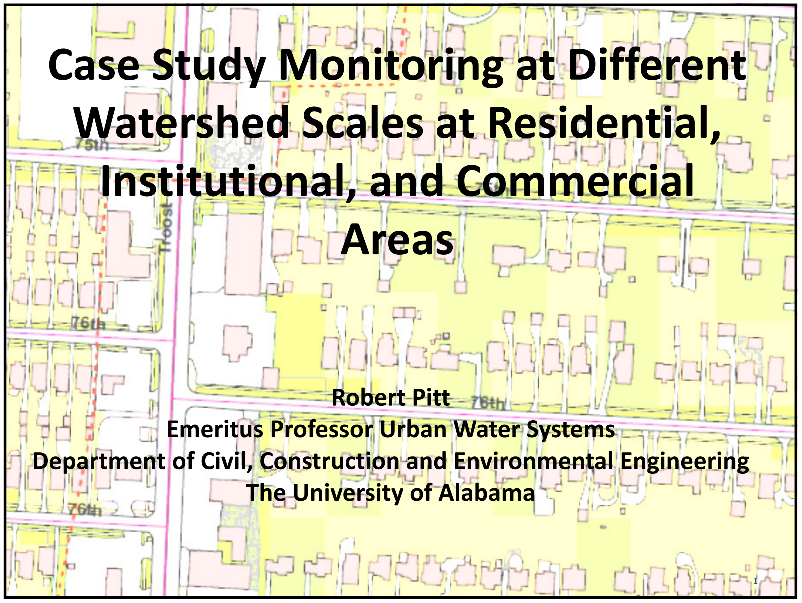

Case Study Monitoring at Different Watershed Scales at Residential, Institutional, and Commercial Areas

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
- Monitoring and modeling of sources, control, and fates of metals and organics in a large urban watershed

2

2

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?**

3

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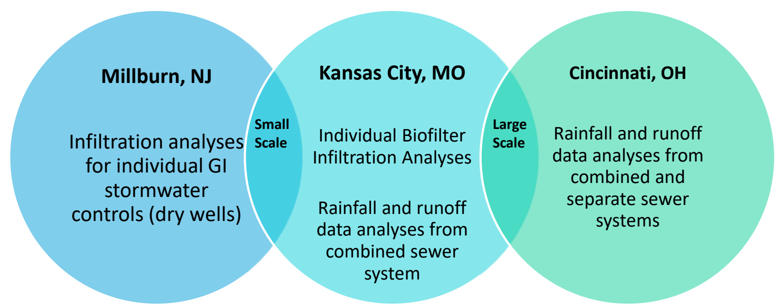
Methodology



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Data Analyses

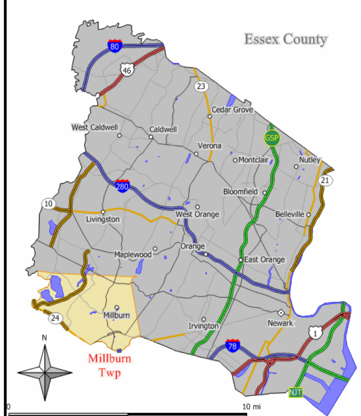
Availability of Data for Different Case Studies

- 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.

Millburn, NJ (Background and Site Descriptions)

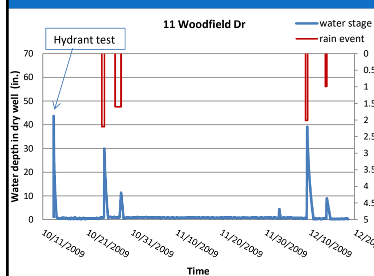
- This project was supported by the Wet Weather Flow Research Program of the US EPA and the City of Millburn to investigate whether increased beneficial uses of the runoff would be a more efficient use of the water instead of infiltrating into the shallow groundwaters, and to verify if the use of dry 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.

