Performance Results from Large-Scale System Monitoring and Modeling of Intensive Applications of Green Infrastructure in Areas Served by Separate and Combined Sewers in Cincinnati, Ohio

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Background

- The Metropolitan Sewer of Greater Cincinnati (MSD) is among the top 5 Combined Sewer Overflow (CSO) dischargers in the country, discharging approximately 14 billion gallons of overflow during a typical year of rainfall.
- About 75 million gallons per year of stormwater removed from the combined system from 22 Green Demonstration projects.
  - 290,000 square feet of bioinfiltration practices;
  - 168,000 square feet of vegetative (green) roofs;
  - 155,000 square feet of porous/pervious paving;
  - 125,000 gallons of rainwater storage for reuse;
  - 2,040 linear feet of storm sewer separation; and
  - 5 large capacity stormwater dry wells.

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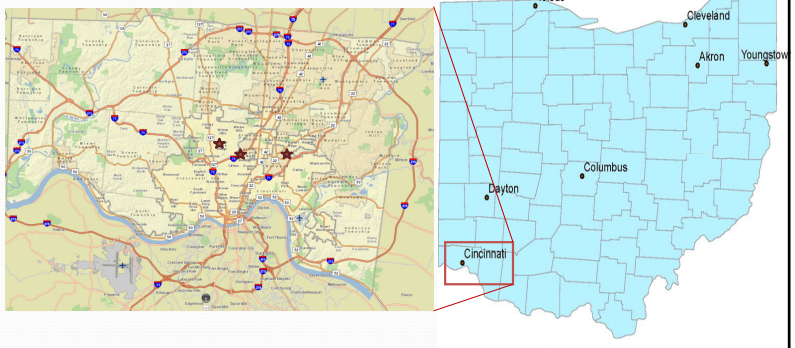
Geographical Locations and Description – Cincinnati, OH



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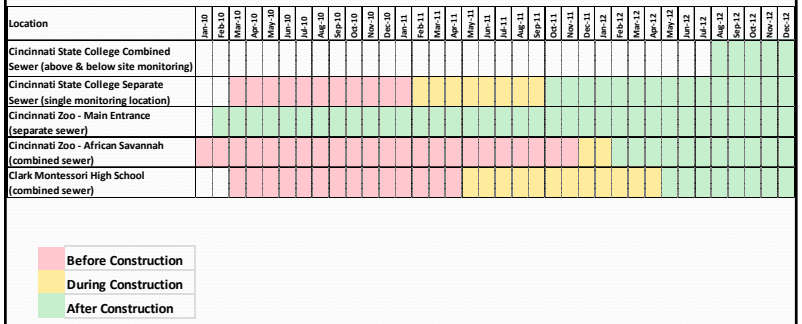
Availability of Data for Different Flowmeters

About 3 years of high-resolution (5-minute) flow measurements from in-system flow monitors located in combined and separate sewers on or adjacent to several green infrastructure installations



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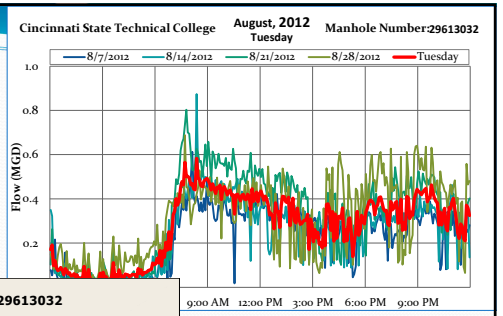
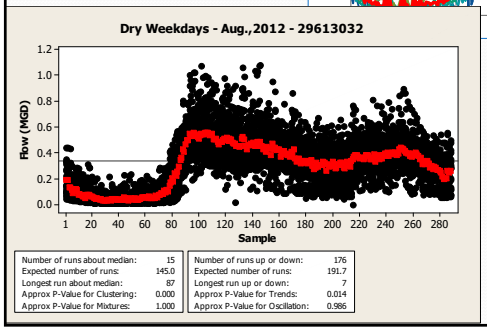
- Determine the base flow and the dry and wet weather flow components from the flow time series in sewer lines





