How Trees and Urban Forest Systems Affect Stormwater Runoff

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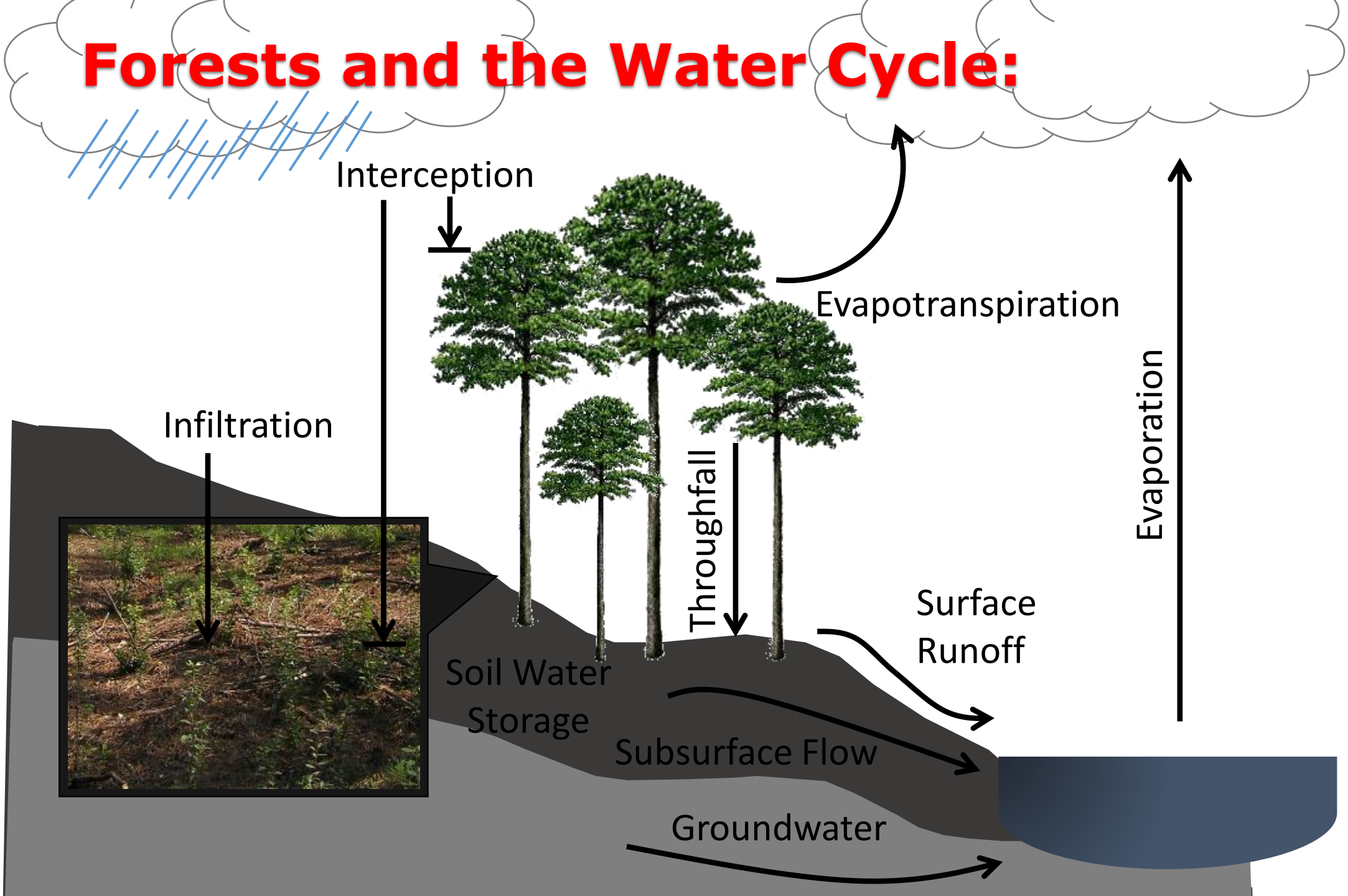
Objectives

- Current research
  - Retention/detention
  - Rainfall intensity reduction
  - transpiration
- Co-benefits of urban trees
- UF management strategies to maximize stormwater benefits
- Using trees to meet stormwater credits

Forests and the Water Cycle:



