



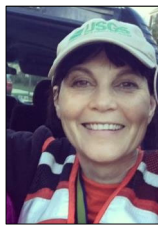
# Rethinking stormwater in our neighborhoods

Krissy Hopkins, Ph.D.  
U.S. Geological Survey  
Raleigh, NC

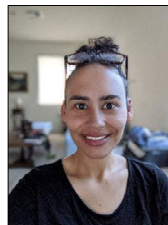
## USGS Urban BMP Team



Krissy Hopkins



Natalie Hall



Brianna Williams



Marina Metes



Charlie Stillwell



Rosemary Fanelli



Dan Jones

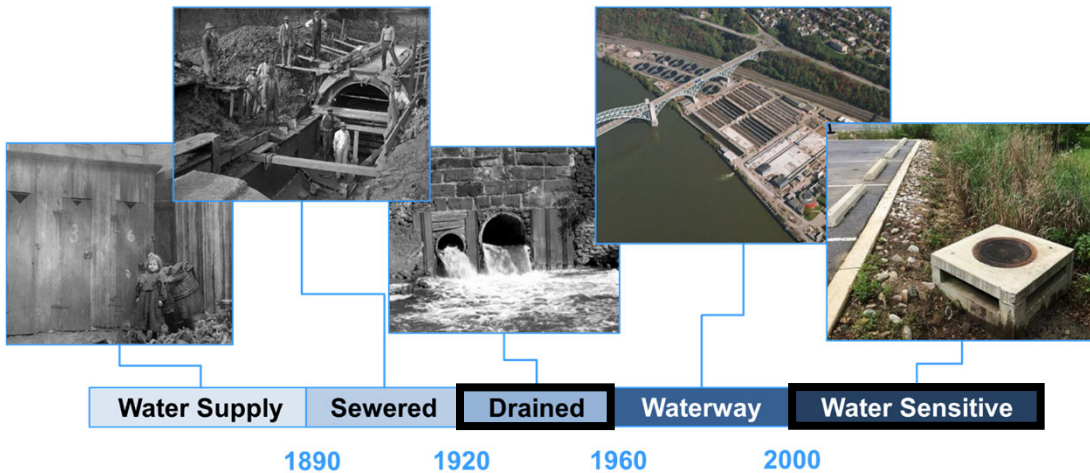


# Road Map

- Brief history of urban water systems
- Highlights from monitoring in Clarksburg, MD
  - Hydrologic
  - Water Quality
  - Ecological
- Urban stormwater futures



## Urban water systems have evolved



Historical photos: Pittsburgh City Photographer Collection  
Urban Water Transitions Framework: Modified from Brown et al. (2009)

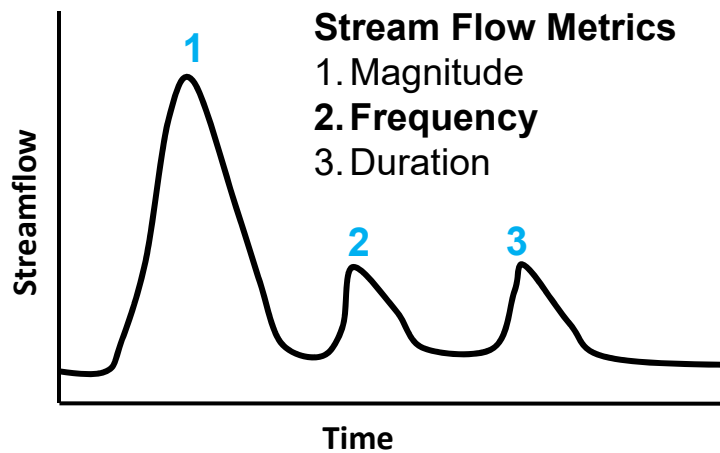




Nine Mile Run, Pittsburgh, PA

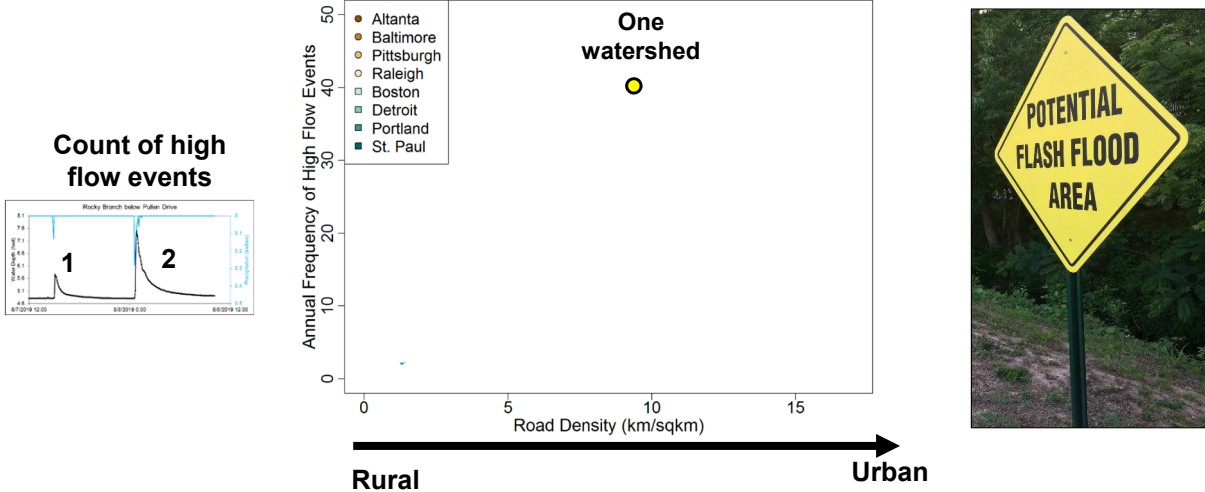
What does **draining**  
a **city** mean for  
**streams and**  
**ivers?**

**10 years of USGS daily mean streamflow used to quantify ecologically relevant flow metrics in 9 cities.**



# Our decisions result in hydrologic changes

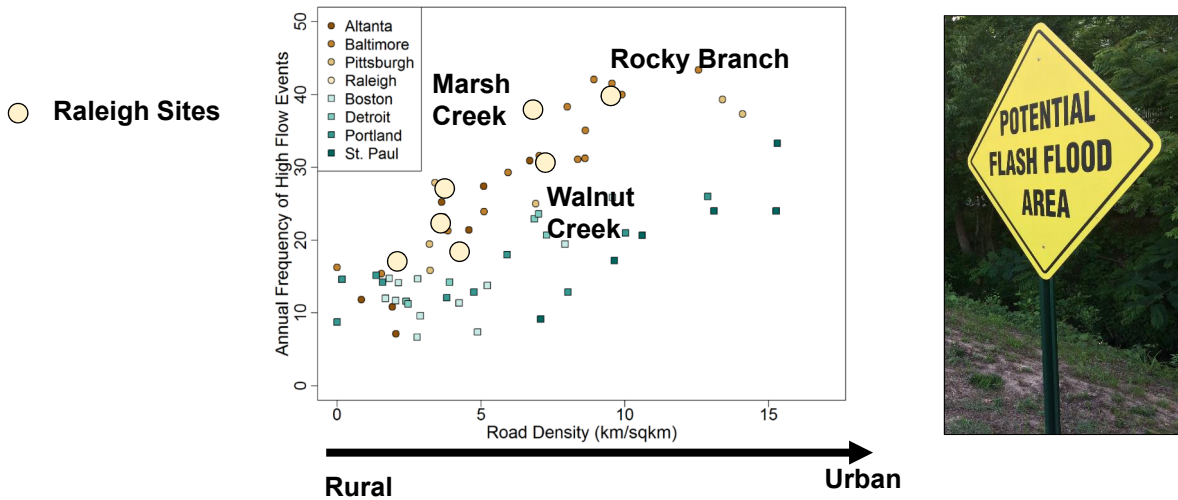
Increased stream flashiness with development



