How Trees and Urban Forest Systems Affect Stormwater Runoff

and tools to help quantify those benefits

Eric Kuehler
Science Delivery/Technology Specialist
USDA Forest Service

ekuehler@fs.fed.us

USDA Forest Service
Objectives

- Current research
  - Retention/detention
  - Rainfall intensity reduction
  - Transpiration
- Co-benefits of urban trees
- Tools to quantify stormwater and co-benefits
- Using trees to meet stormwater credits?
In many places throughout the country urban development begins with the removal of tree canopy and ground cover as well as the rich top soil that helps with infiltration.

These sites are left with dense, clayey subsoil that is further disturbed through compaction and paving.

So now, instead of rainfall being slowed down by canopy cover and permeable ground cover, it hits these impervious surfaces at terminal velocity causing increased accumulation quickly downstream leading to increased stormwater volume and flooding issues.
A comparative watershed study was done in North Carolina comparing stormwater runoff between undisturbed, forested land use and a highly developed land use.

What does all this mean:
• By removing tree canopy cover and ground cover (vegetative and detritus) and covering soil with impervious surfaces (and compacting most of the remaining soil), we have increased water velocity because asphalt and concrete don’t slow the water flow down like ground cover
• By covering the soil with asphalt/concrete we are not allowing the water to infiltrate into the soil and so it runoff as overland flow
• By removing tree cover, water is not being wicked out of the soil in the urban setting as readily as in forests.
Can our built environment be designed to mimic the processes for infiltration employed by forested systems?

Perhaps including layers of tree canopy cover and ground cover to help slow down rainfall, increase rooting volume to maximize tree growth potential, and store runoff belowground so that tree roots can have access to it.
Urban forest systems impact rainfall/stormwater in 5 main ways.

1. Rainfall Retention
2. Stemflow
3. Throughfall
4. Infiltration/percolation
5. Transpiration
Depending on geographical region, urban tree canopy can retain about 20% of the annual rainfall under canopy. Closer to 30% under conifers. This depends on rainfall volume and intensity.

We are currently working with the College of Civil Engineering at Univ. of Tennessee to quantify canopy retention for open-grown trees in the Southeast.

Using troughs and rain gauges we are measuring the rainfall volume and intensity under canopy vs. out in the open.

Using three common urban tree species, we are finding that tree canopy is retaining about 60% of rainfall for a half inch event and 45% for a 1” event for willow oaks.

Red maples retain about 45% for ½” rainfall event and 37% for 0.8” rainfall.

Pine show a more linear retention rate with about 45% retention up to 0.8” rainfall event.
Leaf and branch surface area of tree canopy drive interception.

Richard Keim (now at LSU) demonstrated and quantified two rainfall storage strategies used by tree canopy.

Static storage is that water that is held in the canopy after a rain event and all excess water drips off. This volume is retained in the canopy and evaporates eventually. The average depth of water storage on foliage is about 0.2 mm/m².

Dynamic storage is that rainfall that is temporarily stored in the canopy during the rain event. It will eventually drip off the canopy and become runoff.

Xiao and McPherson quantified dynamic water-holding storage capacities of 20 common street trees in Davis, CA in a rainfall simulation laboratory study.

Because of dynamic storage, tree canopy cover can increase lag time and delay peak flow.

The more surface area there is the greater the interception.
Larger trees have greater leaf and branch surface area.
This graphic demonstrates how leaf area stores rainfall using dynamic storage during a rain event and how excess water on tree canopy drips off to some final steady-state after the event. This final, steady-state is the tree canopy’s static storage capacity. It is this water that will be retained and not become stormwater runoff.
With increased rainfall intensity or longer duration of a rain event, leaf surface area fills. When storage capacity reaches its maximum, excess water drips from the canopy.

This throughfall works its way through the crown until it finally drops to the ground. This delay can be as little as 10 minutes in higher intensity storms to longer than 3 hours in very light intensity storms.

