THE OHIO STATE UNIVERSITY

Introduction to Low Impact Development & Green Infrastructure

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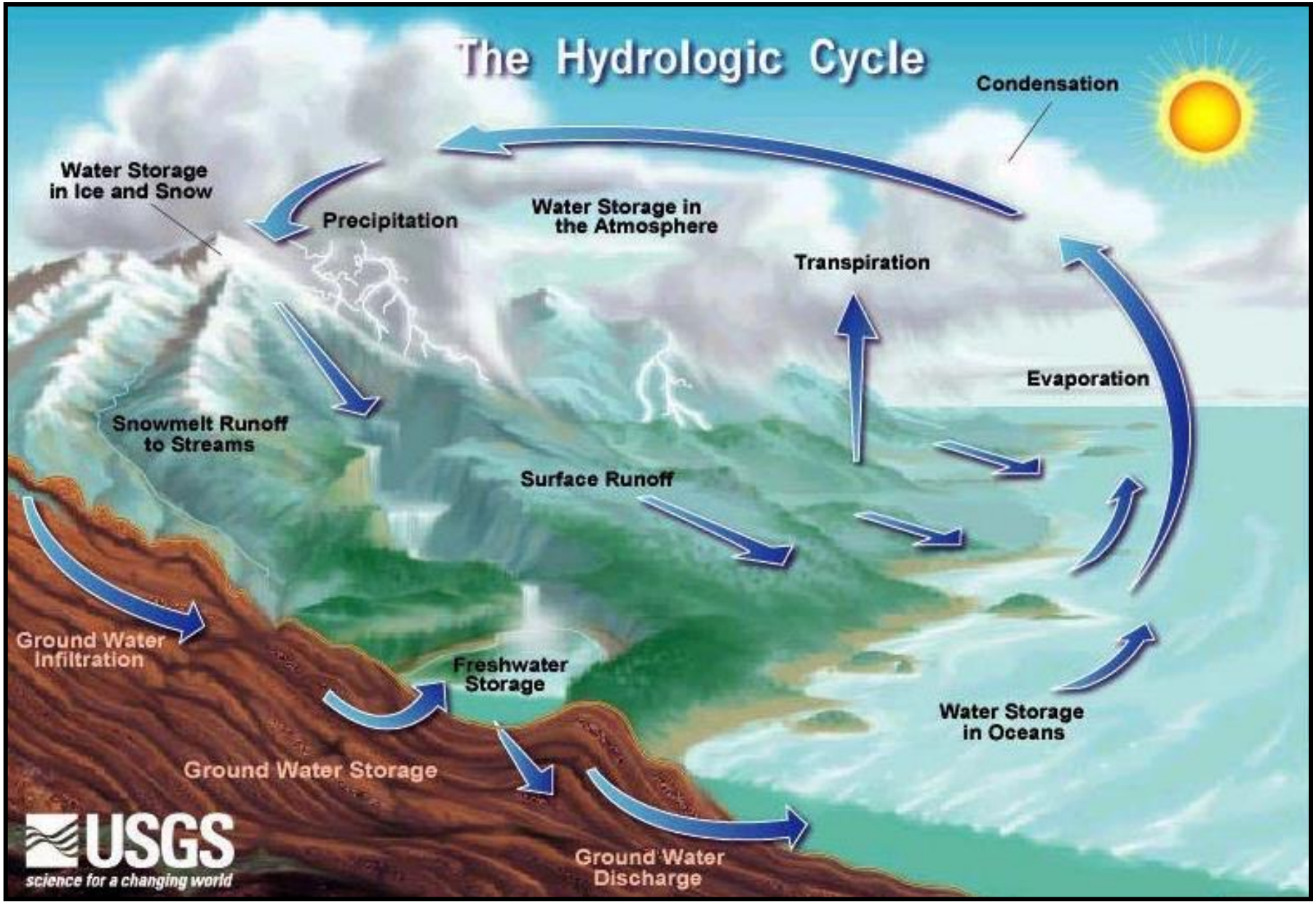
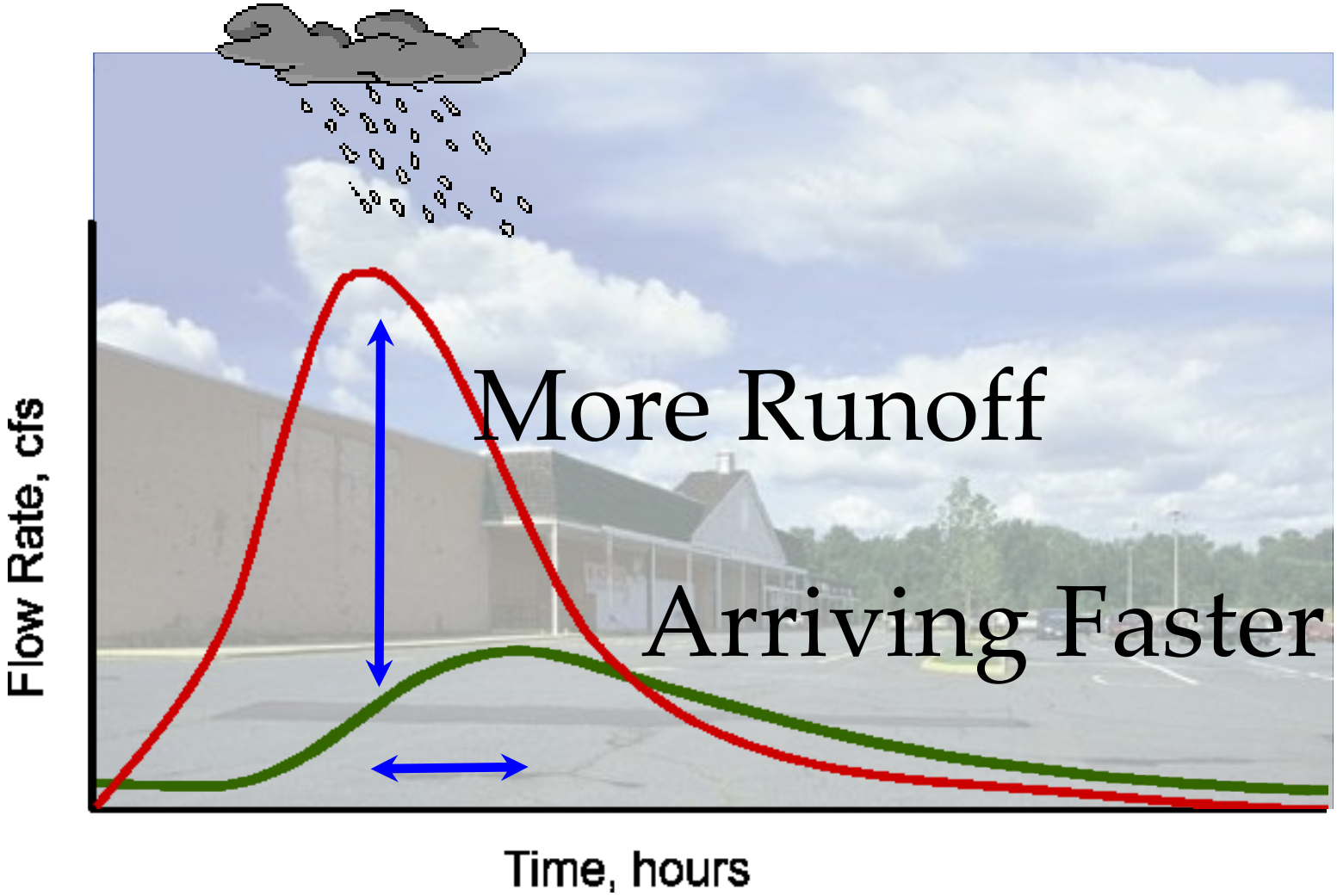
Toledo Green Infrastructure Workshop

4/14/2016

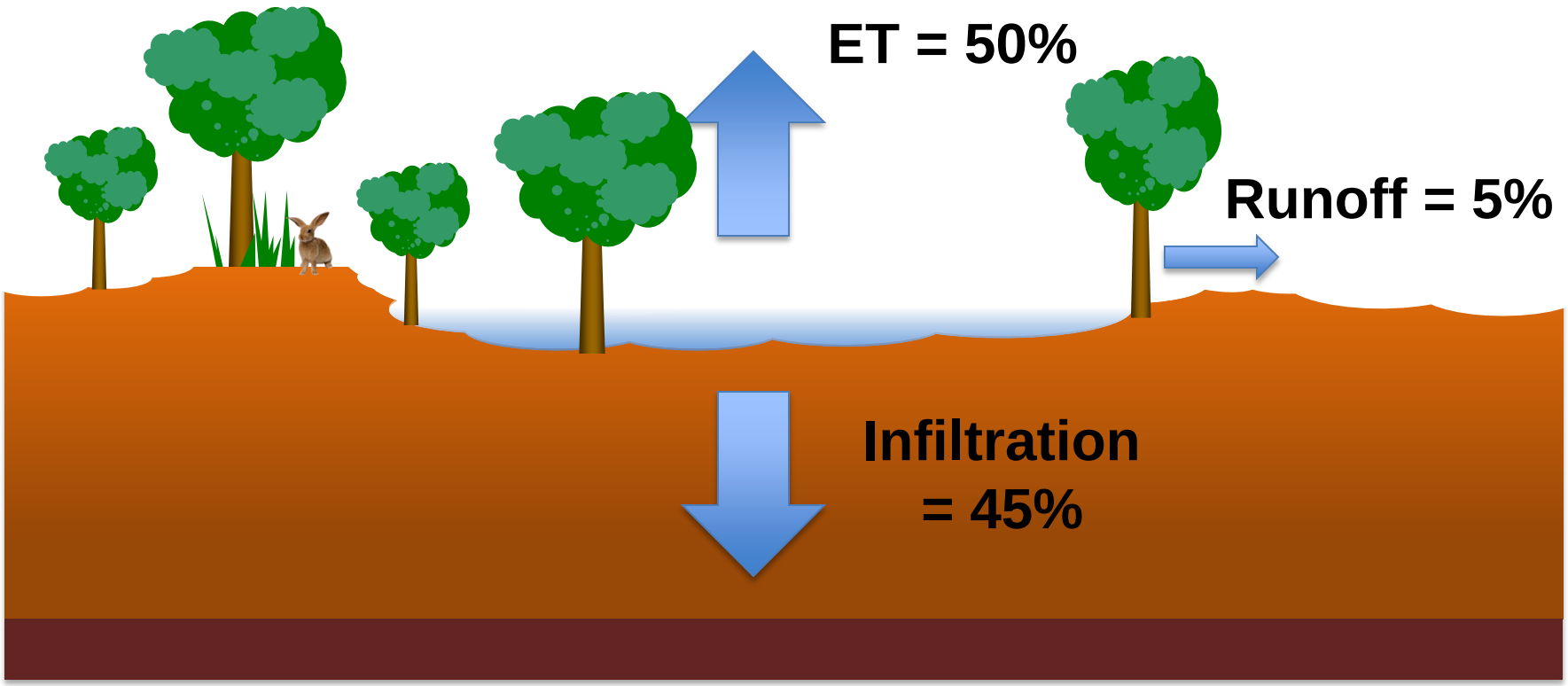

The Hydrologic Cycle
Condensation
Water Storage in Ice and Snow
Precipitation
Water Storage in the Atmosphere
Transpiration
Evaporation
Snowmelt Runoff to Streams
Surface Runoff
Ground Water Infiltration
Freshwater Storage
Water Storage in Oceans
Ground Water Storage
Ground Water Discharge
USGS
science for a changing world