Small-Scale Infiltration Systems at Millburn, NJ

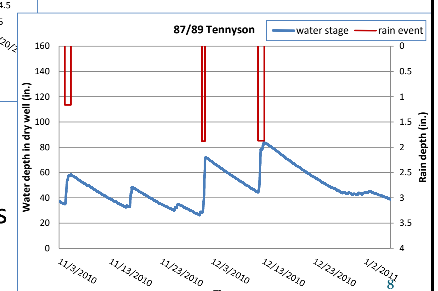


http://upload.wikimedia.org/wikipedia/commons/5/58/Millburn_twp_nj_013.png

Standing Water Conditions in Dry Wells

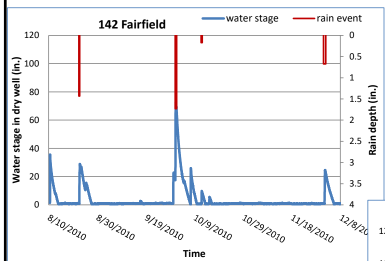


No standing water after all events



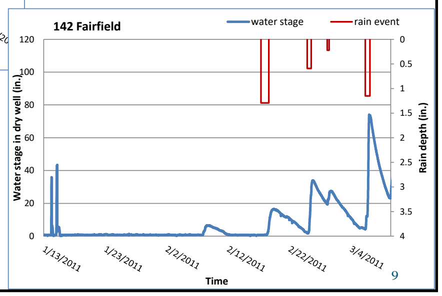
High water conditions after all events

Standing Water Conditions in Dry Wells

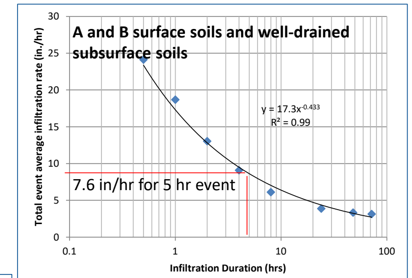


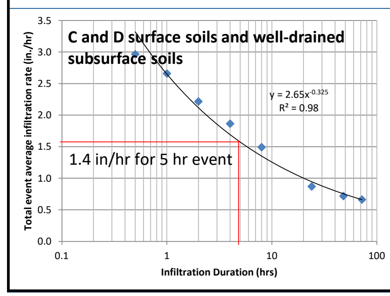
No standing water after some events

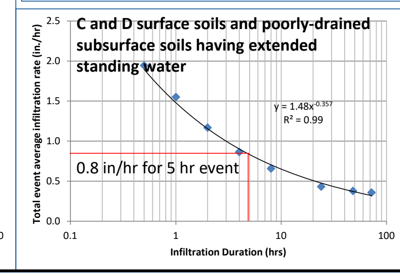
Same site: Possible mounding of water table conditions after some events (very wet period)



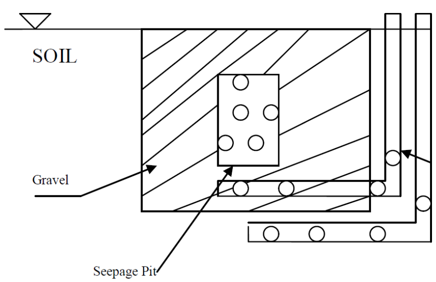
Integrated infiltration rates over the duration of the rain events showed decreasing rates as the rain duration increased. In order to explain some of the data variability, three main groups of data were identified based on surface and subsurface soil conditions and the presence of extended standing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





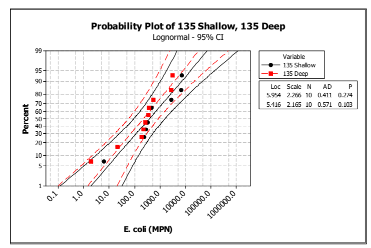


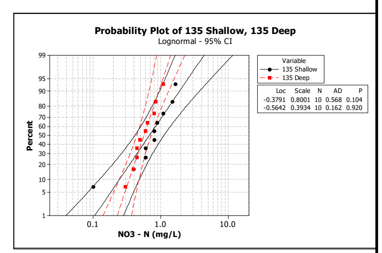
Water Quality below Dry Wells in Millburn, NJ

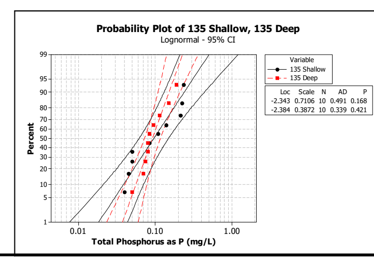


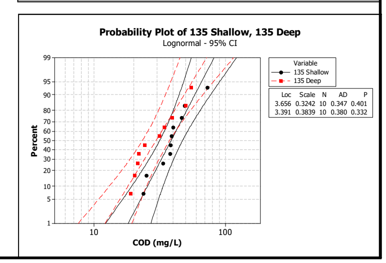
- Three dry wells: a shallow monitoring well immediately below the dry well and a deep monitoring well 2 to 5 ft (60 to 150 cm) below the gravel
- 8 to 10 storms were sampled at each of the three dry wells (all samples were analyzed in duplicate.)

