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OSU Center for Urban &amp; Regional Analysis – Columbus, OH – 17Apr18

# Green Infrastructure & Ecosystem Services: The Future of Stormwater Management

William F. Hunt

WNR Dist. Univ. Professor & Extension Specialist

Bio & Ag Engineering – NC State University

[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)



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Please get to know this guy...

Ryan Winston, OSU F&B  
@ Old Woman Creek, Lake Erie



[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)

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## Example Ecosystems: Mountain Creek



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## Example Ecosystems: Tidal marsh



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## Example Ecosystems: Suburban Backyard Stream

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## Parking Lot Runoff ????

[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)

## Stormwater Green Infrastructure are also created Ecosystems



Level spreader-filter strip



Green roofs



Bioretention cells



Constructed wetlands

[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)

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### Ecological Economics

Volume 41, Issue 3, June 2002, Pages 393–408



SPECIAL ISSUE: The Dynamics and Value of Ecosystem Services: Integrating Economic and Ecological Perspectives

## A typology for the classification, description and valuation of ecosystem functions, goods and services

Rudolf S de Groot<sup>a,\*</sup>, Matthew A Wilson<sup>b,1</sup>, Roelof M J Boumans<sup>a,1</sup>

Ecosystem Services: The benefits  
people obtain from ecosystems.

### Abstract

An increasing amount of information is being collected on the ecological and socio-economic value of goods and services provided by natural and semi-natural ecosystems. However, much of this information appears scattered throughout a disciplinary academic



REGULATION SERVICES		Estimated value (1994 US \$/ac <sup>2</sup> yr <sup>2</sup> )
<b>Water quality</b>		
<b>Erosion control and sediment retention</b>		
<b>Waste treatment</b>		
<b>Nutrient cycling</b>		
<b>Hydrologic regulation</b>		
<b>Climate regulation</b>		
PRODUCTION SERVICES		
<b>Food production</b>		
<b>Raw materials</b>		
INFORMATION SERVICES		
<b>Recreation</b>		

All of these  
have Value

## Green Infrastructure & ecosystem services

- Green Infrastructure designed for 2 important ecosystem services: water treatment and hydrologic regulation
- May also provide other societal benefits:
  - Carbon sequestration
  - Air quality regulation
  - Microclimate regulation
  - Habitat provision and biodiversity maintenance
  - Food and material provision
  - Recreation, educational, and aesthetic opportunities

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## The Basics: Flood Mitigation



[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)

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## The Basics: Erosion Control & Sediment Retention



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## Volume Mitigation at a Commercial Site



Sources: Google Maps

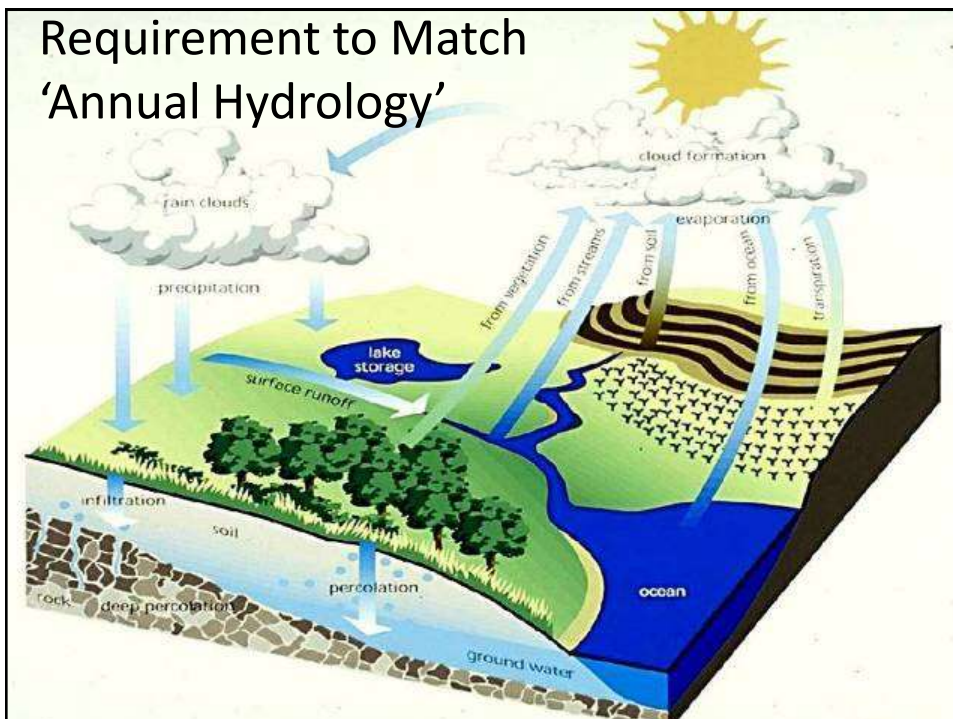
### Low Impact Development Site (Market at Colonnade)

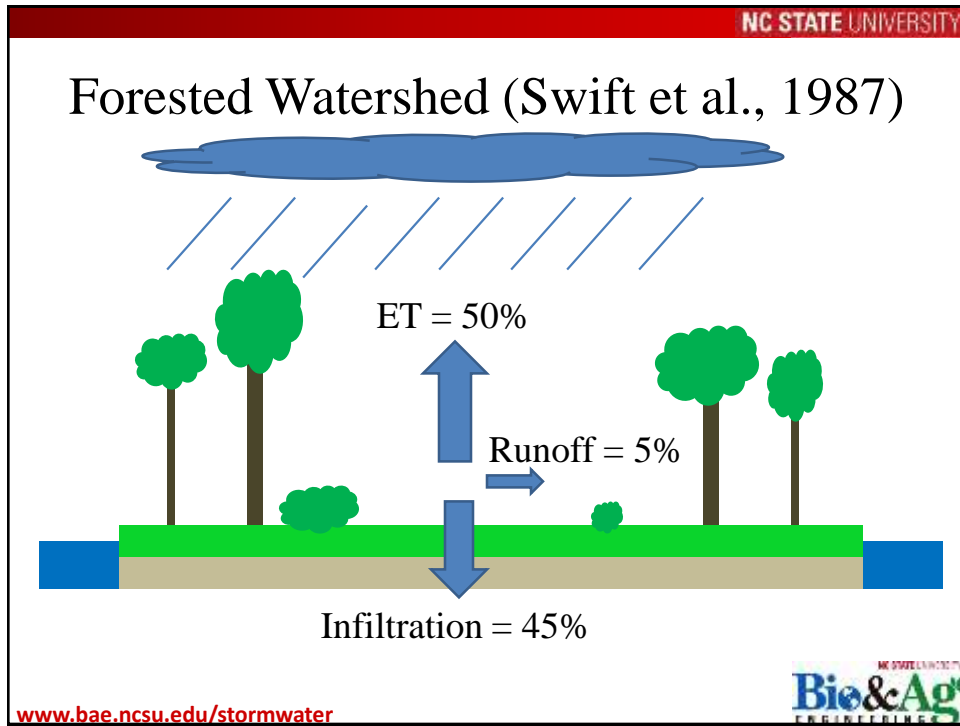
- 2.53 hectares
- 84% Impervious
- Treatment via ISMP

### Conventional Development Site

- 2.76 hectares
- 65% Impervious
- Treatment via Dry Detention

## Requirement to Match 'Annual Hydrology'







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## Site Layout: LID

(above & below ground stormwater harvesting)



