Edith J. Carrier Arboretum
Weather and Stormwater Flow Report

[April 15th 2011 - July 31st 2012]

A report summarizing the weather events and resulting flow data from spring 2011 to summer 2012 in the Edith J. Carrier Arboretum at James Madison University

April 1, 2013

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Background

The Edith J. Carrier Arboretum and Botanical Gardens at James Madison University are valued aesthetic, educational, and environmental resources for the University and the Harrisonburg area. The Arboretum's 125 acres of natural forest and botanical gardens serve as an outdoor biology laboratory as well as an environmental center for the region.

A portion of the Arboretum property lies within the floodplain of an intermittent urban stream that drains approximately 600 acres. When the Arboretum was constructed in 1985, the design incorporated a pond and dry detention area that would serve dual purposes. During dry conditions, the pond would provide an aesthetic amenity and wildlife habitat. During wet weather, the area would provide stormwater detention to reduce on-campus flooding. Since 1985, urban and residential development within the watershed has increased dramatically, and the frequency and severity of flooding in the Arboretum has proportionally increased. This increase in the frequency and severity of flooding has impacted the dual use of this portion of the Arboretum and has increased overall maintenance costs.

The Director of the Arboretum has indicated a desire to redesign the Arboretum's water conveyance system to better manage stormwater, reduce flooding, and maintain aesthetic appeal. She has assembled an ad hoc committee of ISAT faculty, Geology faculty, and University and City of Harrisonburg stormwater professionals to discuss options for redesign of the Arboretum. The first critical need identified by this committee was a lack of monitoring information to characterize current stormwater flow conditions. In Spring 2011, a CISAT mini grant was awarded to purchase monitoring equipment for this purpose. A grant from Dr. Ron Carrier was also awarded to establish an internship position that would be devoted to monitoring in the Arboretum.

This report summarizes monitoring efforts conducted from Spring 2011 to Summer 2012. During this time period, a total of 39 individual storm events were monitored.

Monitoring

Meteorological Data

To provide meteorological monitoring, a Davis Instruments Vantage Pro 2 Weather Station was installed in the Arboretum outside of the Francis Plecker Education Center. The weather station was installed on May 13, 2011 and has been collecting continuous data since June 5, 2011. Table 1 summarizes the suite of parameters monitored by the weather station at 15-minute intervals.

Table 1. Meteorological Parameters Measured in the Arboretum.

Meteorological Parameters	Units	Description (if necessary)
Date		
Time		
Temperature	°F	
High Temperature	°F	Instantaneous high temperature during monitoring period (15 min)
Low Temperature	°F	Instantaneous low temperature during monitoring period (15 min)
Humidity	%	
Dew Point	°F	
Wind Speed	Mph	
Wind Direction	Compass direction	
Wind Run	Miles of wind	Amount of wind passing the station during monitoring period (15 min)
High Wind Speed	Mph	Instantaneous high wind speed during monitoring period (15 min)
High Wind Direction	Compass direction	Direction of highest instantaneous wind
Wind Chill	°F	"Felt" temperature due to wind
Heat Index	°F	"Felt" temperature due to humidity
THW Index	°F	"Felt" temperature due to wind and humidity
Barometric Pressure	Inches of mercury	
Rainfall	Inches	Cumulative rainfall during the monitoring period (15 min)
Rainfall Rate	Inches/hr	Amount of rainfall within the monitoring period extrapolated to an hourly rate
Heating Degree Days	°F (d)	Amount of heating required to reach room temperature
Cooling Degree Days	°F (d)	Amount of cooling required to reach room temperature
Indoor Temperature and Humidity Readings		Measurements taken at the location of the data receiver (inside the Education Center)

Hydrologic Data

To measure flows in various Arboretum drainage ways, six HOBO Water Level Sensors were purchased and installed. Sensors were installed in the five locations identified in Figure 1 and Table 2. Sensors were mounted at the bottom of storm sewer pipes with concrete drop-in anchors and security bolts. One additional sensor was installed in a tree to obtain ambient atmospheric pressure for comparison. The Outlet sensor and reference sensor were installed on 4/15/2011, and the remaining sensors were installed on 5/13/2011. Sensors were removed on 12/17/2011 to avoid damage of the sensors due to winter freezing conditions. Sensors were redeployed on 3/21/2012 when the threat of sustained freezing temperatures was minimal. During deployment, sensors were programed to record at 15-minute intervals.