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

13

13

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.

14

14

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.

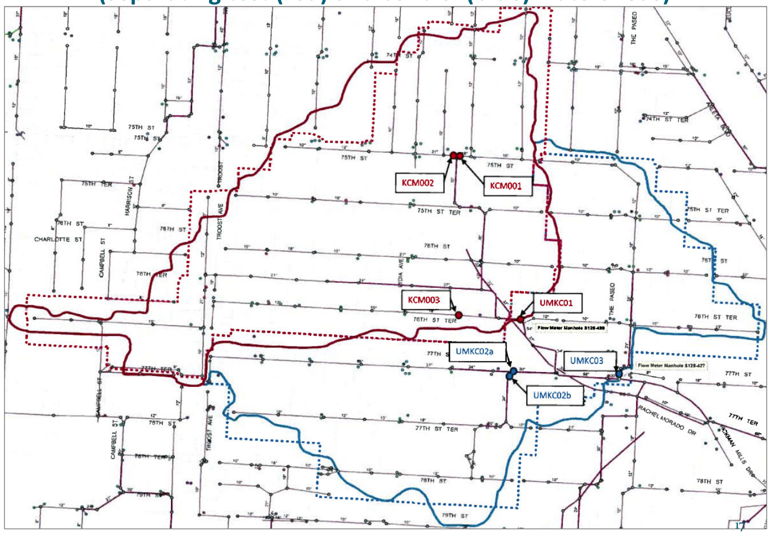
15

Kansas City's CSO Challenge

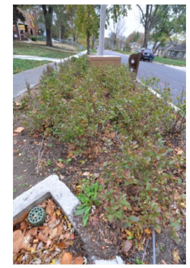
- Combined sewer area: 58 mi^2 (150 km^2)
- Fully developed
- Rainfall: 37 in./yr (94 cm/yr)
- 36 sewer overflows/yr by rain > 0.6 in (1.5 cm); reduce frequency by 65%.
- 6.4 billion gal (24 million m^3) overflow/yr, reduce to 1.4 billion gal/yr (5.3 million m^3)
- Aging wastewater infrastructure
- Sewer backups
- Poor receiving-water quality

16

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






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)

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

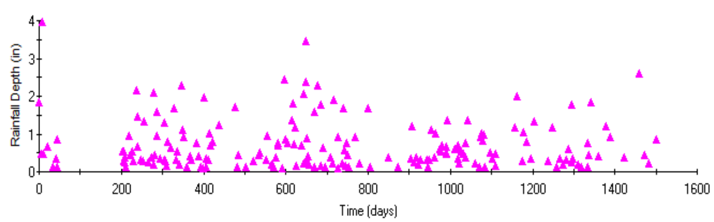
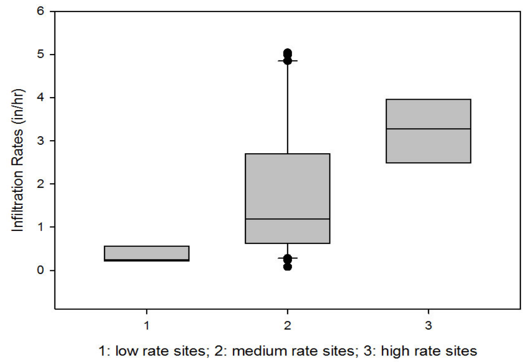


Figure 1 – Aerial photos, topo map, and urban classifications for device #1

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.