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## Site Layout: LID

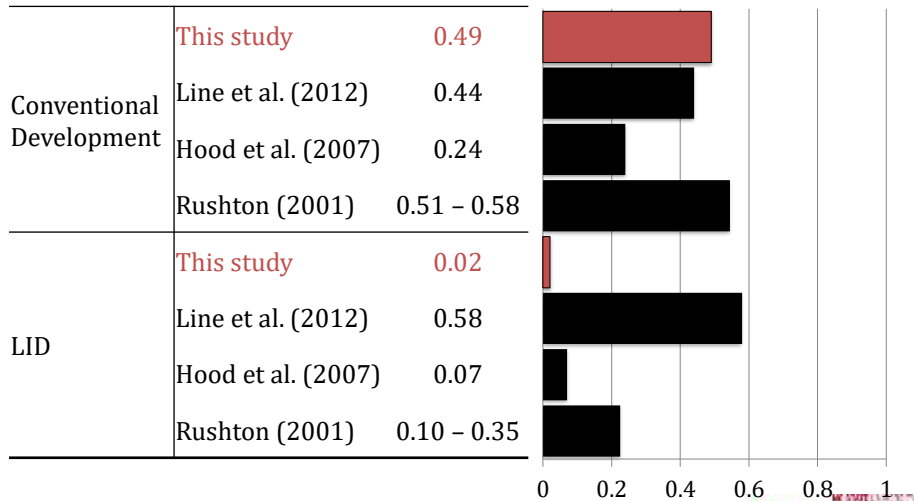
Underground  
detention/infiltration  
system



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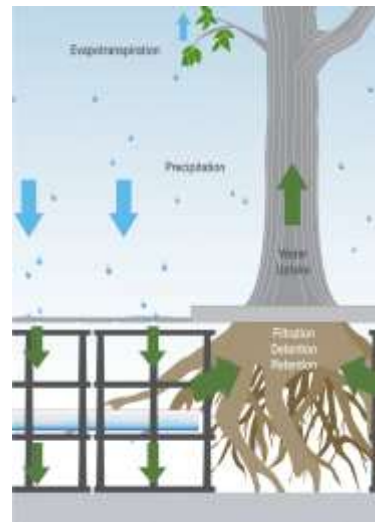
## Hydrology: Runoff coefficient



[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater) Wilson et al. 2015, JEE, (Feb Issue)

## Sending Stormwater to Street Trees

- System designed for stormwater management
  - Runoff routed from street surface
  - Runoff volume (ROv) control
  - Peak discharge (Qp) mitigation
  - Water quality treatment
- Quantify impacts of a tree SCM
  - Hydrology
  - Water quality



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## Example in Clinton, Iowa



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## Installing a Silva Cell in Fayetteville, NC



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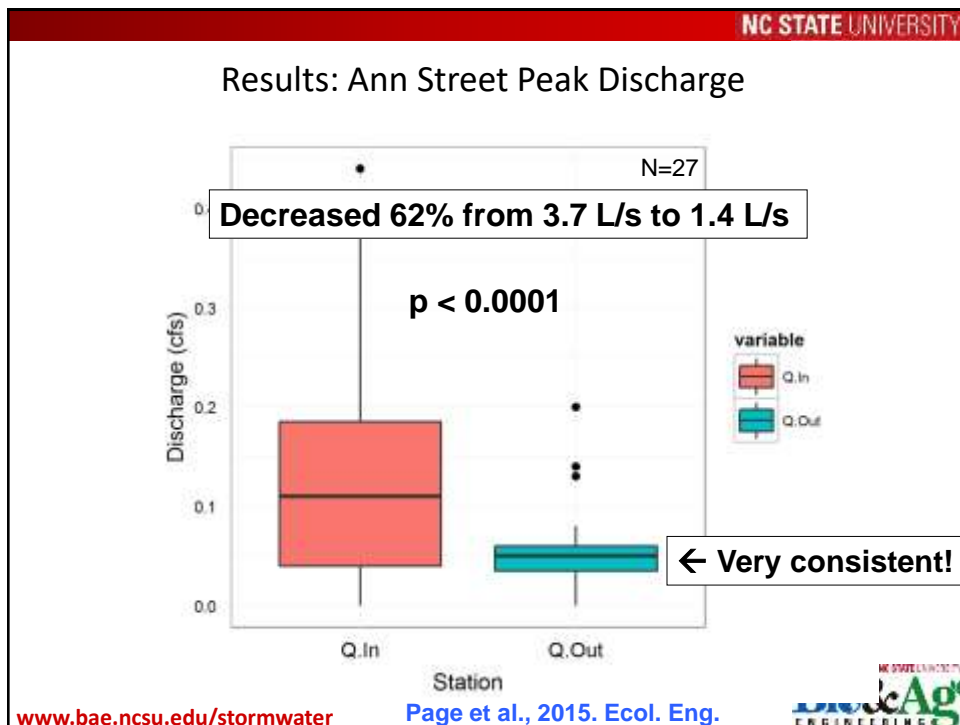
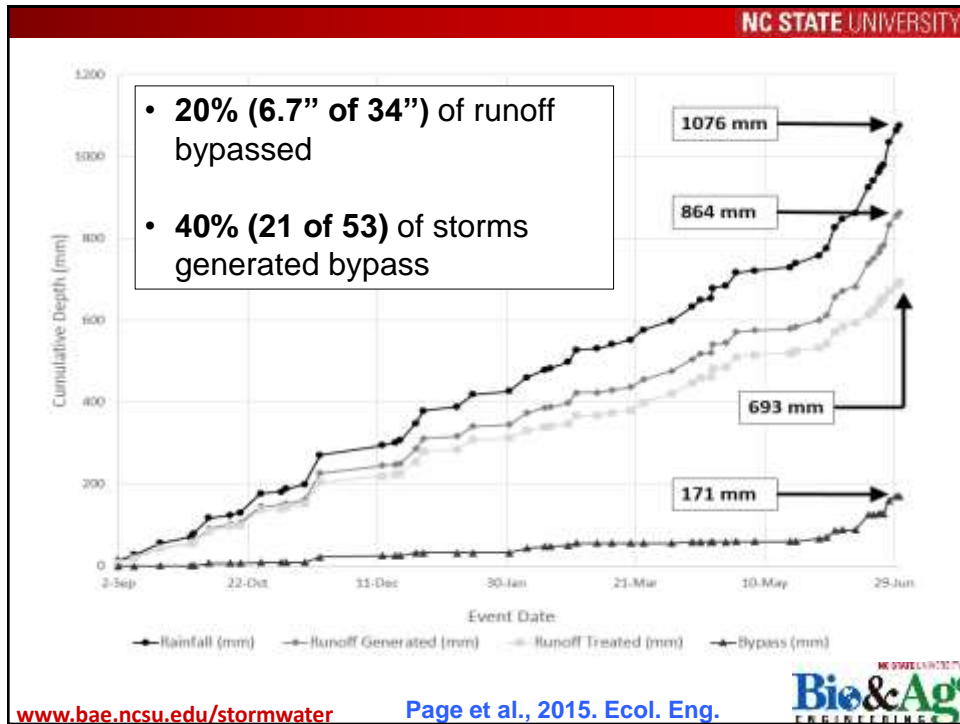


