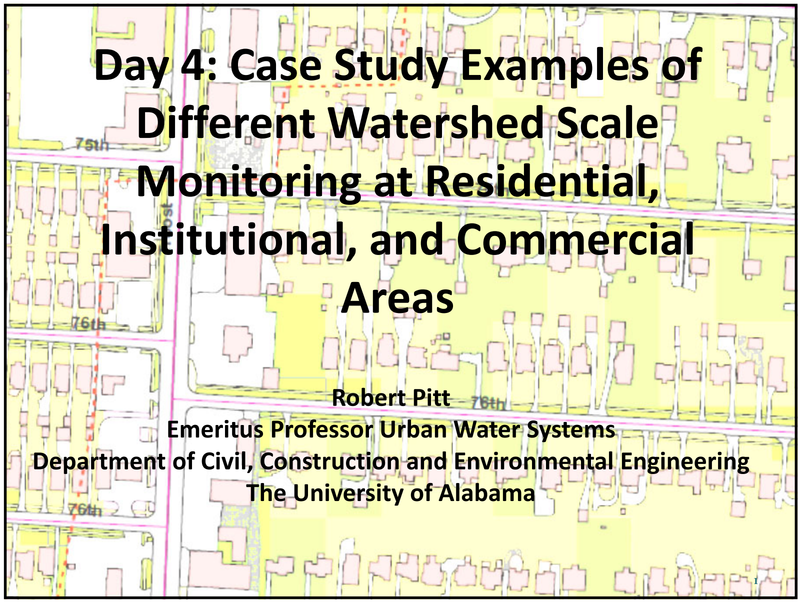

Day 4: Case Study Examples of Different Watershed Scale Monitoring at Residential, Institutional, and Commercial Areas

Robert Pitt
Emeritus Professor Urban Water Systems
Department of Civil, Construction and Environmental Engineering
The University of Alabama

1

Outline of Presentation

- Small to large-scale watershed analyses
  - Methodology
  - Data
  - Conclusions pertaining to scaling results
- Production function modeling based on multi-scale results
- Current monitoring and modeling of sources, control, and fates of metals and organics in a large urban watershed
- Current monitoring of interception losses associated with urban trees

2

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Introduction

- There is great interest in the use of green infrastructure (GI) to mitigate stormwater and combined sewer overflow discharges.
- While there are much data indicating the performance for individual stormwater controls used in GI projects, few data are available describing the performance of multiple GI facilities implemented at large scales, although many modeling studies have been conducted to illustrate the likely results.
- This presentation shows monitoring results from three GI monitoring projects conducted at small to large scales, demonstrating expected performance, along with concurrent modeling.
  - Real time rainfall and runoff data from areas served by GI controls were analyzed before and after their construction.
  - The GI controls at these locations were capable of infiltrating most all flows from common small to intermediate rains.
  - Large-scale monitoring confirmed that the overall performance was directly related to the amount of the drainage area flows that were directed to the GI controls.
- High levels of control are challenging and expensive to achieve when retrofitting in existing developed areas, but more effective in institutional areas where greater control of the site runoff is available, and in newly developing areas where GI controls can be integrated into the overall design.

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Questions to be Addressed in Presentation

- **How effective are source area controls in reducing outfall discharges?**
- **Can individual device data be extrapolated to system scales?**
- **How do you ensure high levels of performance at the system level?**
- **How do you monitor system to verify performance?**
- **How much information is necessary to verify performance?**

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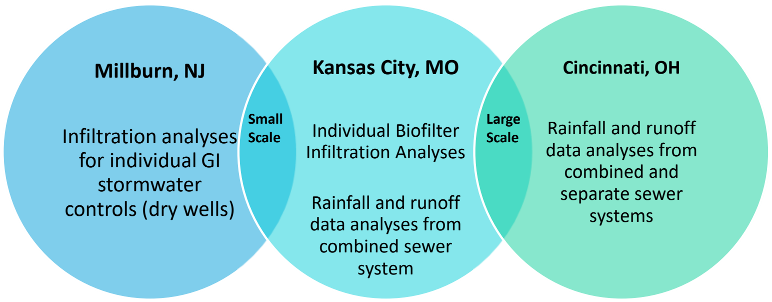
Methodology



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Millburn, NJ (Background and Site Descriptions)

- This project was supported by the Wet Weather Flow Research Program of the US EPA and the City of Millburn to investigate whether increased beneficial uses of the runoff would be a more efficient use of the water instead of infiltrating into the shallow groundwaters, and to verify if the use of dry wells are effective in reducing the increased stormwater flows.
- The city of Millburn has required dry wells/cisterns to infiltrate the increased flows from newly developed areas.
- Some water storage tanks are used to store the increased stormwater for later irrigation.
- There are substantial data available for this community, which we supplemented with detailed site information and dry well infiltration measurements to allow a comprehensive review of beneficial stormwater uses.

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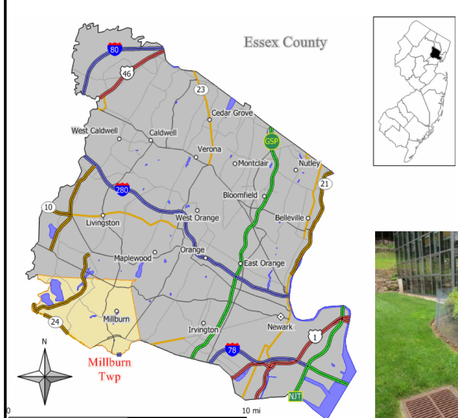
Small-Scale Infiltration Systems at Millburn, NJ



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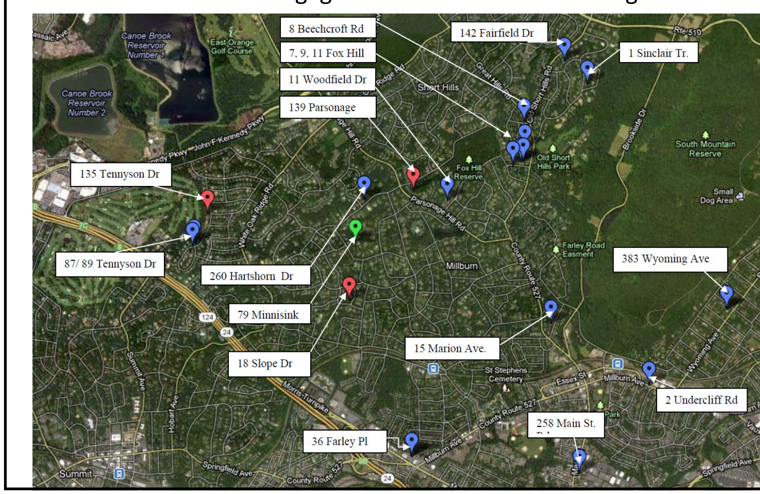
Water elevations at 15 dry wells were monitored from 2 months to one year during many rains, plus controlled seepage tests at new sites using domestic water. Four rain gages were also installed throughout area.



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Kansas City's CSO Challenge

- Combined sewer area: 58 mi² (150 km²)
- Fully developed
- Rainfall: 37 in./yr (94 cm/yr)
- 36 sewer overflows/yr by rain > 0.6 in (1.5 cm); reduce frequency by 65%.
- 6.4 billion gal (24 million m³) overflow/yr, reduce to 1.4 billion gal/yr (5.3 million m³)
- Aging wastewater infrastructure
- Sewer backups
- Poor receiving-water quality

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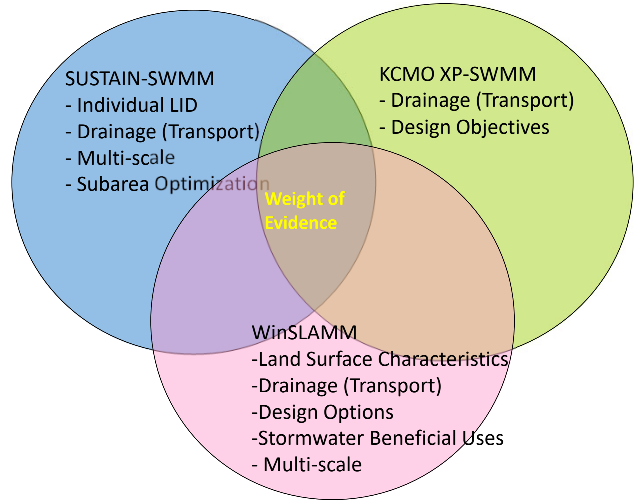
KC's Modeling Connections



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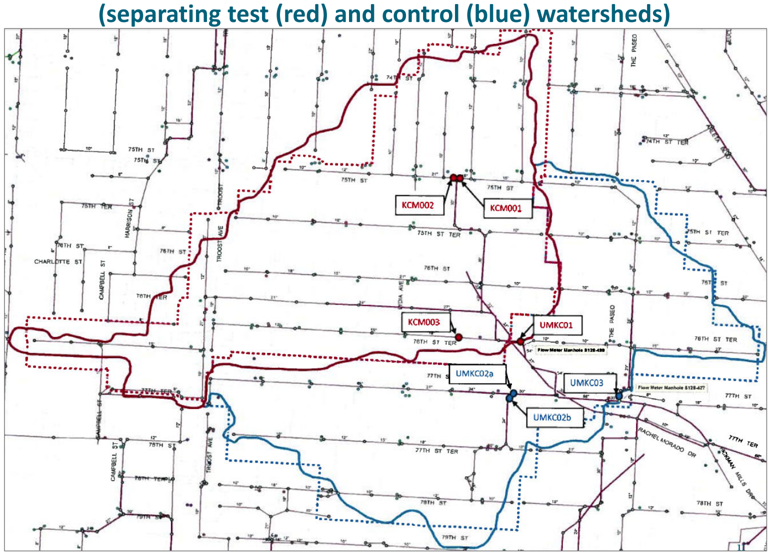
Large-scale performance monitoring at Kansas City, MO (separating test (red) and control (blue) watersheds)



