URBAN DRAINAGE AND FLOOD CONTROL DISTRICT

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SUMMARY REPORT

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SUBJECT: Water quality summary report of the EPA Alliance Center Control Roof

DATE: July 7, 2015

In 2011, Urban Drainage and Flood Control District (UDFCD) partnered with the non-profit organization Alliance for Sustainable Colorado to monitor the aggregate rooftop of the Alliance Center located at 1536 Wynkoop Street in Denver, Colorado. UDFCD collected, measured, and analyzed runoff from the roof to better understand the characteristics of stormwater runoff from a conventional aggregate roof located in downtown Denver.

From 2011 to 2013, UDFCD was responsible for monitoring the 0.15 acre aggregate rooftop of the Alliance Center. A rain gage and anemometer were used to measure rainfall and wind speed at the site. Wind speed was used to correct and calibrate the measured rainfall volumes with a higher accuracy due to the rooftop sampling location. Both rainfall and wind speed were measured from similar points on the roof (as seen in Figure 1).

At ground level of the south-corner of the building, located in the alley between Wynkoop St. and Wazee St., UDFCD used an automated ISCO water quality sampler and an V-notch flume apparatus to collect composite samples and measure flow rates. Both the water quality sampler and V-notch flume apparatus were protected from any outside urban pollutants by two large job boxes that housed the sampling equipment at the base of the building. It should be noted that, due to space constraints, the flume is located just 12 inches from a 90° bend in the downspout. This likely reduces the accuracy of flow measurements. Samples were collected after each storm event and transported to the lab for water quality analyses. Composite samples from each storm event are analyzed for a number of constituents. Data was collected for all storm events that occur during the months of April through October. UDFCD has used data collected from this site for comparison with alternative roof types such as green roofs. Comparisons include effectiveness of reducing flows and stormwater runoff quality.

Figure 1 - Rain Gage and Anemometer located on rooftop of Alliance Center

Data Analysis

The following report is divided into two sections–flow and water quality. Flow corresponds to the calculated (precipitation corrected for wind speed over the roof area) and measured (at the V-notch) runoff for different storm events. Data is provided for each of the years, 2011, 2012, and 2013. Water quality data corresponds to the composite samples taken during each of the storms analyzed. Note that runoff at this site is only in contact with any atmospheric deposition and surface particles from the aggregate roof and from the downspout.

1. Flow

   The following section in the report provides all calculated and measured runoff data for the three years on record, 2011-2013. In addition to the volume comparisons plots between the calculated and measured runoff volume, all collected data is also provided for each of the storm events during the monitoring period. Figures 2-4 provide volume comparisons for the 2011, 2012, and 2013 sampling seasons. Tables 1-3 provide all relevant event data collected for each storm event analyzed for the monitored years and used to generate the plots shown. The final correlation summary is provided for calculated vs. measured runoff volumes in Figure 5.

