United States Environmental Protection Agency

Green Infrastructure 101

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National Risk Management Research Laboratory

Summary of Presentation

- Background & problem statement for urban stormwater Regulatory authority for point discharges
- Brief history of stormwater controls
- Six case studies:
  - Effect of soil compaction on infiltration
  - Accotink stream restoration Fairfax, Virginia
  - New York City Staten Island Bluebelt projects
  - Green roofs
  - Camden, NJ
  - Green Infrastructure at the Edison Environmental Center in Edison, New Jersey
- Publications and references
- Questions

Traditional Urban Drainage Problems

- Roads/parking lots account for **70%** total impervious cover (NRC, 2009)
- **80%** of impervious cover, i.e. roads, parking lots, and roofs, are **directly connected to drainage system** (NRC, 2009)
- "Urban municipal separate stormwater conveyance systems have been designed for flood control …failed to address the more frequent rain events (**<2.5 cm**)…. **small storms** may only generate runoff from paved areas and **transport** the "first flush" of **contaminants**." (NRC, 2009)

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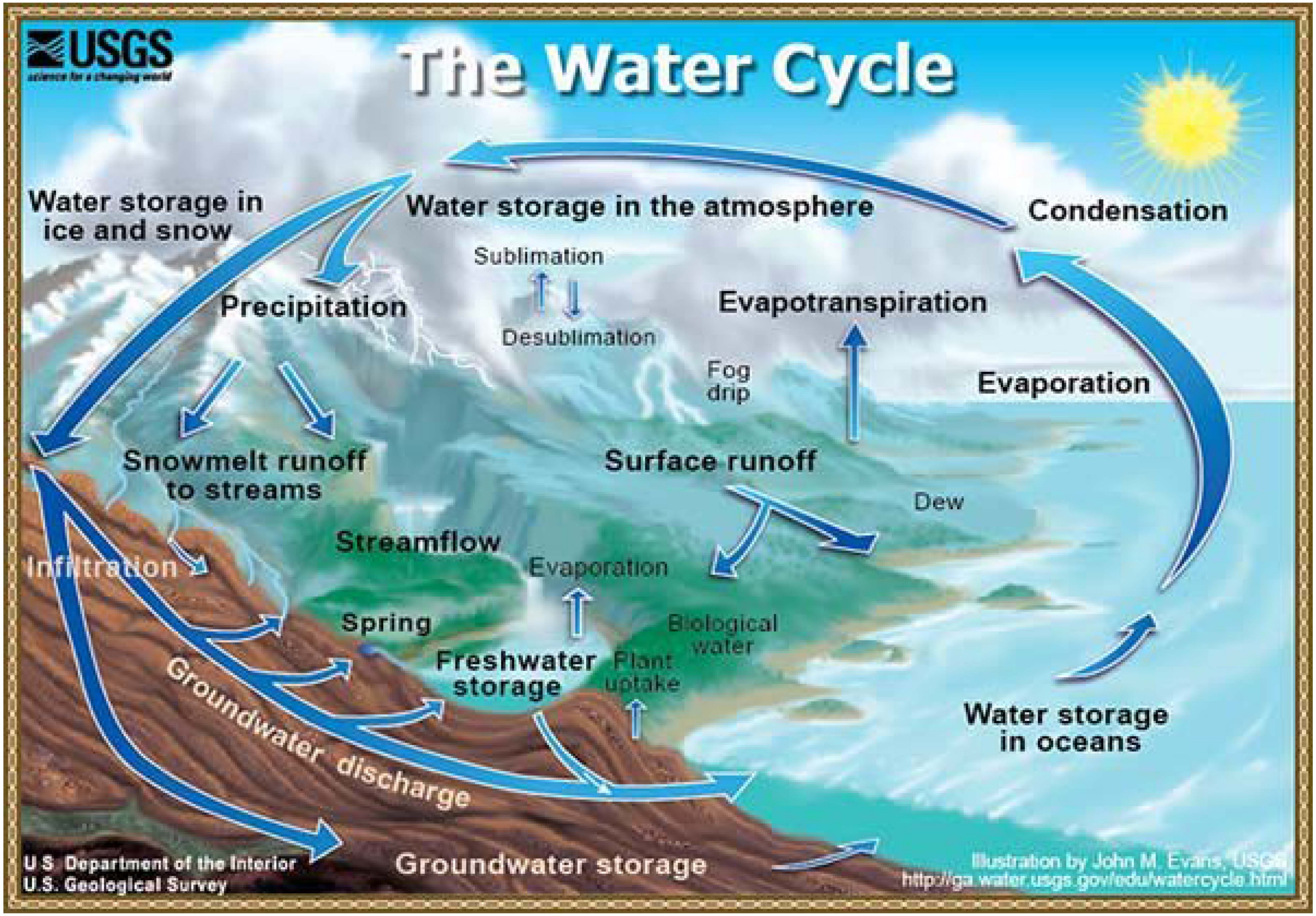
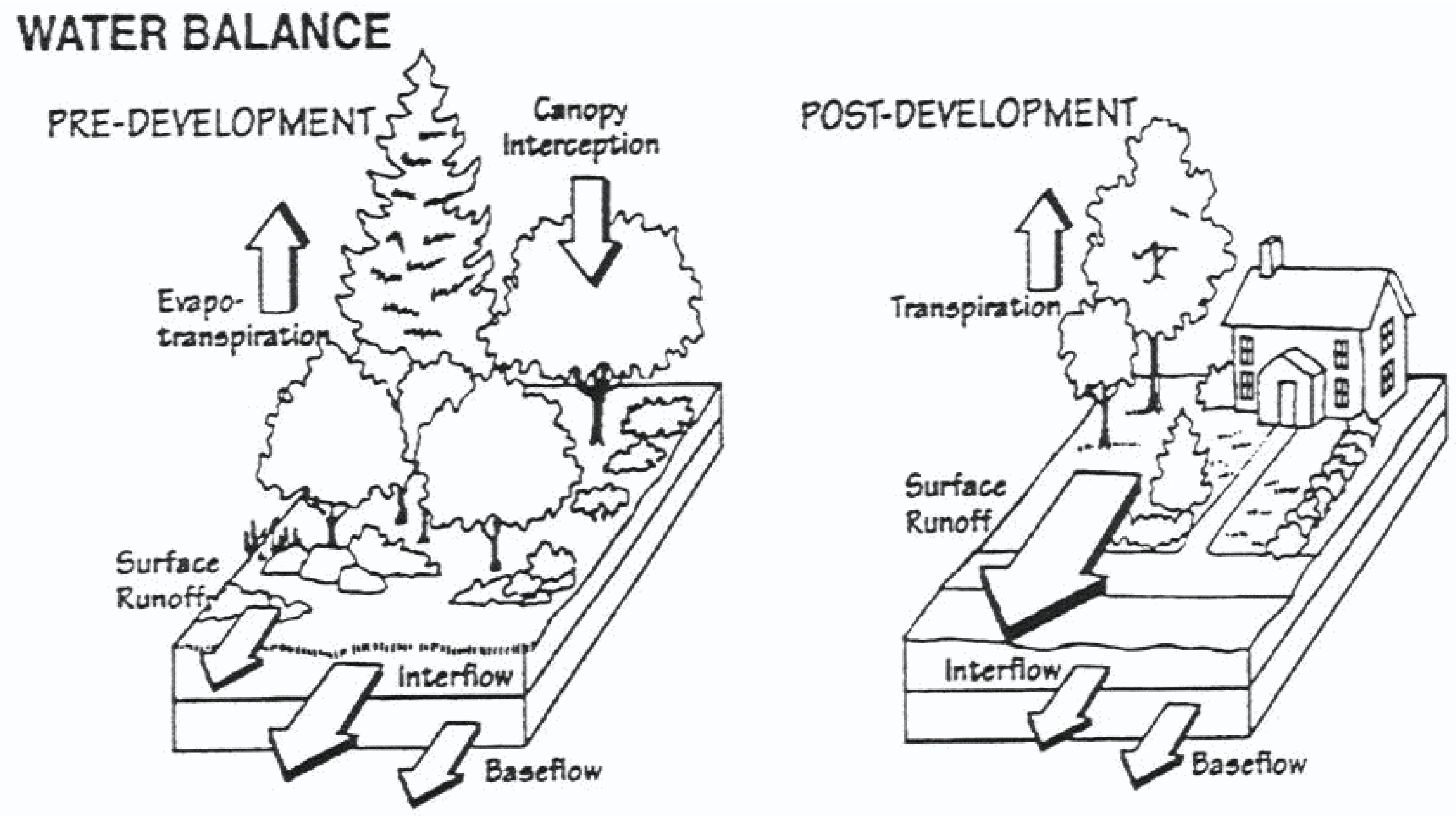


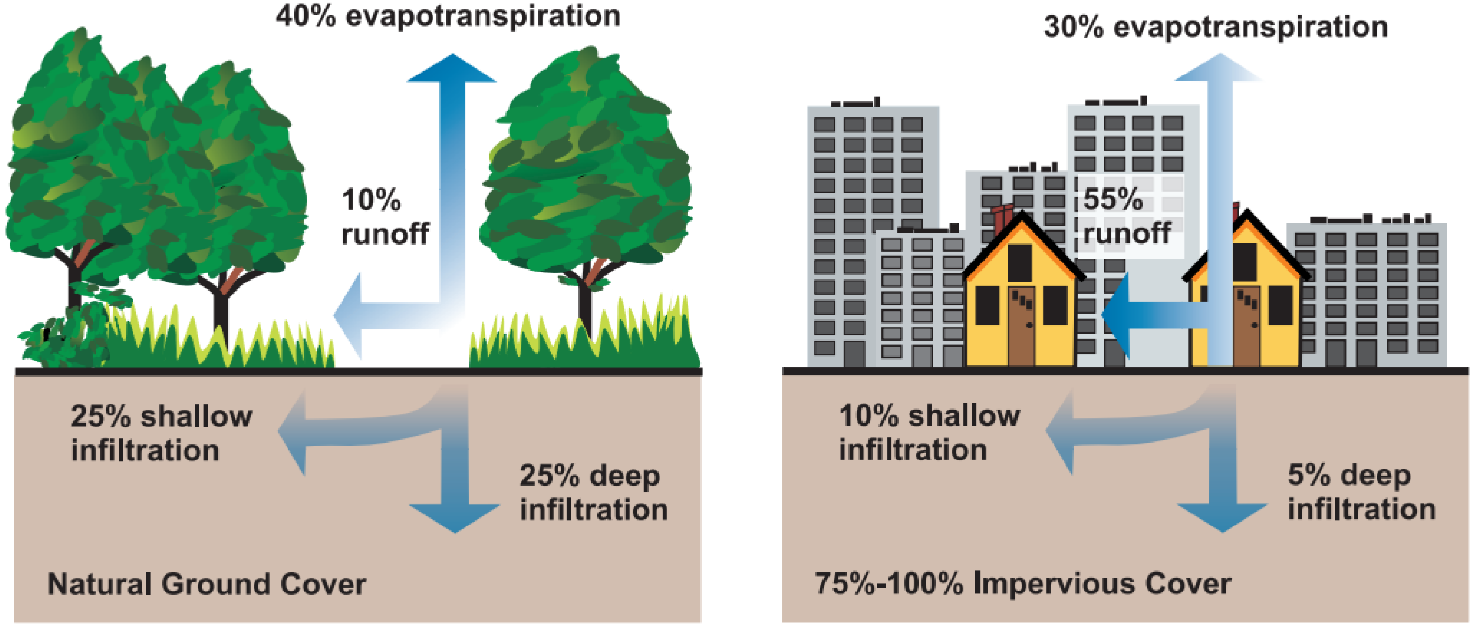
http://ga.water.**usgs.gov/edu/watercycle.html**

Effect of Development on Water Cycle



EPA (2004)

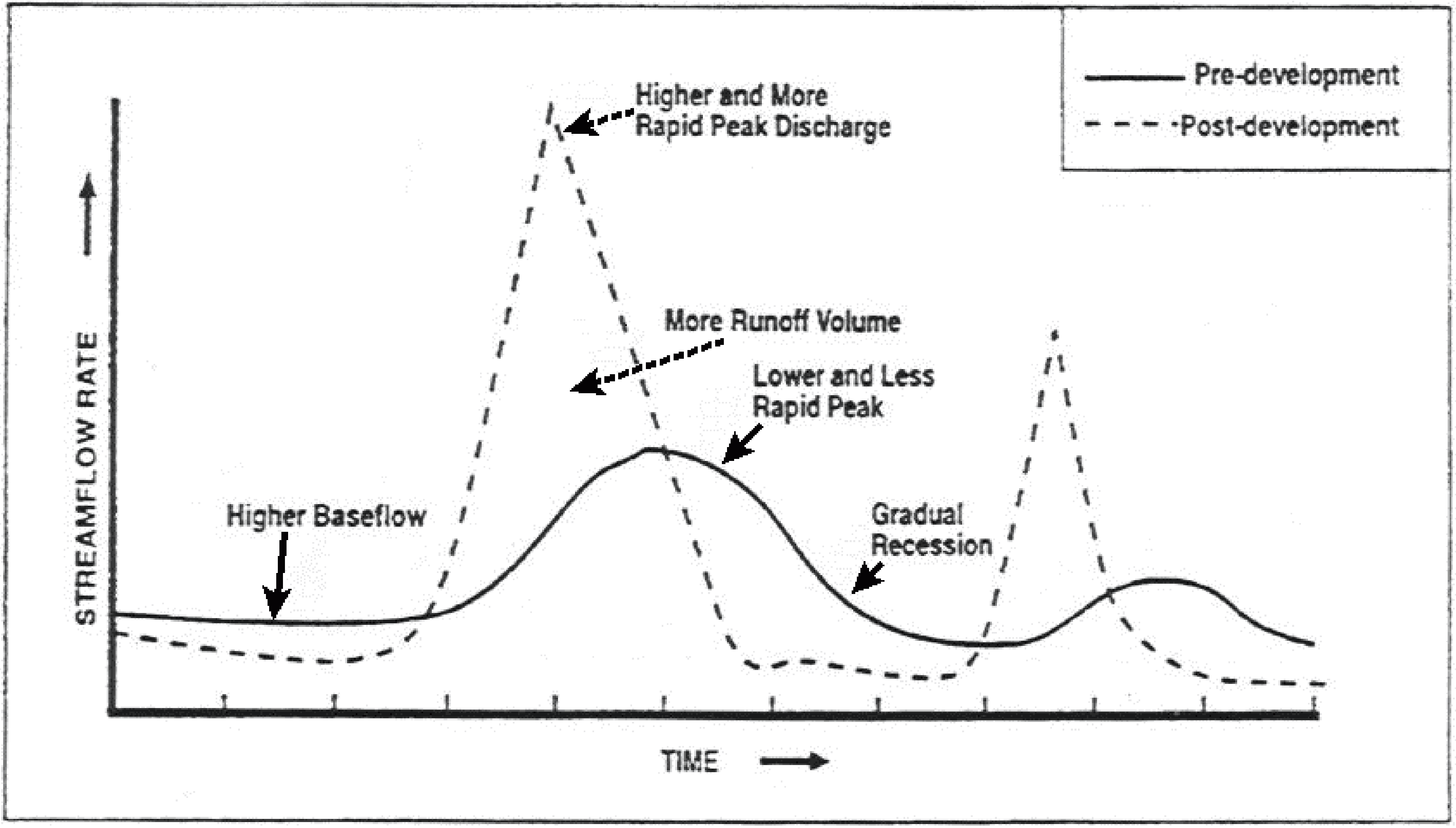
Effect of Urbanization on Water Cycle



Relationship between impervious cover and surface runoff. Impervious cover in a watershed results in increased surface ruunoff. As little as 10 percent impervious cover in a watershed can result in stream degradation.

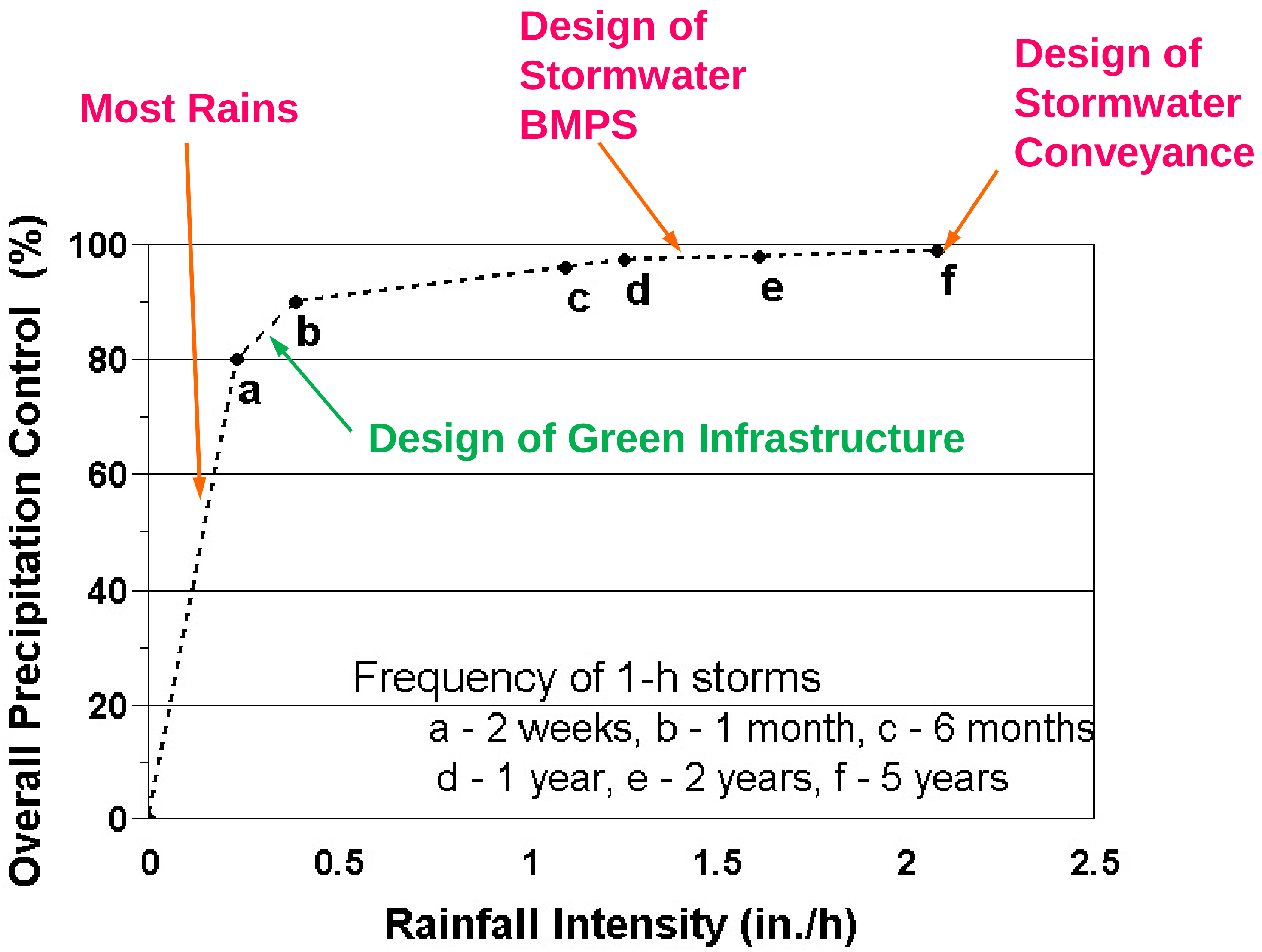
EPA 841-F-03-003
http://www.epa.gov/sites/production/files/2015-10/documents/nps_urban-facts_final.pdf

Effect of Development on Stream Flow (Hydrograph)



EPA (2004)

Overall Percent Precipitation Control vs. Rainfall Intensity (Data - Atlanta, GA, 1948 - 1972) (EPA-600/2-77-064b, NTIS PB 266 005)



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STORMWATER RUNOFF REGULATION AUTHORITY

National Regulatory Authority

- Environmental Protection Agency (1970)
- Clean Water Act (1972)
- National Pollution Discharge Elimination System (NPDES): **Permits for point sources**
  - Wastewater Treatment
  - Combined Sewer Overflows (CSOs)
    - Nine minimum controls, Long term control plan
    - Consent decrees
  - Stormwater discharges from three potential sources: municipal separate storm sewer systems (MS4s), construction activities, and industrial activities
    - MS4s Phase 1 (1990) and Phase 2 (1999)
    - Total Maximum Daily Loads (TMDLs)

Local Authority

- States
  - New Jersey Stormwater Best Management Practices Manual New Jersey Department of Environmental Protection, Division of Watershed Management (http://www.nj.gov/dep/stormwater/bmp_manual/NJ%20SWBMP%20covcon%20CD.pdf)
- Municipality
  - Phase 1 – population > 100,000
  - Phase 2 – population > 10,000

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Water Quality Monitoring

- Volume, flow, rainfall
- Traditional - biochemical oxygen demand (BOD); chemical oxygen demand (COD)
- Solids - suspended solids (SS), sediment, turbidity
- Nutrients – nitrogen, phosphorous
- pH, temperature
- Metals, organics
- Biological (e.g., pathogenic indicator microorganisms, macroinvertebrates, biomass)

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STORMWATER CONTROLS AND MANAGEMENT: PROGRESSION OF APPROACH

Flood Control Basins (1960s)

- Typically large basins
- Downstream property protection
- New construction and development

Flood control detention basin (concrete lined)
Rutgers Campus Piscataway, NJ


Best Management Practice (BMP) (1970s and 1980s)

- Typically large retention/detention basins
- Multiple discharge elevations
- Combining property and receiving water quality protection
- New construction and development

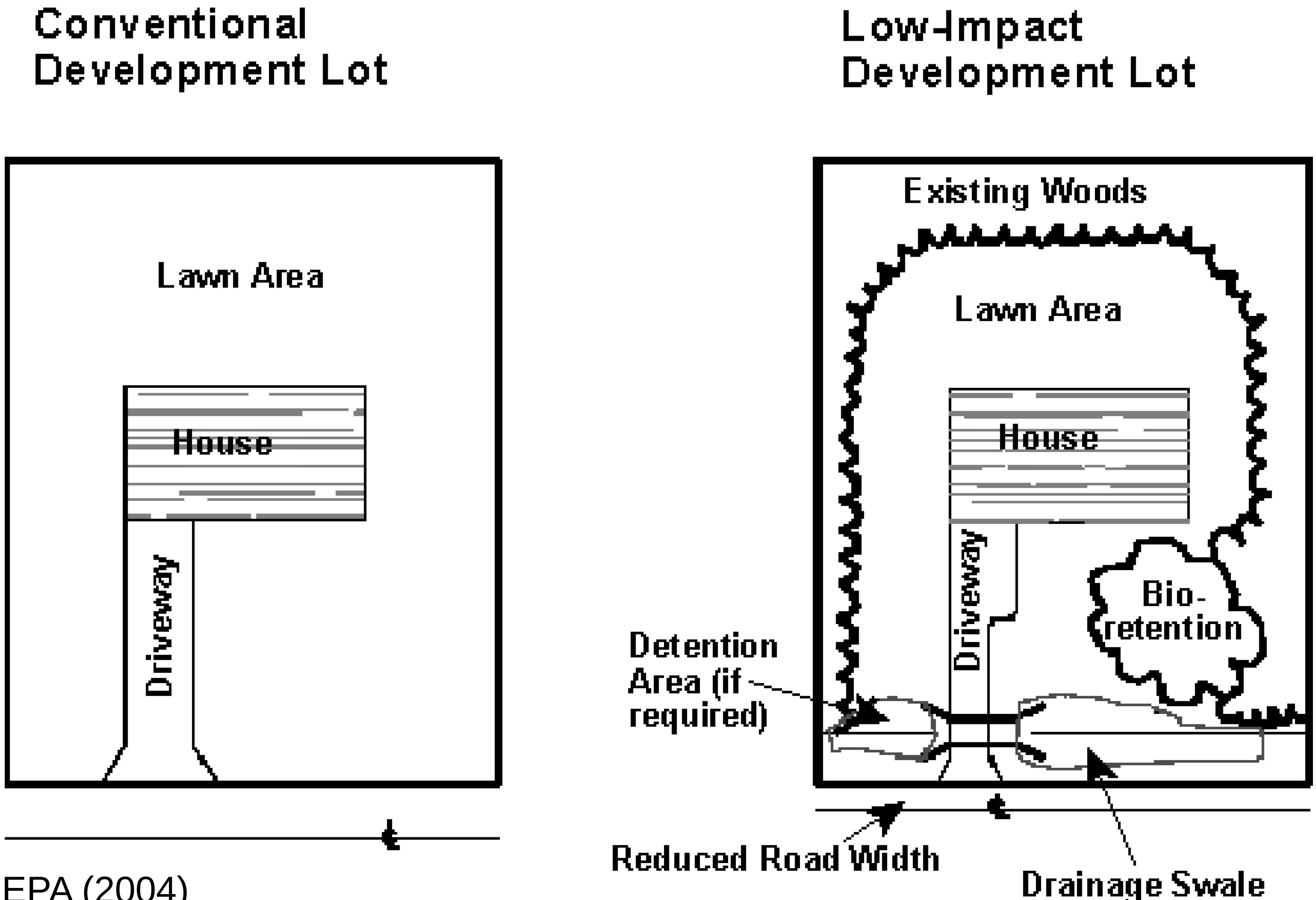
Example of retrofit Retention Basin, Villanova University, Philadelphia, PA

Low Impact Development (LID) (late 1990s)

- On site treatment
- Small scale techniques: permeable pavement, swales, bioretention/bioinfiltration, rain barrels, green roofs
- Disconnection of impervious cover
- New construction and development

Swale with Check Dams and Rain Garden on Private Lot

Single Lot LID Principles



EPA (2004)

Stormwater Controls and Management (continued)

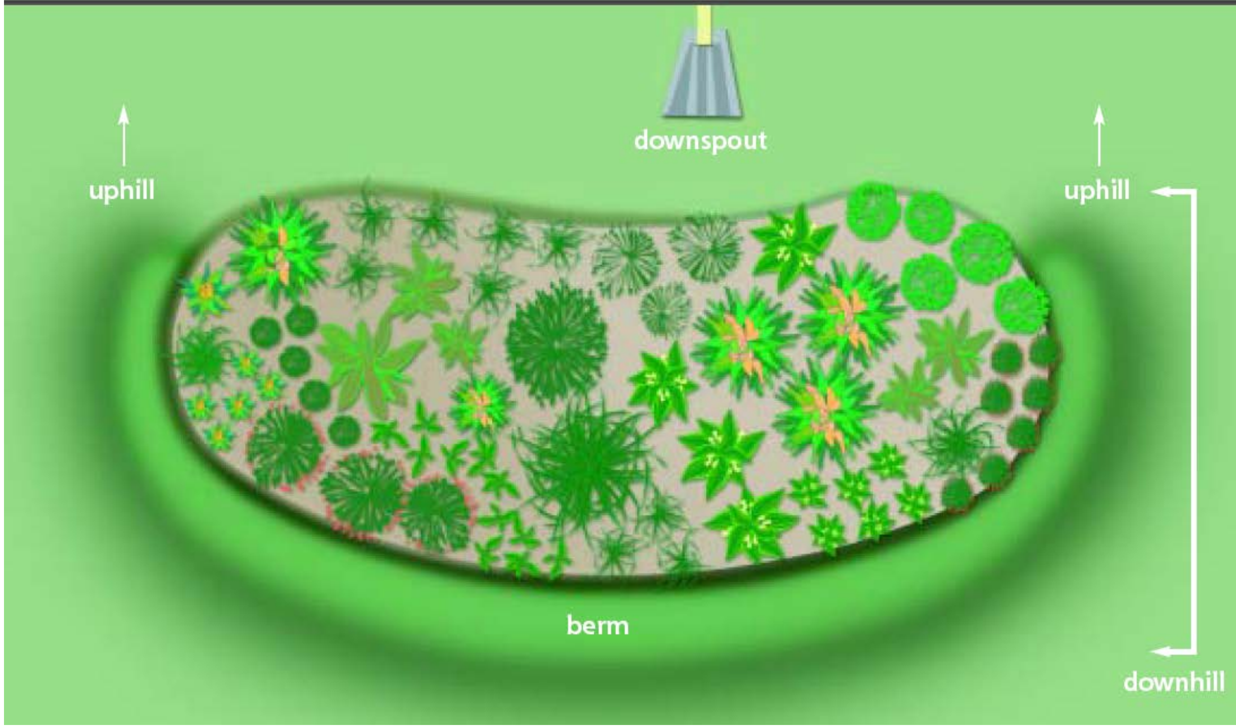
- Green Infrastructure (GI) (circa 2010)
  - Incentives to property owners to capture runoff
  - Municipal rights-of-way (ROW) for storm capture
  - Small scale - same techniques as LID - but on larger drainage area scale
  - New and existing (**retrofit**) infrastructure and buildings
  - Supplements existing grey infrastructure, i.e., sewers

Narrow Street **Reduces** Impervious Cover

Sea Streets, Seattle, WA

Bioretention to Manage Stormwater Runoff

Typical Residential Rain Garden Design



Wisconsin Department of Natural Resources
DNR Publication PUB-WT-776 2003

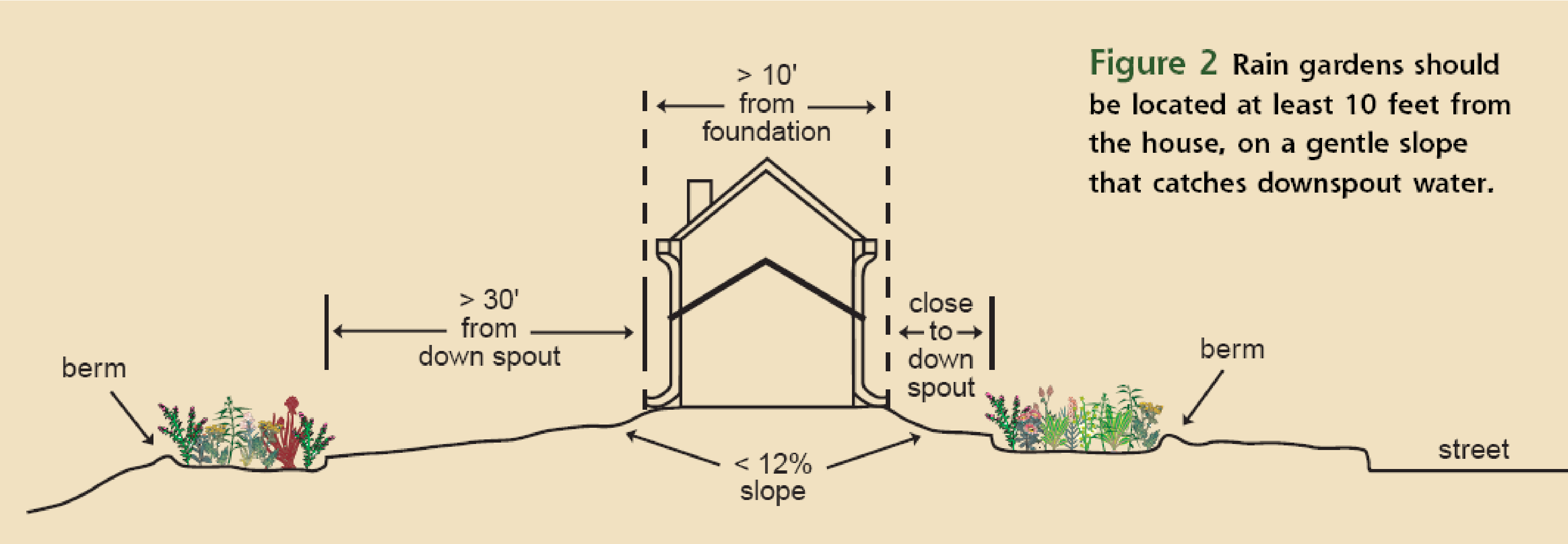
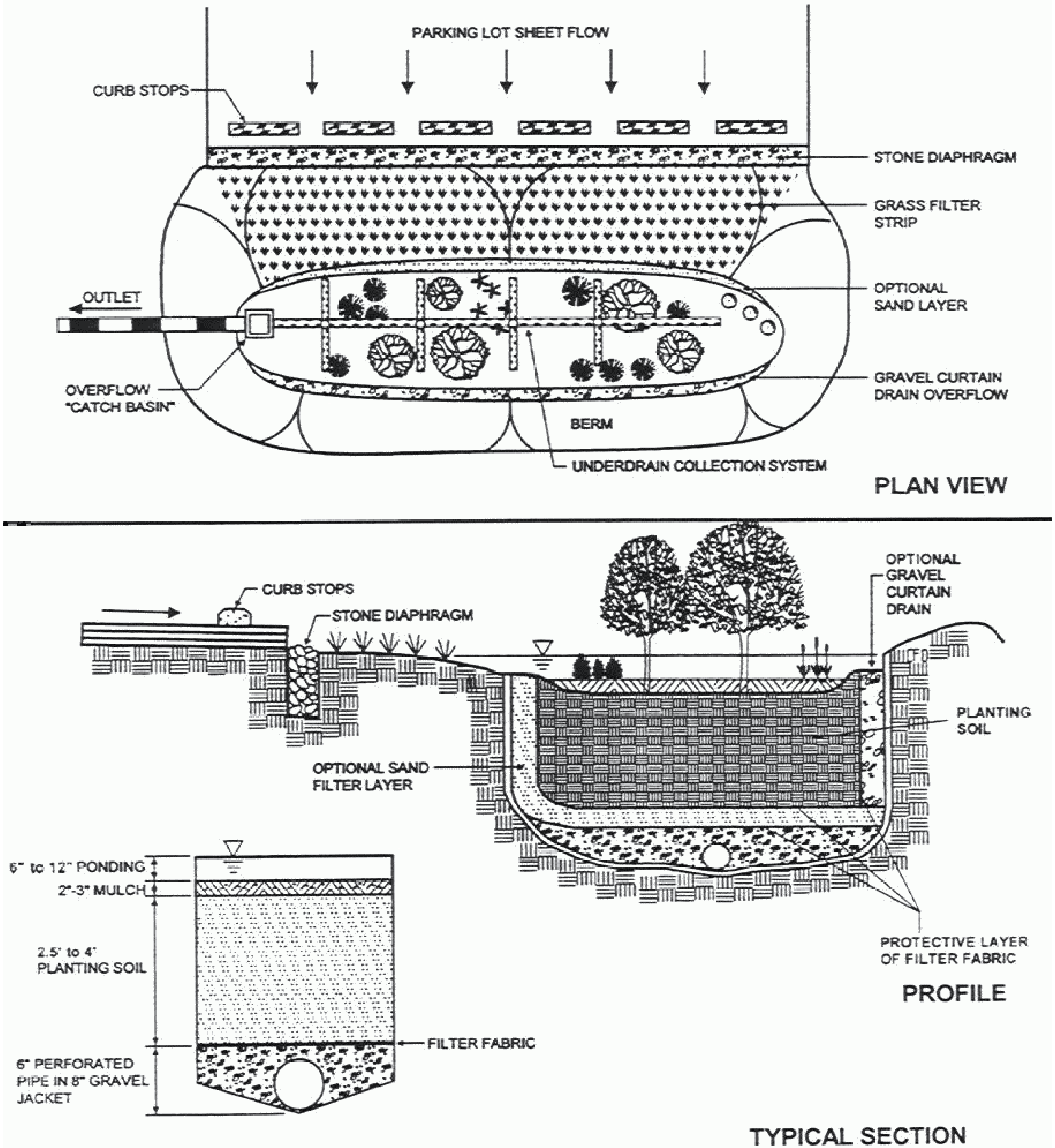


Figure 2 Rain gardens should be located at least 10 feet from the house, on a gentle slope that catches downspout water.