Urban Water Cycle

Urban Hydrology

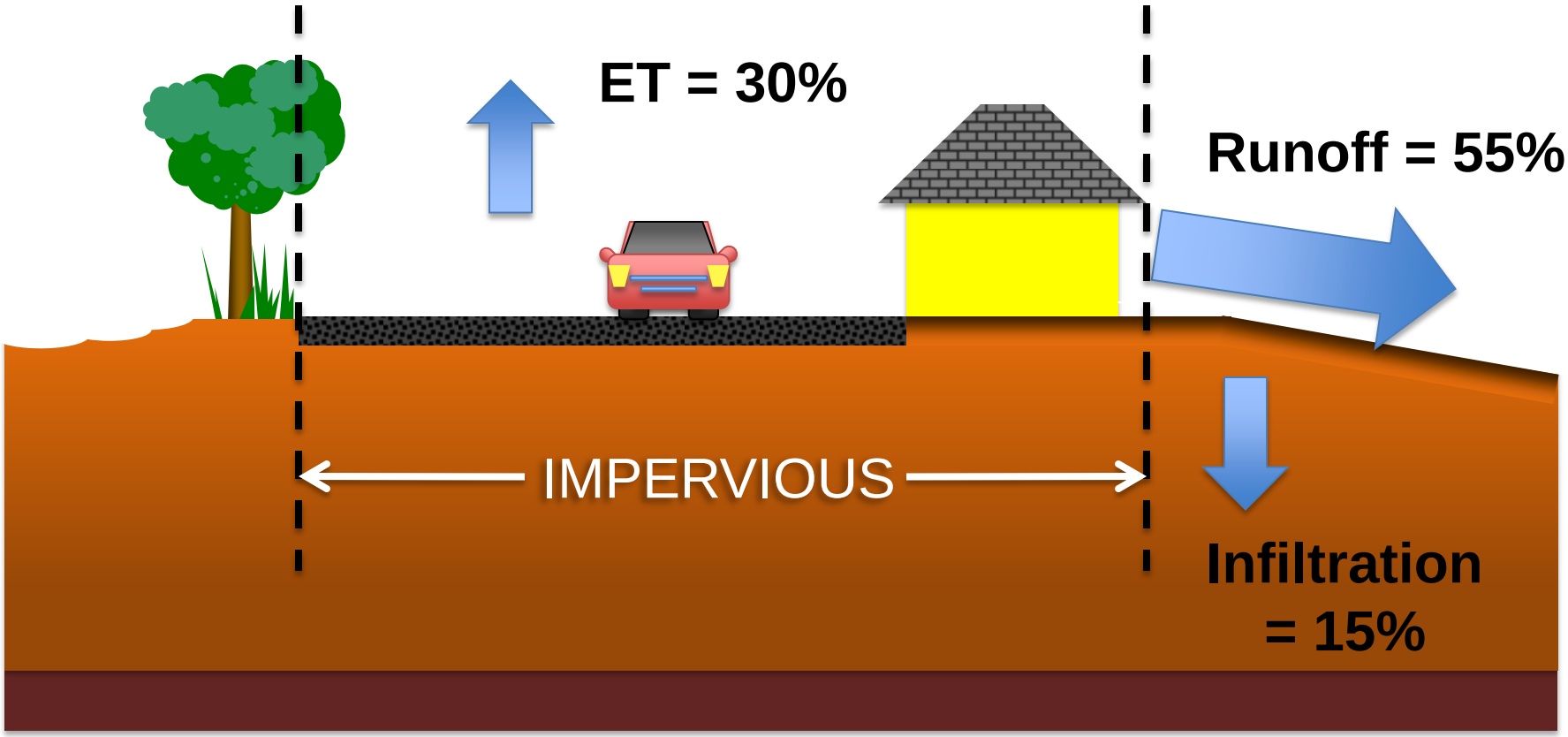


The Water Budget: Predevelopment



Source: Swift et al. 1987

Postdevelopment (Urban) Hydrology



Source: Tourbier and Westmacott 1981

Why Do We Care about Stormwater Management?

Flooding: threatens human life & property

Increased stormwater volume: accelerates stream erosion

Increased pollutant load: impairs water quality for humans & other organisms

Matt Hood 2008, with permission

US EPA, 2011

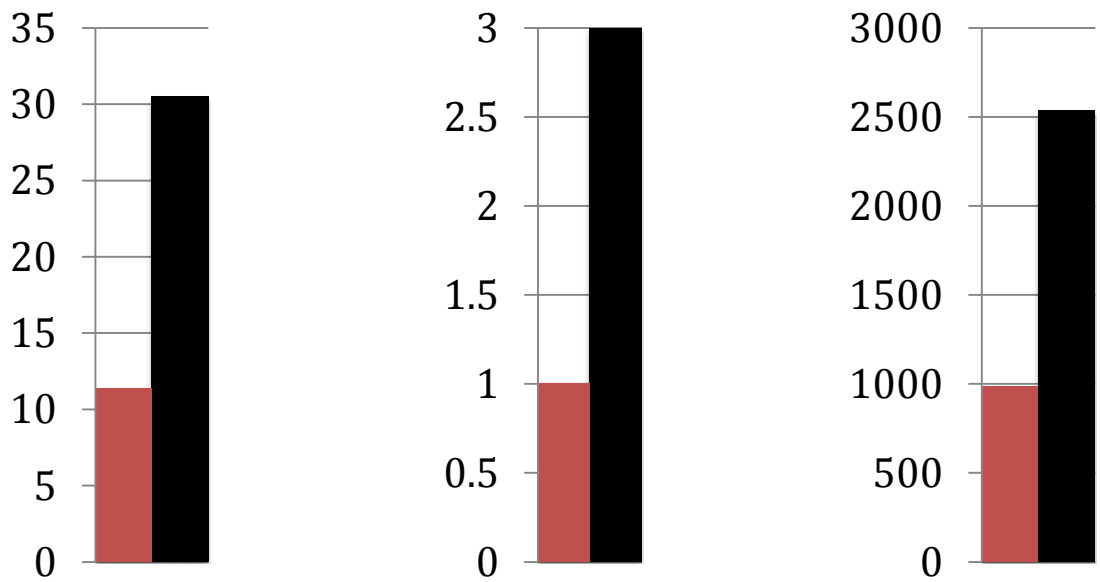
Erosion

Loss of Real Estate

Effects of Development on Pollutant Export

(Line and White, 2007)

	Pollutant Export Rate (kg/ha/yr)		
	TN	**TP**	**TSS**
Undeveloped	11.4	1.0	986
Developed	30.5	3.0	2535



Pollutants

- Nitrogen
  - Atmospheric deposition (car exhaust, etc.)
  - From fertilizer
  - Water soluble
  - Feeds algal blooms
  - Contaminates shallow groundwater

Phosphorus
  - Associated with sediment
  - 1/3 soluble, 2/3 insoluble in water
  - Feeds algal blooms

Excess Nutrients

- Cause algal blooms and eutrophication

2014 Lake Erie algal blooms
Photo Credit: ESA

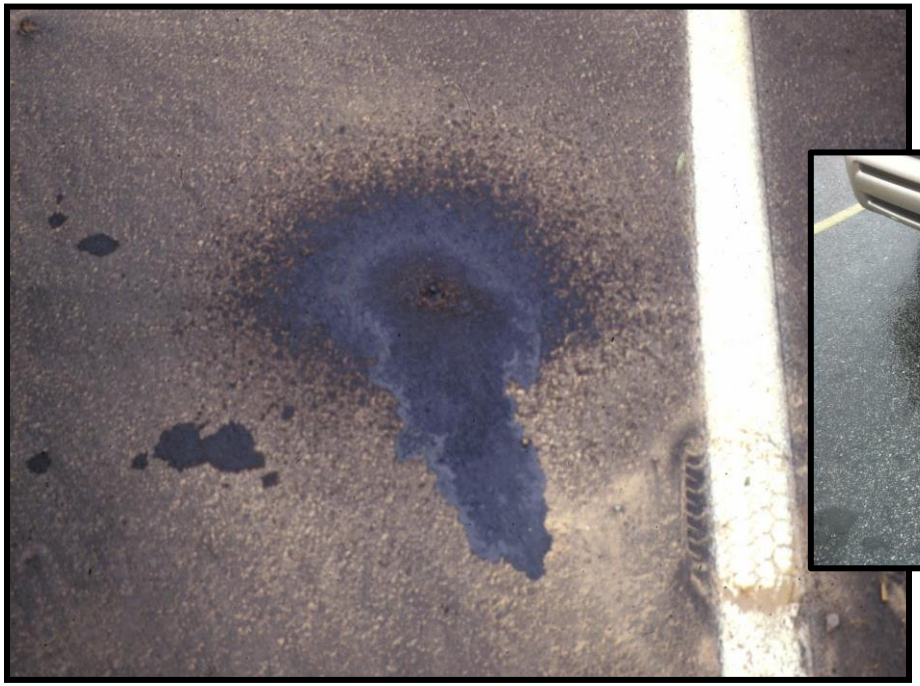
Pollutants

- Sediment
  - # 1 water pollution problem in the USA
  - Often total suspended solids in stormwater
- Heavy Metals
  - Lead, zinc, cadmium, chromium, copper
  - Sources: cars, truck, industrial processes

Construction Site Runoff

Pollutants

- Hydrocarbons
  - Oil, gas, grease, etc. from cars/trucks
- Bacteria
  - Fecal coliform, enterococcus
  - Pet waste, dumpsters, diapers



Bacteria: Good for tourism?

Tourism and Water

The Columbus Dispatch

Bacteria making some Ohio beaches no vacation

28 beaches are under health advisories for E. coli

View Larger

By Reis Thebault

The Columbus Dispatch • Thursday June 11, 2015 12:35 PM

Share 9161 Tweet 71 sharethis 11.9K

More than two dozen beaches across Ohio — most of them on Lake Erie — are contaminated with E. coli, ranking the state among the most-polluted in the nation.

REQUEST TO BUY THIS PHOTO

CHRIS RUSSELL | DISPATCH

Signs warning of high bacteria levels in the water are posted at many Ohio beaches.

As of Wednesday afternoon, 28 of Ohio's 134 public beaches were under bacteria advisories, according to the Ohio Department of

Trash

Trash as a Pollutant?

What Can We Do?