Pressure measurements recorded by the HOBO sensors were corrected for atmospheric pressure and translated to water level data using HOBOware software. Water level data were downloaded and stored in Microsoft Excel. Within Microsoft Excel software, water level data were converted to a discharge (or flow) at each location using Manning Equation:

$$Q = A \times \frac{1.486}{n} \times R^{\frac{2}{3}} \times S^{\frac{1}{2}}$$

Where,

Q = discharge (cfs)

A = Cross sectional area of flow (ft^3)

n = Manning roughness coefficient

R = Hydraulic radius (ft)

S = Slope of pipe (ft/ft)

Table 2. Description of Water Depth Sensor Locations Within the Arboretum.

Location	Pipe Description	Pipe Diameter (ft)	Pipe Slope (ft/ft)	Mannings Roughness Coefficient
Inlet	Rectangular, concrete	12	0.00147	0.022
Costco	Circular, concrete	1	0.0238	0.012
Sinclair	Dual circular, concrete	0.75	0.0670	0.014
Outlet	Circular, concrete	2.5	0.0181	0.012
Road	Circular, corrugated plastic	0.75	0.0637	0.009

Figure 1. Location of Water Depth Sensors in the Arboretum.

Data and Results

Continuous Record

Precipitation and flow data were collected at 15-minute intervals from 4/15/2011 to 12/17/11 and from 3/21/12 to 7/31/2012. With a total of 21 meteorological parameters and 6 flow sensors recording at each interval, this equated to approximately 1.1 million data points collected during this time period. Figures 2 and 3 show the continuous records of precipitation and flow at each of the monitoring locations.

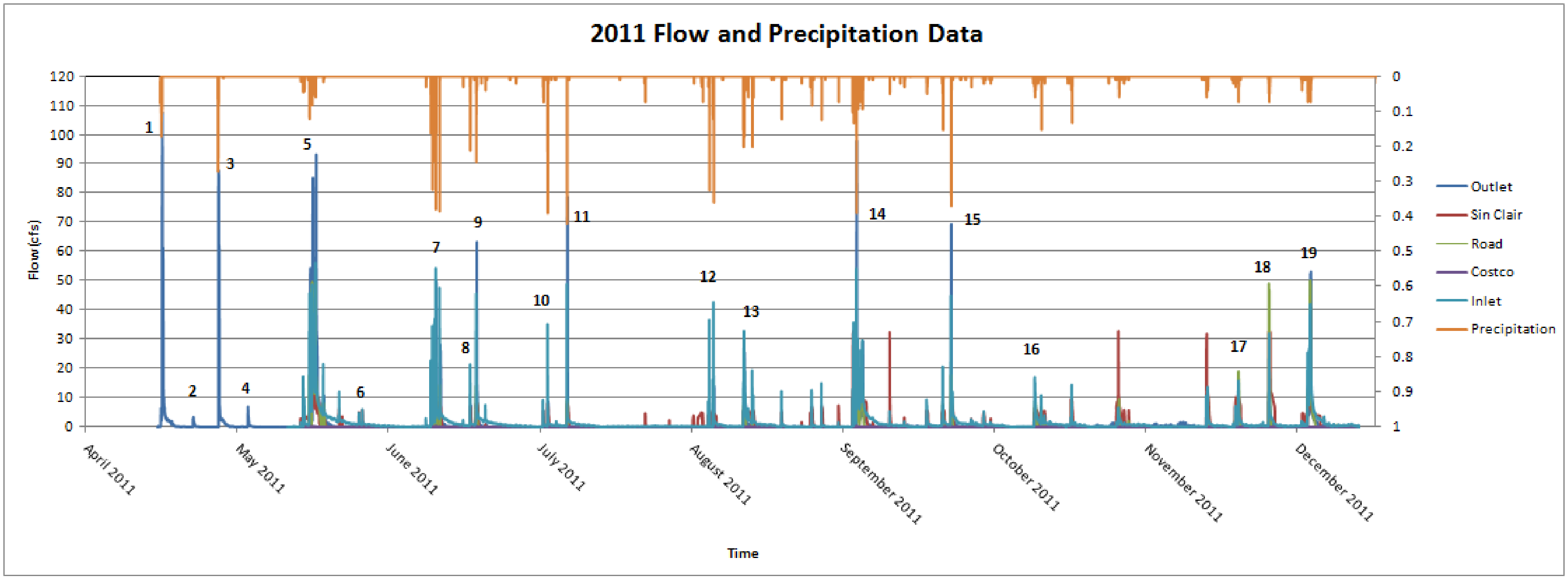

Figure 2. 2011 Precipitation and flow data collected in the JMU Arboretum.