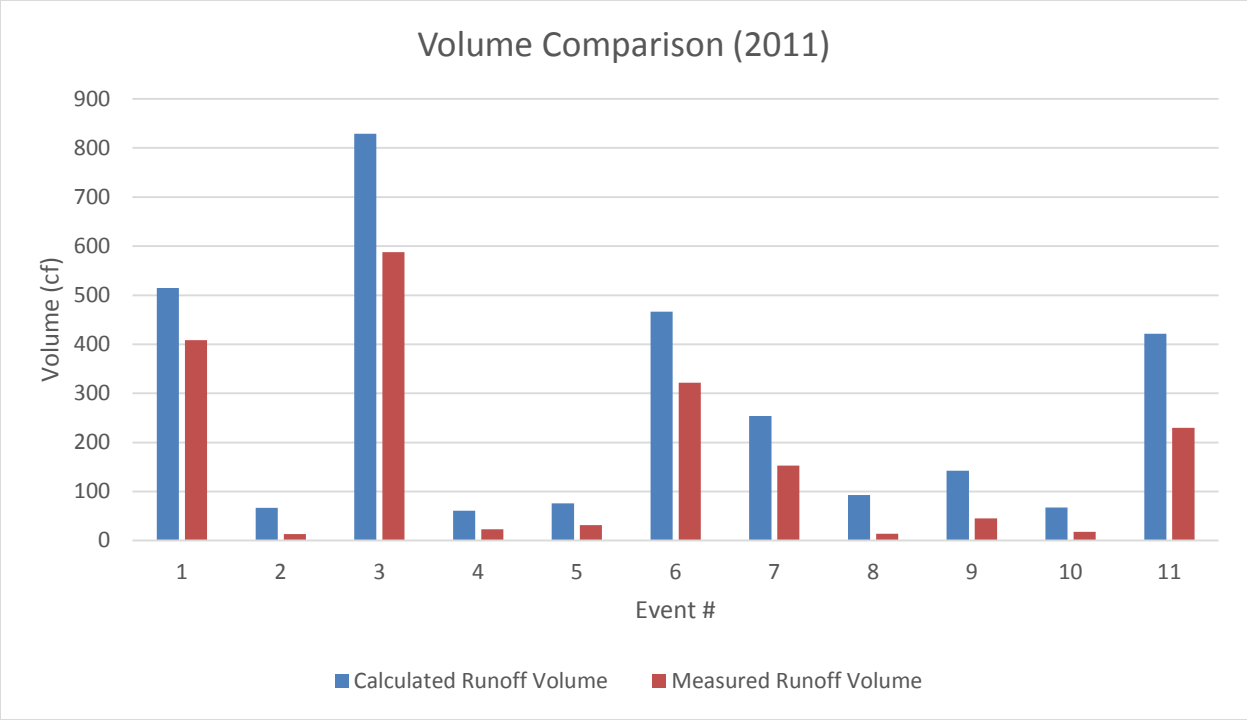

Figure 2 - Calculated vs. Measured Volume Storm Event Comparisons (2011)

Table 1 - Flow Data for Storm Events (2011)

Storm Event	Start Date	Start Time	End Date	End Time	Flow Duration [hours]	Wind Calibrated Rainfall [in]	Peak One Hour Intensity [in/hr]	Calculated Runoff Volume [cf]	Measured Runoff Volume [cf]	Percent Reduction [%]
1	6/20/11	1:58	6/20/11	10:58	9:00	0.75	0.21	514.9	408.6	-21%
2	6/30/11	22:07	7/1/11	0:26	2:19	0.10	0.07	67.0	13.3	-80%
3	7/7/11	16:48	7/8/11	0:49	8:01	1.21	0.94	829.2	587.7	-29%
4	7/8/11	19:46	7/8/11	21:15	1:29	0.09	0.09	60.7	23.3	-62%
5	7/11/11	18:39	7/11/11	20:39	2:00	0.11	0.09	75.7	31.6	-58%
6	7/12/11	21:29	7/12/11	23:49	2:20	0.68	0.63	466.5	322.0	-31%
7	7/13/11	18:34	7/13/11	23:55	5:21	0.37	0.37	253.9	152.5	-40%
8	7/19/11	6:27	7/19/11	19:55	13:28	0.14	0.14	93.0	14.1	-85%
9	7/26/11	18:21	7/26/11	20:12	1:53	0.21	0.21	142.5	45.2	-68%
10	9/7/11	13:44	9/7/11	15:46	2:02	0.10	0.08	67.2	17.9	-73%
11	9/14/11	18:59	9/15/11	2:56	7:57	0.62	0.15	421.6	229.8	-45%
									Average Reduction	-54%