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Small-scale performance monitoring at Kansas City, MO

12





1324 76th St. monitoring location, biofilter and adjacent porous concrete sidewalk (one of 10 monitored, along with the large-scale system monitoring of whole drainage areas)

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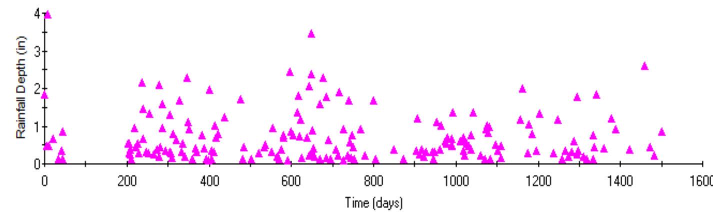
September 2, 2008 to October 12, 2012 Rains Monitored in the Kansas City Green Infrastructure Test Area



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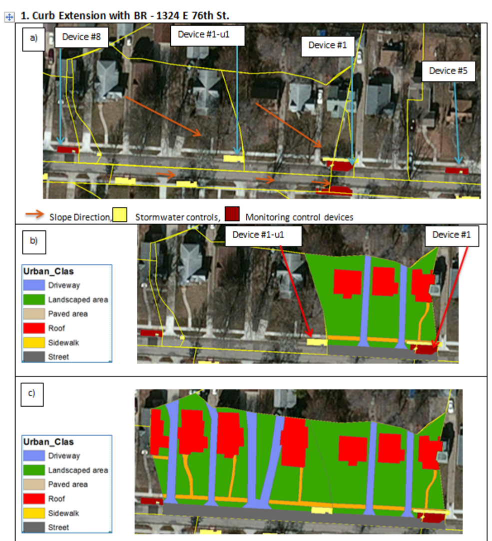

Figure 1 – Aerial photos, topo map, and urban classifications for device #1

Example micro flow and drainage area analysis for a set of stormwater controls in the test area, examining both direct runoff area to biofilters and overflows from upgradient biofilters.

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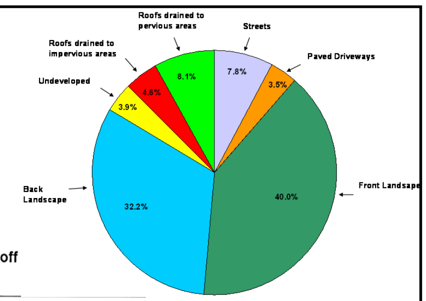
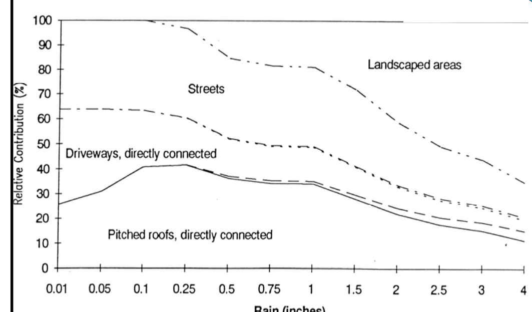
Medium Density Residential Area, Runoff





Surveys were conducted for each house and lot in the study area. This information was used with the GIS data and WinSLAMM to determine the sources of the runoff during different rain conditions

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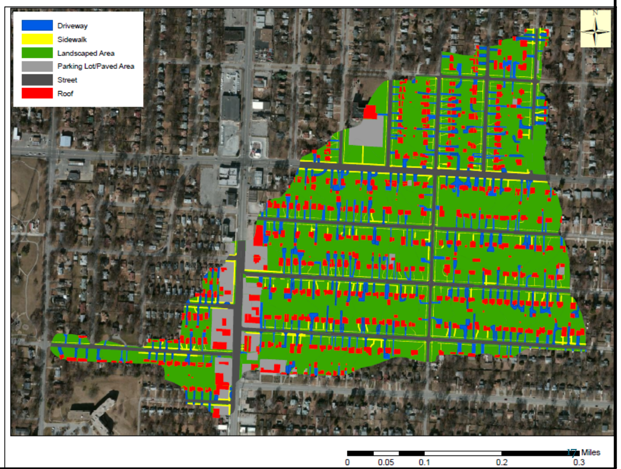
Watershed Analysis and Land Cover Description

- Landscaped areas: 58%
- Roofs: 15%
- Streets: 11%
- Driveways, sidewalks, and parking lots: 16%

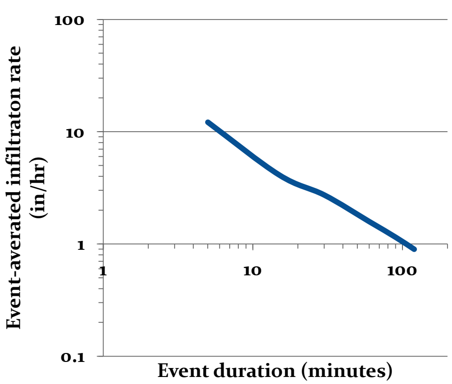


Major Land Use Components in Residential Portion of Study Area (% of area and % of total annual flow contributions)

	Roofs	Drive-ways	Side-walks	Park-ing	Streets	Land-scaped	Total
Directly connected	2 (6)	4 (9)	1 (3)	2 (5)	9 (21)		18 (44)
Disconnected	11 (7)	4 (3)	1 (1)				16 (11)
Landscaped						66 (45)	66 (45)
Total area	13 (13)	8 (12)	2 (4)	2 (5)	9 (21)	66 (45)	100

Based on KCMO GIS mapping and detailed site surveys, along with WinSLAMM calculations.

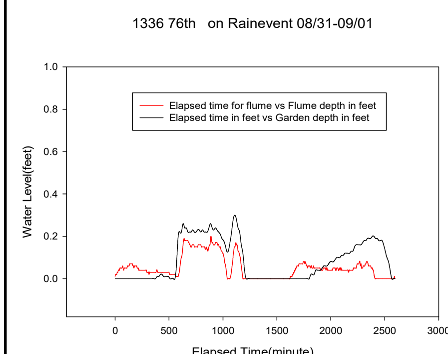
Small-Scale Biofilter Monitoring: Varying-duration Site Infiltration Rates

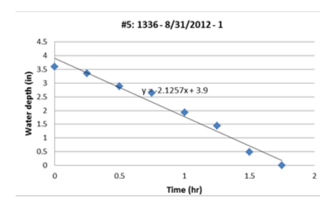


This plot shows the time-averaged infiltration rates based on the individual incremental values. The surface infiltration rates are less than 25 mm/hr for rains about 2 hrs long and longer.

Additional site measurements and deep soil profiles have indicated that infiltration rates may be low for most of the area during the large and long-duration critical events for overflows.

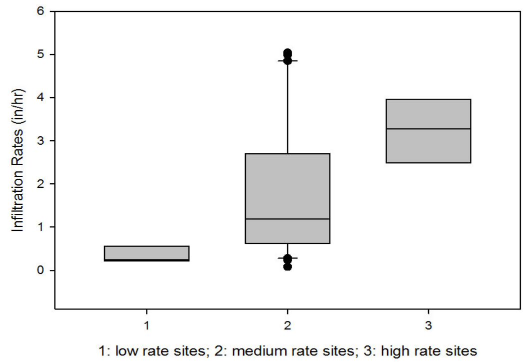
Example Water Level in Influent H Flume and Water Stage Recordings in Biofilter used for Calculating Infiltration Rates during Rains





Example plot of recession limbs and infiltration rate calculation (after influent flows ceased).

Measured Biofilter Infiltration Rates During Actual Rains, Separated into Three Categories



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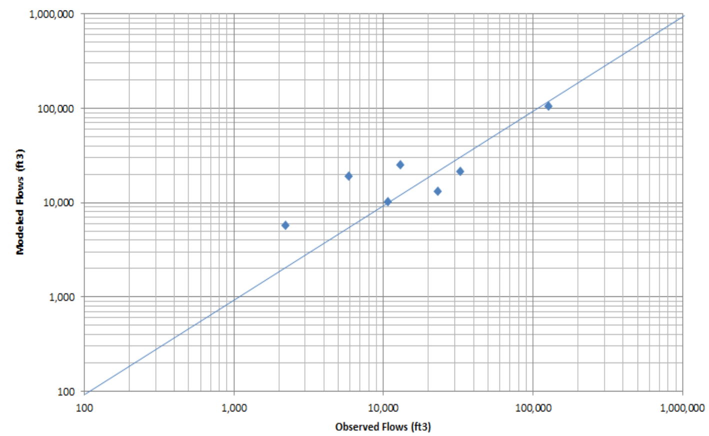
Observed vs. Modeled Flows during Final Baseline Conditions



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Summary of Constructed Stormwater Controls in Test Area

Design plan component	Number of this type of stormwater control units in 100 acre (40 ha) test (pilot) area	Device as a % of the drainage area	Average drainage area for each unit (ac)	Total area treated by these devices (ac)
Bioretention	24 (no curb extensions)	1.6	0.40	9.6
	28 (with curb extension)	1.5	0.40	11.2
	5 (shallow)	1.6	0.40	2.0
Bioswale	1 (vegetated swale)	8.9	0.50	0.5
Cascade	5 (terraced bioretention cells in series)	1.9	0.40	2.0
Porous sidewalk or pavement	18 (with underdrains)	100.0	0.015	0.3
	5 (with underground storage cubes)	99.9	0.015	0.1
Rain garden	64 (no curb extensions)	2.8	0.40	25.6
	8 (with curb extension)	1.5	0.40	3.2