Trend Analysis

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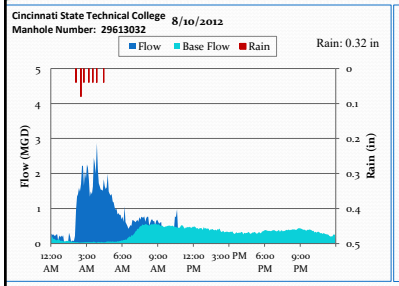

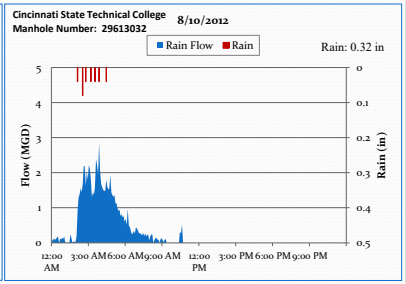

Prepare individual storm event data summaries that are coordinated with the rain data for each monitoring point, including:

- start/end time of rain,
- rain duration,
- antecedent dry days,
- total rain,
- peak and average rain intensity,
- pipe-flow start/end time,
- total pipe-flow discharge volume,
- total runoff,
- peak and average flow discharge rates,
- R_v (the ratio of runoff to rainfall depth).

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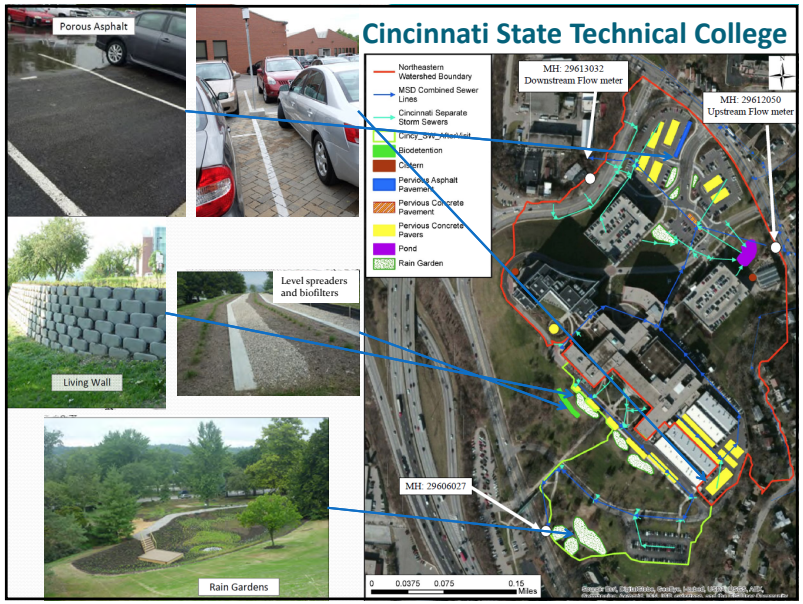

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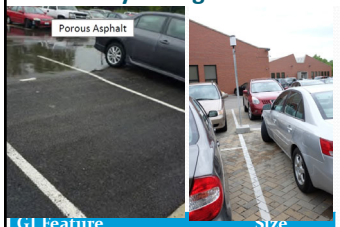
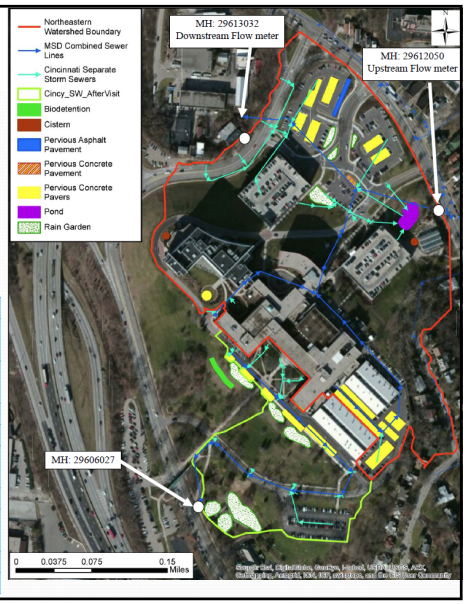
Cincinnati State Technical and Community College