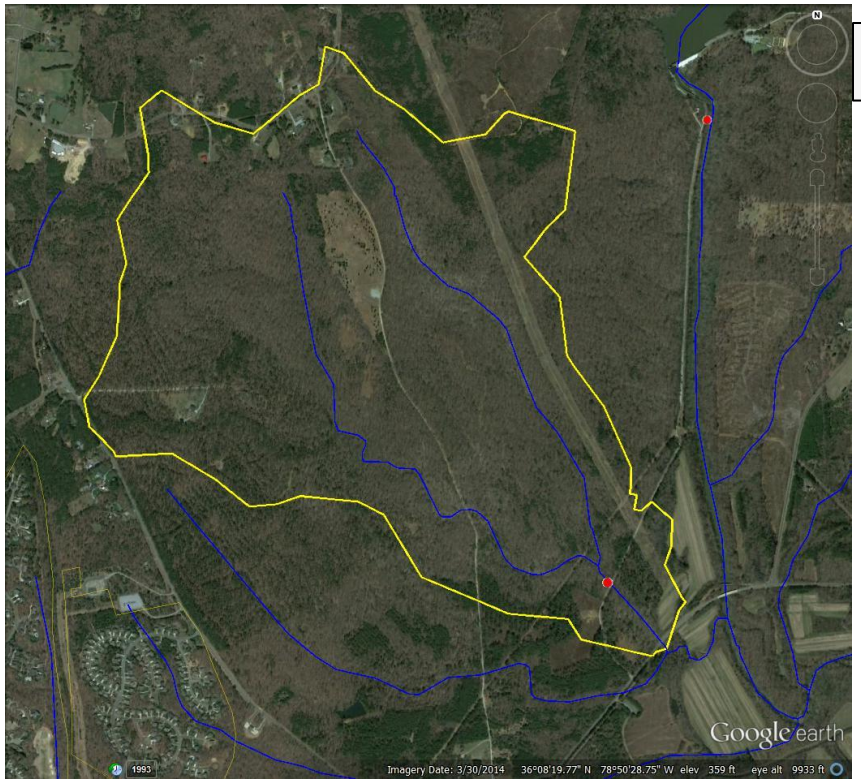
Typical Urban Development

- Remove tree canopy cover
- Remove ground cover
  - Vegetative
  - Detritus (mulch)
- Remove permeable top soil
  - Leaving dense subsoil
- Disturb/compact/pave over remaining soil
- Grass sod over subsoil