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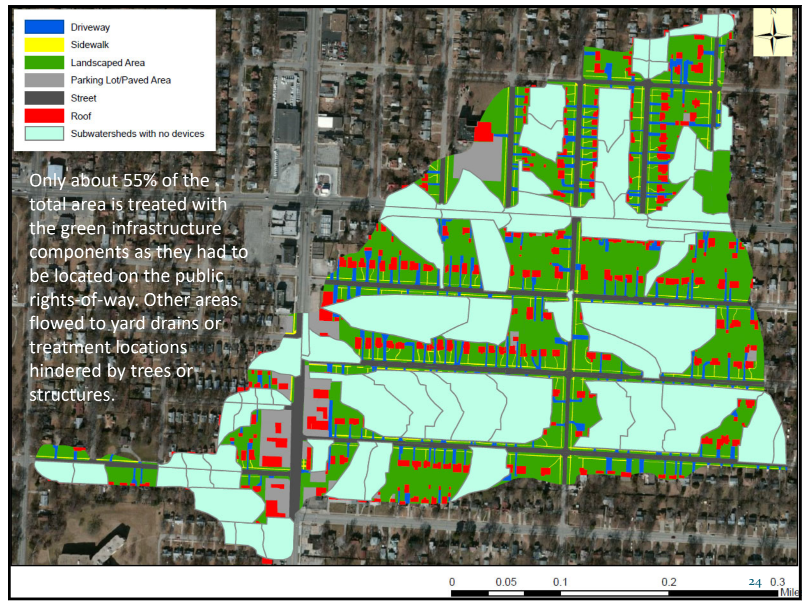

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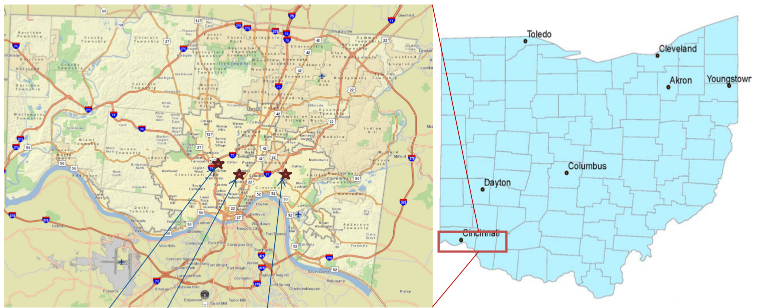
Cincinnati, OH, Test Watershed Locations



Cincinnati State College

Cincinnati Zoo

Clark Montessori High School

The Metropolitan Sewer District of Greater Cincinnati is among the top 5 CSO dischargers in the country (14 billion gallons (53 million m^3) of overflows annually)

About 75 million gallons (280,000 m^3) per year of stormwater removed from the combined system from 22 Green Demonstration projects.

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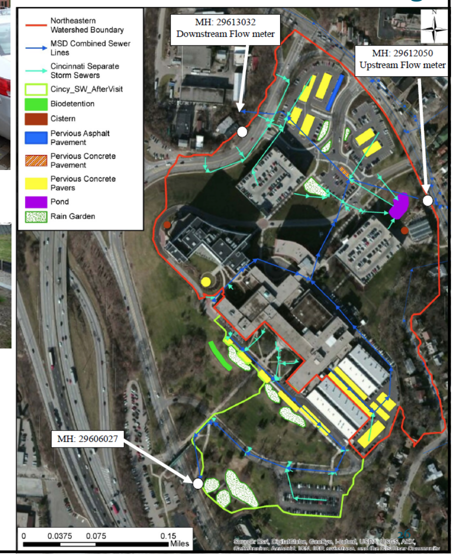
Cincinnati State Technical College



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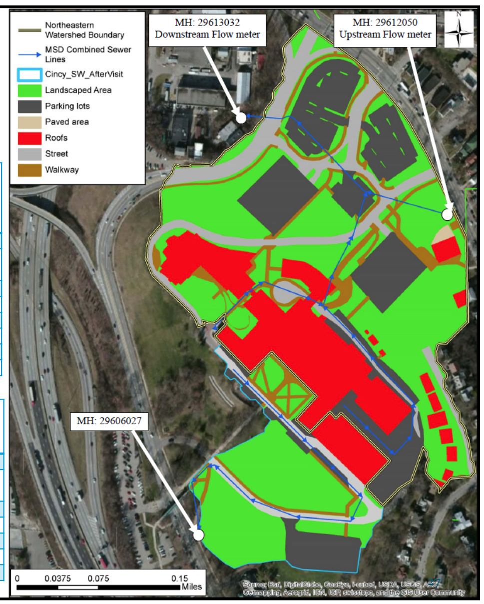
Land Cover Description

Land Cover type	Northern part of campus Areas drain into Downstream Flow Meter with manhole number 29613032	
	Area (ft²)	Area (%)
Landscaped area	486,835	39.7
Parking lot	270,558	22.1
Paved area	2,687	0.2
Roof	241,644	19.7
Street	156,707	12.8
Walkway	68,532	5.6
Total	1,226,962	100.0

Land Cover type	Southern part of campus Areas drain into manhole number 29606027	
	Area (ft²)	Area (%)
Landscaped area	227,411	59.9
Parking lot	48,556	12.8
Roof	35,539	9.3
Street	43,050	11.3
Walkway	25,101	6.7
Total	379,657	100



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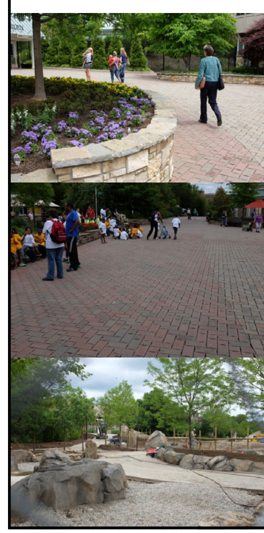
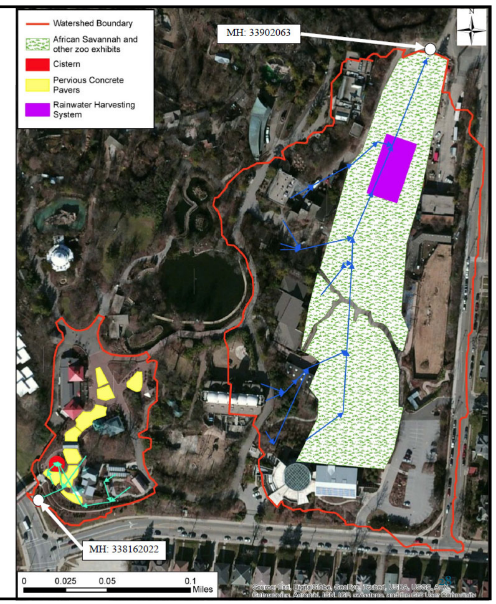
Cincinnati Zoo





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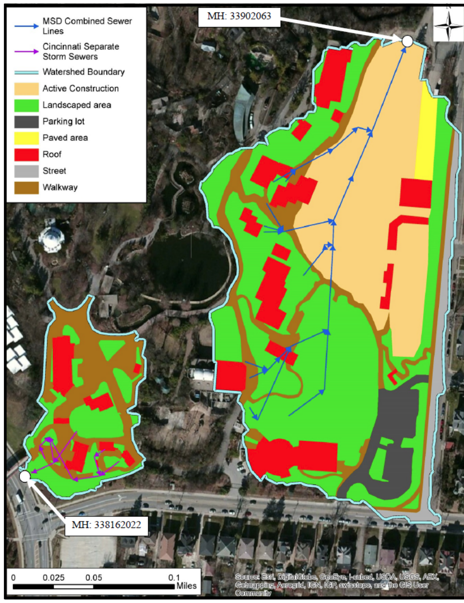
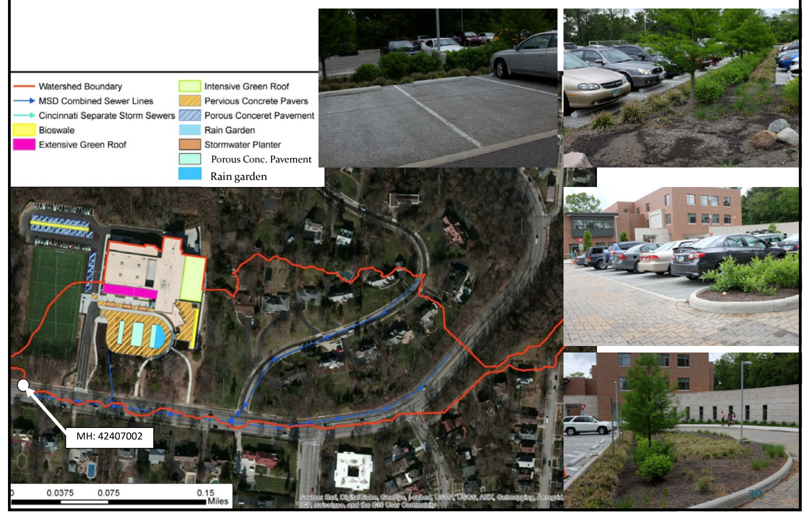


Land Cover Description

Land Cover type	Area (ft²)	Area (%)
Landscaped area	228,614	39.2
Active Construction	152,923	26.2
Parking lot	30,521	5.2
Paved area	10,058	1.7
Roof	76,676	13.1
Street	24,907	4.3
Walkway	59,466	10.2
Total	583,166	100