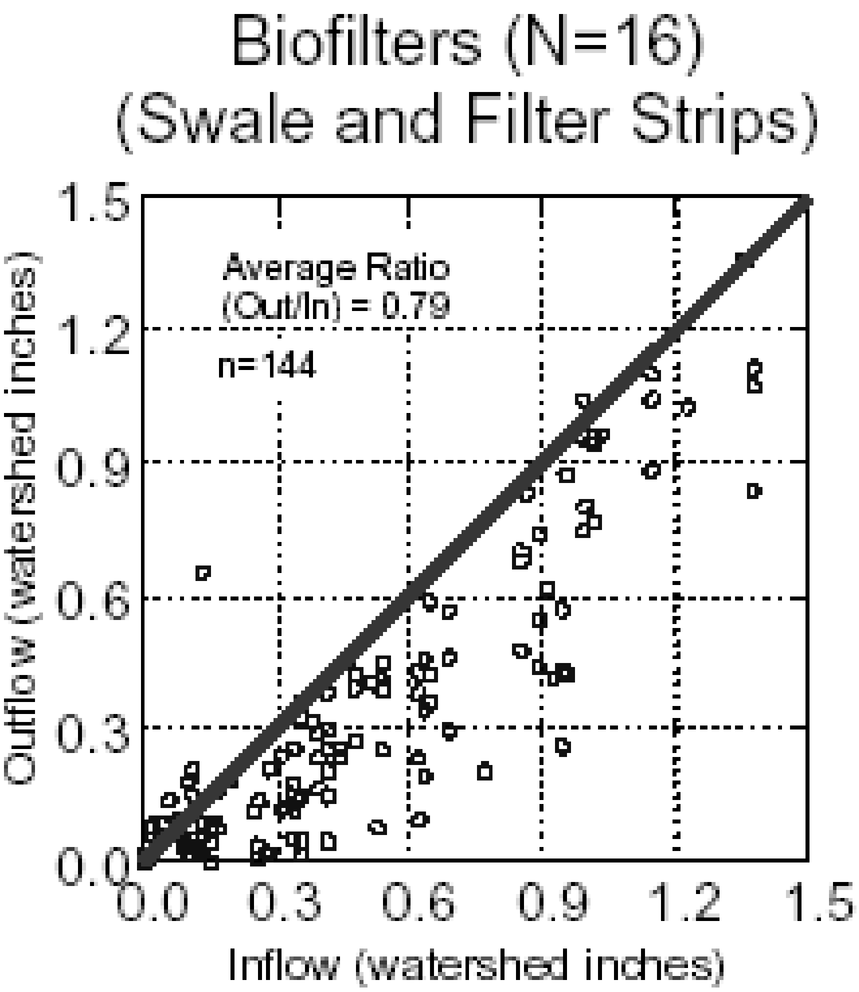
Typical Municipal ROW Bioretention Design – Example for Parking Lot



EPA (2004)

Runoff Volume Control

Early results of ASCE BMP Database shows ratio of outflow to inflow < 1 for Biofilters, <u>0.79</u>.



From presentation “ASCE BMP Database Update”
by E. Strecker to EPA Washington on February 10, 2003

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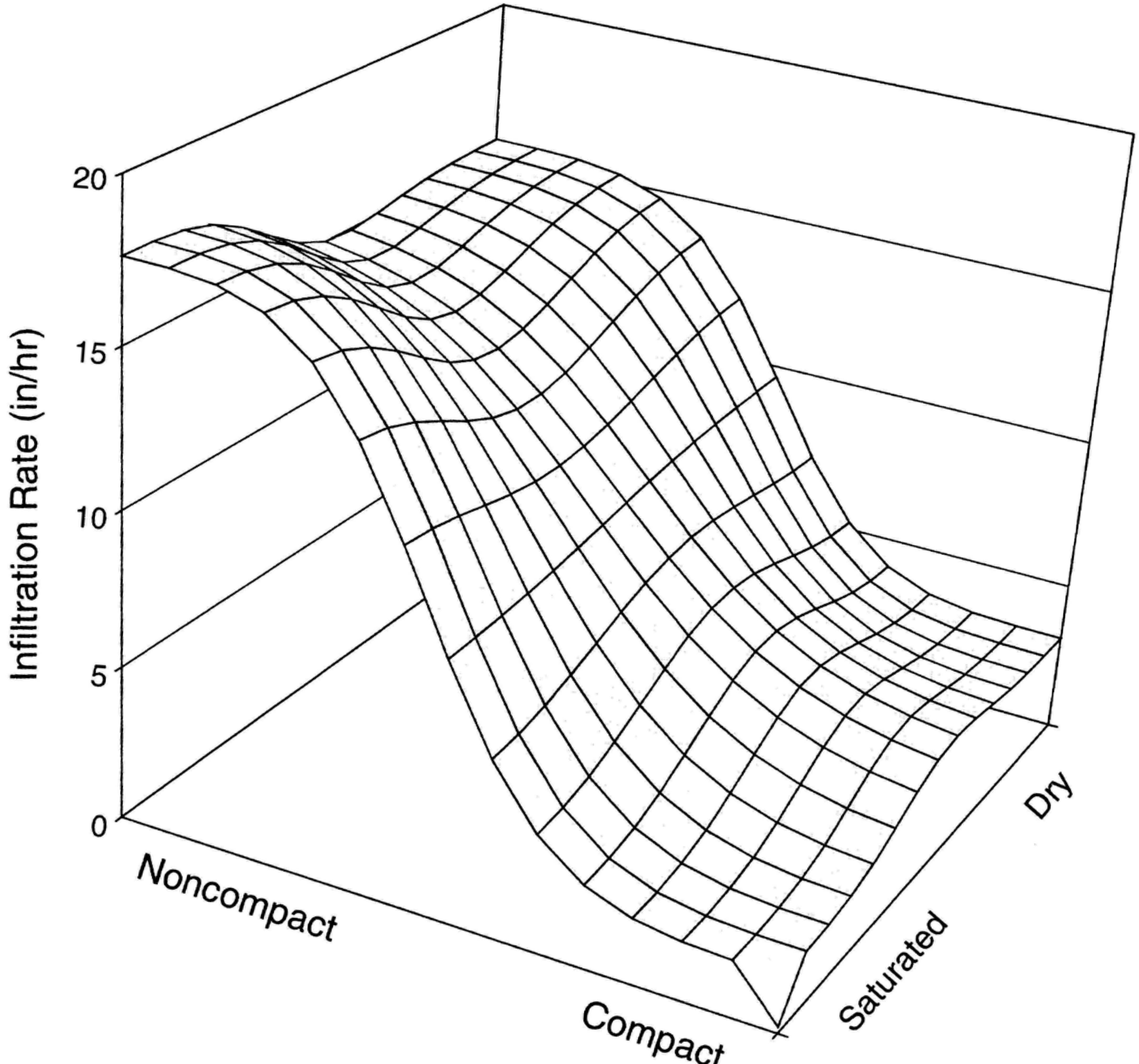
Case Study 1
Report: Infiltration Through Disturbed Urban Soils and Compost-amended Soil Effects on Runoff Quality and Quantity

EPA 600/R-00/020, (NTIS PB2000-102012)

http://www.epa.gov/ednnrmrl/reports/SR00016/index.html

Three dimensional plot of infiltration rates for sandy soils



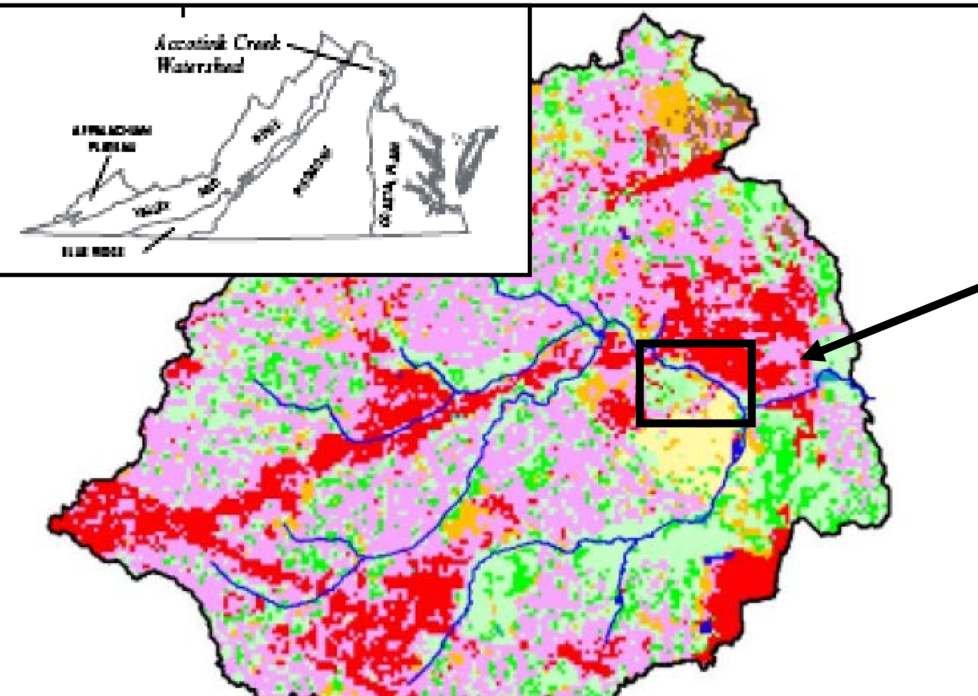
Conclusion and Recommendation

- Errors in soil infiltration rates can be made if published soil maps and most available models are used for typically disturbed urban soils, as these tools ignore compaction.
- Knowledge of compaction can be used to more accurately predict stormwater runoff quantity.

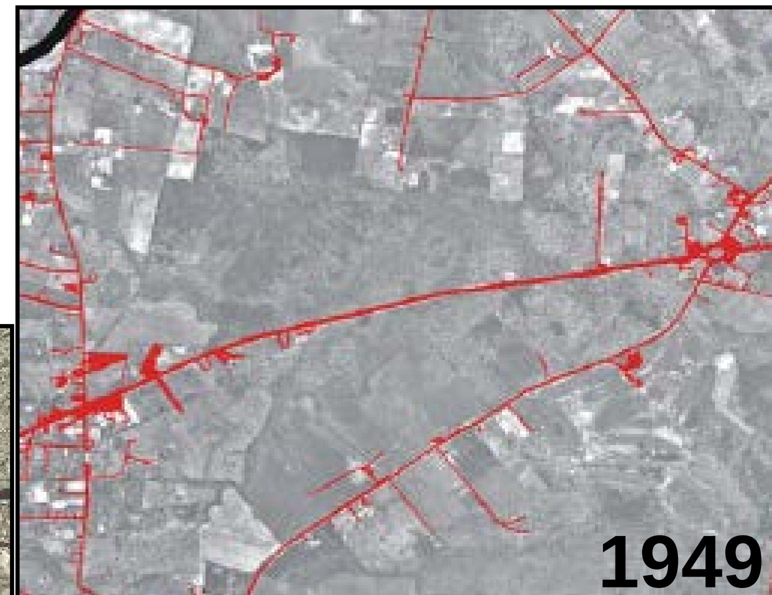
CASE STUDY 2: ACCOTINK CREEK STREAM RESTORATION, FAIRFAX, VA

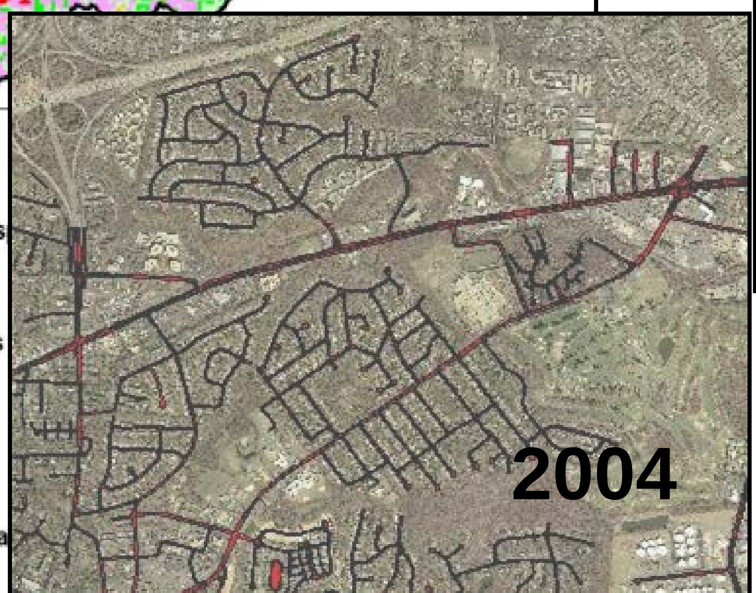
Selvakumar et al. (2009)

Accotink Watershed Land Use



Area of Interest for Restoration



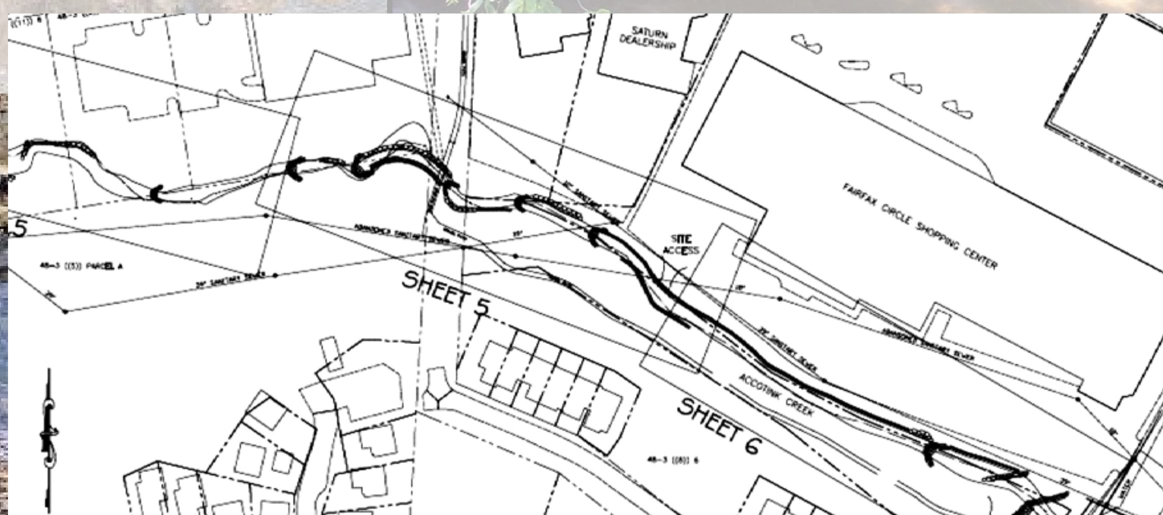


Accotink Creek, VA

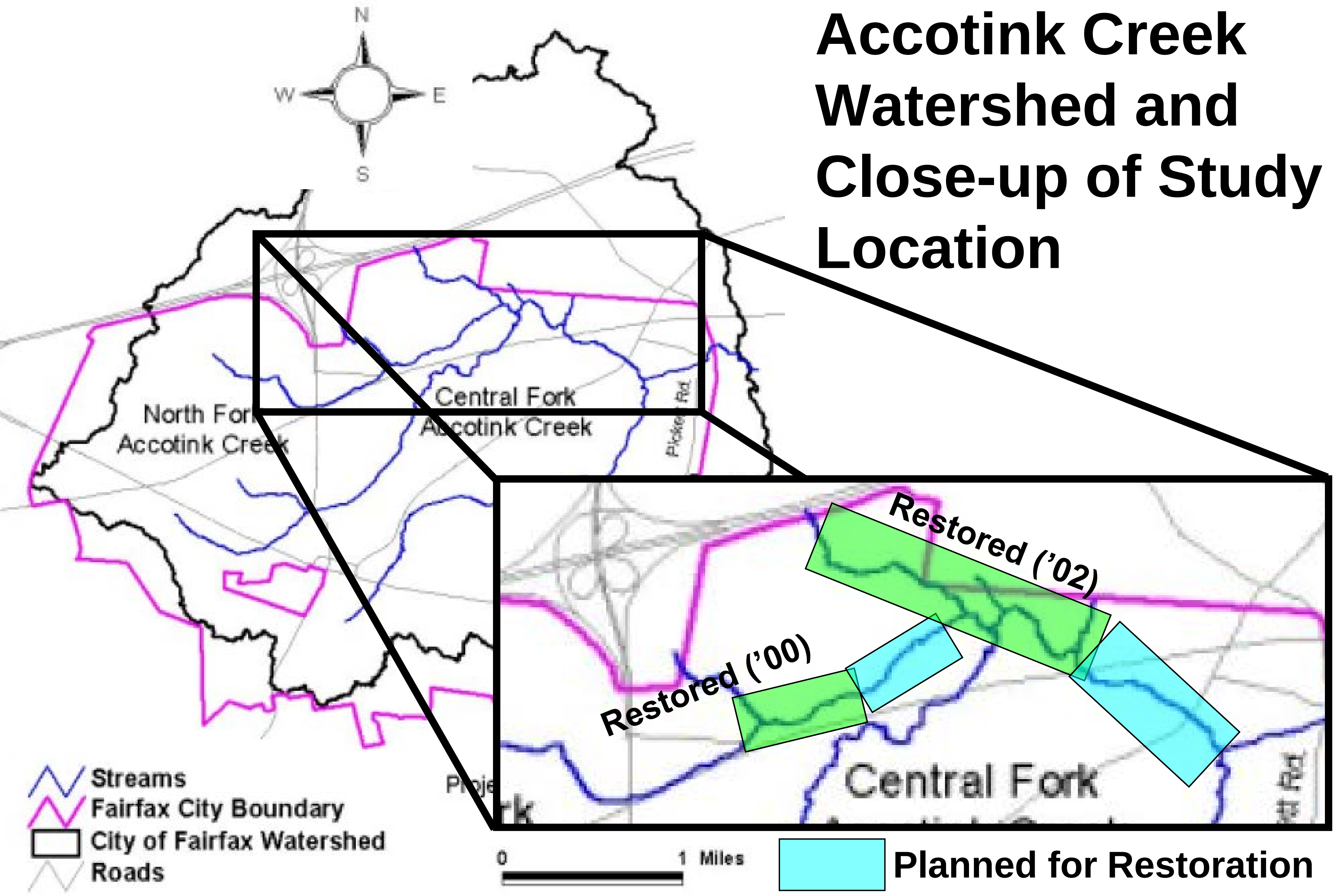
Restore 1800 Linear Feet of Stream Channel

Tools:

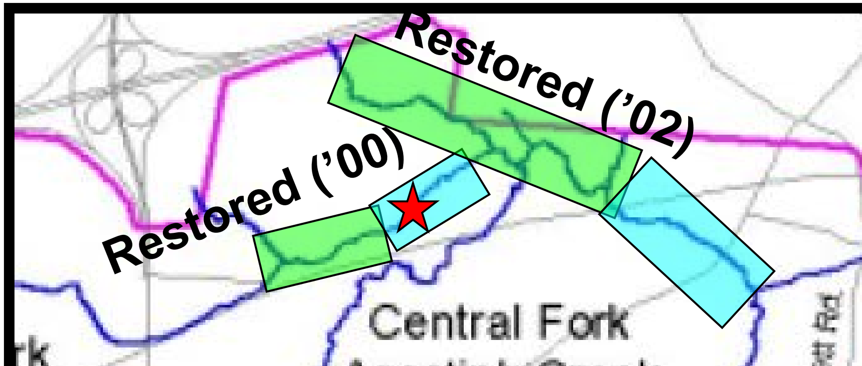
- Rock veins for slope reduction and pool formation
- Reducing slope of bank
- Widen stream channel (where possible)
- Imprecated rock wall/Stream bank armoring



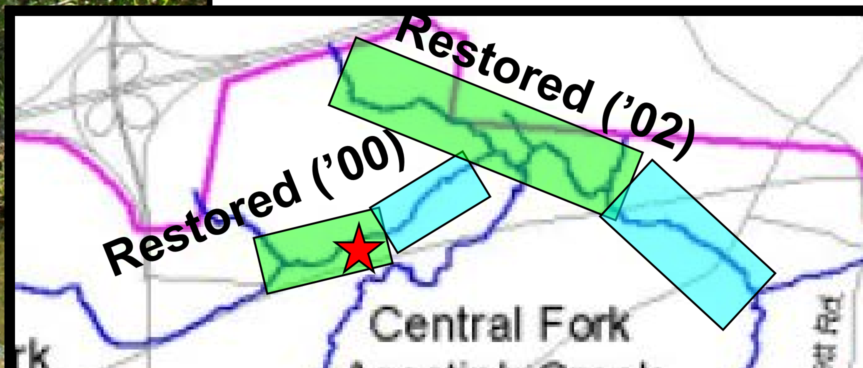
Accotink Creek Watershed and Close-up of Study Location

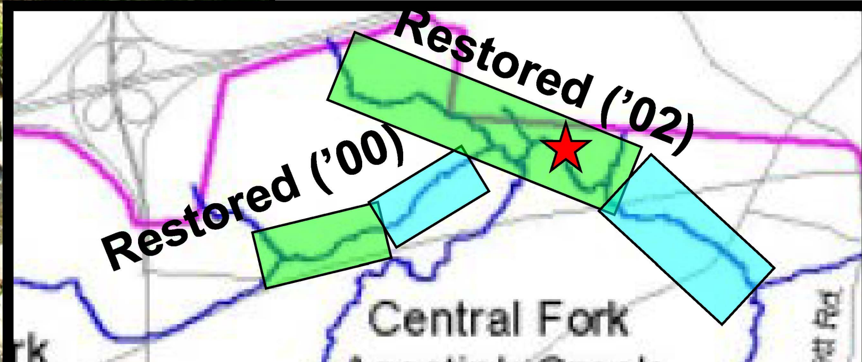


Unrestored Reach



Restored Reach




Restored ('02)
Restored ('00)
Central Fork

Monitoring of Restoration

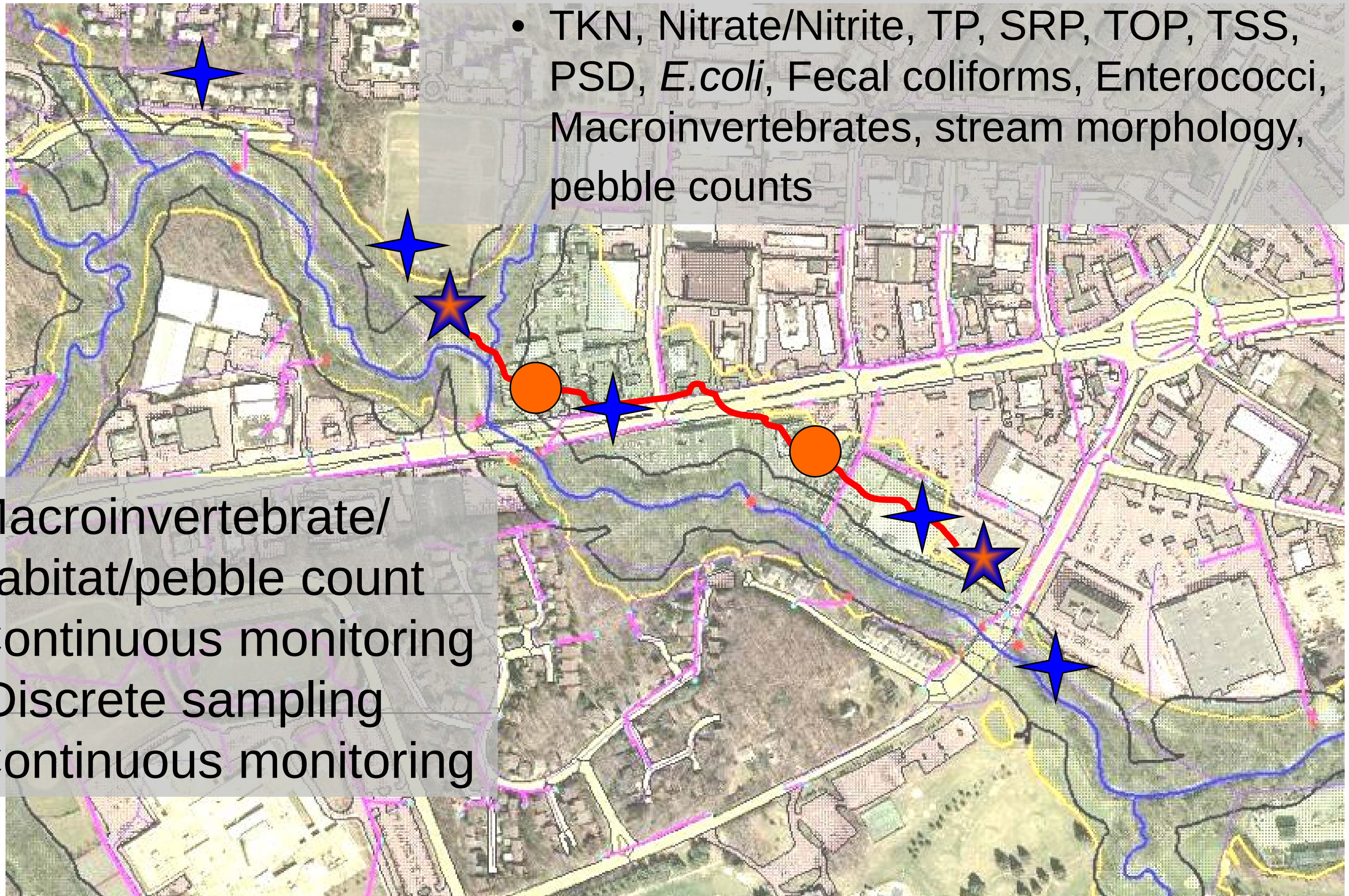
- Continuous monitoring of water quality and flow using YSI-EDS's and American Sigma velocity/depth probes
- Water quality for wet and dry weather discrete samples
- Quarterly biological sampling
  - Benthic macroinvertebrates
  - Vegetation cover
- Annual stream morphology sampling
  - Cross-sectional surveying
  - Longitudinal surveying
- Quarterly stream pebble counts

Continuous Monitoring:

- pH, Turbidity, Temp, Conductivity, DO, Depth, Velocity

Discrete Monitoring

- TKN, Nitrate/Nitrite, TP, SRP, TOP, TSS, PSD, *E.coli*, Fecal coliforms, Enterococci, Macroinvertebrates, stream morphology, pebble counts