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



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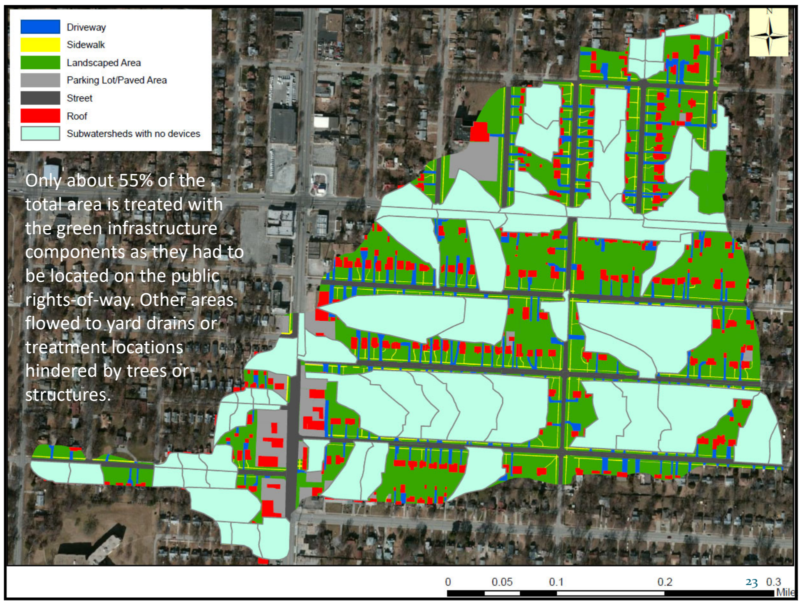
21

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

22



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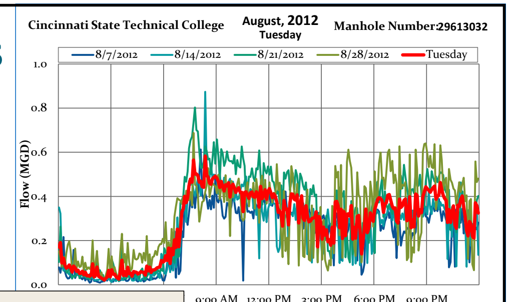
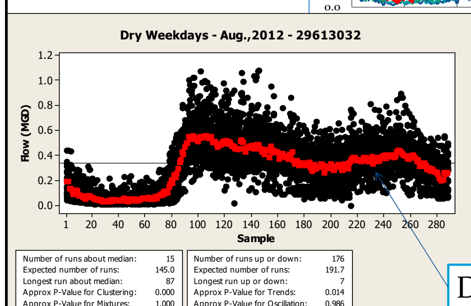
Data Analyses

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

24

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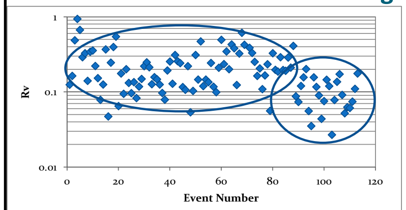
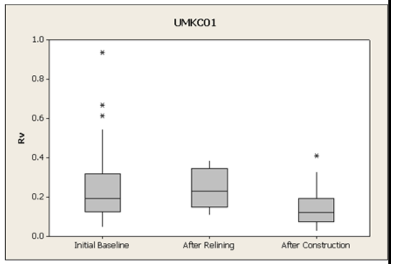
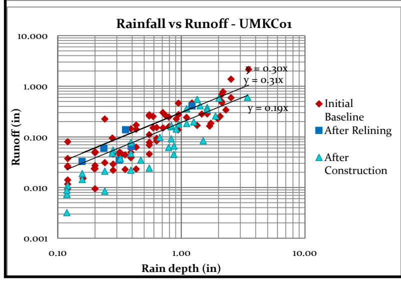
Data Analyses

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

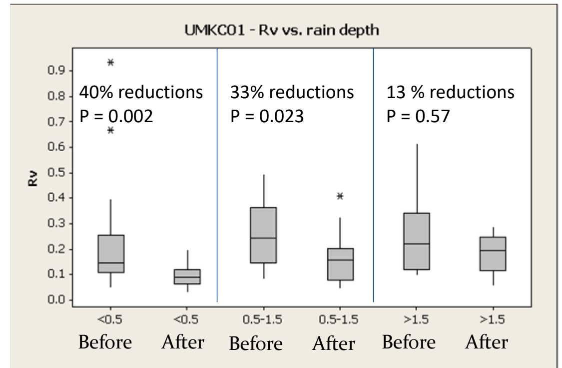
2 groups (Initial and after relining combined, vs. after construction): p<0.001

25

25

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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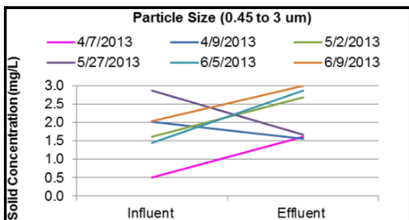