Land Cover type	Area (ft²)	Area (%)
Landscaped area	43,060	40.2
Paved area	47,996	44.8
Roof	16,150	15.1
Total	107,206	100

Clark Montessori High School



Land Cover Description

Land Cover type	Area (ft²)	Area (%)
Driveway	22,842	3.6
Landscaped area	369,455	57.5
Parking lot	22,082	3.4
Paved area	15,026	2.3
Roof	86,624	13.5
Soccer Field	25,867	4.0
Street	86,134	13.4
Walkway	14,956	2.3
Total	642,986	100.0

Data Analyses

Availability of Data for Different Case Studies

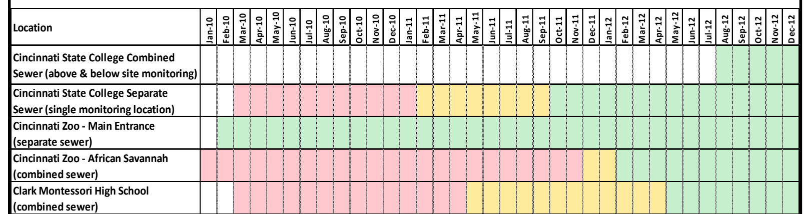
- Millburn, NJ
  - 14 dry wells monitored for infiltration purposes
  - Short and long-term periods (ranging from 2 months to one year)
  - Actual rains and controlled tests using township water from fire hydrants.
- Kansas City, MO
  - 100-acre (40 ha) pilot watershed
  - 179 green infrastructure-based stormwater controls
  - 3 curb extension biofilters, 2 curb-cut biofilters, 2 biofilters with smart drains, and a cascade biofilter were monitored for infiltration for several months.
  - Flow data in the combined sewer system for before, during, and after the green infrastructure component construction periods, for both the pilot and control watersheds.

Monitoring Periods in Test/Pilot and Control Area Watersheds (Kansas City, MO)

Monitoring period	Dates corresponding to monitoring period	Number of monitored storms in each monitoring period*
Initial baseline	03/23/09 – 06/19/10	69 events
After re-lining	01/22/11 – 03/19/11	7 events
After construction	04/07/13 – 10/30/13	37 events

Availability of Data for Different Case Studies

Cincinnati, OH
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

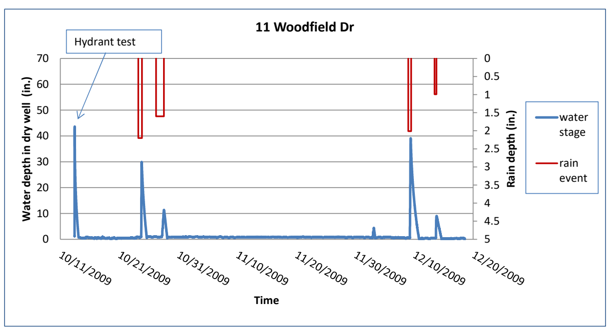


Before Construction
During Construction
After Construction

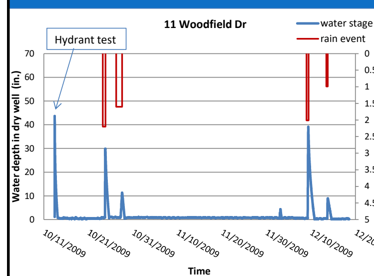
Data Analyses
Infiltration Tests in Dry Wells and Biofilters

Infiltration Analyses in Dry Wells at Millburn, NJ

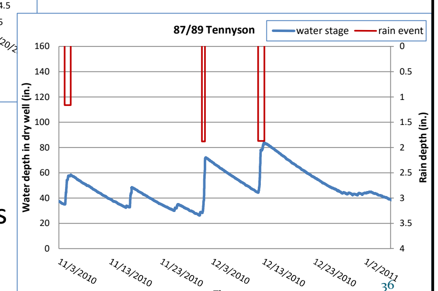
- 84 total separate infiltration observations for fourteen monitored dry wells.



Standing Water Conditions in Dry Wells

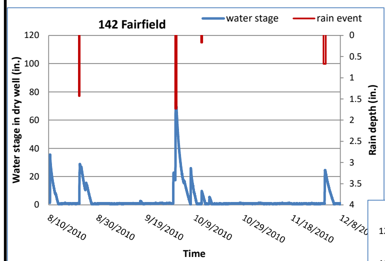


No standing water after all events



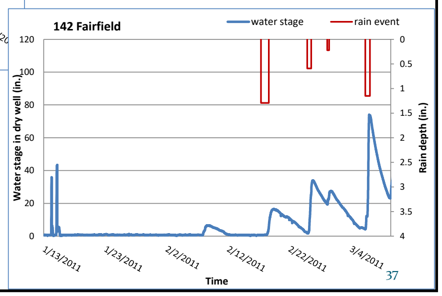
High water conditions after all events

Standing Water Conditions in Dry Wells

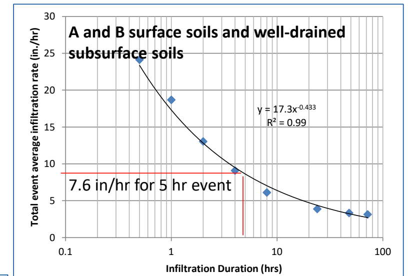


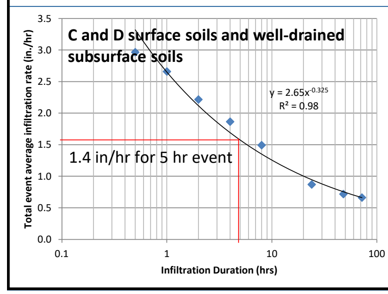
No standing water after some events

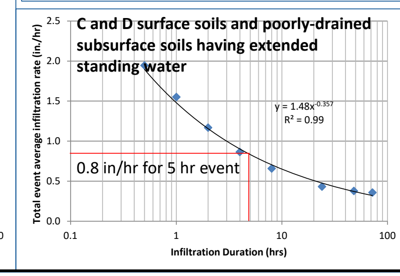
Same site: Possible mounding of water table conditions after some events (very wet period)



Integrated infiltration rates over the duration of the rain events showed decreasing rates as the rain duration increased. In order to explain some of the data variability, three main groups of data were identified based on surface and subsurface soil conditions and the presence of extended standing water.

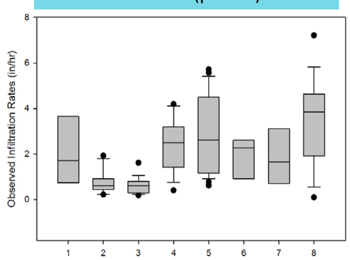




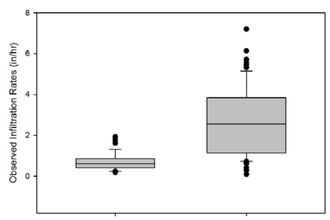


Infiltration Rates at Biofilters at Kansas City, MO

Kruskal-Wallis One Way Analysis of Variance on Ranks (p<0.05)



Site 1: 1324 E. 76th St. curb-extension biofilter; site 2: 1325 E. 76th St. curb-extension biofilter;
Site 3: 1419 E. 76th Terrace curb-extension biofilter; site 4: 1612 E. 76th St. curb-cut biofilter;
Site 5: 1336 E. 76th St. curb-cut biofilter; site 6: 1140 E. 76th Terrace shallow curb-cut biofilter with SmartDrain;
Site 7: 1222 E. 76th St. shallow curb-cut biofilter with SmartDrain; site 8: 1112 E. 76th Terrace cascading swale biofilter



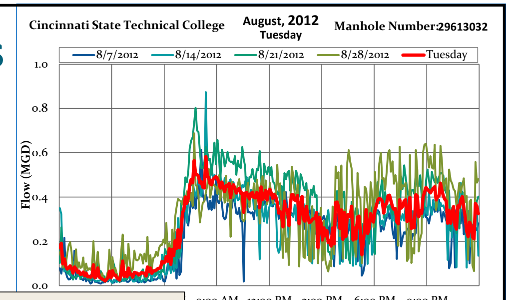
Group 1: low rates (sites 2 and 3)
Group 2: normal rates (all other sites)

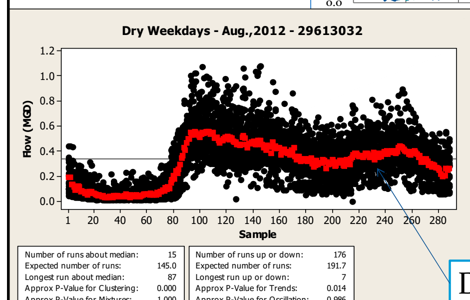
P = <0.001

Group	N	Median	25%	75%
Slow (1325 and 1419)	34	0.62	0.41	0.86
Fast (all others)	76	2.56	1.14	3.85

Data Analyses

Base Flow Analysis System Scale Monitoring in Combined Sewers



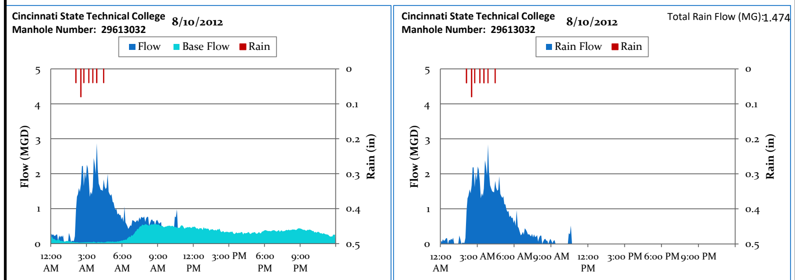


Trend analysis for all dry Tuesdays in August 2012

Then compared all weekdays with all weekends for each month

Dry Weather Base Flow

Base flow analyses to separate dry weather base flows from combined flows to obtain direct runoff



