	00:53:00	17	NA ^[k]	NA
Green 1	0.007	06:20:00	344	0.27	20.24
Green 2	NF	NF	NF	NF	NF

Table 2010-25-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.2	1	0	0.8
Green 2	NF	NF	NF	NF

Comments: System stopped collecting data at 06:45:00, 12/30/2010.

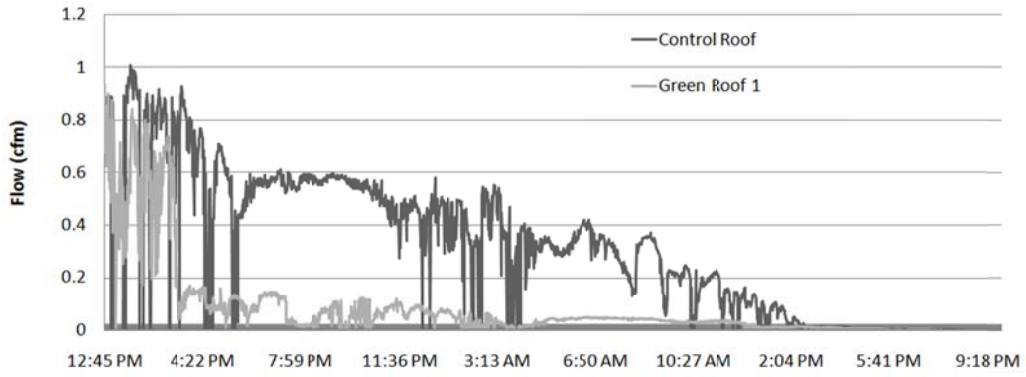


Figure 2010-1 Control Roof and Green Roofs Discharge Hydrographs for Storm 2010-1, Jan 14-15,2010

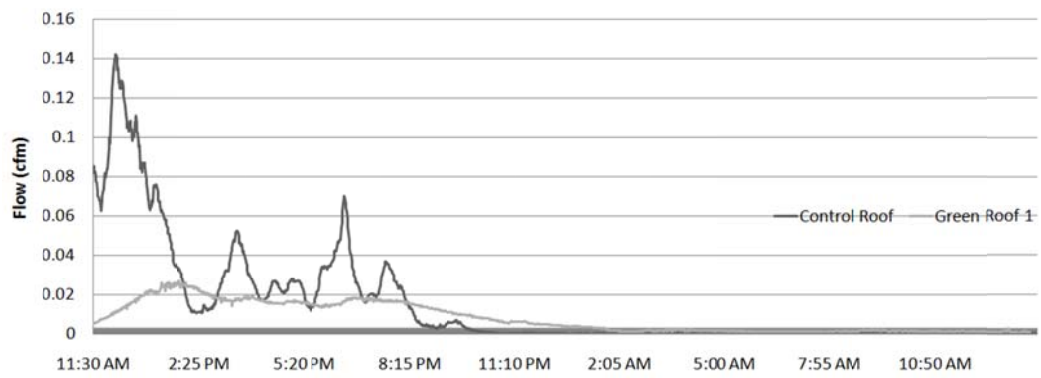


Figure 2010-2 Control Roof and Green Roofs Discharge Hydrographs for Storm 2010-2, Jan 17,2010

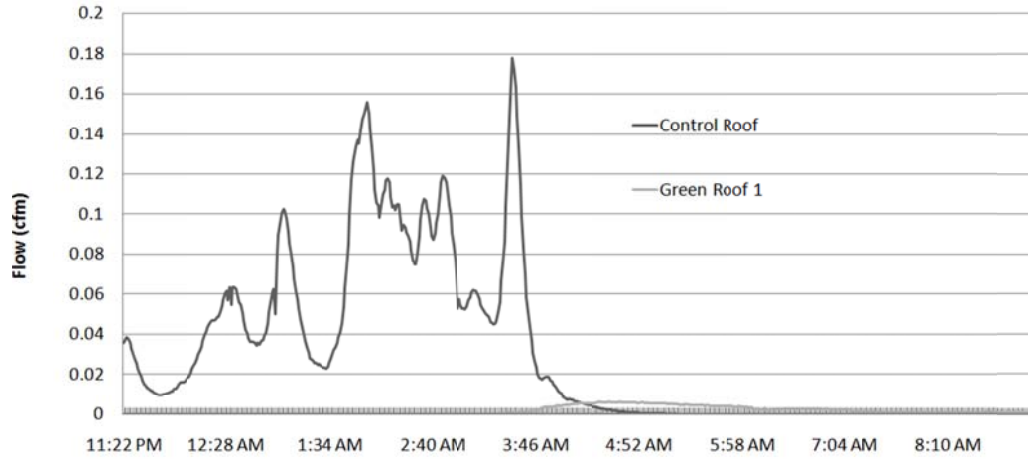


Figure 2010-3 Control Roof and Green Roofs Discharge Hydrographs for Storm 2010-3, March 11-12,2010

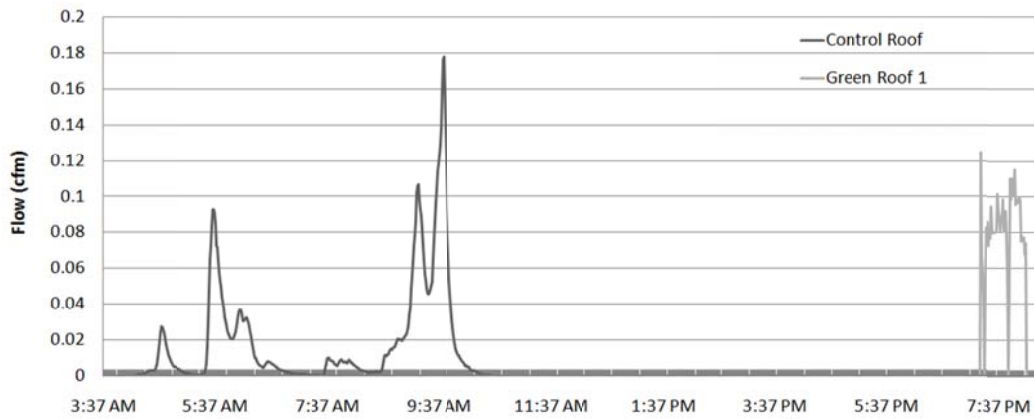


Figure 2010-4 Control Roof and Green Roofs Discharge Hydrograph for Storm 2010-4, March 22(a),2010

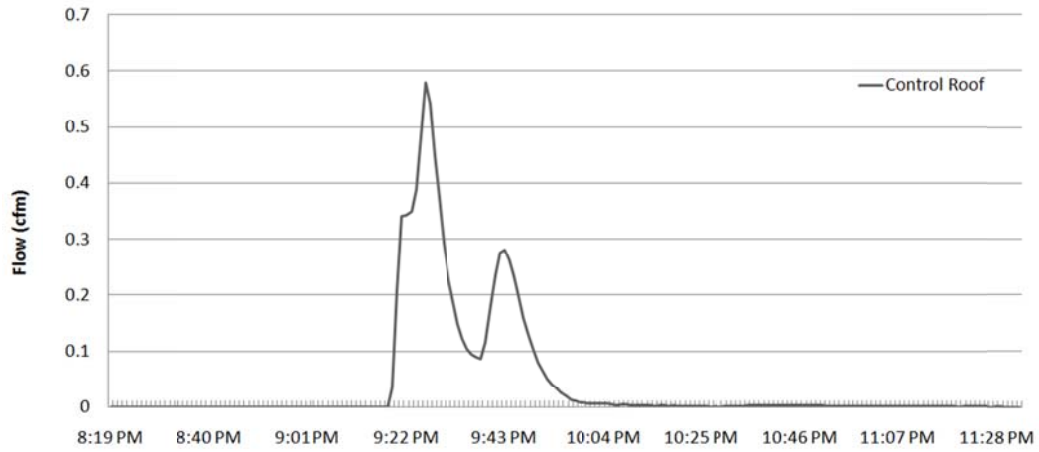


Figure 2010-5 Control Roof and Green Roofs Discharge Hydrographs for Storm 2010-5, March 22, 2010