GI Feature	Size
Pervious Asphalt Pavement	2,000 ft²
Pervious Concrete Pavement	1,650 ft²
Pervious Concrete Pavers	40,040 ft²
Rain Gardens	56,220 ft²
Cistern for Rainwater Harvesting	24,000 gallons
Infiltration trench	1,540 ft²
Bioretention (with level spreaders)	420 ft²
Pond	6,900 ft²
Living wall biofilter	140 ft



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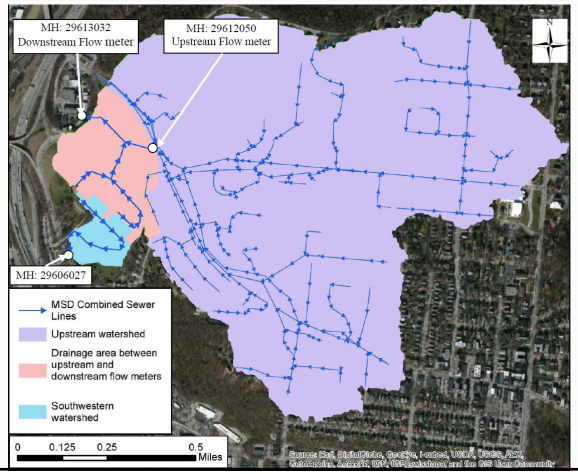
Watershed Analysis



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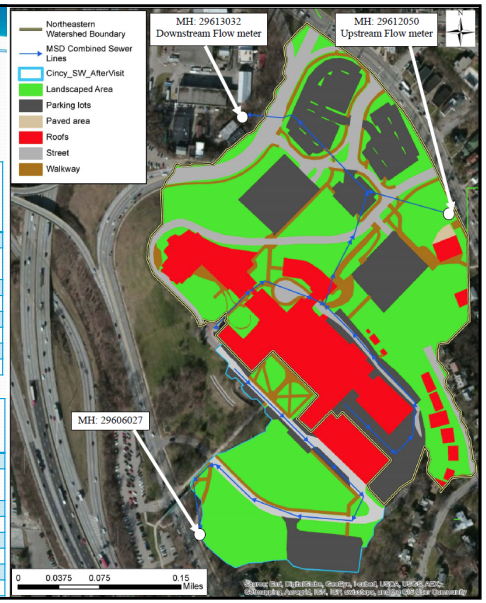
Land Cover Description

Land Cover type	Northern part of campus Areas drain into Downstream Flow Meter with manhole number 29613032	
	Area (ft²)	Area (%)
Landscaped area	486,840	39.7
Parking lot	270,560	22.1
Paved area	2,690	0.2
Roof	241,640	19.7
Street	156,700	12.8
Walkway	68,530	5.6
Total	1,226,960	100.0

Land Cover type	Southern part of campus Areas drain into manhole number 29606027	
	Area (ft²)	Area (%)
Landscaped area	360,250	58.3
Parking lot	89,990	14.6
Paved area	0	0
Roof	62,000	10.0
Street	70,340	11.4
Walkway	35,490	5.7
Total	618,070	100



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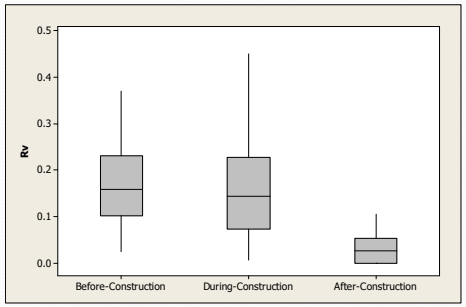
Cincinnati State College