Enter the Stormwater Control Measure (SCM)

- **Flooding**
  - *Detain* runoff and release at controlled rate
- **Increased stormwater volume**
  - *Retain* runoff by infiltration or ET
- **Increased pollutant load**
  - *Treat* captured runoff physicochemically

Traditional Stormwater Controls

- Temporarily detain runoff from large events to release at a rate below pre-developed condition
- *Focus* → Extreme Events
- Examples: retention and detention basins

Lots of Wet Retention Ponds

Dry Detention Basins

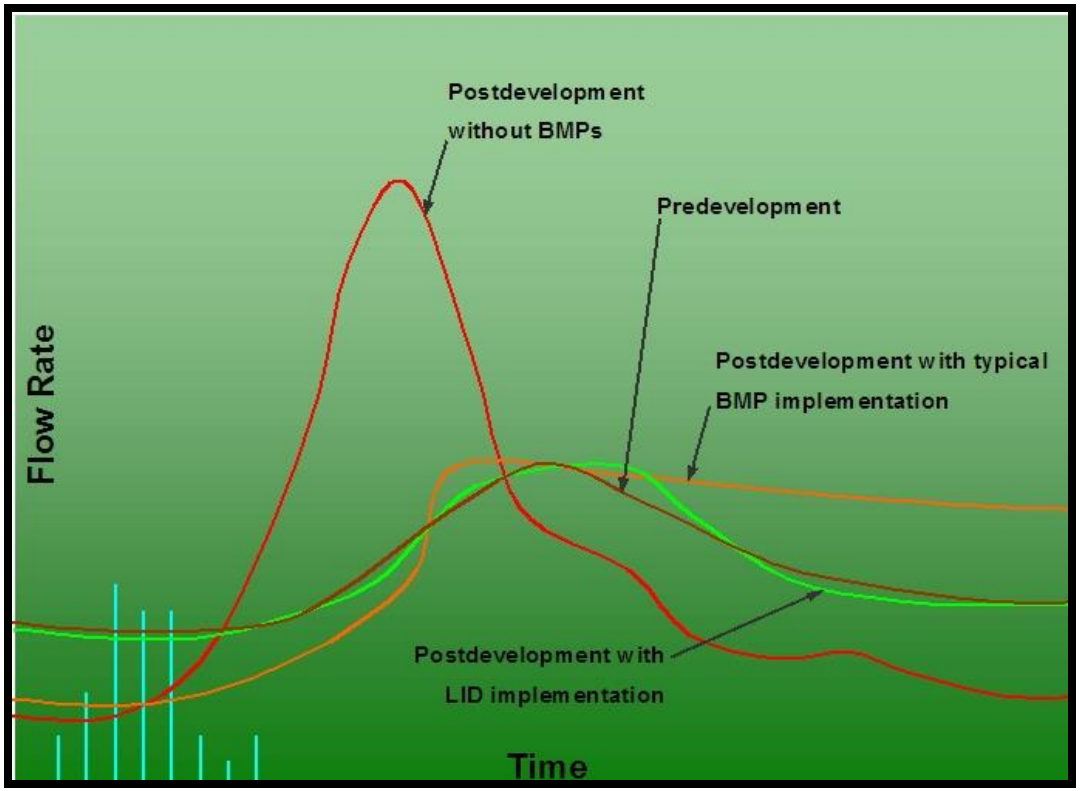
Indeed.

Photo courtesy of Dr. Michael Barrett, Univ. of Texas at Austin

Stormwater Wetlands

Stormwater Wetland?

Low Impact Development

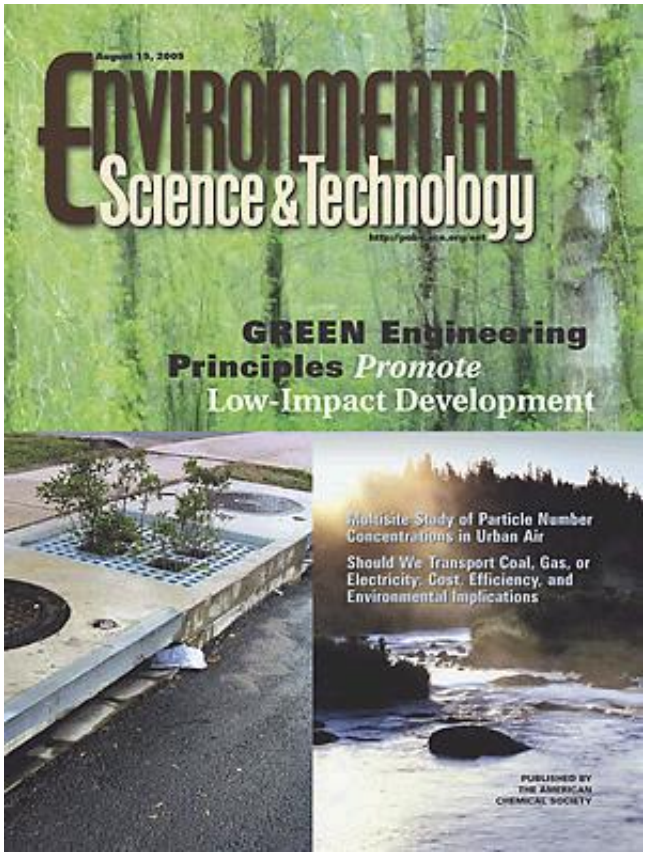


Low Impact Development

- Green Infrastructure
- Environmental Site Design
- Water Sensitive Urban Design
- Sustainable Urban Drainage Systems
- Active, Beautiful, Clean

Low Impact Development

- Pre-development Quantity & Quality
- Keep Stormwater On Site
- Promote Infiltration; more ET
- Filtering and other Natural Treatment Mechanisms



- Apply **Green Engineering** Principles to Land Development

LID Characteristics

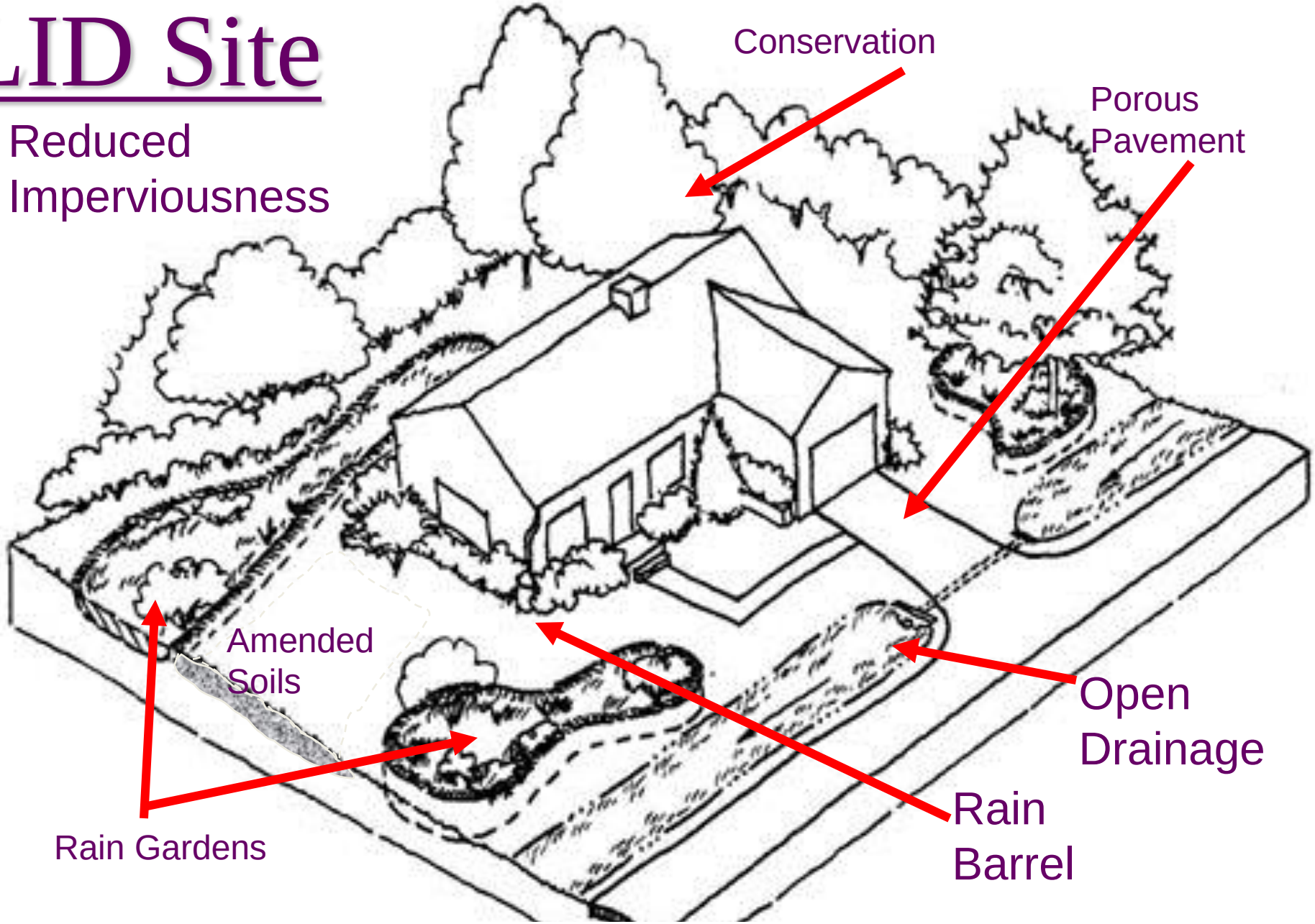
- Distributed practices…
  - Disconnection/reduction of impermeable surfaces
  - Maintaining forest cover
  - Stream buffers
  - Clustered imperviousness
  - Maintain runoff rate and duration of flow
  - Reduce runoff volume through stormwater control measures
  - Mimic water balance

LID Stormwater Controls

- Infiltration-based
  - Contact with vegetation and soil/specialized media
- *Focus* → First Flush (80-90% of annual runoff vol.)
- Examples: vegetated swales, filter strips, infiltration basins, permeable pavement, and bioretention