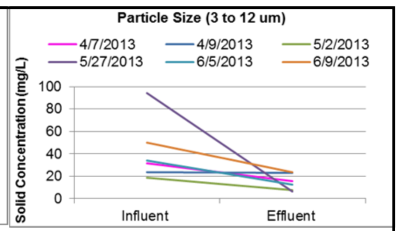

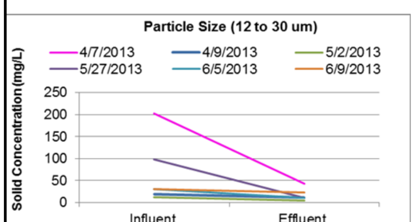

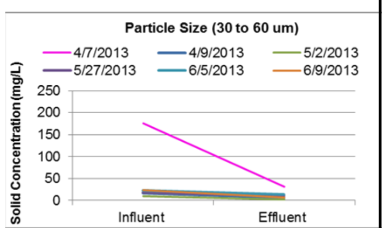

Removal of stormwater particulates by size by Kansas City test area biofilters

27

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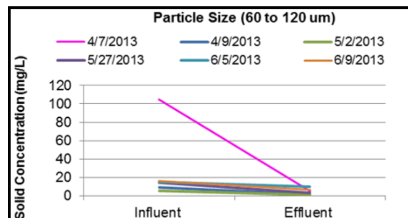
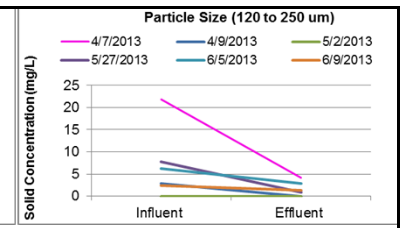
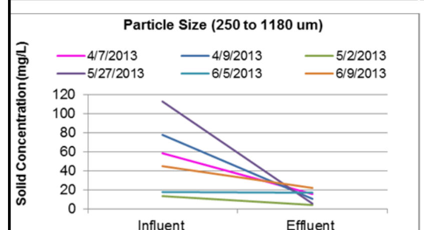




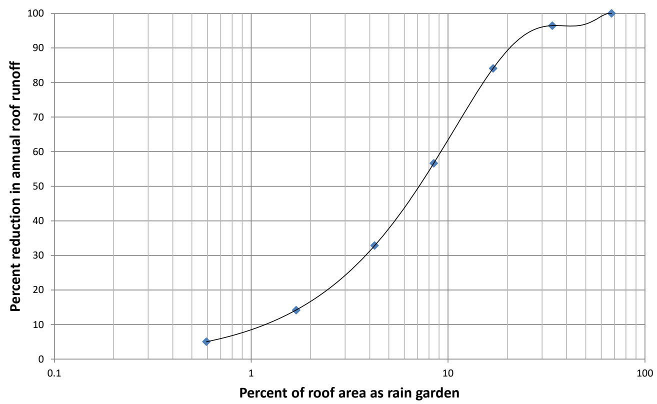


- The biofilters effectively removed a broad range of particle sizes, from 3 µm and larger, along with associated particulate bound pollutants (especially heavy metals). However, phosphorus and nitrogen concentrations increased in the effluent due to the large amount of compost in the media mixture.
- 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.

28

28

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.

29

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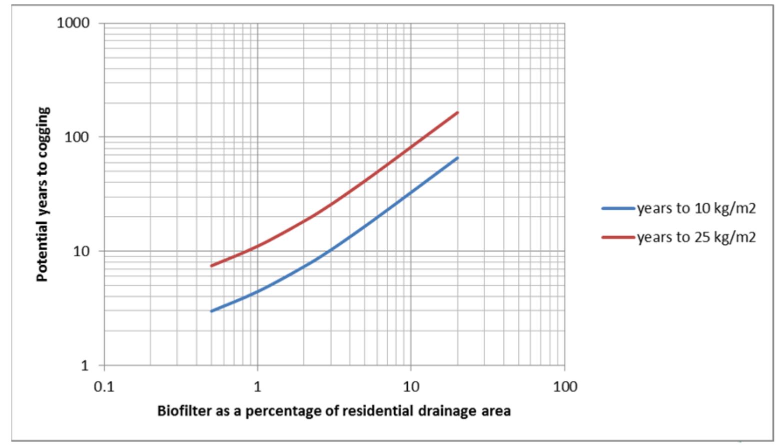
Example WinSLAMM Production Functions: Clogging Potential for Biofilters in the Kansas City Test Area



