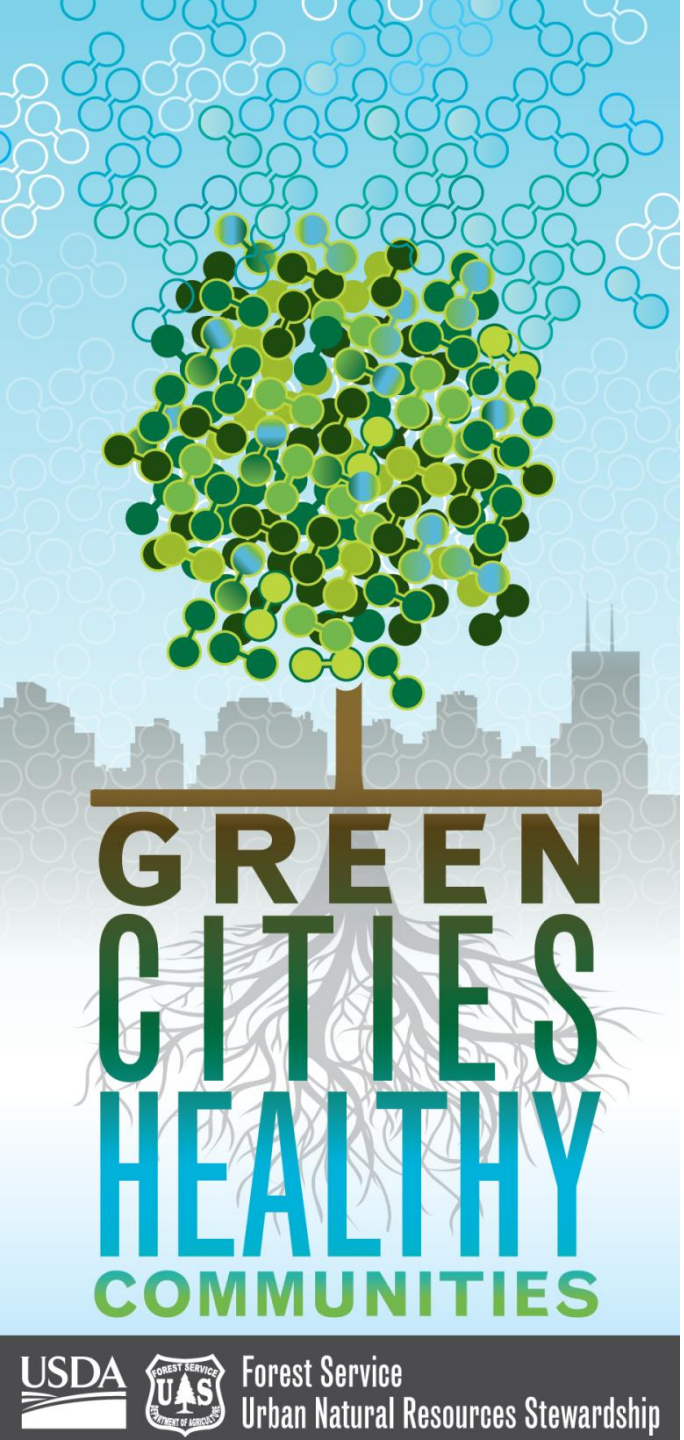

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More Than Good Looks: How trees influence urban stormwater management in green infrastructure practices

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More Than Good Looks:

How trees influence urban stormwater management in green infrastructure practices

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Urban Forest Connections Webinar Series

May 8, 2019

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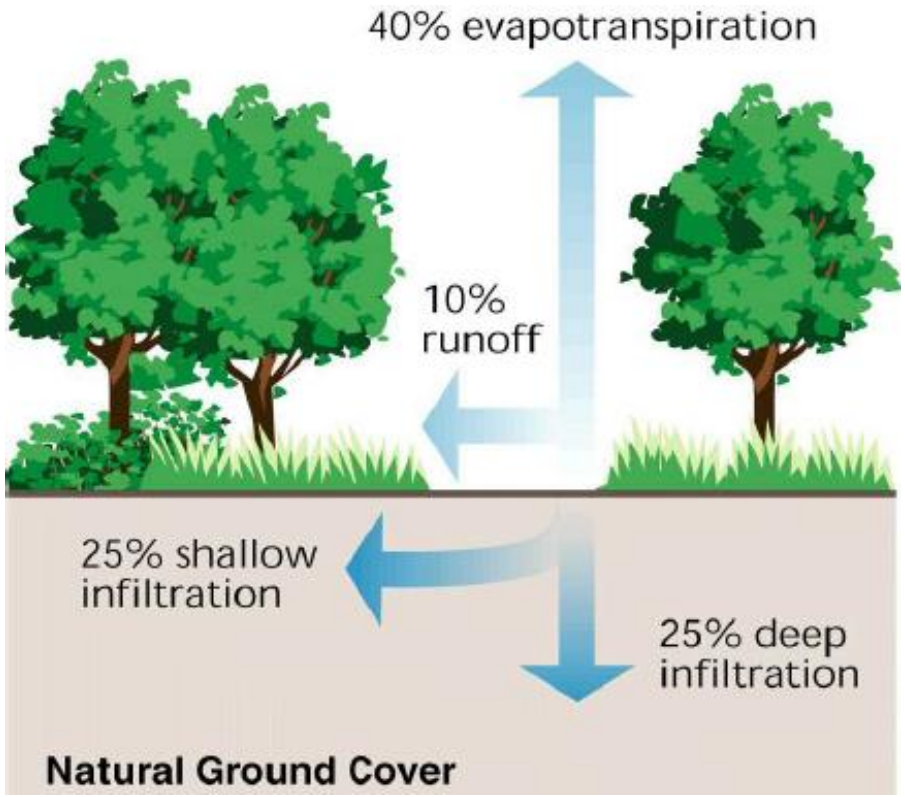
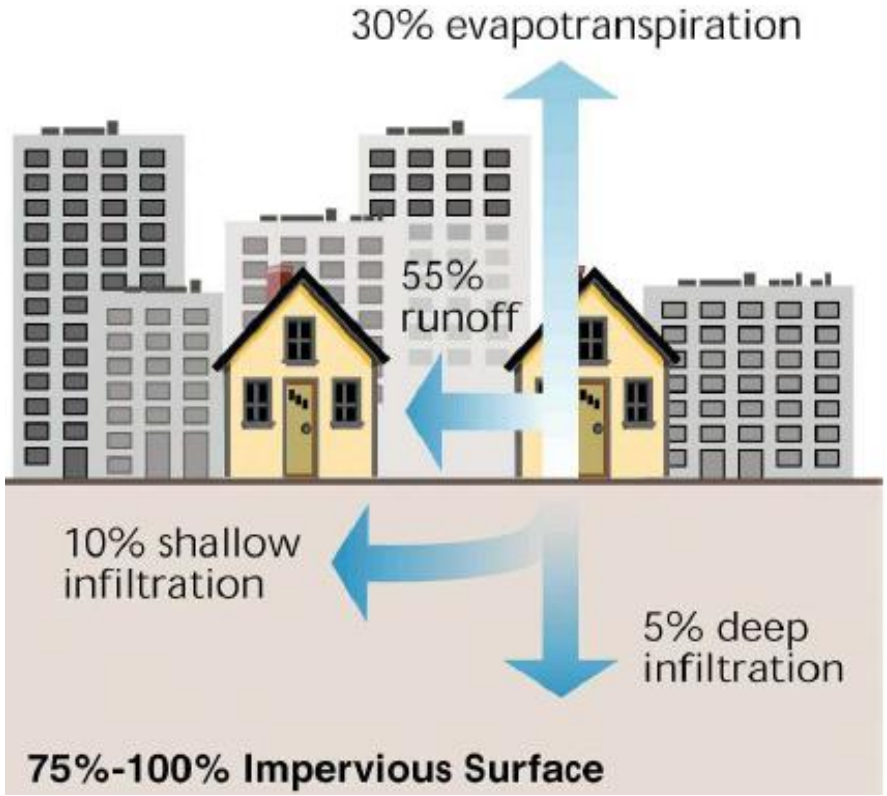
Urban Stormwater Challenges