LID Site

Reduced Imperviousness

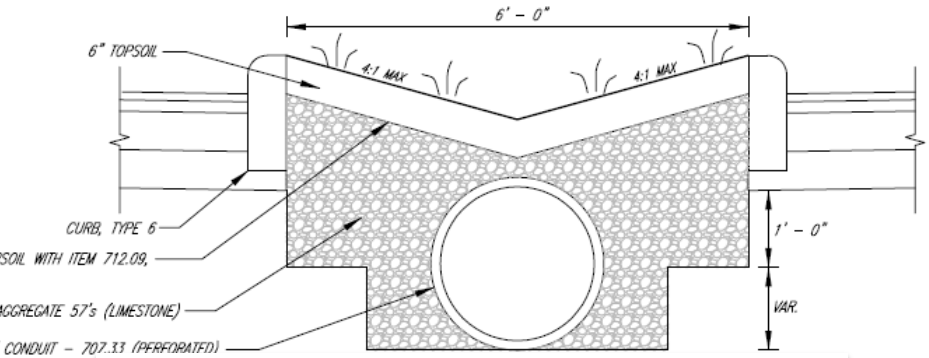


Commercial LID site

LID Designer Needs Tools

- Stormwater controls used must help mimic Pre-development hydrology

Vegetated Swales

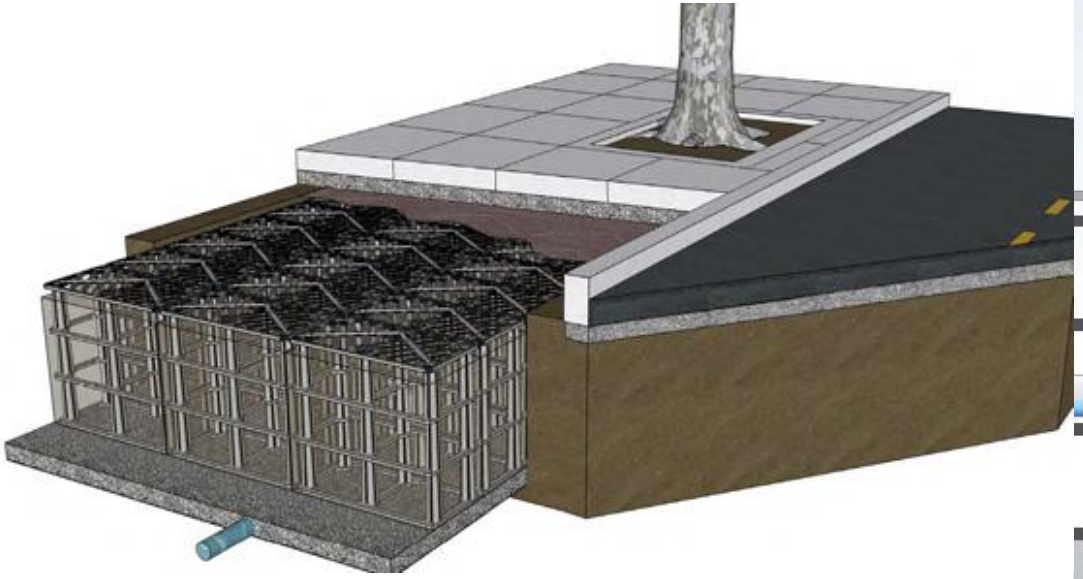


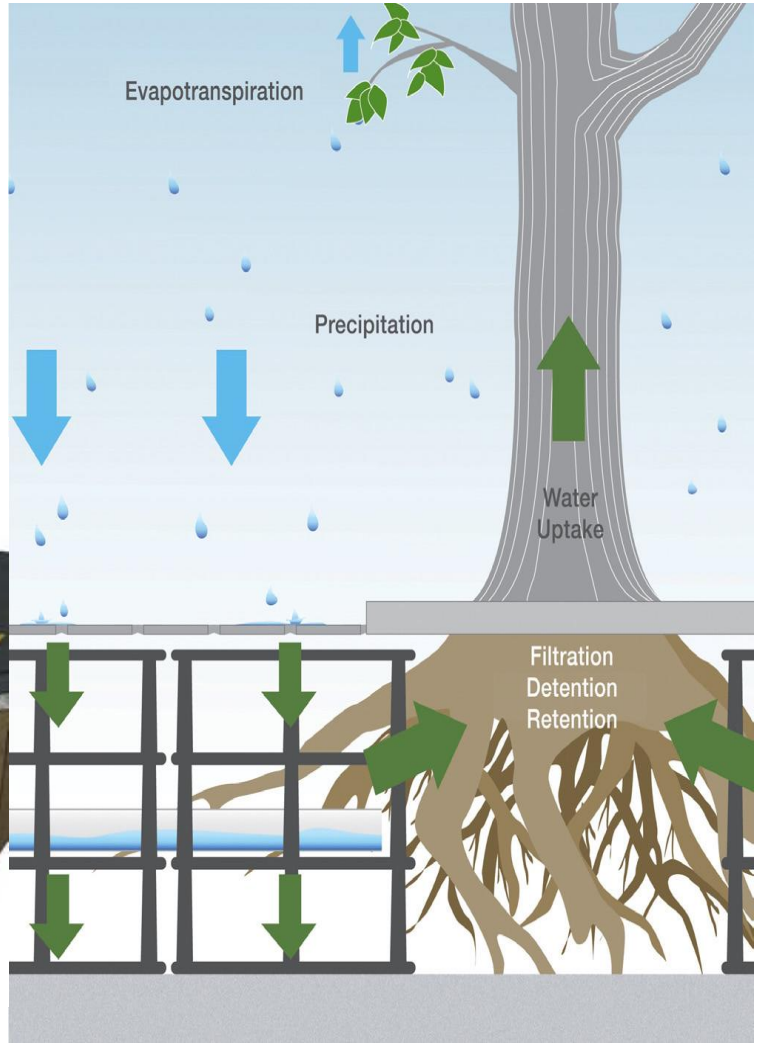
Filter Strips

Cisterns / Water Harvesting

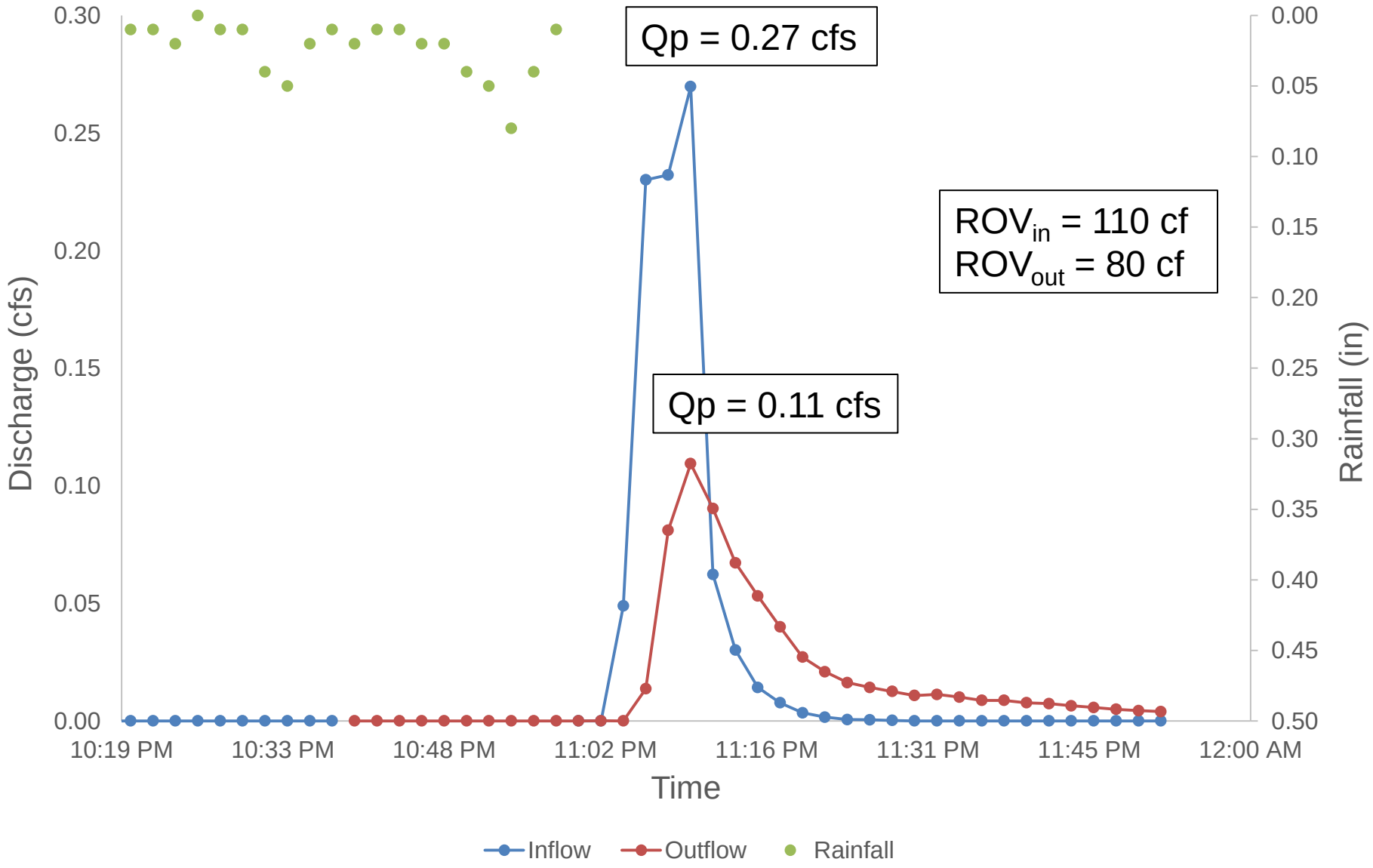
Street Trees for Stormwater Management

- Quantify impacts of a single tree/soil filter
  - Hydrology
  - Water quality



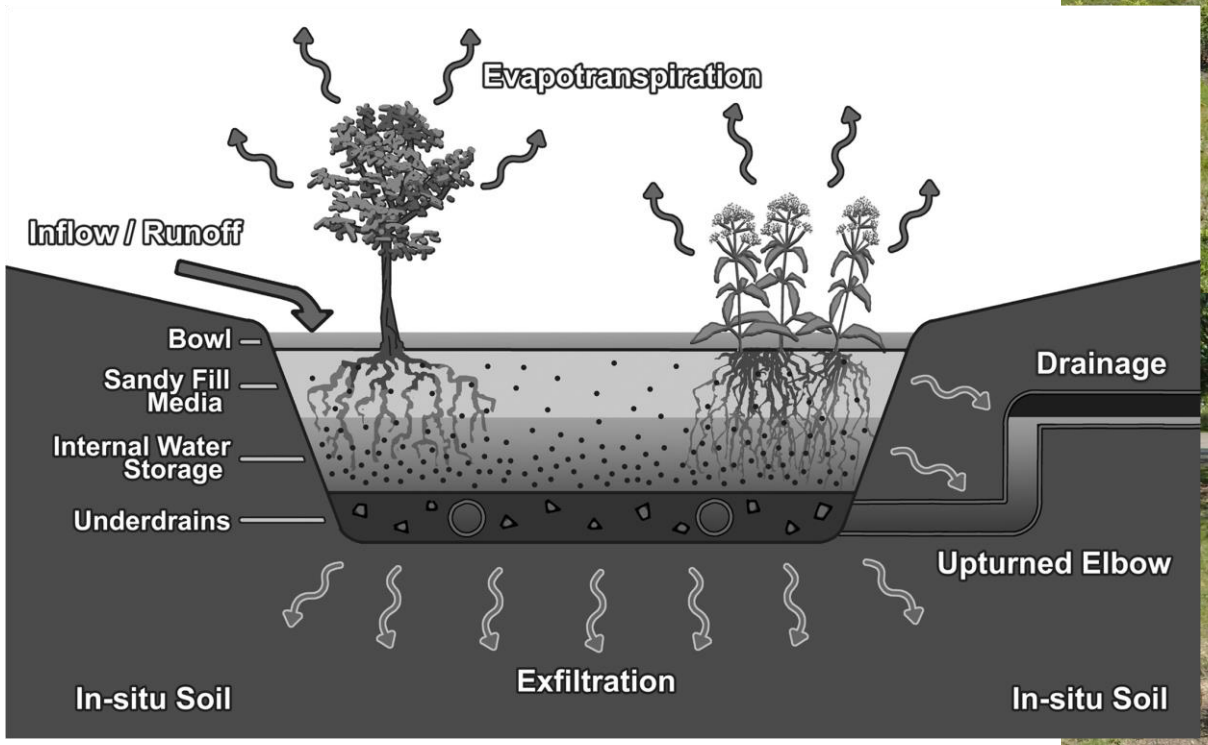


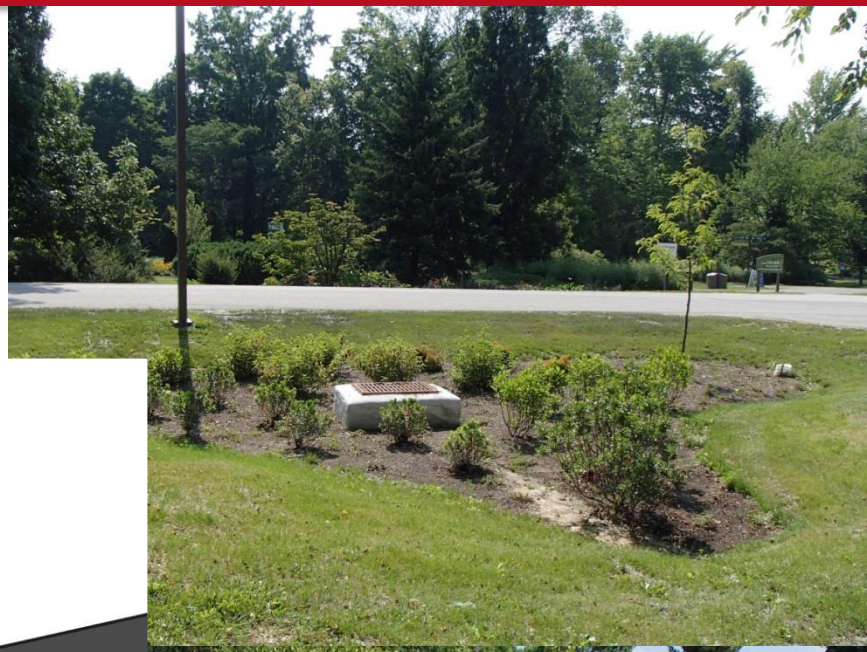
0.52" Rainfall Event - September 2, 2012



Page et al. (2015), *Ecological Engineering*

Bioretention Cells



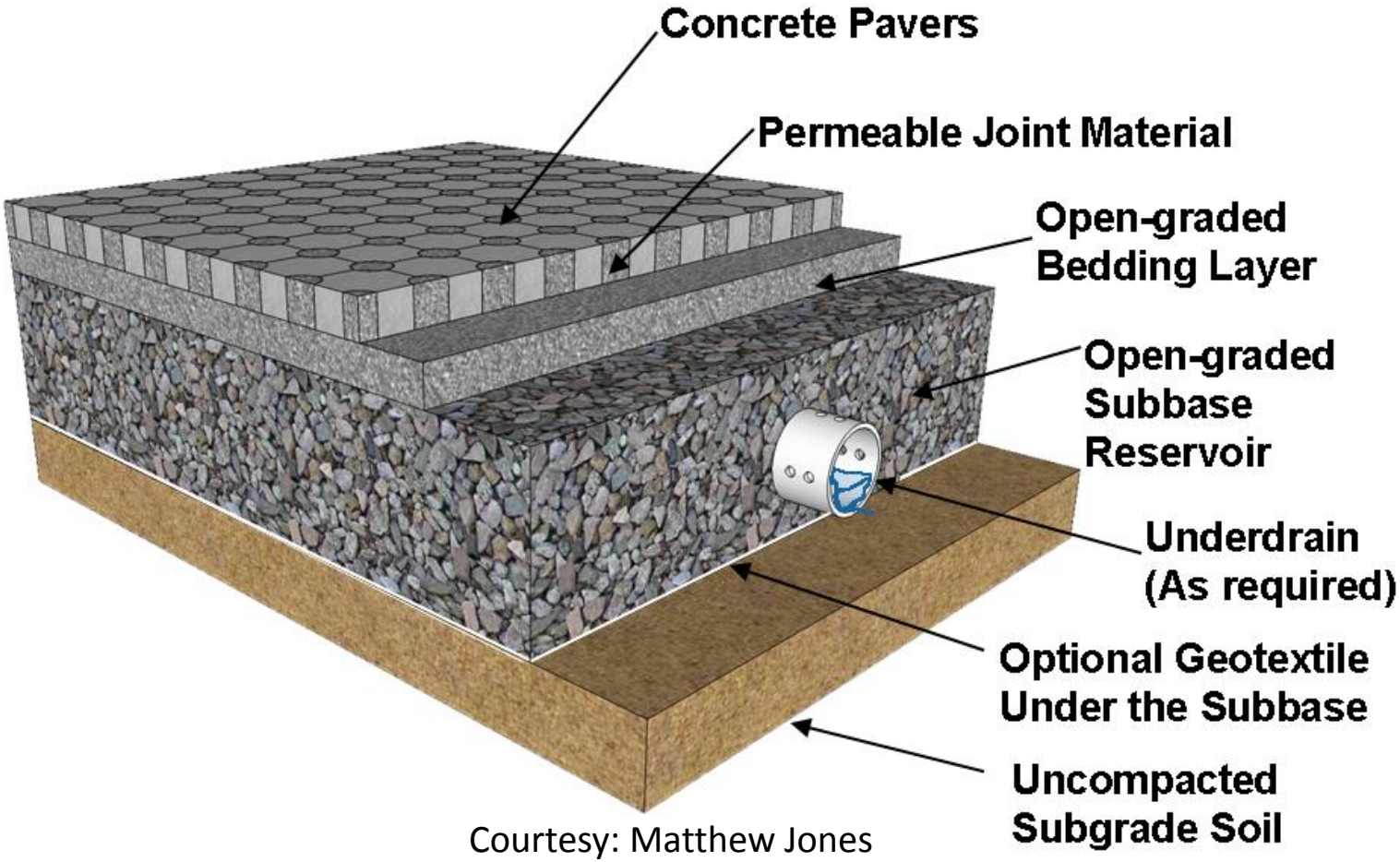


+ 4 Hours

+14 Hours

- No water in bowl within 24 hours of end of rainfall
- Media drained within 48 hours