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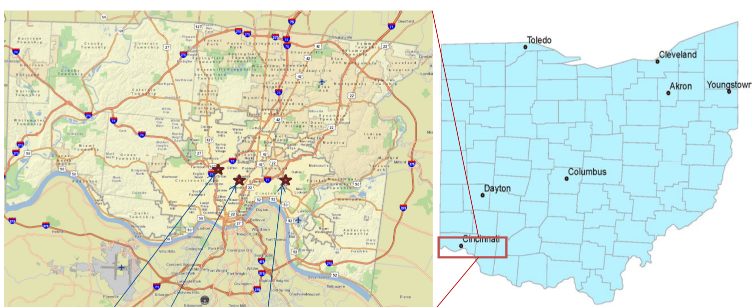
Cincinnati, OH, Test Watershed Locations



Cincinnati State College

Cincinnati Zoo

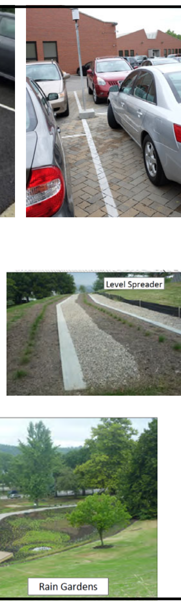
Clark Montessori High School

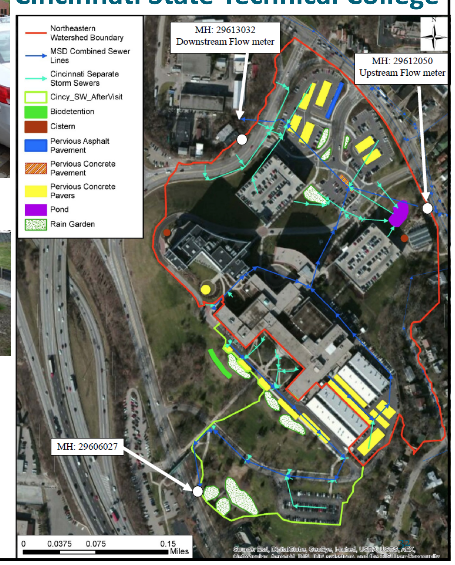
The Metropolitan Sewer District of Greater Cincinnati is among the top 5 CSO dischargers in the country (14 billion gallons (53 million m^3) of overflows annually)

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

31

Cincinnati State Technical College





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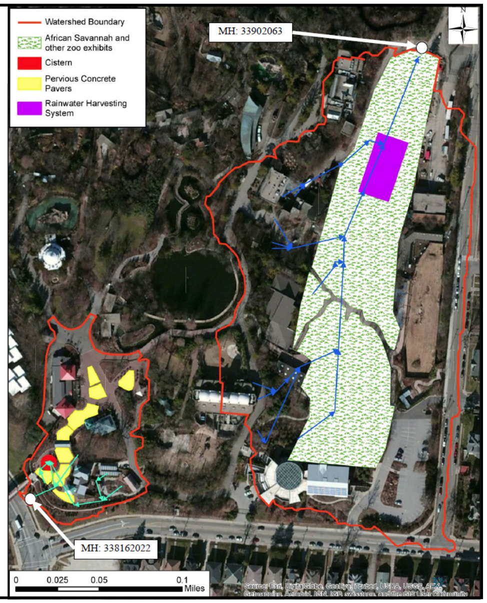
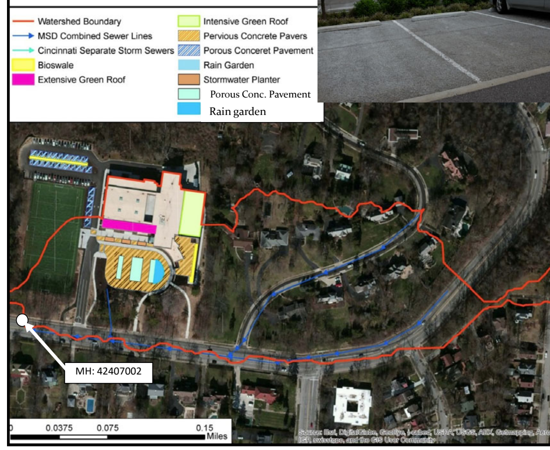
Cincinnati Zoo