(Single Flowmeter)

R_v values for different study periods for Cincinnati State College separate sewer system (manhole number 29606027)



Kruskal-Wallis One Way Analysis of Variance on Ranks test

Group	N	Missing	Median	25%	75%
Before Construction	41	0	0.160	0.1000	0.230
During Construction	51	0	0.140	0.0700	0.230
After Construction	78	25	0.0300	0.000	0.0550

H = 73.412 with 2 degrees of freedom. (P = <0.001)

post-hoc comparison test (Tukey's test)

	N	Mean	Grouping
Before Construction	41	0.16919	A
During Construction	51	0.16242	A
After Construction	77	0.03266	B

Means that do not share a letter are significantly different.

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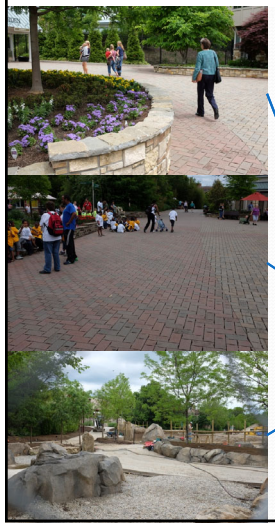
Cincinnati Zoo



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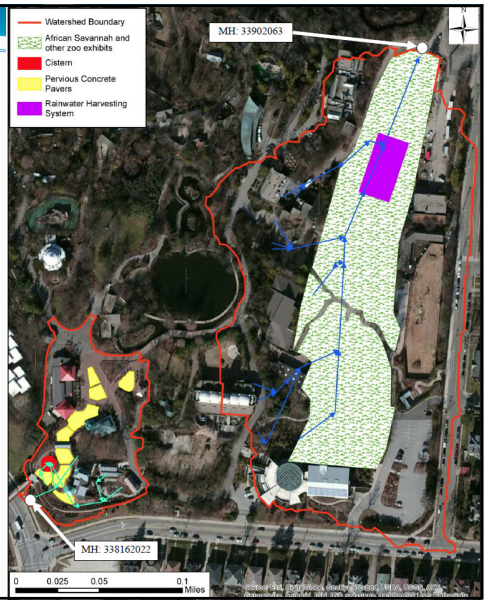
GI Features

- Approximately 180,000 ft² of enhanced turf grass will replace the existing impervious parking lot.
- The rainwater harvesting (RWH) system has a capacity of 16,000 cubic feet and the collected water will be reused for on-site irrigation for outdoor zoo water features.
- The main entry area has 30,760 ft² of pervious pavers, and a 10,000 gallon storage tank to collect runoff from 11,700 ft² of rooftop for reuse for irrigation of landscaped areas.



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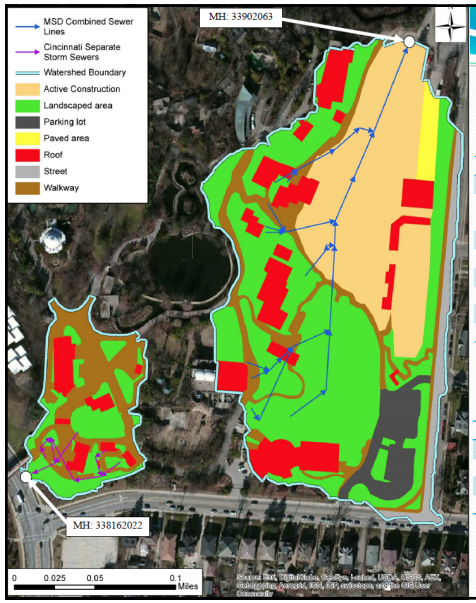