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## “End” Result (in Wilmington)







# Blue Roofs & Green Roofs

Retrieved from the City of Chicago



Retrieved from the USEPA



Retrieved from the NYCDEP



[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)

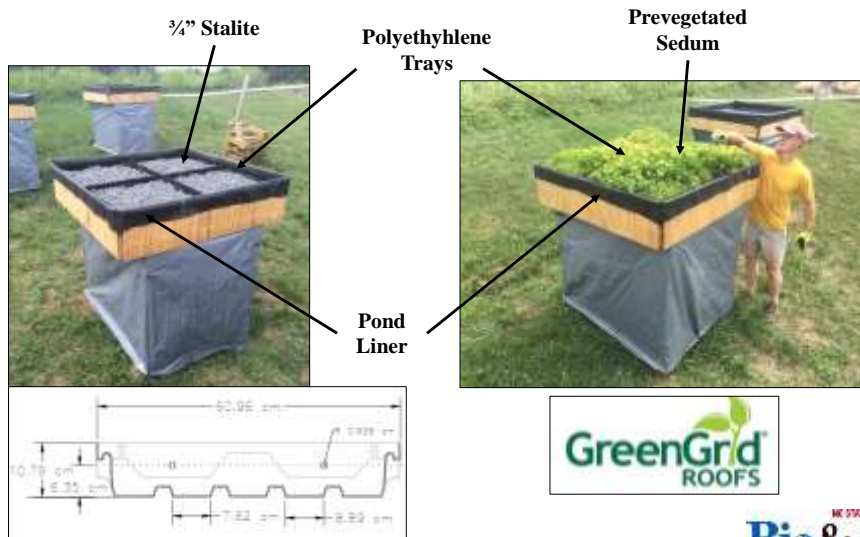
# Project Design



Photo Credit: Dr. Rich McLaughlin

[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)

# Project Design



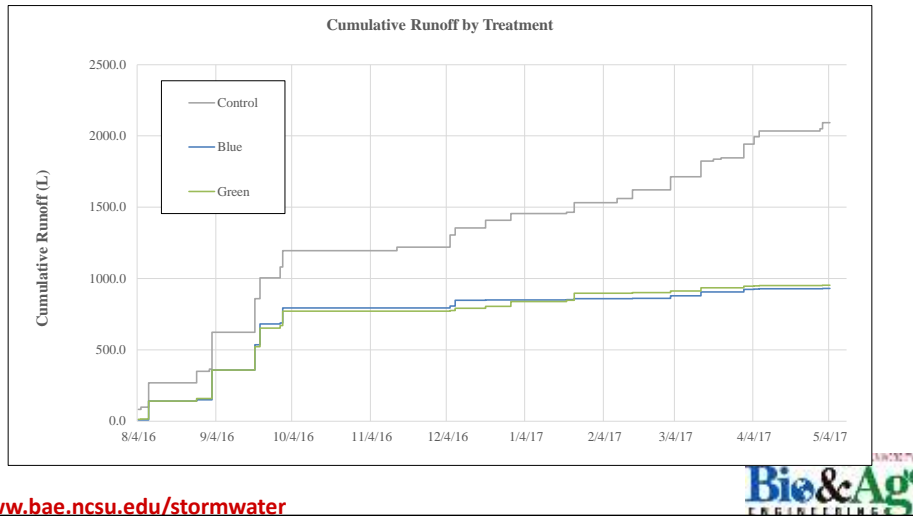
[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)



[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)

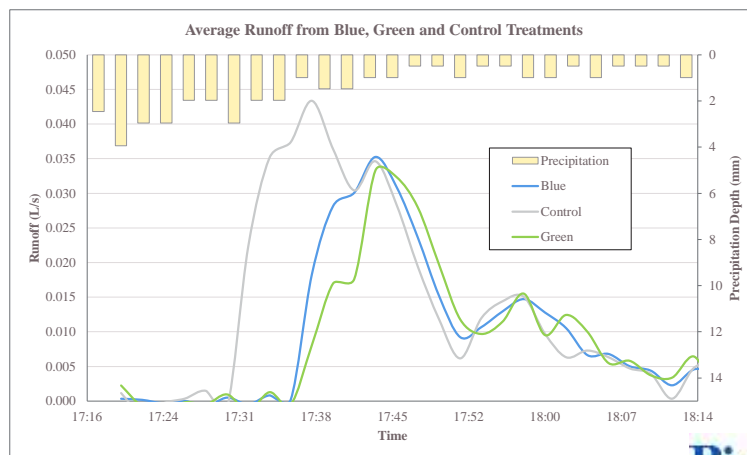
# Water Quantity Results

## Outflow Reduction



# Water Quantity Results

## Peak Flow Mitigation





## The Basics<sup>+</sup>: Nutrient Cycling



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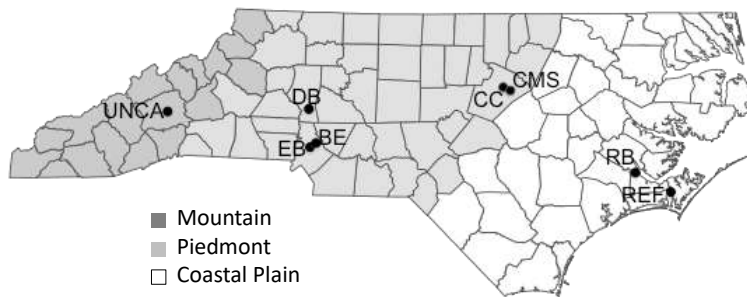
## Constructed Stormwater Wetlands



[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)

## Methods Moore et al. (2011) Ecol. Eng.

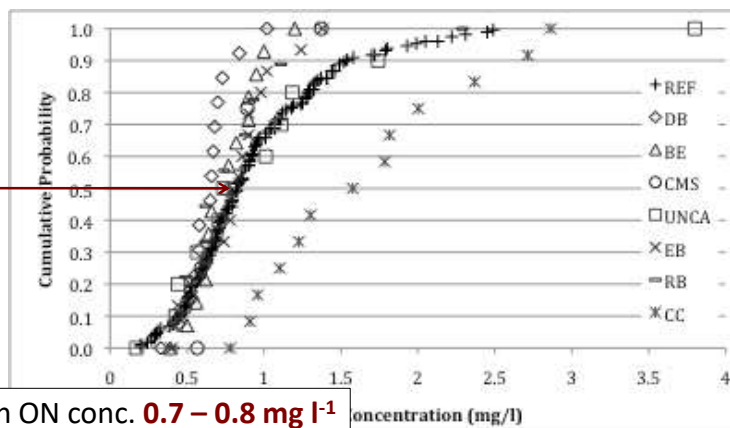
- Analyzed ON event mean concentration data from 7 CSWs and 1 naturally occurring wetland (REF)



[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)

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## Results



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Moore et al. (2011), Ecol. Eng.