Sampling Results

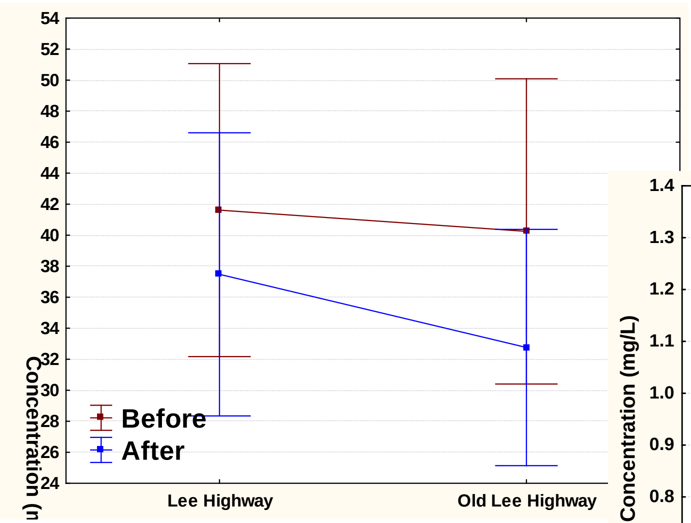





Discrete Wet-Weather Flow Data

Before and After Restoration

COD



NO_3

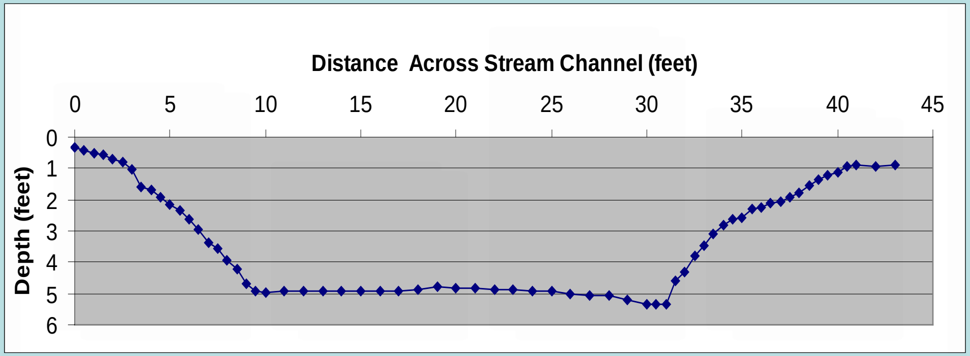
TKN

Before N = 7

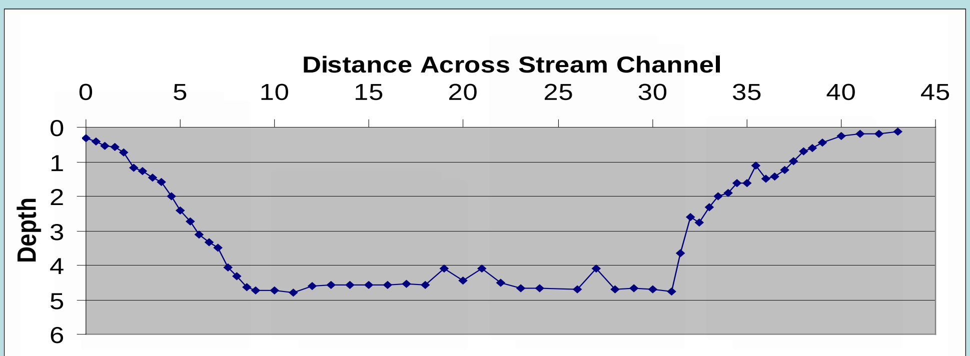
After N = 6

Cross-Sections

Site A – Upstream of Restoration

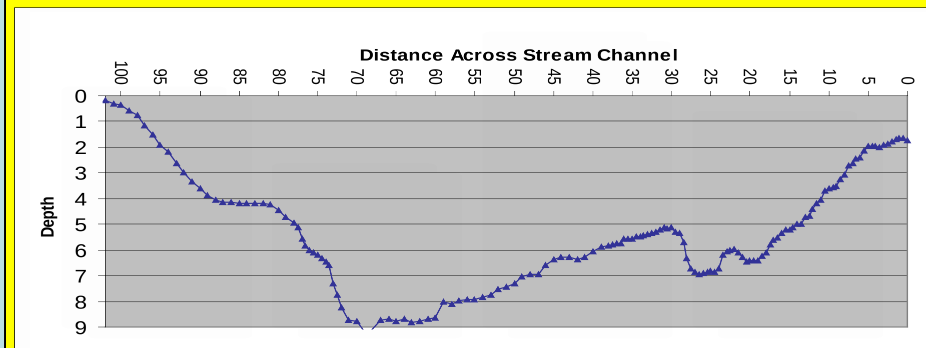


Before Restoration

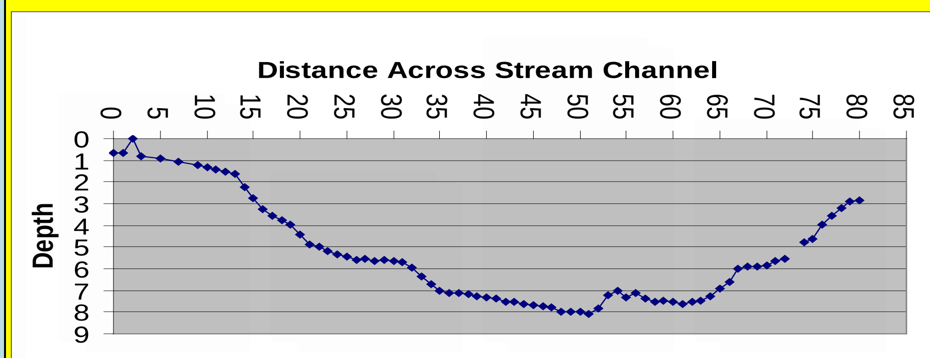


After Restoration

Site C – Lower Part of Restoration

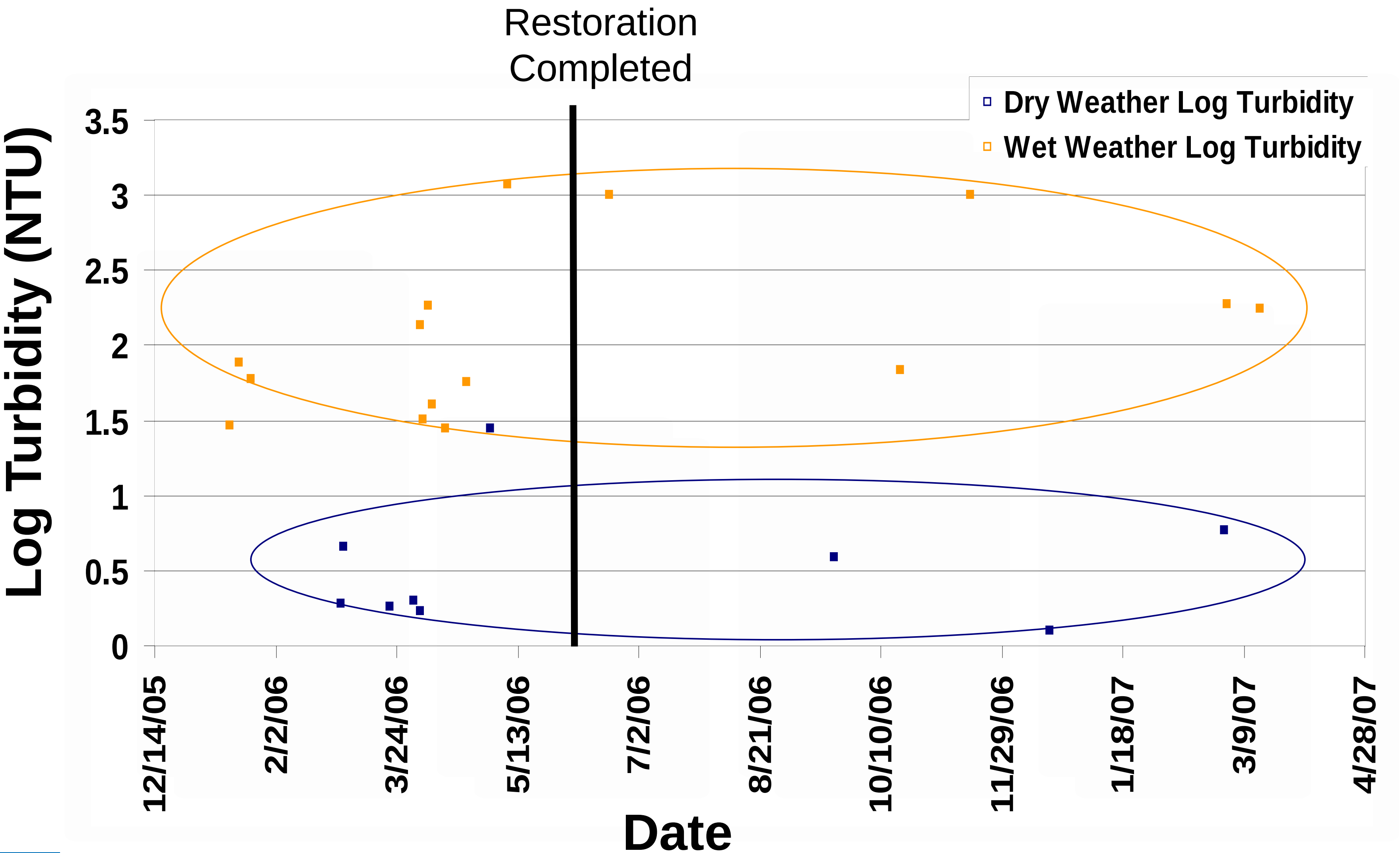


Before Restoration

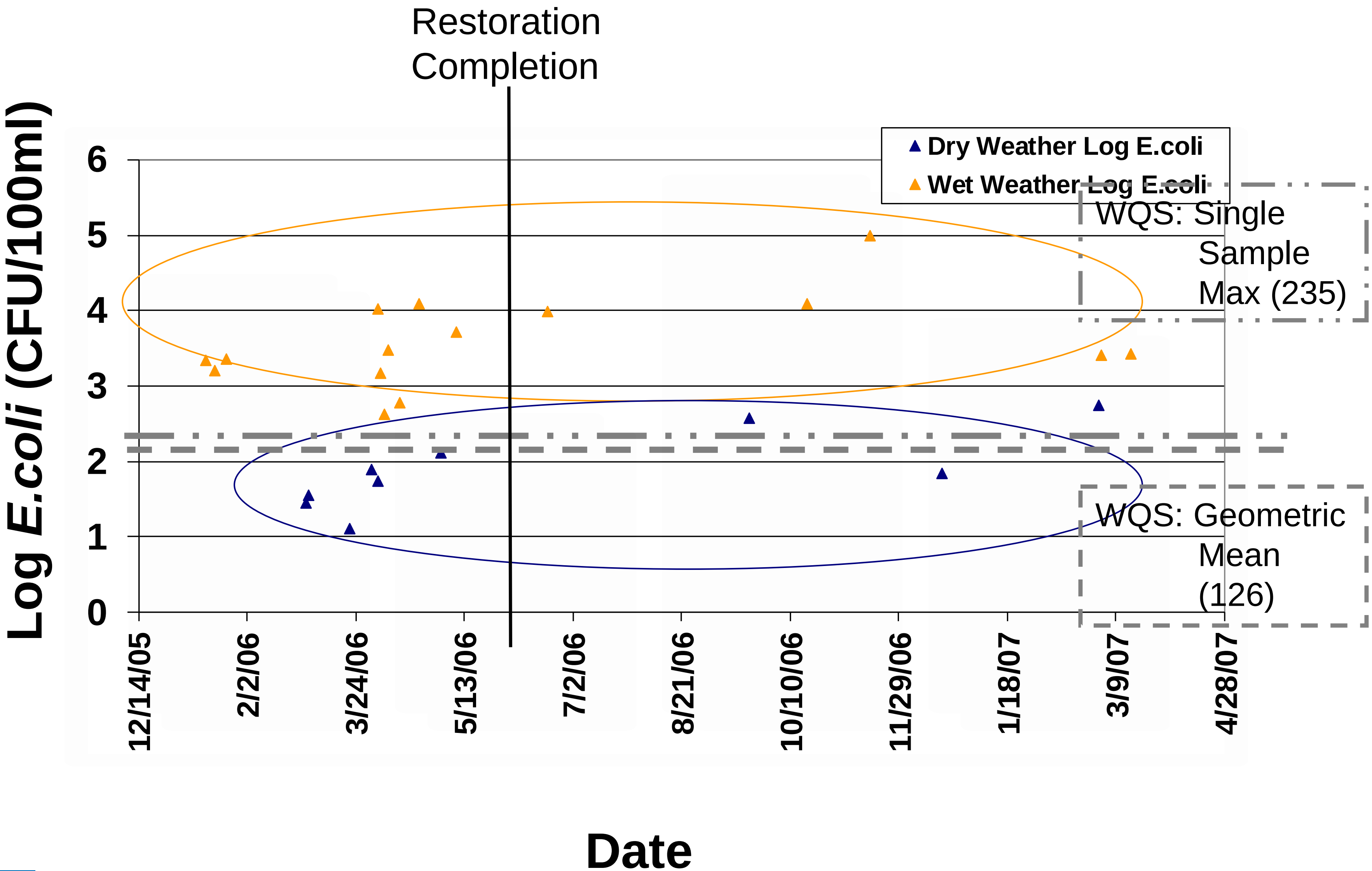


After Restoration

Turbidity Data

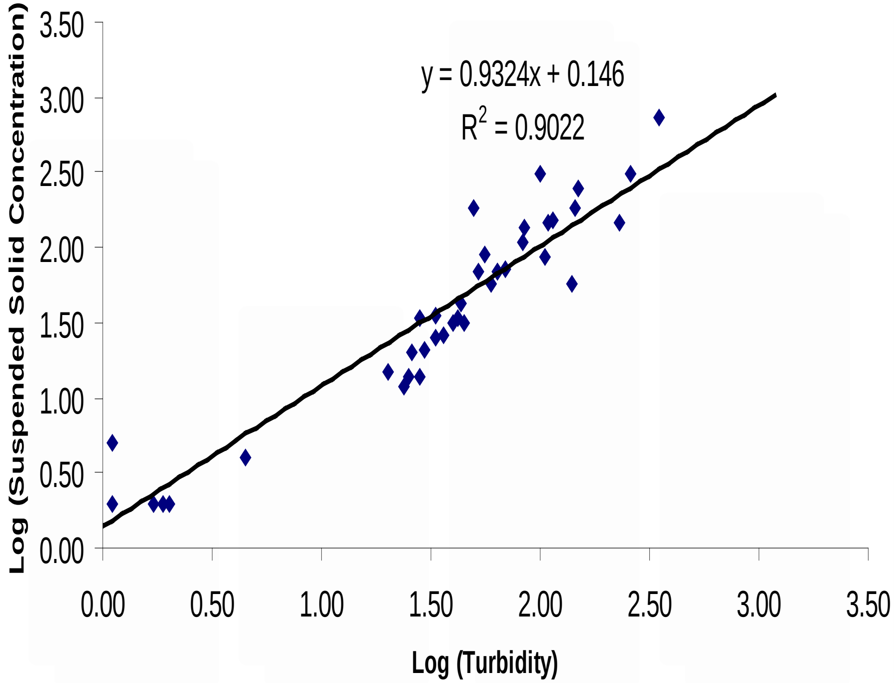


E.coli Concentrations

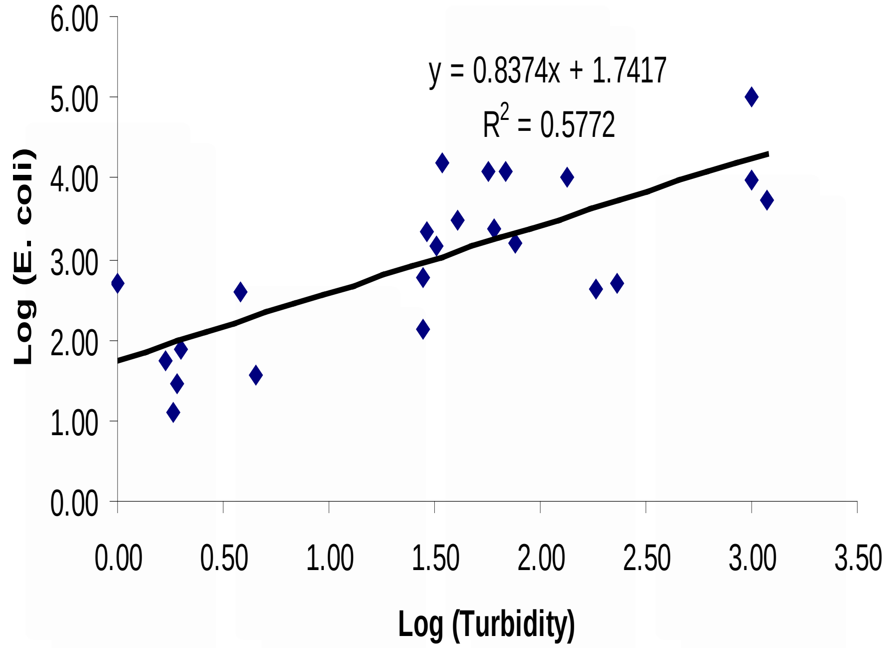


WQS – Water Quality Standard

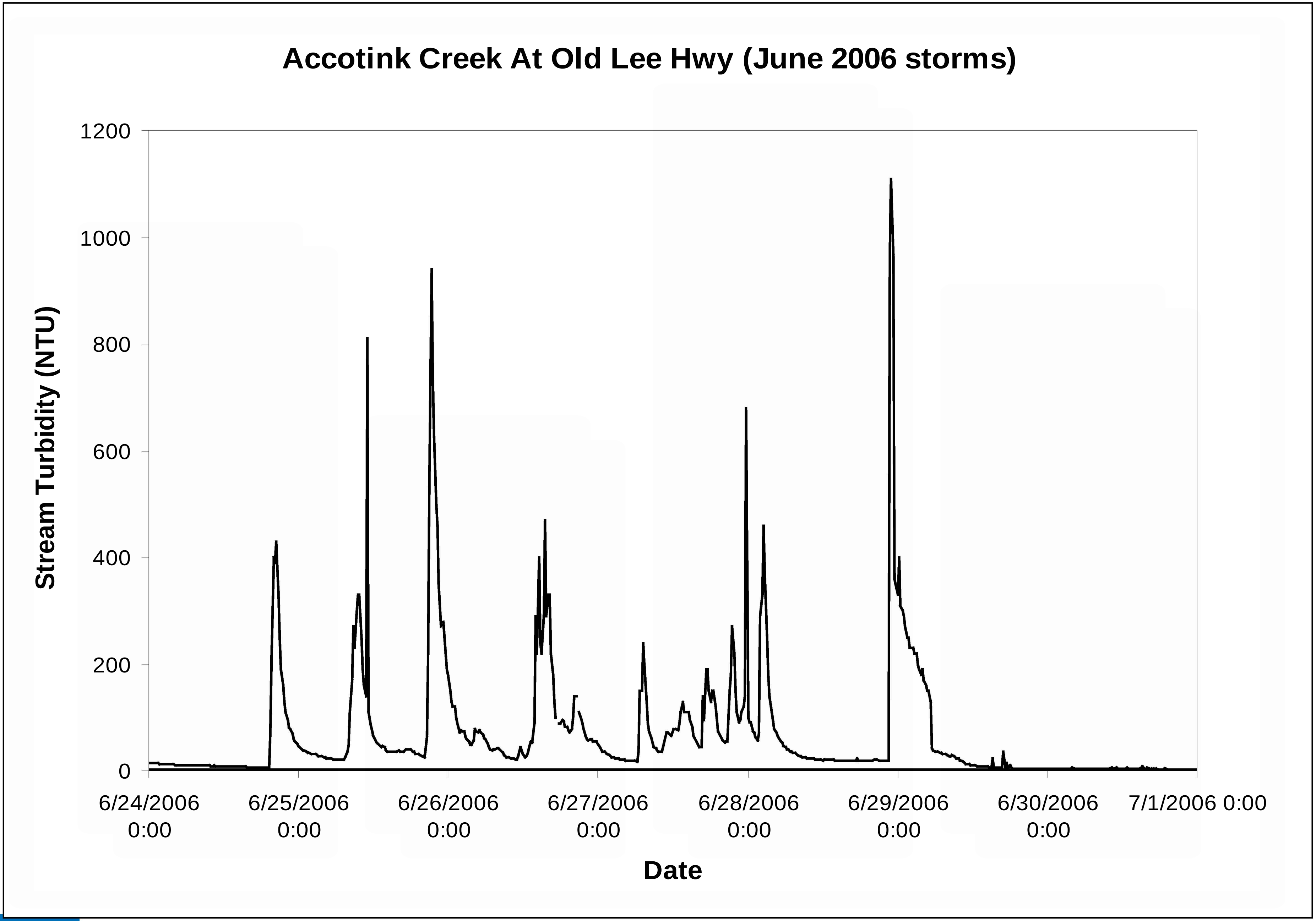
Combining Discrete and Continuous Data

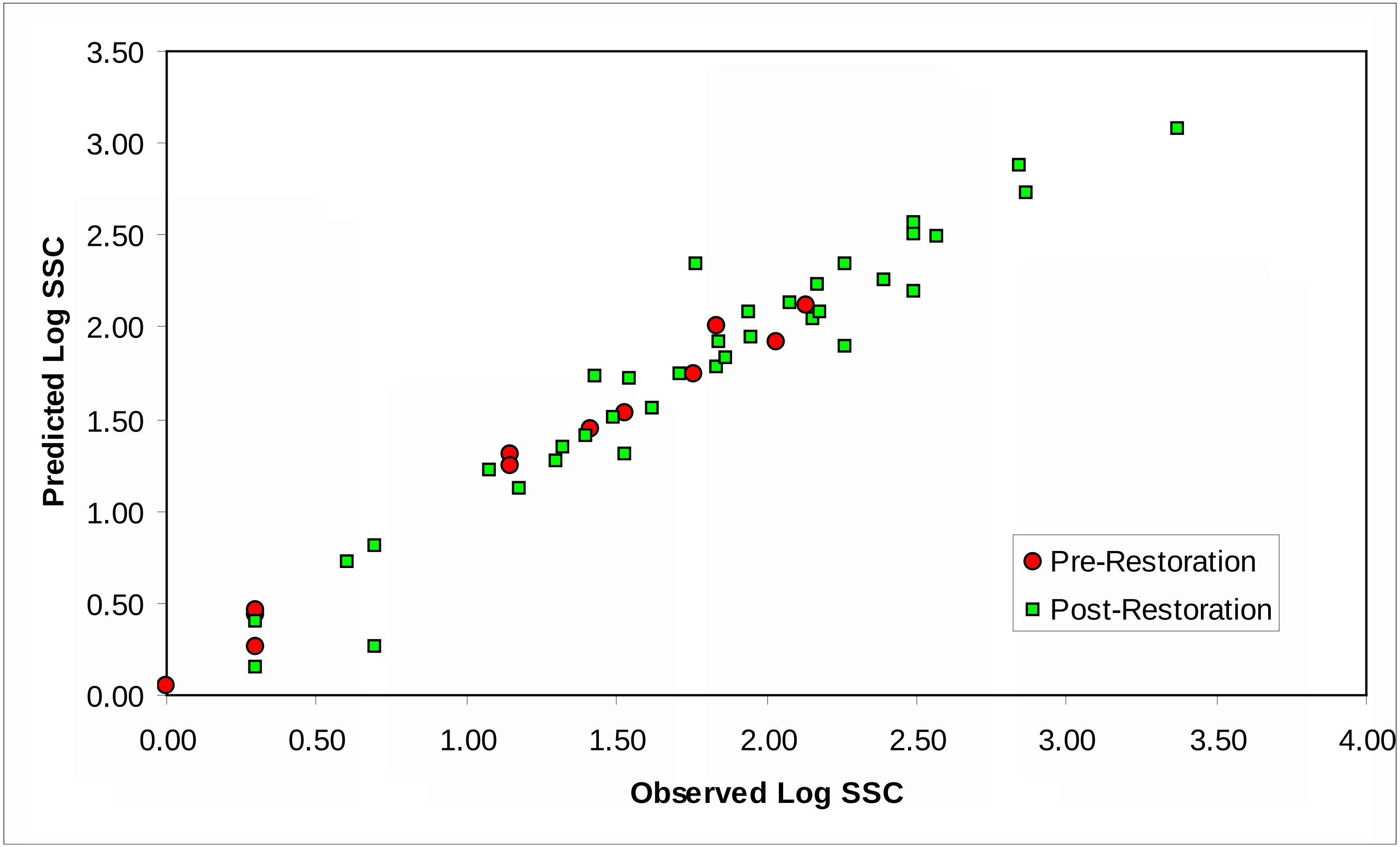


Correlation between turbidity and SSC

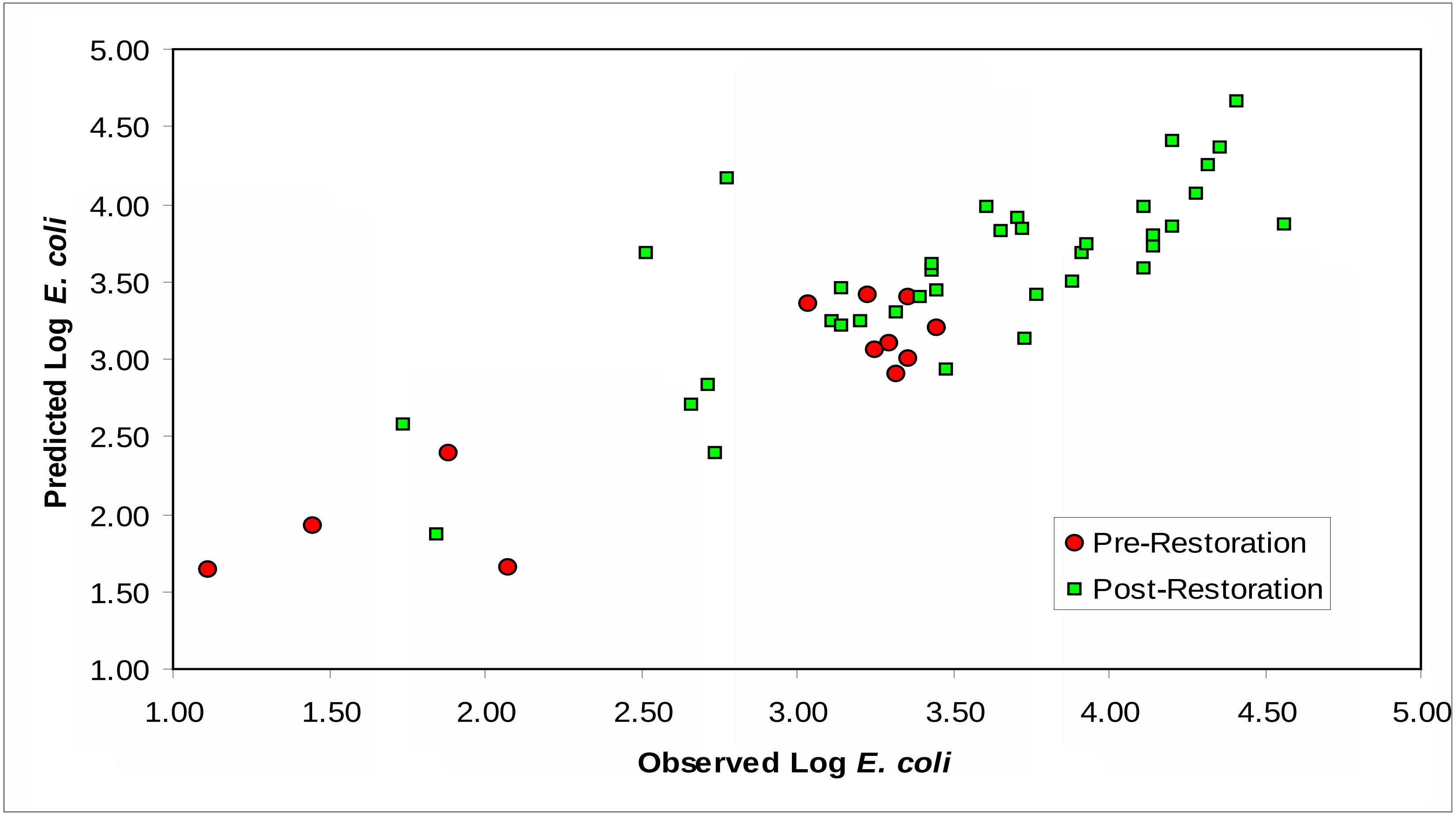


Correlation between turbidity and *E. coli*


Accotink Creek At Old Lee Hwy (June 2006 storms)
Stream Turbidity (NTU)
1200
1000
800
600
400
200
0
6/24/2006 0:00
6/25/2006 0:00
6/26/2006 0:00
6/27/2006 0:00
6/28/2006 0:00
6/29/2006 0:00
6/30/2006 0:00
7/1/2006 0:00
Date



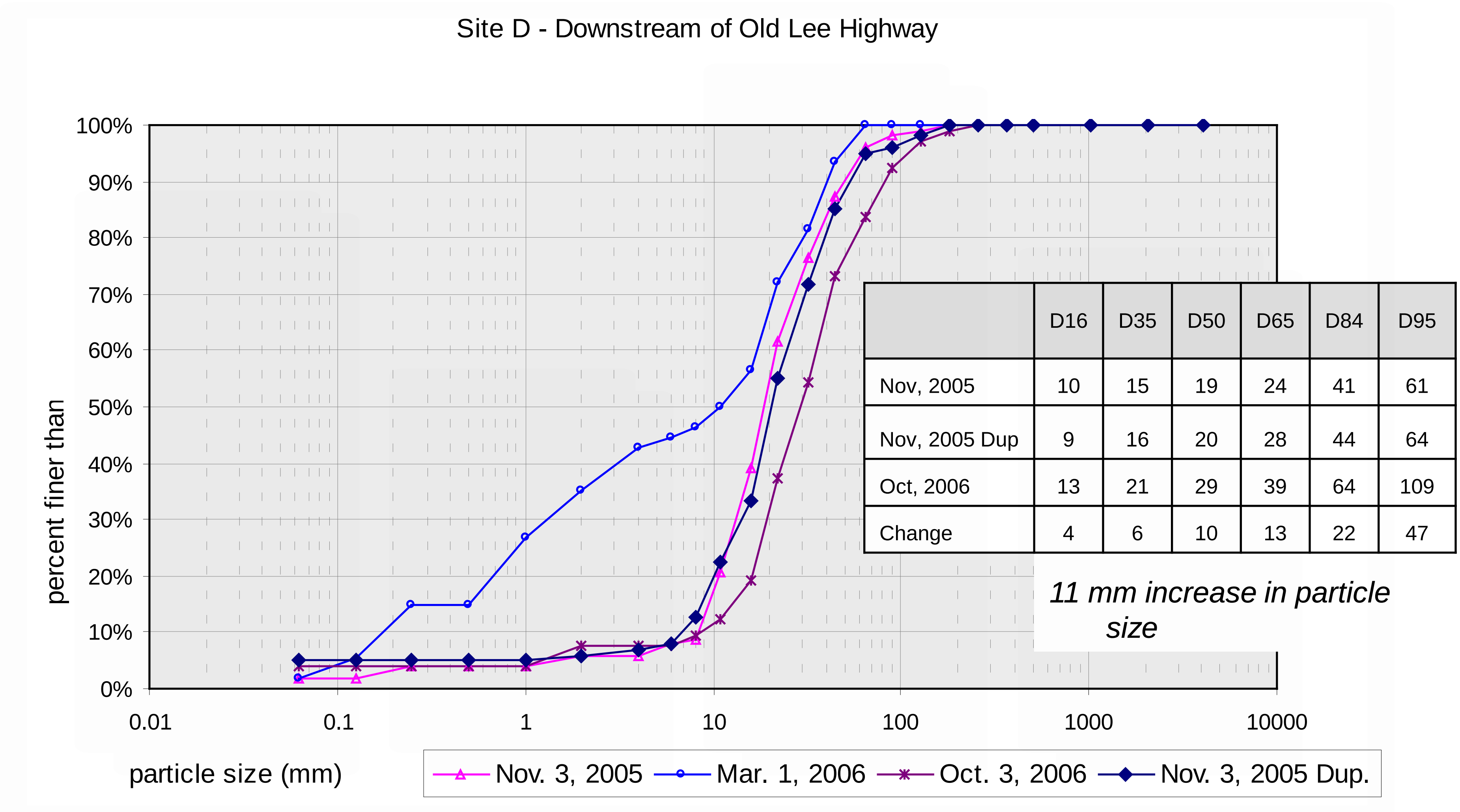
No statistically significant difference between Pre- and Post-Restoration data.



No statistically significant difference between Pre- and Post-Restoration data.

Pebble Count Data – Changes in streambed substrate?

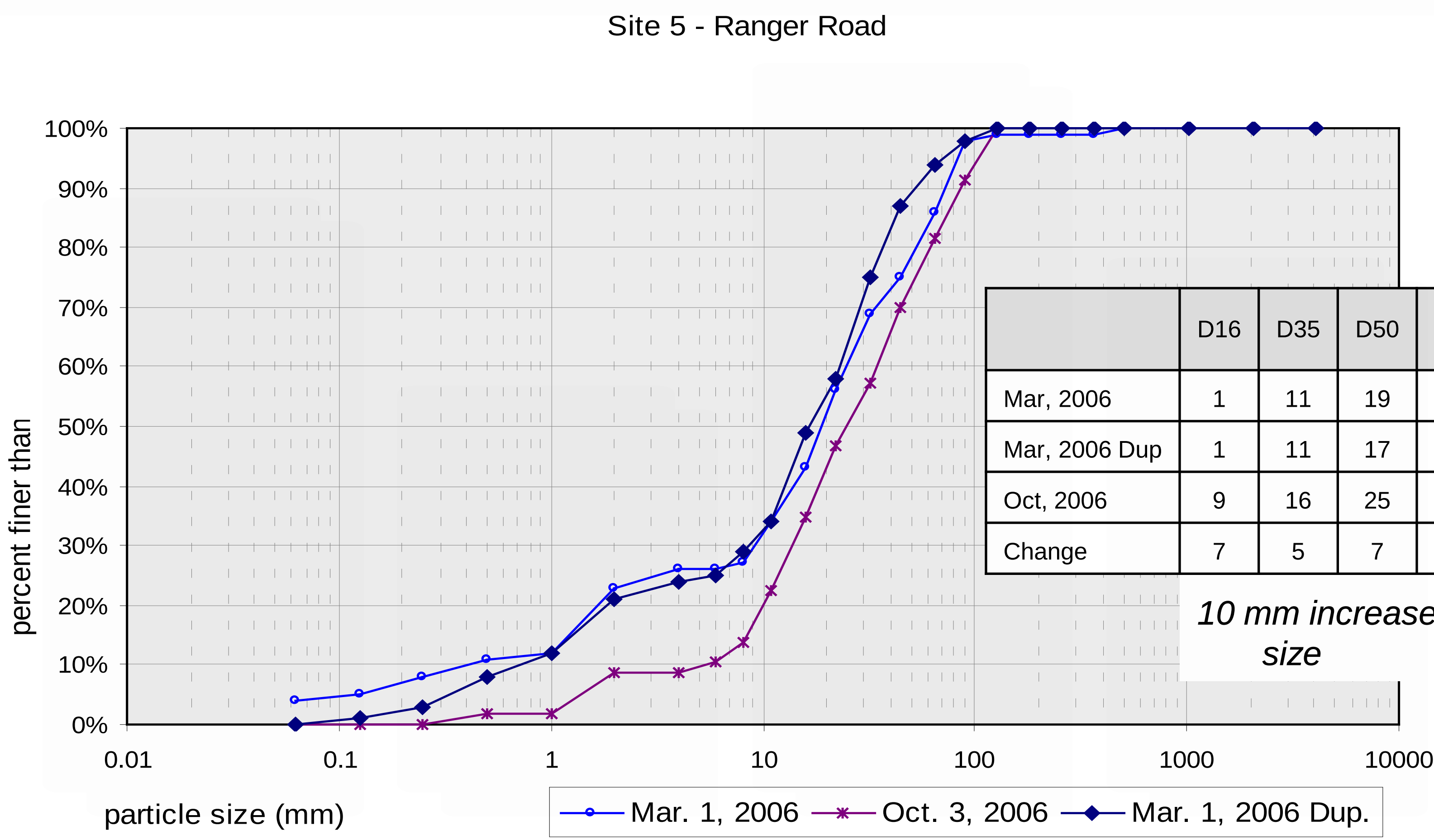
Below Restoration



	D16	D35	D50	D65	D84	D95
Nov, 2005	10	15	19	24	41	61
Nov, 2005 Dup	9	16	20	28	44	64
Oct, 2006	13	21	29	39	64	109
Change	4	6	10	13	22	47

Pebble Count Data – Changes in streambed substrate?

Above Restoration

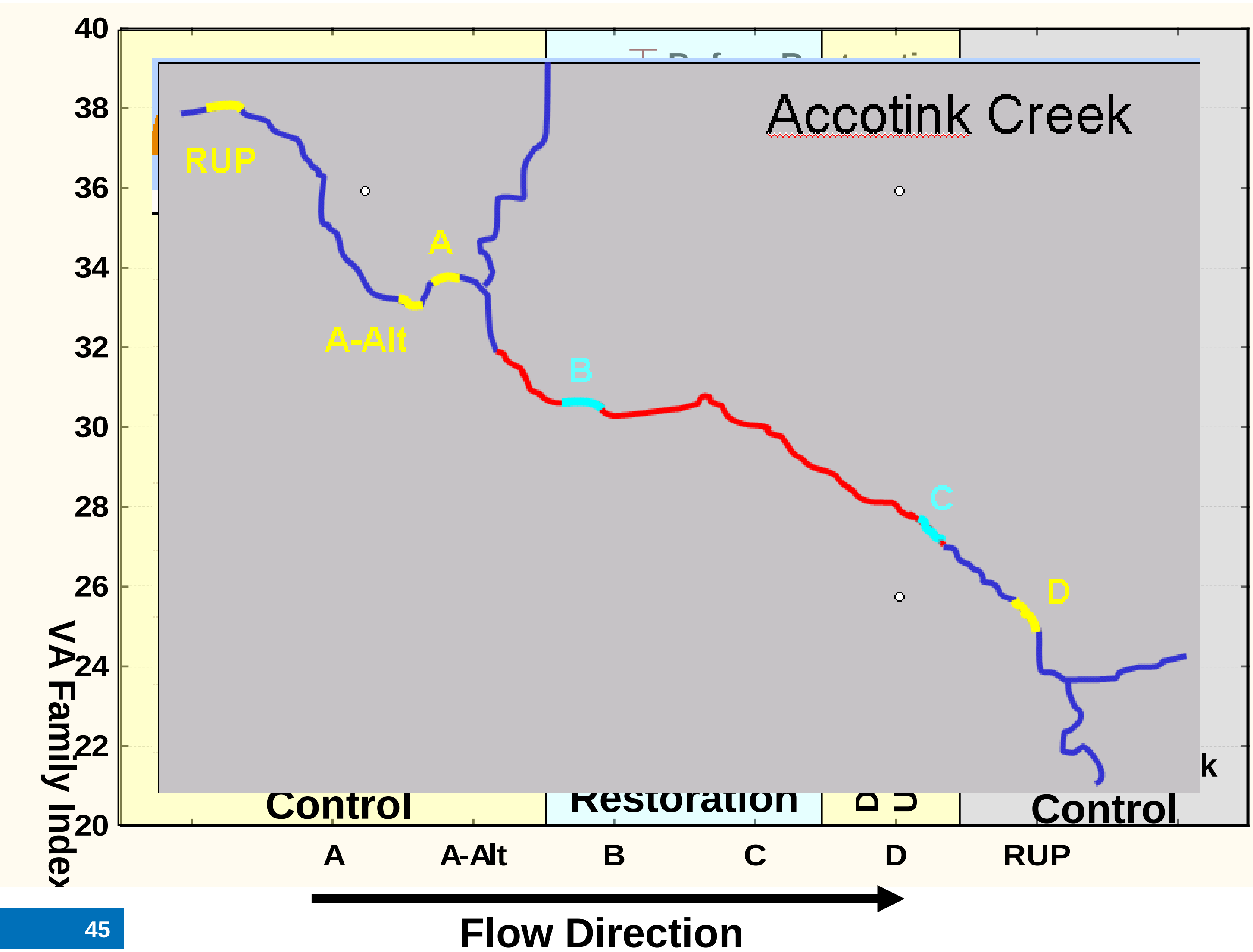


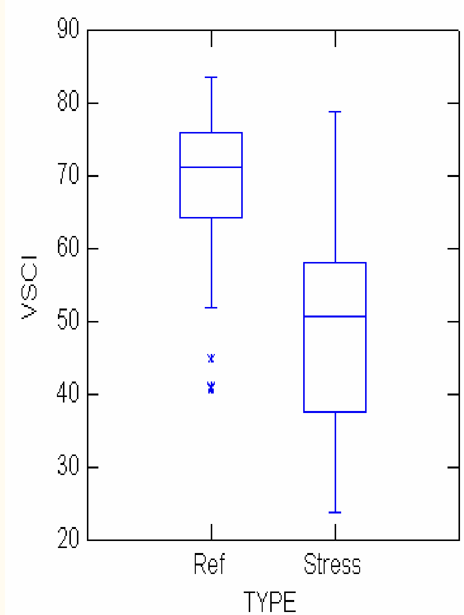
	D16	D35	D50	D65	D84	D95
Mar, 2006	1	11	19	29	60	83
Mar, 2006 Dup	1	11	17	26	41	70
Oct, 2006	9	16	25	39	70	105
Change	7	5	7	12	19	28

10 mm increase in particle size

Particle size change may not result from restoration, based on upstream control.

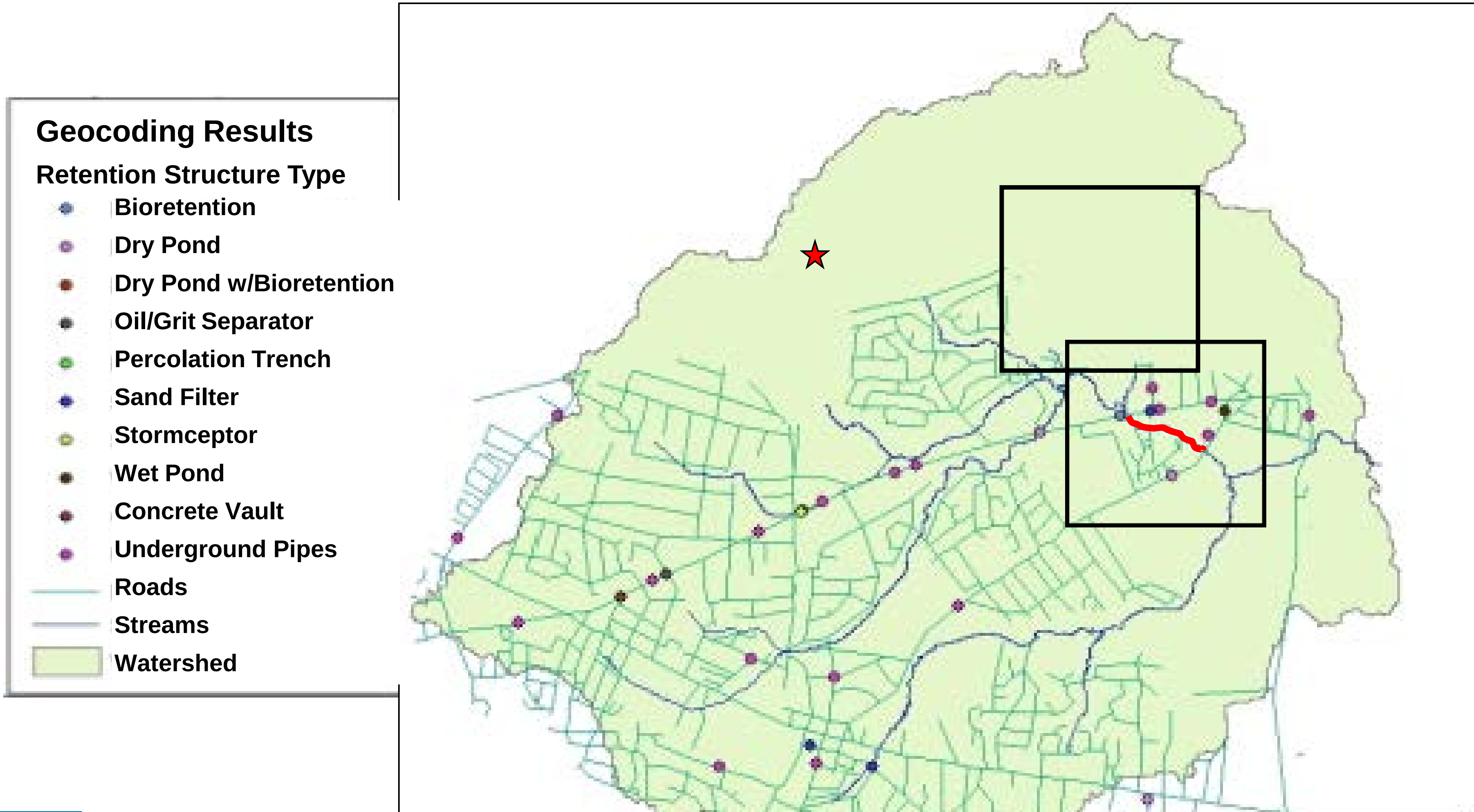
Macroinvertebrate Indices-Overall





Source: Using Probabilistic Monitoring Data to Validate the Non-Coastal Virginia Stream Condition Index. 2006. VDEQ Technical Bulletin WQA/2006-001

Existing BMP Types and Locations



Accotink Stream Restoration Conclusions

- Restoration stabilized stream banks and protected property and infrastructure
- Restoration did not significantly improve water quality or biological indices
- More BMPs required upstream in watershed