Hopkins et al. (2015) ES&T



# Raleigh streams cluster toward the top



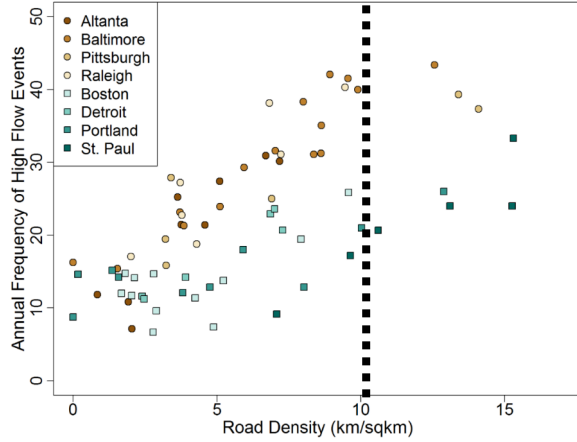
Hopkins et al. (2015) ES&T



# Why is there so much variability between cities?



**Rainfall amount and type**



Rural → Urban

Hopkins et al. (2015) ES&T



# Landscape features can act as hydrologic buffers



**Lakes**

**Topography**

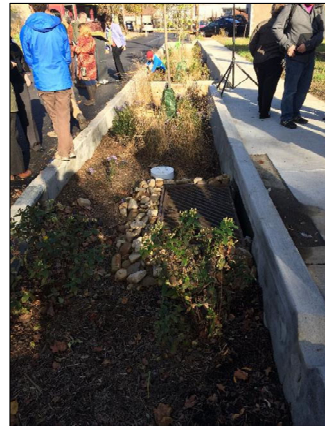
**Wetlands**

Hopkins et al. (2015) ES&T

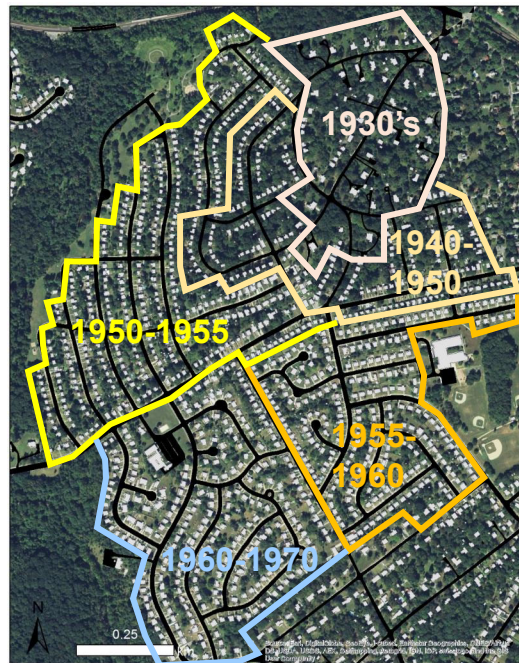
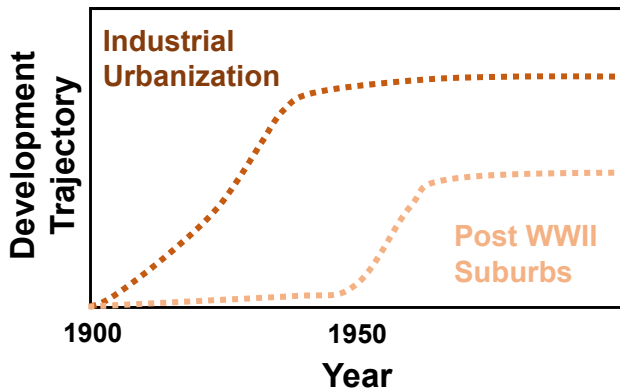


# Stormwater features as buffers

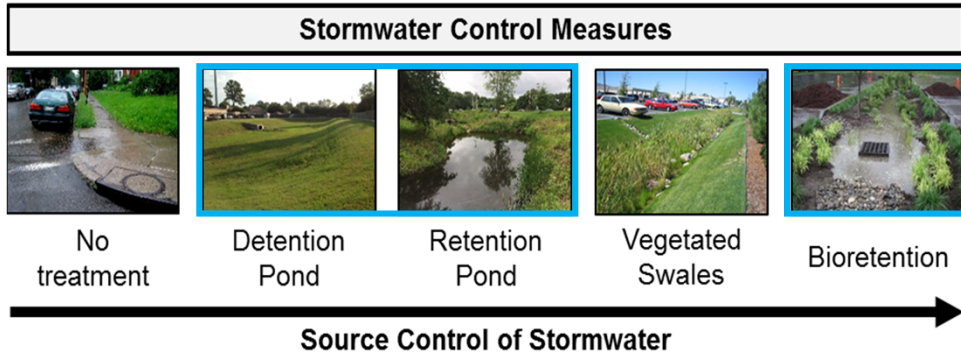
But how many and what kinds?



# Not all neighborhoods are created equally



## Neighborhood age often determines the type of stormwater plumbing



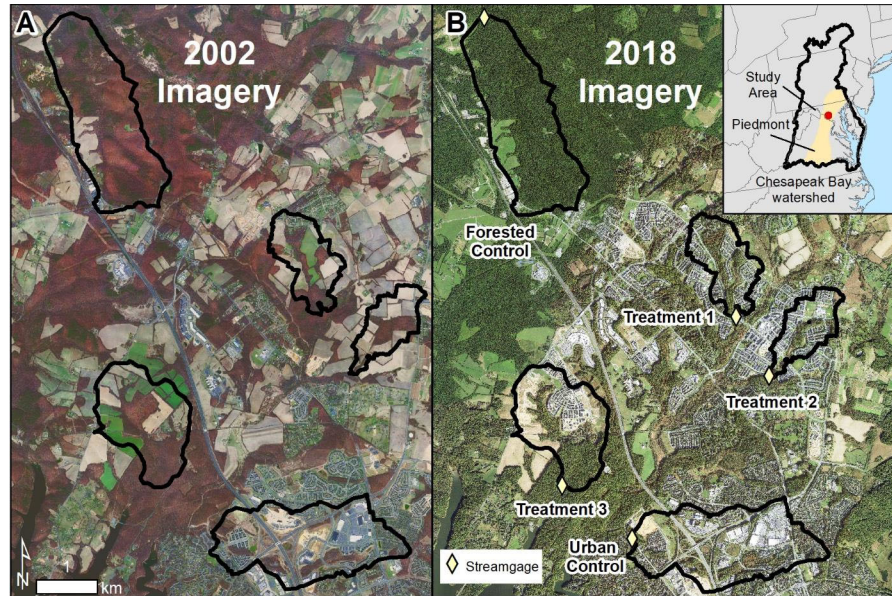
**FEW  
LARGE  
CENTRALIZED**

**VS**

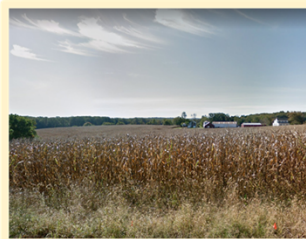
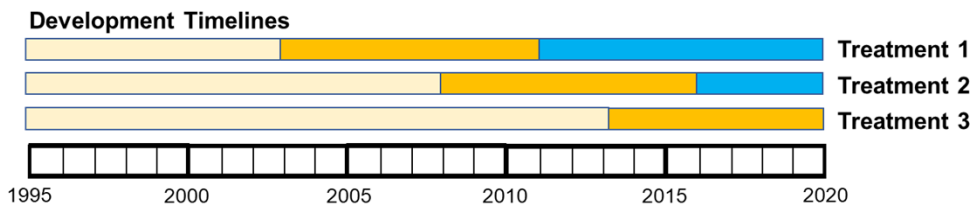
**MANY  
SMALL  
DISTRIBUTED**

# Lessons learned from study sites in Maryland

Controls vs Treatments



## Substantial land cover changes in Treatments



Row crop agriculture



Land grading with erosion and sediment control



Suburban with green stormwater infrastructure



# 100% of impervious surfaces are treated

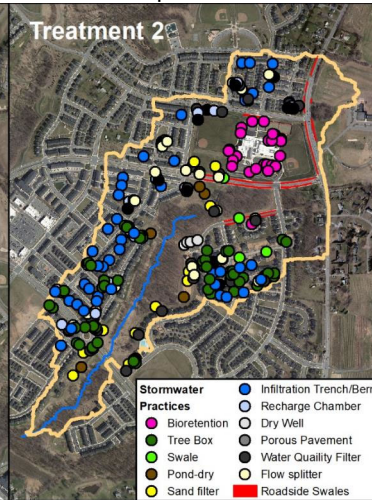
Dry wells  
infiltration  
detention  
swales



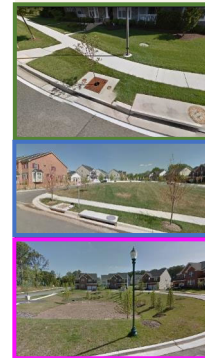
33% impervious  
91% single family detached  
105 practices/km<sup>2</sup>



44% impervious  
50% detached, 50% townhouse  
274 practices/km<sup>2</sup>



Tree boxes and  
infiltration  
detention



- Stormwater Practices**
- Infiltration Trench/Berm
  - Recharge Chamber
  - Dry Well
  - Bioretention
  - Tree Box
  - Swale
  - Pond-dry
  - Sand filter
  - Porous Pavement
  - Water Quality Filter
  - Flow splitter
  - Roadside Swales



## Stormwater practices arranged in treatment trains

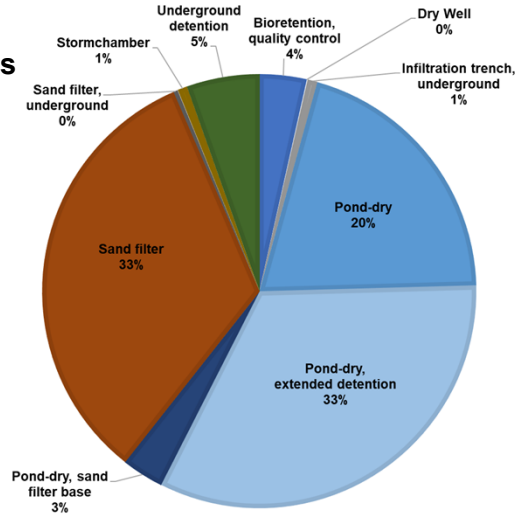
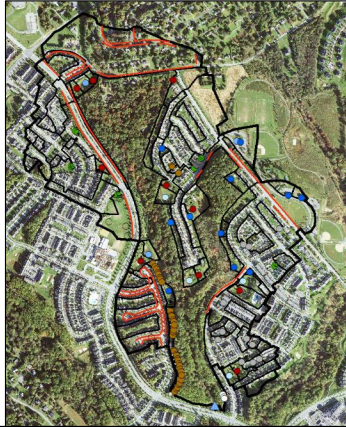


# Stormwater Storage: Treatment 1

Total estimated storage 687,177 cf

Storage (ft<sup>3</sup>) / Impervious (ft<sup>2</sup>) = 0.17 ft = 2.0 inches

- 33% impervious
- 89% storage in dry ponds or sand filters



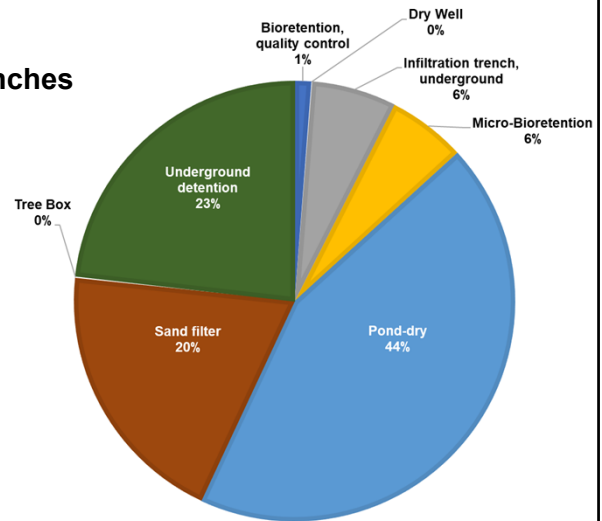
Preliminary Information-Subject to Revision.  
Not for Citation or Distribution.