- Impervious surfaces limit infiltration, increase runoff quantity delivered to receiving waters, leading to degraded stream conditions
- Pollutants associated with urban areas (sediment, nutrients, heavy metals) impact chemistry and aquatic ecosystems of receiving waters

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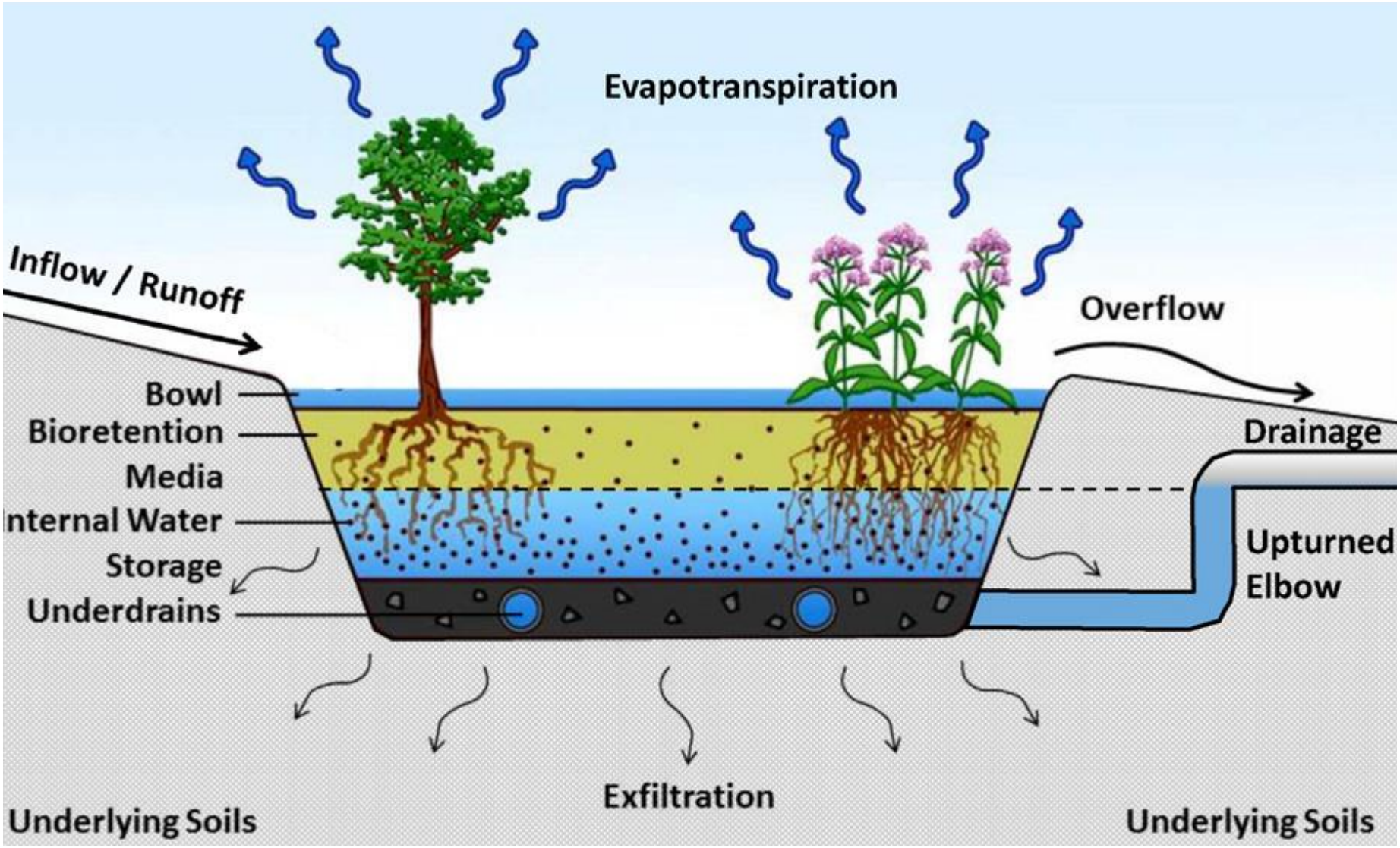
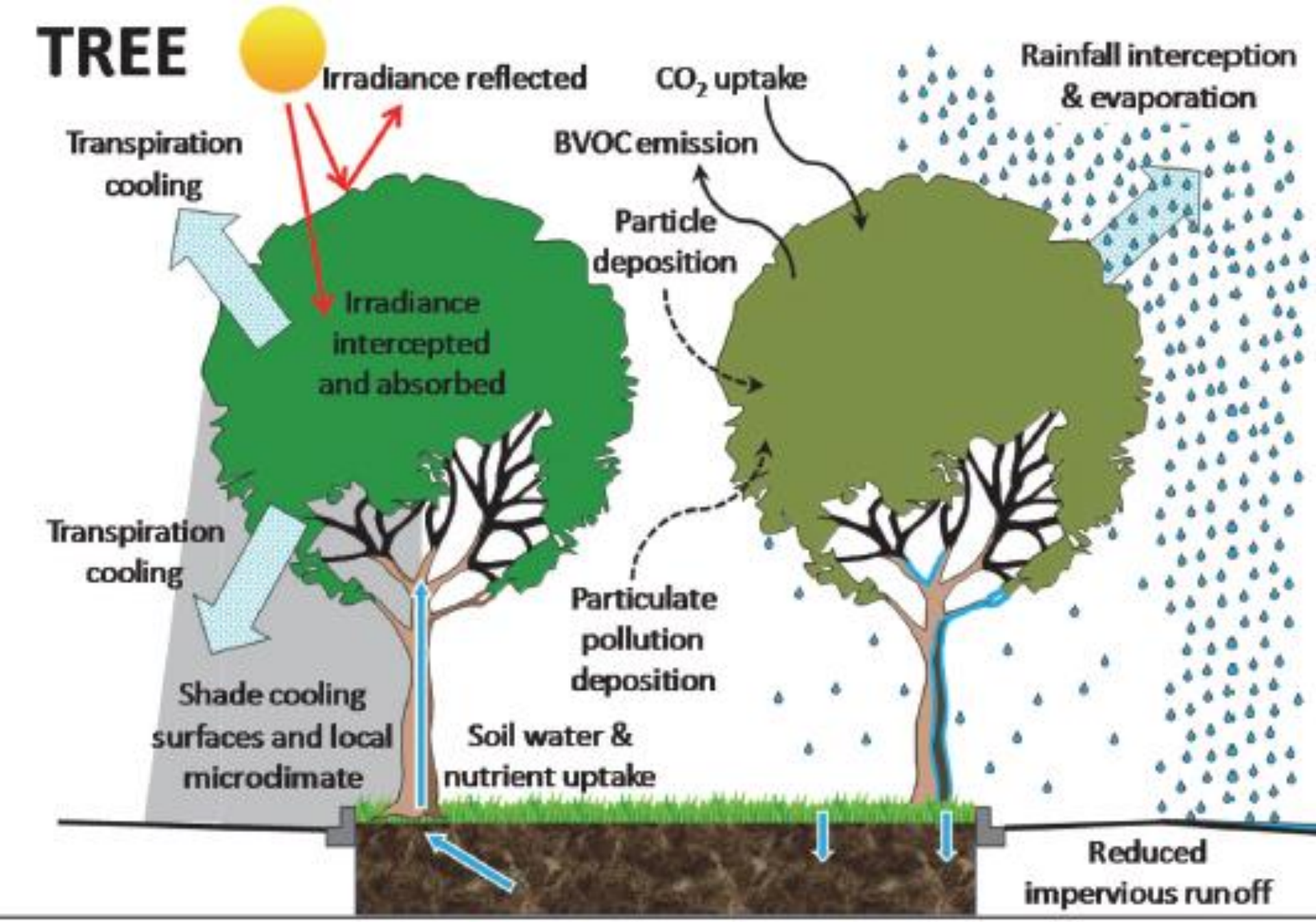
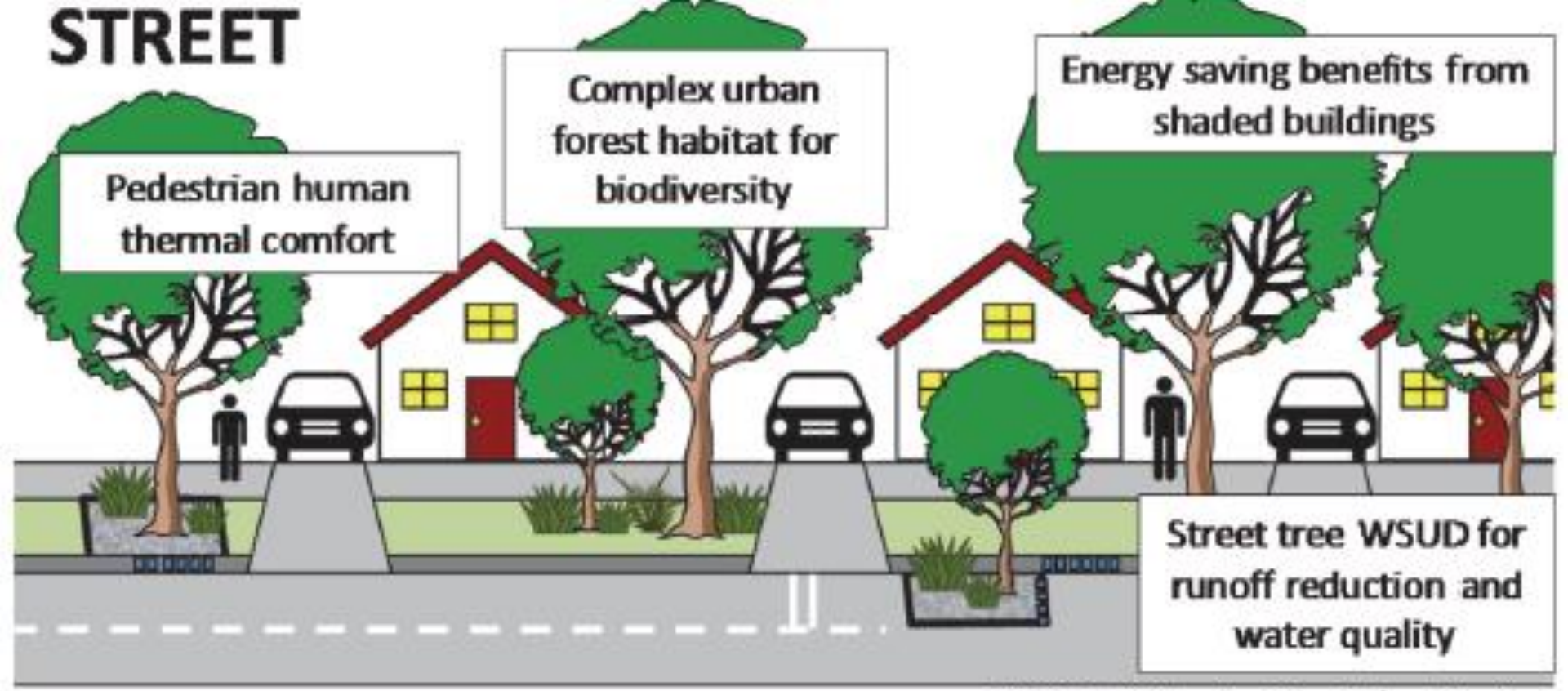
Bioretention Practice: Overview