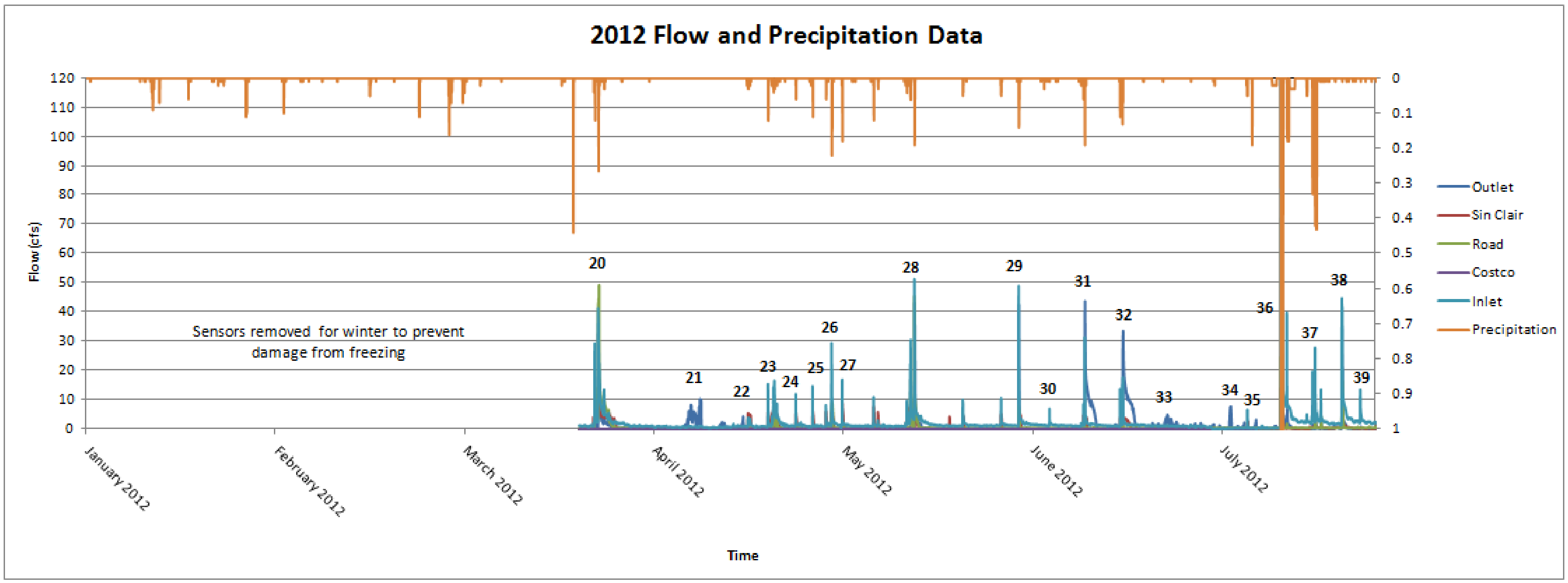

Figure 3. 2012 Precipitation and flow data collected in the JMU Arboretum.

Storm Event Analysis

Precipitation and flow data were analyzed to identify individual storm events within the Arboretum. Storm events were identified in the database as periods of flow in the Arboretum Outlet that exceeded 2 cfs. The beginning of the storm event was the time at which flow first exceeded 2 cfs and the end of the storm event was the time at which flow decreased to pre-storm levels.

Based on this analysis, 39 storm events were identified in the Arboretum from 4/15/2011 to 7/31/2012. Table 3 identifies the date, duration, and rainfall amounts from each of these storm events. Of the identified storms, 10 (storms 21-23, 32-35, and 37-39) had increased flow but no recorded precipitation. This could be due to 1) malfunction of the weather station, 2) rain that occurred within the watershed, but not at the precise location of the weather station, or 3) non precipitation events within the Arboretum that could cause flow (such as irrigation). Most of these events were small (<10 cfs), with the exception of storm 38, which recorded a flow of 34.2 cfs. In addition to the 10 storms with no recorded precipitation, known malfunction of the weather station accounted for missing precipitation data for Storms 2, 4 and 6.