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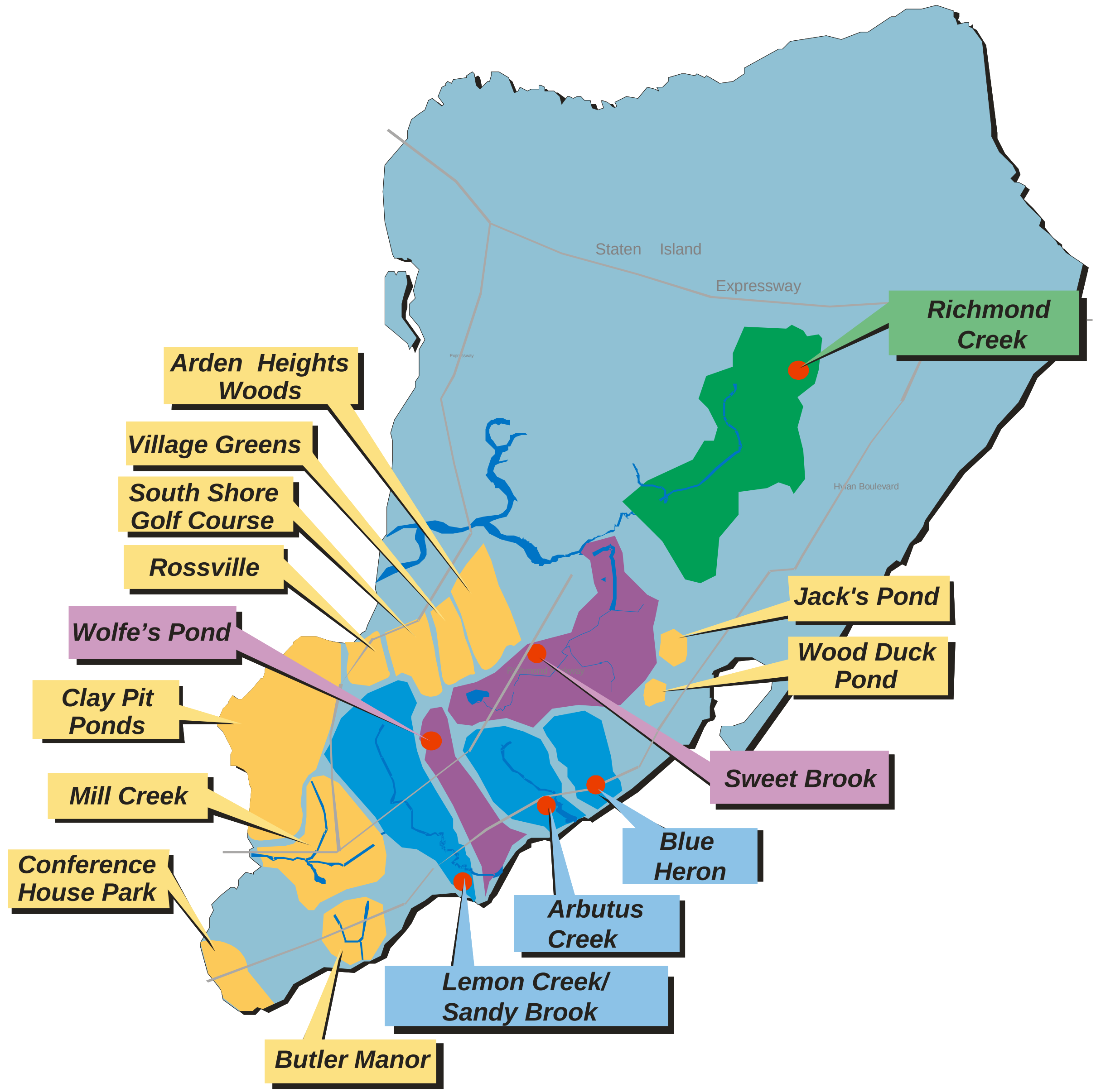
CASE STUDY 3: STATEN ISLAND BLUEBELT, RICHMOND CREEK (RC) BMP

Bluebelt Drainage Areas

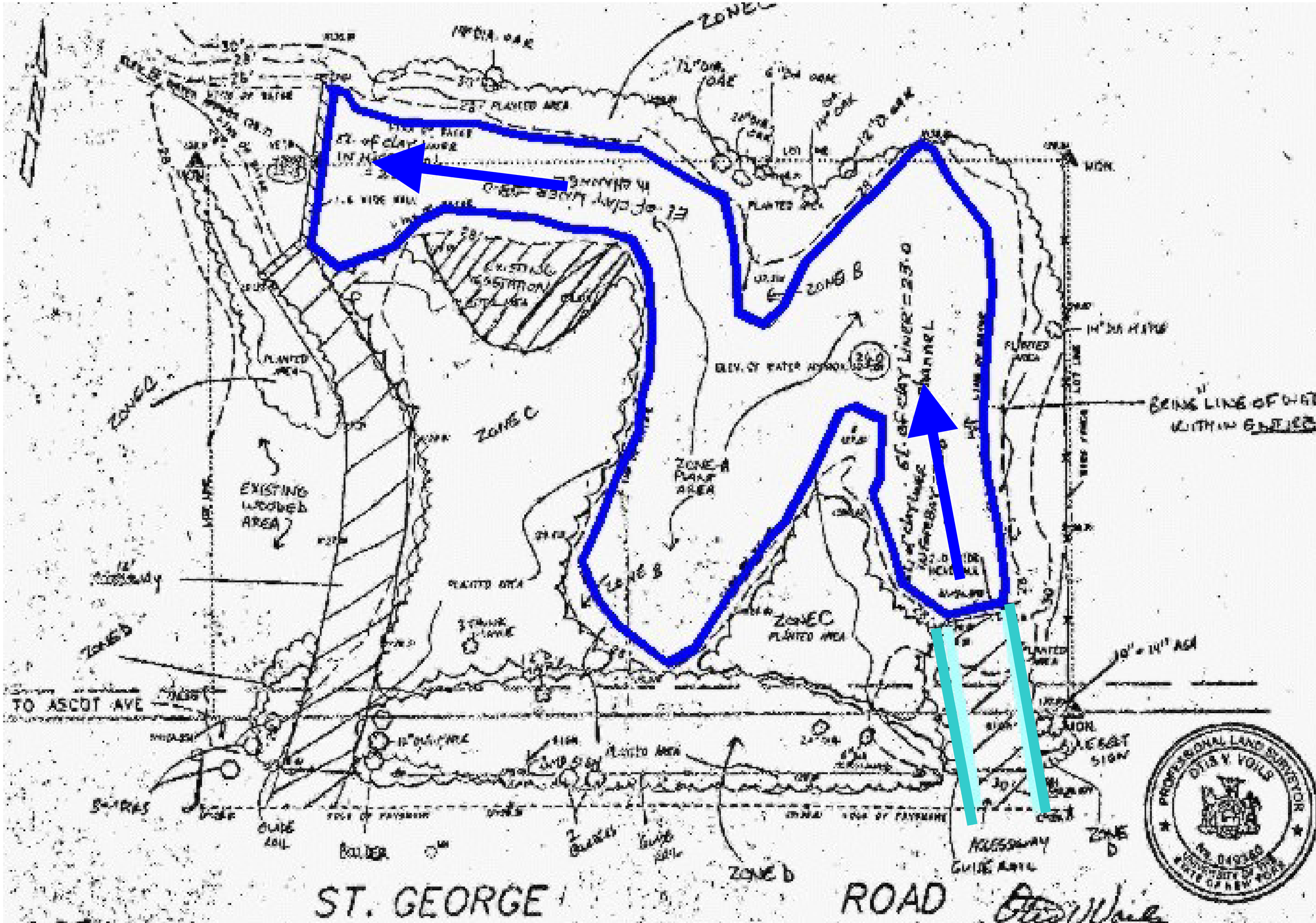


Details Staten Island Bluebelt RC-5 BMP

- Open water wetland marsh with forebay and stilling basin
- Drainage area is 23 acres, BMP surface area 0.1acre
- 1-yr design flow is 24 ft^3/s; 5-yr is 32 ft^3/s
- Designed for full build out of 60% impervious cover
- Designed to capture sediment in forebay
- Forebay and stilling basin are concrete lined
- Predicted suspended solids (SS) removal 55-57%
- Predicted phosphorous removal 25%

O'Connor and Rossi (2009)

As-built Plan View RC-5



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Staten Island BLUEBELT

DEP

BMP Site: RC-5
Location: St. George Road (Richmond Creek Watershed)
Facility: Constructed Storm Water Wetland

Major Areas of BMP:

1) Forebay (see Location A)
2) Micropool (see Location B)
3) Outlet Structure (see Location C)
4) Low Marsh (see Location D)
5) High Marsh (see Location E)

SHORT-TERM MEASURES (FREQUENCY: DAILY TO MONTHLY)

Drainage Issues:

1) Inspect E.D. wetland surface area.
2) Visually inspect the inlet pipe.
   - Remove accumulated debris by hand or skimmer; use waders if required.
   - Repair cracks using a sealant, if required.
3) Inspect the 30-foot long weir wall (see Location C on Fig.1).
   - Complete Dam Inspection Checklist (attached).
   - Repair cracks/damage, if present.
   - If debris is lodged in notch, remove manually; use waders if required.
   - Secure weir plate by tightening bolts.
4) Inspect adjacent catch basin grates and manhole covers.
   - Remove accumulated debris.
   - Secure manhole covers using a hook.

Landscaping Issues:

5) Inspect overall condition of installed vegetation.
   - Remove vegetative invasives manually, ensuring root removal. Contact Restoration Specialist for advice.
   - Relocate herbivorous critters or provide exclusion devices; consult Restoration Specialist if required.
   - Cut grass located along the site perimeter or maintenance accessway.
   - Trim or remove specified trees, as required.

Perimeter Treatment:

6) Inspect overall condition of the perimeter treatment items.
   - Remove accumulated litter/debris by hand.
   - Promptly notify DEC police regarding illegal dumping issue.
   - Lubricate locks and hinges, as required.
   - Repair damaged sidewalks, as required.
   - Refurbish wood chips on accessway, as required.

MODERATE-TERM MEASURES (FREQUENCY: SEMI-ANNUAL)

Drainage Issues:

1) Measure the sediment depth in forebay/micropool (see Locations A and B on Fig.1).
2) Inspect for unstable embankments

5) Inspect for herbivore damage.
   - Repair burrows/damage created by herbivorous critters.

LONG-TERM MEASURES (FREQUENCY: ANNUAL)

Drainage Issues:

1) Vactoring Activity
   - Vactor sediment from forebay/micropool.
   - Vactor sediment from adjacent catch basins.

LONG-TERM MEASURES (FREQUENCY: 10-YEAR INTERVAL)

Drainage Issues:

1) Vactor accumulated sediment from entire E.D. wetland.

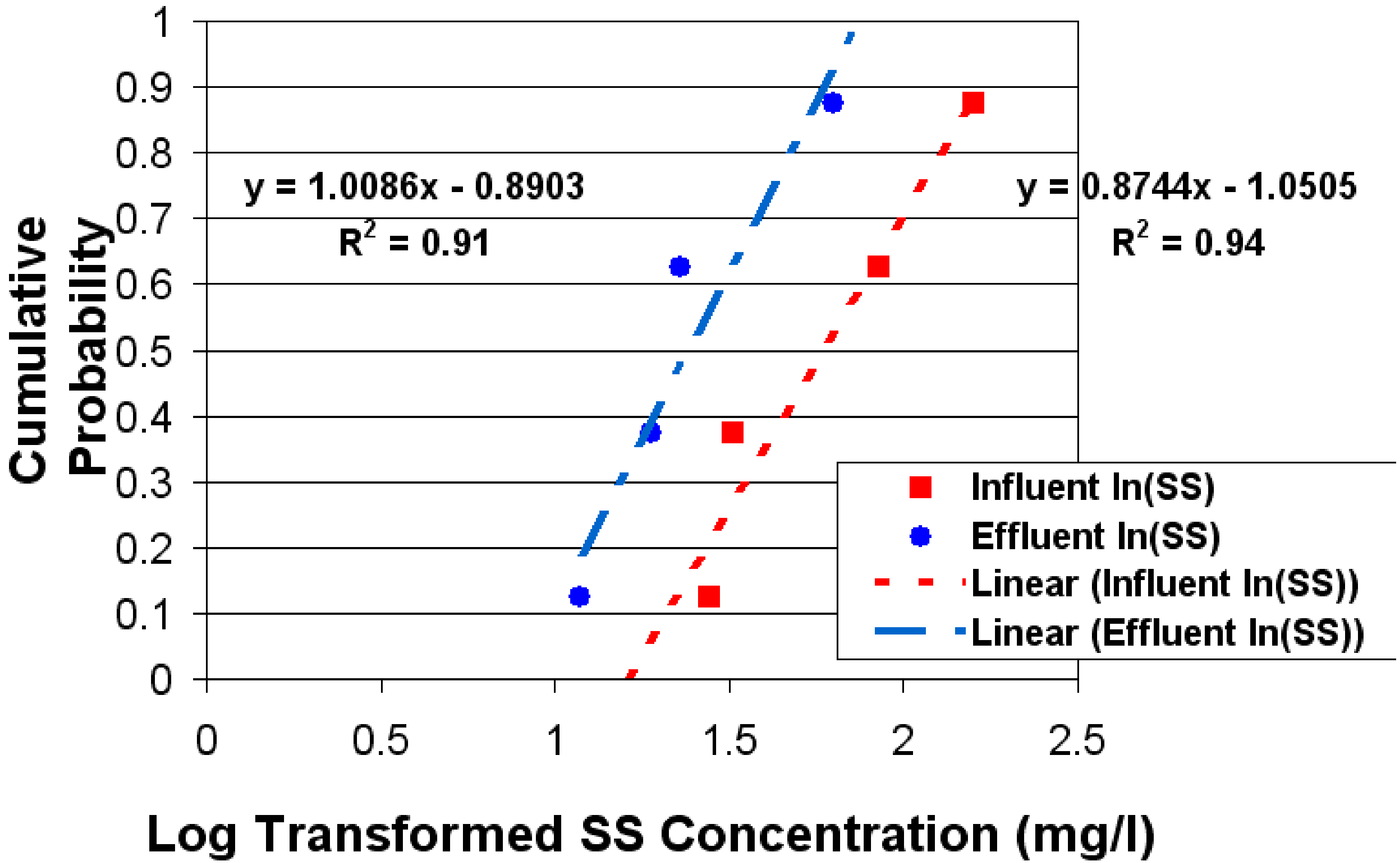
Note: Fill out the attached General Inspection Checklist during inspection of the s

Established Arrow Arum Plantings in RC-5 S-turn

Forebay

Effluent

Log-normal Paired Composite Suspended Solids



Pre-maintenance Results

- BMP removing solids
- High levels of chemical oxygen demand (COD) observed in effluent

Preliminary Estimate of Post-maintenance Events Needed to Observe Statistical Drop in Effluent COD Concentration

Power (β)	Average percent reduction in post maintenance concentration	Number of events (n) needed
0.80 (0.2)	50	2
0.80 (0.2)	25	9

Assumes equal variance.

Statistical Test on Effluent Pre- and Post-maintenance

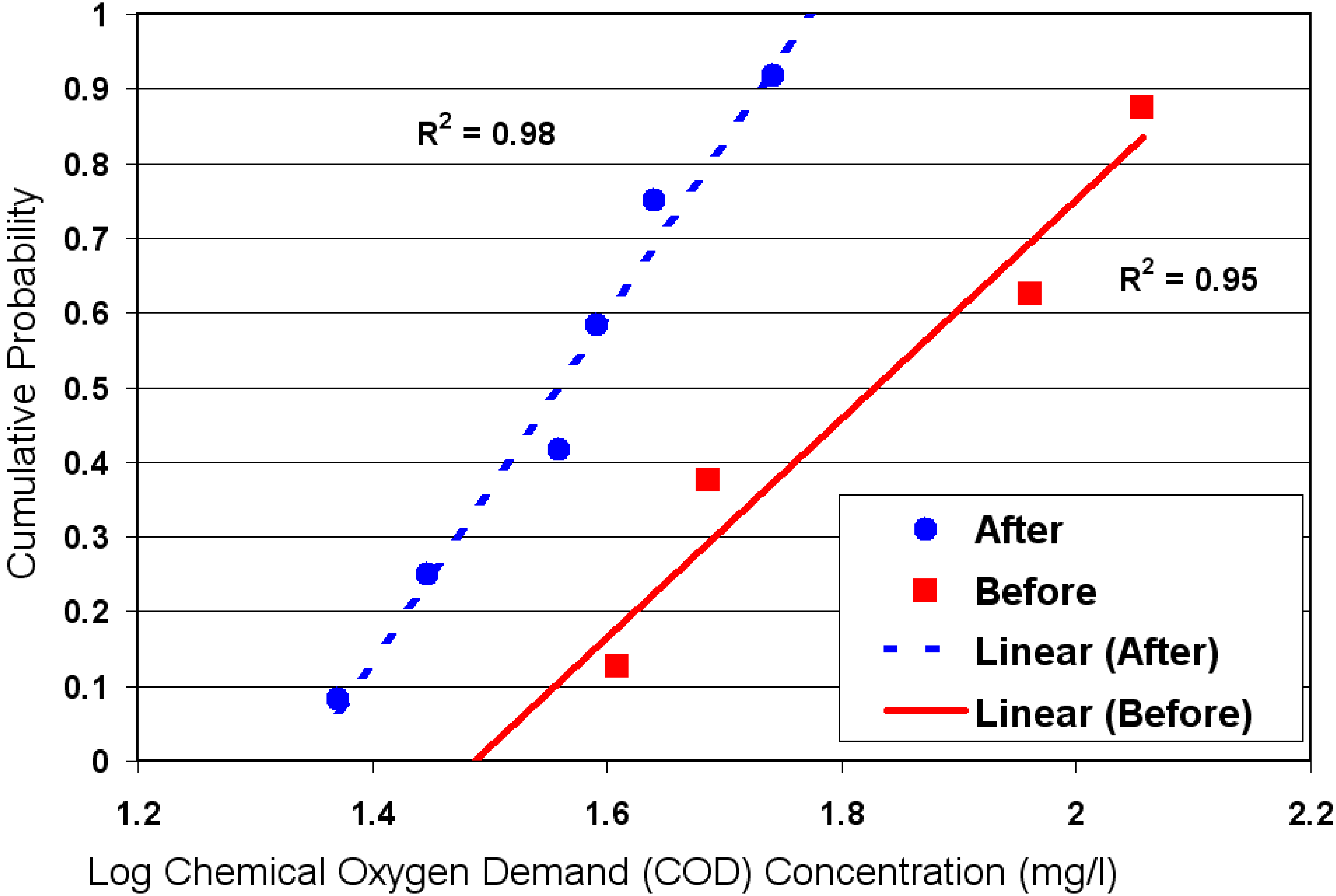
- Log-normal test of COD had statistically different results, though below power of 0.80
- Total phosphorous had statistically significant difference t-test result, though below the desired power of 0.80
- Pre-maintenance much more variable for both
- Suspended solids not significantly different

Maintenance: Vacuum Truck

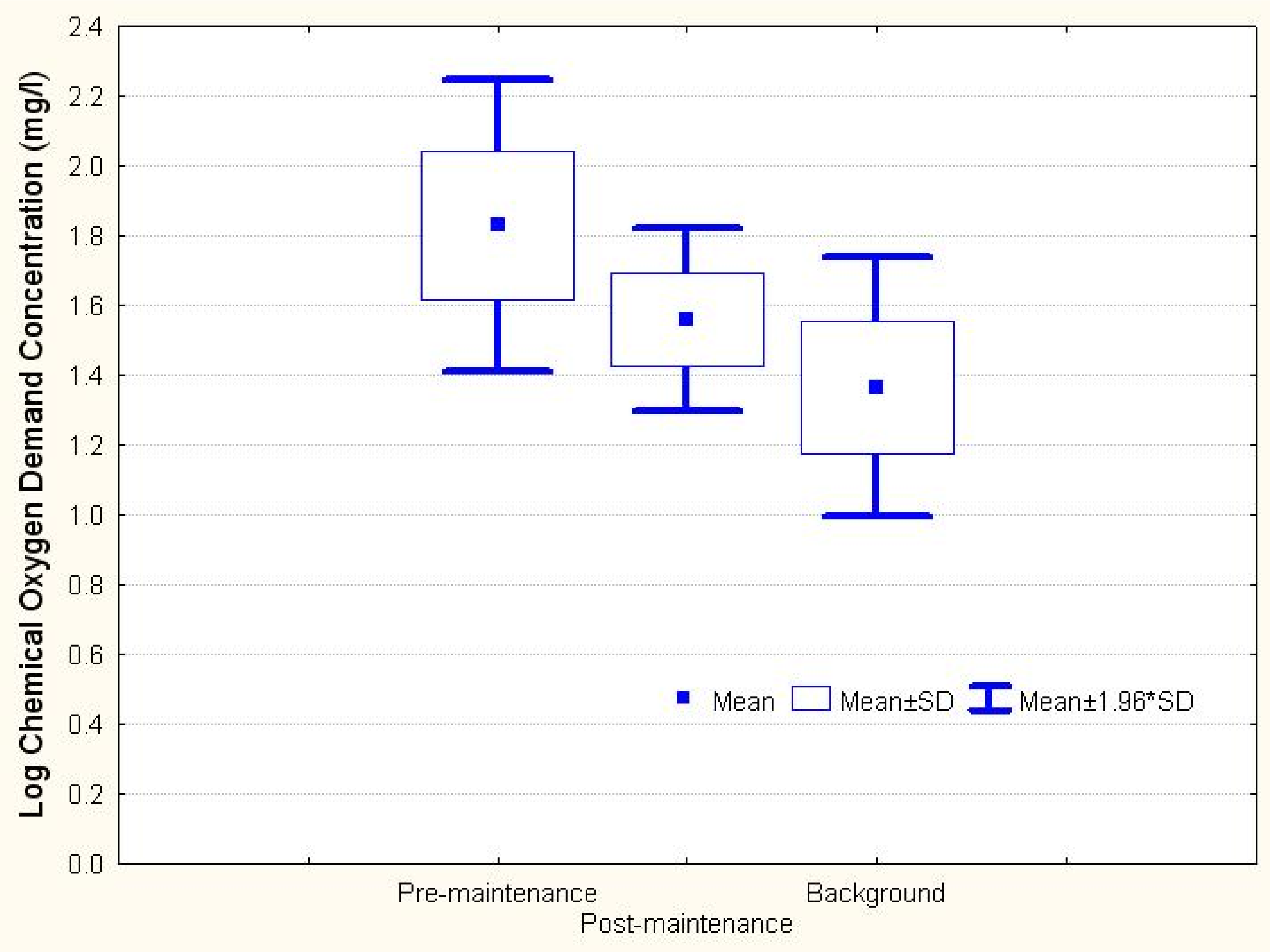
Maintenance: Hard Labor

Probability Plot for Chemical Oxygen Demand Pre- and Post-maintenance

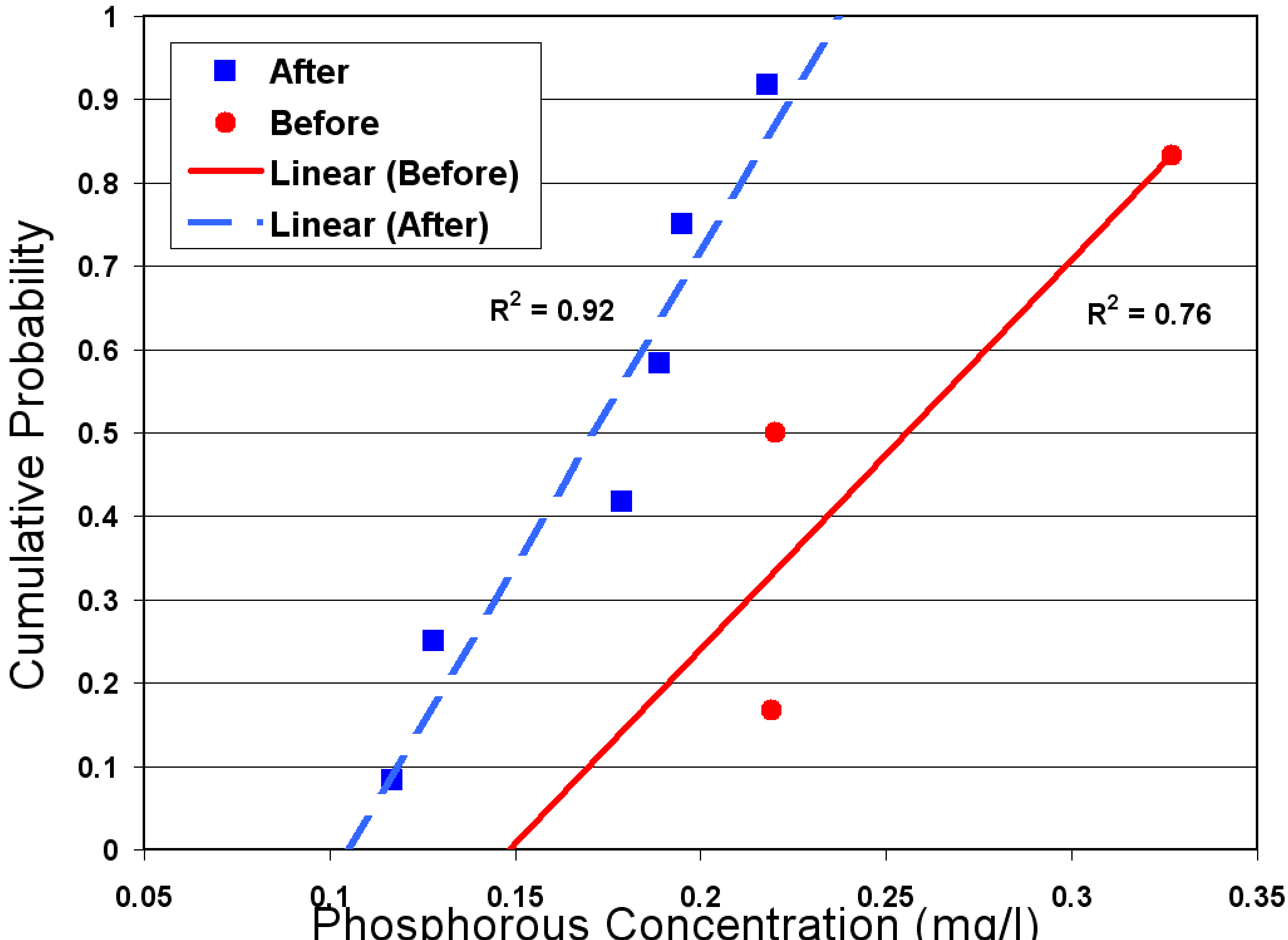
Ranking probability = (i - 0.5) / n



Comparison of Log Chemical Oxygen Demand Concentrations



Probability Plot for Phosphorous Pre- and Post-maintenance



Sediment Accumulation Rate and Calculation of Maintenance Activity

Urban Runoff Quality Management WEF Manual of Practice No. 23 and ASCE Manual and Report on Engineering Practice No. 87, p. 188, 1998

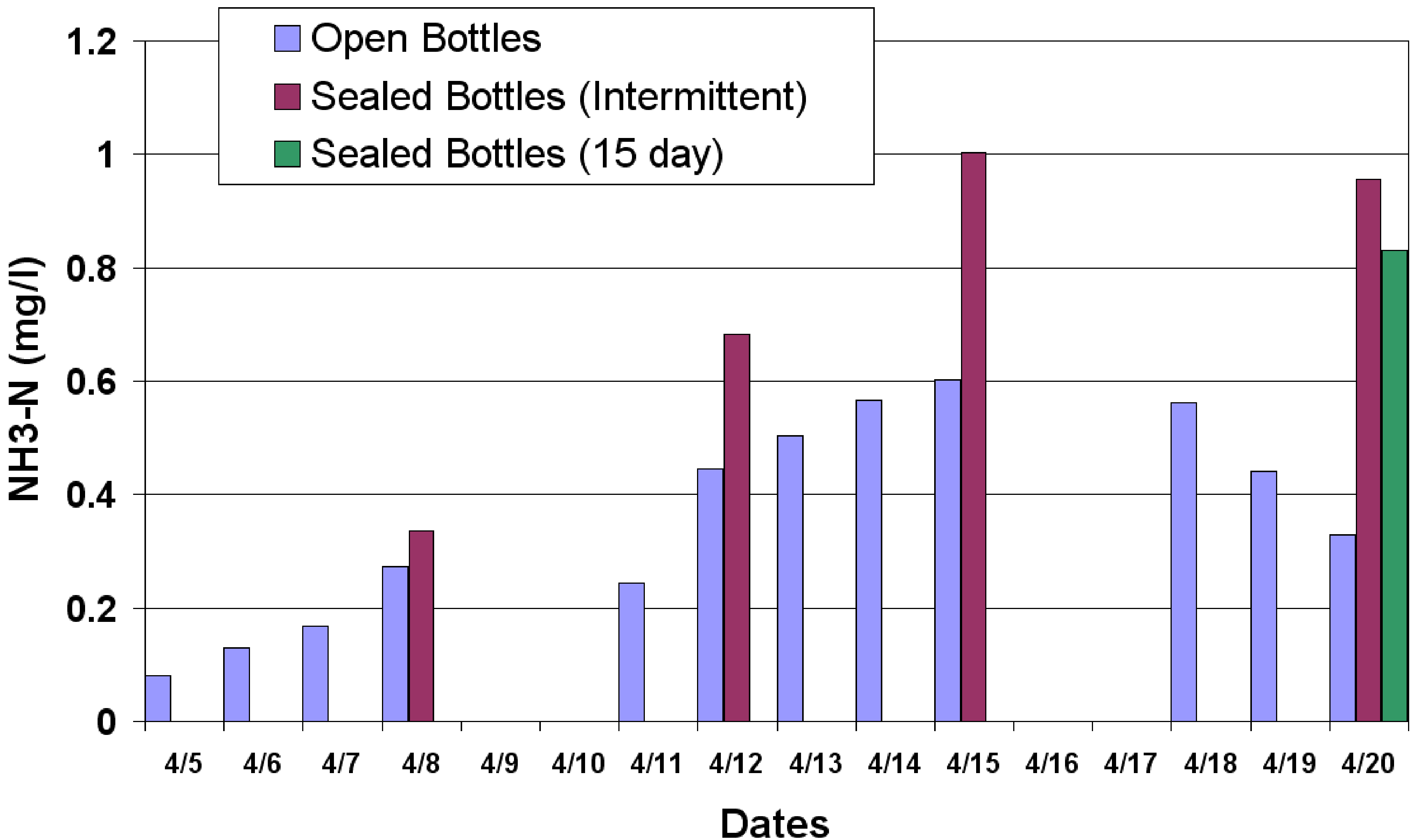
Calculation of Dredging Rate	Annual Accumulation Rate (mm/yr)	Years until dredging, assuming 305 mm (1 ft) sediment accumulation (yr)
RC-5 Calculated	15	*21*
RC-5 Measured (35.2 m^3)	20	*15*
Forebay & Micropool @ 15% pond Surface Area RC-5 and Assuming 60% Removal by Forebay		
Forebay RC-5 Calculated	59	*5*
Forebay RC-5 Measured	81	*4*

Original Environmental Impact Statement recommended Forebay cleanout 2 yrs.

Leaf Decomposition in Saturated Conditions

- A single maple leaf consumes 75% of its weight through oxygen demanding decay over a 13 month period
- Cut grass starts breakdown in matter of days but can take up to half-a-year (England, 2001)
- Observed leaves breaking down into ammonia in a matter of days (O'Connor, 2010)

Lab Study: Ammonia Readings from Leaves Soaked in Rainwater



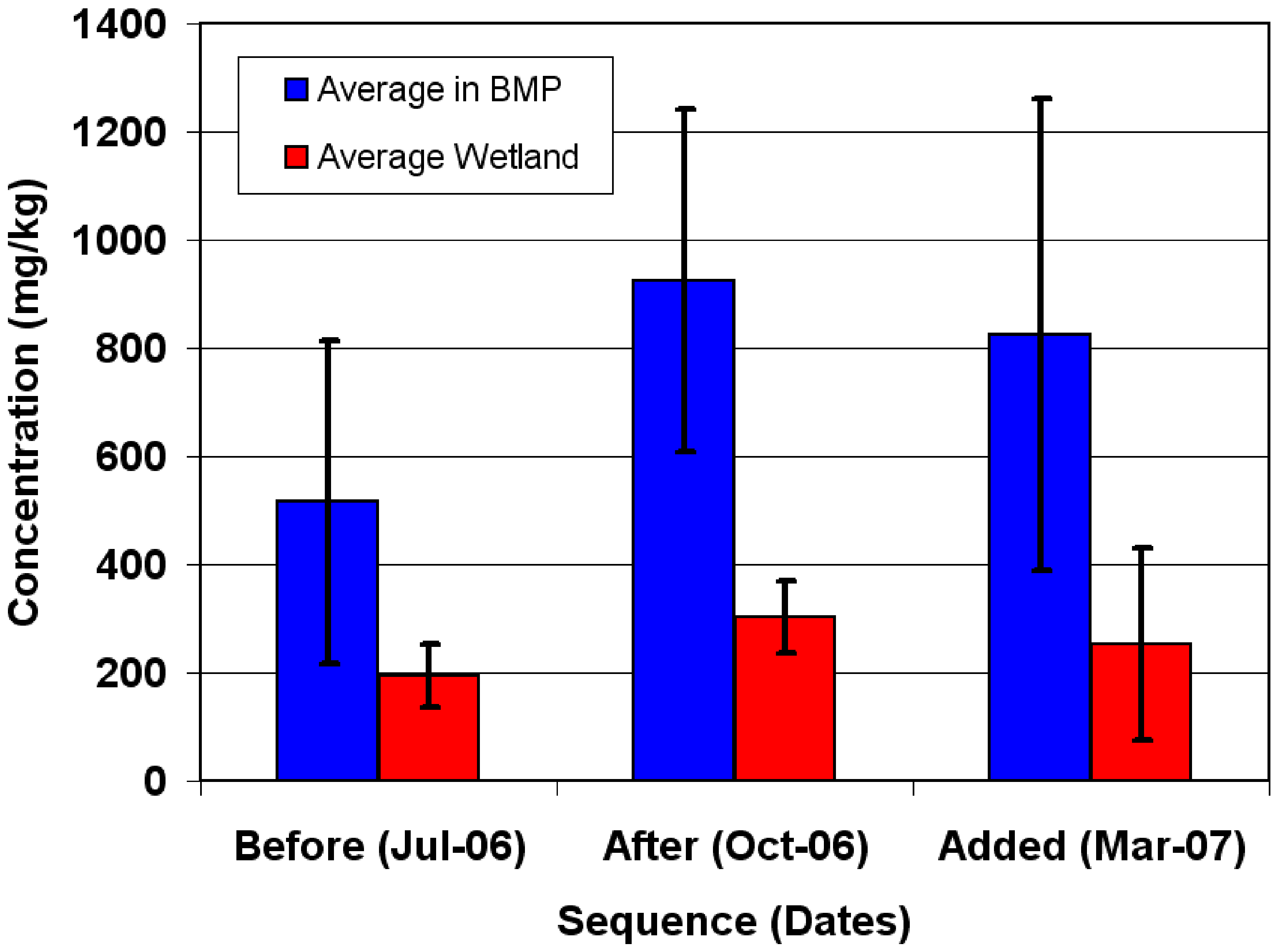
Implications of Breakthrough

- Concept of breakthrough: influent = effluent, i.e. equilibrium
- Earliest breakthrough components may exceed influent before settling to equilibrium
- Predicted breakthrough of sediments for BMPs on order of decades – detailed predictive model
- Observed breakthrough of COD 3 to 4 years – no model
- Breakthrough for nutrients may actually be shorter than COD - if this is the case, will never be statistically practical to observe removal in open water BMPs
- If not statistically observable, may require surrogates for nutrients - COD, volatile suspended solids