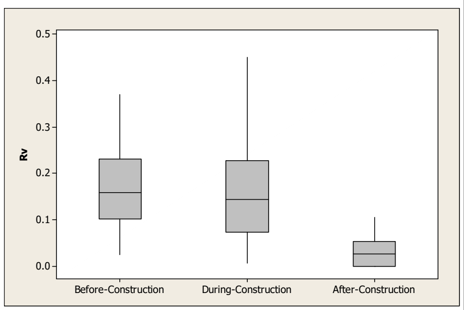
Clark Montessori High School



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

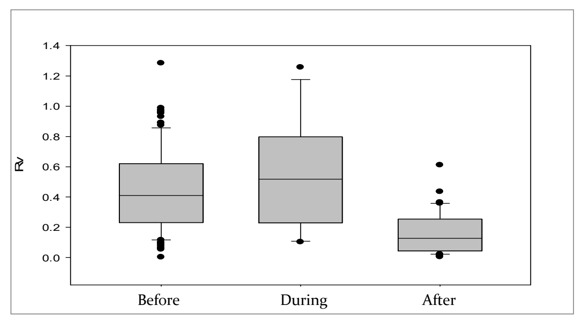
H = 73.412 with 2 degrees of freedom. (P = <0.001)

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. 35

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

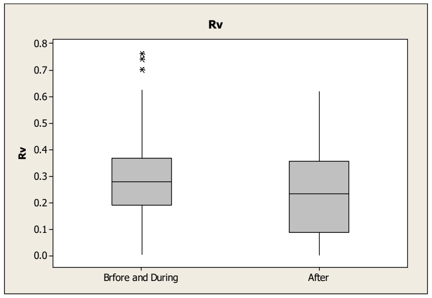
There is a statistically significant difference for at least one data set (P = <0.001)

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 36

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)

37

37

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, second phase research (2019 to 2021) in San Diego, CA, and Puget Sound, WA

38

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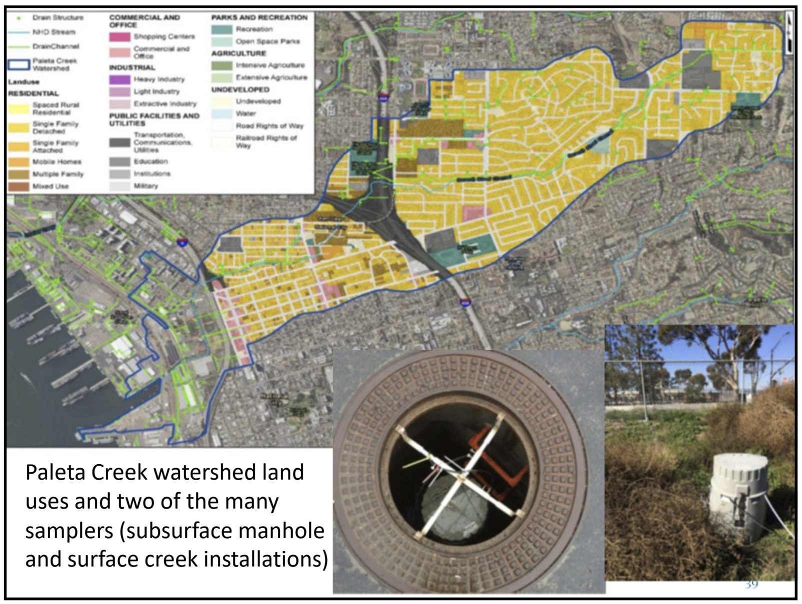
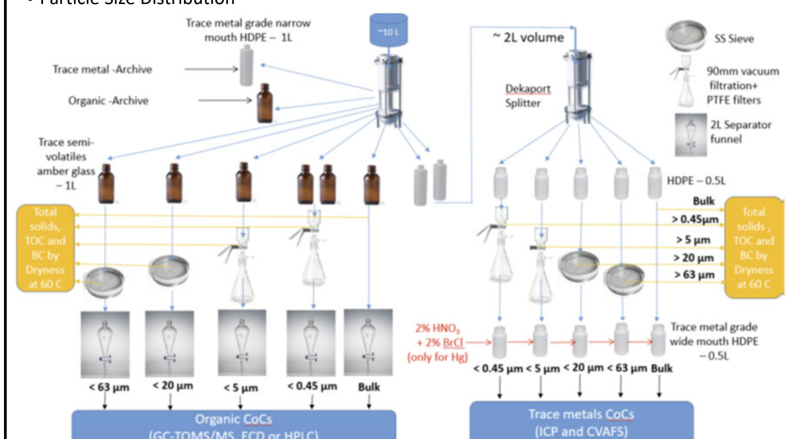


