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:

- Infiltration
- Interception
- Throughfall
- Soil Water Storage
- Subsurface Flow
- Groundwater
- Evapotranspiration
- Surface Runoff
- Evaporation
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

- Size: 2.95 km²
- Forest/Open Space: 99%
- Impervious: 1%
- Peak flow rate: 5.8 (mm/day) 76.6 UR > 13x
- Storm flow volume: 7.1 (mm/day) 77.9 UR > 11x
- Mean ET: 77% 58%

Urban – Pigeon House Creek

- Size: 0.70 km²
- Forest/Open Space: 56%
- Impervious: 44%

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 Rainfall

• ~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 ft³ / 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 mi²
- Avoided runoff = 94.1 million ft³
  - 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
  - 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/m² canopy cover
  • Chen et al. (2011)
  • Wang et al. (2012)
• 0.3 – 2.6 mm/day/m² leaf area
  • Kjelgren & Montague (1998)
  • Fair et al. (2012)
• 7000 ft² leaf area = 7 - 60 ft³/day
  • @ 0.3-2.6mm/m²/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 m² 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
    - $\uparrow$CC 10%, $\downarrow$T 1.2° C, $\downarrow$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?
Retrofitting Trees in Extra-Urban Settings

Growing trees in gravel beds
Using Trees to Meet Stormwater Credit

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<tr>
<th>Location</th>
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| 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 ft² 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 ft² 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 ft³; New Trees = 10 ft³                                               |
How Trees and Urban Forest Systems Really Affect Stormwater Runoff

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