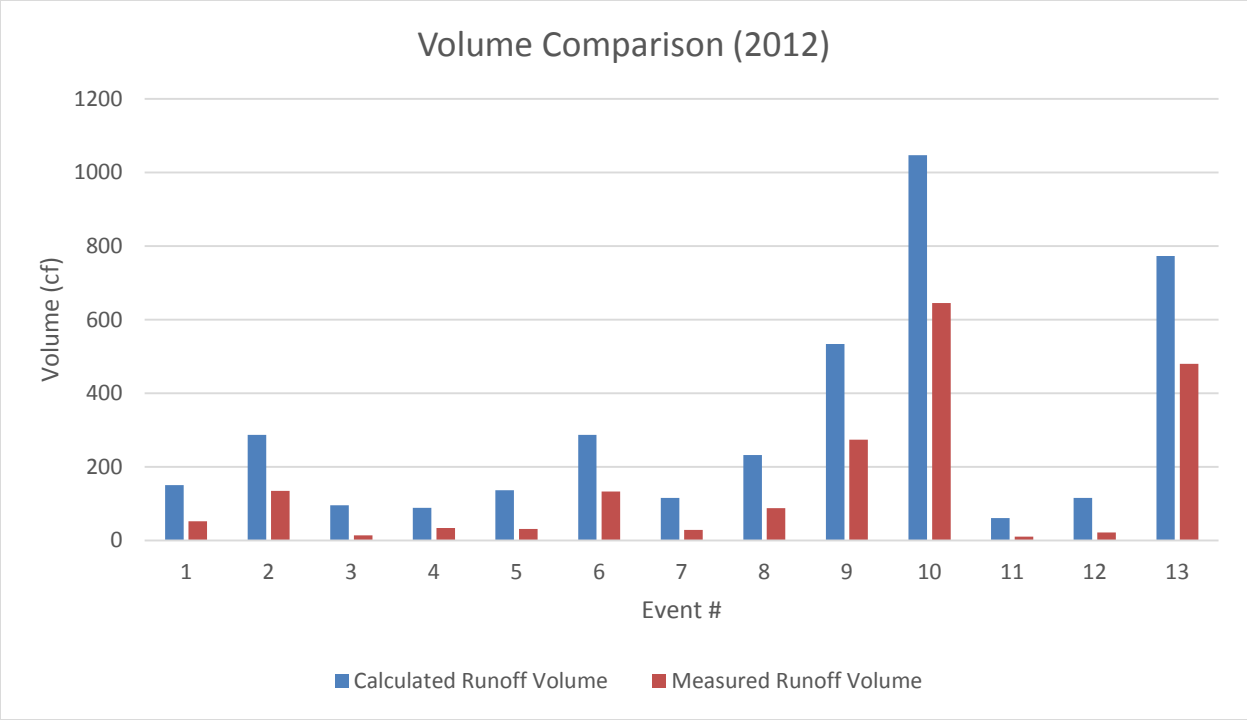

Figure 3 - Calculated vs. Measured Volume Storm Event Comparisons (2012)

Table 2 - Flow Data for Storm Events (2012)

Storm Event	Start Date	Start Time	End Date	End Time	Flow Duration [hours]	Wind Calibrated Rainfall [in]	Peak One Hour Intensity [in/hr]	Calculated Runoff Volume [cf]	Measured Runoff Volume [cf]	Percent Reduction [%]
1	5/5/12	21:48	5/5/12	23:18	1:30	0.22	0.21	150.5	52.4	-65%
2	5/6/12	21:45	5/7/12	14:08	16:23	0.42	0.09	287.4	134.8	-53%
3	5/11/12	16:02	5/11/12	23:10	7:08	0.14	0.09	95.8	13.9	-85%
4	5/12/12	20:07	5/12/12	22:21	2:14	0.13	0.13	89.0	34.3	-61%
5	5/19/12	6:20	5/19/12	13:10	6:50	0.20	0.13	136.9	31.3	-77%
6	5/23/12	17:49	5/24/12	0:41	6:52	0.42	0.15	287.4	133.0	-54%
7	6/7/12	0:49	6/7/12	2:39	1:50	0.17	0.14	116.3	29.3	-75%
8	7/6/12	21:40	7/7/12	4:09	6:29	0.34	0.13	232.6	88.3	-62%
9	7/7/12	16:35	7/8/12	7:23	14:48	0.78	0.30	533.7	274.2	-49%
10	7/9/12	7:36	7/9/12	13:22	5:46	1.53	0.87	1046.9	645.6	-38%
11	7/16/12	21:54	7/16/12	23:15	1:21	0.09	0.07	61.6	10.9	-82%
12	7/31/12	14:02	7/31/12	15:15	1:13	0.17	0.17	116.3	22.0	-81%
13	9/12/12	2:00	9/12/12	14:14	12:14	1.13	0.20	773.2	480.4	-38%
									Average Reduction	-63%