Of the 26 storm events with recorded rainfall, all exhibited at least 0.24 inches of precipitation, most (77%) exhibited rainfall of more than 0.5 inches, and half (13) exhibited rainfall of more than 1 inch. The largest event was on 7/14/12, where 3.12 inches of rain were recorded. This event caused significant flooding on campus.

Table 3. Precipitation Data for Identified Storm Events in the JMU Arboretum.

Storm Precipitation Data					
Storm Number	**Start Date**	**End Date**	**Length of Rainfall (Days:Hr:Min)**	**Total Rainfall (in)**	**Samples Taken**
1	4/16/2011	4/16/2011	0:10:15	1.48	Yes
2	4/22/2011	4/23/2011			No
3	4/27/2011	4/29/2011	1:5:00	1.46	Yes
4	5/4/2011	5/5/2011			No
5	5/15/2011	5/20/2011	4:19:45	2.86	Yes
6	5/23/2011	5/23/2011			No
7	6/10/2011	6/12/2011	1:20:45	2.38	No
8	6/18/2011	6/18/2011	0:2:30	0.54	No
9	6/19/2011	6/20/2011	0:7:00	1.00	No
10	7/4/2011	7/4/2011	0:3:00	0.54	No
11	7/8/2011	7/9/2011	0:10:30	0.91	No

12	8/7/2011	8/7/2011	0:3:15	0.55	No
13	8/13/2011	8/15/2011	2:1:45	2.46	No
14	9/5/2011	9/7/2011	2:3:00	3.34	No
15	9/23/2011	9/28/2011	4:22:00	1.48	No
16	10/11/2011	10/13/2011	1:11:45	0.89	No
17	11/22/2011	11/23/2011	0:11:30	0.29	No
18	11/29/2011	11/29/2011	0:7:00	0.76	No
19	12/7/2011	12/7/2011	0:20:30	1.46	No
20	3/24/2012	3/28/2012	4:16:45	1.86	No
21	4/8/2012	4/10/2012			No
22	4/14/2012	4/14/2012			No
23	4/17/2012	4/17/2012			No
24	4/22/2012	4/23/2012	1:6:15	1.08	No
25	4/26/2012	4/26/2012	0:2:30	0.25	No
26	5/2/2012	5/2/2012	0:5:30	0.43	No
27	5/3/2012	5/3/2012	0:3:00	0.24	No
28	5/14/2012	5/15/2012	0:22:15	1.23	No
29	6/1/2012	6/2/2012	0:7:30	0.93	No
30	6/12/2012	6/12/2012	0:4:15	0.30	No
31	6/18/2012	6/18/2012	0:2:30	0.38	No
32	6/25/2012	6/26/2012			No
33	6/27/2012	6/27/2012			No
34	7/6/2012	7/6/2012			No
35	7/10/2012	7/10/2012			No
36	7/14/2012	7/16/2012	1:9:00	3.12	No
37	7/20/2012	7/20/2012			No
38	7/24/2012	7/25/2012			No
39	7/31/2012	8/1/2012			No

For each storm event, the total volume of discharge and the peak discharge was also calculated and recorded (Table 4). During the 4/15/2011 to 7/31/2012 period, the median storm event had a peak flow of 10.3 cfs and totaled 251,000 cf in total discharge. The average storm, which is skewed by the largest events, had a peak flow of 36.1 cfs and totaled 721,000 cf in total discharge. The storm with the largest peak flow (301 cfs) was the 3.12 inch event on 7/14/2012. The storm with the largest calculated volume was the more extended 4-day event on 5/15/2011 – 5/20/11, with a total of 4,366,129 cf.

Table 4. Storm Flow Data for the JMU Arboretum.