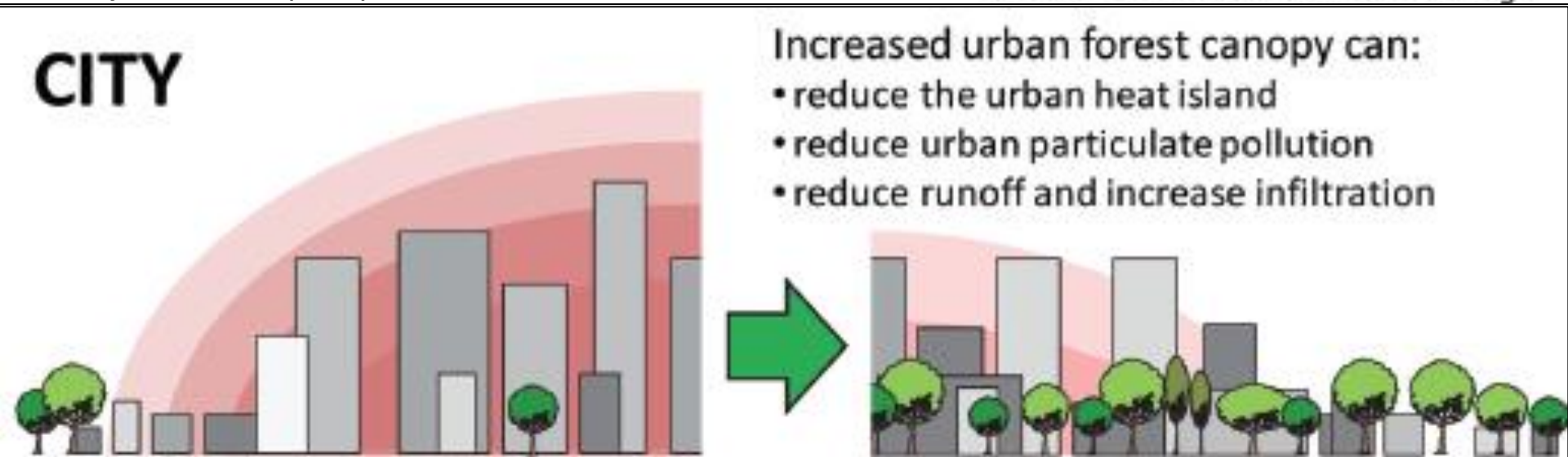
BVOC = Biological volatile organic compounds

Livesley, S. J. et al. (2016)



Livesley, S. J. et al. (2016)

WSUD = Water Sensitive Urban Design



Knowledge Gaps

- Many studies are limited to grasses, shrubs, and sedges, leaving the need to explore other plant types in bioretention
- Few studies have explored the specific role of trees in bioretention
- Very little research has produced guidance for tree species selection based on physiological aspects that may account for performance contributions

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Research Overview

Study 1

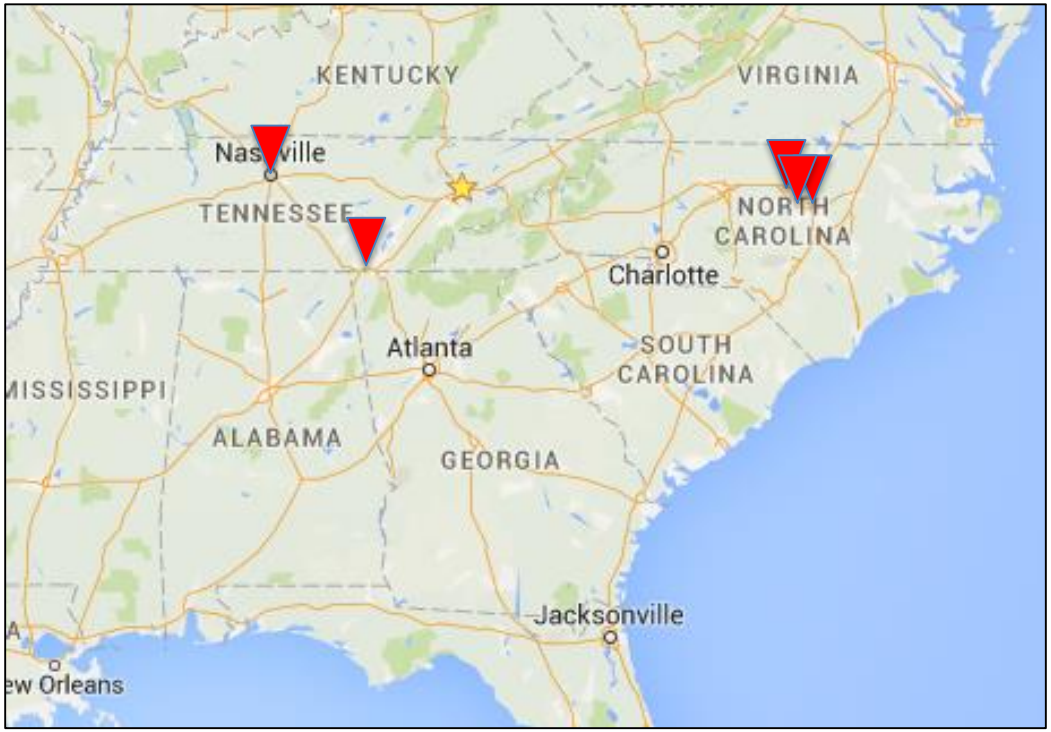
Field health survey of trees in existing bioretention practices in Tennessee and North Carolina