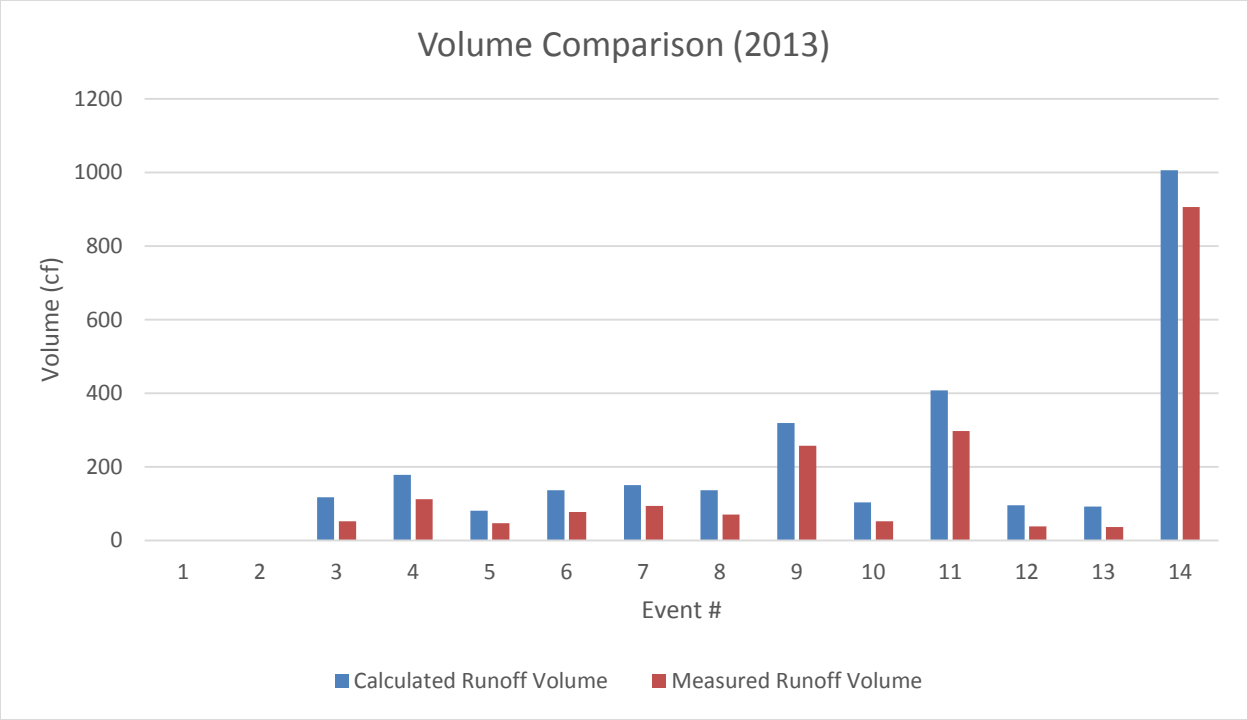

Figure 4 - Calculated vs. Measured Volume Storm Event Comparisons (2012)

Table 3 - Flow Data for Storm Events (2013)

Storm Event	Start Date	Start Time	End Date	End Time	Flow Duration [hours]	Wind Calibrated Rainfall [in]	Peak One Hour Intensity [in/hr]	Calculated Runoff Volume [cf]	Measured Runoff Volume [cf]	Percent Reduction [%]
1	5/8/13	-	-	-	-	-	-	-	-	-
2	5/9/13	-	-	-	-	-	-	-	-	-
3	5/15/13	16:58	5/15/13	19:11	2.22	0.17	0.17	117.6	52.7	-55%
4	5/29/13	6:10	5/29/13	13:30	7.33	0.26	0.19	178.5	112.5	-37%
5	6/4/13	18:20	6/5/13	3:10	8.83	0.12	0.10	80.9	47.4	-41%
6	6/23/13	19:50	6/23/13	23:10	3.33	0.20	0.15	136.5	77.7	-43%
7	6/28/13	22:20	6/29/13	0:30	2.17	0.22	0.22	150.5	94.5	-37%
8	7/11/13	21:05	7/12/13	0:25	3.33	0.20	0.18	136.7	71.1	-48%
9	7/13/13	17:55	7/13/13	22:10	4.25	0.47	0.38	319.7	257.4	-19%
10	7/27/13	20:00	7/28/13	0:50	4.83	0.15	0.10	103.6	52.5	-49%
11	8/3/13	19:10	8/3/13	21:40	2.50	0.60	0.54	407.9	297.6	-27%
12	8/8/13	17:30	8/8/13	20:10	2.67	0.14	0.13	95.5	38.4	-60%
13	8/12/13	20:10	8/13/13	5:25	9.25	0.14	0.05	92.7	36.9	-60%
14	9/10/13	15:10	9/12/13	11:15	44.08	1.47	0.35	1006.0	906.6	-10%
									Average Reduction	-41%