Permeable Pavement Typical Cross-Section



Courtesy: Matthew Jones

Monitoring Sites: Northern Ohio

Green Roofs/Walls

Soil Preservation & Restoration

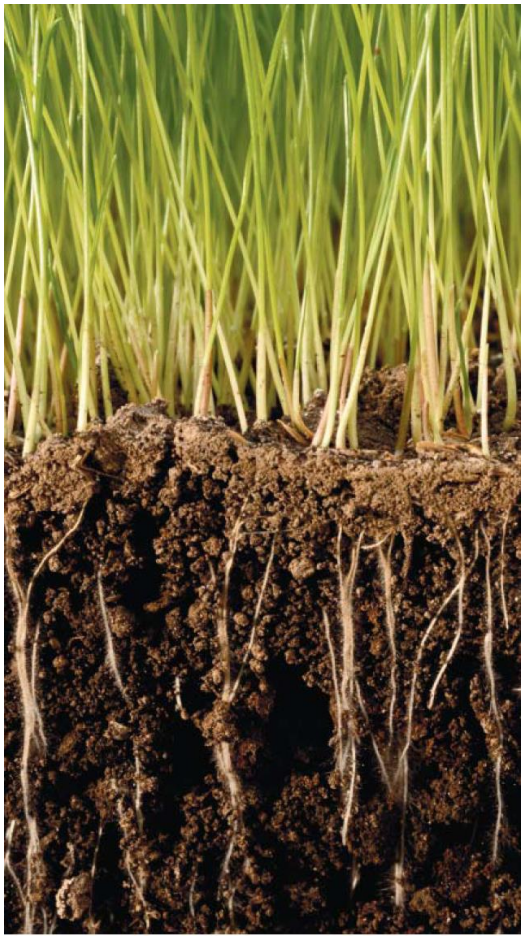


Photo from King County , Washington

- Healthy soils reduce runoff
- Minimize soil disturbance and protect soil from compaction
- Restore disturbed soils
  - Till subsoil to 15-18”
  - Incorporate compost top 12”
  - Replace topsoil to min. 4” depth

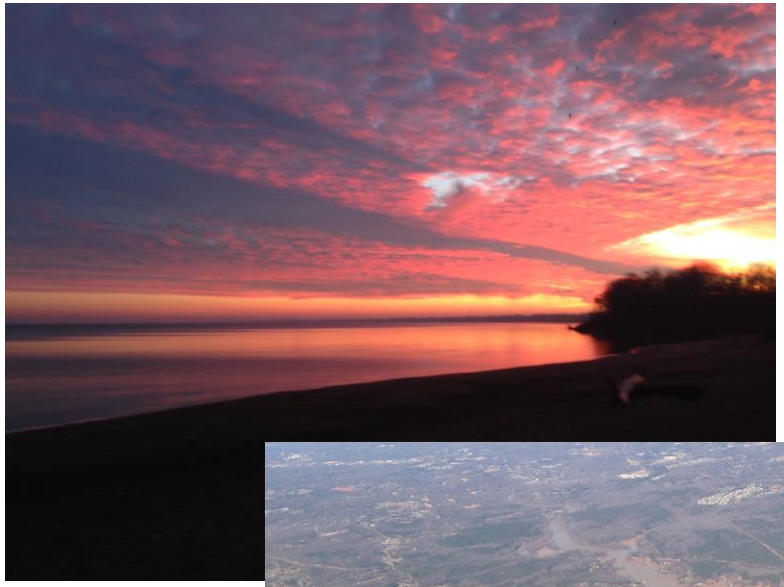
Old Metrics for BMP Success

- Peak Flow Reduction
- Percent Removals
- Adding Percent Removals for Multiple Treatments (BMP math)

BMP	Median TSS Removal (%)
Dry Pond	47
Wet Pond	80
Stormwater Wetland	76
Filtering Practices	86
Infiltration Practices	95

- Example:
  Dry pond + bioretention
  - 0.14*100 mg/L = 14 mg/L
  - 0.53*14 mg/L = 7 mg/L?
  - Hard to clean “clean water”