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## Back to Blue Roofs & Green Roofs



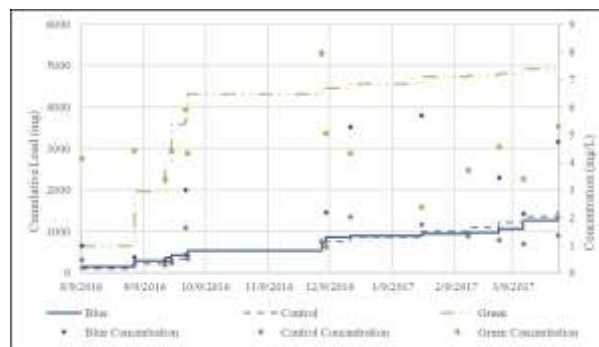
Photo Credit: Katy Conroy

[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)

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## Water Quality Results

Nitrogen Load (*B3 excluded on graph*)



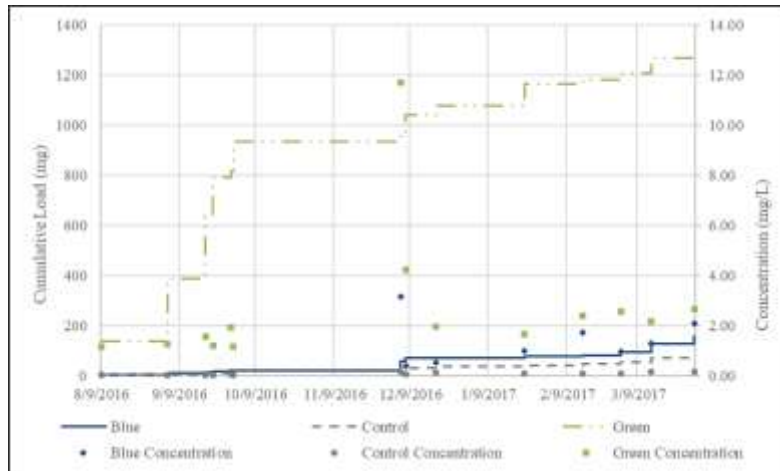
	Cumulative Load (mg)		Load per Area (mg/m <sup>2</sup> )	
	Including B3	Excluding B3	Including B3	Excluding B3
Blue	3600	700	7.0	1.4
Control	1100	-	2.1	-
Green	5000	-	9.7	-

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## Water Quality Results

### Phosphorus



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## The Basics<sup>+</sup>: Waste Treatment



Cuyahoga River, Ohio, 1969 – USEPA photo

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## Pathogens - Problems

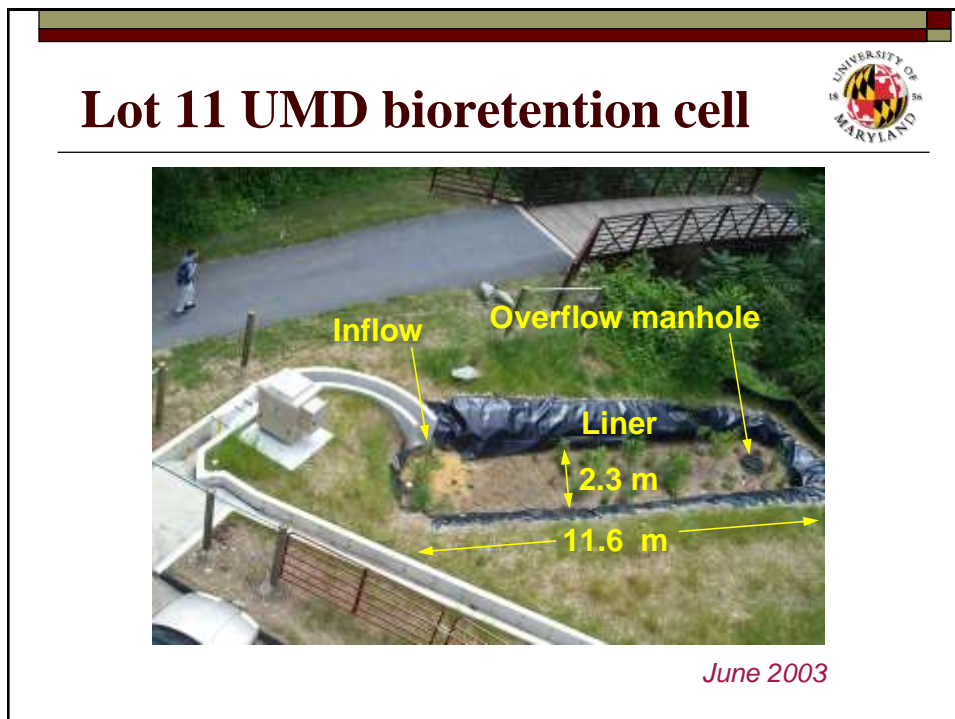
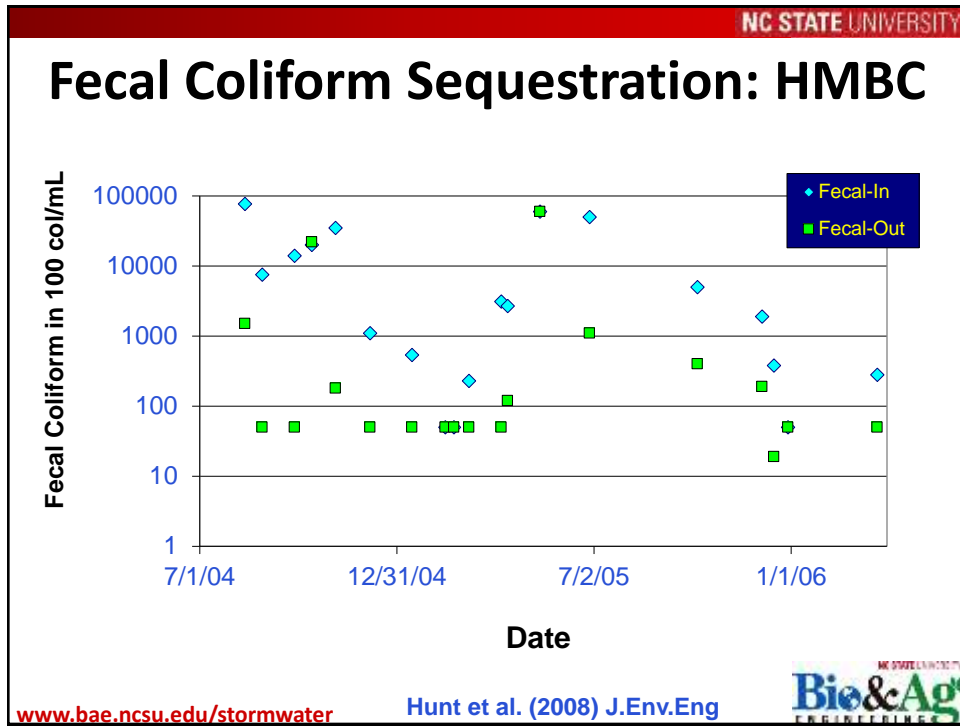


[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)

## Case Study: Bioretention



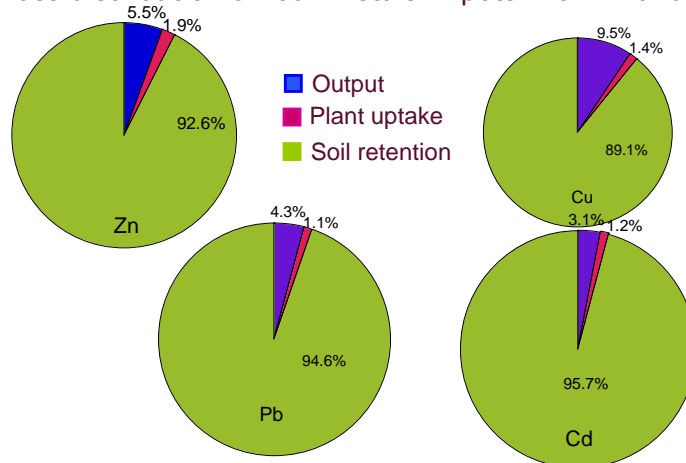
[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)



## Results- Mass Balance



Mass distribution of four metals in pots with PV and low loading



Majority of metals stay in the soil. Little is translocated to the plants.