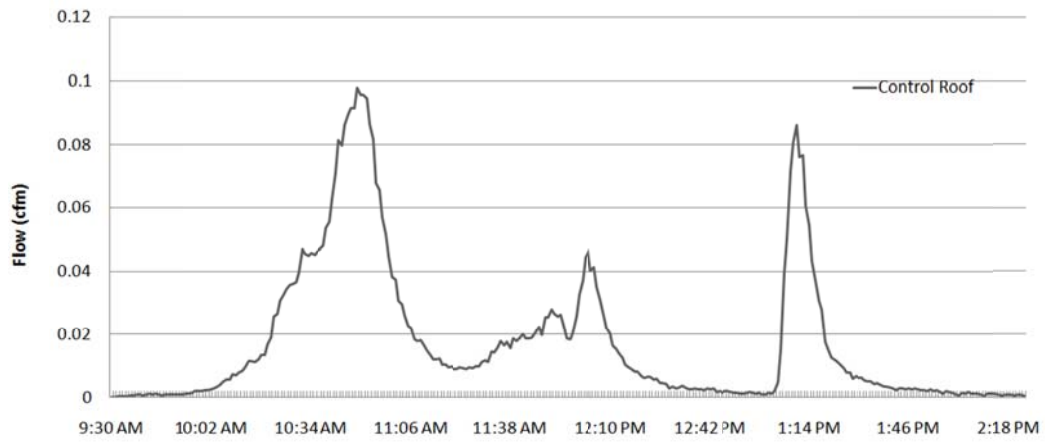


Figure 2010-6 Control Roof and Green Roofs Discharge Hydrographs for Storm 2010-6, March 23, 2010

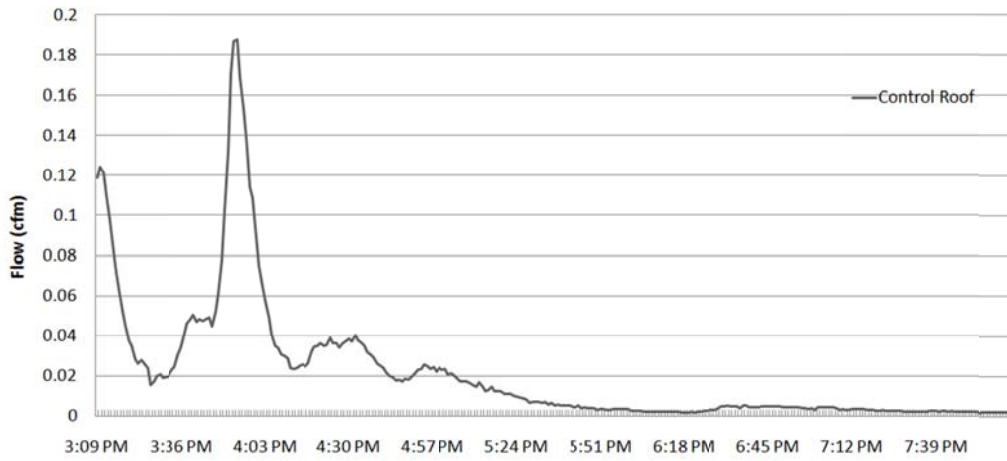


Figure 2010-7 Control Roof and Green Roofs Discharge Hydrographs for Storm 2010-7, April 8, 2010

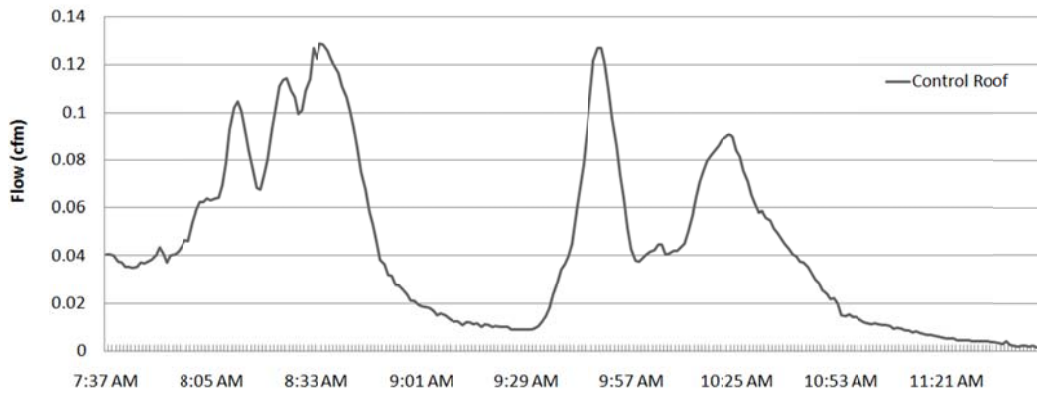


Figure 2010-8 Control Roof and Green Roofs Discharge Hydrographs for Storm 2010-8, April 13, 2010

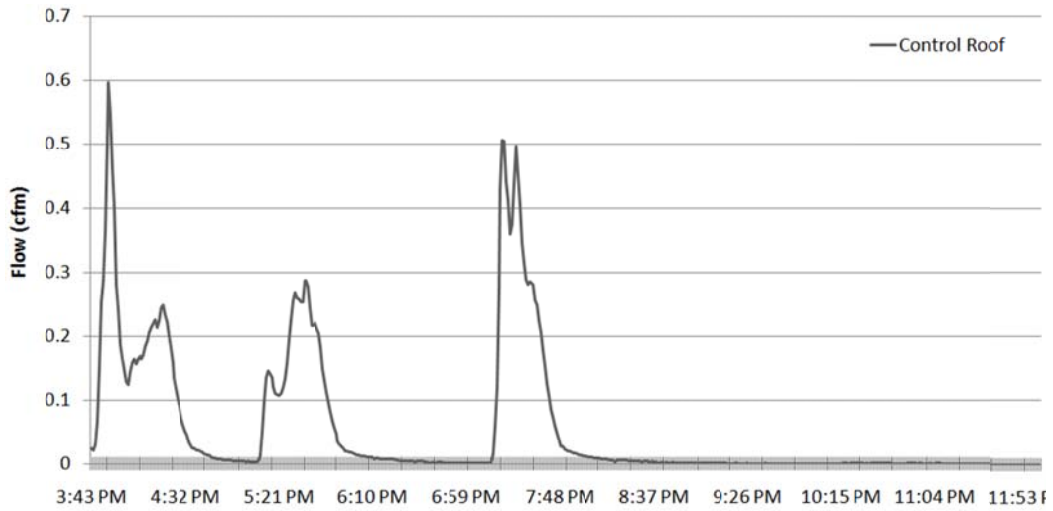


Figure 2010-9 Control Roof and Green Roofs Discharge Hydrographs for Storm 2010-9, April 16, 2010