Stormwater Management Goal: The Bottomline

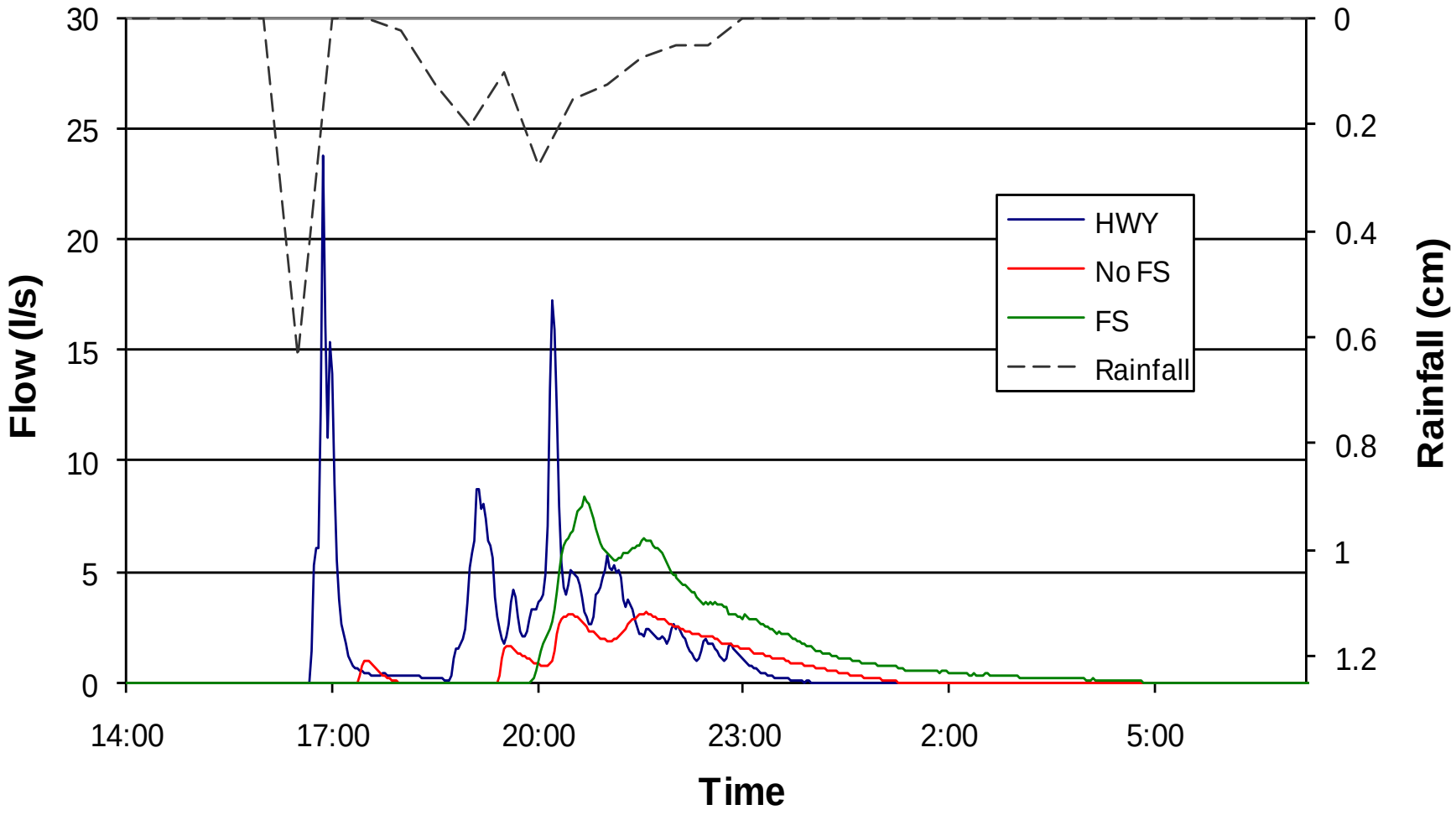


- Preserve and/or Improve the Quality of Downstream Water Bodies
- We care about:
  - Water Quality
  - Flooding
  - Stream Integrity
  - Annual Hydrology
  - Benthic & Fauna Health

New Metrics for Success

- Volume Reduction through increased:
  - Evapotranspiration
  - Infiltration/Exfiltration
- Matching long-term hydrology
- Pre/Post Development Flow Duration
- Matching streamflow magnitude (per watershed acre basis)
- Effluent concentrations compared to in-stream concentrations
  - Numeric effluent limits
- Effluent temperature & thermal load
- Provisioning of ecosystem services

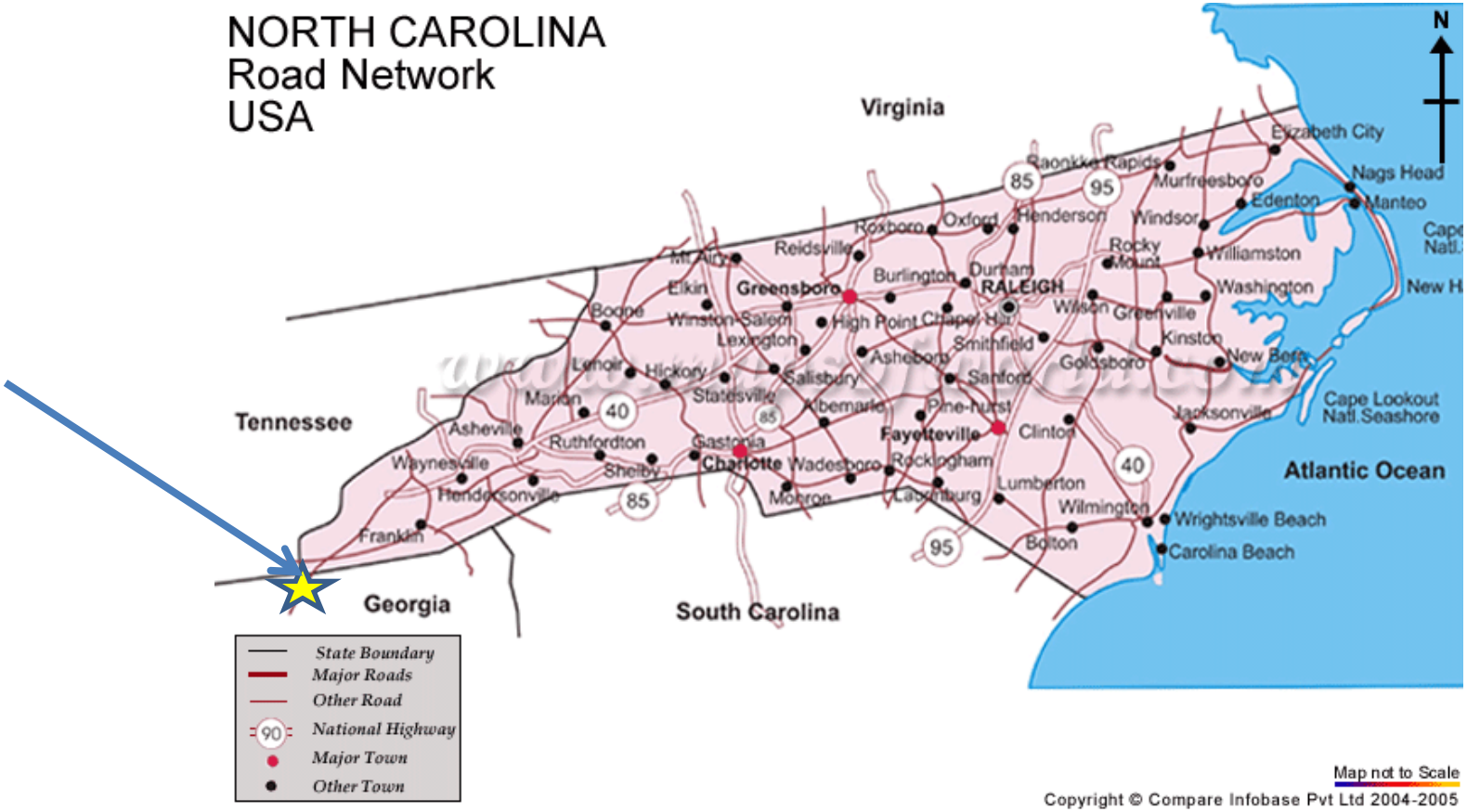
Swale Hydrograph: Volume Reduction



Davis et al. (2012) *Water Research*

Establishing the Target Condition

- In North Carolina, Coweeta
  - US Forest Service Research Station



Establishing Target Condition

- Coweeta Hydrologic Laboratory
  - Forested mountain watersheds
  - Longest Term Hydrologic Record (Runoff, Infiltration, and ET) in the world for a forest site
- Records used for this study were 37 and 50 years old
  - Rain Shed Mountain Region
- Drawback: Annual Precipitation in excess of 60”
  - Data From Swift, LW, G.B. Cunningham, J.E. Douglass. 1987. “Climatology and Hydrology.” *Forest Hydrology and Ecology at Coweeta*. Eds: W.T. Swank and D.A. Crossley. Springer Verlag. New York, NY, pp 35-57.

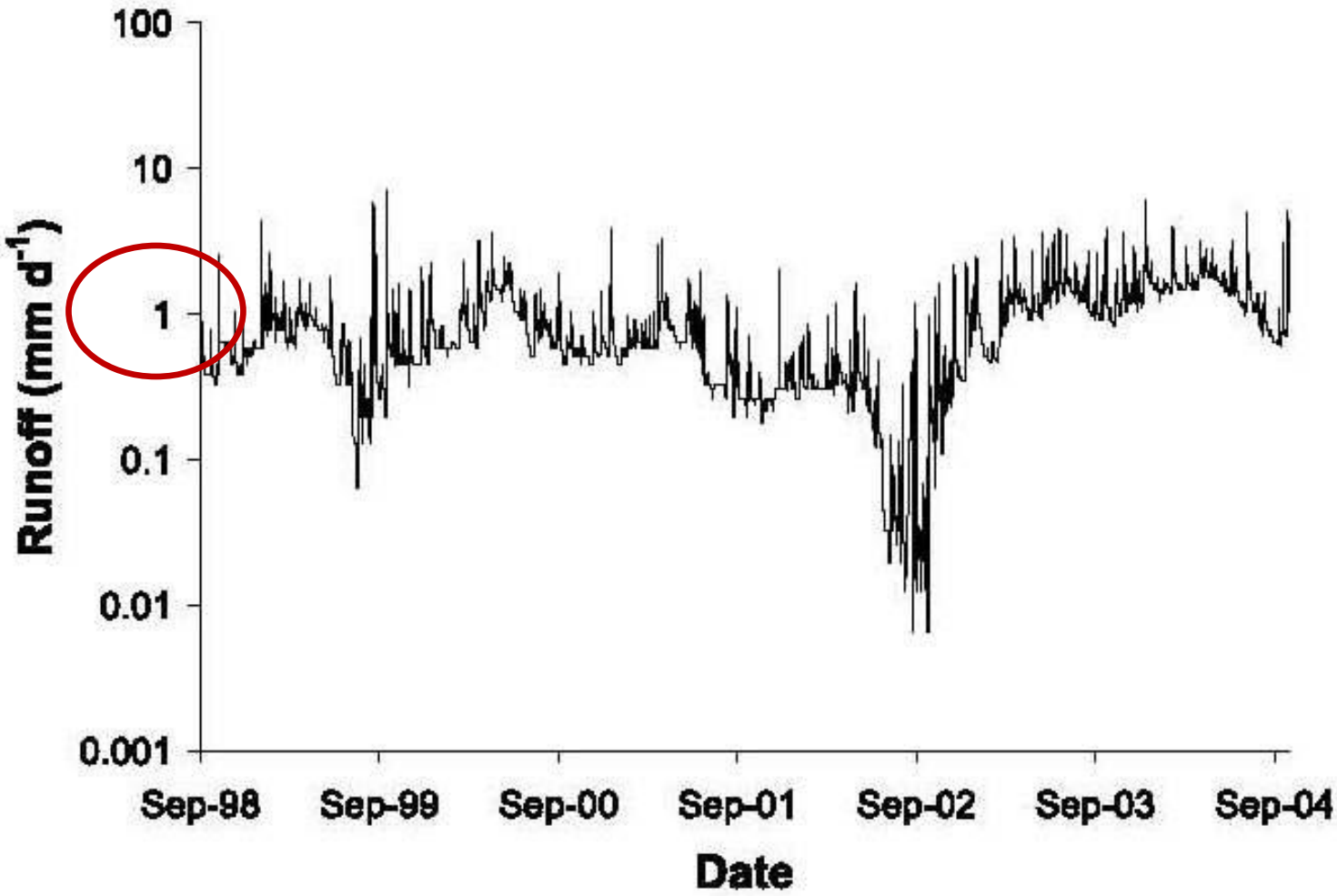
Establishing Target Condition

Annual Hydrologic Fate	Average Amount	Percent of Total Precipitation
Precipitation	1770 mm (70 in)	100%
Runoff	80 mm (3 in)	5%
Evapotranspiration	890 mm (35 in)	50%
Infiltration	800 mm (31 in)	45%
Shallow Interflow	770 mm (30 in)	44%
Deep Seepage	30 mm (1 in)	2%