45

Sun & Davis, Chemosphere, 2007

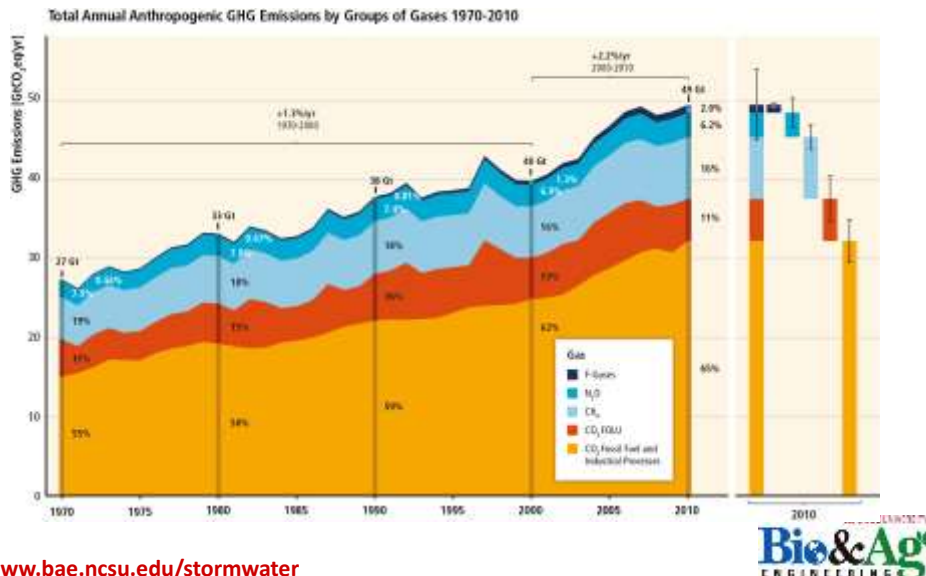
## Why Limit Our Returns to Original Design Intent?

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## For Example... Climate Change Mitigation




- Executive Order 13514:

It is therefore the policy of the United States that Federal agencies shall increase energy efficiency; **measure, report, and reduce their greenhouse gas emissions** from direct and indirect activities; conserve and protect water resources through efficiency, reuse, and **stormwater management**...



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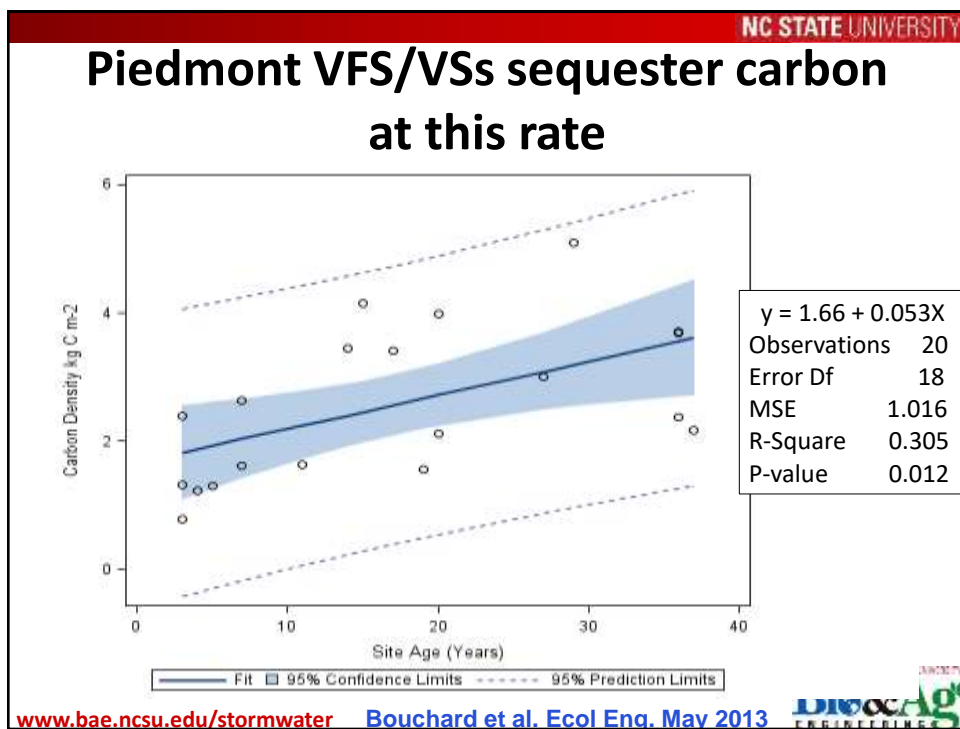
## Vegetated SCMs & Carbon



- Bioretention
- Vegetated Filter Strips
- Swales
- Wet Swales
- Wetlands & Ponds

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## 'Classic' Swale – DOT along I-40