Image courtesy of Google Earth

Research Basis for Forest Systems and Stormwater Mitigation

Forest – Flat River Tributary



2.95 km^2 Size 0.70 km^2

99% Forest/Open Space 56%

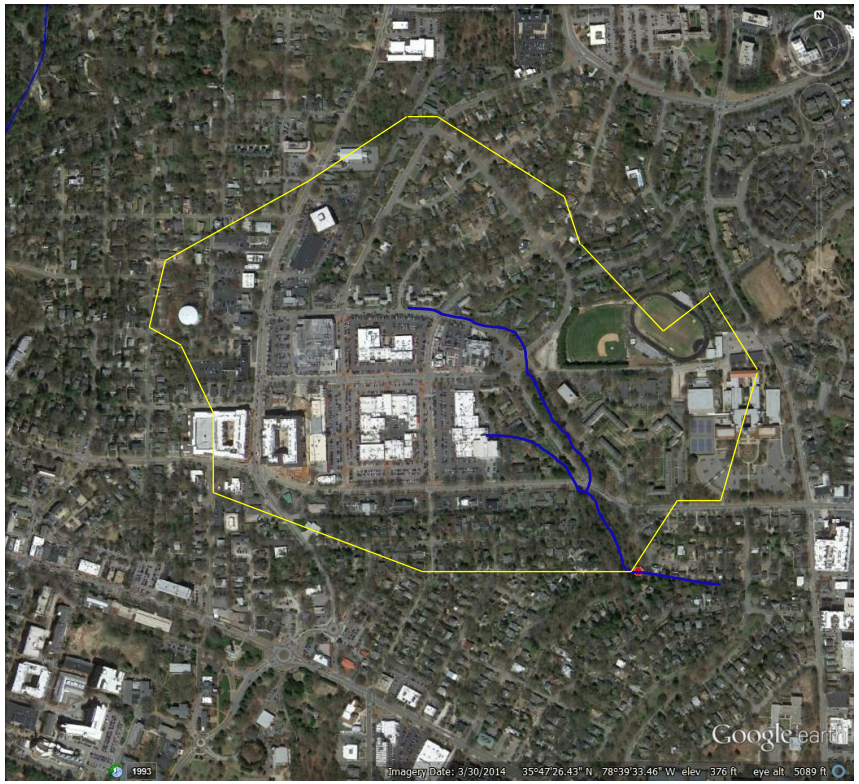
1% Impervious 44%

Peak flow rate:
5.8 (mm/day) 76.6
UR > 13x

Storm flow volume:
7.1 (mm/day) 77.9
UR > 11x

77% Mean ET 58%

Urban – Pigeon House Creek



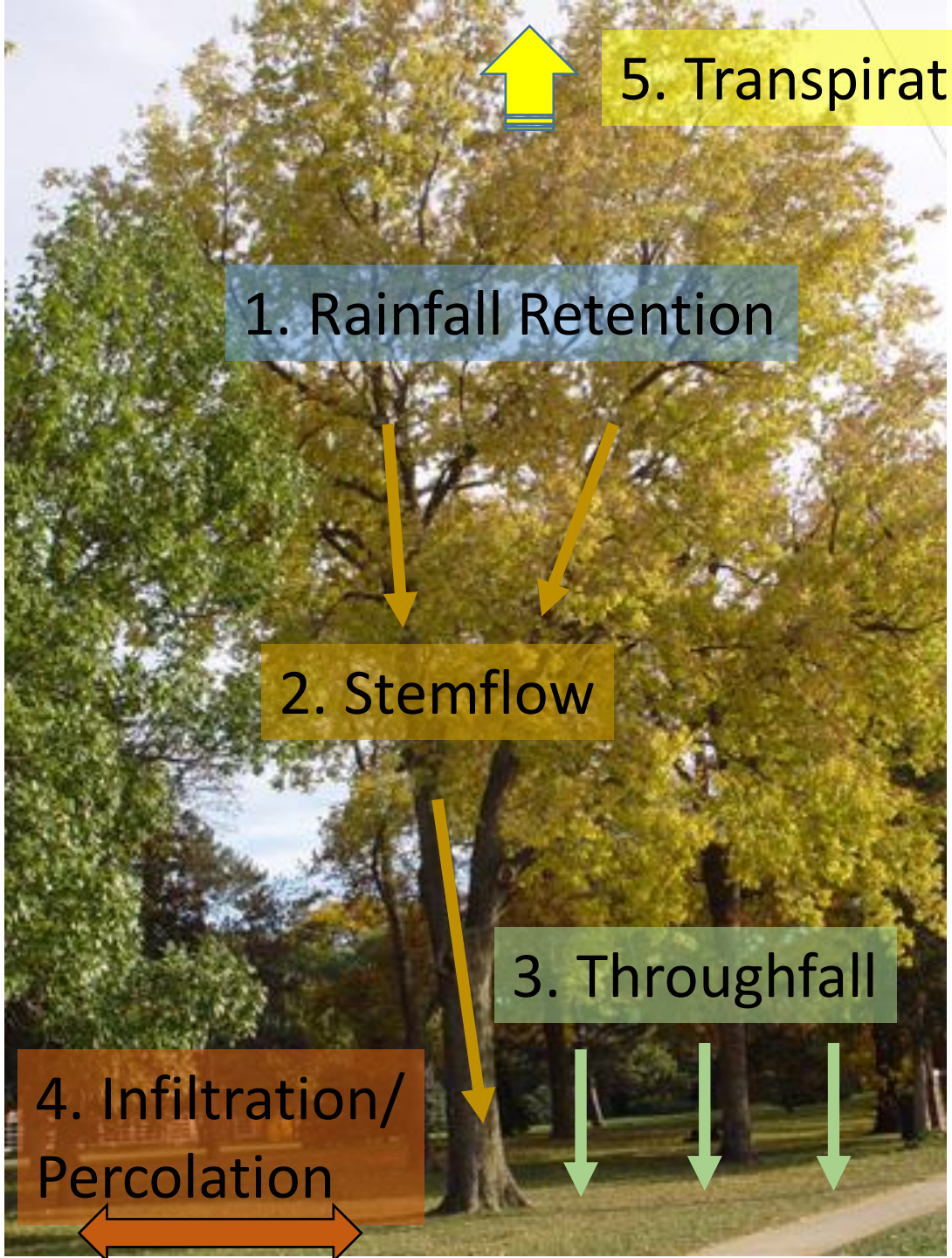
Boggs & Sun (2011) Urbanization alters watershed hydrology in the Piedmont of North Carolina, Ecohydrology, 4, 256-264

Can Cities Be Designed to Mimic Forested Systems?

- Layered forest structure
  - Over-story
  - Mid-story
  - Groundcover (mulch or veg)
  - Where appropriate
- Provide more rooting volume
  - Permeable soils / macro-pores
- Store runoff belowground
  - GSI / Greenspace conservation
  - Rocks?