Paleta Creek watershed land uses and two of the many samplers (subsurface manhole and surface creek installations)

39

39

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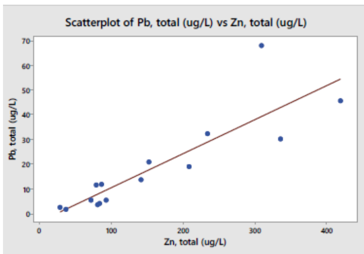
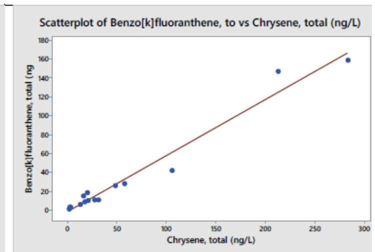
The following scatterplots show two sets of strong correlations between zinc and lead, and between chrysene and benzo[k]fluoranthene. Many other strong paired correlations were also identified, indicating similar sources and behaviors.





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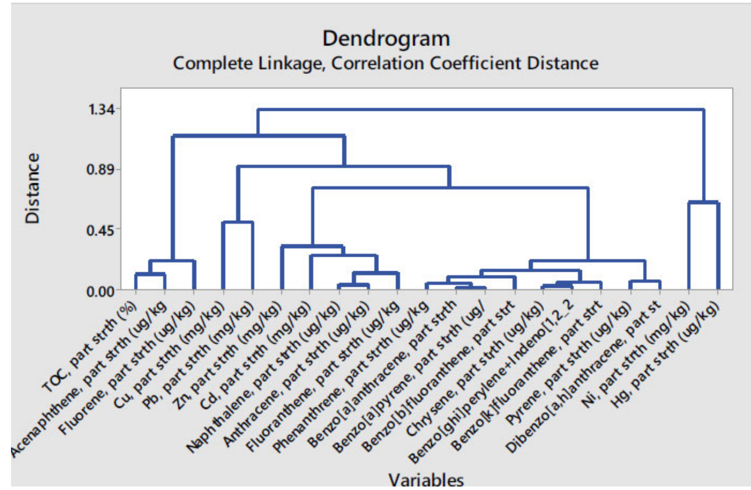

42

42

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.

43

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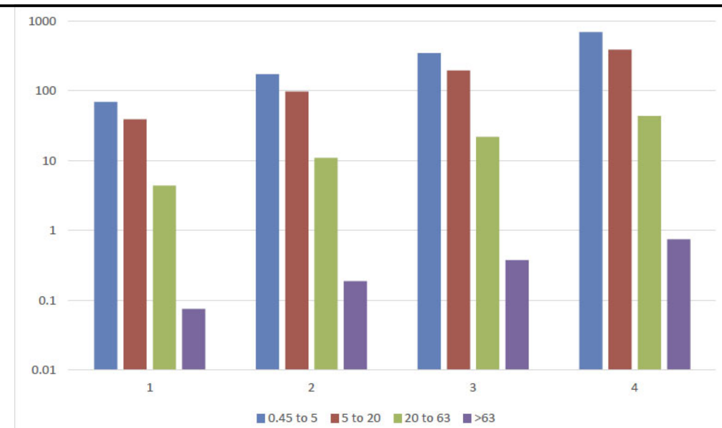


Approximate settling (hours) for 10, 25, 50, and 100 ft. water depths for different particle size ranges.

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

44

44

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.

45

45

Conclusions and Recommendations for Flow Monitoring for Green Infrastructure Performance

- Depth to groundwater 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.

46

46

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.**

47

47

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

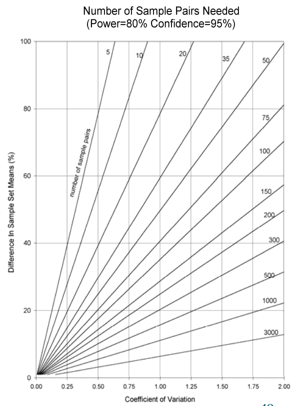
- Most monitored flows from common rains may only result in shallow depths in the sewerage, a flow condition that is difficult to accurately monitor.
- Flow sensors may fail more often than expected.
- Costs of flow monitoring is small compared to green infrastructure investment.
  - **Use redundant 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.**

48

48

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

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