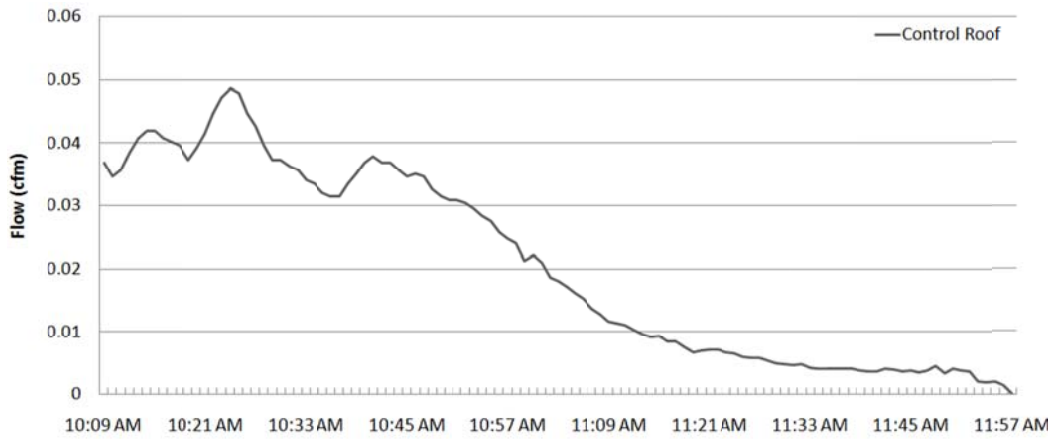


Figure 2010-10 Control Roof and Green Roofs Discharge Hydrographs for Storm 2010-10, April 24(a), 2010

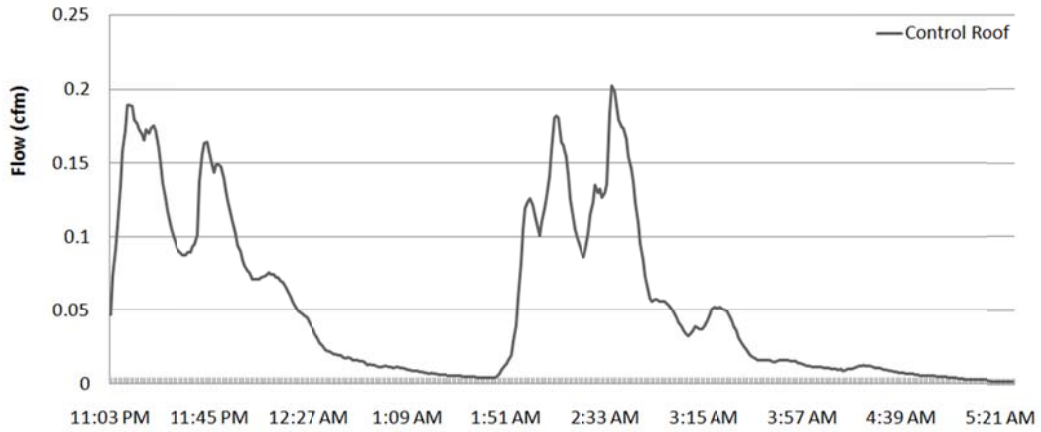


Figure 2010-11 Control Roof and Green Roofs Discharge Hydrographs for Storm 2010-11, April 24(b), 2010

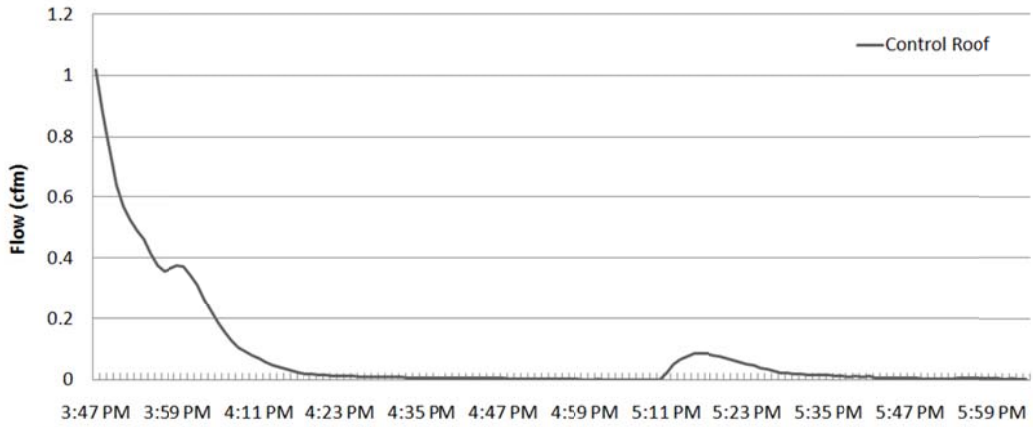


Figure 2010-12 Control Roof and Green Roofs Discharge Hydrographs for Storm 2010-12, April 25, 2010

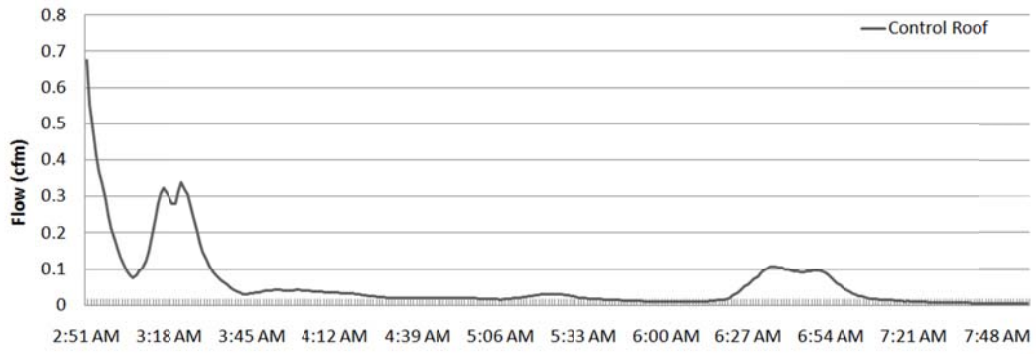


Figure 2010-13 Control Roof and Green Roofs Discharge Hydrographs for Storm 2010-13, April 26(a), 2010

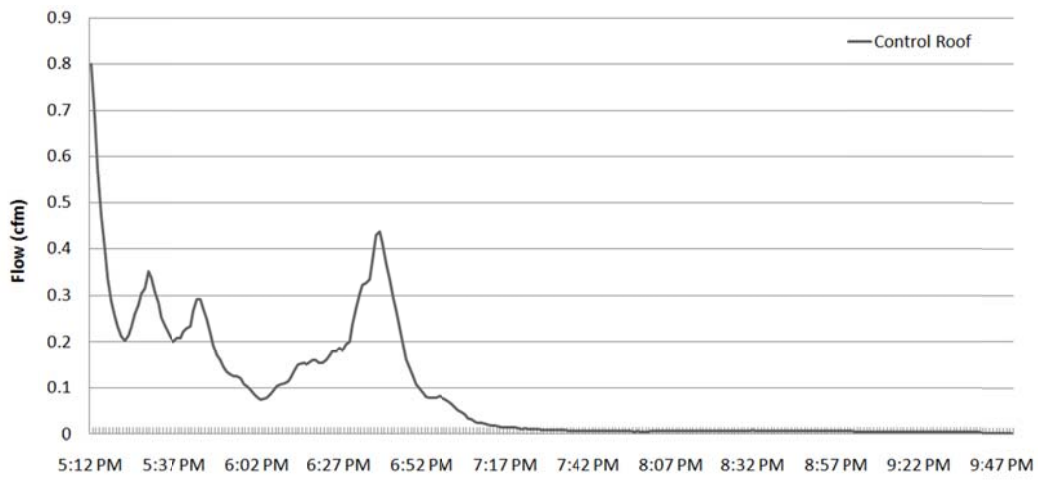


Figure 2010-14 Control Roof and Green Roofs Discharge Hydrographs for Storm 2010-14, April 26(b), 2010