Various Ways Urban Forest Systems Impact Rainfall and Stormwater

1. Rainfall Retention
2. Stemflow
3. Throughfall
4. Infiltration/percolation
5. Transpiration

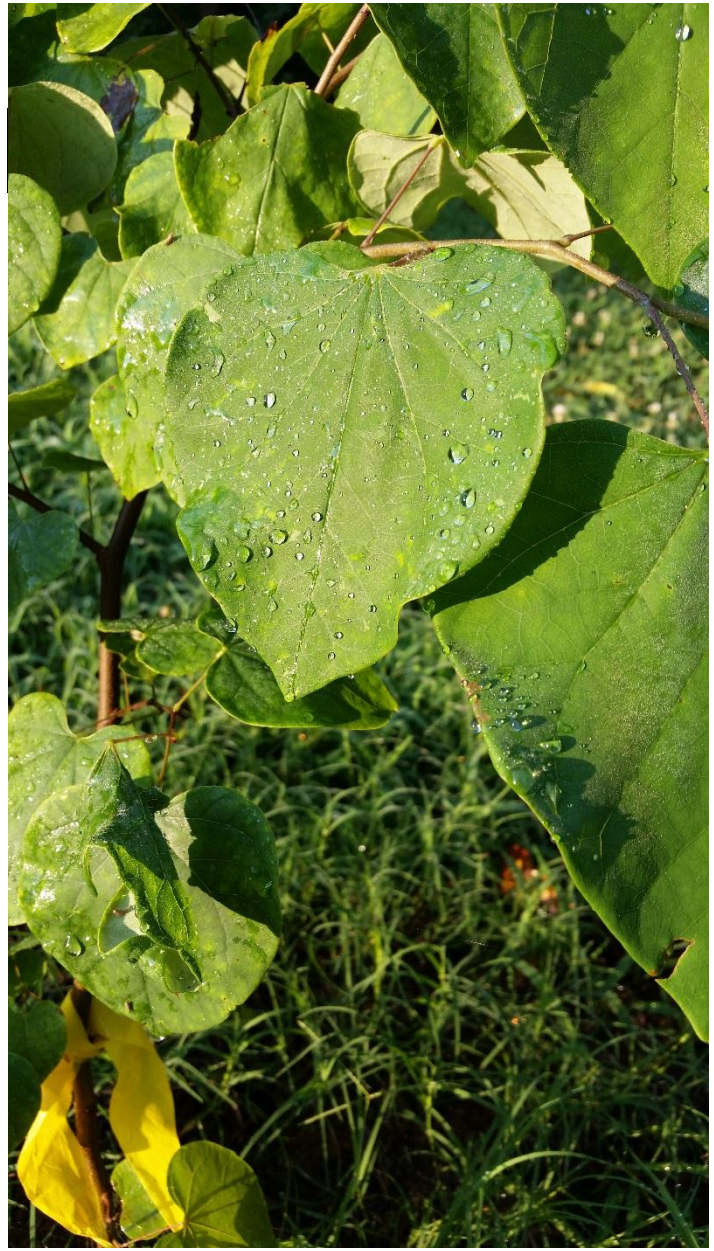


Tree Canopy Retains Rainfa

- ~20% annual retention under canopy
  - 14 – 61% range depending on region
  - Depends on volume and intensity
- Canopy holds first 2-4mm of rainfall
    - Xiao et al. (2000); Livesley et al. (2014)
  - 1 ac @ 25% cover = 71-143 ft^3 / event
    - 531 – 1070 gallons
- More leaf area = more retention
  - Larger trees
  - Evergreen trees

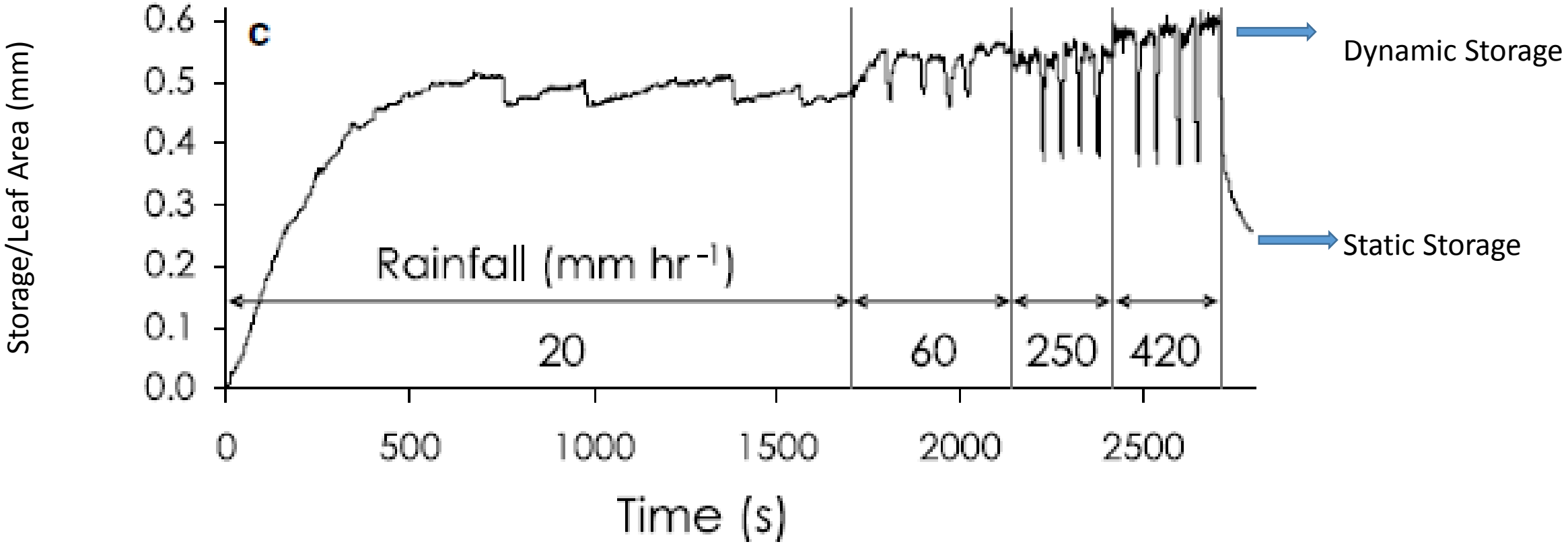
Tree Canopy Retains Rainfall

- Leaf area drives rainfall retention
- Static storage (Keim et al., 2006)
  - Water held after rain event ends
  - ~0.2 mm per m^2 leaf area
- Dynamic storage
  - Temporary water storage during rain event
  - Broadleaf = 0.77 mm
  - Coniferous = 1.25 mm
    - Xiao and McPherson (2016)
- Large trees can have hundreds of m^2 of leaf area



Static vs. Dynamic Storage

Keim et al. (2006)