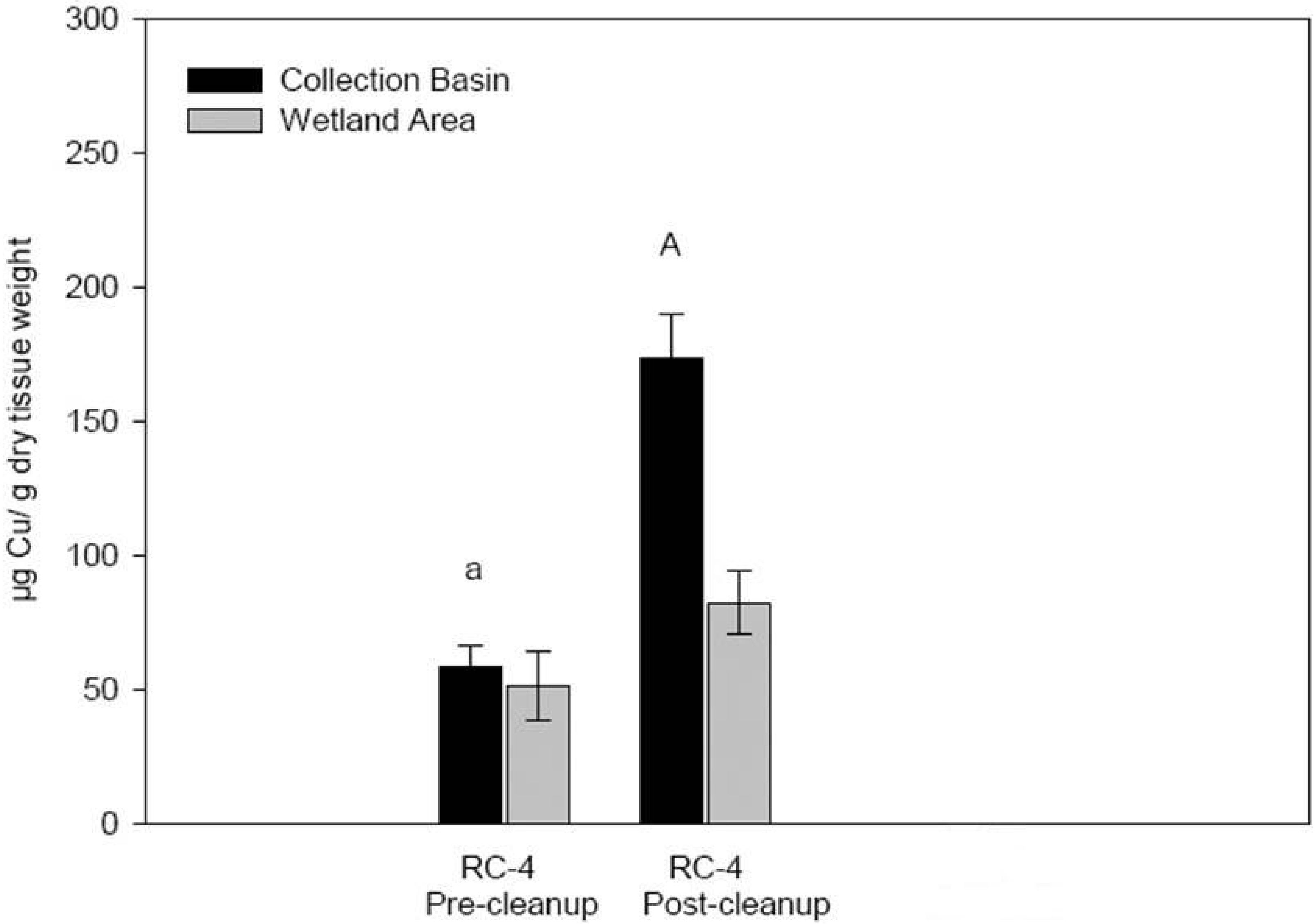
Bluebelt BMP RC-4

- Before and after maintenance (July and October, 2006)
  - Performed sediment sampling for metal content using serial extraction
  - Performed macroinvertebrate sampling for metals concentration in tissue
- Sampled additional sediment (March 2007)

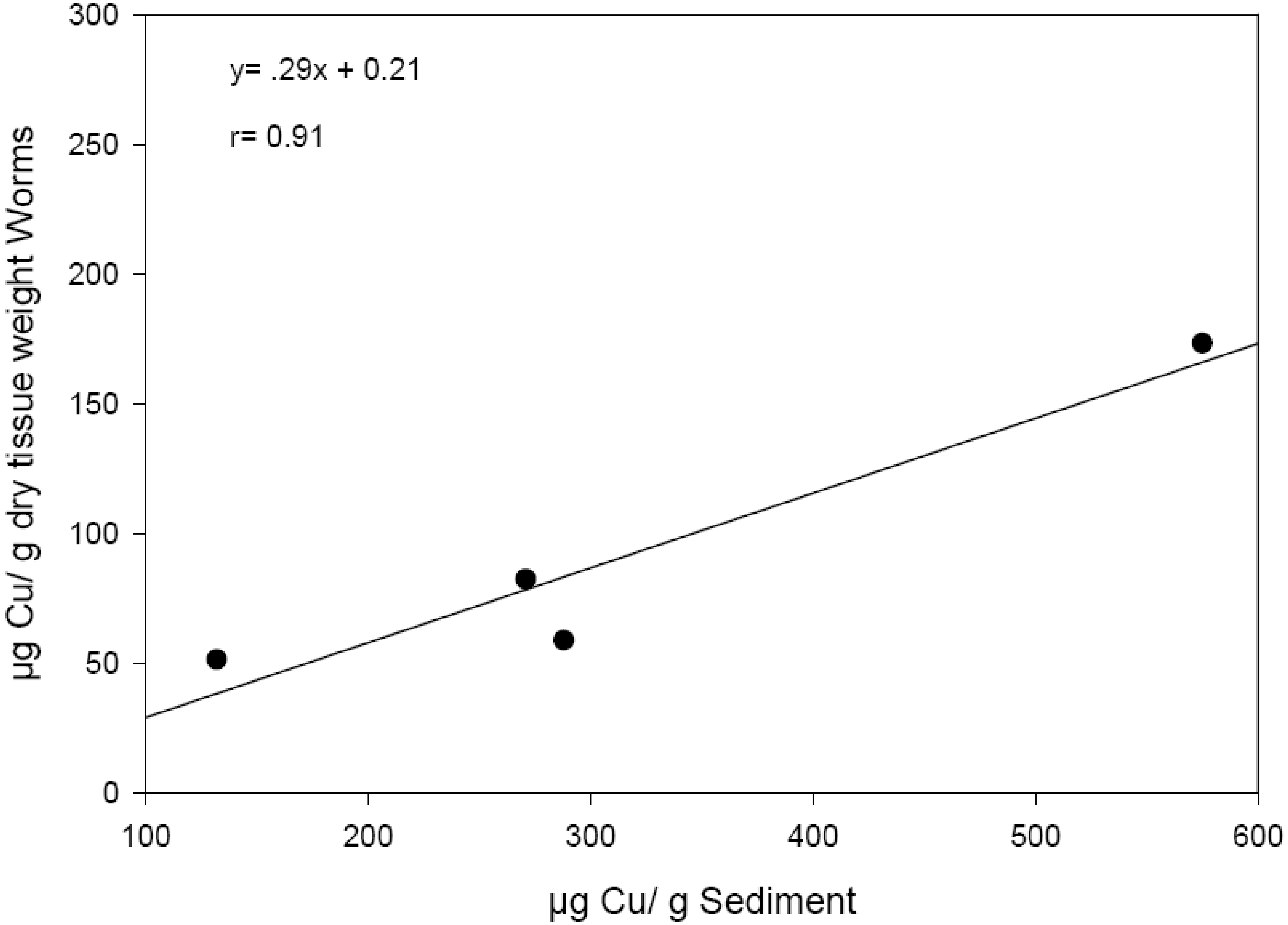
Copper Sediment
Total Concentrations



Copper Tissue Sample Concentration for RC-4



Regression of Tissue Samples to Sediment Concentrations for Copper

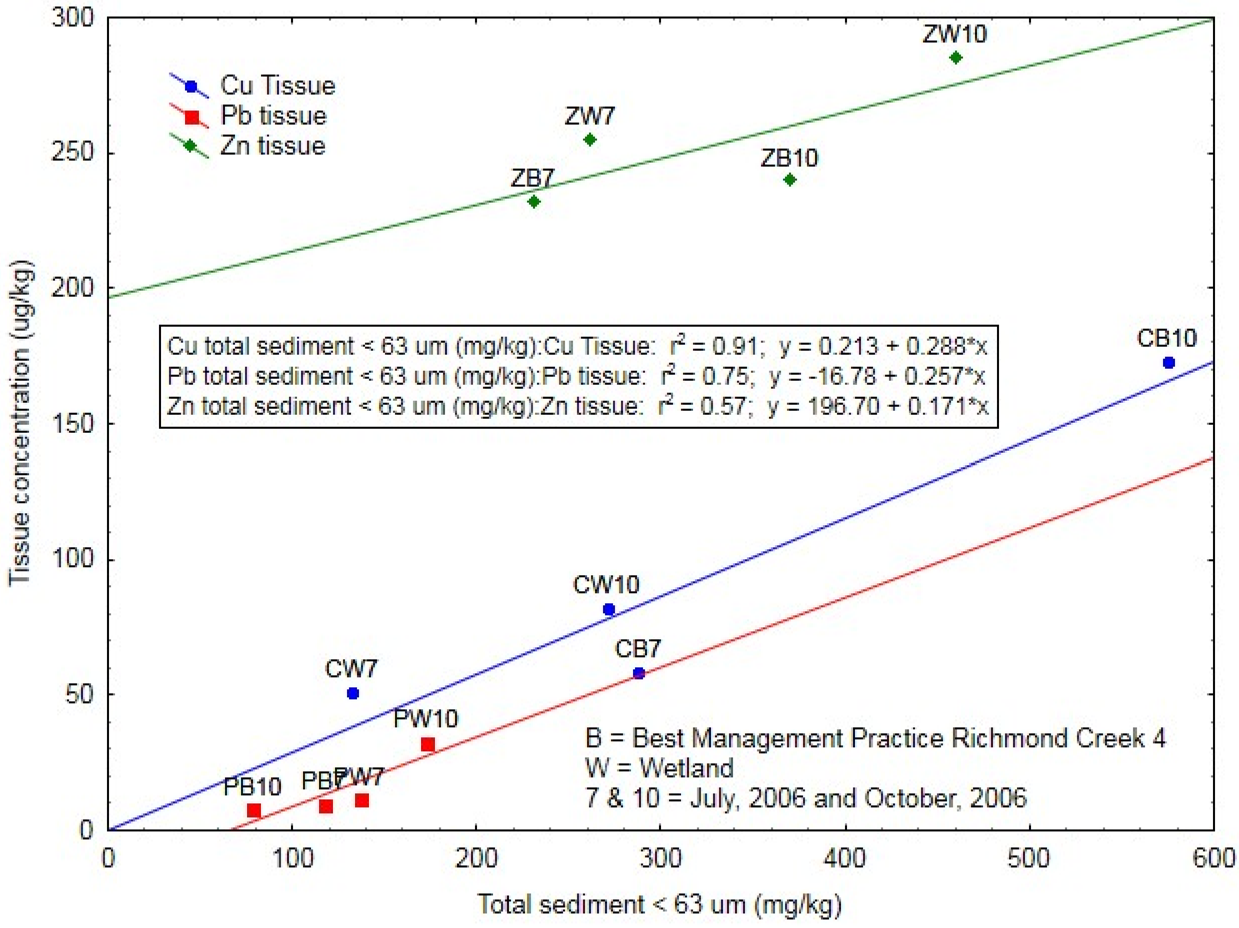


United States Environmental Protection Agency

Not the Anticipated Result!!

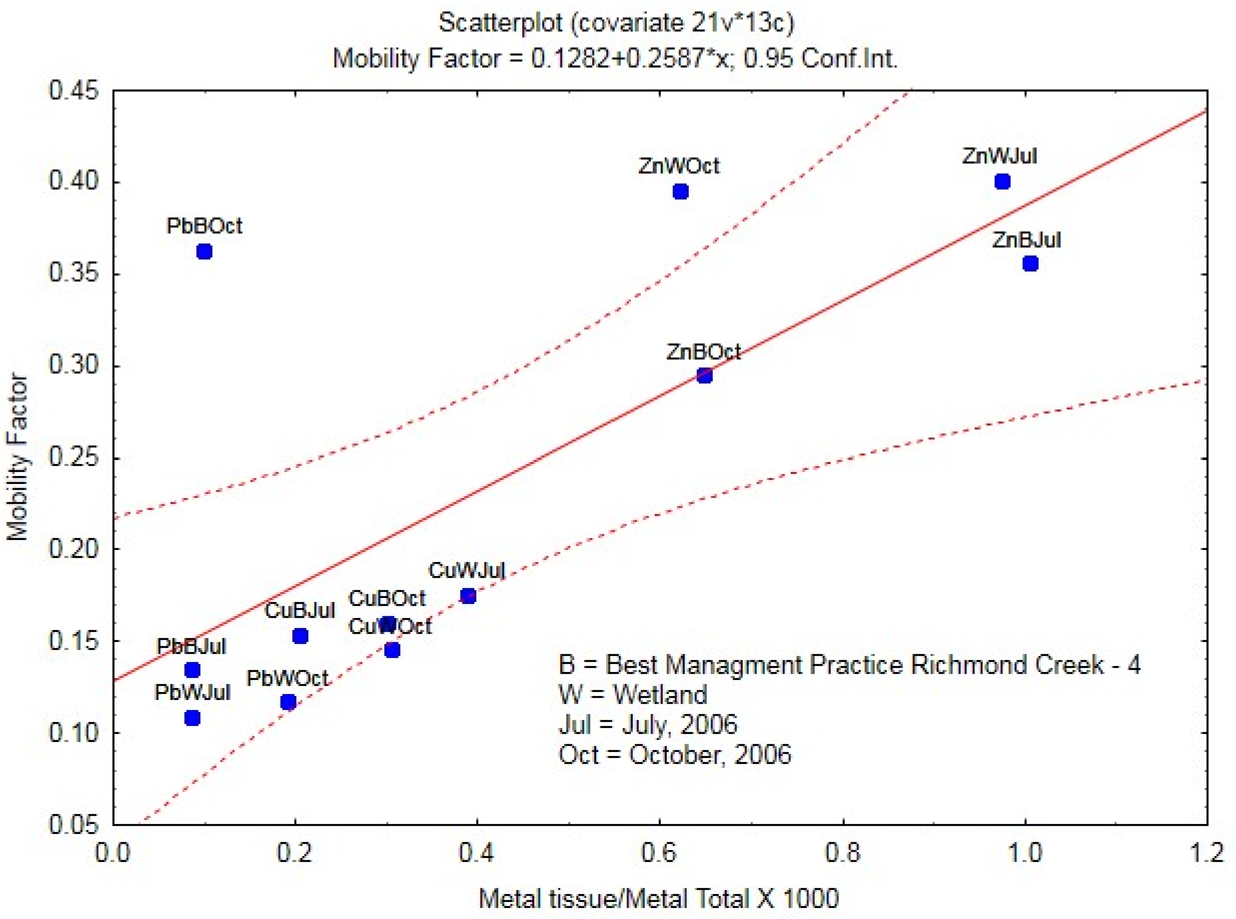
- Expected drop in metals concentration at all locations
- Maintenance affected heavy metal sediment concentrations
- Disturbance may impact BMP performance for metals removal and increase bioavailability
- Mobility factor (MF) = fraction simplest extraction over total metal content

Covariant metal analysis



Can be described by one common slope of 0.26 (O’Connor et al. 2012)

Normalized ratio of tissue burden to total sediment compared to mobility factor



R^2 of 0.82 excluding outlier (O'Connor et al. 2012)

Bluebelt BMP Monitoring Conclusions

- BMP removing solids – maintenance did not improve SS removal
- Reduction in COD and total phosphorous effluent discharge appears to be due to maintenance activity
- Leaves appear to be major contributor to COD and phosphorous load
- Need predictive relationships for maintenance schedules tailored to all contaminants of concern, not just sediment

Bluebelt BMP Monitoring Conclusions (continued)

- Surrogates (e.g., COD) may be easier and cheaper to track than nutrients
- Maintenance activity temporarily increased metal availability (MF)
- MF of sediment samples may be good indicator for scheduling maintenance in BMP subject to trace metal loadings
- <u>Other types of BMPs may perform differently, requiring separate maintenance schedules</u>

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Agency

United States Environmental Protection Agency

CASE STUDY 4: GREEN ROOF RESEARCH

Green Roof Types

- Intensive roofs, designed for plant growth
  - deep (> 6 in) soil profile for bushes, trees and grasses
- Extensive roofs, designed to drain
  - Shallow (< 6 in.) soil-less media comprised of expanded clay, shale or slate
  - Plants: Stone crop (e.g. Sedums, Delosperma) Crassulacean Acid Metabolism (CAM) plants - take in carbon dioxide from atmosphere at night. Photosynthesis in water limited environments with minimal water loss by plant.
  - Mat, trays or landscaped (built in place)

Green Roof Research

- Investigated green roofs as control for stormwater discharge and pollutant content
  - Measured volume, turbidity, nitrate, conductivity, pH and color
- Measured temperature effects on building
- Penn State Center for Green Roof Research
- Design specifications and materials of green roofs

Green Roof Research Data Set Acquisition to Model Storm Water Runoff From Green Roofs

CR 83124401
Region 3
RARE

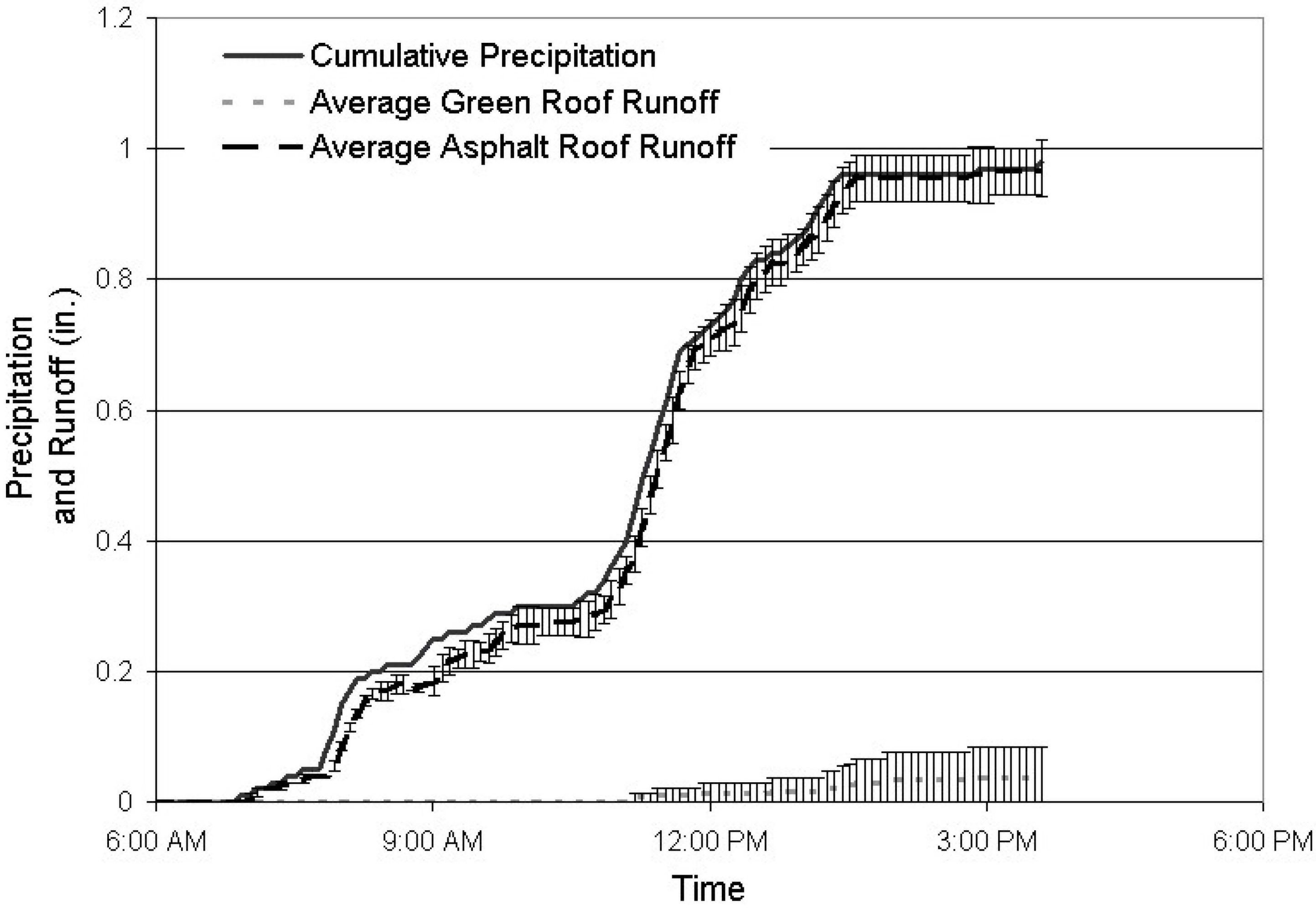
United States Environmental Protection Agency

Roof Top Side-by-Side Demonstration

Green Roof with Monitoring Equipment November 2003

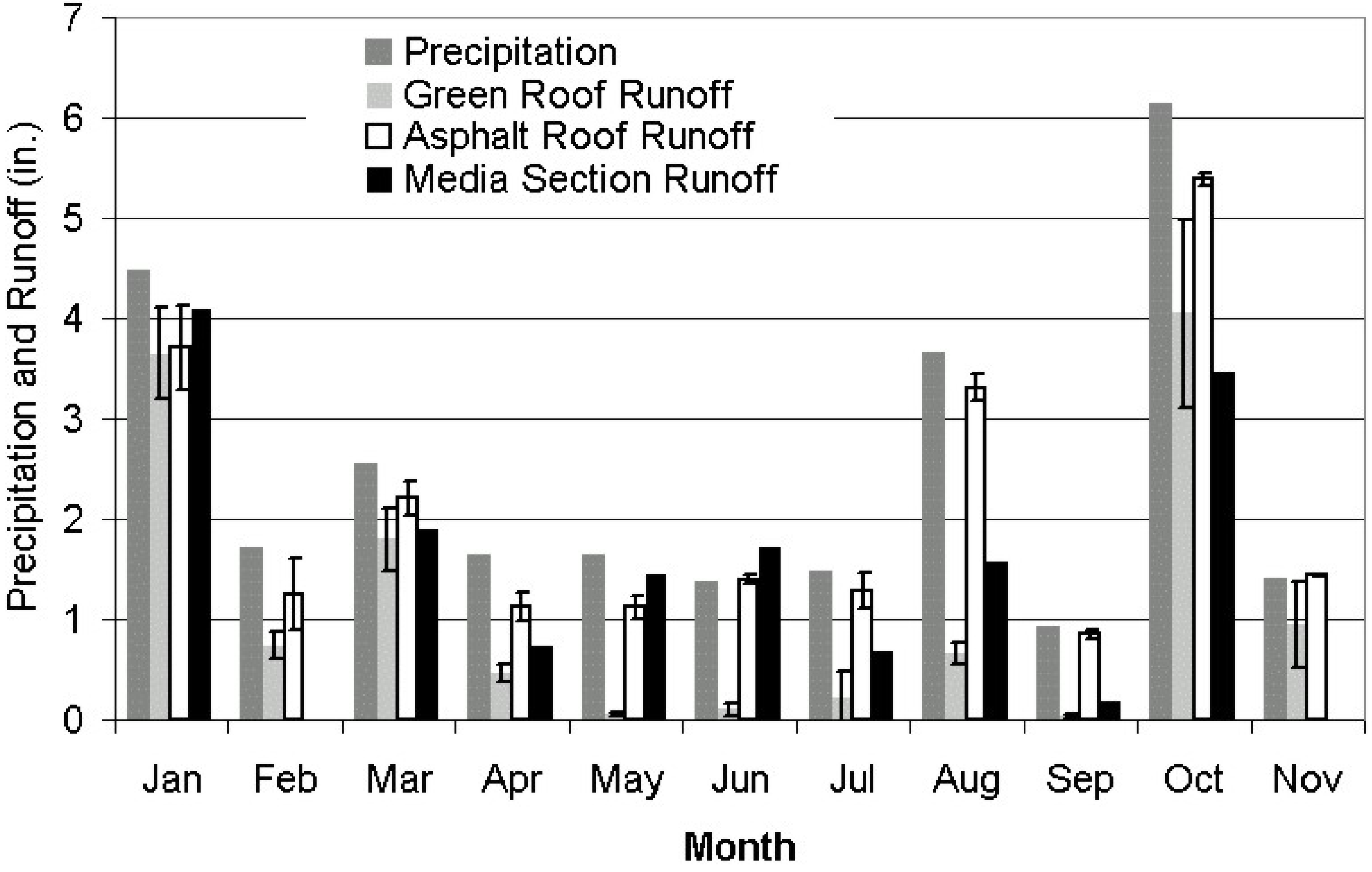
United States Environmental Protection Agency

Precipitation and runoff from green and flat asphalt roofs on August 16, 2005



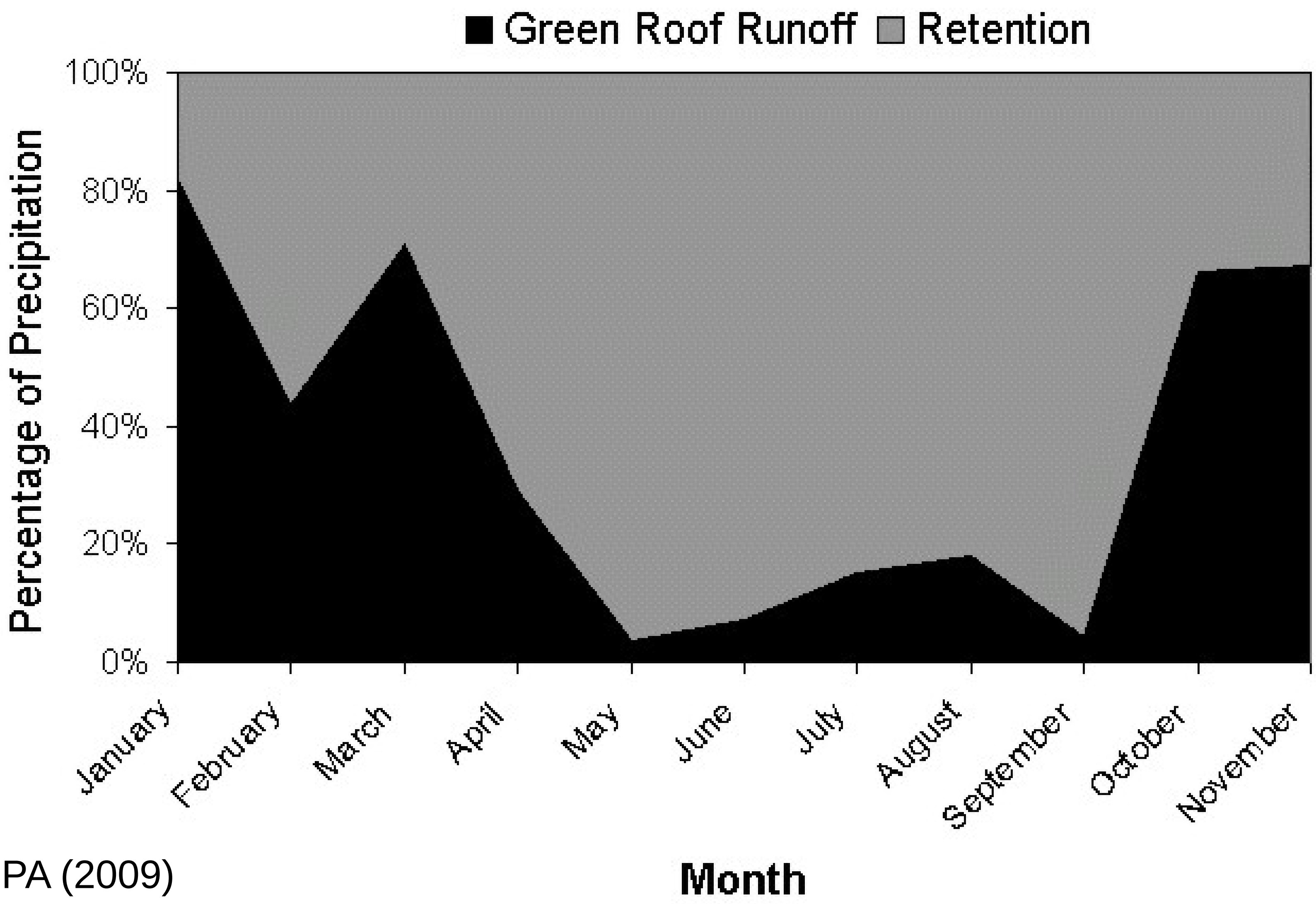
EPA (2009)

Monthly average precipitation and runoff for green and asphalt roofs including unplanted media roof section



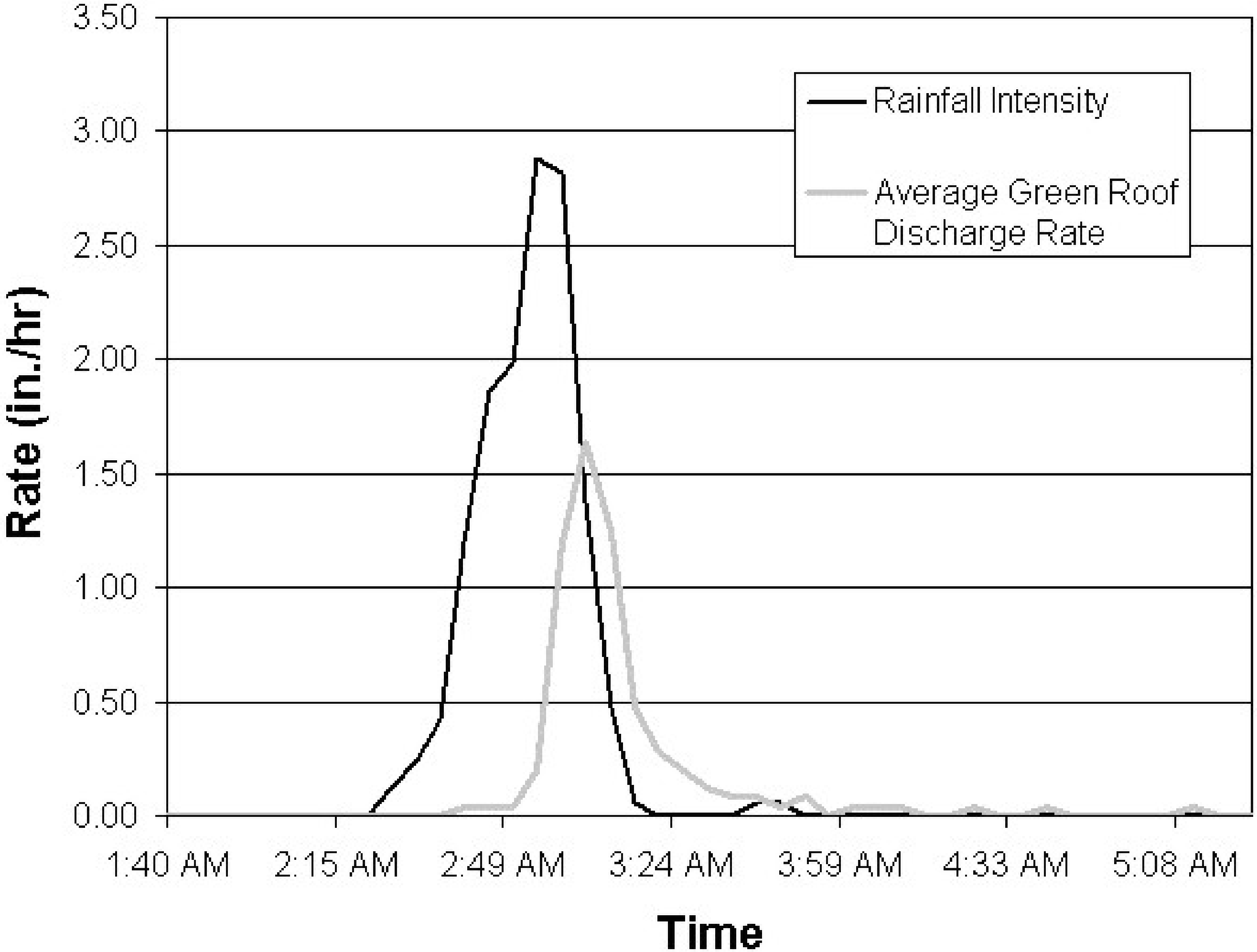
EPA (2009)

Relative Percentage Runoff to Retention



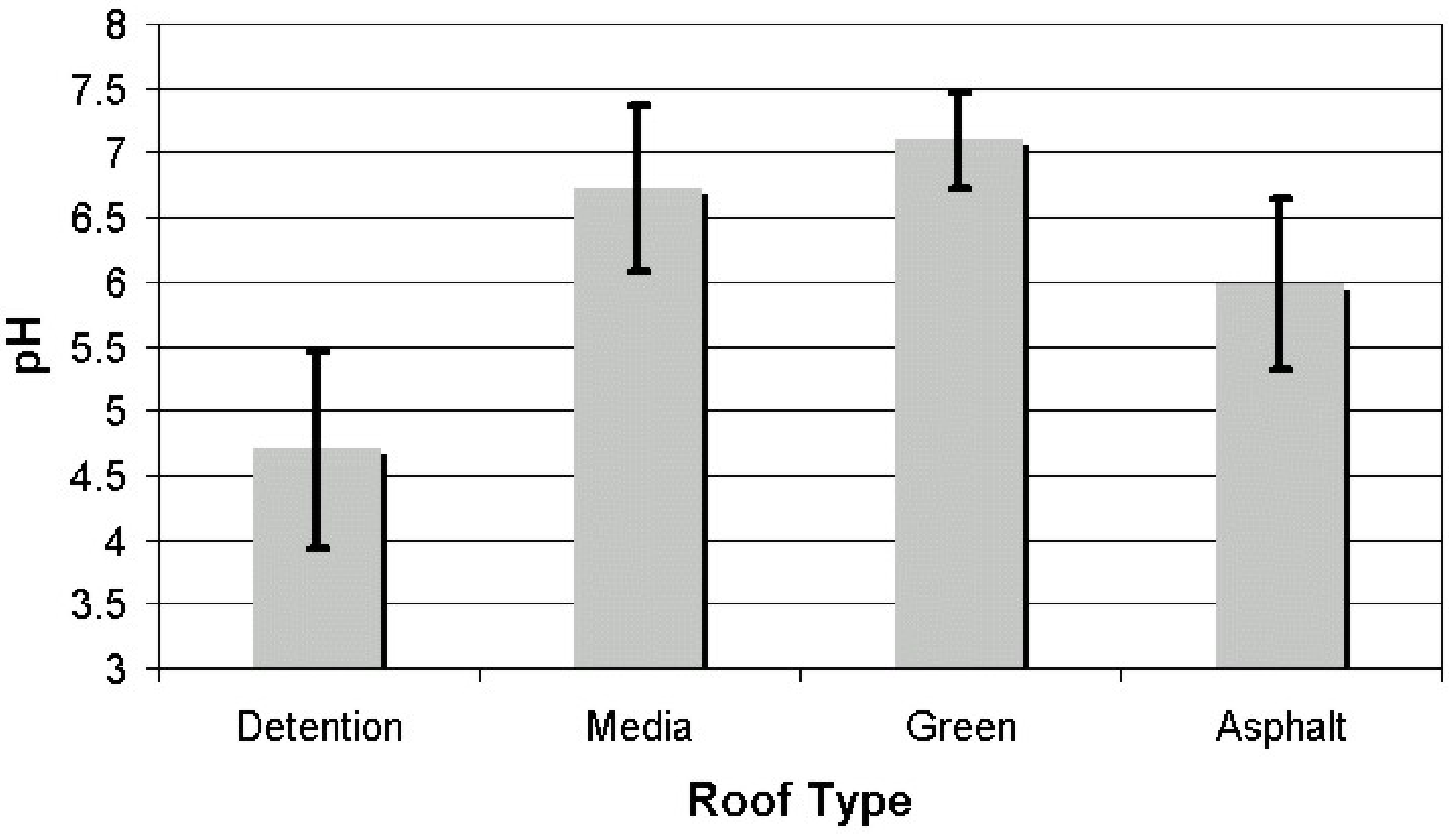
EPA (2009)