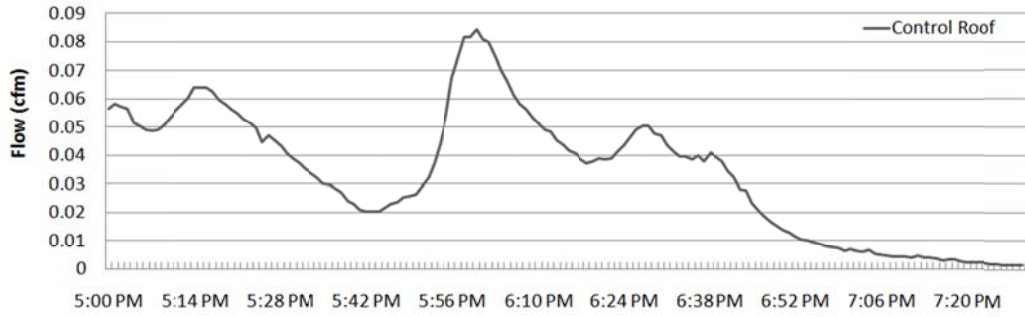


Figure 2010-15 Control Roof and Green Roofs Discharge Hydrographs for Storm 2010-15, October 03, 2010

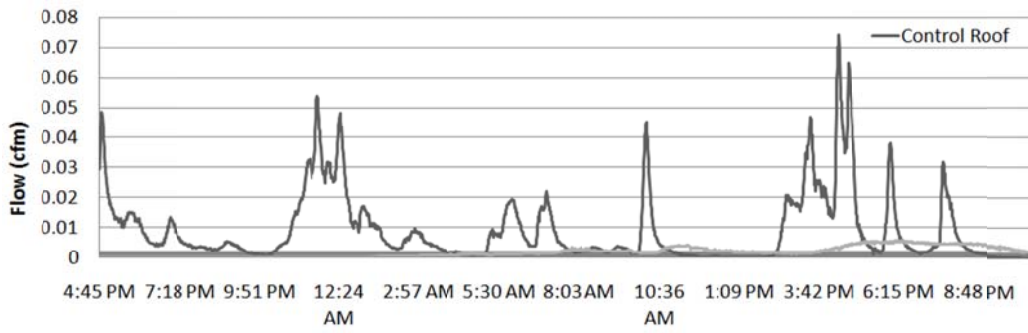


Figure 2010-16 Control Roof and Green Roofs Discharge Hydrographs for Storm 2010-16, October 5-6, 2010

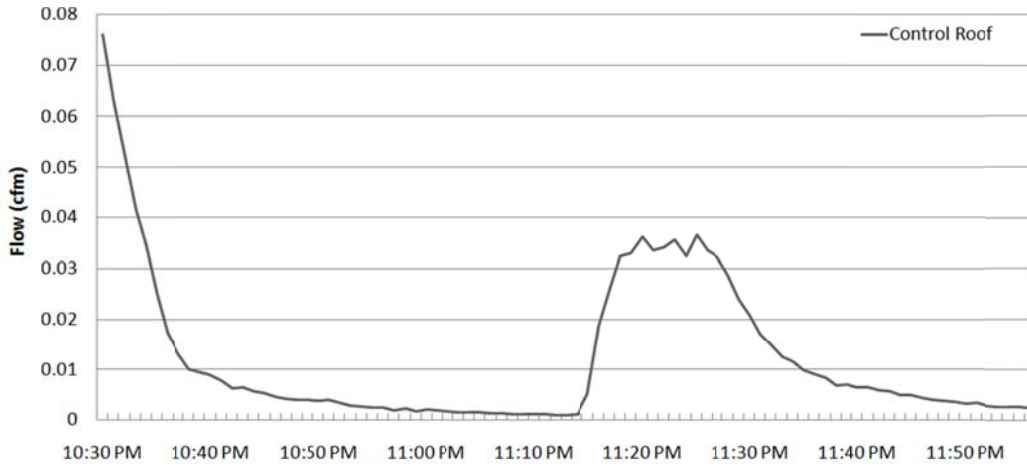


Figure 2010-17 Control Roof and Green Roofs Discharge Hydrographs for Storm 2010-17, October 11,2010

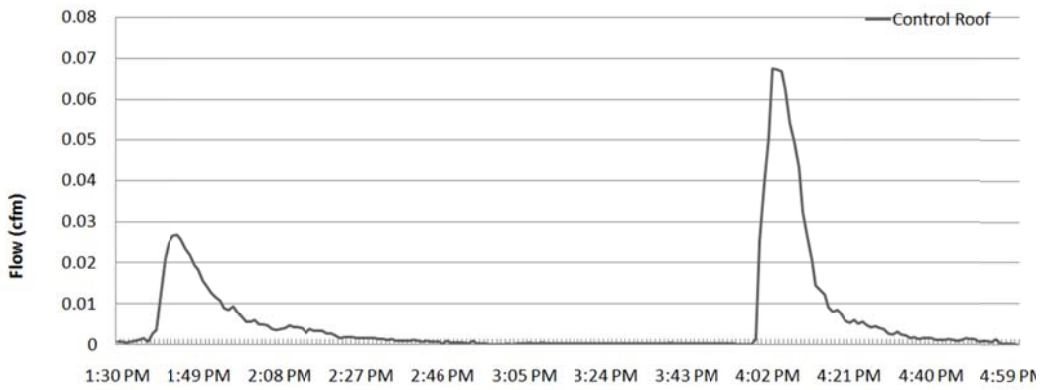
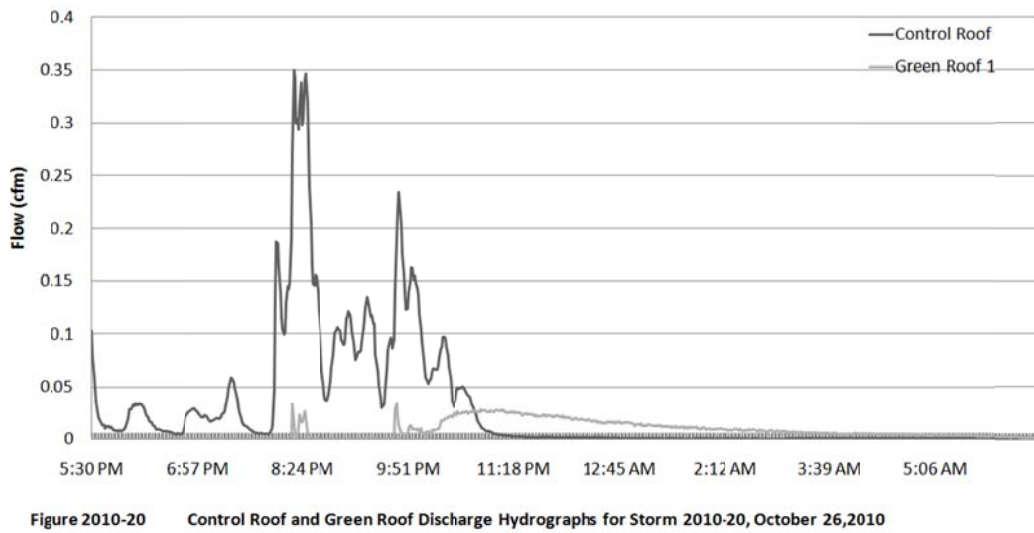
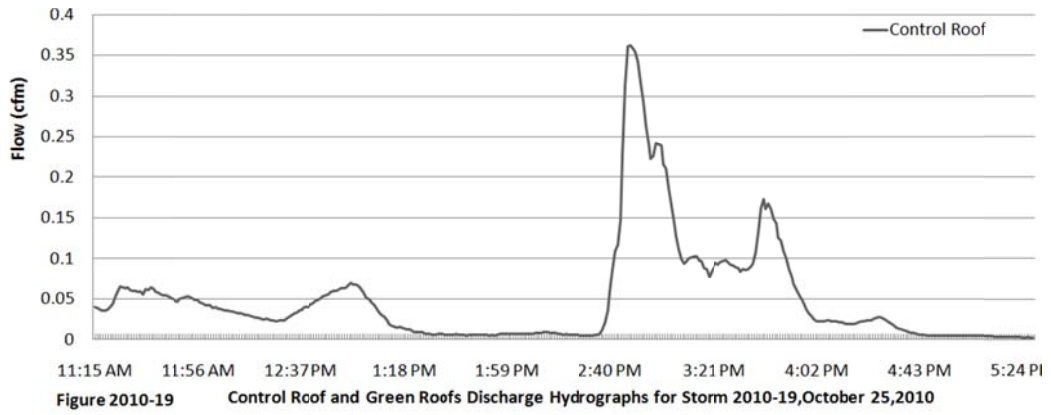