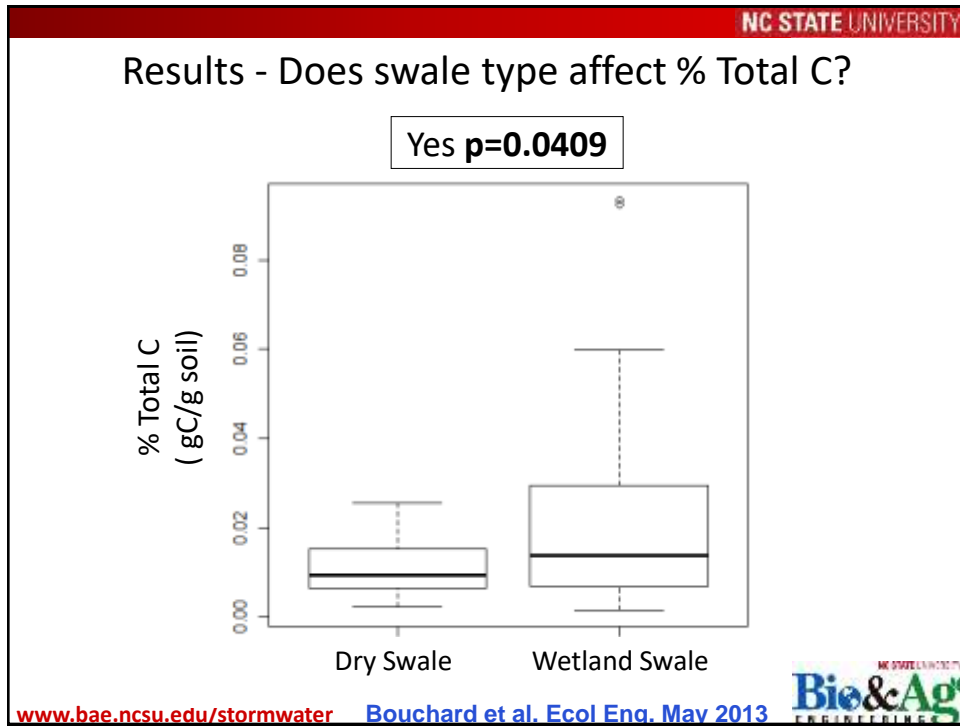


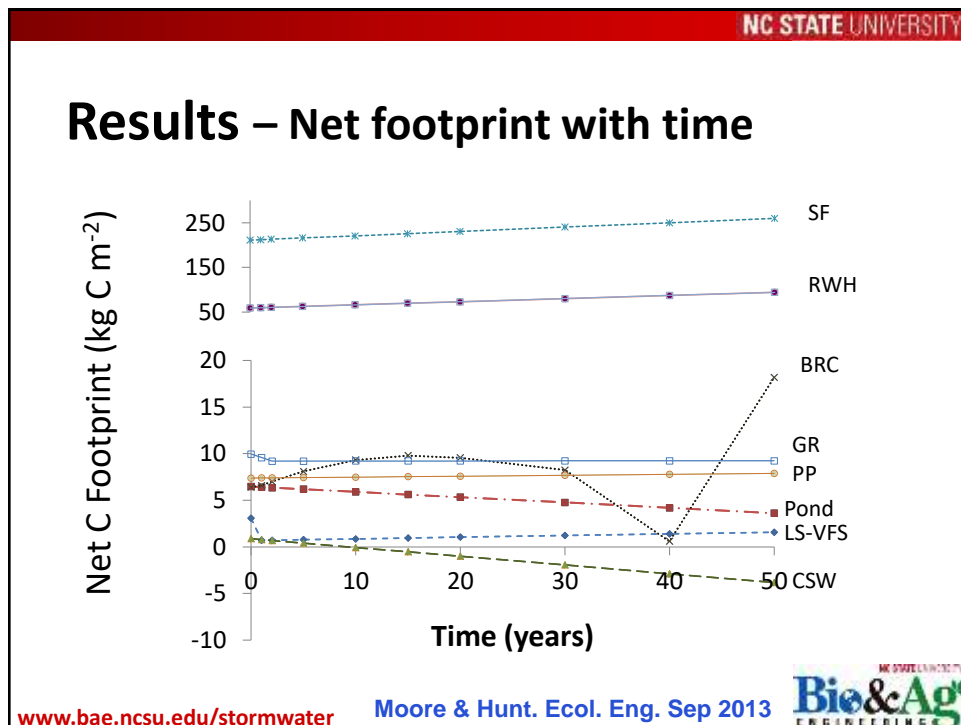
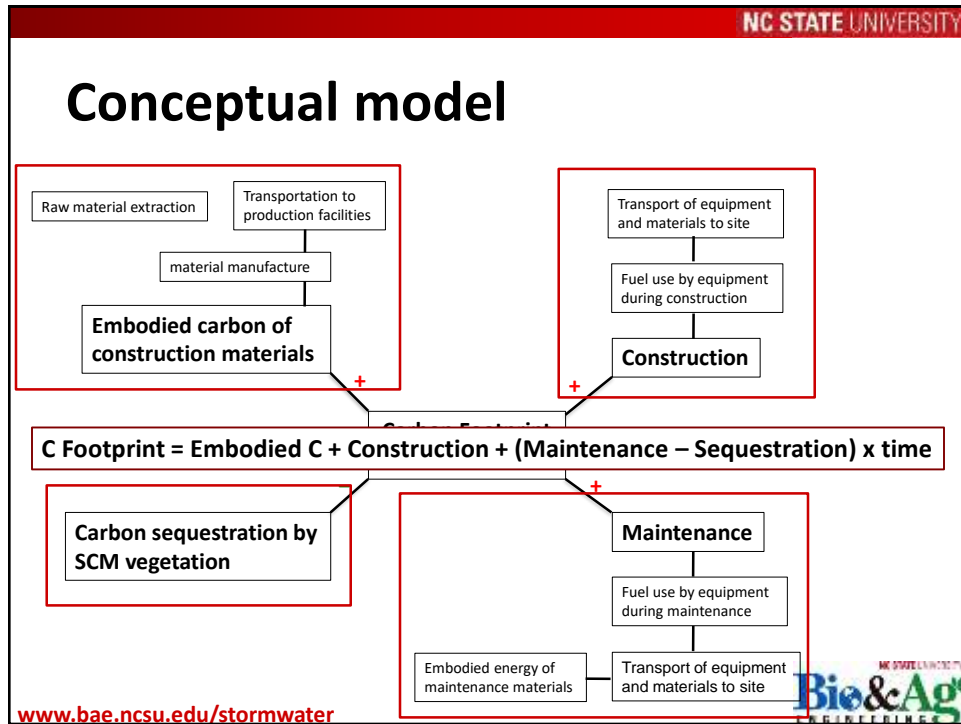
[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)

## Swale Converting to Wetland



[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)







Tree Run



### Patients

[www.bae.ncsu.edu/staff/robertmccoy](http://www.bae.ncsu.edu/staff/robertmccoy)

**Add a new landscape**

To add a new landscape, please choose the type, enter a unique Landscape tag, and click the 'Add' button.

Landscape Type	Landscape Tag
Permeable Pavement	landscape1
Permeable Pavers	
Standard Pavement	
Bombardier	
Planting Bed Trees	
Wetland Wetland	
Concreteness	
Sand Filter	
Level-Sprayer Vegetated Filter Strips	
Green Roof	
Rain Water Harvesting System	
Landscape Area	
Landscape Area	

Landscape Tag: landscape1

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New Run

Previous Runs

Runs

Search in Trees

noCMs duLandscape

landscape + wind

with wind

no wind

View

0:07

Delete

### Carbon Footprint Results

Category	Carbon Footprint	Unit
Materials Embodied Carbon	77522	kg
Construction Generated Carbon	14234	kg
Maintenance Generated Carbon	888	kg per year
Sequestration Generated Carbon	-1788	kg per year
Maintenance Period	20	year
Carbon Emission	106635	kg
Carbon Sequestered	-30779	kg
Carbon Footprint	72856	kg

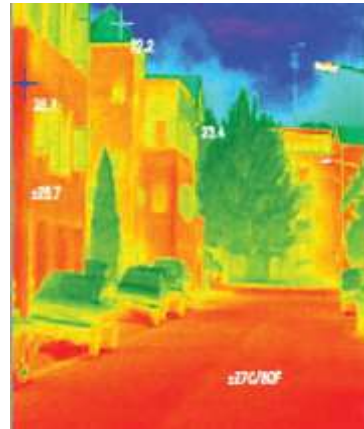
A 3D pie chart illustrating the carbon footprint components. The chart is divided into two segments: a large yellow segment representing 'Carbon Emission' at 100%, and a smaller blue segment representing 'Carbon Sequestered' at 33%.

Category	Value	Percentage
Carbon Emission	106635 kg	100%
Carbon Sequestered	-30779 kg	33%
<b>Carbon Footprint</b>	<b>72856 kg</b>	

**www.**

## Urbanization and Urban Heat Island

- Urban Heat Island
  - More Pronounced in larger cities
  - Increased extreme heat events
- Mitigation Measures
  - Increasing albedo by whitewashing buildings
  - Use of green roofs
  - Planting or protecting existing vegetation
  - Effectiveness of parks or one large greenspace?