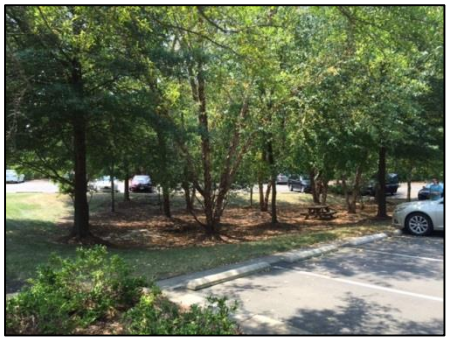
Study 2

Field-scale study of two suspended pavement systems designed to function as bioretention practices

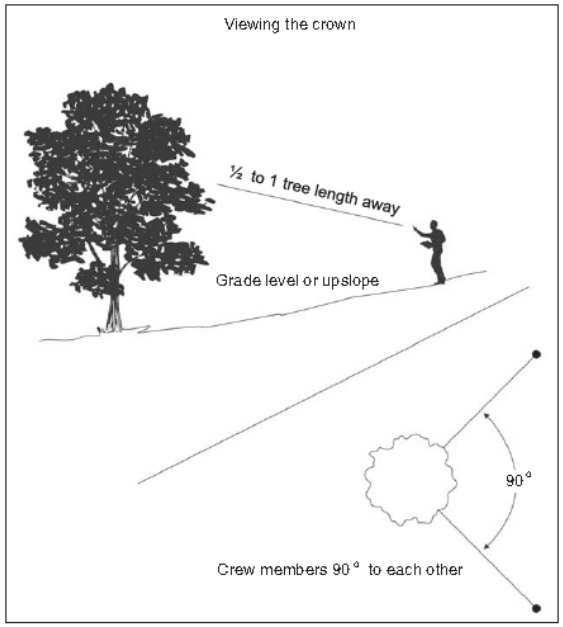
Bioretention Tree Health Surveys

- June-August ‘15
- 38 practices
- 97 trees from 22 species
  - Six species accounted for ~75% of total

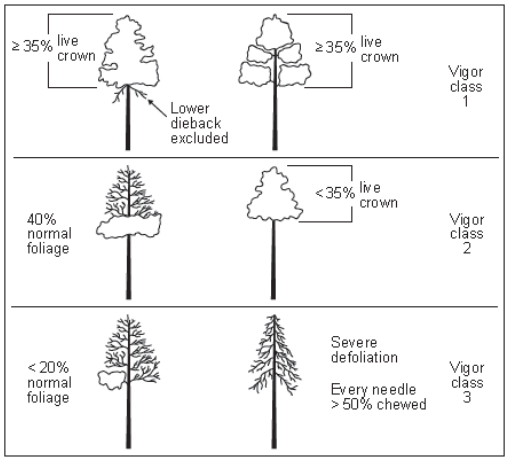




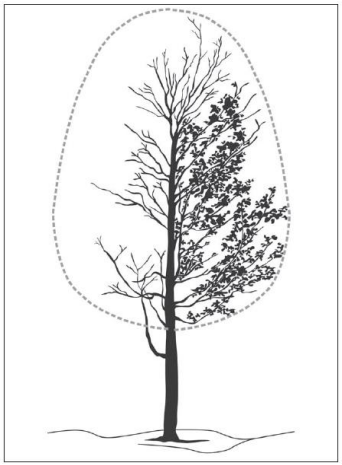
Crown Condition Indicators



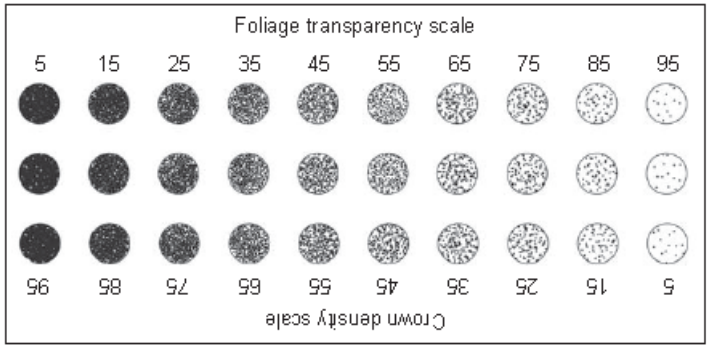
Rating Crown Condition Indicators



Vigor Class

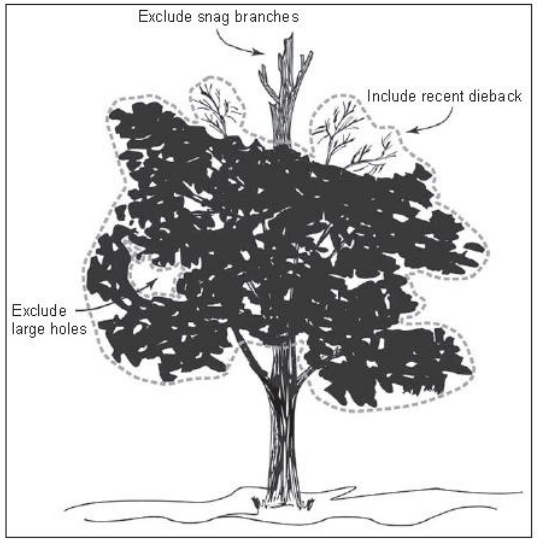


Crown Density



Density/Transparency Scale

Foliar Transparency



Crown Dieback

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Composite Crown Indicators (CCI)