# Stormwater Storage: Treatment 2

Total estimated storage 654,397 cf

Storage (ft<sup>3</sup>) / Impervious (ft<sup>2</sup>) = 0.155 ft = 1.9 inches

- 44% impervious cover
- 63% of storage in dry ponds or sand filters



Preliminary Information-Subject to Revision.  
Not for Citation or Distribution.



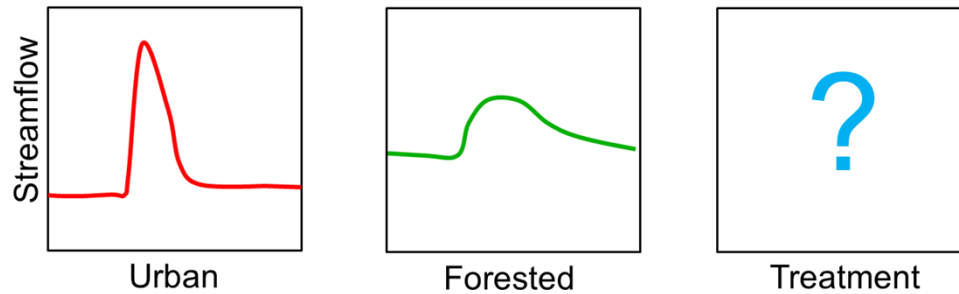
**Tracking change as watersheds transition from agriculture to suburban development**



**How does the flow regime change after development?**

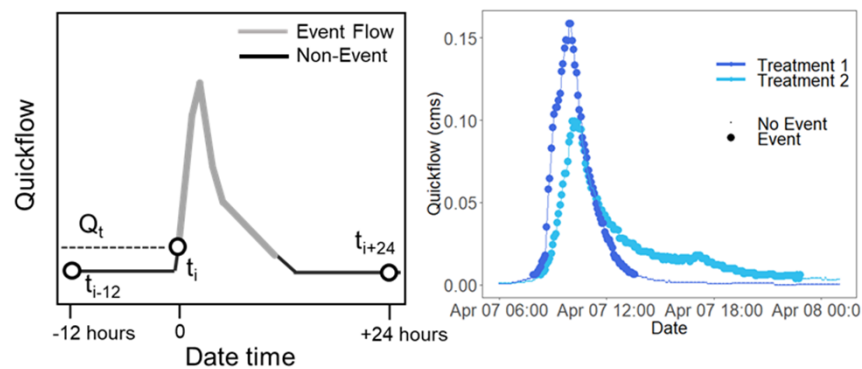
## What's happening to the flow regime?

1. How much rain does it take to initiate a flow response?
2. Do peak flows and runoff amounts change?
3. Does baseflow change?



## Identified streamflow response from 14 years of 5-min streamflow data: Oct 2004 – Sept 2018

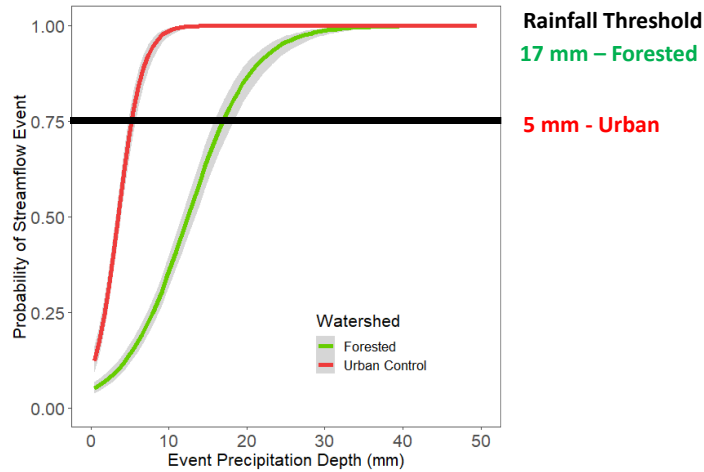
1. One parameter digital filter to separate baseflow and quickflow
2. Used discharge and quickflow thresholds to identify 1000+ events



Hopkins et al. 2020 *Hydro Processes*

## How much rainfall does it take to trigger flow?

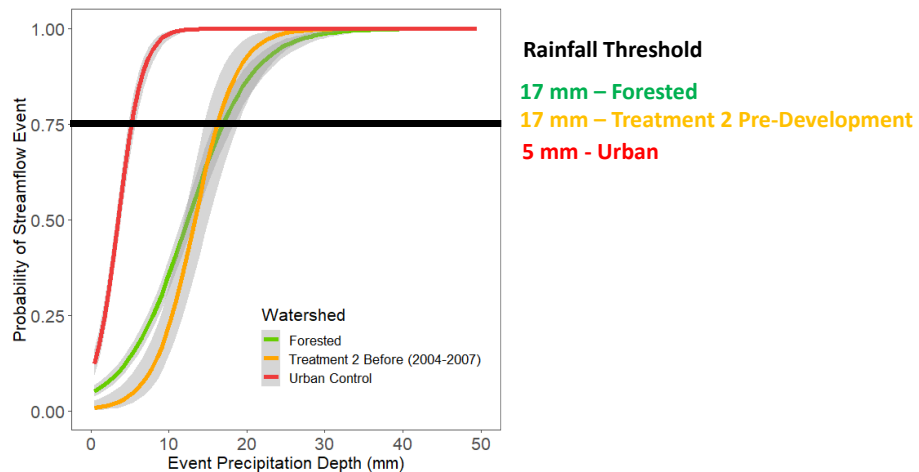
Takes more rain in the forested and less in the urban



Hopkins et al. 2020 *Hydro Processes*

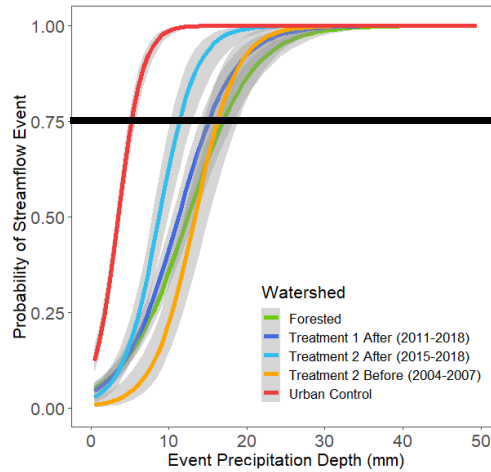
## How much rainfall does it take to trigger flow?

Treatment 2 pre-development is similar to forest



Hopkins et al. 2020 *Hydro Processes*

## How much rainfall does it take to trigger flow? Treatment 1 post-development similar to the forest



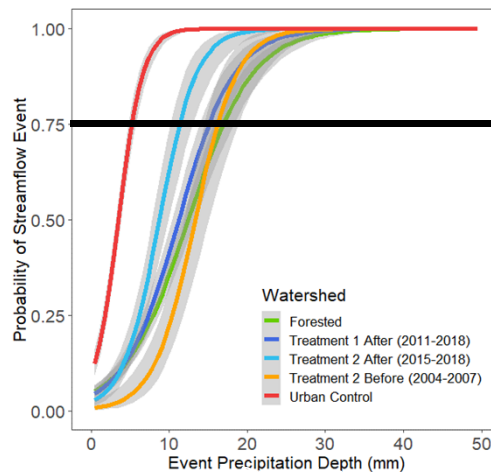
**Rainfall Threshold**

- 17 mm – Forested
- 17 mm – Treatment 2 Pre-Development
- 16 mm – Treatment 1 Post-Development
- 12 mm – Treatment 2 Post-Development
- 5 mm - Urban



Hopkins et al. 2020 *Hydro Processes*

## How much rainfall does it take to trigger flow? Biological relevance = Frequency of disturbance



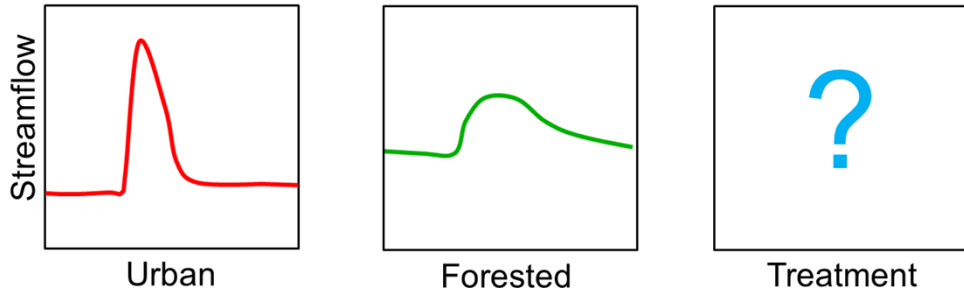
**Rainfall Threshold**

- 0.67 in – Forested
- 0.67 in – Treatment 2 Before
- 0.47 in – Treatment 2 After
- 0.63 in – Treatment 1 After
- 0.20 in - Urban

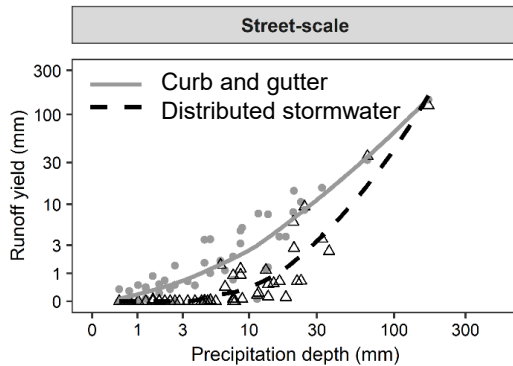


Hopkins et al. 2020 *Hydro Processes*

## What happens to runoff yield?



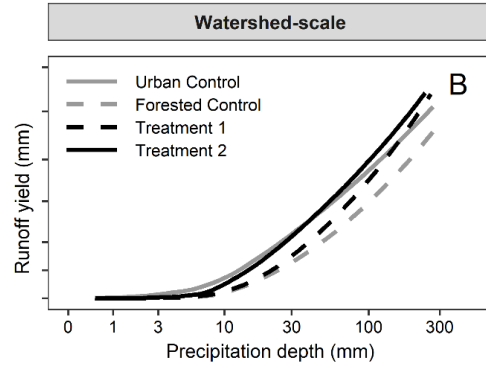
## What happens to runoff yield at the street scale? More runoff from the curb and gutter neighborhood



Street scale data: Woznicki et al. 2018  
Watershed scale data: Hopkins et al. 2020

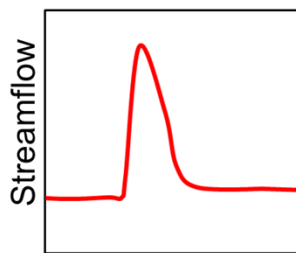
## What happens to runoff yield at the watershed scale?