Land Cover Description

Land Cover type	Area (ft²)	Area (%)
Landscaped area	228,610	39.2
Active Construction	152,920	26.2
Parking lot	30,520	5.2
Paved area	10,060	1.7
Roof	76,680	13.1
Street	24,910	4.3
Walkway	59,470	10.2
Total	583,170	100

Land Cover type	Area (ft²)	Area (%)
Landscaped area	43,060	40.2
Paved area	47,990	44.8
Roof	16,150	15.1
Total	107,200	100

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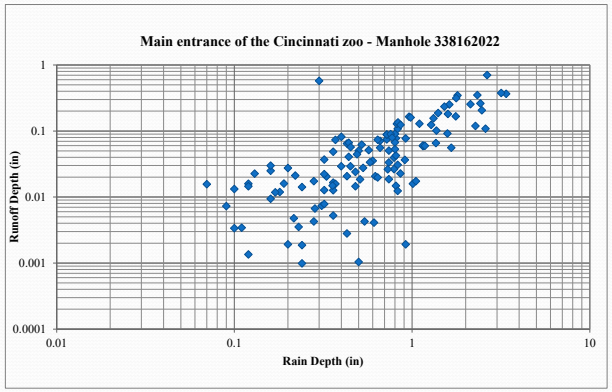
Cincinnati Zoo – Main Entrance

176 after construction events



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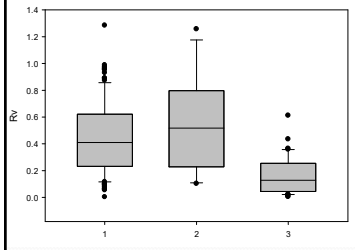
African Savannah Zoo



Kruskal-Wallis One Way Analysis of Variance on Ranks of Rv Values

Group	N	Missing	Median	25%	75%
Before	111	4	0.41	0.23	0.62
During	15	0	0.52	0.23	0.80
After	40	0	0.13	0.044	0.25

There is a statistically significant difference (P = <0.001)

All Pairwise Multiple Comparison Procedures (Dunn's Method):

Comparison	Diff of Ranks	Q	P<0.05
During vs After	61	4.3	Yes
During vs Before	7.9	0.61	No
Before vs After	53	6.1	Yes

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Clark Montessori High School

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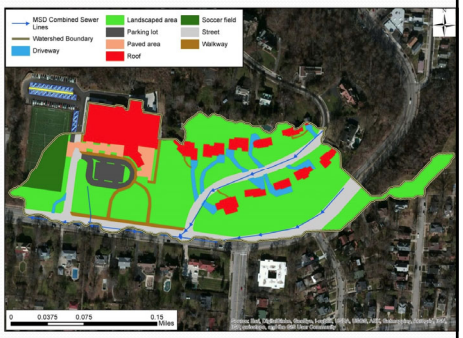
Land Cover Description

Land Cover type	Area (ft²)	Area (%)
Driveway	22,840	3.6
Landscaped area	369,450	57.5
Parking lot	22,080	3.4
Paved area	15,030	2.3
Roof	86,620	13.5
Soccer Field	25,870	4.0
Street	86,130	13.4
Walkway	14,960	2.3
Total	642,980	100.0



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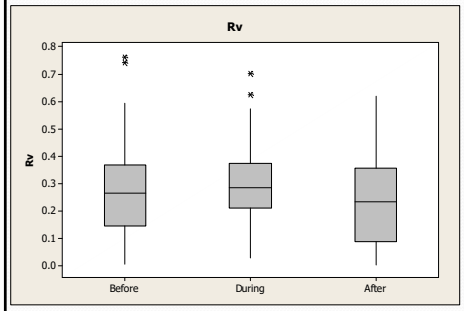
Clark Montessori High School



Grouping Information Using Tukey Method for Rv Values:

	N	Mean Rv	Grouping
During	80	0.30	A
Before	47	0.27	A B
After	39	0.23	B

Means that do not share a letter are significantly different.