Hydrograph of most intense period of August 30–31, 2005 event

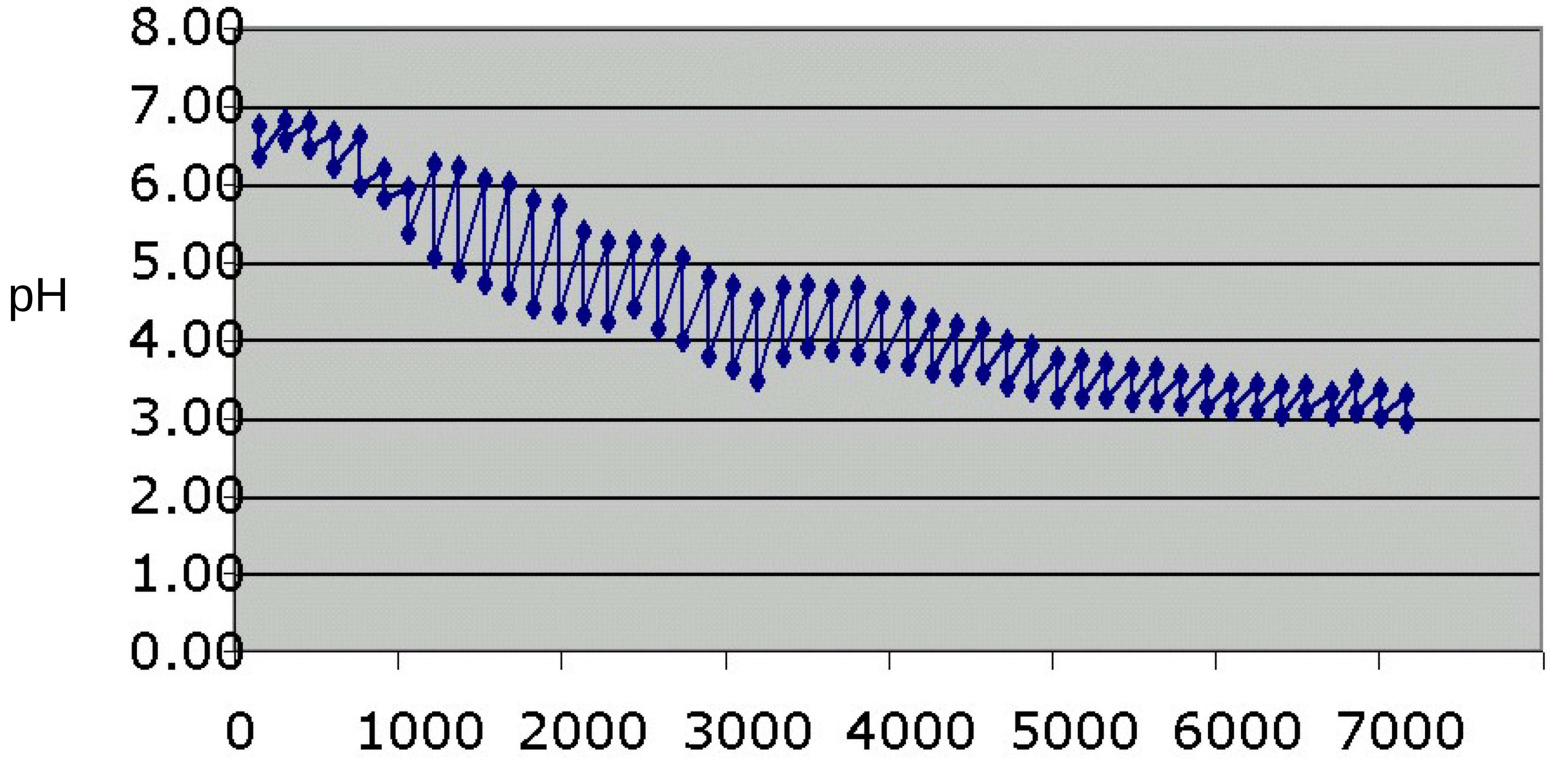


EPA (2009)

Average pH of runoff from all roof types

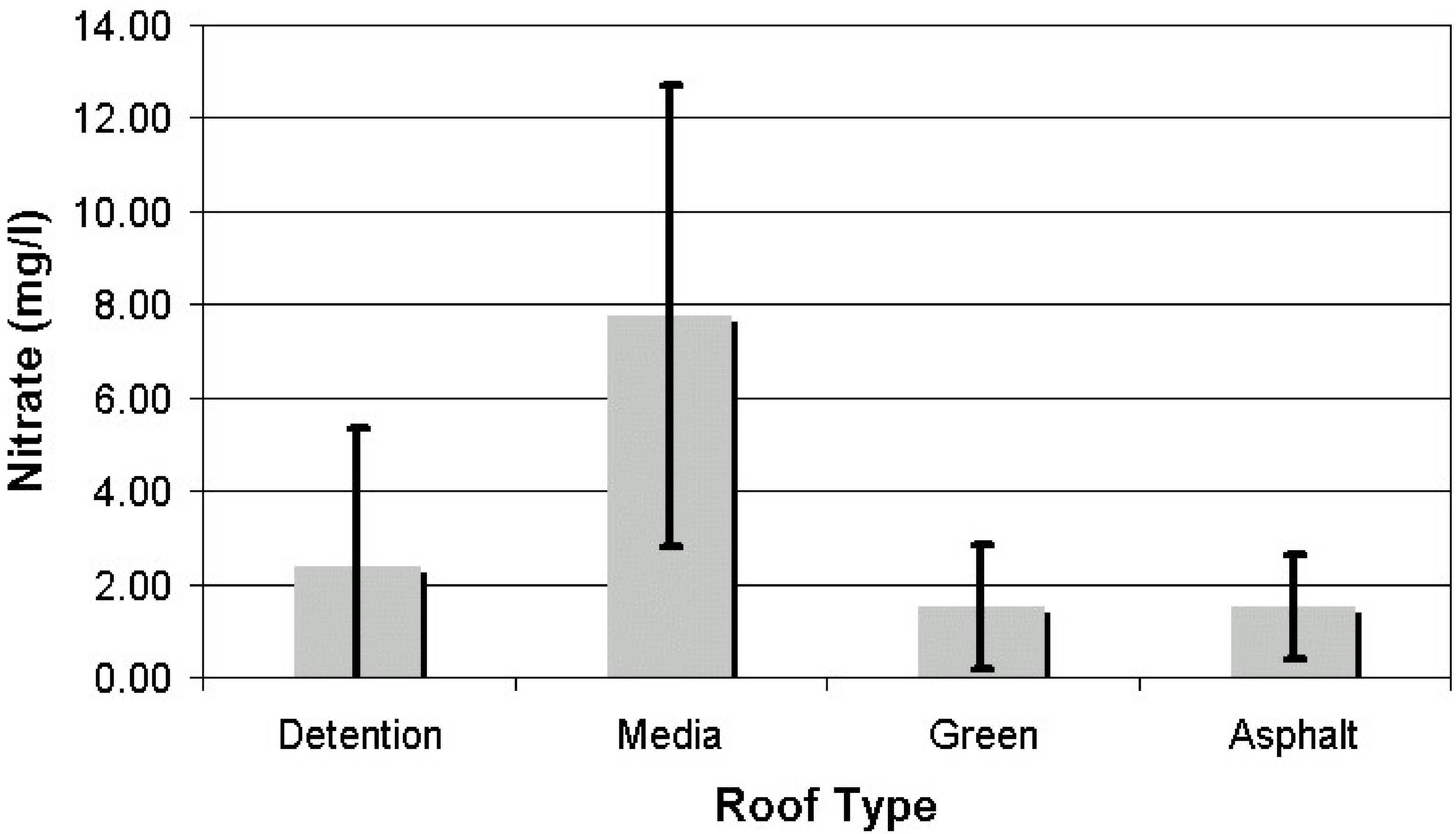


Accelerated Acid Rain
Clay Based Medium

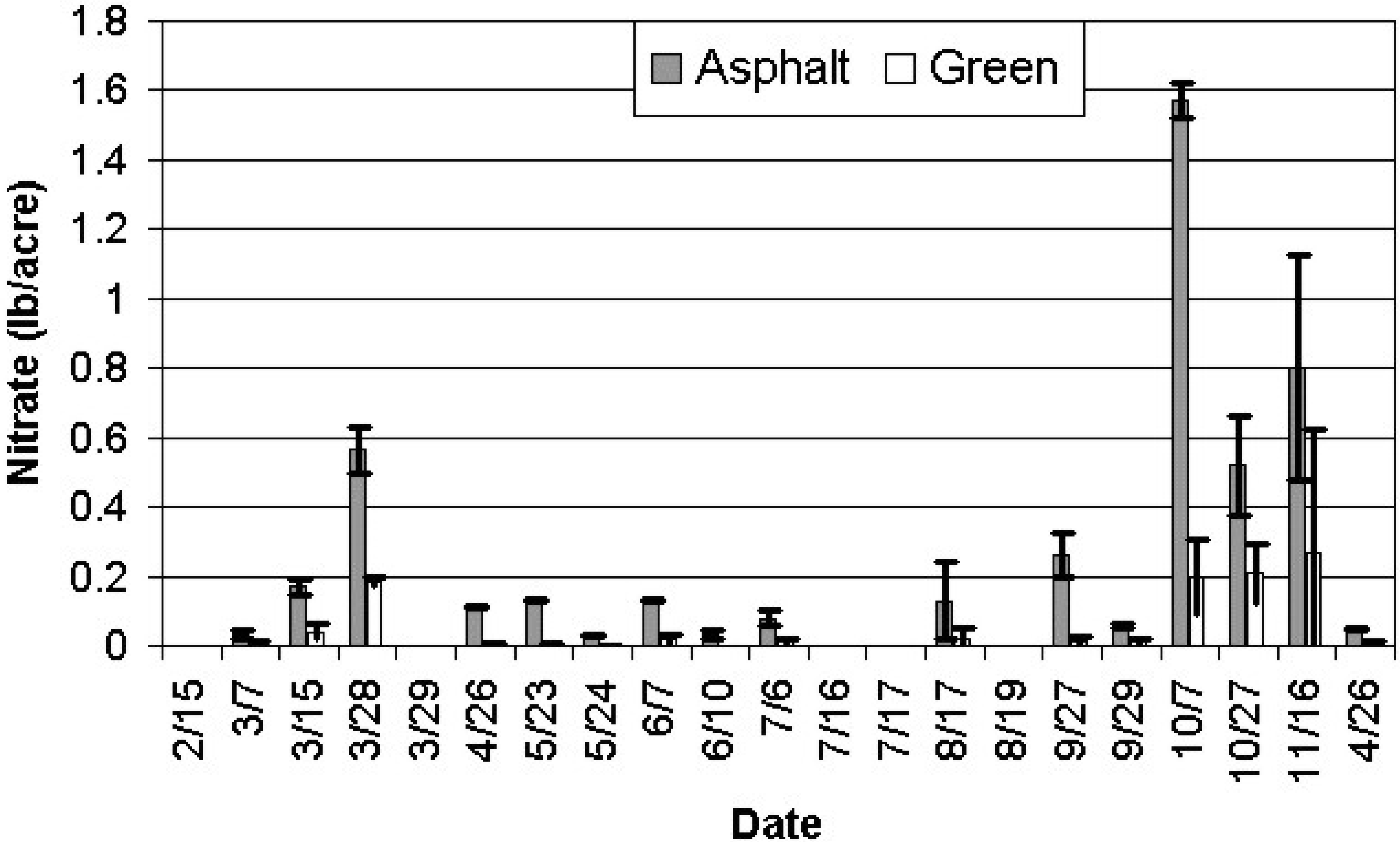


Simulated acid rain (cm) on a 9 cm deep roof

Average nitrate concentration in runoff from all roof types



Nitrate (pounds/acre) in runoff from green and asphalt

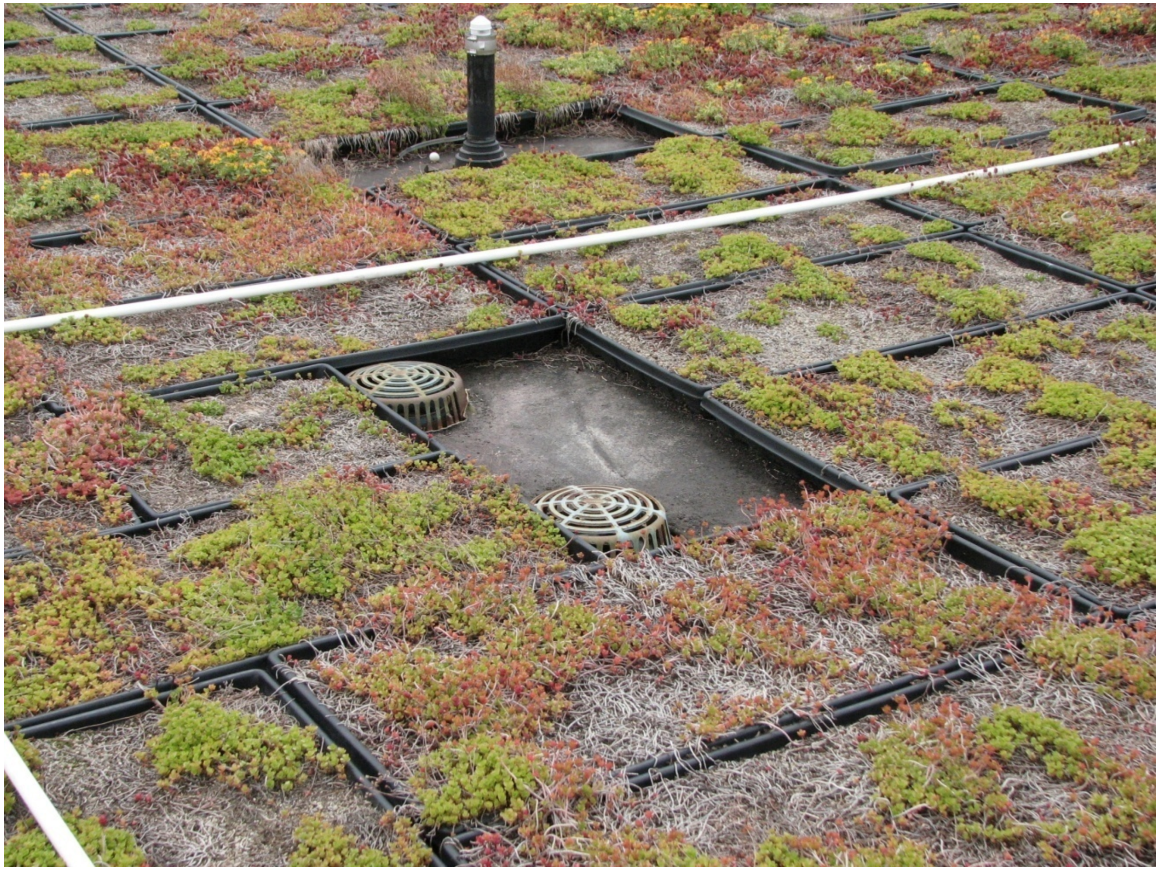


Region 8 Green Roof

- Colorado State University
  - CA X3-83350101 “Characterization of Green Roof Performance Parameters in the High Elevation, Semi-arid, Temperate Colorado Front Range Region”
- Evaluation of green roof plants in arid climate
- Extensive roofs
  - Tray system 10 cm (4 in.) deep
  - Eight species including natives
  - Tested zeolite as amendment
- Required irrigation
- ORD approved QAPP of greenhouse and full-scale field experiments

Region 8 Green Roof, Denver, CO

Tray or modular green roof system, solar panels to left of picture



Region 8 Green Roof, Denver, CO

Tray or modular green roof system, irrigation required

Region 8 Green Roof, Denver, CO

Area of green roof: 20,000 ft^2

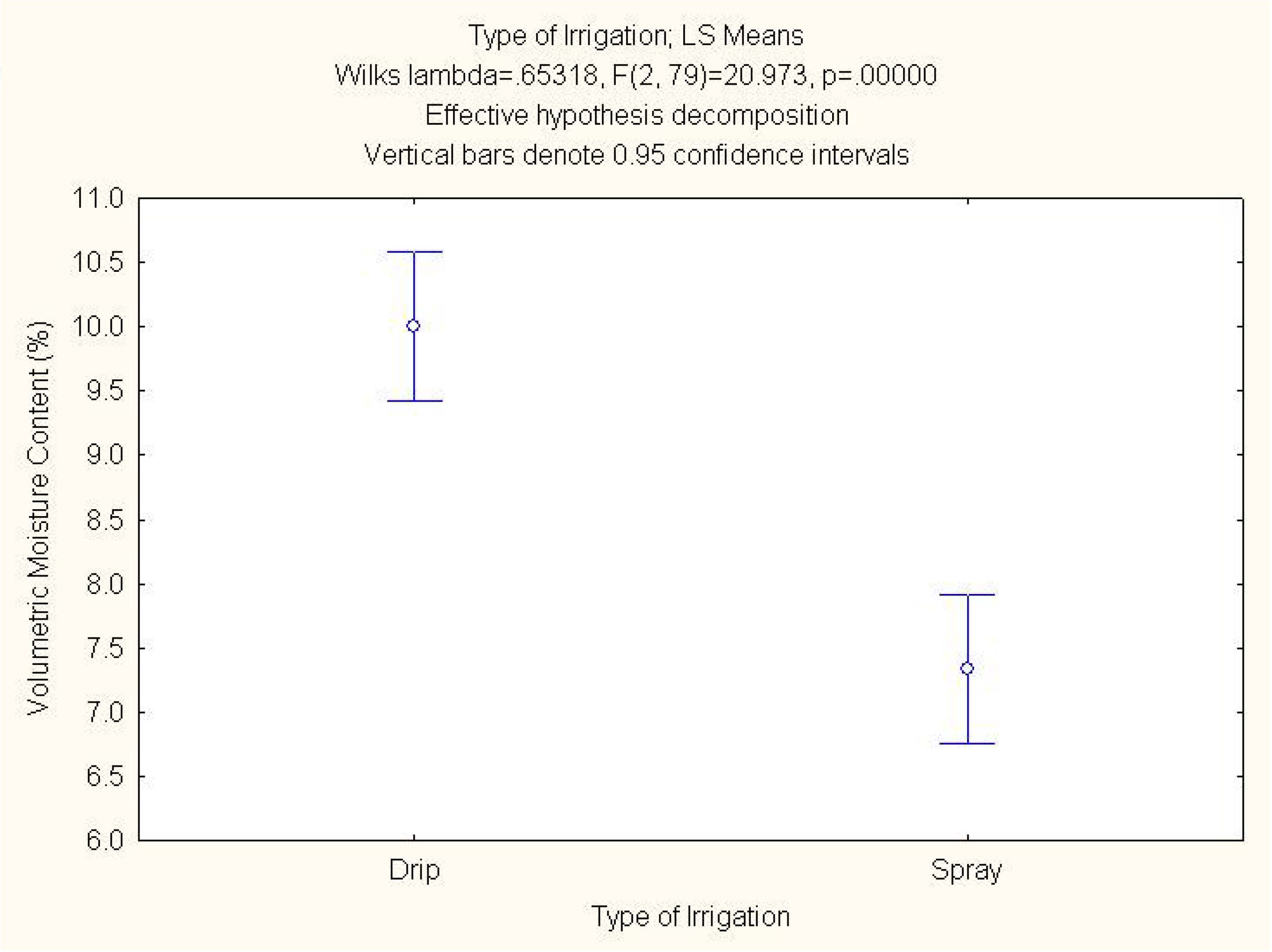
Irrigation and rainfall comparison for months July through September

Year	Irrigation Type	ET_0 (mm)	Rain (mm)	Irrigation (mm)	Total (mm)
2008	Drip	450	88	270	358
2009	Spray	429	97	205	302
Percent Difference in 2009		5% Decrease	9% Increase	32% Decrease	18% Decrease

ET_0 = Calculated monthly reference evapotranspiration (FAO Irrigation and Drainage Paper 56)

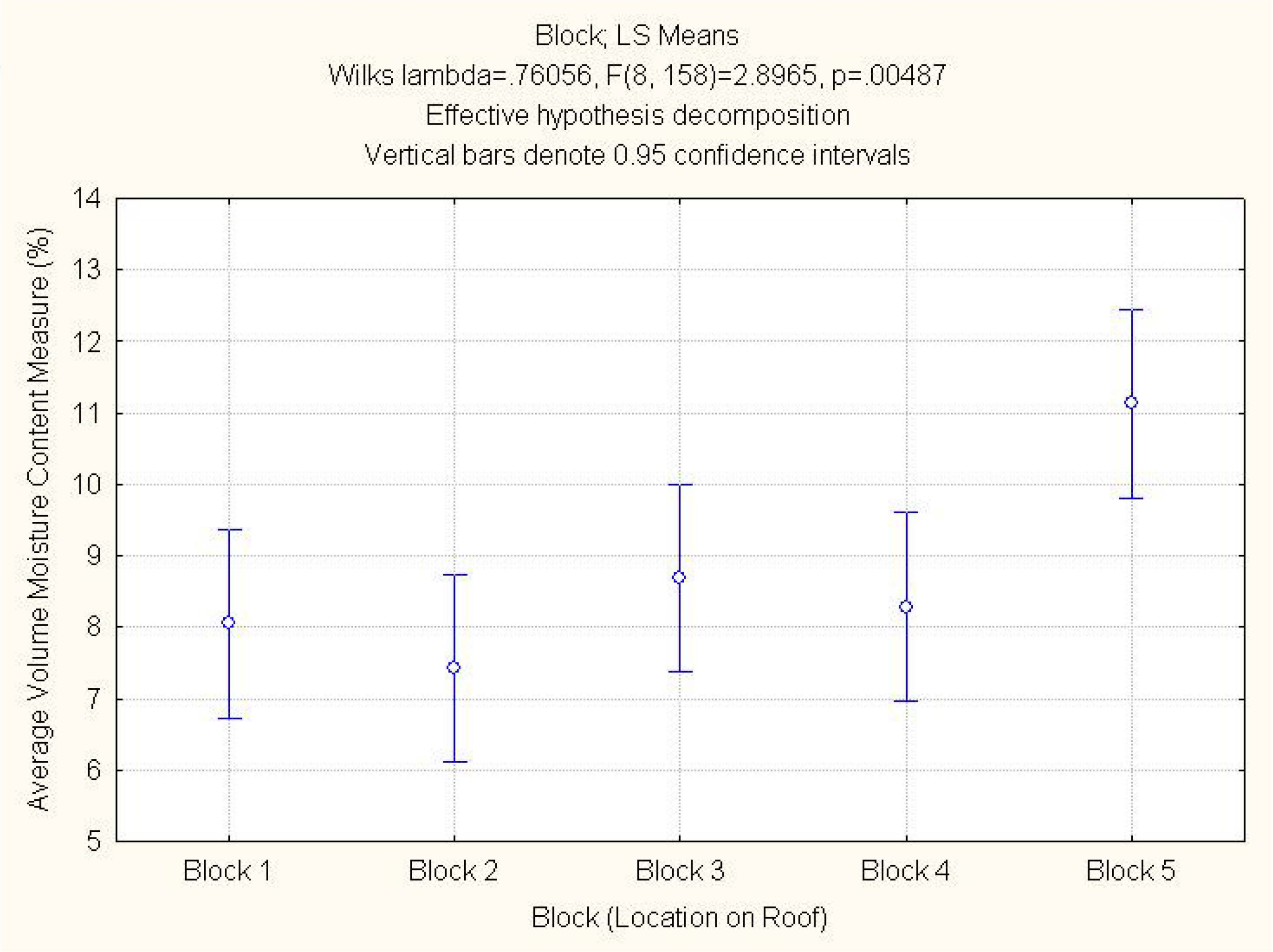
(EPA 2012)

United States Environmental Pro Agency



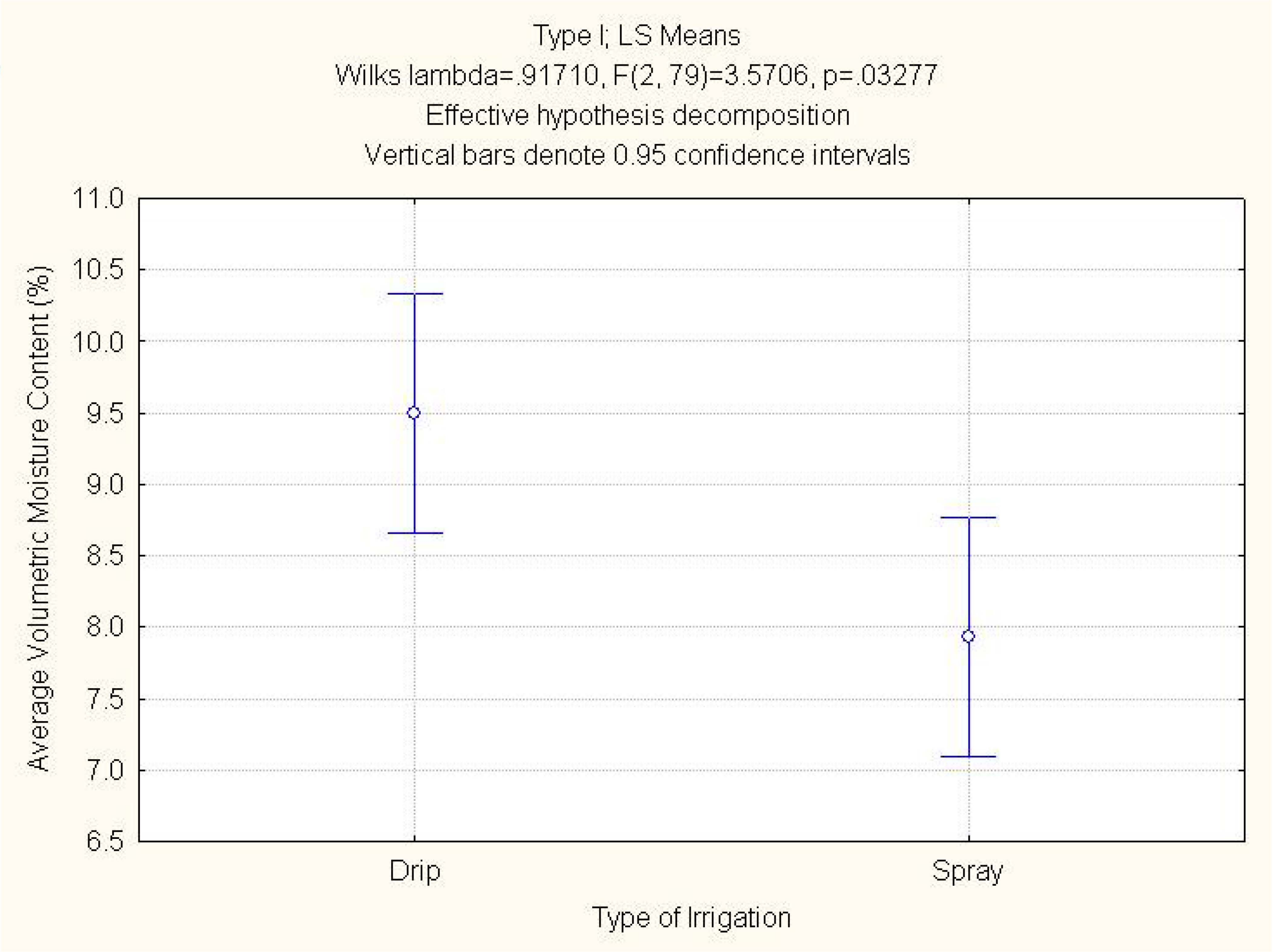
Box and whisker plot of effect of block on volumetric moisture content for study 1

(EPA 2012)



Box and whisker plot of effect of block on volumetric moisture content for study 1 – Block 5 received most shading

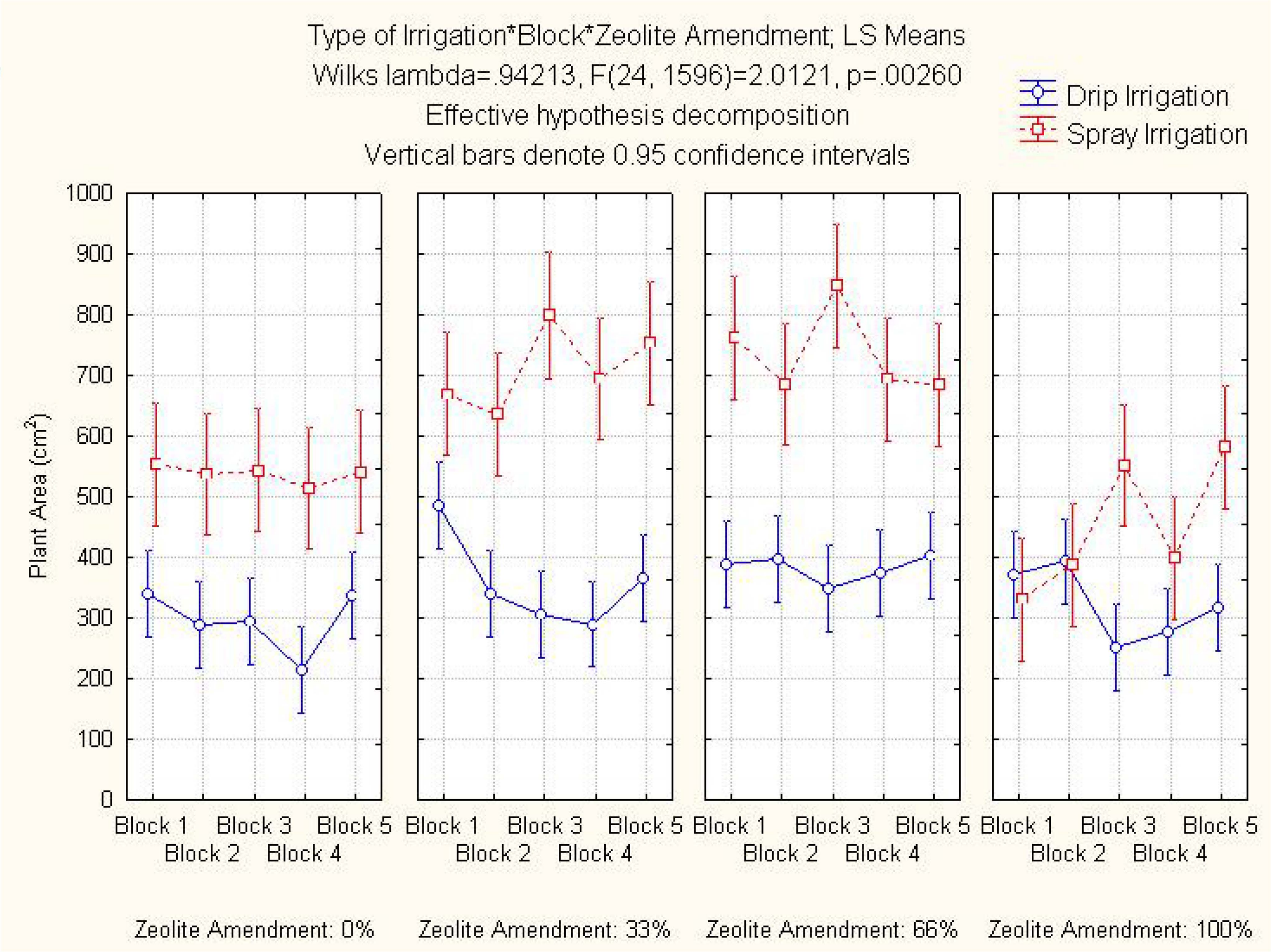
(EPA 2012)



Box and whisker plot of effect of type of irrigation on volumetric moisture content for study 3

(EPA 2012)

United States Environmental Pro
Agency

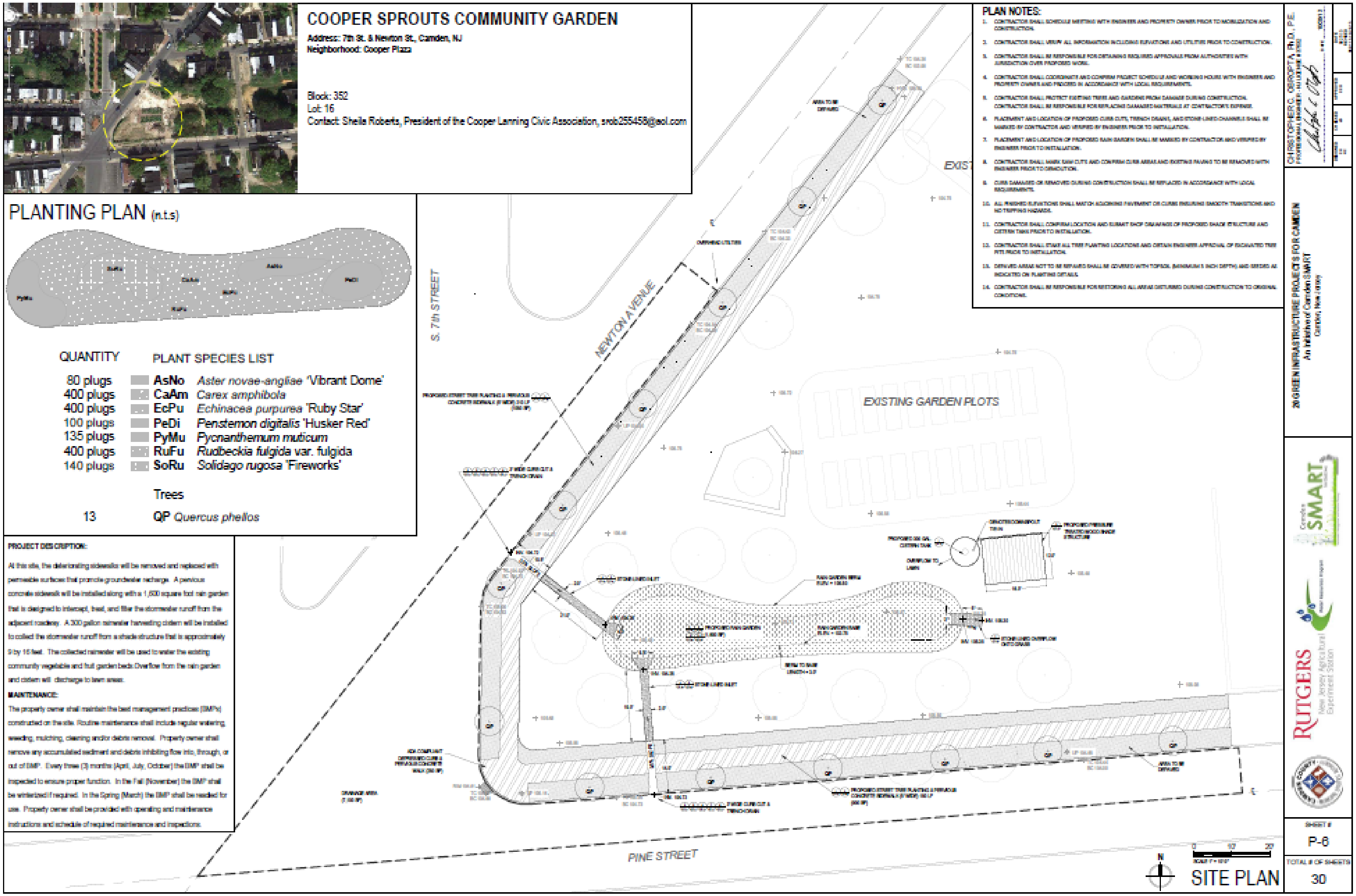


Box and whisker plot of effect of block, irrigation type and zeolite amendment on volumetric moisture content

(EPA 2012)

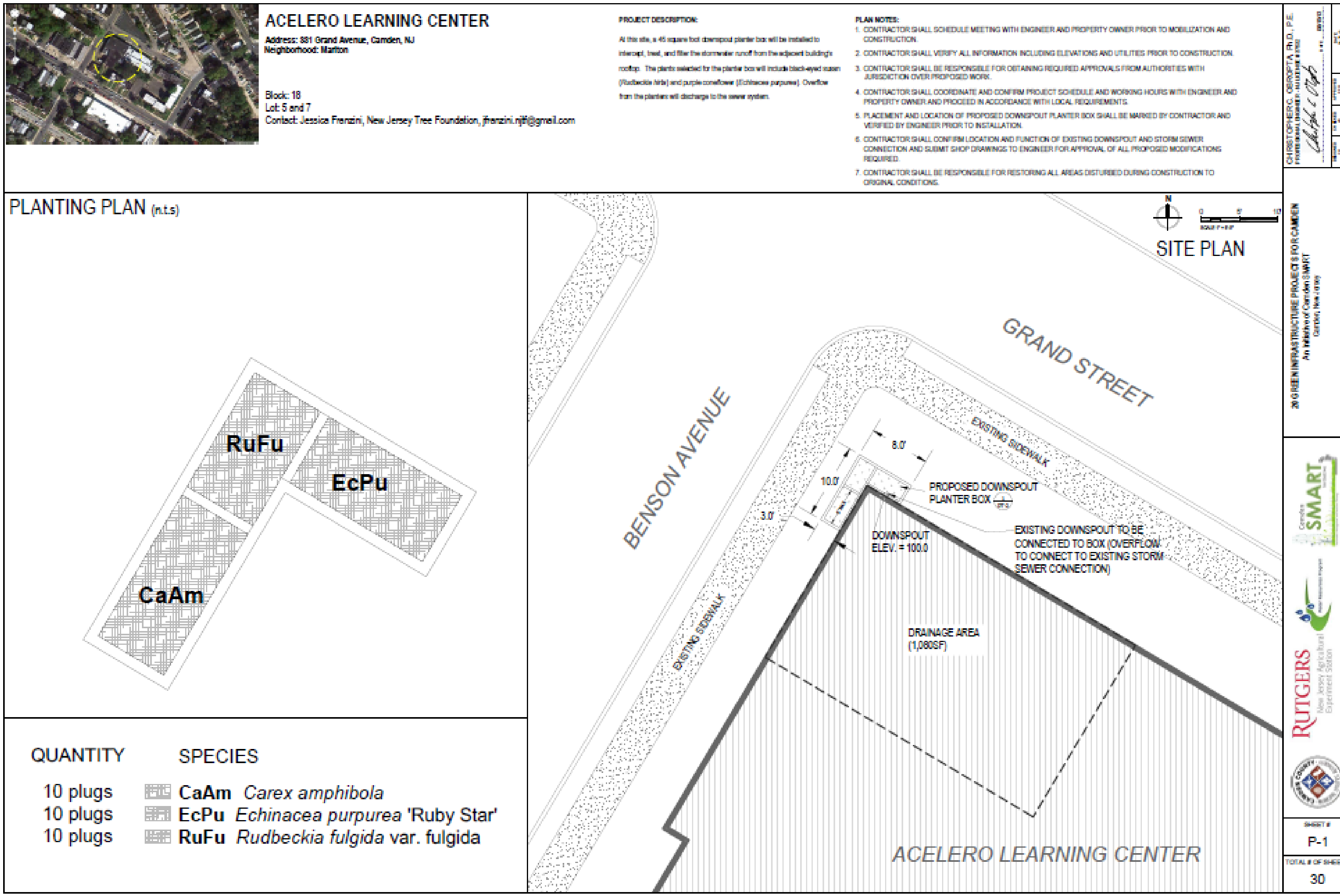
CASE STUDY 5: CAMDEN, NJ IMPLEMENTING GI