More runoff from centralized stormwater control and Treatment 1

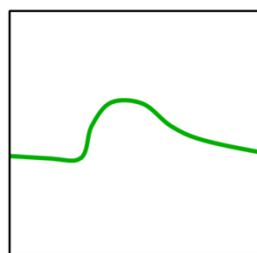


Street scale data: Woznicki et al. 2018  
 Watershed scale data: Hopkins et al. 2020

## What happens to peak flows?



Urban



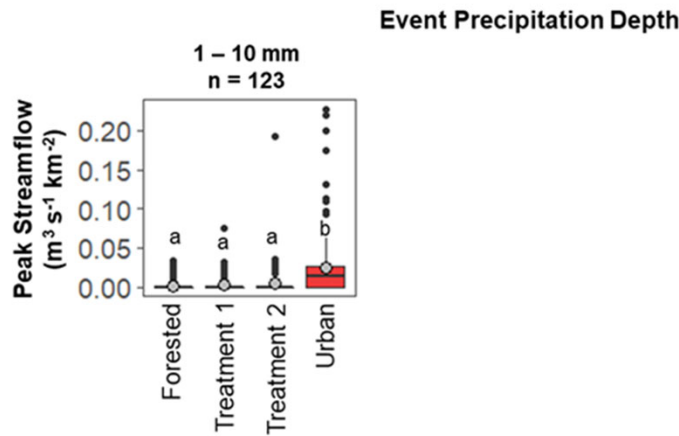
Forested



Treatment

### Post-Development in Treatment 1 and 2

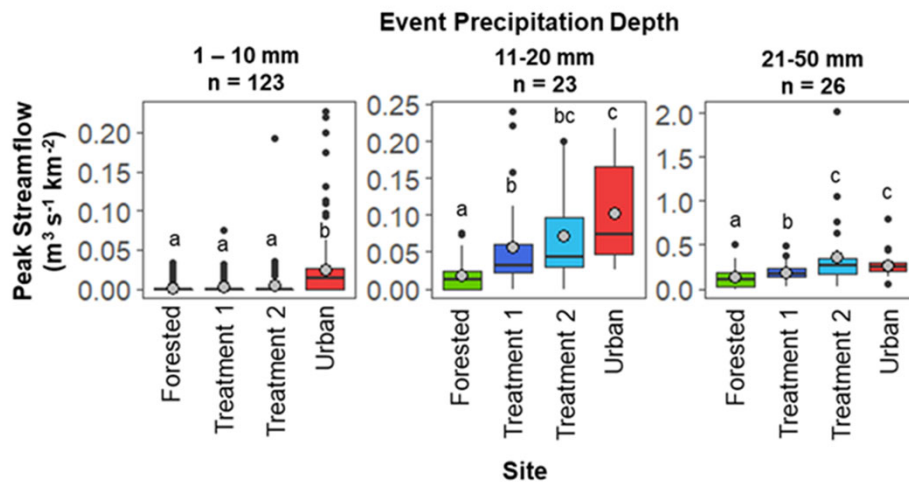
Peak flows were attenuated for small precipitation events (< 10mm)



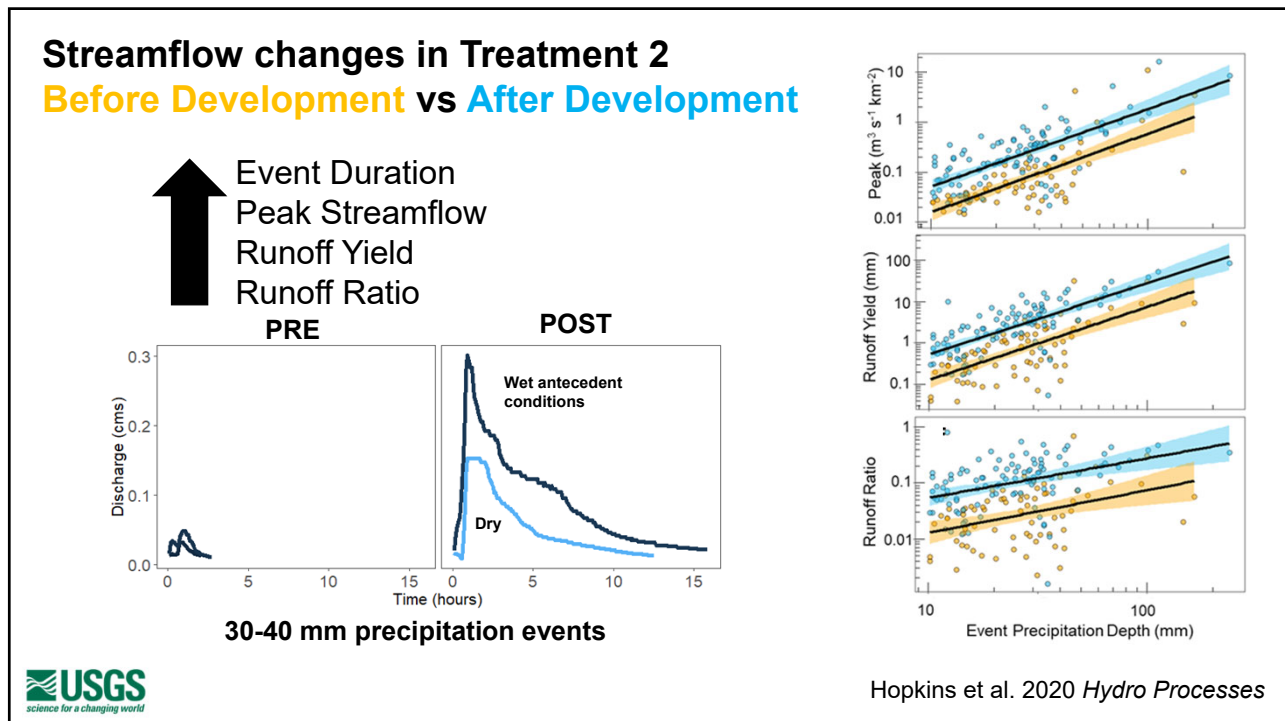
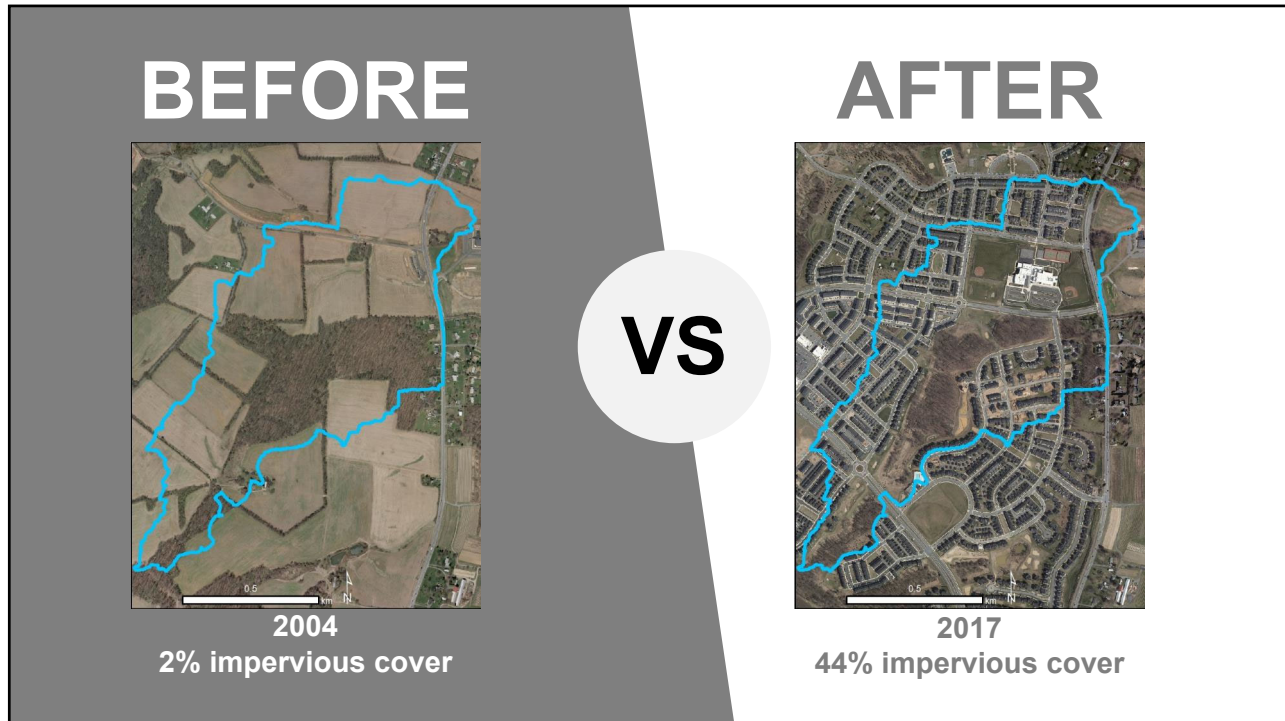
Hopkins et al. 2020 *Hydro Processes*