Figure 2010-18 Control Roof and Green Roofs Discharge Hydrographs for Storm 2010-18,October 14,2010



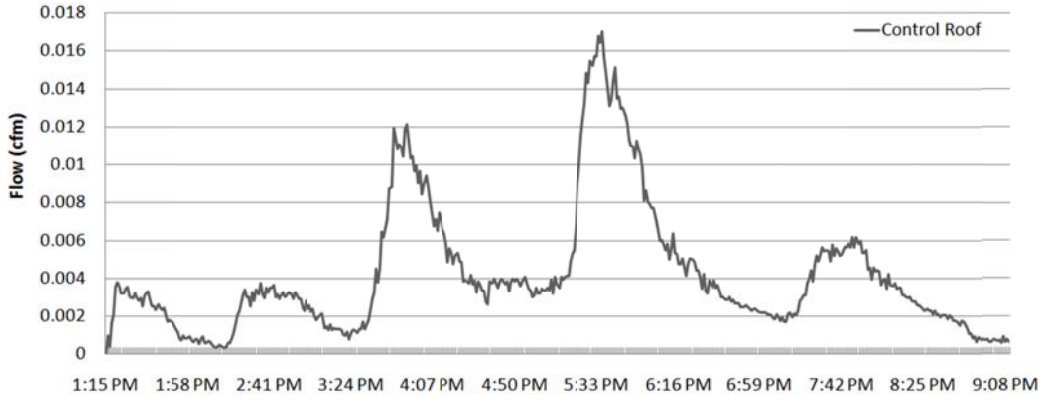


Figure 2010-21 Control Roof and Green Roofs Discharge Hydrographs for Storm 2010-21, Nov 4, 2010

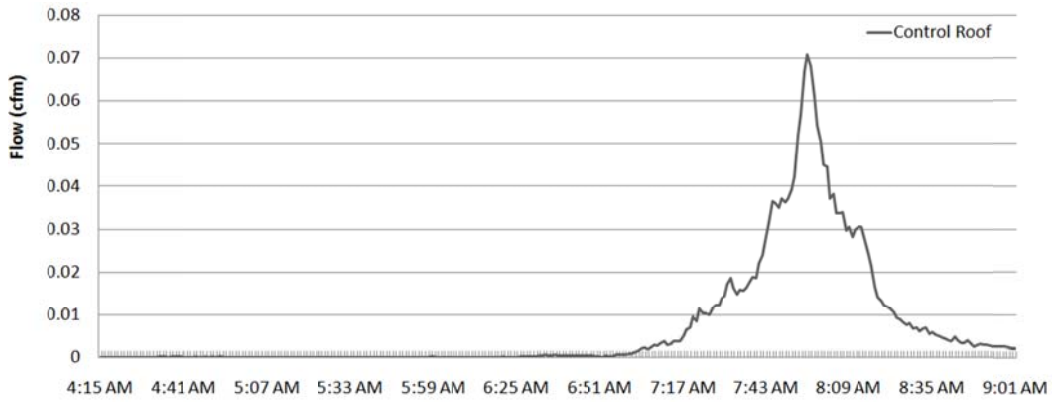


Figure 2010-22 Control Roof and Green Roof Discharge Hydrographs for Storm 2010-22, Nov 5, 2010

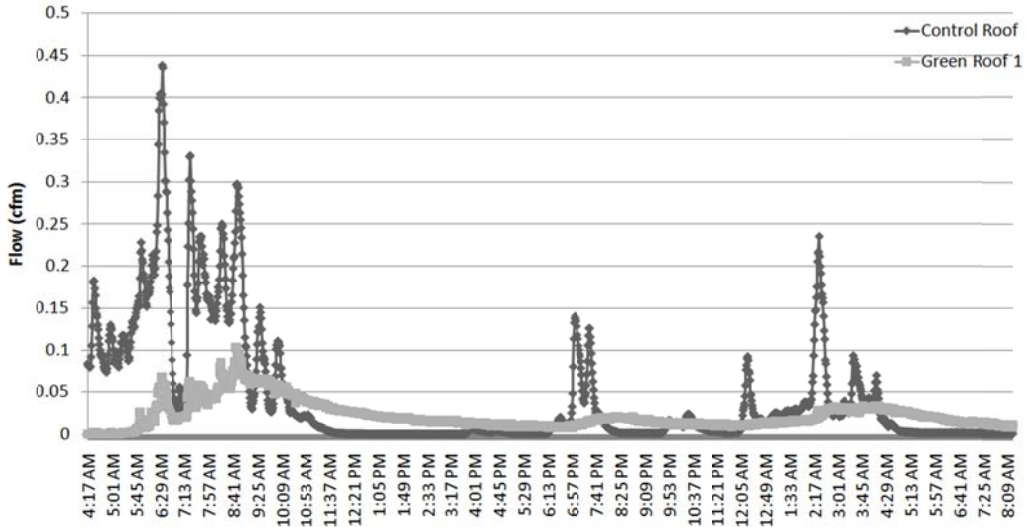


Figure 2010-23 Control Roof and Green Roof Discharge Hydrograph for Storm 2010-23 11/25/2010

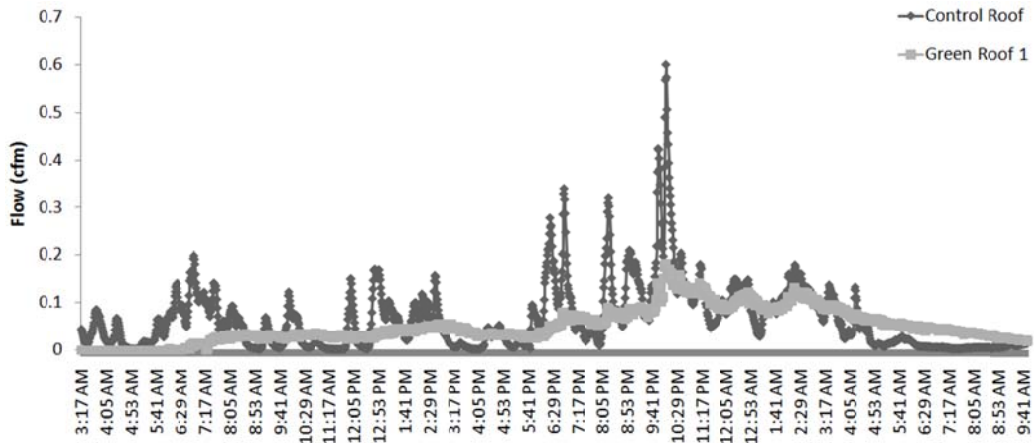


Figure 2010-24 Control Roof and Green Roofs Discharge Hydrograph for Storm 2010-24, 11/30/2010