Prepared individual storm event summaries that were coordinated with the rain data for each monitoring location, 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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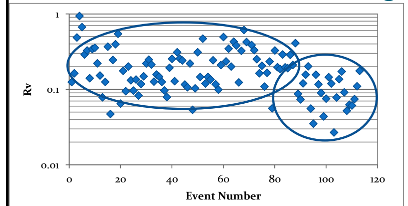
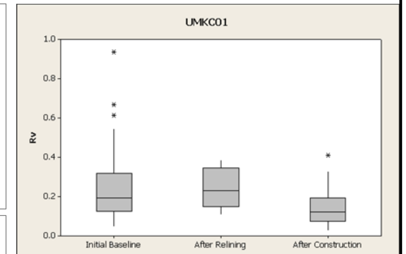
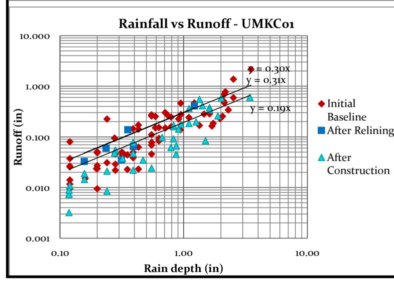
Data Analyses

Large-Scale GI Performance Analyses – UMKC01 (Kansas City, MO)
Flow reductions associated with green infrastructure







3 groups (Initial, after relining, after construction): p=0.002

2 groups (Initial and after relining combined, vs. after construction): p<0.001

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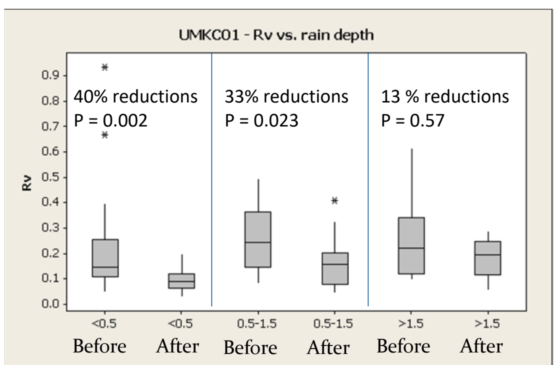
Comparisons of Rv Values at UMKC01 for Before and After GI Facility Construction Monitoring Periods for Different Size Rain Events

Significant reductions for <0.5 inch (12 mm) and 0.5 to 1.5 inch (12 to 38 mm) rains, but not statistically significant for >1.5 inch (38 mm) rains



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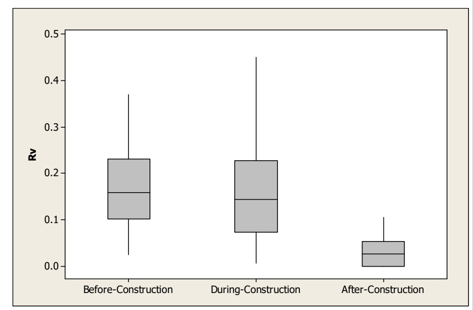
Cincinnati State College, Cincinnati, OH

(Southwestern drainage in separate storm sewer)

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.

44

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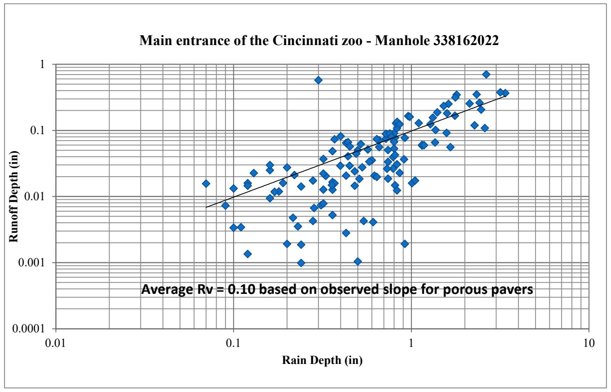
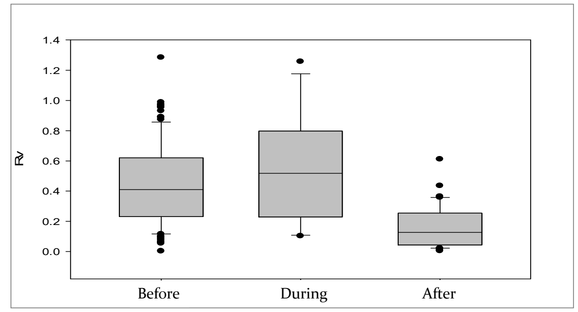
Cincinnati Zoo – Main Entrance (Cincinnati, OH)

176 after construction events



African Savannah Zoo (Cincinnati, OH)



Kruskal-Wallis for 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

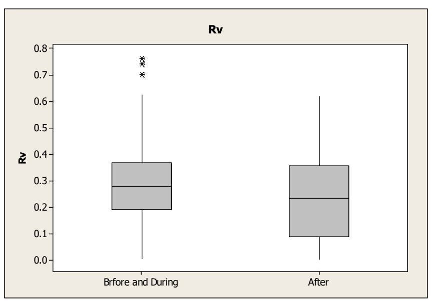
There is a statistically significant difference for at least one data set (P = <0.001)

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

Therefore, combine before and during monitoring data

Clark Montessori High School (Cincinnati, OH)



Kruskal-Wallis One Way Analysis of Variance on Ranks

Group	N	Missing	Median	25%	75%
Before and During	127	0	0.280	0.190	0.370
After	39	0	0.230	0.090	0.360

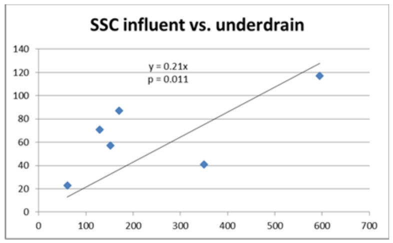
H = 4.918 with 1 degrees of freedom. (P = 0.027)

Performance from Cincinnati Monitoring at Green Infrastructure Sites

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

Water Quality Improvements Associated with Green Infrastructure

- Most of the monitored Kansas City biofilters completely infiltrated the stormwater. Only 6 out of 79 monitored events resulted in under drain flows. The influent median particle size ranged from about 13 to 50 µm.
- The SSC influent concentrations ranged from about 50 to 600 mg/L, while the effluent concentrations ranged from about 20 to 120 mg/L.



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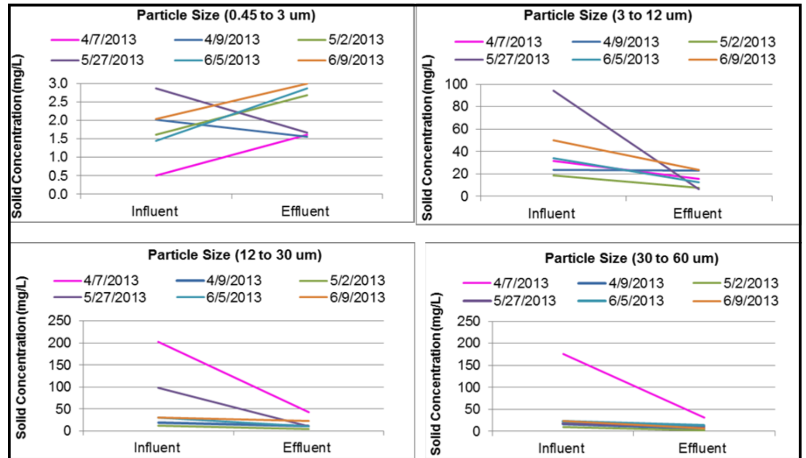

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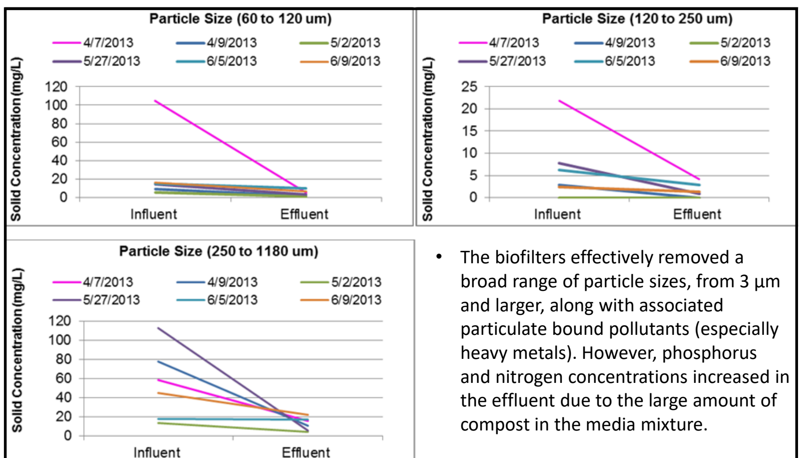

- The biofilters effectively removed a broad range of particle sizes, from 3 µm and larger, along with associated particulate bound pollutants (especially heavy metals). However, phosphorus and nitrogen concentrations increased in the effluent due to the large amount of compost in the media mixture.
- Overall, the pollutant mass reductions were very large, mostly due to the infiltration of the stormwater, but also assisted with the effective reduction in most pollutant concentrations.