Rain Garden and Cistern Design



Pictures of Rain Garden and Shade Structure for Cistern

Downspout Planter Box Design



Unplanted Downspout Planter Box

CASE STUDY 6: EPA EDISON ENVIRONMENTAL CENTER (EEC) PERMEABLE PAVEMENT, RAIN GARDENS AND RAINWATER HARVESTING FOR AIR CONDITIONING DEMAND

Edison Environmental Center (EEC) former Raritan Arsenal

Full-scale
- **porous pavement**
- **rain gardens**

Roof runoff collection and use

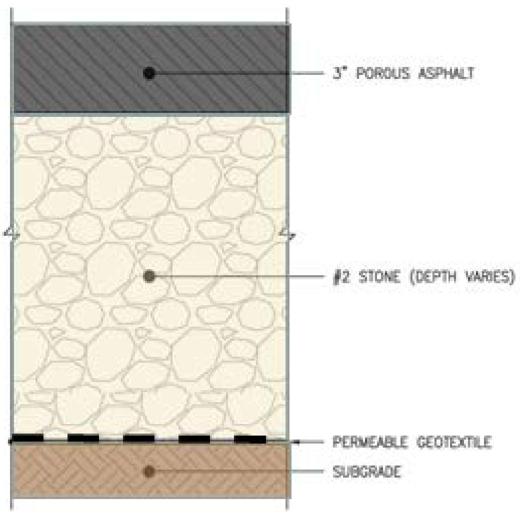
UWRF
- **swales**
- **rain gardens**
- **rainwater sampling**
- **pipelines**

Permeable Pavement and Rain Garden Research and Demonstration Site

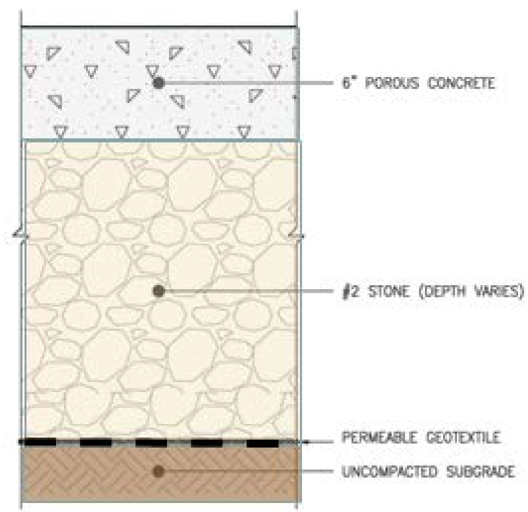
- Side by side testing of three permeable parking surfaces
- Evaluation of effect of hydraulic loading on bioinfiltration hydrologic performance
- Continuous and event-based sampling for water quantity and quality parameters

Vertical cross sections of permeable surfaces vary slightly from material to material

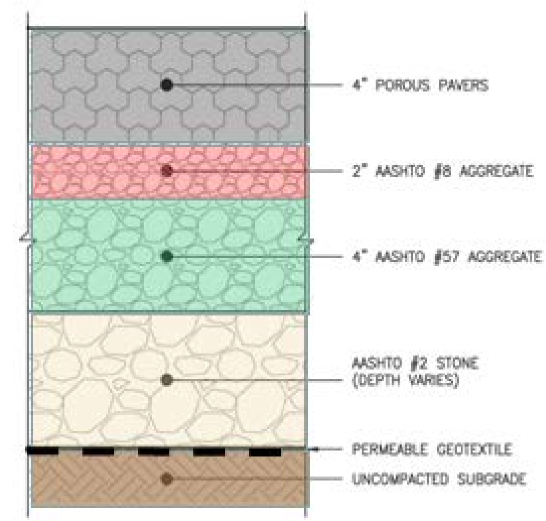
Not to scale



Porous Asphalt (PA)

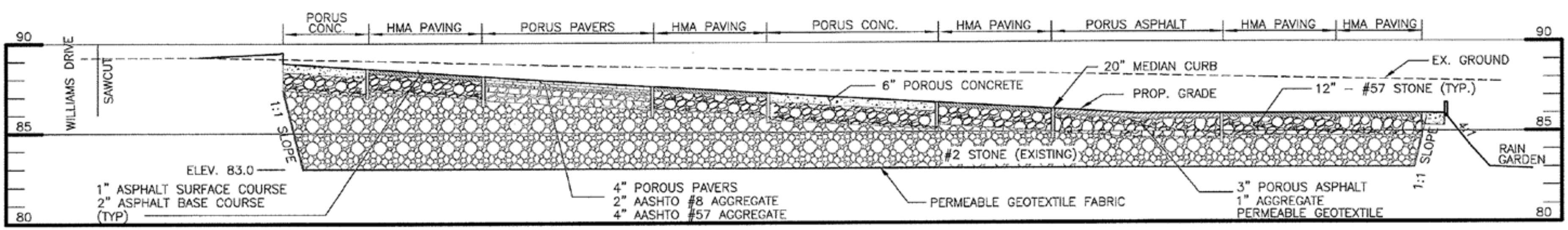


Porous Concrete (PC)



Permeable Interlocking Concrete Pavers (PICP)

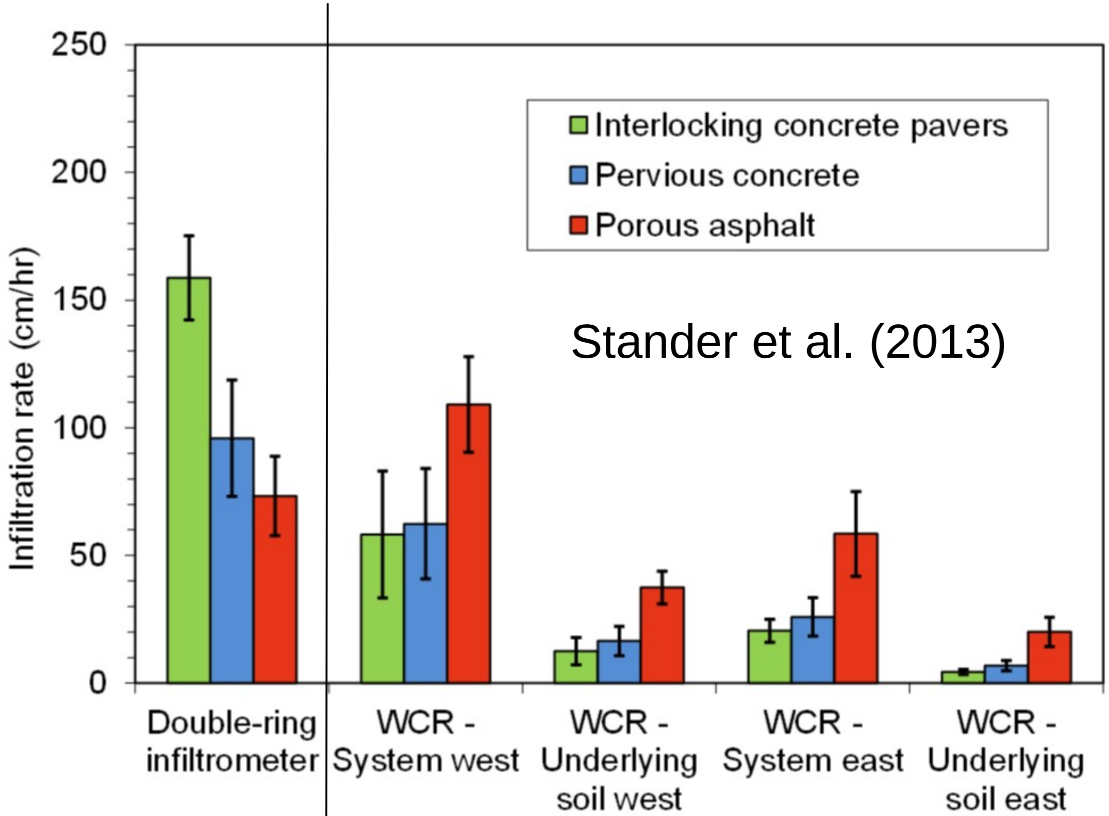
*Courtesy of Morris Ritchie and Associates, 2009



SECTION A-A

SCALE: H: 1" = 20' V: 1" = 5'

Underlying Soil Infiltration Testing



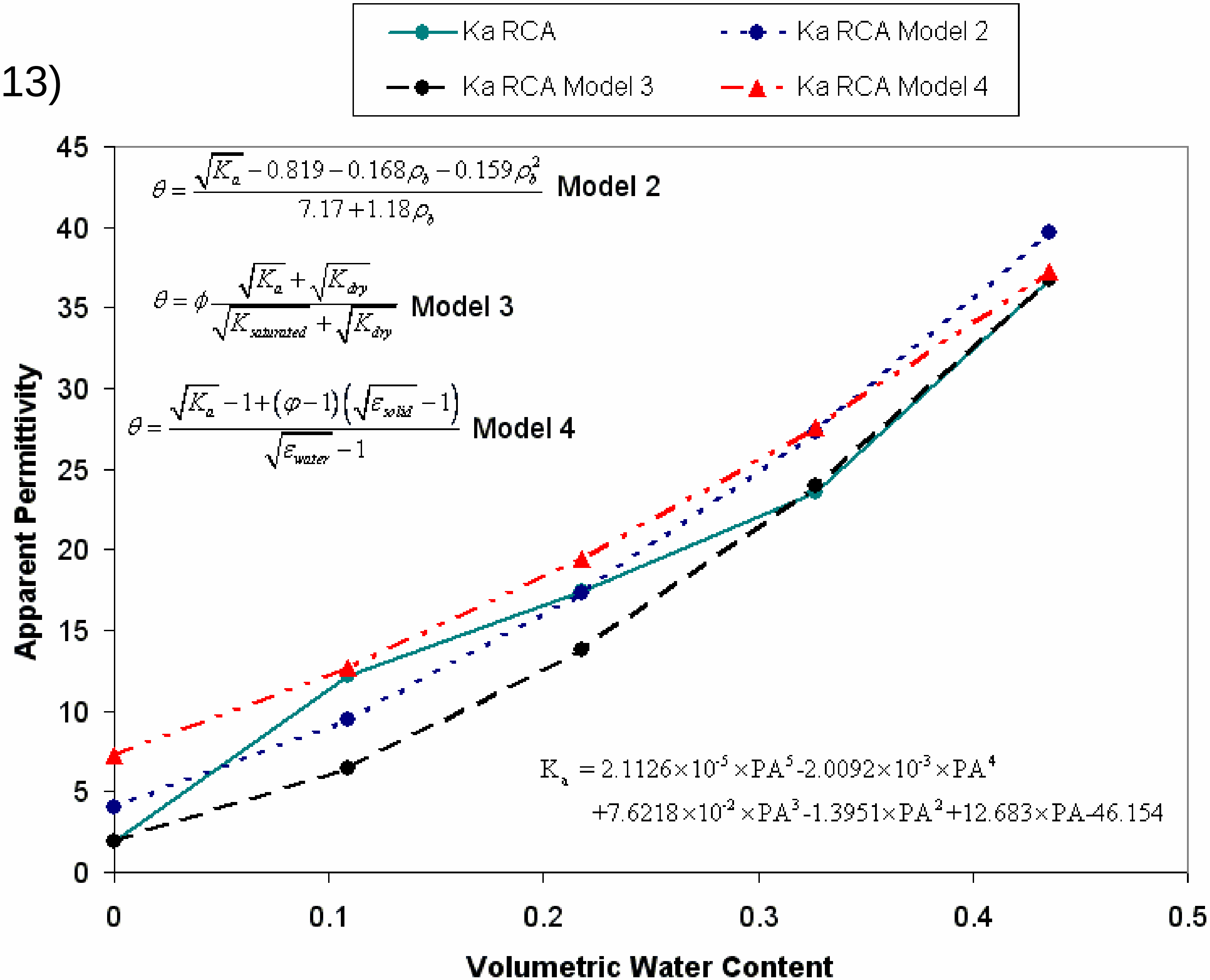
Pre-construction infiltration test

Post-construction soil moisture measurements

Water content reflectometer (WCR) installation

Calibration of water content (time domain) reflectometers in large aggregate for storage

Stander et al. (2013)



Permeable Interlocking Concrete Pavers (PICP)

Porous Concrete (PC)

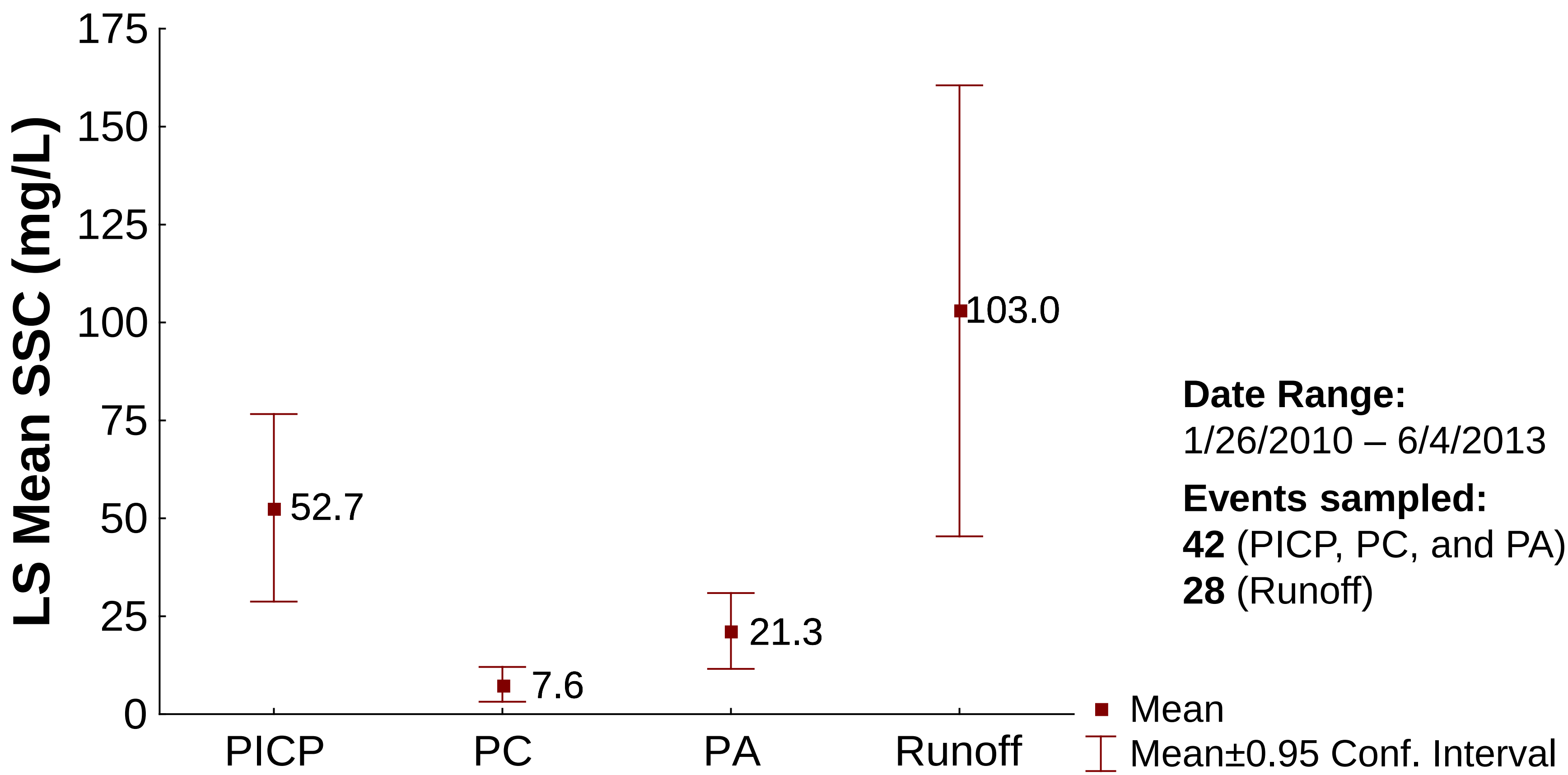
Permeable Asphalt (PA)

The permeable pavement parking lot at the EEC allows evaluation of water quality effects.

- Published or in review
  - Chloride
  - Speciated nitrogen
  - Organic carbon
  - Phosphate
  - pH
- In production
  - SVOCs
  - Metals
- Just starting
  - Microbial indicators

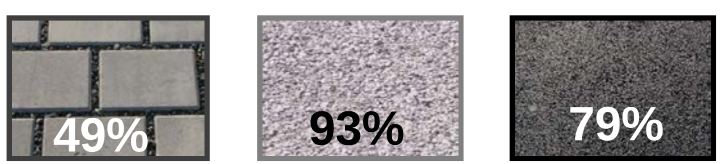
Note: Preliminary Data

All permeable surfaces reduced Suspended Sediments Concentration (SSC).



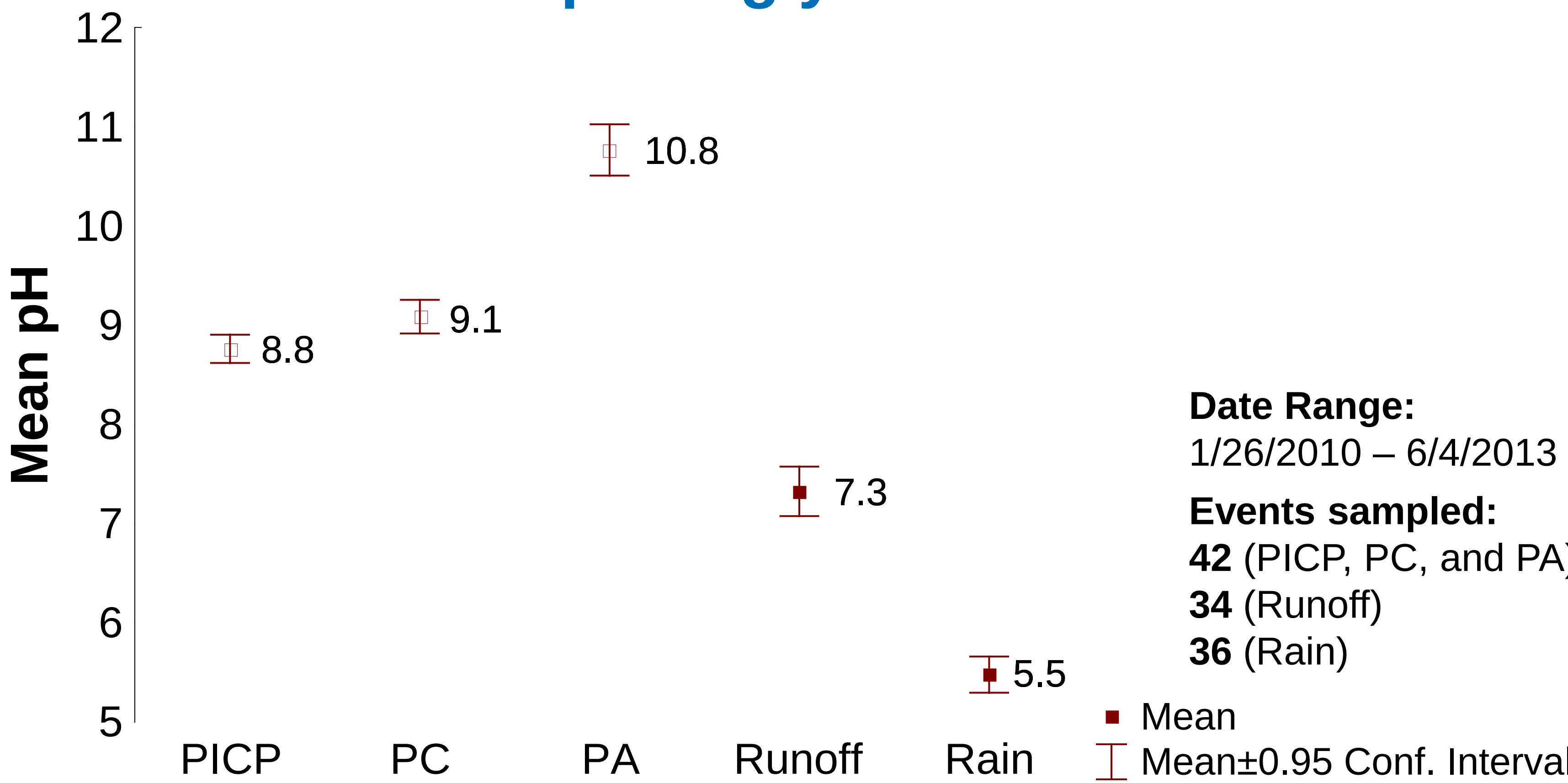
Date Range:
1/26/2010 – 6/4/2013

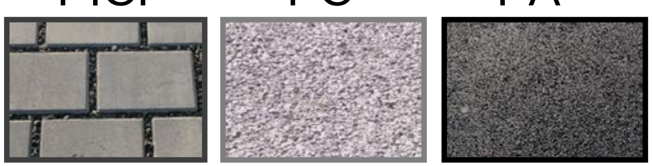
Events sampled:
42 (PICP, PC, and PA)
28 (Runoff)



Note: NSQD TSS commercial median 98 mg/L

Acidic rainfall is buffered by all pavement surfaces, and PA exfiltrate is surprisingly basic.





Date Range:
1/26/2010 – 6/4/2013

Events sampled:
42 (PICP, PC, and PA)
34 (Runoff)
36 (Rain)

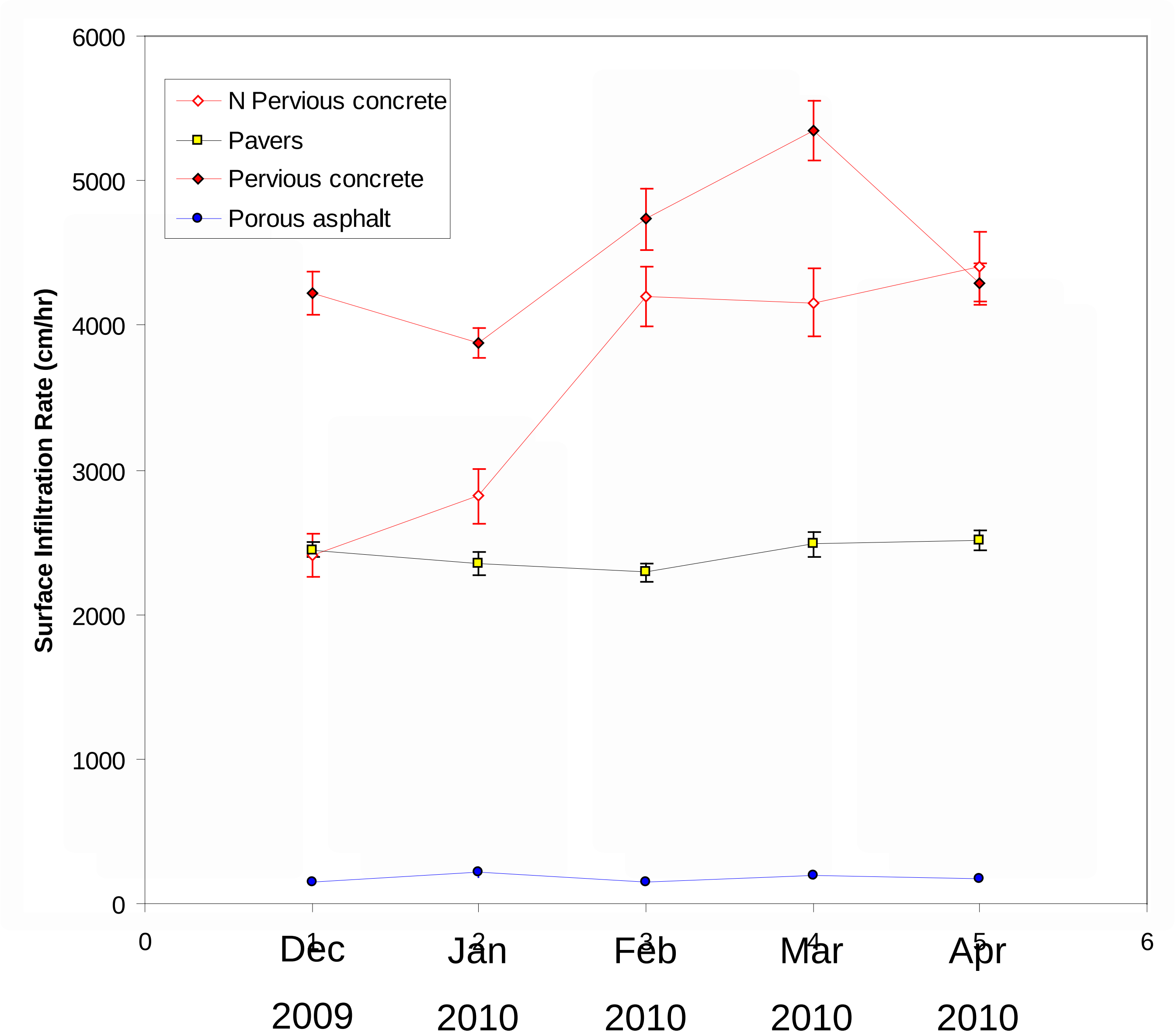
NSQD median for commercial property 7.3

Initial Surface Infiltration Rates

Modified ASTM C1701 apparatus

Surface type	Initial surface infiltration rate (cm/hr ± 1SD)	Literature reported infiltration rate (cm/hr)
PICP	2440 ± 305	2000 (Bean et al., 2007)
PC	4220 ± 876	4000 (Bean et al., 2007)
PA	147 ± 43	430 (Ferguson, 2005)

Surface Infiltration Rates

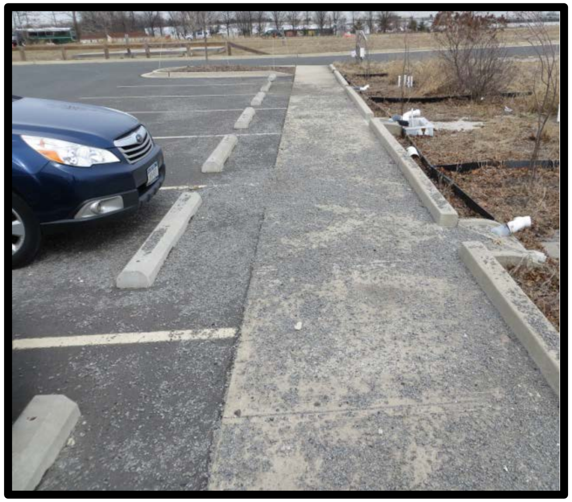


EPA (2010)

Sediment accumulates (*and clogging progresses*) from the upgradient edge.

Large portions of the pervious concrete disaggregated.

The problem first became apparent about 18 months after pouring concrete. It was repaired by the contractor in May 2011, but has recurred.



NRMCA revised O&M guidance (2015)

“Deicing chemicals should not be used on any type of concrete in the first year.”

Rain Garden Demonstration Site

This site demonstrates and allows EPA to document the capabilities of rain gardens to allow stormwater to seep, or infiltrate, into underlying soil where it will eventually recharge groundwater and nearby streams. Infiltration of stormwater in rain gardens serves to reduce stormwater runoff volumes, improve water quality through removal of stormwater contaminants, and enhance the physical and biological integrity of streams.

Research

Stormwater runoff from Building 205 and the adjacent parking lot is directed through a pipe and curb cuts into the rain garden. The rain garden has six cells of different sizes separated by walls, allowing researchers to study how size affects the ability of rain gardens to infiltrate stormwater runoff created by a wide range of storm sizes. Instruments buried in the media and underlying soil measure how quickly runoff infiltrates through the rain garden profile into the underlying soil.

Results

The rain garden will help EPA study:

- How rain gardens mimic natural drainage processes and reduce stormwater runoff volume to the conventional storm sewer system.
- The effects of surface area on drainage properties of rain gardens.

Acknowledgements

This project is a joint research effort between EPA's Office of Administration and Resources Management, Region 2, and the Office of Research and Development.

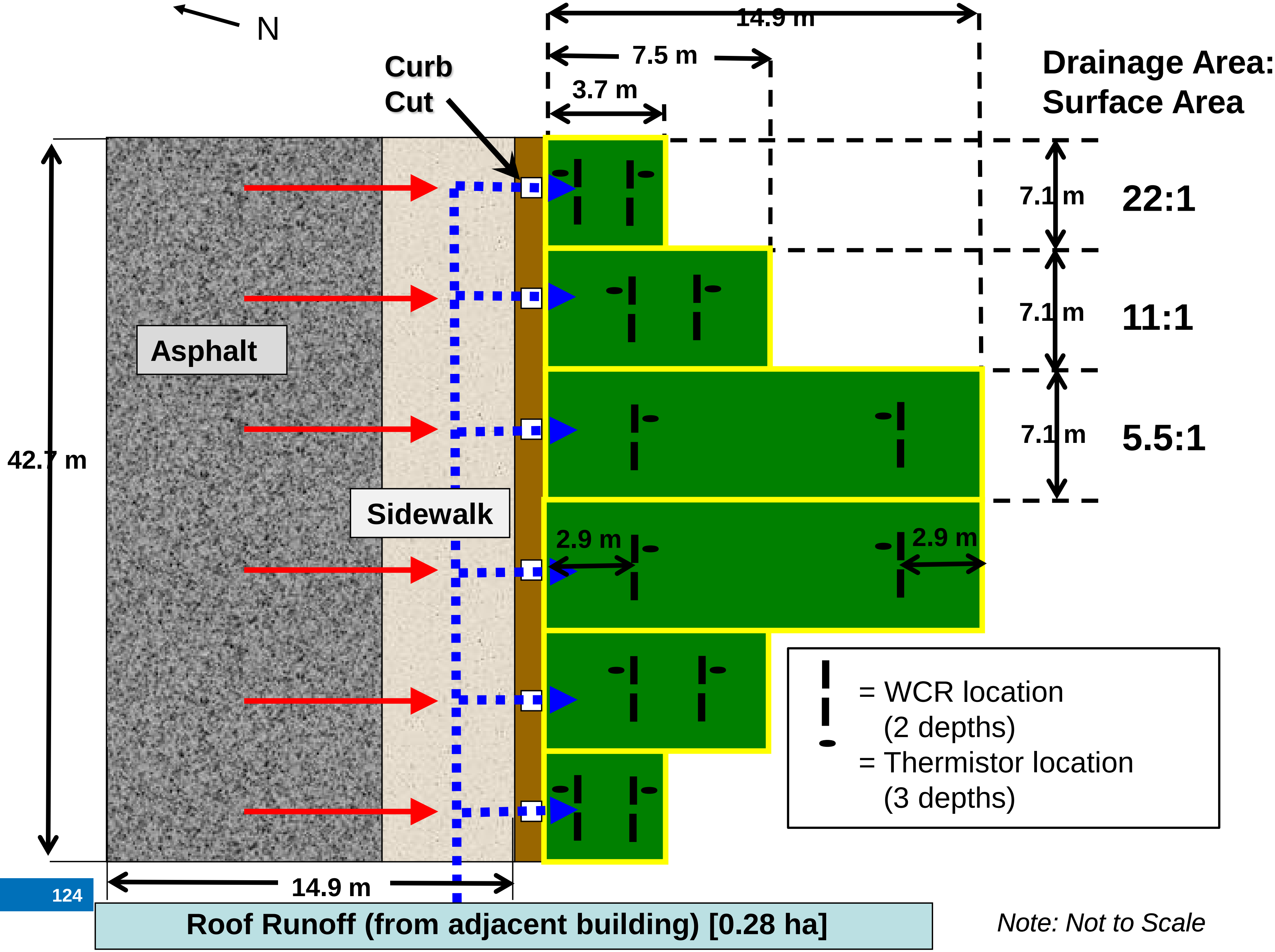
Native Plants for Mid-Atlantic Rain Gardens

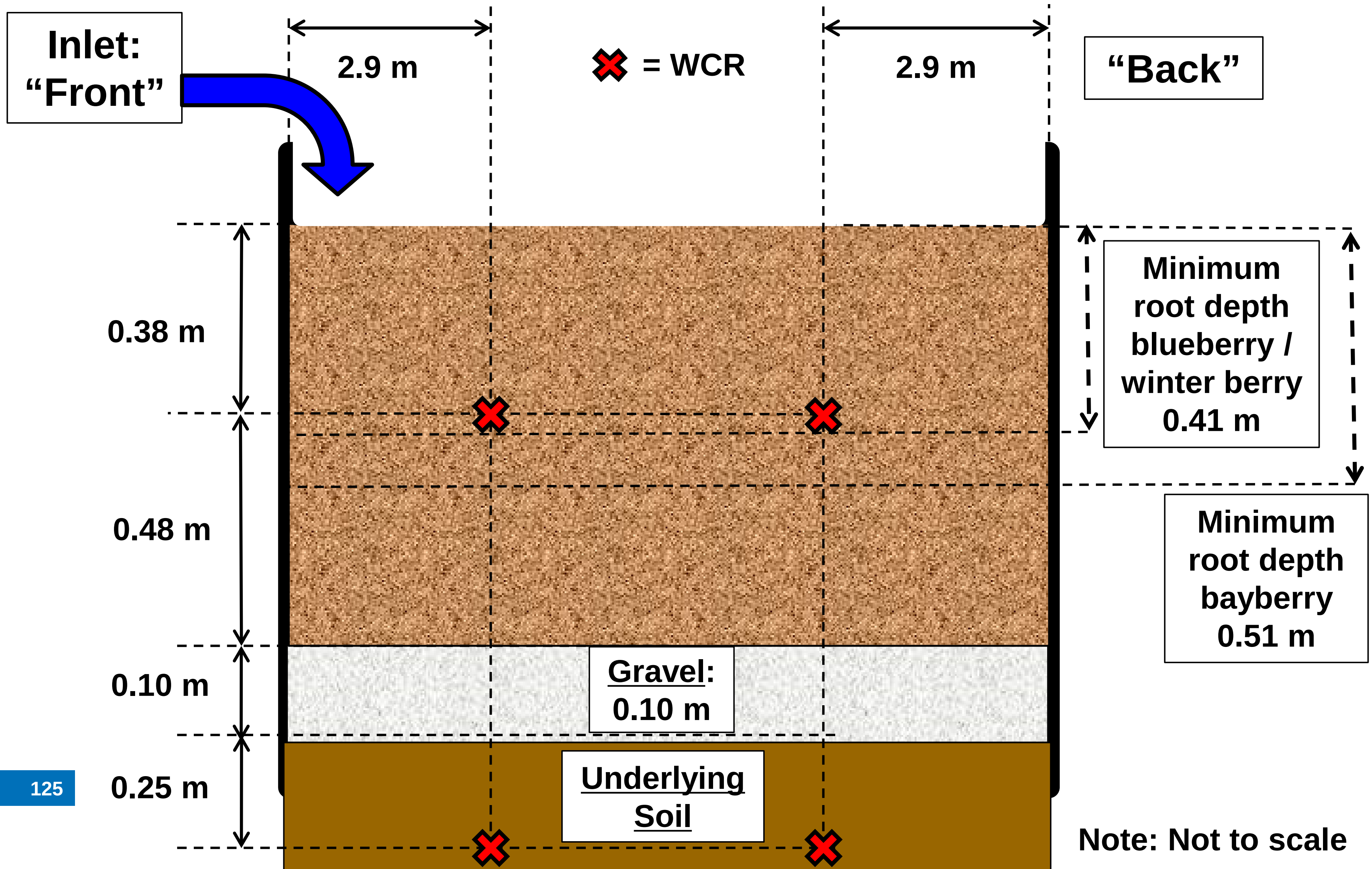
Trees
Red Maple
Redosier
Dogwood

Grasses/Rushes
Switchgrass
Indian Grass
Big Bluestem
Common Rush

Shrubs
Highbush Blueberry
Beach Plum
Winterberry
Black Chokeberry
Groundsel Tree

Herbs
Seaside Goldenrod
Blue Flag
Sunflower
Golden Zizia


N
Curb
Cut
14.9 m
7.5 m
3.7 m
Drainage Area:
Surface Area
7.1 m
22:1
7.1 m
11:1
7.1 m
5.5:1
Asphalt
Sidewalk
42.7 m
2.9 m
2.9 m
= WCR location
(2 depths)
= Thermistor location
(3 depths)
14.9 m
Roof Runoff (from adjacent building) [0.28 ha]
Note: Not to Scale