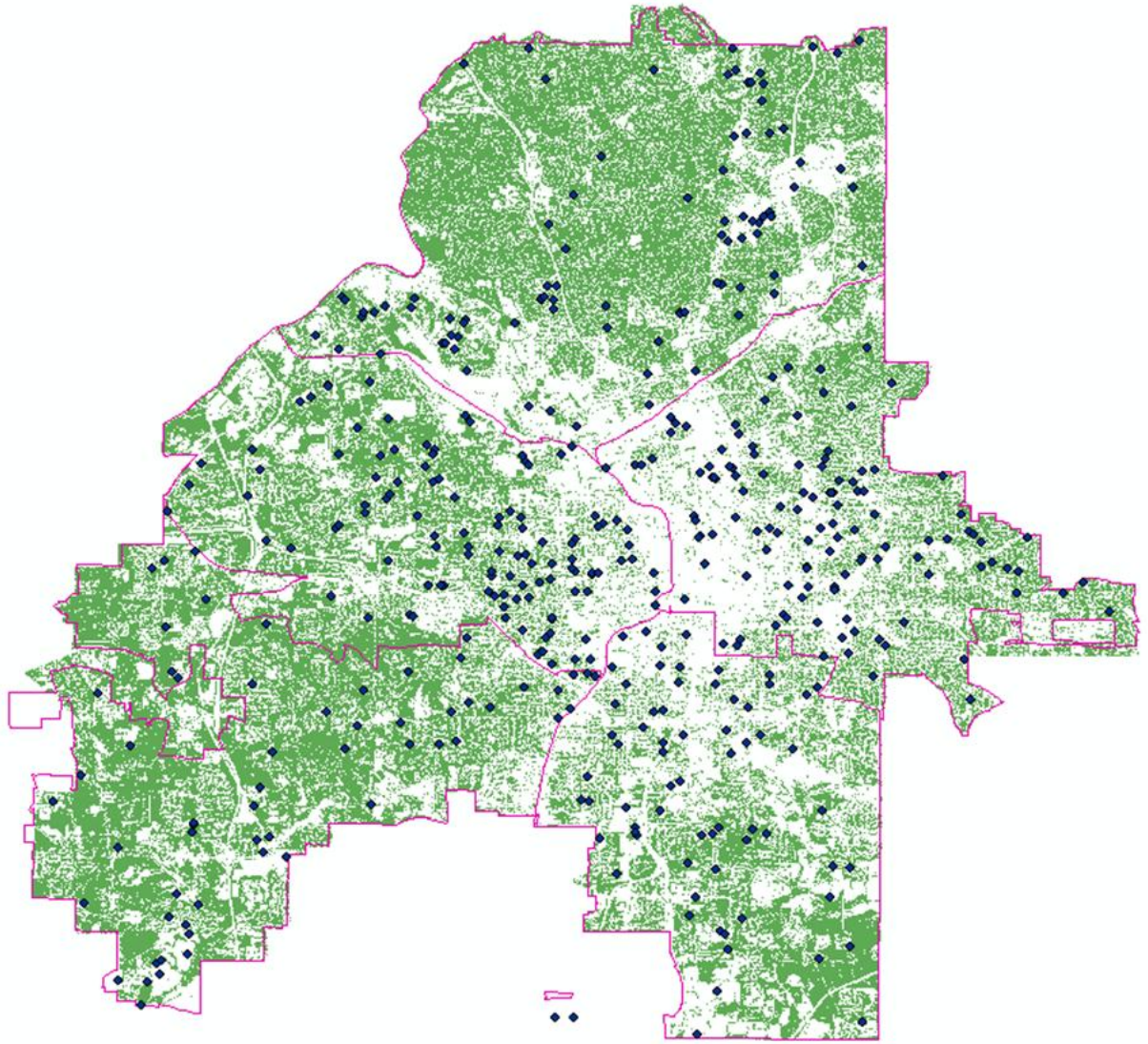


Tree Canopy Retains Rainfall

- Hackberry example
  - 14” DBH
  - 50’ HT
  - 35’ crown width
  - Leaf area ~ 7000 ft^2
- Static storage = ~34 gallons
  - @ 0.2mm/m^2
- Dynamic storage = ~ 132 gallons
  - @ 0.77mm/m^2

Tree Canopy Retains Rainfall

- Entire urban forest example
  - City of Atlanta
- i-Tree Eco project
  - 443 1/10th acre plots
  - Randomly located around city
  - 2013 meteorological data
- Estimated leaf area = 235 mi^2
- Avoided runoff = 94.1 million ft^3
  - 704 million gallons
  - 3.3% of annual rainfall