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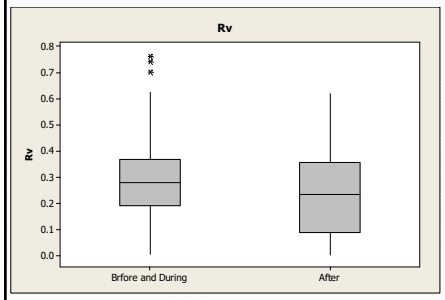
Clark Montessori High School



Grouping Information Using Tukey Method for Rv Values

	N	Mean	Grouping
Before & During	127	0.29	A
After	39	0.23	B

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Summary

Location	Runoff Volume Reduction (%) Compared to Pre-Construction Data
Cincinnati State College – Southern Area (bioinfiltration and rain gardens)	80
Cincinnati Zoo – Main Entrance (extensive paver blocks)	Average Rv values after construction: 0.1 (compared to about 0.8 for conventional pavement in area)
Cincinnati Zoo – African Savannah (rainwater harvesting system and pavement removal)	70
Clark Montessori High School (green roofs and parking lot biofilters on small portion of watershed)	21

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Conclusions and Recommendations for Flow Monitoring for Green Infrastructure Performance

- Monitor both test and control areas both before and after construction of stormwater controls, if possible, for the greatest reliability (to account for typical year-to-year rainfall variations and to detect sensor problems early).
- Test areas should have most of their flows treated by the control practices to maximize measurable reductions.
  - **Any untreated upgradient areas should be very small in comparison to the test areas. Difficult to subtract two large numbers (each having measurement errors and other sources of variability), such as above and down gradient monitoring stations, and have confidence on the targeted flows.**

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Conclusions and Recommendations for Flow Monitoring for Green Infrastructure Performance (Cont.)

- Most monitored flows from common rains may only result in shallow depths in the sewerage, a flow condition that is difficult to accurately monitor.
- Flow sensors may fail more often than expected.
- Costs of flow monitoring is small compared to green infrastructure investment.
  - **Use redundant sensors, such as an area-velocity sensor (or bubbler) in addition to an acoustic depth sensor mounted on the crown.**
  - **Calibrate the flow sensors at the beginning and periodically throughout the project period.**
  - **Review flow data frequently and completely to identify sensor failures or other issues.**
  - **Supplement the flow sensors with adequate numbers and placement of rain gages in the watersheds.**

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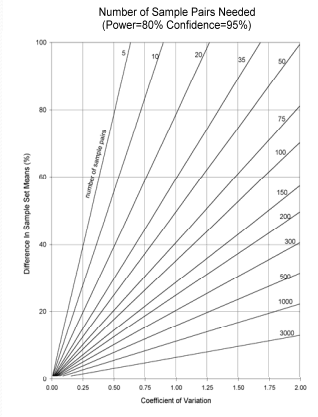
Conclusions and Recommendations for Flow Monitoring for Green Infrastructure Performance (Cont.)

- Monitor sufficient numbers of events to have statistically valid results for the performance expectations.
  - **As an example, with a COV of 1 (a typical value for stormwater), 50 pairs of samples would enable differences of about 50% or greater to be detected with 95% confidence and 80% power.**
  - **It is very difficult to detect small differences with suitable confidence and power (the reason why most of the runoff needs to be treated).**



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Future Work

- Utilizing a calibrated version of WinSLAMM for each study area:
  - To predict pre-development conditions for comparison to monitored results for those sites that do not have pre-construction flow data available (i.e. main entry of the Cincinnati Zoo)
  - To provide guidance for placement of flow monitoring equipment in other demonstration areas (predict flow conditions with and without green infrastructure controls).
  - To extrapolate monitoring results to other areas and conditions in the city.

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THANK YOU!

QUESTIONS?

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