### After Development in Treatment 1 and 2

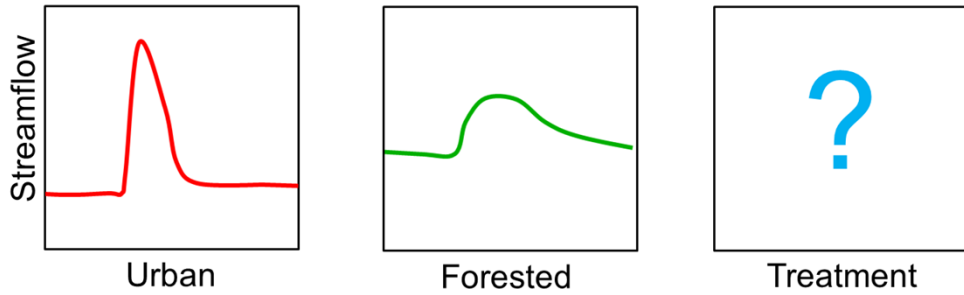
Peak flows were 2-3 higher in treatments than forested site (11-20 mm)



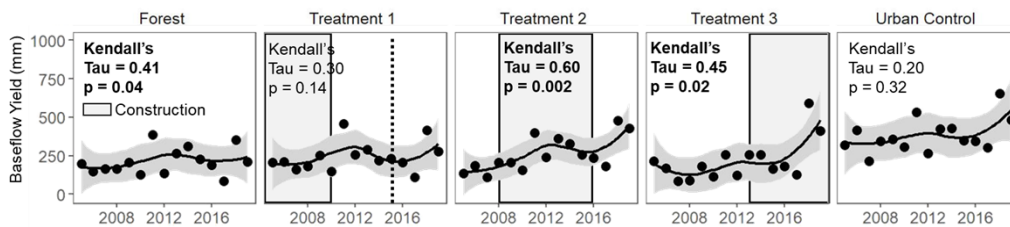
Hopkins et al. 2020 *Hydro Processes*



## What happens to baseflow?

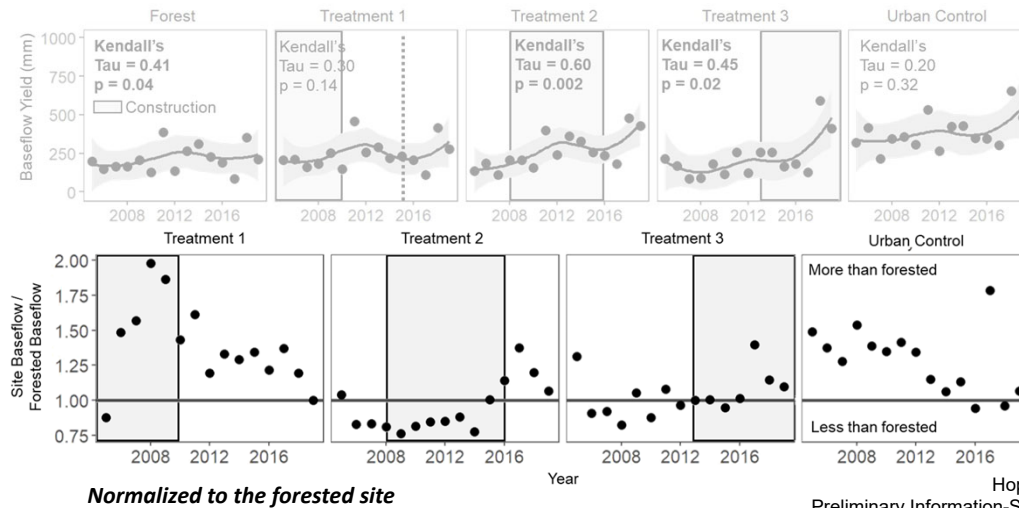


## Distributed stormwater control can increase baseflow, but increases are temporary



Hopkins et al. In prep  
 Preliminary Information-Subject to Revision  
 Not for Citation or Distribution

## Distributed stormwater control can increase baseflow, but increases are temporary



## Can distributed stormwater control maintain hydrologic function?

**It can** attenuate peak flows and runoff volumes, **but** storage capacity matters.

**It can** increase baseflow, **but** increases may be temporary.

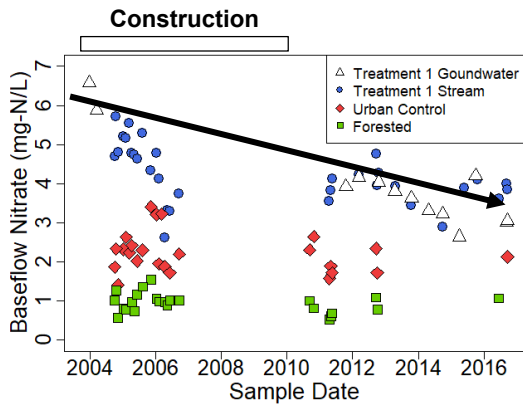
**More distributed** control **isn't always better**, if you have more impervious cover.





## Nitrate concentrations

- Treatment 1 groundwater nitrate concentrations declined by half.
- May be result of removal of agriculture soils and reduction in fertilizer inputs



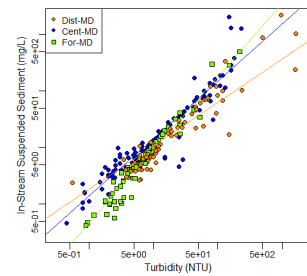
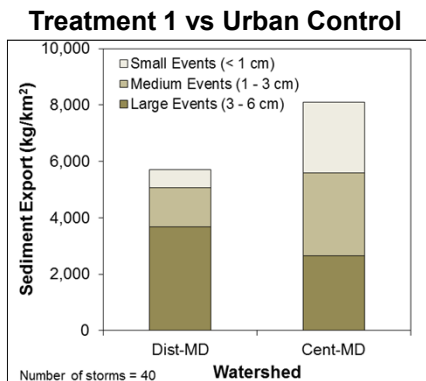
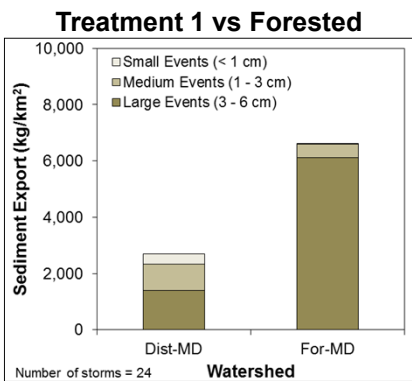
Hopkins et al. 2017 *J. Env Manage*





**What happens to sediment?**

**Based on total export, Treatment had LESS sediment export than urban control and forested.**



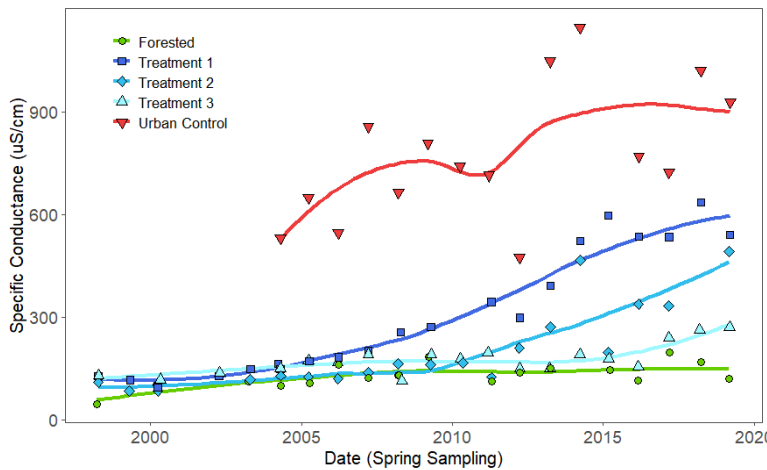
**Developed surrogate model for sediment**



Hopkins et al. 2017 *J. Env Manage*



## Rising specific conductance trends in all three treatment watersheds



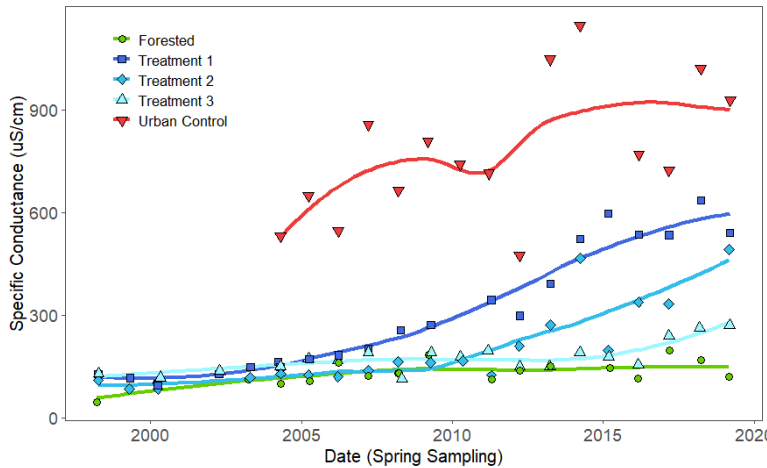
32  $\mu\text{S}/\text{cm}$  per year increase

21  $\mu\text{S}/\text{cm}$  per year increase

6  $\mu\text{S}/\text{cm}$  per year increase

Hopkins et al. In prep  
 Preliminary Information-Subject to Revision  
 Not for Citation or Distribution

## Rising specific conductance trends in all three treatment watersheds



Likely driven by increased ion inputs from impervious cover, a stressor not targeted by stormwater facilities

Hopkins et al. In prep  
Preliminary Information-Subject to Revision  
Not for Citation or Distribution