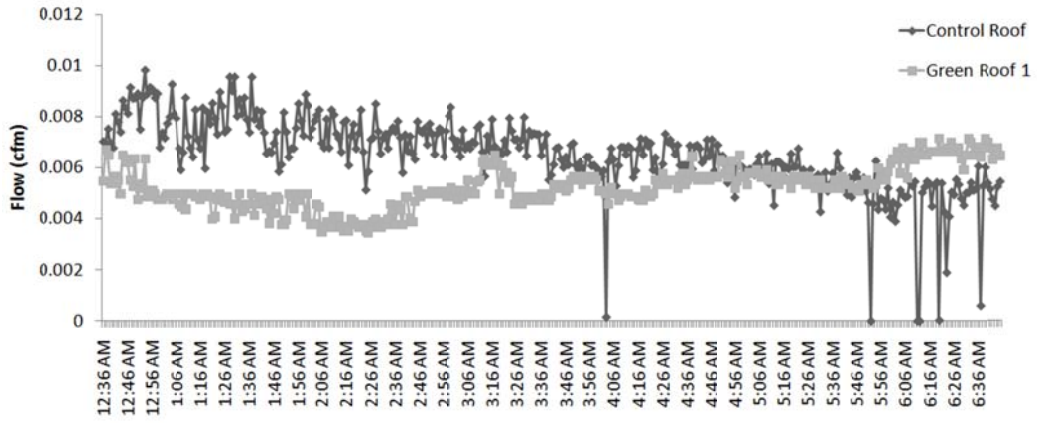


Figure 2010-25 Control Roof and Green Roof Discharge Hydrograph for Storm 25-2010,12/30/2010

Appendix C 2011 Storm Summary and Individual Storm Data

Metrics used in Appendix C

Metric	Equation/definition
Vol. Reduction ^[a]	$\frac{V_{CR,RUNOFF} - V_{GR,RUNOFF}}{V_{CR,RUNOFF}}$
Relative Duration ^[b]	$\frac{D_{GR}}{D_{CR}}$
Duration Extension ^[c]	$\frac{D_{GR} - D_{CR}}{D_{CR}}$
Runoff Vol. Ratio ^[d]	$\frac{V_{GR,RUNOFF}}{V_{CR,RUNOFF}}$
Qp ^[e]	Obtained from runoff hydrograph
Time to Peak ^[f]	(Time of peak runoff rate)-(runoff start time)
Qp Reduction ^[g]	$\frac{Q_{P,CR} - Q_{P,GR}}{Q_{P,CR}}$
Time to Peak Extension ^[h]	$\frac{t_{P,GR} - t_{P,CR}}{t_{P,CR}}$
NF ^[j]	Sensor not functioning
NA ^[k]	Not Applicable

Storm 2011-1, Jan 18, 2011

Table 2011-1-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
1/18/2011	12:47:00	1/18/2011	13:25:00	38

Table 2011-1-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
1/18/2011	48	32	Rain

Table 2011-1-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	1/18/2011	12:47:00	1/18/2011	14:02:00	75
Green 1	1/18/2011	12:47:00	1/18/2011	14:02:00	75
Green 2	1/18/2011	12:47:00	1/18/2011	14:02:00	75

Table 2011-1-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.14	7.58
Control Roof Flume	0.11	6.15

Table 2011-1-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	6.15
Green 1	0
Green 2	0

Table 2011-1-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.43	13:25:00	38	NA ^[k]	NA
Green 1	0	12:47:00	0	1	-1
Green 2	0	12:47:00	0	1	-1

Table 2011-1-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	1	1	0	0
Green 2	1	1	0	0

Comments:

Storm 2011-2, Jan 18-19, 2011

Table 2011-2-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
1/18/2011	23:23:00	1/19/2011	03:20:00	237

Table 2011-2-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
1/18/2011	48	32	Rain
1/19/2011	37	27	Rain

Table 2011-2-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	1/18/2011	23:23:00	1/19/2011	04:03:00	280
Green 1	1/18/2011	23:23:00	NF ^[j]	NF	NF
Green 2	1/18/2011	23:23:00	1/19/2011	04:03:00	280

Table 2011-2-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.81	43.88
Control Roof Flume	0.78	42.21

Table 2011-2-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	42.21
Green 1	NF
Green 2	0.49

Table 2011-2-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.3	23:24:00	1	NA ^[k]	NA
Green 1	NF	NF	NF	NF	NF
Green 2	0.26	00:21:00	58	0.14	1

Table 2011-2-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	NF	NF	NF	NF
Green 2	0.99	1	0	0.012

Comments:

Storm 2011-3, Jan 25, 2011

Table 2011-3-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
1/25/2011	03:15:00	1/25/2011	12:31:00	556

Table 2011-3-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
1/25/2011	36	30	Rain

Table 2011-3-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	1/25/2011	03:15:00	1/25/2011	15:41:00	746
Green 1	1/25/2011	03:15:00	NF ^[j]	NF	NF
Green 2	1/25/2011	03:15:00	1/25/2011	16:34:00	799

Table 2011-3-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.23	12.45
Control Roof Flume	0.21	11.43

Table 2011-3-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	11.43
Green 1	NF
Green 2	3.22

Table 2011-3-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.02	11:02:00	467	NA ^[k]	NA
Green 1	NF	NF	NF	NF	NF
Green 2	1.15	10:23:00	428	-50.36	0.71

Table 2011-3-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	NF	NF	NF	NF
Green 2	0.72	1.071	0.071	0.28

Comments:

Storm 2011-4, Jan 26, 2011

Table 2011-4-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
1/26/2011	11:30:00	1/26/2011	16:23:00	293

Table 2011-4-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
1/26/2011	34	25	Rain

Table 2011-4-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	1/26/2011	11:30:00	1/26/2011	17:27:00	746
Green 1	1/26/2011	11:30:00	NF ^[j]	NF	NF
Green 2	1/26/2011	11:30:00	1/26/2011	17:27:00	799

Table 2011-4-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.08	4.56
Control Roof Flume	0.08	4.56

Table 2011-4-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	4.56
Green 1	NF
Green 2	0

Table 2011-4-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.03	12:35:00	65	NA ^[k]	NA
Green 1	NF	NF	NF	NF	NF
Green 2	0	11:31:00	1	1	3.55

Table 2011-4-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	NF	NF	NF	NF
Green 2	1	1	0	0

Comments:

Storm 2011-5, Feb 27, 2011

Table 2011-5-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
2/27/2011	00:00:00	2/27/2011	13:28:00	808

Table 2011-5-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
2/27/2011	55	34	Rain

Table 2011-5-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	2/27/2011	00:00:00	2/27/2011	15:03:00	903
Green 1	2/27/2011	00:00:00	2/27/2011	17:51:00	1071
Green 2	2/27/2011	00:00:00	2/27/2011	17:51:00	1071

Table 2011-5-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.23	12.45
Control Roof Flume	0.23	12.45

Table 2011-5-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	12.45
Green 1	7.72
Green 2	0