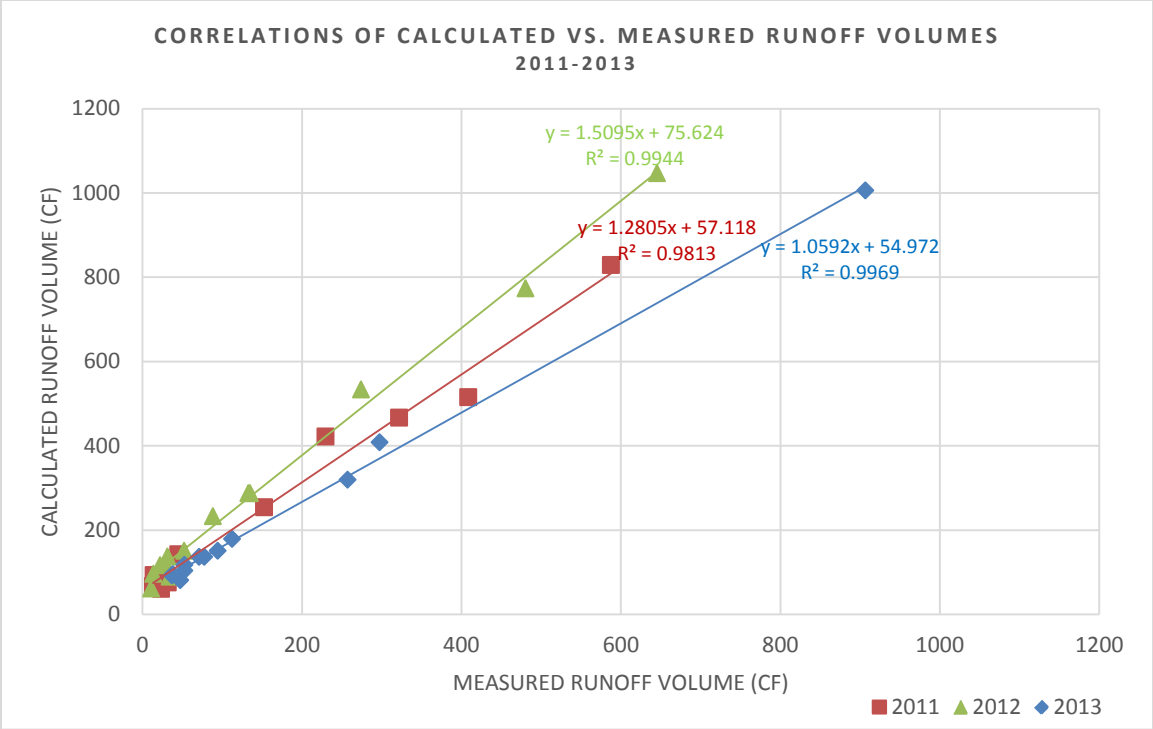

Figure 5 - Correlations for Calculated vs. Measured Runoffs (by year)