All values rounded to the nearest 10 mm or 1 in.
Infiltration is the sum of Shallow Interflow and Deep Seepage

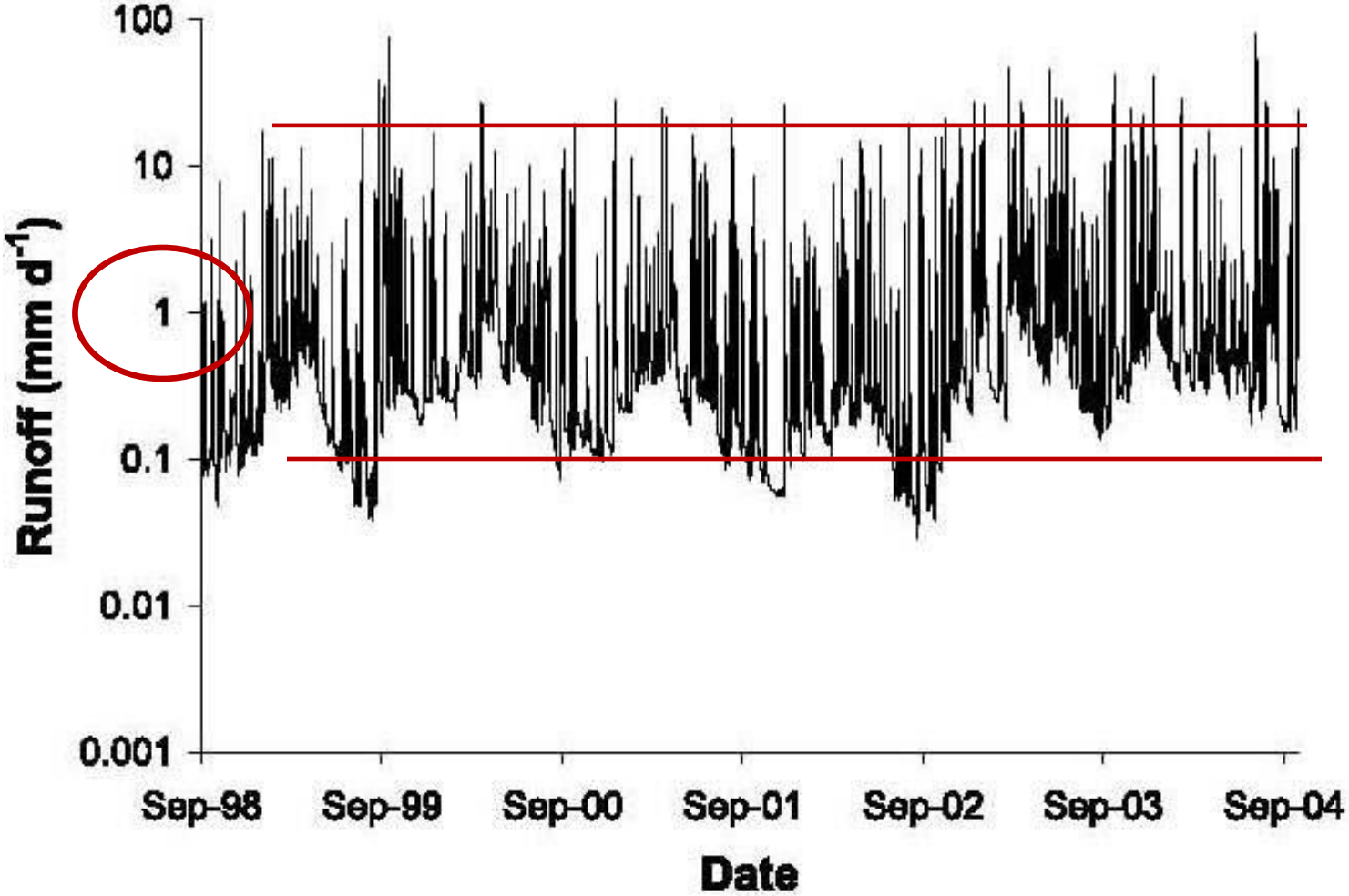
LID Metrics: Should We Look to Streams for the Answer?

Forested Stream Flow



Shields et al. (2009). *Water Resources Research*

Urban Stream Flow

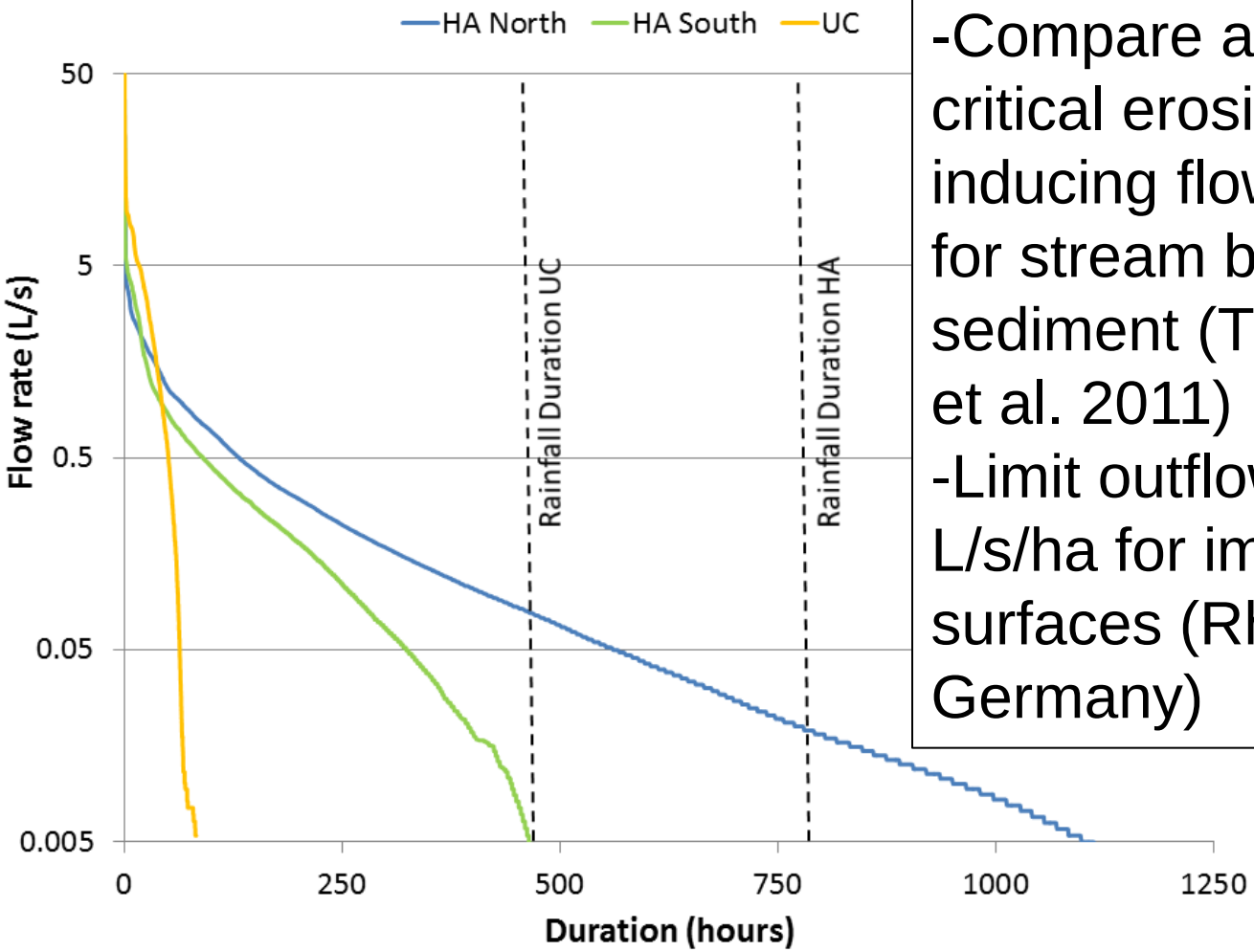


Shields et al. (2009). *Water Resources Research*

Flow Duration

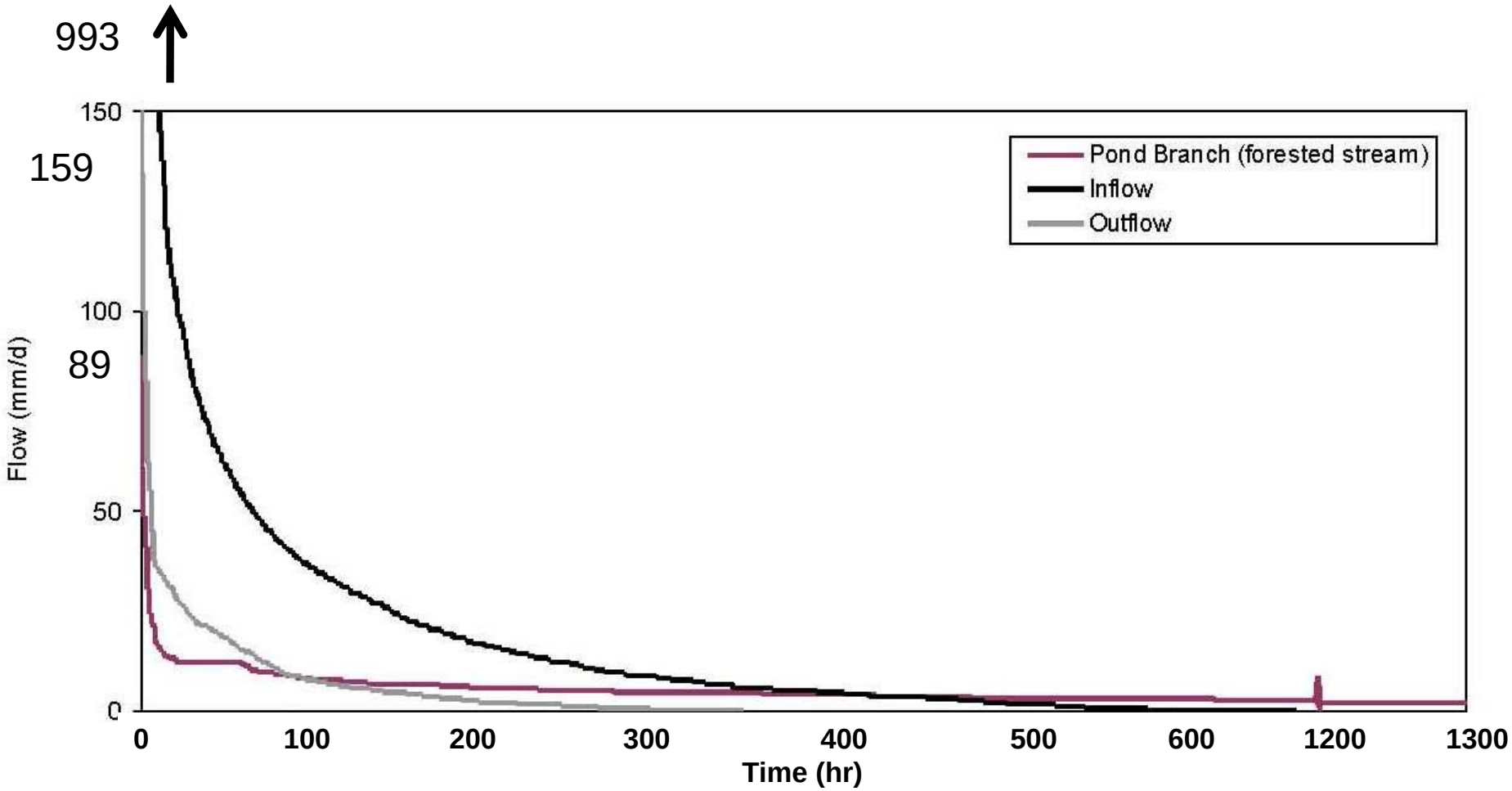
- Evaluate all flows over a long-term period of interest (not just peaks)
- Rank flows from smallest to largest
  - 2-minute intervals (stormwater)
  - 15-minute intervals (streams)