Storm Flow Data			
Storm Number	**Length of Increased Flow (Days:Hr:Min)**	**Total Water Volume (cf, Measured at Arboretum Outlet)**	**Peak Flow (cfs)**
1	2:23:15	2141088.74	107.3534903
2	1:1:00	76618.94	3.407581949
3	3:0:45	1158393.54	87.73044476
4	1:4:30	111939.06	7.068073956
5	5:10:15	4366129.04	93.33649214
6	0:7:30	26451.93	3.538479689
7	5:14:45	1166345.89	50.15000731
8	0:5:45	44071.44	7.450659879
9	1:11:00	523007.28	63.42891689
10	0:17:00	52139.20	8.729921766
11	0:18:15	273296.39	78.3939888
12	0:14:00	73279.85	14.01341995
13	2:10:00	2713835.55	25.80531425
14	6:3:15	1759654.00	97.7865352
15	5:0:45	528262.50	69.29544841
16	1:3:15	105033.04	6.156595567
17	1:9:30	76599.15	6.333747675
18	2:3:15	226648.91	16.51280287
19	4:1:15	1868601.31	53.36351104
20	5:22:15	1075354.77	39.64628639
21	2:7:30	937712.31	10.33948508
22	0:13:45	80252.74	2.362240825
23	0:5:30	45963.08	4.30424575
24	1:0:45	251148.11	7.386181913
25	0:2:45	15248.70	2.694962638
26	0:13:45	81486.56	8.280702228
27	1:11:00	38137.55	2.810958445
28	1:23:00	858813.78	43.15051359
29	0:19:15	253044.72	42.54454444
30	2:5:00	1688787.70	43.76035318
31	2:10:45	1967236.12	33.5207897
32	1:8:45	324656.00	4.857913873
33	0:5:00	36159.81	2.544261876
34	0:9:00	167736.00	7.777329803
35	0:3:30	28138.62	3.23703317

36	1:20:15	2348680.21	300.6158191
37	0:9:45	42938.34	4.040365627
38	1:0:30	447590.32	34.2006484
39	0:21:30	150038.26	10.1119107

The relationship between precipitation and total runoff volume or peak flow is complicated and depends on the duration and intensity of rainfall, the antecedent moisture conditions, soil type, watershed land use characteristics, temperature, and many other factors. In general, however, the relationship between precipitation and total runoff volume fit an exponential curve (Figure 4). While a complete hydrologic model of the watershed would be needed to more accurately predict the volumes and peak flows of certain precipitation events, these exponential regressions can be used to provide ballpark estimates of runoff volumes and peak flows in the Arboretum. Based on these regressions, a 10-inch rain event (possible in hurricane remnant storms) would generate approximately 30 million cubic feet of runoff and peak flows of approximately 630 cfs.