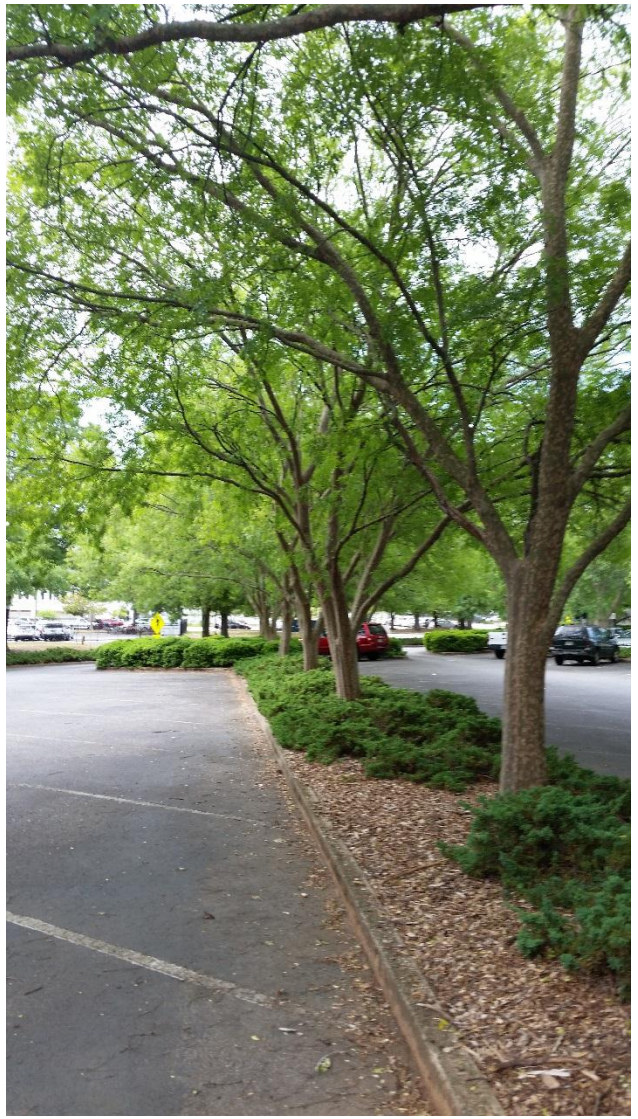
Stemflow

- Slows runoff rate
- Funnels stormwater to base of tree
- Encourages infiltration
- Leaf-on season
  - 3-8% of rain falling on tree canopy
  - Leaves encourage throughfall
- Leaf-off season
  - 9-15% of rain falling on canopy
  - Typical winter rainfall intensity less than summer intensity

Credit: City of Kamloops, BC, Canada

To Maximize Stemflow (and Minimize Runoff)

- Per Schooling & Carlyle-Moses (2015)
- Provide sufficient infiltration capacity at base of tree
- Select larger canopy trees
- Select smooth(er) bark trees
- Select trees with co-leaders or more acute branch angles
  - What are the trade-offs?
- Encourage canopy cover over impervious surfaces



Tree Canopy Temporarily Detains Rainfall

- Delayed throughfall via dynamic storage
  - Depends on storm intensity
  - Crown surface area
- From 10 min. to > 3 hours
  - Aston (1979) in Australia
  - Asadian and Weiler (2009) in Vancouver, BC
- Canopy cover increases lag time
  - Xiao et al (2000)
  - Keim (2003)
  - Livesley et al (2014)

Canopy Cover Reduces Rainfall Intensity

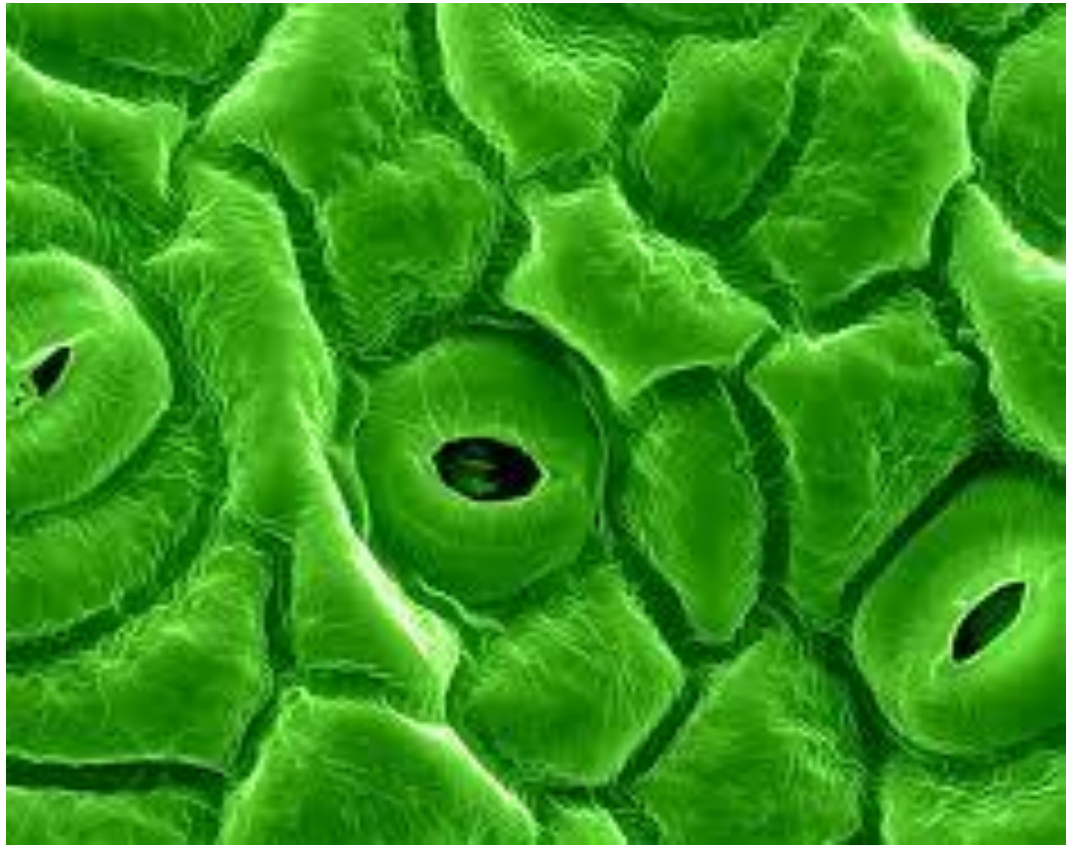
- 15%-21% reduction in deciduous forest
  - Trimble and Weitzman (1954)
- 21%-52% reduction in Oregon
  - Keim and Skaugset (2003)
- May be greater for urban trees
- Canopy cover acts as volume control measure
  - Increases BMP efficiency?