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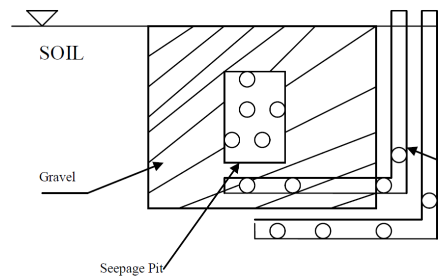
Water Quality below Dry Wells in Millburn, NJ



- Three dry wells: a shallow monitoring well immediately below the dry well and a deep monitoring well 2 to 5 ft (60 to 150 cm) below the gravel
- 8 to 10 storms were sampled at each of the three dry wells (all samples were analyzed in duplicate.)

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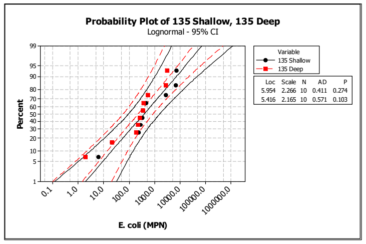
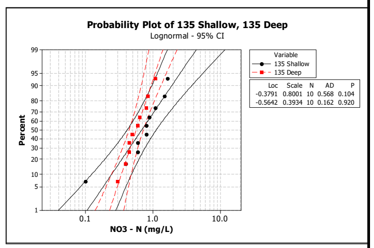
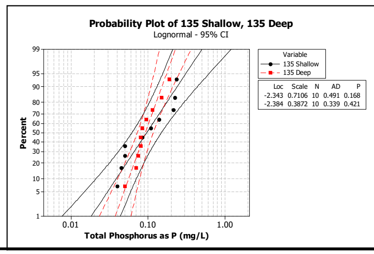
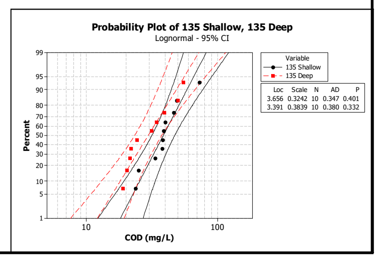
Water quality (nutrients, bacteria, pesticides, and metals) of samples collected from within were compared to samples collected at least 3 ft below the dry wells indicated no significant differences, as shown on the following examples:









Summary of Paired Sign Test for Metal analysis

Metal	79 Inflow vs. 79 Cistern	135 Shallow vs. 135 Deep	18 Shallow vs. 18 Deep	139 Shallow vs. 139 Deep
Lead	> 0.06	> 0.06	0.18	> 0.06
Copper	0.125	*	>0.06	*
Zinc	0.45	0.45	>0.06	>0.06

* All the results are below the detection limit (BDL), therefore it is not possible to do a statistical comparison test

Groundwater Quality Criteria for the State of New Jersey Compared to Observed Water Quality from Dry Wells (mg/L)

Constituent	Groundwater Quality Criterion	Observed Range	Fraction of samples that exceed the criteria
Microbiological criteria	Standards promulgated in the Safe Drinking Water Act Regulations (N.J.A.C. 7:10-1 et seq.): 50 MPN/100 mL	Total coliform: 1 to 36,294 MPN/100 mL *E. coli*: 1 to 8,469 MPN/100 mL	Total coliform: 63 of 71 samples exceeded the criterion for total coliforms *E. coli*: 45 of 71 samples exceeded the criterion for *E. coli*
Nitrate and Nitrite	10	BDL to 16.5 (one sample had a concentration of 16.5 mg/L)	1 of 71 samples exceeded the criterion for nitrates plus nitrites
Nitrate	10	0.1 to 4.7	0
Phosphorus	n/a	0.02 to 1.36	n/a
COD	n/a	5.0 to 148	n/a
Lead	0.005	BDL to 0.38	33 of 71 samples exceeded the criterion for lead
Copper	1.3	BDL to 1.1	0
Zinc	2.0	BDL to 0.14	0

There were no significant reductions identified for any stormwater pollutant below the dry wells.

Findings from the Millburn Dry Well Investigations

- Most of the dry wells functioned well, but a small fraction had long-term standing water due to unknown shallow groundwater (groundwater conditions should be monitored in any area considering infiltration to obtain better water table information).
- Subsurface infiltration conditions were much better than the surface infiltration conditions, and the dry wells were not much affected by compacted surface soils.
- There were no significant water quality changes with the dry wells. State requirements only allow roof runoff to be infiltrated in dry wells, but many installations also collected water from paved and landscaped areas. Bacteria and some metal concentrations exceeded the regulated limits, even at roof runoff installations.
- The variability/uncertainty of the infiltration conditions are not accurately predicted using conventional methods; modeling in large areas require better knowledge of the regional infiltration potential.

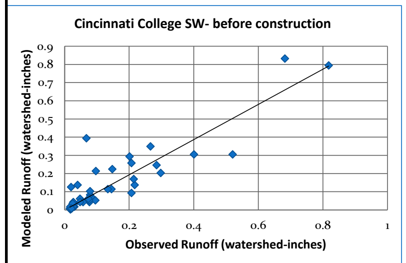
WinSLAMM (Source Loading and Management Model)

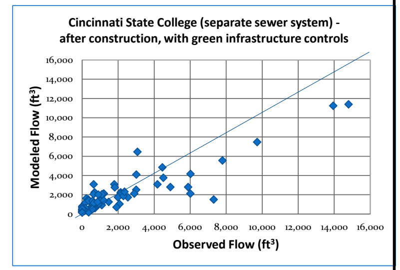
- Using the local continuous rain records, WinSLAMM evaluates the runoff volume as well as pollutant loadings from each individual source area within each land use category and for the whole watershed area considering the individual microsites and how they are connected.

- In this research, WinSLAMM calculated:
  - the effectiveness of GI stormwater controls, based upon long series of rainfalls, the source area characteristics, and the characteristics of stormwater control (such as size and location).
  - the stormwater contributions from the source areas in the watersheds to assist in locating the most effective controls.
  - production functions to illustrate the magnitude of runoff and pollutant controls for different applications of different green infrastructure controls.
  - likely maintenance intervals associated with clogging and breakthrough.
  - life-cycle costs of different green infrastructure controls, based on different design attributes.

Production Function Modeling

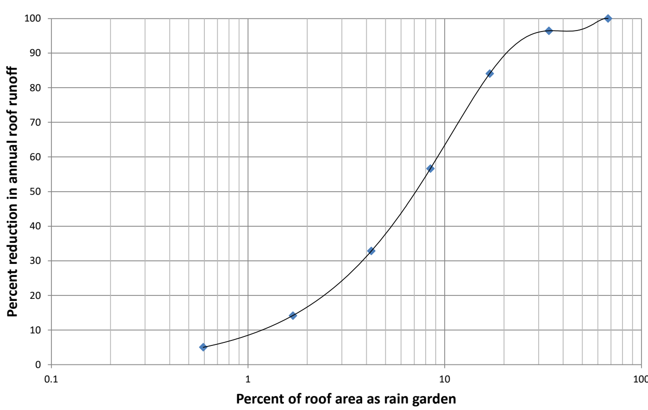
- WinSLAMM was calibrated and verified using these monitoring results to better understand the limitations and usefulness of the green infrastructure controls and to extrapolate the measured performance to other sites and conditions.





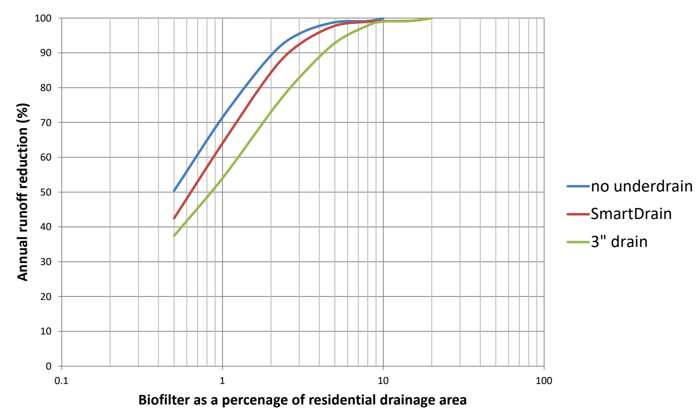
No statistically significant differences between observed and modeled runoff amounts

Example WinSLAMM Production Function: Percentage Reductions of Annual Runoff Flows with Rain Gardens



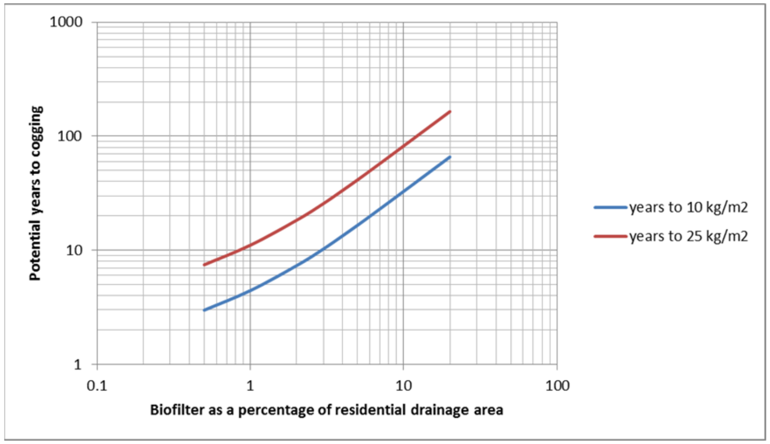
Not as effective on a same area comparison as a biofilter due to lack of large amounts of runoff storage in rain gardens.

Example WinSLAMM Production Functions: Effects of Underdrains in Biofilters on Annual Runoff Reductions (0.5 in/hr subsurface soil infiltration rates)



Unrestricted underdrains result in short-circuiting of infiltration, reducing their performance; design restrictions as needed to reduce standing water problems.