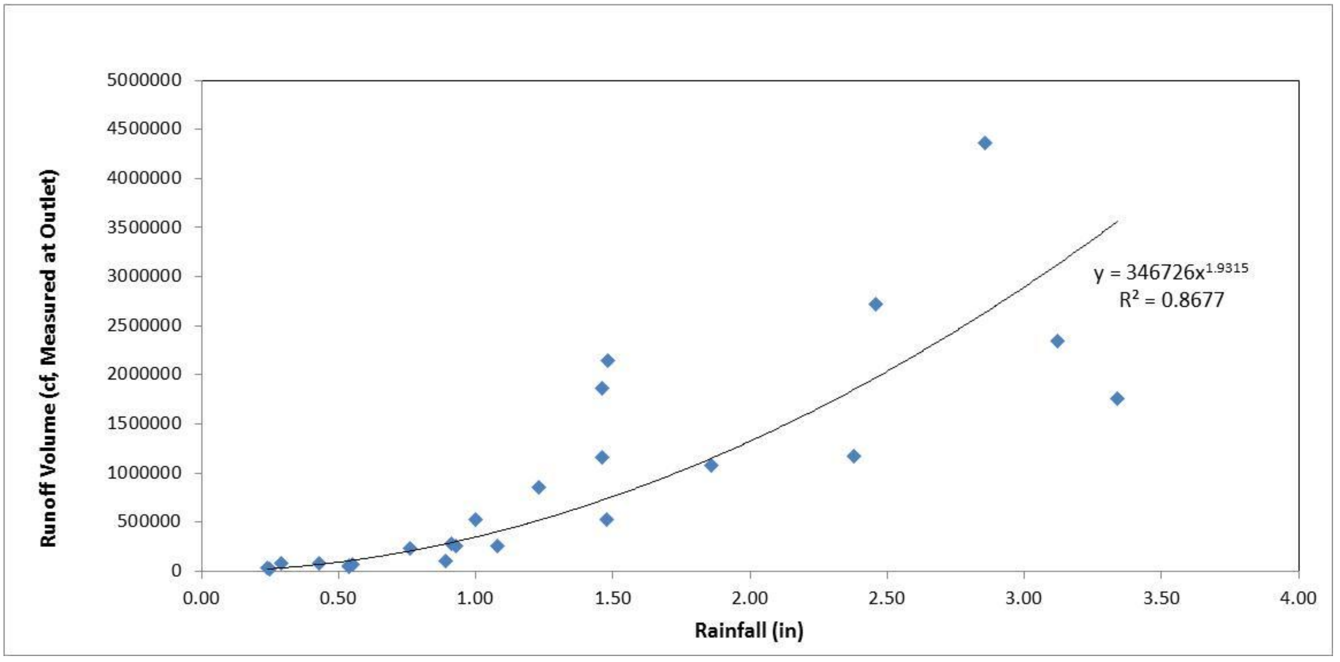

Figure 4. Relationship between precipitation and total runoff volume.

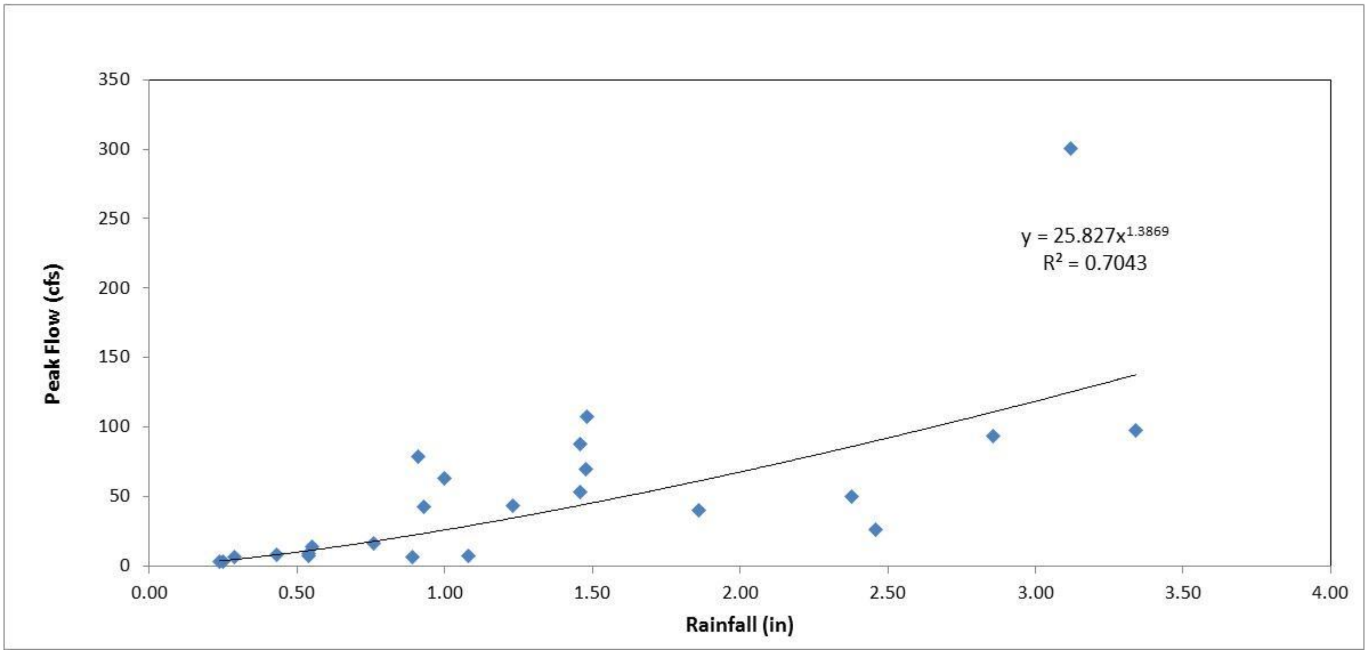

Figure 5. Relationship between precipitation and peak flow.

A cumulative probability distribution function was also developed for the JMU Arboretum outlet location. This function describes the cumulative probability of flows exceeding a given value. For most of the time, there is no flow in the Arboretum outlet. The probability of measurable flow (>2 cfs) in the Arboretum outlet was only 6.6%. This means that only 6.6% of the time is measureable flow present in the Arboretum outlet. The probability of flows exceeding 100 cfs is only 0.1%.