Infiltration and Percolation

- Soils store, delay, and filter
- Urban soils typically compacted
- Tree roots penetrate compacted soil
- 69 – 354% greater water infiltration under tree canopy
  - Zadeh & Sepaskhah (2016)
- Infiltration rates increased by 800% in clay loam soils under canopy
- Root mass is credited with higher infiltration

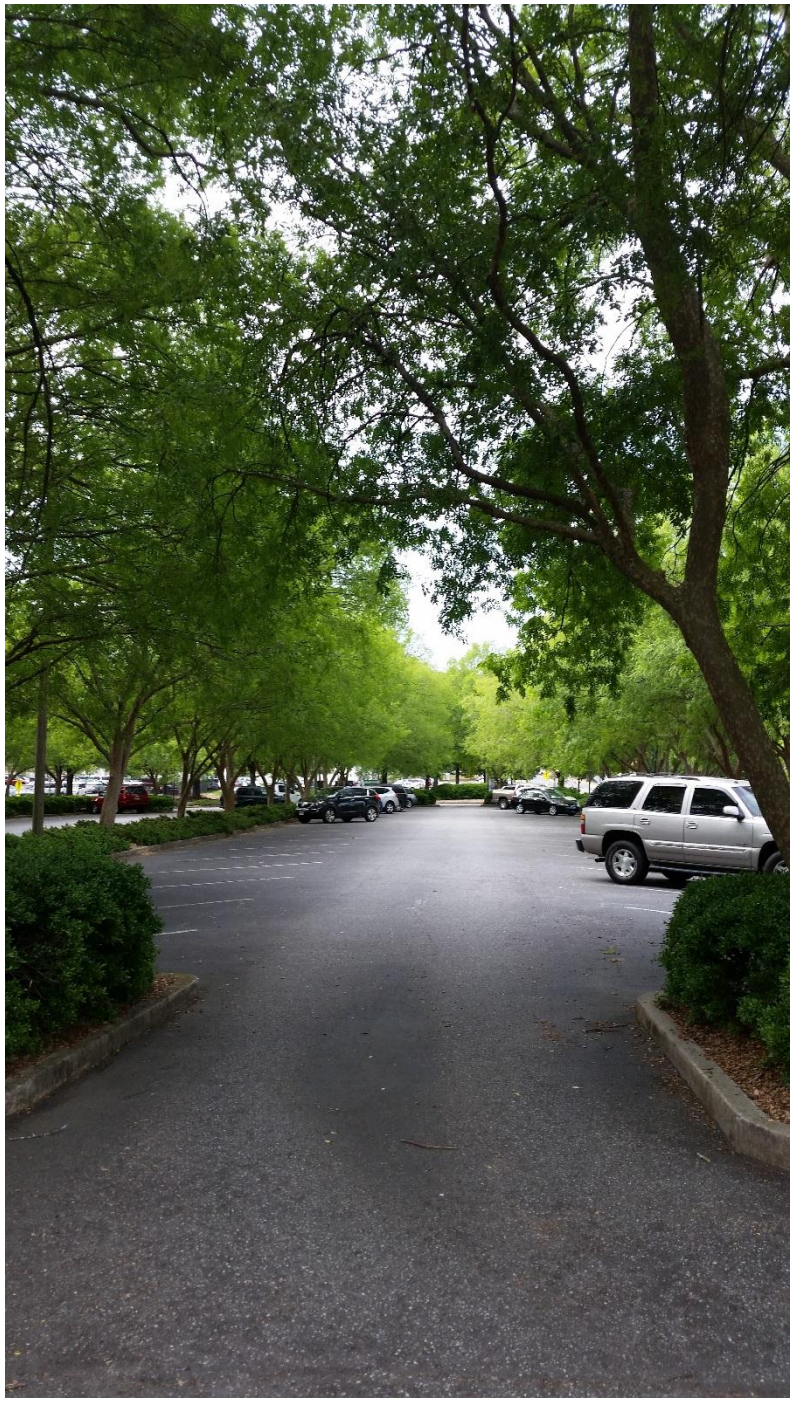
Transpiration Allows More Storage in Soil