Flow Duration (NE Ohio Bioretention)



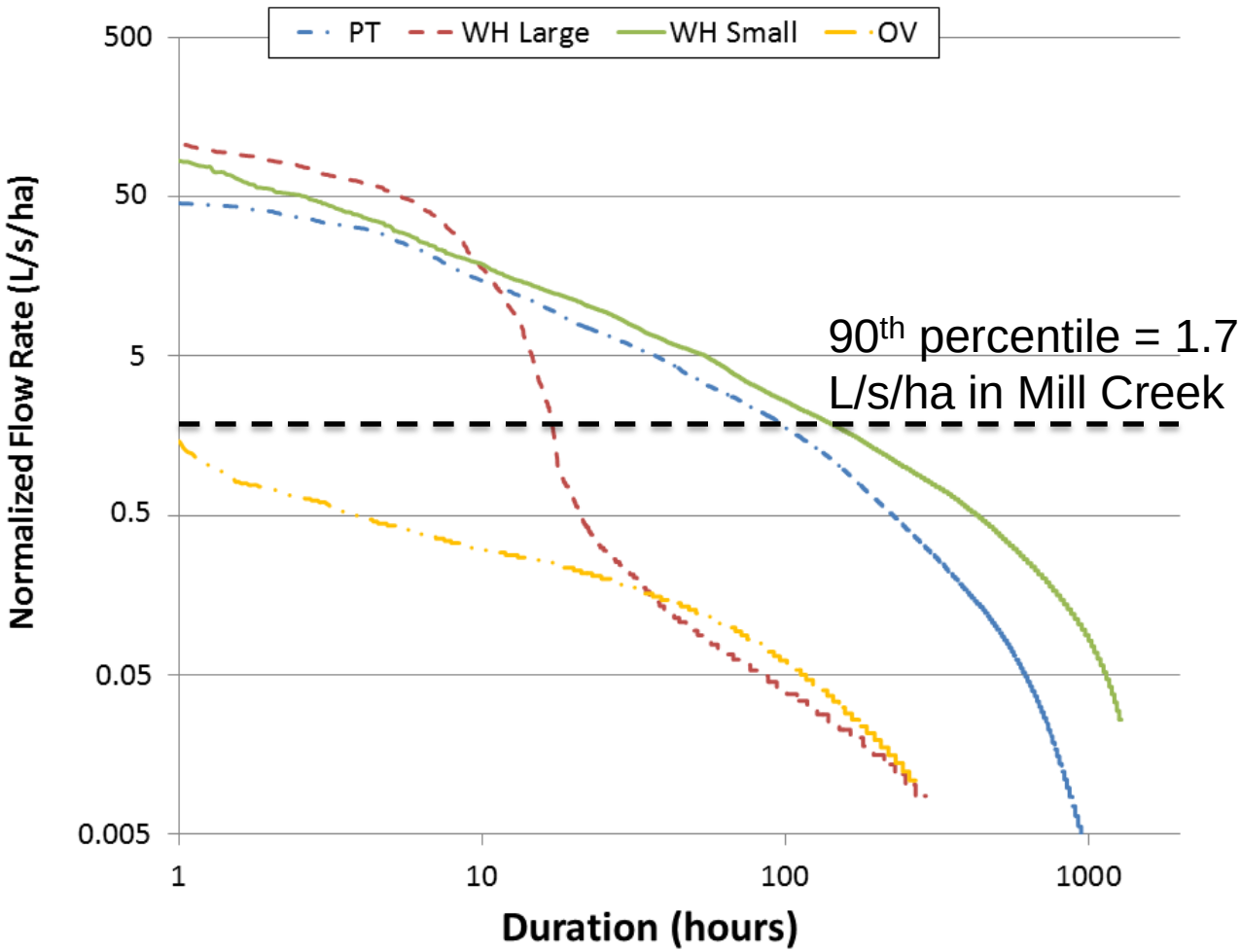
-Compare against critical erosion inducing flow rates for stream bank/bed sediment (Tillinghast et al. 2011)
-Limit outflow to 15 L/s/ha for impervious surfaces (Rhineland, Germany)

Bioretention (Maryland)



Olszewski & Davis (2013) *Journal of Irrigation and Drainage Engineering*

Permeable Pavement (NE Ohio)



- Compare to nearby agricultural watershed (Mill Creek, OEPA 2011)
- Four permeable pavements had outflow <1.7 L/s/ha between 88%-100% of the time
- High flows similar to or better than agricultural watershed

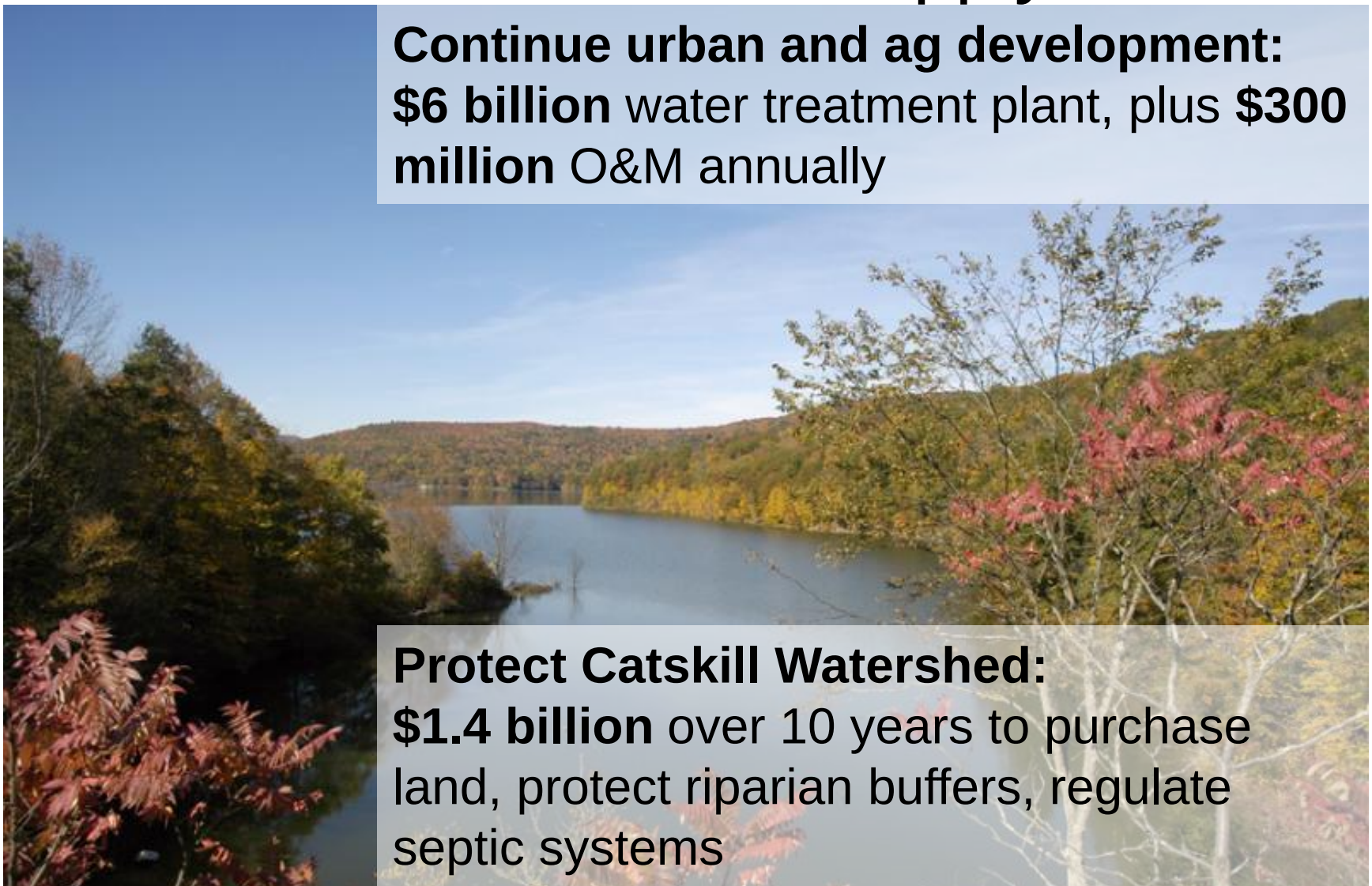
Ecosystem services defined

Ecosystem services are the benefits people obtain from ecosystems. These include:

1. **Provisioning services** such as food and water
2. **Regulating services** such as regulation of floods, quality of air and water
3. **Habitat services** to maintain biological and genetic diversity
4. **Information services** such as recreational, educational, and other cultural benefits

–Millennium Ecosystem Assessment, UN

Valuing ecosystem services: case of the NYC water supply



Continue urban and ag development:
$6 billion water treatment plant, plus **$300 million** O&M annually

Protect Catskill Watershed:
$1.4 billion over 10 years to purchase land, protect riparian buffers, regulate septic systems

Summary

- LID/GI methods use distributed stormwater controls as opposed to pond/pipe mentality
- Volume reduction/annual hydrology/flow duration in relation to stream health more important than peak attenuation
- Other ecosystem services derived from vegetated systems

QUESTIONS?