- Tree health based on 3D crown shape:
  - Crown Volume

$$CCV = \left(0.5\pi R^2 (CL)\right)\left(\frac{CDEN}{100}\right)$$

  - Crown Surface Area

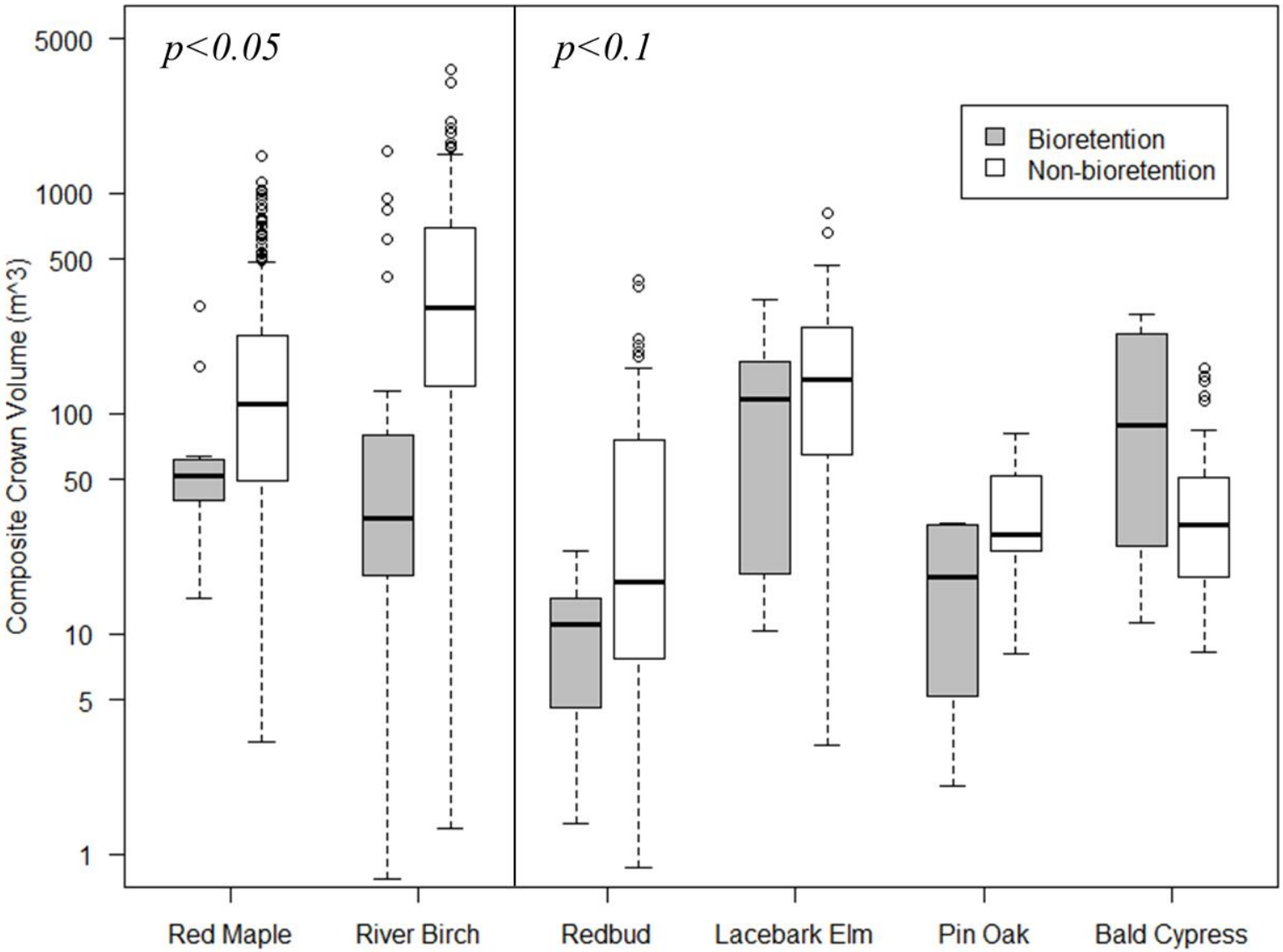
$$CSA = \frac{4\pi CL}{3R^2}\left[\left(R^2 + \frac{R^4}{4CL^2}\right)^{1.5} - \left(\frac{R^4}{4CL^2}\right)^{1.5}\right]\frac{CDEN}{100}$$

- **Larger CCI Values = Increased Tree Health**

Zarnoch et al. (2004)

How does the health of bioretention trees compare to other urban trees?

Bioretention vs. Non-bioretention Trees



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Comparing Tree Health

- Many species were *less healthy* in bioretention
- Incompatibility with species-specific growing preferences for soil moisture, texture, etc.

Species	***Soil pH***	***Saturated or very wet soil***	***Moist, well-drained soil***	***Occasionally dry soil***	***Very dry soil***
Bald Cypress	4.5-6.0				
Pin Oak	4.5-6.5				
River Birch	3.0-6.5				
Red Maple	4.7-7.3				
Redbud	5.0-7.9				
Lacebark Elm	4.8-7.0				

Bassuk et al. (2009)

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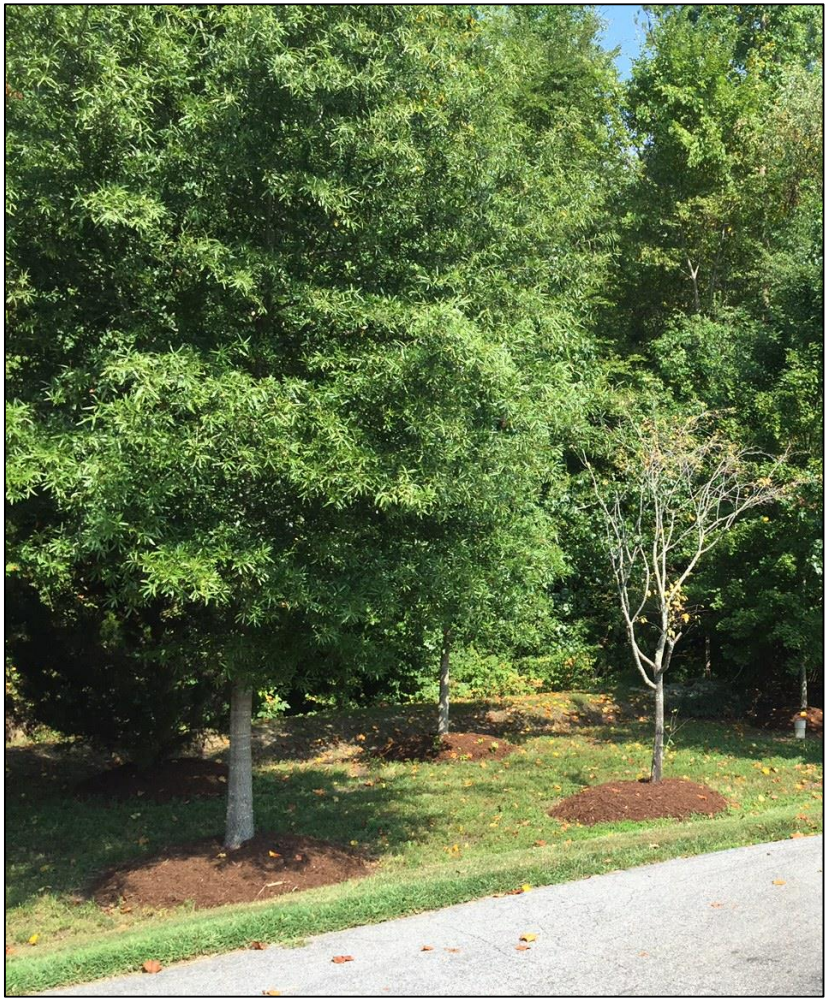
Comparing Tree Health

- **Eastern redbud:** not found in sandy soils
- **River birch:** prefer tight clay soils, high soil moisture
- **Pin oak:** found in heavy-textured, poorly drained soils
- **Bald cypress:** best growth in moist, fine sandy loam soils without competition

What bioretention parameters influence tree health?