Example WinSLAMM Production Functions: Clogging Potential for Biofilters in the Kansas City Test Area



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Sources, Treatment, and Fate of Stormwater Metallic and Organic Pollutants in a Large Urban Watershed

- Paleta Creek, San Diego, CA, stormwater monitoring and data analysis (*Assessment and Management of Stormwater Impacts on Sediment Recontamination*)
- Sponsored by Strategic Environmental Research and Development Program (SERDP)
- Texas Tech, Geosyntec Consultants, and Robert Pitt
- First phase report prepared in 2018, starting next phase research (2019 to 2021) in San Diego, CA, and Puget Sound, WA

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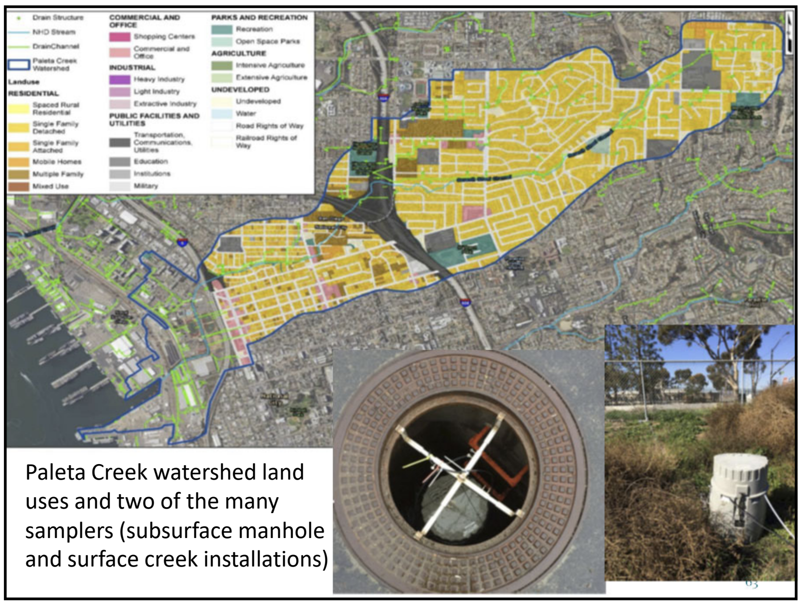

Paleta Creek watershed land uses and two of the many samplers (subsurface manhole and surface creek installations)

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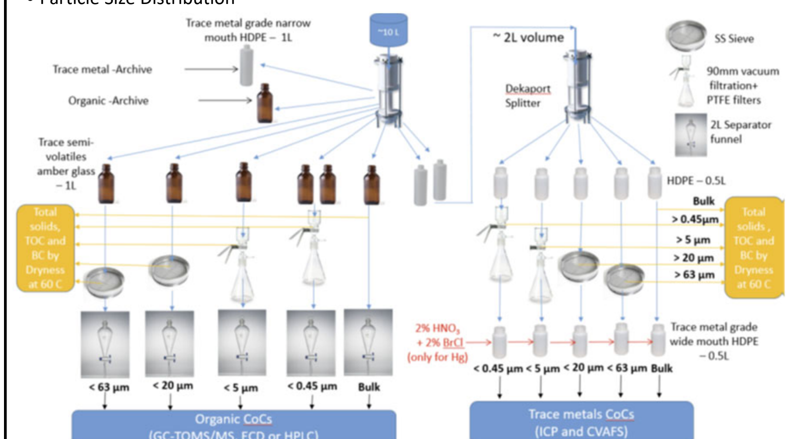
The following parameters were analyzed:

- Metals (total and dissolved): Al, Cd, Cr, Cu, Fe, Pb, Zn, Hg
- PAHs
- PCBs and chlordane
- General: Total solids, TOC, BC, SSC, pH, carbonate, alkalinity, Cl, SO_4
- Particle Size Distribution



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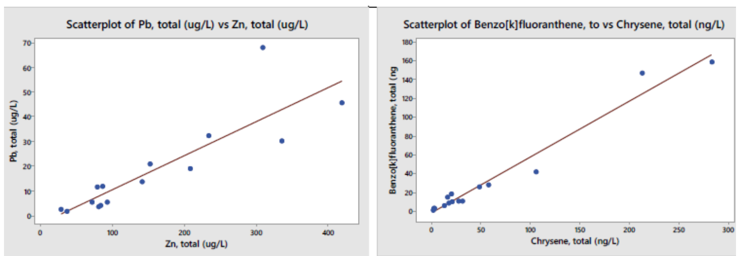
The following scatterplots show two sets of strong correlations between zinc and lead, and between chrysene and benzo[k]fluoranthene. Many other strong paired correlations were also identified, indicating similar sources and behaviors.



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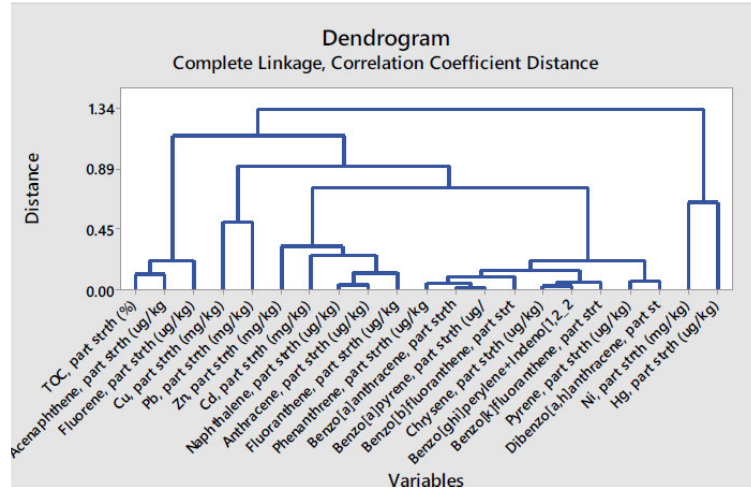

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The dendogram for particulate strength concentrations has five major data groups:

Group one: TOC, acenaphthene, and fluorene

Group two (weak): Cu and Pb

Group three: Zn, Cd, naphthalene, anthracene, and fluoranthene

Group four (strong): Phenanthrene, benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, chrysene, benzo[k]fluoranthene, pyrene, benzo[ghi]perylene+indeno, and dibenzo[a,h]anthracene

Group 5 (weak): Ni and Hg

Correlated constituents likely have similar sources and behaviors in the watershed. The strongest correlations are for the PAHs.

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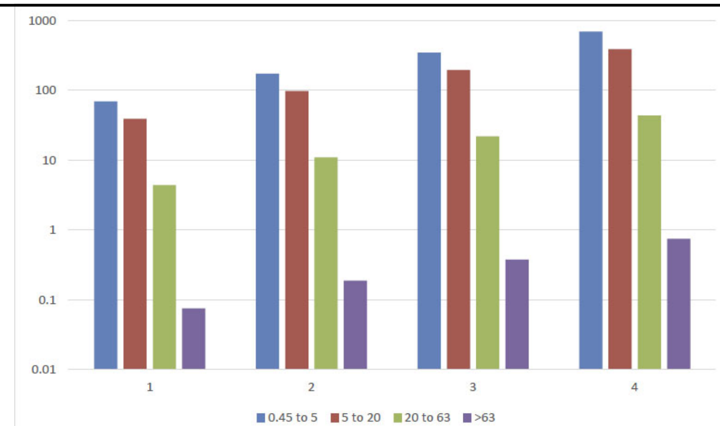

Approximate settling (hours) for 10, 25, 50, and 100 ft. water depths for different particle size ranges.

Upper Watershed Particulate Constituents having more than 75% of Expected Annual Mass Discharges in >63 µm Particle Size Category: As, Hg, Pb, Zn, Acenaphthene, Anthracene, and Fluoranthene

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Determining the recontamination potential of previously dredged areas with discharged stormwater particulates is a primary objective of this research. Settling rates were calculated using Newton's (turbulent) and Reynold's (laminar) settling equations to estimate the settling zones associated with each particle size category.

• Near field effects: The largest particles (>63 µm) would require about 1 hour to settle in 100 ft (30 m) of water, and only about 5 minutes to settle in 10 ft (3 m) of water. These particles have the greatest potential of affecting areas close to the discharge location and would not be widely dispersed.

• Far field effects: The intermediate particles (20 to 63 µm) would require about 50 hours to settle in 100 ft (30 m) of water and about 5 hours to settle in 10 ft (3 m) of water. These particles would affect distant locations in harbors or closer if slowly flowing water.

• The smallest particles (<20 µm) would require even longer times to settle: about 500+ hrs in 100 ft (30 m) of water and 50+ hours to settle in 10 ft (3 m) of water. Unless impounded, these particles would likely be transported a large distance beyond the discharge location, with minimal potential of affecting nearby areas.

About 24% of the stormwater particulates from the creek are in the >63um particle size range, affecting the near zone after discharge. The Tentative TMDL report indicates a 9 acre area of impairment for sediment toxicants. This most settleable portion of the stormwater discharges would result in about an inch of sedimentation over about a 25 year period, if evenly distributed.