Table 2011-5-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.13	06:14:00	374	NA ^[k]	NA
Green 1	0.02	15:15:00	915	0.83	2.45
Green 2	0	00:00:00	0	1	-1

Table 2011-5-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	0.38	1.19	0.19	0.62
Green 2	1	1.19	0.19	0

Comments:

Storm 2011-6, April 24, 2011

Table 2011-6-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
4/24/2011	09:56:00	4/24/2011	11:23:00	87

Table 2011-6-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
4/24/2011	67	59	Rain

Table 2011-6-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	4/24/2011	09:56:00	4/24/2011	12:15:00	139
Green 1	4/24/2011	09:56:00	4/24/2011	12:15:00	139
Green 2	4/24/2011	09:56:00	4/24/2011	12:15:00	139

Table 2011-6-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.05	2.7
Control Roof Flume	0.047	2.57

Table 2011-6-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	2.57
Green 1	0
Green 2	0

Table 2011-6-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.05	10:24:00	28	NA ^[k]	NA
Green 1	0	09:56:00	0	1	-1
Green 2	0	09:56:00	0	1	-1

Table 2011-6-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	1	0	-1	0
Green 2	1	0	-1	0

Comments:

Storm 2011-7, April 25, 2011

Table 2011-7-A Storm Duration Parameters

Storm Start Date	Storm Start Time	Storm End Date	Storm End Time	Storm Duration(min)
4/25/2011	15:54:00	4/25/2011	17:21:00	85

Table 2011-7-B Weather Condition for the Storm Event^[i]

Date	Max T(° F)	Min T(° F)	Event
4/25/2011	82	57	Rain

Table 2011-7-C Control Roof and Green Roof Runoff Parameters

Roof	Runoff Start Date	Runoff Start Time	Runoff End Date	Runoff End Time	Runoff Duration(min)
Control	4/25/2011	15:54:00	4/25/2011	18:43:00	169
Green 1	4/25/2011	15:54:00	4/25/2011	18:43:00	169
Green 2	4/25/2011	15:54:00	4/25/2011	18:43:00	169

Table 2011-7-D Rainfall Data from two Measurements Devices

Measurement Type	Depth (in)	Volume(ft ³)
Rain Gauge	0.13	7.04
Control Roof Flume	0.118	6.4

Table 2011-7-E Total Runoff Volume

Roof	Runoff Volume(ft ³)
Control	6.4
Green 1	0
Green 2	0

Table 2011-7-F Characteristics of Peak Flows

Roof	Qp ^[e] (cfm)	Time of Peak	Time to Peak ^[f] (min)	Qp Reduction ^[g]	Time to Peak Extension ^[h]
Control	0.46	15:54:00	0	NA ^[k]	NA
Green 1	0	15:54:00	0	1	-1
Green 2	0	15:54:00	0	1	-1

Table 2011-7-G Green Roof Water Retention Characteristics for Storm

Roof	Vol. Reduction ^[a]	Relative Duration ^[b]	Duration Extension ^[c]	Runoff Volume Ratio ^[d]
Green 1	1	0	-1	0
Green 2	1	0	-1	0

Comments:

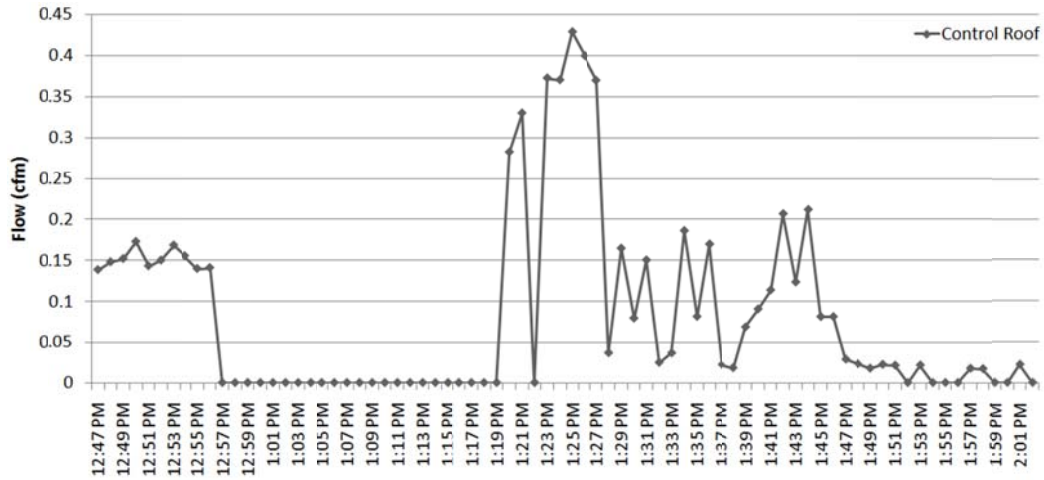


Figure 2011-1 Control Roof and Green Roof Discharge Hydrographs for Storm 2011-1, Jan 18, 2011

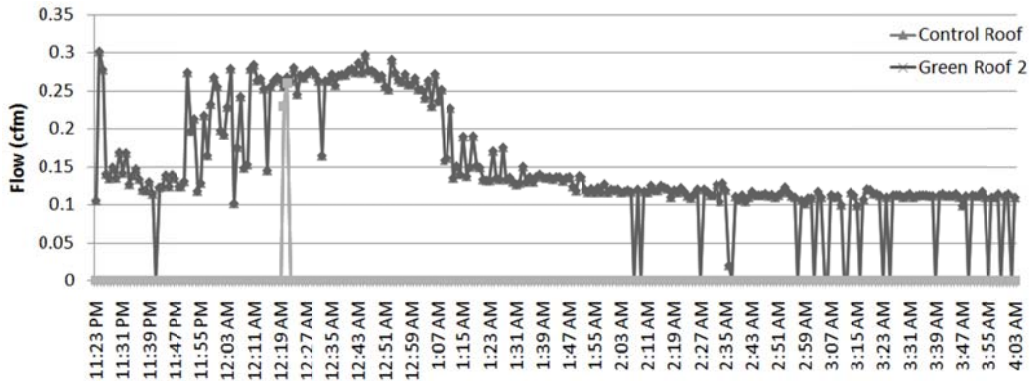


Figure 2011-2 Control Roof and Green Roof Hydrographs for Storm 2011-2, Jan 18-19, 2011

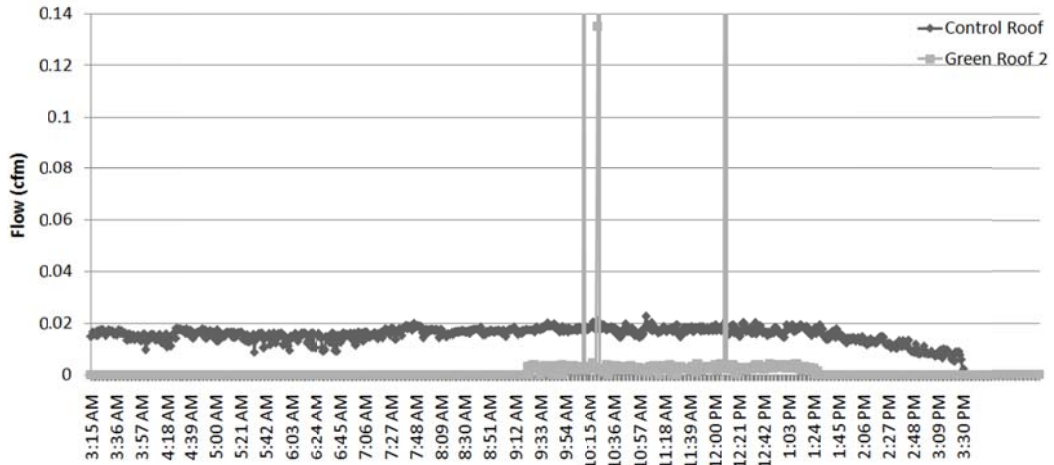


Figure 2011-3 Control Roof and Green Roof Discharge Hydrographs for Storm 2011-3, Jan 25, 2011