Factors Influencing Health

- Species selection
- Soil pH
- Soil Chemistry
  - Nutrients, metals
- Soil Composition
  - % Sand, % Fines, OM
- Bioretention Design
  - Surface Area
  - Tree planting location
  - Ponding Depth



High-Importance Design Parameters

Category	*Predictor Variable*	*Comments*
Bioretention Media Composition	Fines (%)	Reinforces findings in tree health comparison study; media should align with species-specific habitat preferences
	Sand (%)	
	Organic Matter (%)	Influences soil fertility, structure; OM standards vary
Bioretention Media Chemistry	Buffer pH	Controls fluctuations in soil pH which could impact root function; influences nutrient availability in media
	Copper	Micronutrient; deficiency leads to crown defoliation and dieback (other micronutrients are also key)
	Potassium	Vital to plant functions (photosynthesis, water regulation, cell expansion); required in large amounts
Tree Selection and Planting	Planting Location	Should reflect tree tolerance to inundation
	Species Selection	Species should be tolerant of bioretention environment

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Tree Health Survey Conclusions

1. Trees should be selected based on their ability to tolerate the unique conditions found in bioretention practices. Species-specific preferences for growing conditions should be considered during selection.

2. Species selection should be guided by analysis of bioretention media composition, prioritizing high-importance parameters.

Suspended Pavement Systems - Introduction

- Urban soil conditions present challenges to tree, root growth
  - High compaction, low nutrients, poor aeration (Craul et al., 1985)
- Suspended pavement systems improve root access to air and water in an uncompacted soil matrix; take advantage of limited land availability in ultra-urban landscapes
- Very little research on suspended pavement systems designed as subsurface bioretention to-date
  - Suspended pavement system lined with impermeable membrane in Wilmington, NC (Page et al., 2015)
  - Peak flow rates reduced by 62%; significant pollutant removal
  - Lined system may not be applicable to installations outside research