## Can distributed stormwater control maintain water quality?

**It can** reduce nitrate concentrations, **but** total export remained the same.

**It can** reduce sediment, **but** in-stream sources may dominate during large storms.

**It can** increase ion loads, **but** that's due to more impervious cover and winter salting.



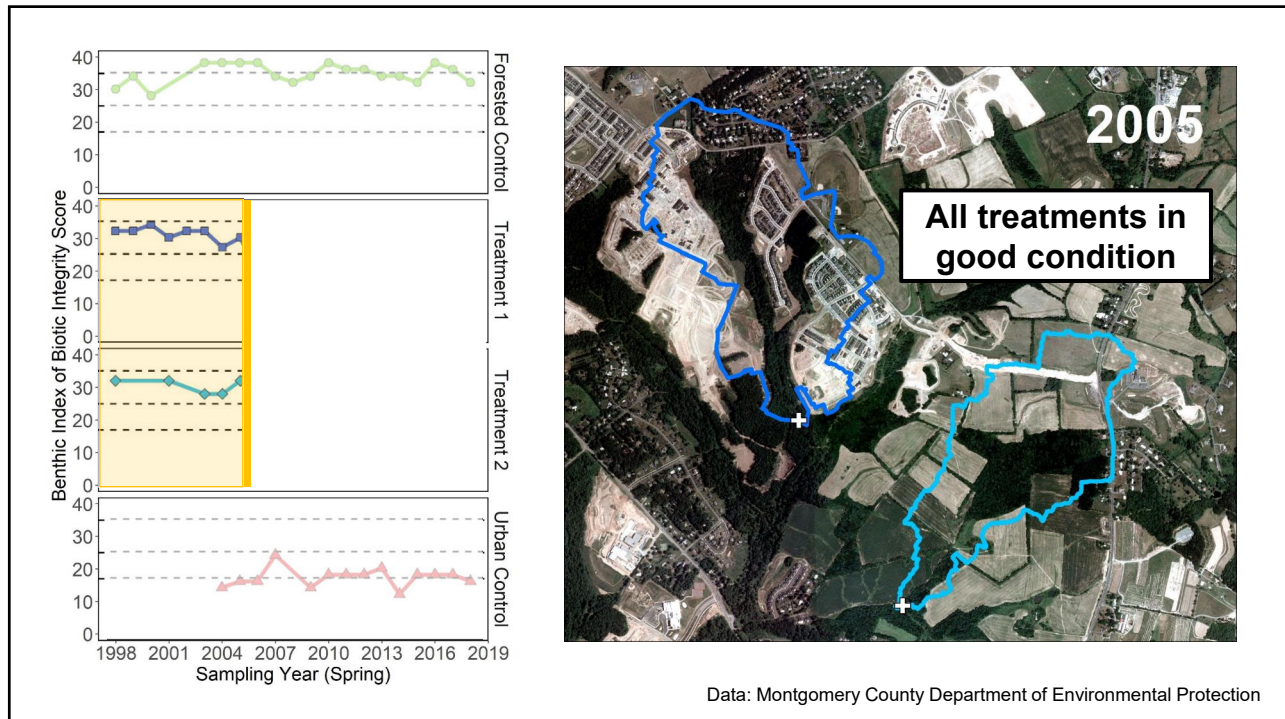
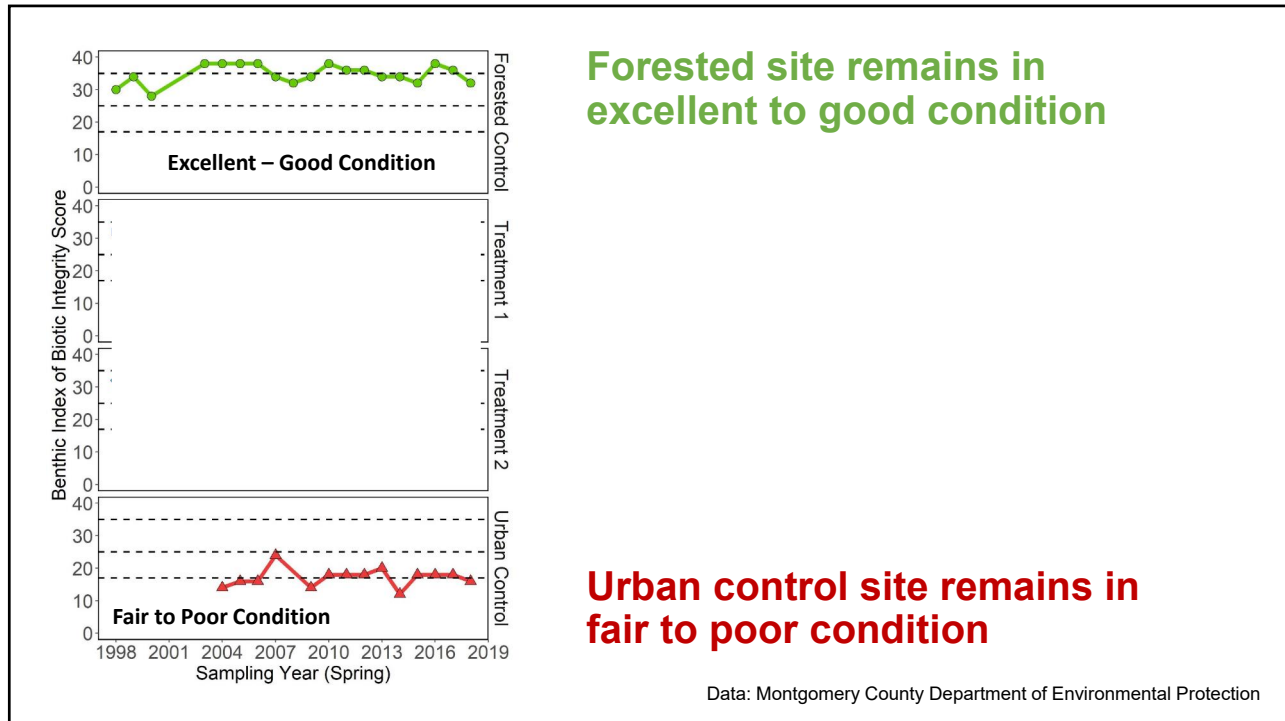
**Benthic Community**      **Water Quality**      **Geomorphology**      **Hydrology**

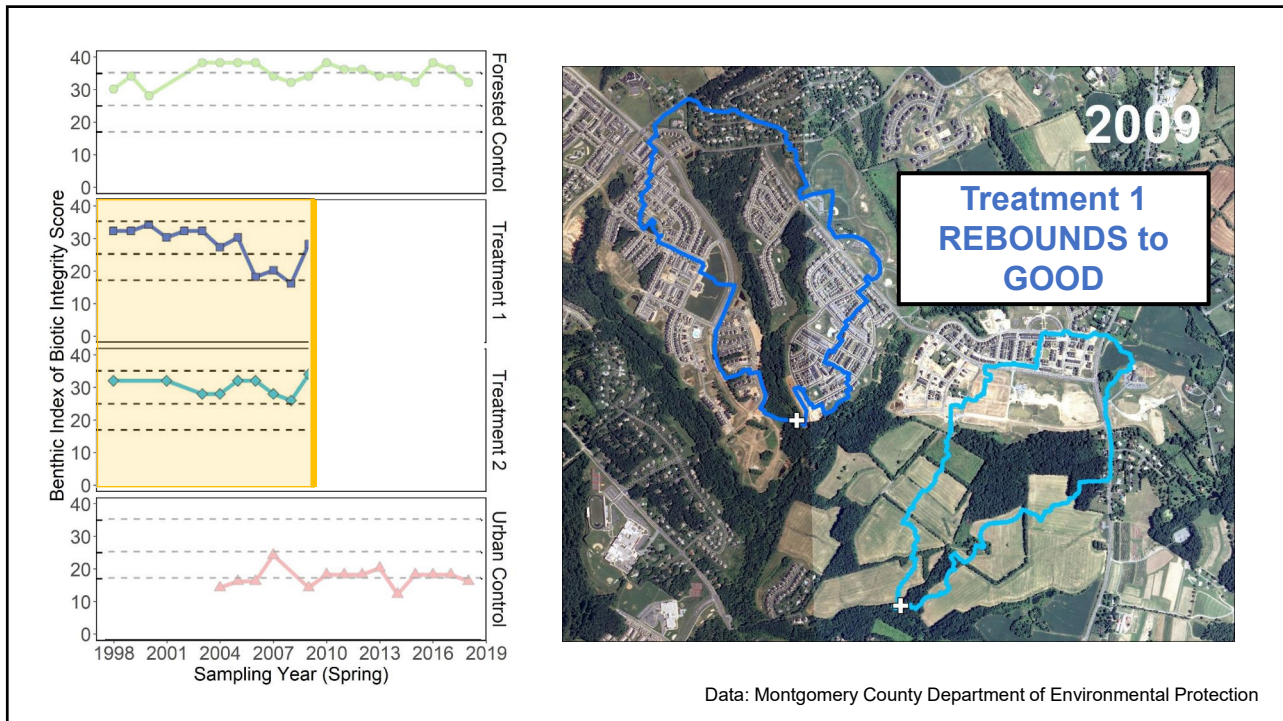
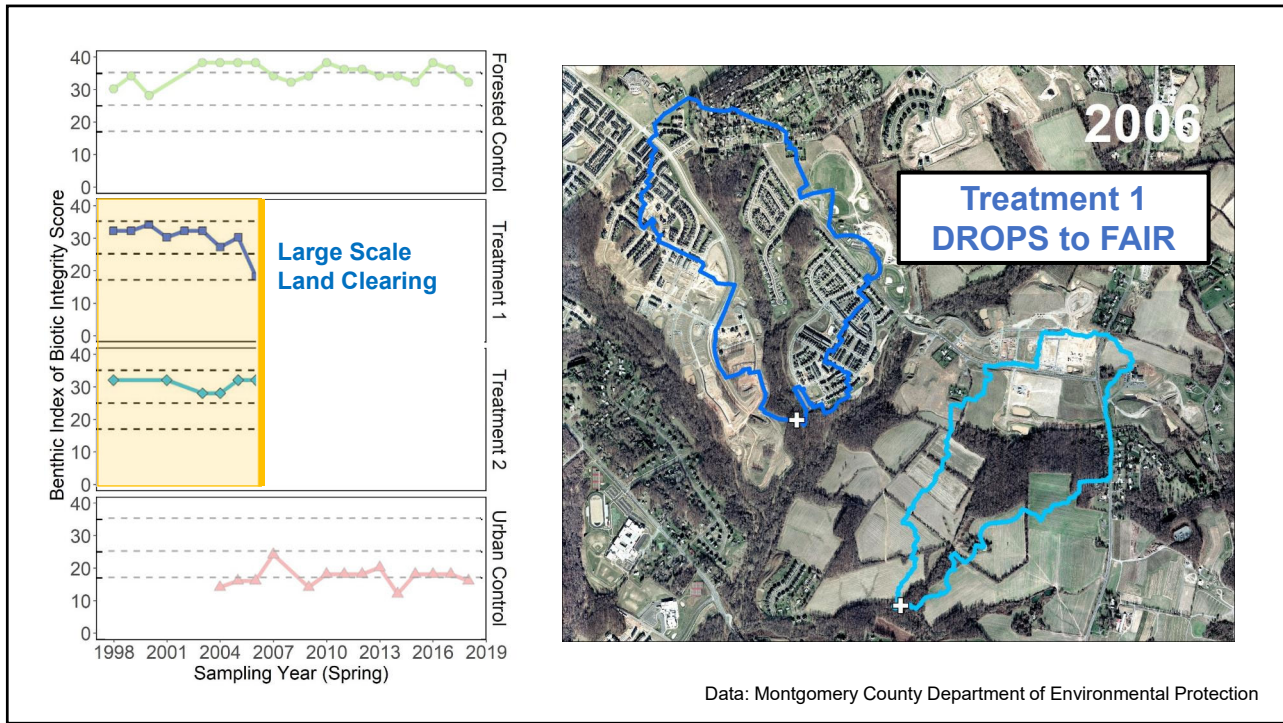
**What happens to the benthic community?**