Numeric Targets for Toxic Pollutants at the Creek Mounts of Paleta, Chollas, and Switzer Creeks (California Regional Water Quality Control Board, San Diego)

Contaminant of Concern	Numeric Target
Sediment Concentration	
Total Chlordane	2.1 µg/kg
Priority Pollutant PAHs[1]	2,965 µg/kg
Total PCBs[2]	168 µg/kg
Water Column Concentration	
Total Chlordane	0.00059 µg/L
Benzo(a)pyrene	0.049 µg/L
Total PCBs	0.00017 µg/L
Fish Tissue Concentration	
Total PCBs	3.6 µg/kg wet weight

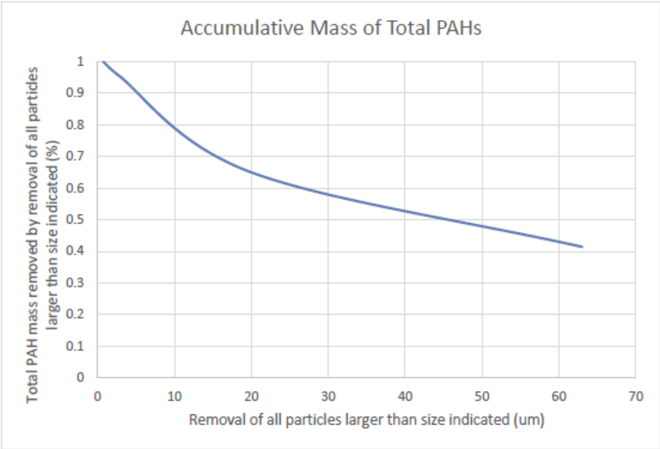
[1] Priority Pollutant PAHs = Σ [Acenapthene] [Acenapthylene] [Anthracene] [Benz(a)anthracene] [Benzo(a)pyrene] [Benzo(b)fluoranthene] [Benzo(k)fluoranthene] [Benzo(g,h,i)perylene] [Chrysene] [Dibenz(a,h)anthracene] [Fluoranthene] [Fluorene] [Indeno(1,2,3-c,d)pyrene] [Naphthalene] [Phenanthrene] [Pyrene]

[2] Total PCBs is sum of 41 congeners

PAH Components for Upper Paleta Creek Watershed

upper Paleta Creek watershed (mostly residential)	µg/kg	%	accumulative %
Fluoranthene	1,277	49.4	49
Pyrene	571	22.1	71
Phenanthrene	224	8.7	80
Benzo[a]anthracene	122	4.7	85
Benzo[ghi]perylene+Indeno[1,2,3-cd]pyrene	104	4.0	89
Chrysene	95	3.7	93
Benzo[a]pyrene	66	2.5	95
Naphthalene	43	1.7	97
Benzo[k]fluoranthene	36	1.4	98
Acenaphthene	23	0.9	99
Fluorene	18	0.7	100
Dibenzo[a,h]anthracene	7	0.3	100
Anthracene	0	0.0	100

Maximum observed total priority pollutant PAH concentration in Upper Paleta Creek Watershed: 3,807 µg/kg vs. 2,965 ug/kg tentative limit.



Fluoranthene (49%) and pyrene (22%) are the only PAHs that comprise more than 10% of the total sum of PAH particulate strengths for the upper watershed areas. Limit could be achieved by removal of relatively large particulate bound PAHs.

Because of their low volatility (low Henry's Law constant), high octanol-water partition coefficients (KOW) and high soil organic coefficients (KOC), many of the stormwater PAHs are preferentially adsorbed to particulate matter.

Literature has shown that the smaller and larger particles can have relatively higher PAH particulate strength values compared to the intermediate sized particles, depending on the organic content of the material.

PAHs can be controlled using the same controls that are effective for the particulates and most metals.

These controls need to be verified for site conditions for these compounds and for different particle size ranges. The current research phase is conducting these verification tests.

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Urban Tree Interception Monitoring (or how not to install a rain gage network!)

- Recently, the role of urban trees in stormwater management has received increasing interest.
- The interception of rainfall by urban trees has been proposed to provide substantial benefits by reducing runoff rates and quantities.
- However, few data are available for rainfall interception of trees in typical urban settings, in contrast to research from natural forests having dense standings of trees.
- Lacking data includes how interception changes for different seasonal changes in urban tree canopies for different types of trees, how these interception values vary for different rains (and during rains), and the fate of rainfall under trees that is not intercepted.

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- If a tree is located in a pervious area of the watershed (over lawns or in park areas for example), interception may not affect outfall runoff quantities much; any un-intercepted rainfall is likely to be infiltrated with or without the trees.
- However, trees likely maintain good soil characteristics and minimize compaction, which would improve the infiltration of rainfall.
- The largest hydrological benefit of urban trees would be when directly connected impervious areas (roofs, walkways, parking areas, and streets) are heavily covered by an overstory of trees. If tree-covered impervious areas are directly connected to the drainage system, these benefits would be the greatest, but if the tree-covered impervious areas drain to pervious areas (such as disconnected roofs or walks surrounded by lawns), the benefits would be low.

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- The following describes a series of direct interception measurements under urban trees to quantify some of these hydrologic benefits for inclusion in WinSLAMM.
- This study, described below, includes a standard rain gage located in an open area and rain gages under deciduous oak and evergreen pine trees. Four similar setups are also being used for comparative monitoring.
- About 45 events have been monitored from early December 2018 through April 2019 and have been statistically evaluated.
- These tests will be conducted through next winter to allow observations for all seasons.
- These results will be used to add urban tree interception benefits to WinSLAMM for appropriate conditions (tree overstory above directly connected paved areas).
- Only direct interception is considered, as trunk flow is assumed to infiltrate near the base of an urban tree in the surrounding landscaped or tree planter box area.

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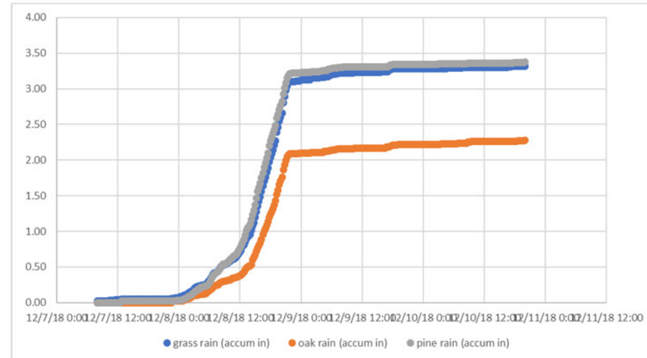
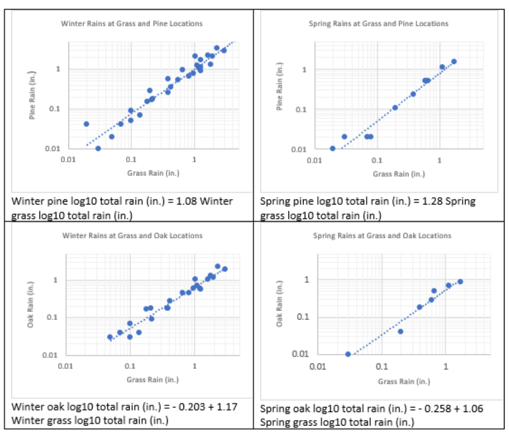
Urban tree interception rain gages



For this winter rain, the measured rain fall under the pines had little difference compared to the background rainfall, while the oak had a substantial reduction. The total rain was about 3.32 inches. The steepest portion of the accumulated rain curve indicated about 2.1 inches over 7.25 hours, for a fairly constant rain intensity of about 0.29 inches per hour.



The plots and ANOVA statistical tests were conducted on log10 transformed rain depth data, indicating highly significant regressions. The pine data did not result in significant constant (intercept) terms so the regression only has a slope coefficient term, while the oak data had both significant intercept and slope coefficients. The residual analyses indicated satisfactory patterns.

Conclusions and Recommendations for Flow Monitoring for Green Infrastructure Performance

- Groundwater table information is needed in the study area, especially if promoting recharge of groundwater and development of local water supplies as beneficial uses. This is also needed to evaluate the potential of groundwater interfering with the subsurface structures and infiltration processes, and also affects potential groundwater intrusion into the drainage systems.
- Soil surveys at pilot-scales are needed to identify site selection of GI stormwater controls in order to maximize their benefits.
- It is essential to have adequate rain gauges (at least several) near the flow sensors in the study area.

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

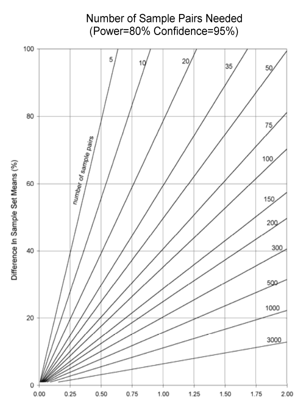
- Monitor both test and control areas before and after construction of stormwater controls, if possible, for the greatest reliability (to account for typical year-to-year rainfall variations and to detect sensor problems early).
- Test areas should have most of their flows treated by the control practices 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.**

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.**

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).**



Acknowledgements

- Many research sponsors have supported our research in recent years addressing stormwater treatment, including:
  - US EPA
  - US Navy
  - NSF
  - National Research Council of the National Academy of Sciences
  - American Society of Civil Engineers
  - Water Environment Research Foundation
  - Metropolitan Sewer District of Greater Cincinnati
  - Kansas City
  - City of Tuscaloosa
  - TetraTech
  - Geosyntec
  - HydroInternational
  - Institute of Scrap Recycling Industries
  - The Boeing Co.

Many of our research reports, students theses, and dissertations are available at my teaching and research web site at:

- http://rpitt.eng.ua.edu/index.shtml

- Most importantly, many students have contributed to our recent research during their graduate studies, including but not limited to:
  - Dr. Laith Alfaqih
  - Dr. Humberto Avila
  - Dr. Jejal Bathi
  - Ryan Bean (current PhD student)
  - Yezhao Cai
  - Dr. Vijay Eppakayala
  - Dr. Kenya Goodson
  - Dr. Alex Maestre
  - Dr. Renee Morquecho
  - Yukio Nara
  - Dr. Olga Ogburn
  - Dr. Radahegn Sileshi
  - Dr. Noburo Togawa
  - Dr. Brad Wilson
- Also colleagues, and their students, at other institutions that participated in our recent research activities
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