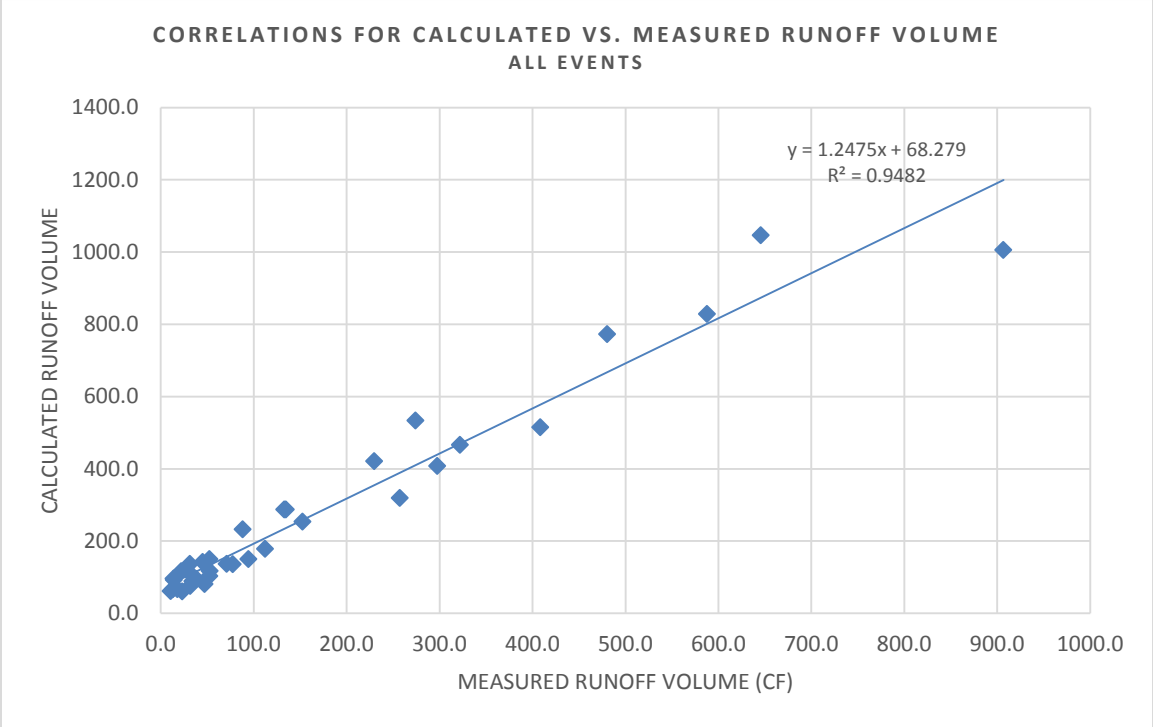

Figure 6 - Correlation for Calculated vs. Measured Runoff Volumes (all years)