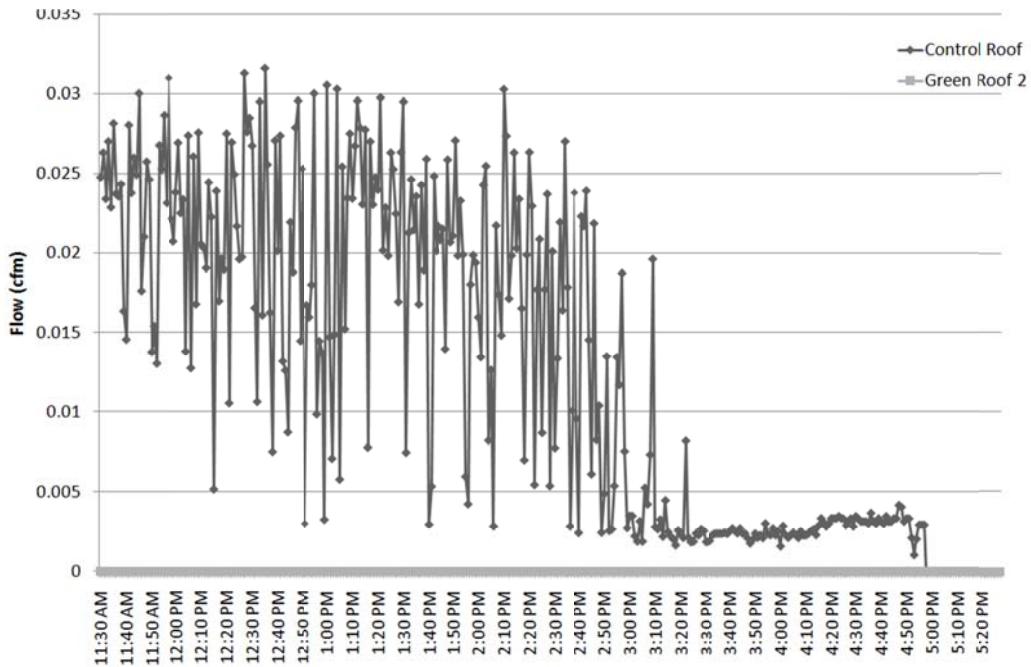


Figure 2011-4 Control Roof and Green Roof Hydrographs for Storm 2011-4, Jan 26, 2011

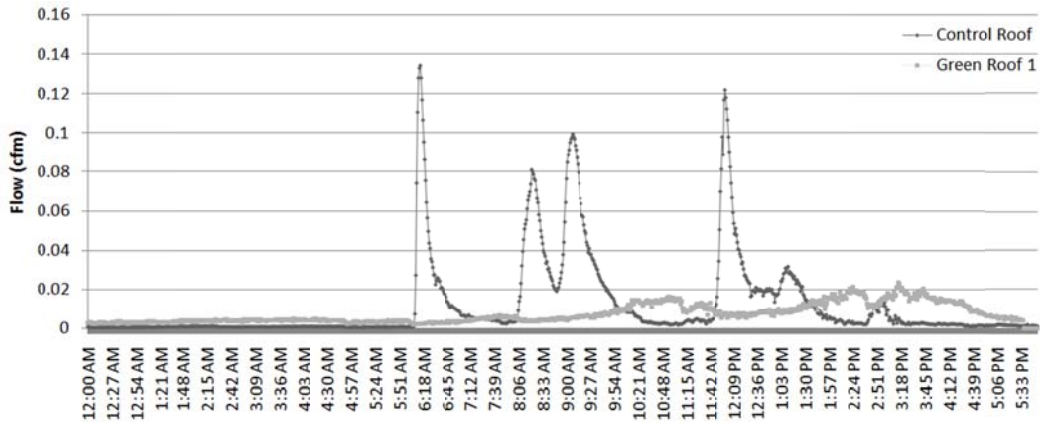


Figure 2011-5 Control Roof and Green Roof Discharge Hydrographs for Storm 2011-5, Feb 27, 2011

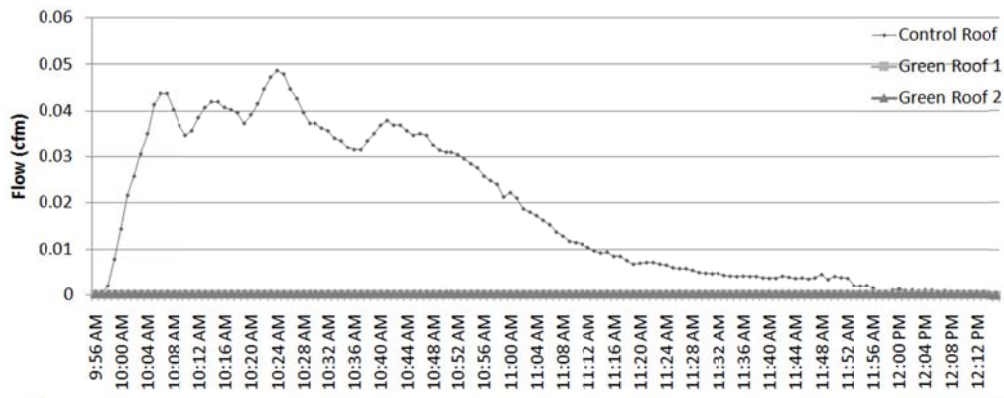


Figure 2011-6 Control Roof and Green Roof Discharge Hydrographs for Storm 2011-6, 4/24/2011

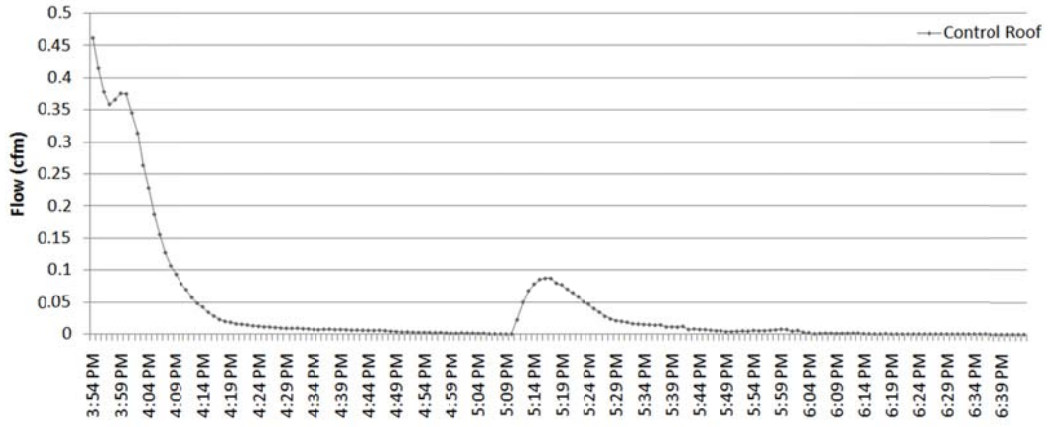


Figure 2011-7 Control Roof and Green Roof Discharge Hydrographs for Storm 2011-7, April 25, 2011