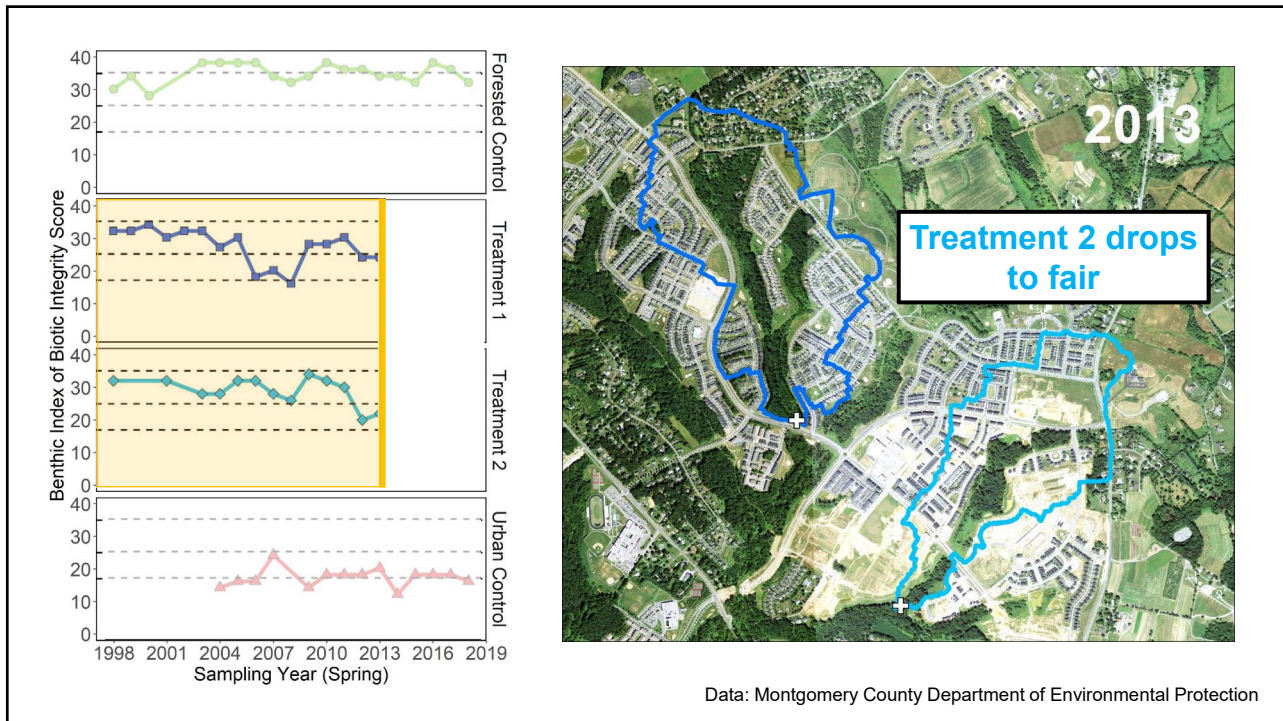
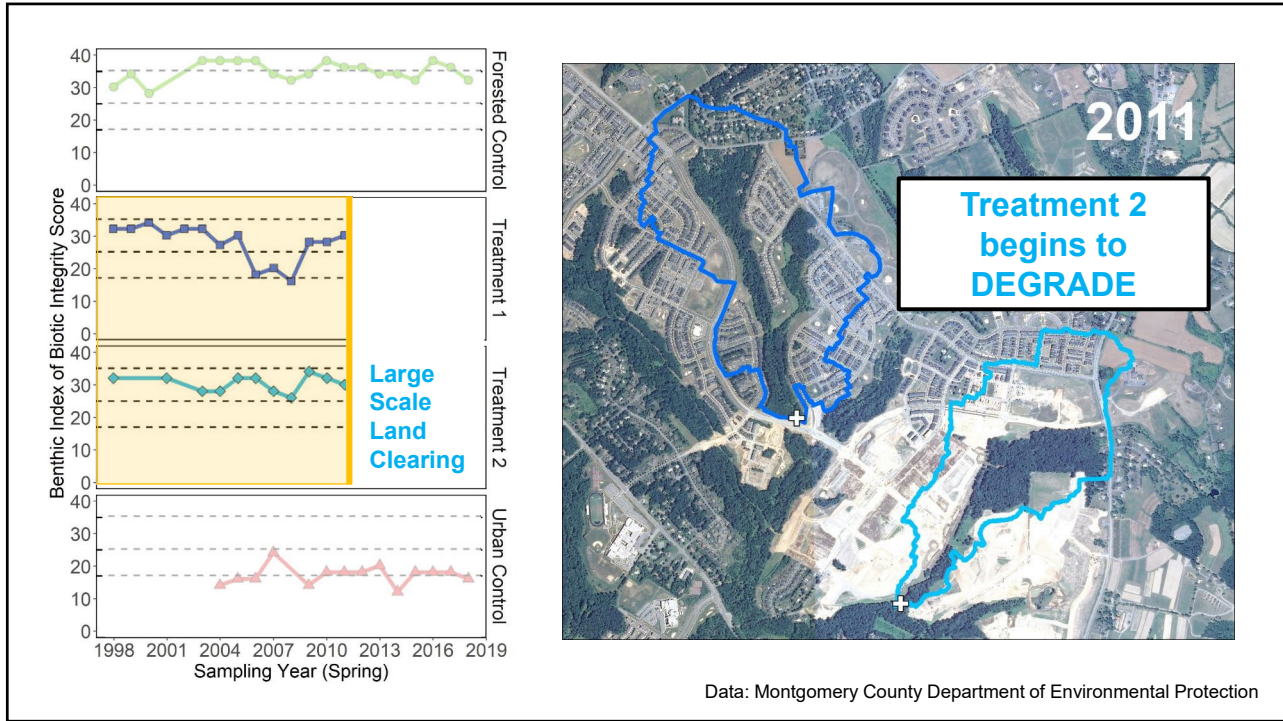
**What happens to the benthic macroinvertebrate community after development?**