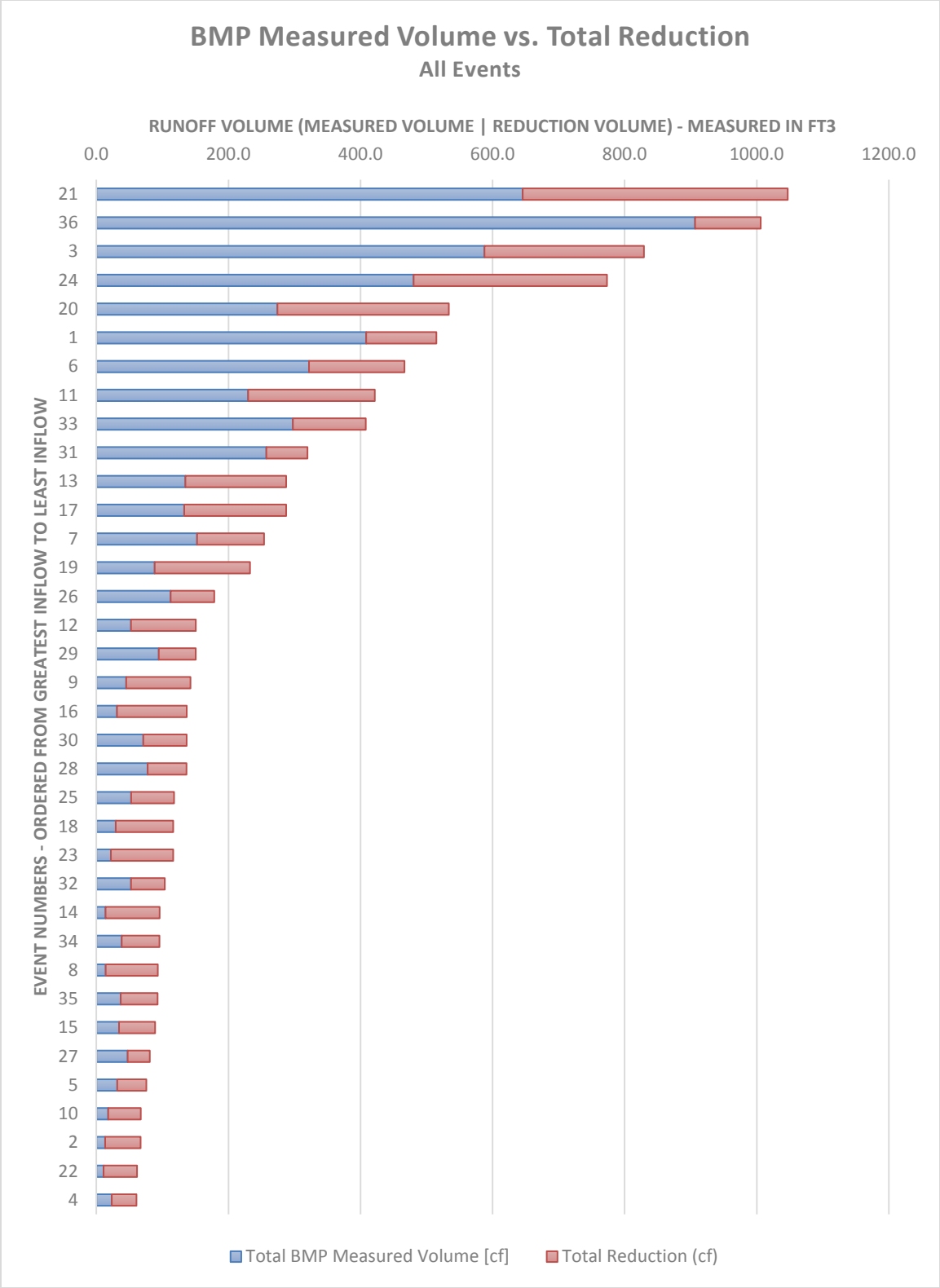

Figure 7 - Summary of BMP Measured Volume vs. Reduction Volume (ordered by greatest to least inflow)

2. Water Quality

The following section of this report provides a summary of all water quality data that was collected from the Alliance Center rooftop through UDFCD monitored stormwater sampling procedures. There are a total of 14 constituents provided within this analysis. Each constituent was analyzed for all storm events to determine event mean and event median concentrations found in the stormwater runoff of the conventional aggregate roof. The list of constituents can be seen in Table 4 along with event mean and event median concentrations and the corresponding 95% confidence intervals.

Table 4 - Summary of Water Quality Analysis for Alliance Center (All Events)

Conventional Aggregate Roof (Alliance Center)				
Analyte	**Units**	**n**	**Mean (95% CIs)**	**Median (95% CIs)**
Total Kjeldahl Nitrogen	mg/L	27	1.93 (1.59-2.27)	1.8 (1.6-2.1)
Nitrate Plus Nitrite	mg/L	27	2.79 (2.24-3.33)	2.55 (1.91-3.44)
Ammonia Nitrogen as N	mg/L	14	0.75 (0.55-0.95)	0.83 (0.5-1)
Total Phosphorus	mg/L	27	0.21 (0.17-0.25)	0.19 (0.15-0.24)
Dissolved Phosphorus	mg/L	18	0.14 (0.12-0.16)	0.15 (0.11-0.16)
Orthophosphate as P	mg/L	16	0.17 (0.12-0.23)	0.16 (0.09-0.22)
Total Suspended Solids	mg/L	26	33 (15-50)	11 (8-23)
Chemical Oxygen Demand	mg/L	18	46 (32-60)	48 (30-61)
Dissolved Organic Carbon	mg/L	9	29 (4-54)	16 (8-47)
Total Organic Carbon	mg/L	18	14 (11-17)	14 (9-16)
Total Cadmium	µg/L	27	0.34 (0.12-0.55)	0 (0-0.4)
Total Copper	µg/L	27	25 (16-34)	18 (15-22)
Total Lead	µg/L	27	11 (5-17)	6 (0-11)
Total Zinc	µg/L	27	321 (231-411)	247 (207-299)

Note: CI = 95% confidence interval provided for mean and median values. n = number of samples. NP = Not provided due to large percentage of non-detects.