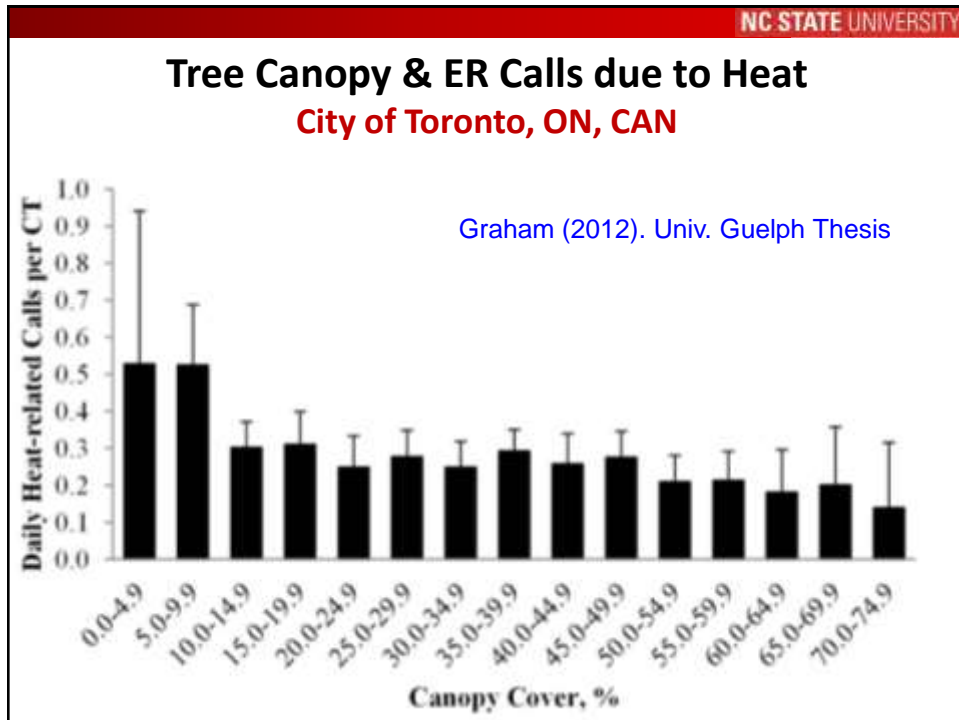
[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)

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FARM TO FORK

- **Knoxville Microclimate Study (Howe, 2016)**
  - Results show that there were significant differences in both intra-neighborhood (0.8 °C Tmax) and inter-neighborhood temperatures (1.6 °C Tmax; 2.2 °C Tmin).
  - Land Cover (Impervious %, Tree Canopy %) at a 500 meter radius had the greatest effect on differences in Tmin across all stations ( $R^2$  of 0.86,  $p < 0.01$ )

## Microclimates





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## Importantly, a goal of Green Streets is to Bring People to The Street...

...and therefore potentially expose them to Particulate Matter

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[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)

## Particulate Matter – Why care?

3.7 million premature deaths since  
2012 linked to PM



Sources: BBC, Carbon Brief, The Guardian, NBC News

[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)

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## GREEN INFRASTRUCTURE & AIR POLLUTION

**DR PRASHANT KUMAR**

READER

DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING

Group member of the:

**EnFlo** – ENVIRONMENTAL FLOW RESEARCH CENTRE


**CEHE** – CENTRE FOR ENVIRONMENTAL AND HEALTH  
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UNIVERSITY OF SURREY, OCTOBER 2015




## VEGETATION BARRIER





**Surrey campus**

● experimental location



Highway road level


Breathing height (~1.4m)

Footpath road level

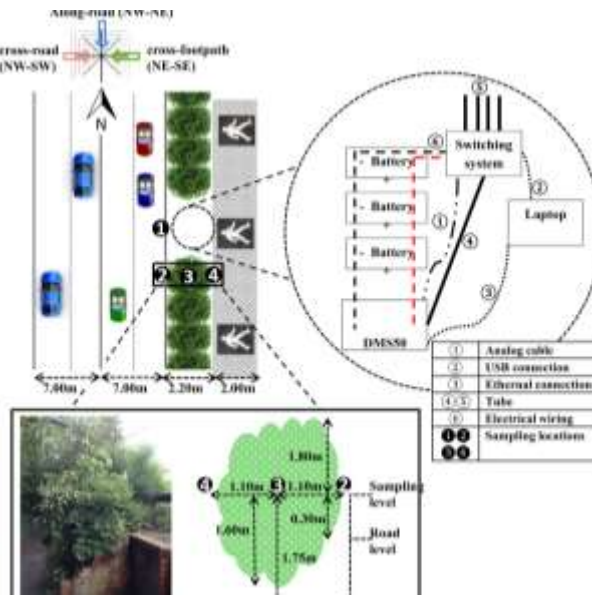
**Source:** Al-Dabbous, A.N., Kumar, P., 2014. The influence of roadside vegetation barriers on airborne nanoparticles and pedestrians exposure under varying wind condition. *Atmospheric Environment* 90, 113-124.

[Dr Prashant Kumar: University of Surrey, Oct 2015]

## VEGETATION BARRIER

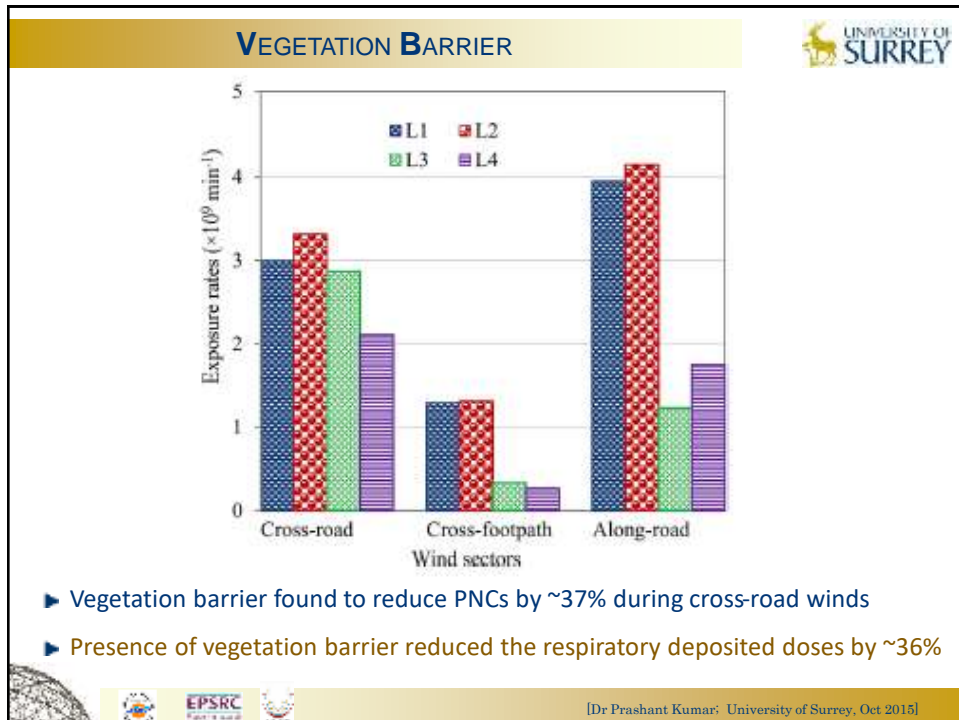


- ▶ DMS50 & 4-way solenoid switching system
- ▶ Three 12 V leisure batteries & laptop for data logging
- ▶ Flexible tubes & electrical connections
- ▶ Pseudo-simultaneous measurements every 20 s at each location
- ▶ Challenges in data separation for individual locations
- ▶ Wind direction key



The diagram illustrates the experimental setup for measuring airborne nanoparticles. It shows a cross-road (NW-SW) and a cross-footpath (NE-SE) with a vegetation barrier in the center. Sampling locations are marked with numbers 1, 2, 3, and 4. A detailed inset shows the electrical connections: (1) Analog cable, (2) USB connection, (3) Ethernet connection, (4) Tube, (5) Electrical wiring, and (6) Sampling location. A table at the bottom right lists these connections and their corresponding symbols.