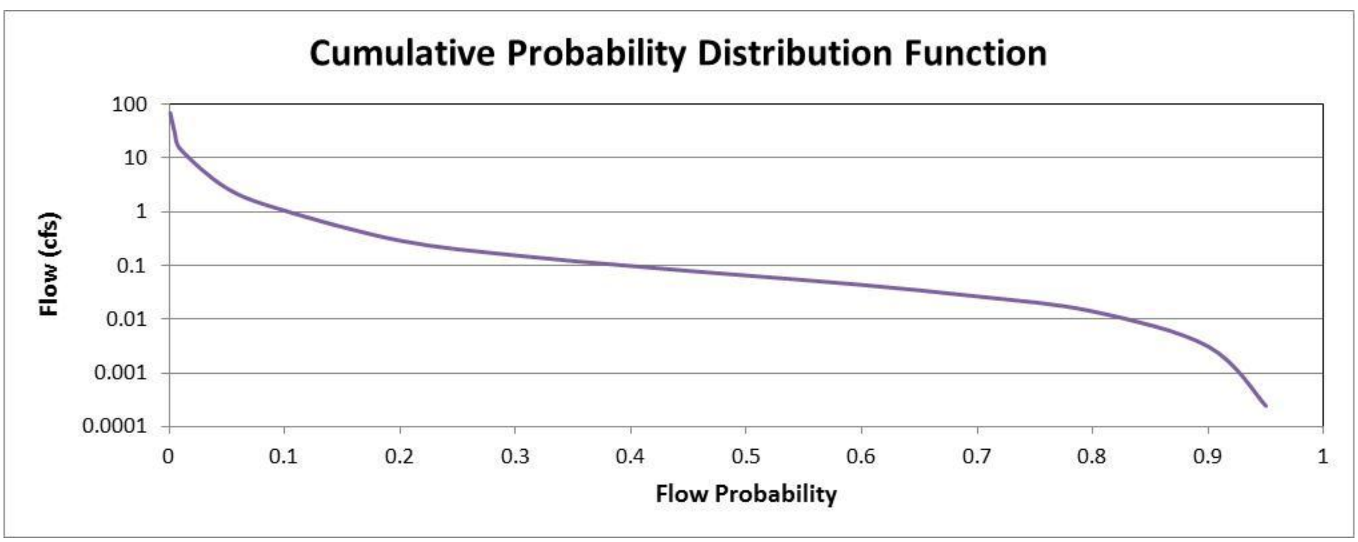

Figure 6. Cumulative probability distribution function for flows in the JMU Arboretum.

Flow Contributions

Flows were monitored within 4 separate inlets to the Arboretum: the main inlet under Neff Avenue (Inlet), runoff from the Costco parking lot (Cosco), runoff through the Sinclair Gardens (Sinclair), and runoff alongside University Boulevard (Road). Flows into the Arboretum were summed over the entire monitoring period, and percent contributions of each inlet were calculated (Figure 7). The main inlet location under Neff Avenue accounted for the majority (58%) of the flow into the Arboretum. Flows from the Sinclair Gardens contributed 28%, and the Road location contributed 14% of the flow. Flows from the Costco location accounted for less than 1% of flows into the Arboretum.

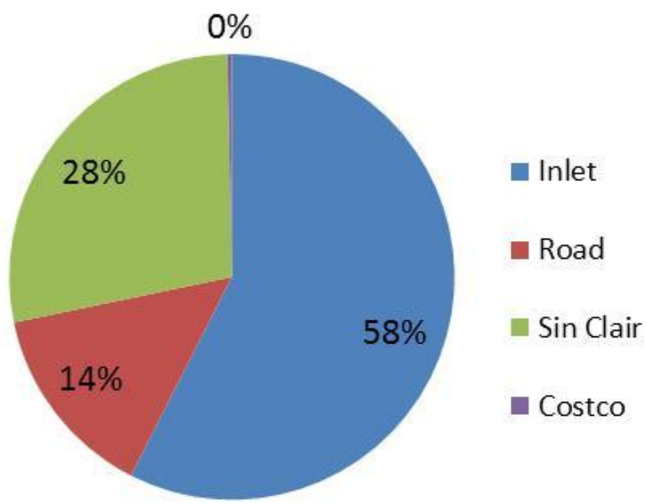

Figure 7: Percentage of total inlet flows during rain events.