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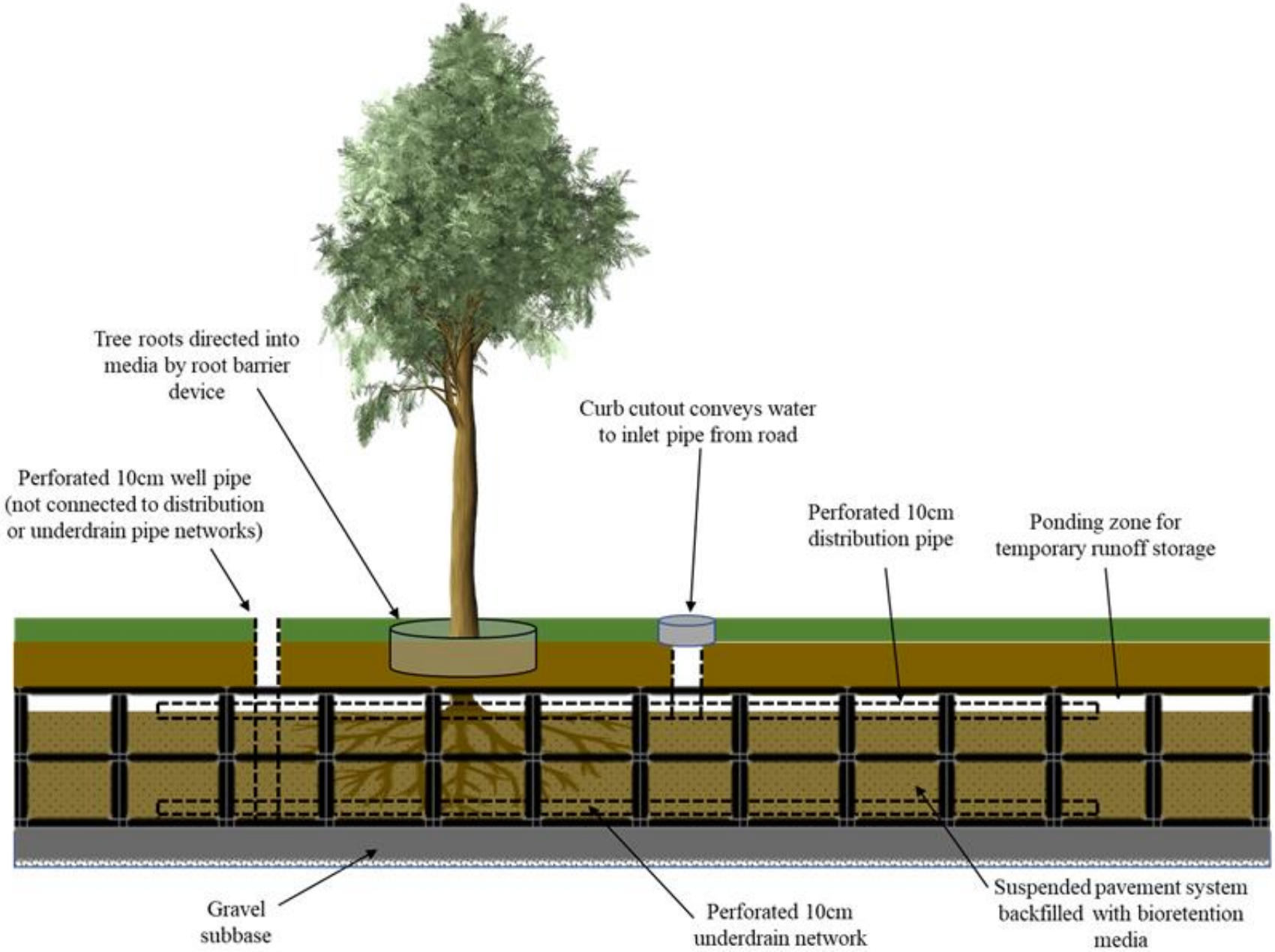
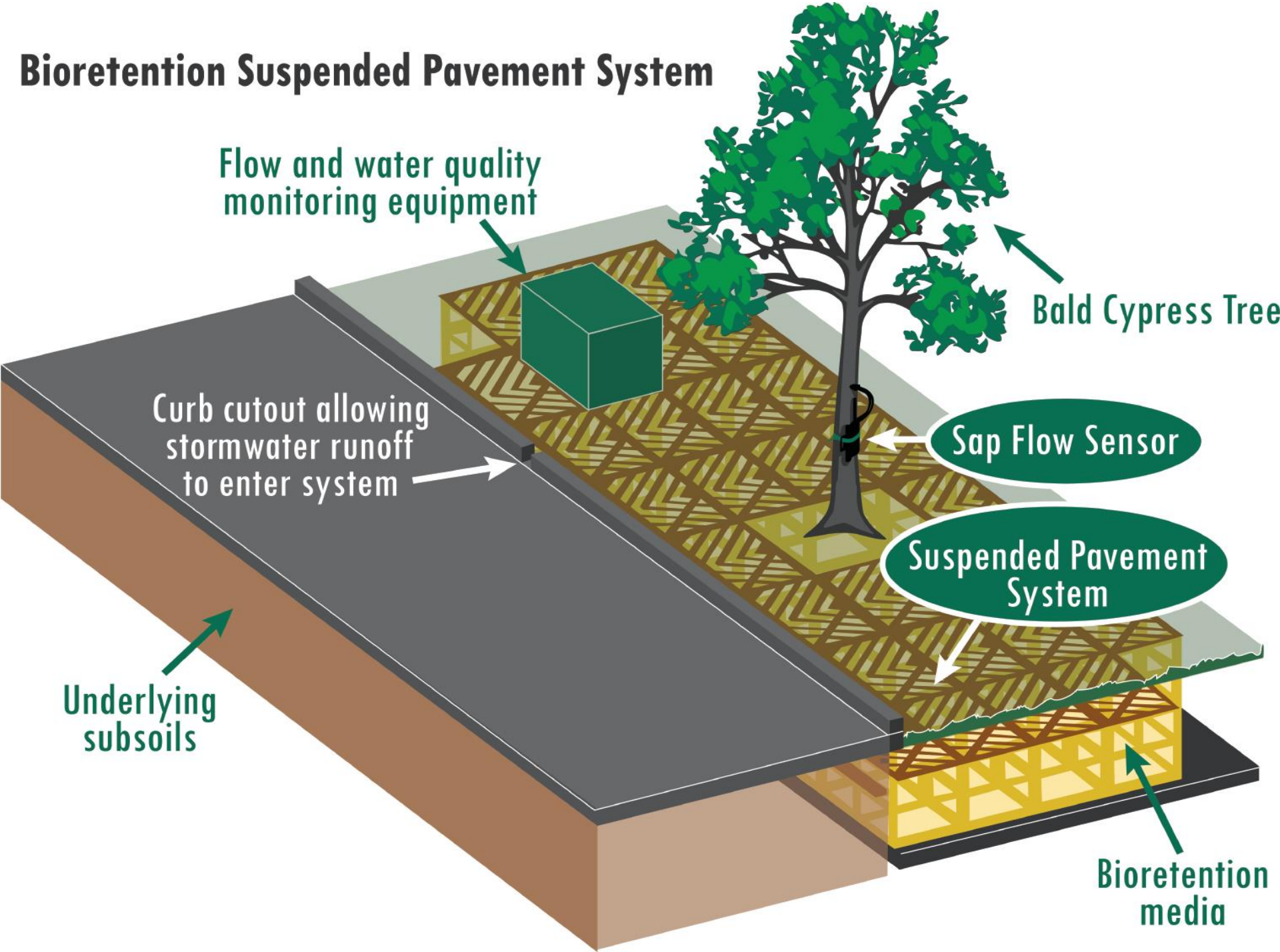

Tree roots directed into media by root barrier device
Curb cutout conveys water to inlet pipe from road
Perforated 10cm well pipe (not connected to distribution or underdrain pipe networks)
Perforated 10cm distribution pipe
Ponding zone for temporary runoff storage
Gravel subbase
Perforated 10cm underdrain network
Suspended pavement system backfilled with bioretention media

Bioretention Suspended Pavement System



Construction and Installation

Study 2: Bioretention Suspended Pavement Systems

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Hydrologic Monitoring Results

	North Site		South Site	
	(mm)	(%)	(mm)	(%)
Inflow	1775	-	1887	-
Outflow	-	-	202	10.7
Overflow	3.3	0.2	11.4	0.6
Exfiltration/ET	1772	99.8	1673	88.7

- Total of 1922mm of rainfall recorded (median event of 8 mm) between April 2016 and July 2018
- 146 and 148 storm events collected for north and south sites
- Exfiltration from upper soil layers may have outweighed low infiltration rates of underlying soils
- 83% of storms completely captured by south site (123/148 storms); 79% at north site (116/146 storms)

Pollutant Removal Performance

Median pollutant conc. (st.dev.) for ten paired events			
Pollutant	Influent	Effluent	Significance
TSS (mg L^{-1})	167 (69)	6 (21)	$p<0.05$
NH_4^+-N (mg L^{-1})	0.01 (0.01)	0.01* (0.00)	-
NO_x-N (mg L^{-1})	0.05 (0.13)	0.11 (0.63)	-
PO_4^{3-} (mg L^{-1})	0.06 (0.03)	0.06* (0.00)	-
Cu (µg L^{-1})	0.5 (1.9)	0.3 (0.08)	-
Pb (µg L^{-1})	1.6* (0.0)	1.6* (0.0)	-
Zn (µg L^{-1})	7.9 (8.8)	7.9 (18.2)	-

Note: Asterisk (*) indicates that pollutant levels in all ten samples were below method detection limit.

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Conclusions

- Suspended pavement systems are effective at reducing runoff volumes
- Limited storage volume ("bowl volumes") in suspended pavement systems can lead to oversized practices
  - Sizing criteria may need to be revisited to account for small ponding volumes and the soil volumes required for tree growth
- Further research on pollutant removal performance needed – potentially linked to low influent concentrations and small sample size

Acknowledgements

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  - University of Tennessee Dept. of Civil & Environmental Engineering
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