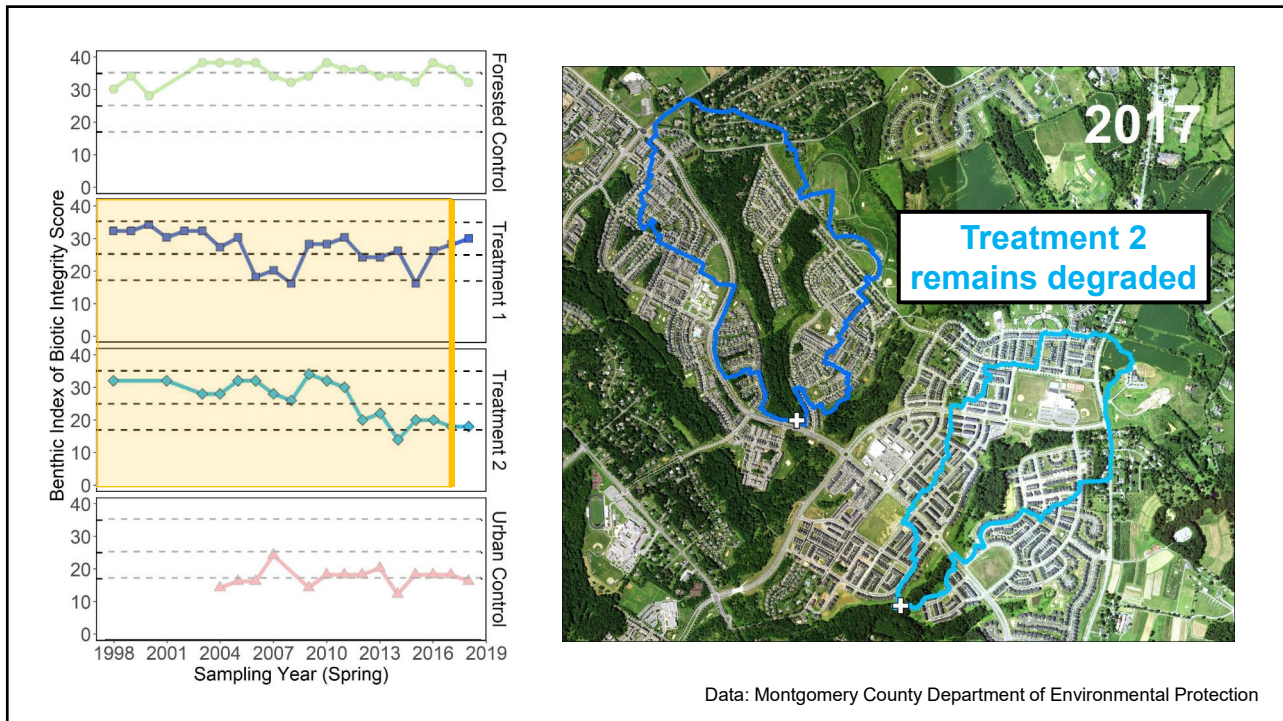
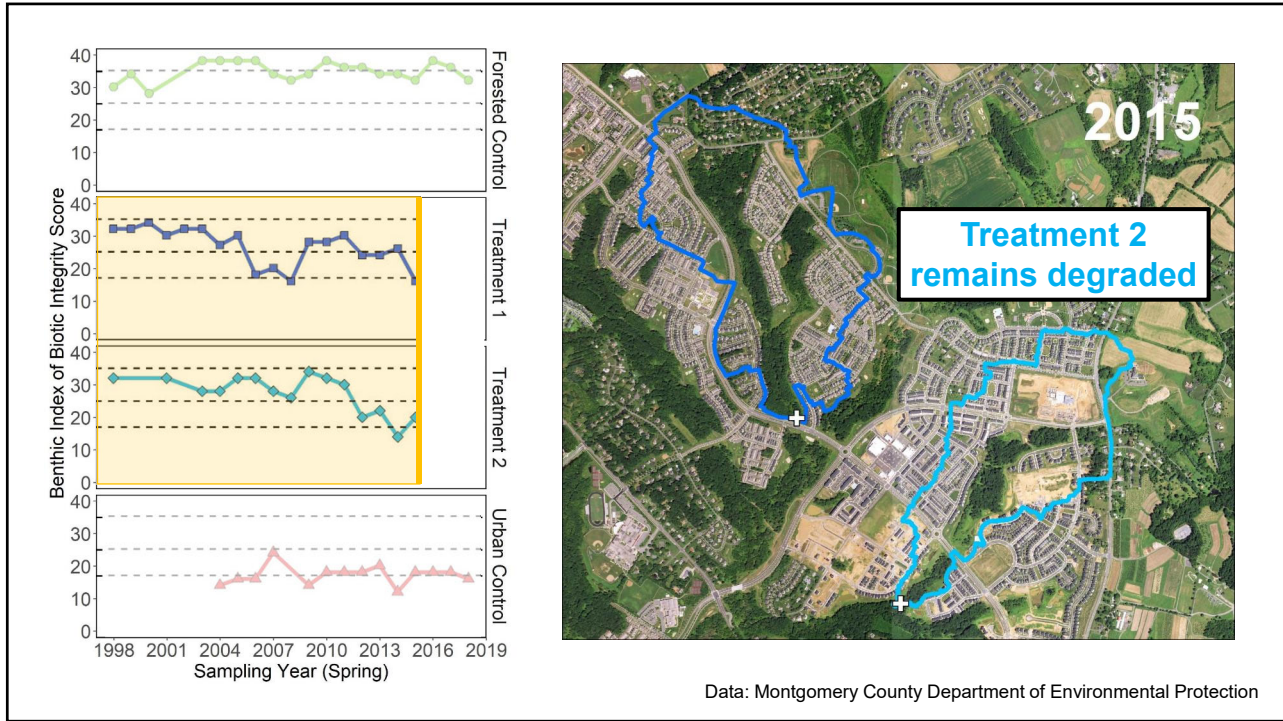
Year	Category
1998	Excellent
2001	Excellent
2004	Good
2007	Good
2010	Fair
2013	Fair
2016	Poor

**Spring sampling**

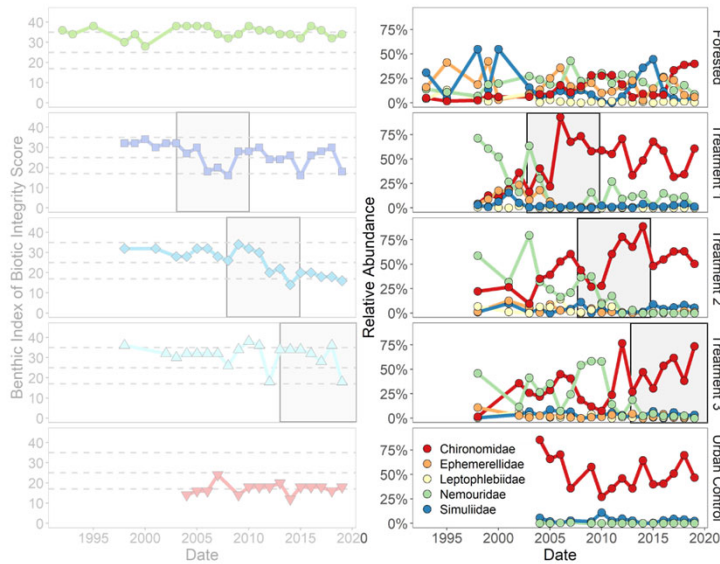








## Dominated by a single tolerant taxon



Data: Montgomery County Department of Environmental Protection

**Benthic assemblages may be somewhat protected by stormwater facilities, but sensitive taxa may not fully recover**

## Can green stormwater infrastructure save suburban streams?

**It can** attenuate peak flows and runoff volumes, **but** storage capacity matters.

**It can** improve water quality for some, **but** not all constituents (e.g., salt).

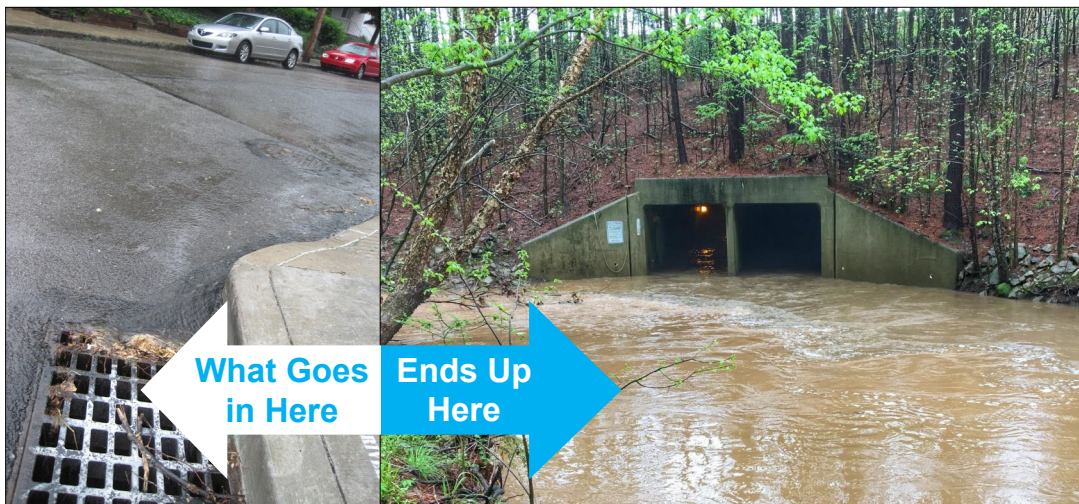
**It can** maintain stream health, **but** the construction phase is important.



# STORMWATER FUTURES

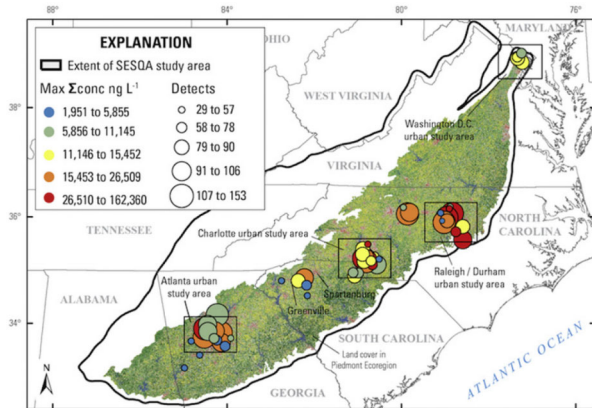
# WHAT'S NEXT

**What goes in, must come out.**

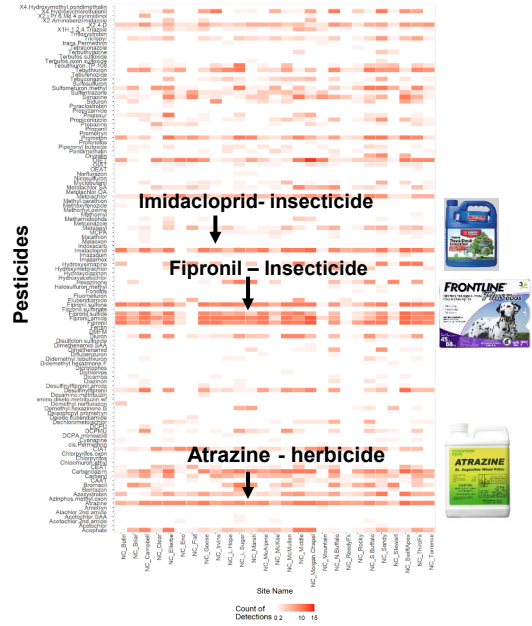




# Contaminants in urban stream across the Piedmont



Bradley et al. 2019 *Science of the Total Environment*



## Distributed stormwater control can minimize impacts, BUT

- Degradation can occur during construction
- The amount of impervious cover may be an important factor for predicting benthic rebound
- More practices and more distributed stormwater control isn't always better
- Emerging contaminants increasingly important

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 @kghopkin