[Dr Prashant Kumar: University of Surrey, Oct 2015]



## Ecosystem Service: Biodiversity

- Biodiversity assessment

Vegetation surveys of OW, SW, and TI zones

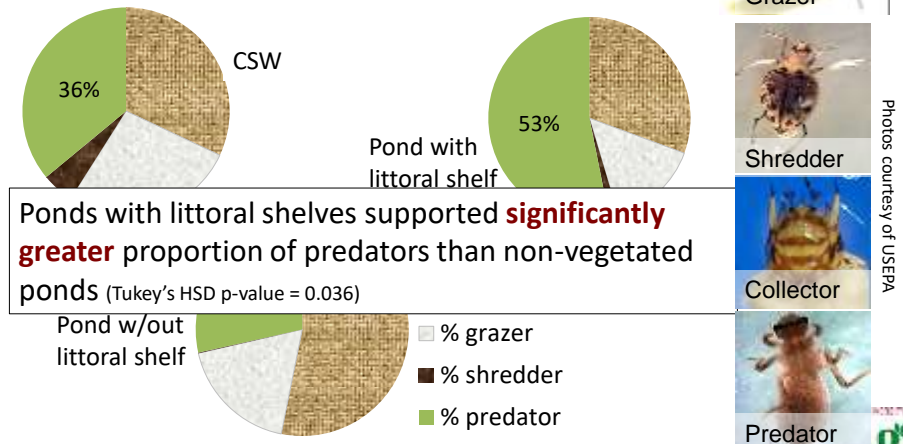
Aquatic macroinvertebrate sampling in SW zones

Richness and Shannon Diversity Index

[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater) Moore & Hunt, Water Research 2012

## Results – macroinvertebrate biodiversity

- Trophic level summary



[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater) Moore & Hunt, Water Research 2012

## Which is important because...



Enables Human-friendly  
(mosquito-resistant)  
design guidance:

Zika virus 'spreading explosively,' WHO leader says



Moore & Hunt, Water Research 2012



[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)

## Other Ecosystem Services Provided

- Cultural services: do SCMs provide similar recreational and educational opportunities?



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## Biotope: Singapore



Creating Pedestrian Friendly Infrastructure  
that treats stream water

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## Wade Wetland – Wilmington, NC



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## Which would you prefer?





## Spurring Economic Development



### **\$500M in Redevelopment**

- Apartments
- Condos
- Ponce City Market



CITY OF ATLANTA DEPARTMENT OF  
**watershed  
management**

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## SEA (Street Edge Alternatives) Street



Well-documented green streets in the greater Seattle metropolitan area.

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## Montgomery Ward Building – Baltimore, MD



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**The Gazette**  
PULITZER PRIZE-WINNING JOURNALISM, EST. 1872

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## Environmentally sound roofs stir green envy

By MEREDITH COHN • August 10, 2009 •



**BALTIMORE** • Atop the National Aquarium in Baltimore, away from the crowds, is a hidden oasis where the turtles and lizards sometimes come to bask in the sun. Their caretaker says it's also a nice spot for wild birds — and him, too.

The Montgomery Park office complex in southeast Baltimore has one of the city's

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Did you know?

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## Check out this Infiltration Basin



**Vaxjo, SWE**

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[www.bae.ncsu.edu/stormwat](http://www.bae.ncsu.edu/stormwat)



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## Permeable Pavement: You can park on it!



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## Rainwater Harvesting: Reduce Potable Uses!



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## Peeing as an Ecosystem Service?



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## Constructed Wetlands Can...

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## Provision Cut Flowers?

Is there a  
Market?  
(I think so)



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## Our Newest Systems turn ponds into horticultural resources



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## Provisioning: Green Roof Food production

Food production saved hotel \$30,000  
per year



Fairmont  
Hotel in  
Toronto is  
now adding a  
Green Roof!

Fairmont Waterfront Hotel in Vancouver  
(photo from [www.greenroofs.org](http://www.greenroofs.org))

[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)



## What other Returns Available? (aka Ecosystem Services)

- Air Quality (removal of particulates)
- Heat Island Mitigation (providing cooler places in the urban landscape)
- Food Provisioning (problematic with uptake?)
- Other Good Provisioning (e.g., cut flowers)
- Aesthetics
- Education
- Recreational

Impact Property  
Values

[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)



## Some Additional Values are Better Known than Others

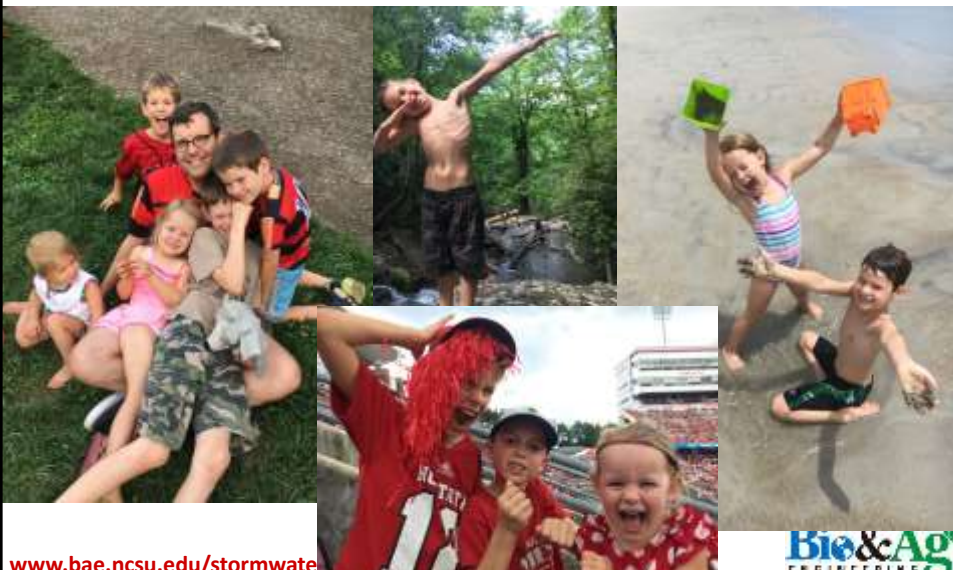
- But accounting for the Full Measure of Dividends will give us a better View of Our Investment
  - And may lead to different (more Green Infrastructure-y) Investments in the Future
- And who benefits?

PEOPLE!!!  
(& our environment)



[www.bae.ncsu.edu/stormwater](http://www.bae.ncsu.edu/stormwater)

## Thanks! Enjoy those Ecosystem Services!



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