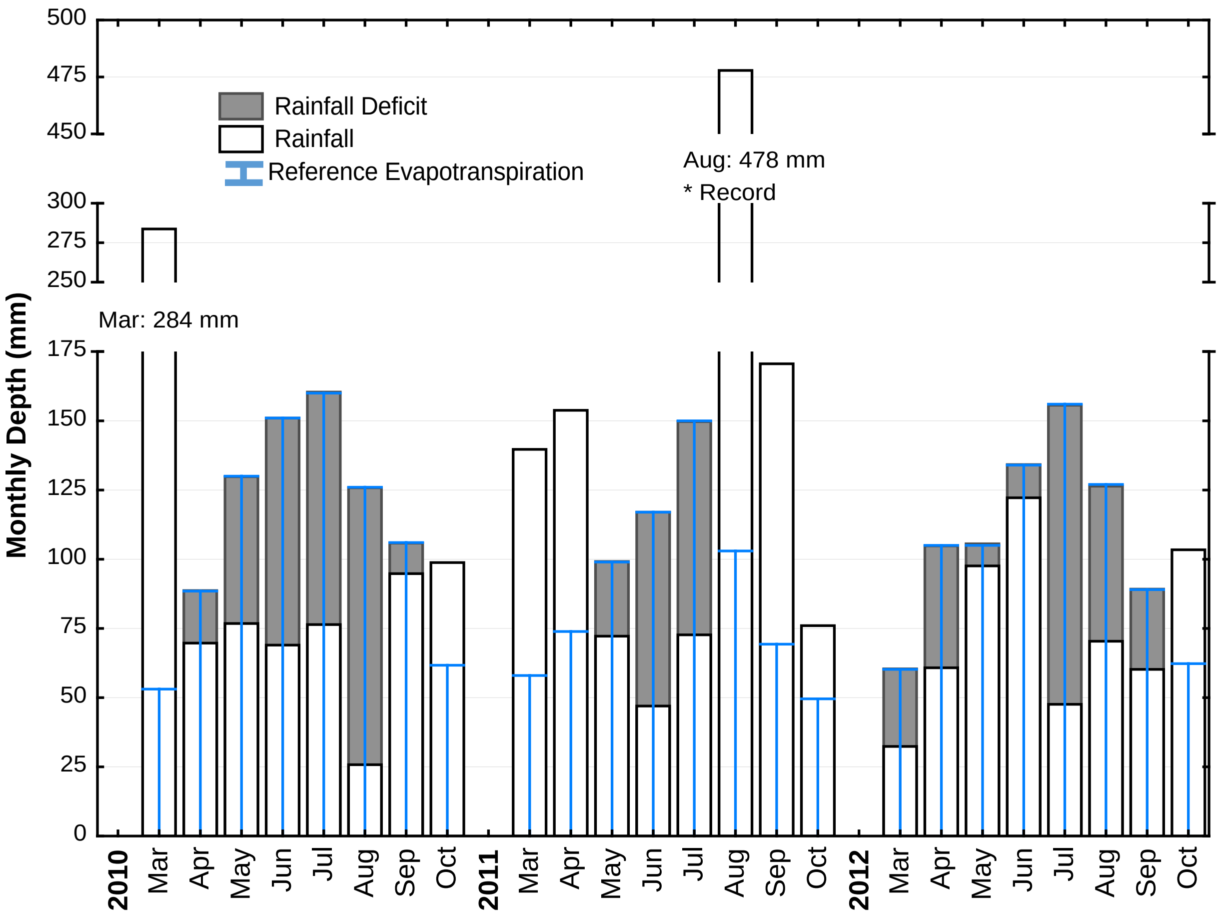

Inlet:
"Front"
2.9 m
= WCR
2.9 m
"Back"
0.38 m
0.48 m
0.10 m
0.25 m
Minimum root depth blueberry / winter berry 0.41 m
Minimum root depth bayberry 0.51 m
Gravel: 0.10 m
Underlying Soil
Note: Not to scale

Rain gardens over time

Number of shrubs per rain garden

Rain Garden Number	Rain Garden Unit Size	Location	Number Measured (Planted)		
			Bayberry	Blueberry	Winter-berry
1	Small	West	1 (1)	1 (1)	2 (2)
2	Medium	West	3 (3)	3 (3)	6 (6)
3	Large	West	9 (11)	9 (11)	6 (7)
4	Large	East	9 (11)	11 (11)	6 (7)
5	Medium	East	3 (3)	1 (3)	5 (6)
6	Small	East	1 (1)	1 (1)	2 (2)

Rainfall and reference crop evapotranspiration for EEC

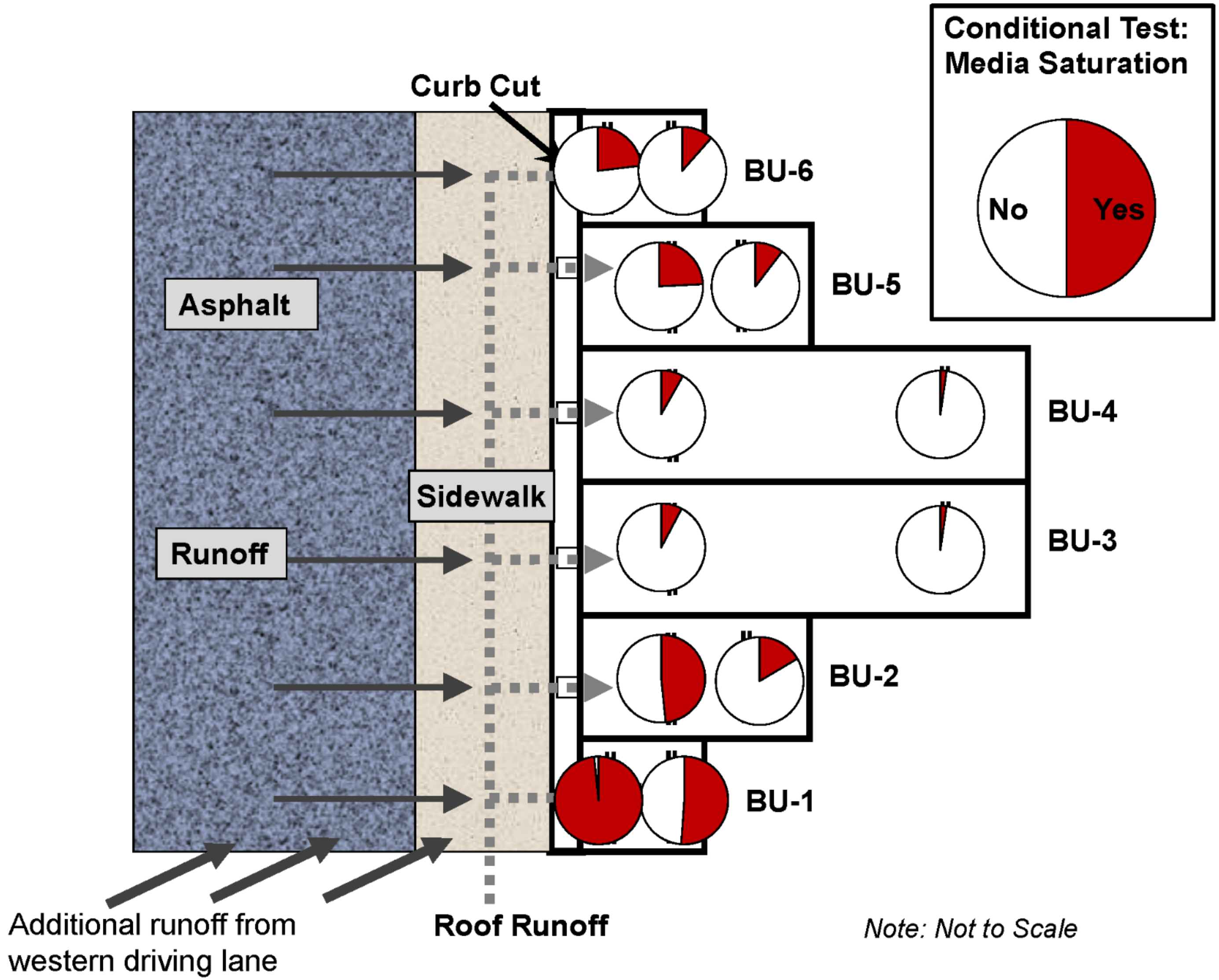


WCR monitoring locations media saturation

91 events analyzed with complete data from all WCR locations.

Period: 2010-2012 growing seasons (April to October)

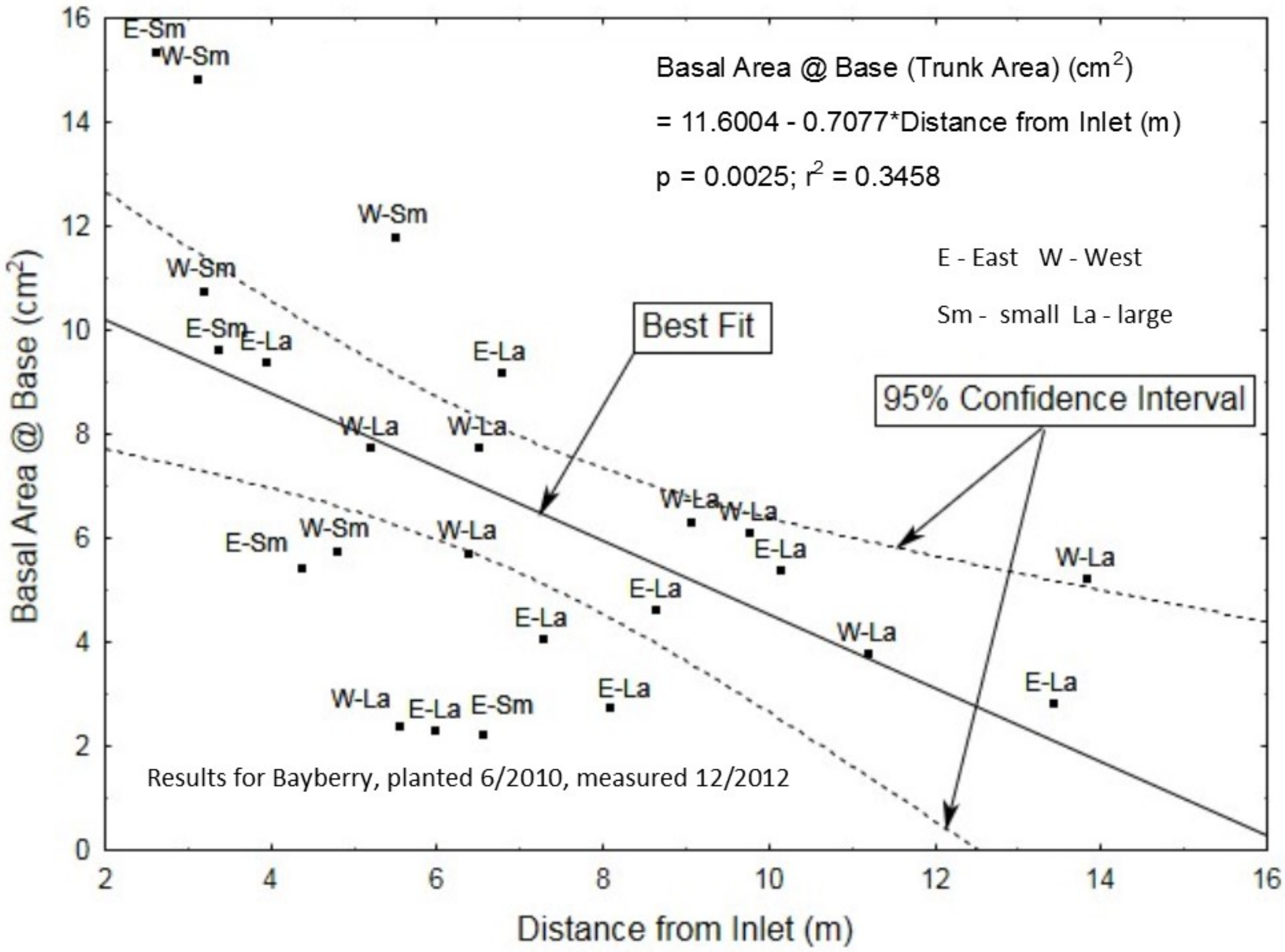
When saturation not frequent, the change in soil moisture was attributed to direct rainfall.



Plant growth assessment

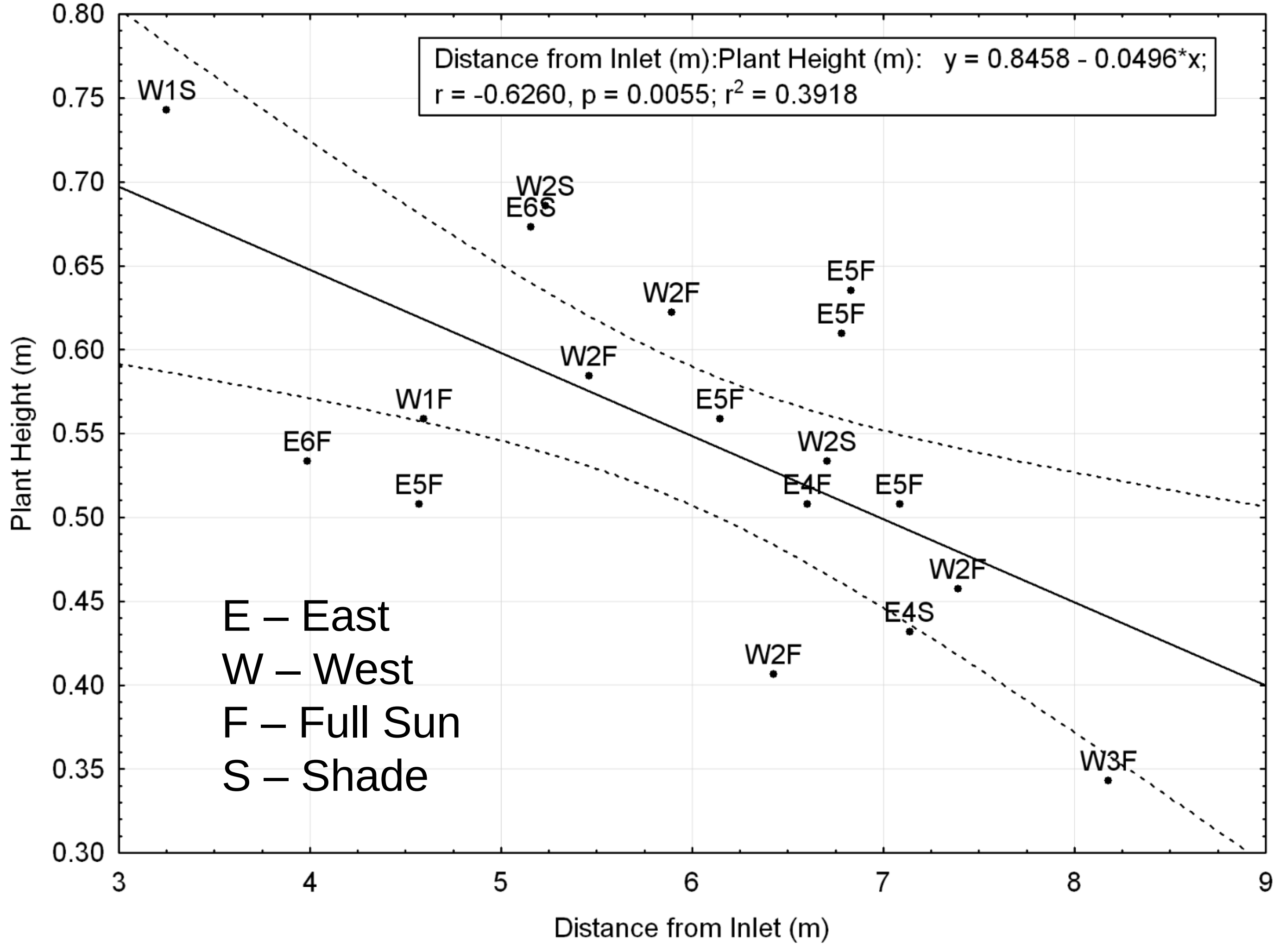
- Measure height
- Measured diameter for modified Basal area
- Assessed shading

Bayberry growth closer to inlet and in smaller rain gardens better than large

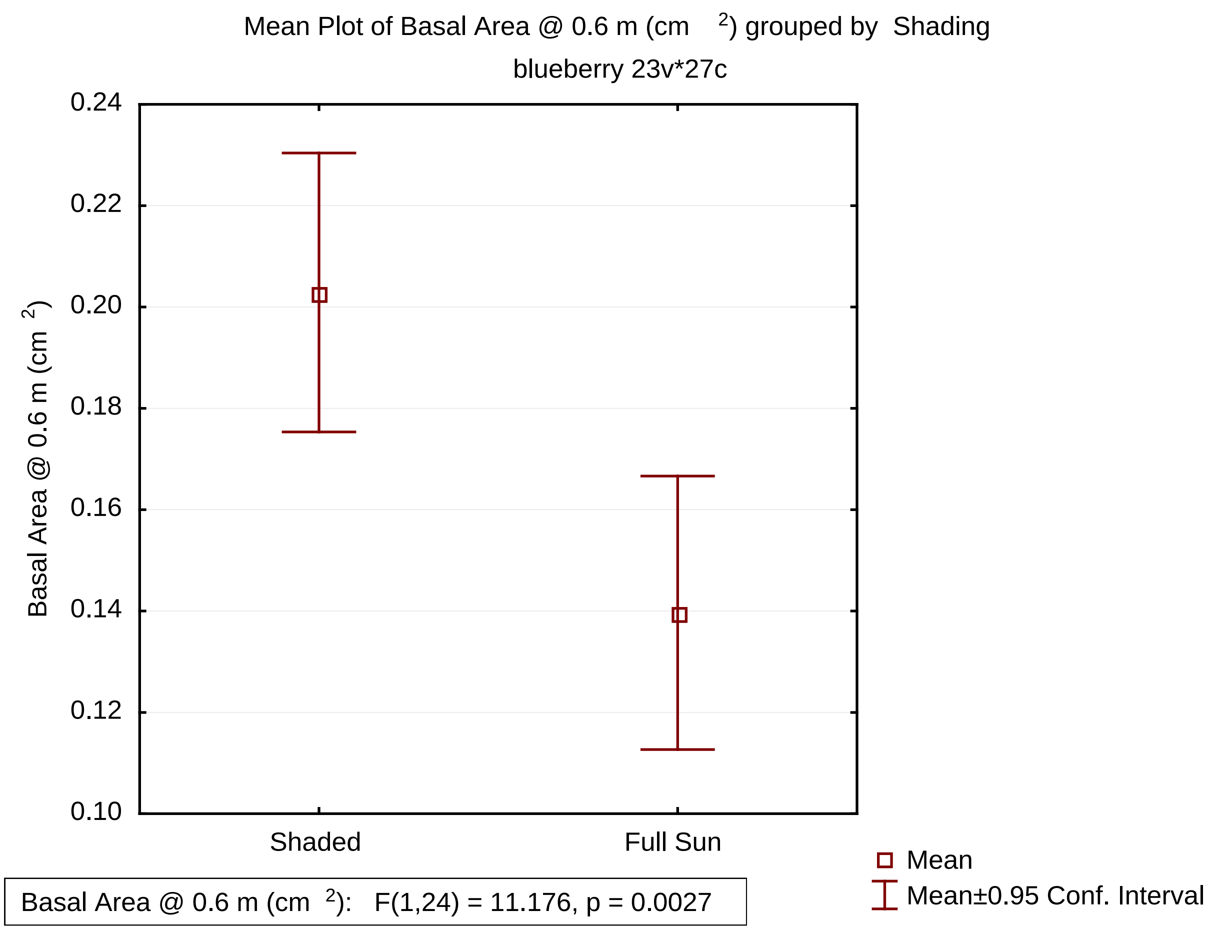


Winterberry height closer to inlet and in smaller rain gardens better than large

Also effect of shading



Blueberry growth in shade better than full sun



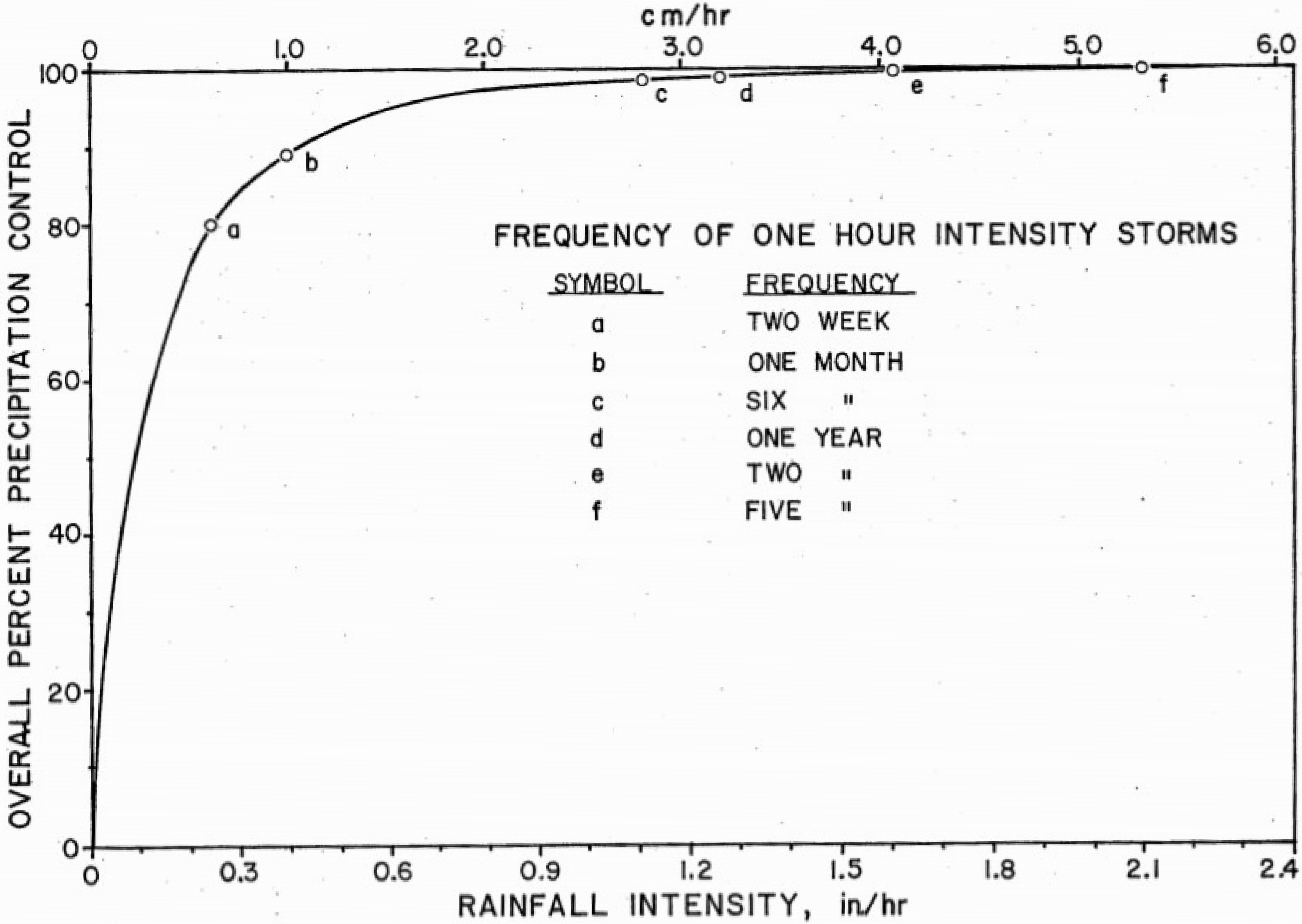


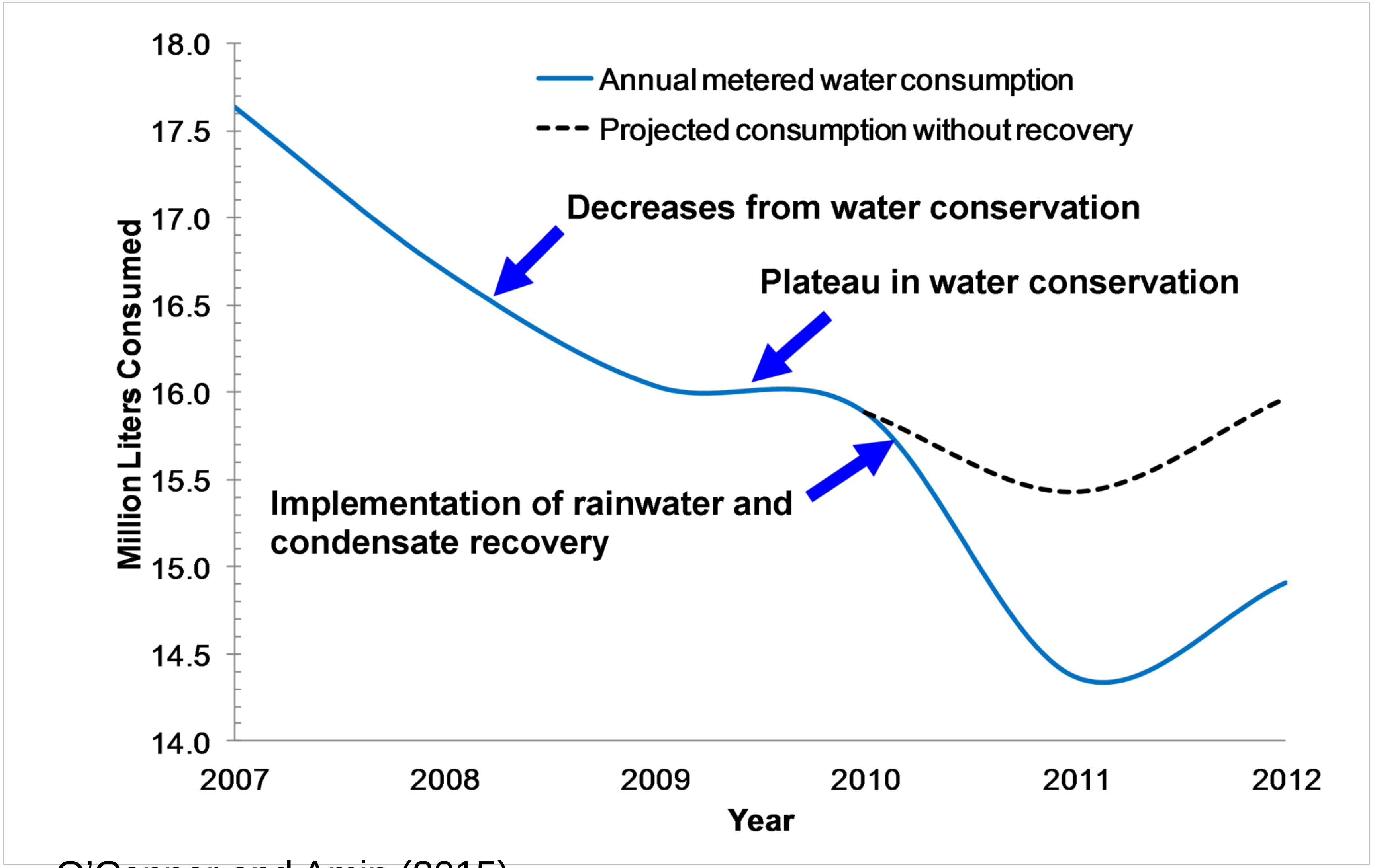
Figure I-2. Overall Percent Precipitation Control vs Rainfall Intensity – Atlanta, GA (1948-1972)

EPA (1977)

Rainwater Harvesting at EEC

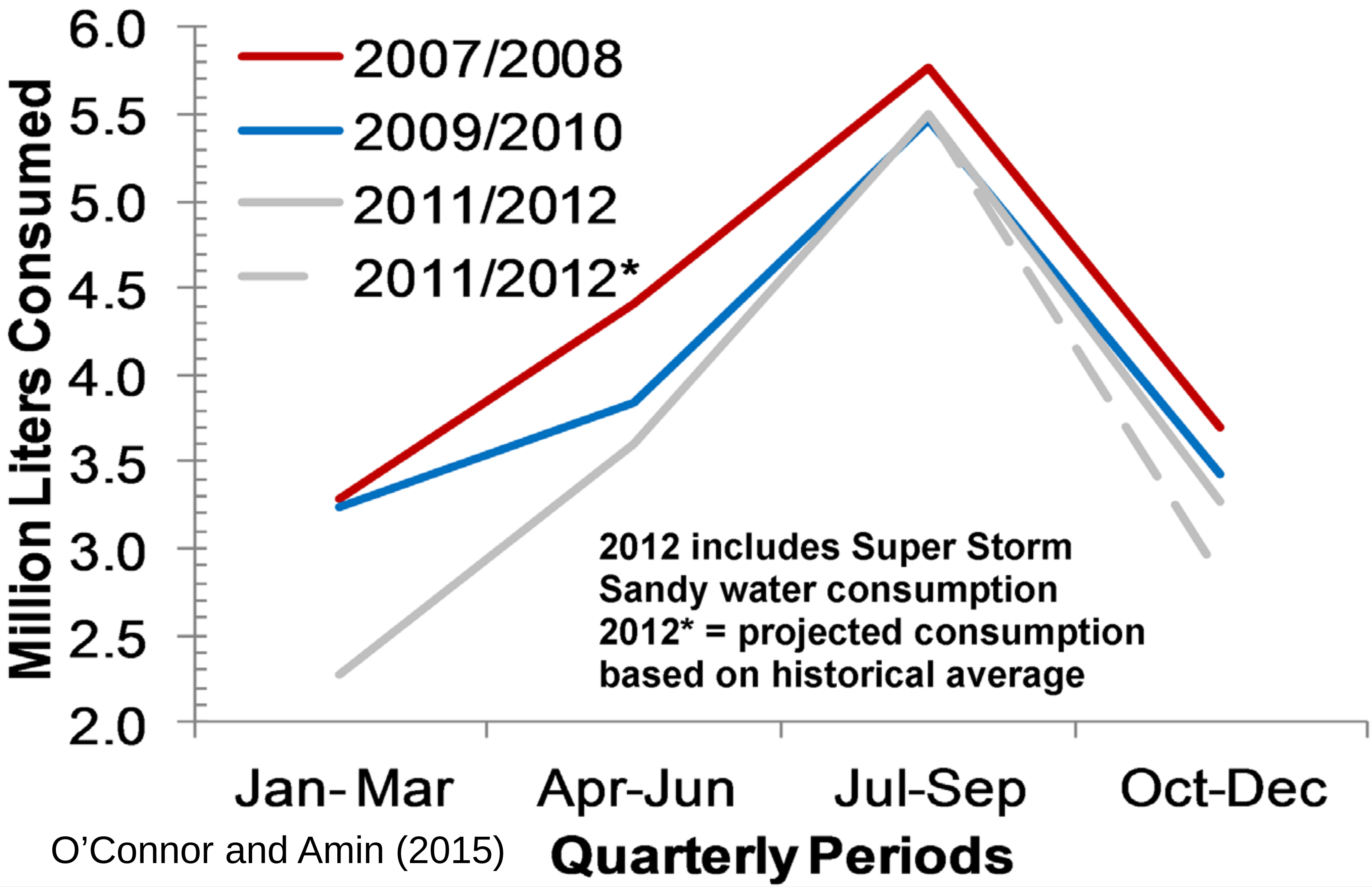
- Laboratory cooling tower is largest consumer of water at EEC
- Peak demand exceeds 4,000 gallons per day
- Rainwater from three 1,500 gallon tanks now supplements demand

EEC Annual Water Consumption



O’Connor and Amin (2015)

EEC Quarterly Water Consumption



O'Connor and Amin (2015)

United States Environmental Protection Agency

Current work

- Updating results on parking lot
- Publishing results on semi-volatiles organic compounds (SVOCs) in parking lot infiltrate
- Continuing SVOC sampling
- Monitoring microorganisms in parking lot infiltrate
- Monitoring green infrastructure at different sites

Journal Articles

- R. Brown, T. P. O’Connor and M. Borst (2015). “Divergent Vegetation Growth Patterns Relative to Bioinfiltration Unit Size and Plant Placement” ASCE’s Journal of Sustainable Water in the Built Environment (JSWBE), Vol. 1, No. 3. (http://ascelibrary.org/doi/abs/10.1061/JSWBAY.0000796)
- T. P. O’Connor and M. Amin (2015). “Rainwater Collection and Management from Roofs at the Edison Environmental Center” ASCE's JSWBE, Vol. 1, No. 1. (http://ascelibrary.org/doi/abs/10.1061/JSWBAY.0000792)
- E. Stander, A. A. Rowe, M. Borst and T. P. O'Connor (2013). "Novel Use of Time Domain Reflectometry in Infiltration-Based Low Impact Development Practices" ASCE's Journal of Irrigation and Drainage Engineering (JIDE), Vol 139, No. 8, pp. 625–634 (http://dx.doi.org/10.1061/(ASCE)IR.1943-4774.0000595).
- T. P. O'Connor. “Explanation for Anomalous Readings during Monitoring of a Best Management Practice” ASCE's JIDE, Vol. 136, No. 8, pp. 527-531, 2010 (http://dx.doi.org/10.1061/(ASCE)IR.1943-4774.0000251)
- A. Selvakumar, T. P. O'Connor, and S. D. Struck “Role of Stream Restoration on Improving Benthic Macroinvertebrates and In-stream Water Quality in an Urban Watershed - a Case Study” ASCE’s Journal of Environmental Engineering, Vol. 136, No. 1, pp. 127 -139, 2010 (http://dx.doi.org/10.1061/(ASCE)EE.1943-7870.0000116)
- T. P. O’Connor and J. Rossi “Monitoring of a Best Management Practice Wetland Before and After Maintenance” ASCE's Journal of Environmental Engineering, Vol. 135, No. 11, pp. 1145 -1154, 2009. (http://dx.doi.org/10.1061/(ASCE)0733-9372(2009)135:11(1145))
- England, R. (2001) “Success Stories of Brevard County, Florida Stormwater Utility” ASCE’s Journal of Water Resources Planning and Management, Vol 127, No. 3, pp. 180-185 (http://dx.doi.org/10.1061/(ASCE)0733-9496(2001)127:3(180))

EPA Reports

- Green Roofs for Stormwater Runoff Control (EPA/600/R-09/026) (http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1003704.txt)
- Evaluation of Receiving Water Improvements from Stream Restoration (Accotink Creek, Fairfax City, Virginia) (EPA/600/R-08/110) (http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1001Q83.txt)
- EPA (1977) “Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges: Volume II: Cost Assessment and Impacts” (EPA-600/2-77-064b) http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=300003OL.txt
- Surface Infiltration Rates of Permeable Surfaces: Six Month Update (EPA/600/R-10/083) (http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1008CH4.txt)
- Evaluation of Green Roof Plants and Materials for Semi-Arid Climates http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100ECC8.txt
- Stormwater Best Management Design Guide
  - (EPA/600/R-04/121) (http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=901X0A00.txt)
  - (EPA/600/R-04/121A) (http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=901X0B00.txt)
  - (EPA/600/R-04/121B) (http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=2000D1L8.txt)

Other Resources

- NRC (2009). “Urban Stormwater Management in the United States” National Research Council (NRC). Washington, D.C., The National Academies (http://www.nap.edu/openbook.php?record_id=12465)

- EPA Green infrastructure (GI) page: (http://water.epa.gov/infrastructure/greeninfrastructure/)

- EPA Science Matters Newsletter: Green Infrastructure Research

  (http://www2.epa.gov/water-research/epa-science-matters-newsletter-green-infrastructure-research)