- Highly dependent on environmental factors and species
- ~1.5 mm/day/m^2 canopy cover
  - Chen et al. (2011)
  - Wang et al. (2012)
- 0.3 – 2.6 mm/day/m^2 leaf area
  - Kjelgren & Montague (1998)
  - Fair et al. (2012)
- 7000 ft^2 leaf area = 7 - 60 ft^3/day
  - @ 0.3-2.6mm/m^2/day
  - 52 - 446 gallons/day



Conclusion

- Tree canopy retains rainfall
  - ~20% annual rainfall under canopy
  - First 2-4 mm of rainfall
  - 0.2 mm per m^2 of leaf area
- Stemflow
  - Directs up to 15% of interception to soil
- Canopy cover reduces rainfall intensity
  - Deciduous canopy 15 – 21%
  - Coniferous canopy 21 – 52%
- Trees increase infiltration under canopy
  - Up to 350%
- Trees transpire 50 to 450 gallons/day
  - Species and microclimate dependent

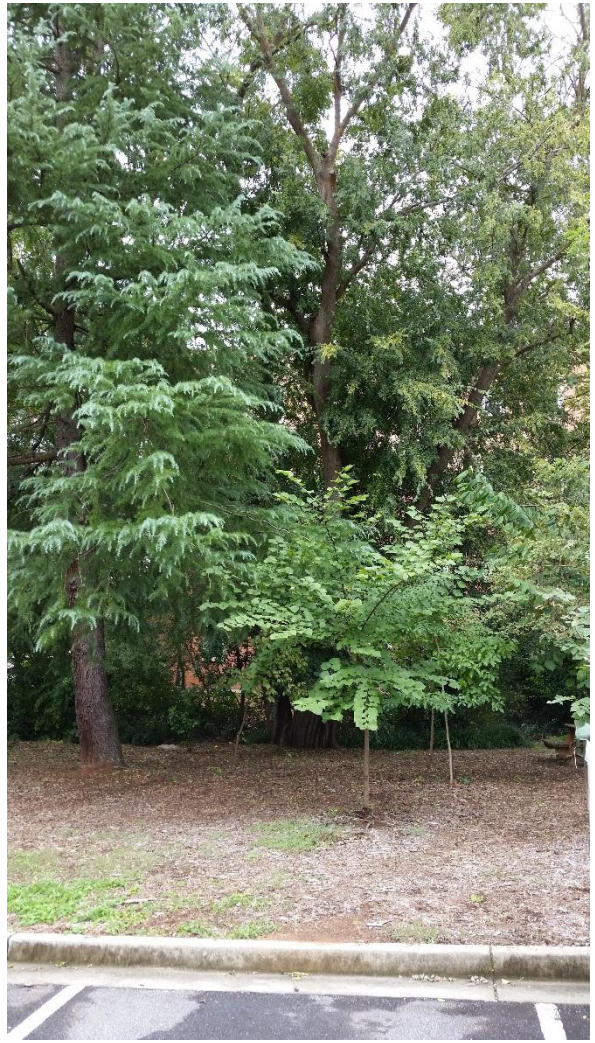


Co-benefits of Urban Forest Systems (Triple Bottom Line)

- Economic
  - Energy conservation
    - ↑CC 10%, ↓T 1.2° C, ↓e^- use ~15%
      - Huang et al. 1987
  - Increased property value (~5%)
- Social
  - Positive relationship with human health
  - http://www.naturewithin.info/urban.html
- Environmental
  - Air pollution removal/avoidance
  - i-Tree tools to quantify
    - www.itreetools.org

Urban Forest Management Strategies to Maximize Stormwater Mitigation

- Layered structure mimics forest systems (reduce/delay runoff)
  - Over story canopy
    - Dominant species
  - Mid-story canopy
    - Shade tolerant species
  - Ground cover (veg/mulch)
- Provide adequate rooting volume for growth and health
  - Suspended pavement systems
  - Gravel under pavement?



Using Trees to Meet Stormwater Credit

Portland, OR — 2004 Stormwater Management Manual

- Subtract Impervious Cover under trees within 25 feet of impervious cover that meets certain criteria
- Existing Tree = 50% of Existing Canopy, New Trees = 100 to 200 ft^2 of impervious cover

Indianapolis, IN — 2007 Stormwater Green Infrastructure Supplemental Document

- Credits for new or exiting tree canopy within 20 feet of impervious surfaces.
- 1 tree= 100 ft^2 of Impervious Cover

Pine Lake, GA — 2003 Ordinance

- Trees count towards site runoff requirements
- Trees = 10 to 20 gallons/in DBH

Minnesota — Volume, TSS, Phosphorus Credit

- Based on interception, evaporation, and infiltration
- Example : Mature Red Maple with infiltration area= 340 cf

Philadelphia, PA — 2011 Stormwater Manual

- Reduction in impervious area

Washington, DC — 2013 Guidebook

- Trees receive retention value
- Preserved Trees = 20$ft^{3;}$ New Trees = 10 ft^3

How Trees and Urban Forest Systems Really Affect Stormwater Runoff

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