Research suggests than tree canopy cover increases stormwater lag time, but we have a research gap in urban systems regarding how much delay there is in peak discharge. Research is on-going to quantify this and develop models to calculate.
Tree Canopy RainfallRetention per Event

- Sugarberry example
  - 14” DBH
  - 50’ HT
  - 35’ crown width
  - Leaf area ~ 650 m² (~7000 ft²)
- Static storage = ~34 gallons
  - @ 0.2 mm/m² (0.00073”/ft²)
- Dynamic storage = ~132 gallons
  - @ 0.77 mm/m² (0.003”/ft²)
  - 98 gallons released over time
    - 132 gal. - 34 gal. = 98 gal.

7000 ft² = 651 m² * .0002 m = 0.13 m³ * 264 = 34 gallons
Current research has shown that open-grown deciduous tree canopy reduces rainfall intensity by 35 to 61% under canopy and by 20-72% under coniferous canopy.

As the graphic from Zabret et al. shows, tree canopy cover dampens rainfall intensity.

Preliminary data from the Knoxville study shows that under open-grown willow oak canopy not only is volume reduced but peak 5 minute intensity is reduced by 78%.

Through retention and temporary detention tree canopy cover acts to control stormwater volume and intensity.

So, as we move toward retrofitting our urban impervious areas with GSI, I envision the retention of tree canopy cover to help slow the velocity of runoff so that those practices can work more efficiently.
Soils store much more stormwater than tree canopy does, but urban soils are typically so compacted that their ability to store stormwater is inhibited.

Given adequate soil moisture tree roots can penetrate compacted soil and help the soil to accept greater volume of runoff.

A recent study on an urban college campus showed that soil under tree canopy was able to infiltrate more water and at a greater rate than soil not under tree canopy.

This higher infiltration volume and rate was attributed to greater root mass under canopy compared to not under canopy.

The implication for stormwater management is that green spaces having tree canopy cover can infiltrate more stormwater runoff at a faster rate than green spaces without tree canopy cover.
The infiltrated water is then pulled from the soil through the process of transpiration which creates more space in the soil profile to store stormwater.

Transpiration is highly dependent on environmental factors such as heat, light, wind, soil moisture, etc. as well as species and stem diameter.

It turns out that the architecture of the wood which is basically a bunch of pipes defines the rate at which water moves through the stem.

For diffuse porous trees like maples, yellow-poplars, sweetgum, etc. (the blue line), large trees can use 40 gallons of water per day. These trees pull between 0.6-2.0 gallon/inch/day. These are the water hogs.

On the other end of the spectrum are the water conservationists. Ring porous species like oaks tend to use water sparingly. Large trees with this architecture uses less than 12 gallons per day. On average it is about 0.3 gal/inch/day.

Hickories and pines are somewhere in between.
If diverting water to large green spaces for temporary storage like parks, it is recommended to plant diffuse porous tree species to help move the water out of the soil quickly.

Plant ring porous species in drier, upland sites.
Recent review articles outline the volume control measures that trees provide.

Early in 2019, the Water Research Foundation will release materials on the benefits of urban forest systems specifically designed for stormwater utilities.
Some tools are available to help a city quantify the benefits of trees including stormwater benefits.

An i-Tree Eco project was conducted in 2014/2015 for the City of ATL.

All trees on 443 randomly located plots within the city limits were inventoried, and i-Tree Eco extrapolated those data to estimate structure, function, and value of the urban forest.

The model estimated that ATL had 235 square miles of leaf area.

Multiply this leaf area by the depth of water storage yields about 32 million gallons of rainfall retained per event

235 mi² = 608,600,000 m² * 0.0002 m = 121,720 m³ * 264 = 32,134,000 gallons / rainfall event

Using weather data from a dry, average, and wet year, Eco calculated that 2-3 billion gallons of rainfall were retained in canopy cover equaling about 2-3% of the total rainfall.
Eco also estimated that 10-12 billion gallons of water were transpired out of the soil allowing for more infiltration of runoff (between 6-15% of total rainfall).
Urban forest systems contribute to the triple bottom line.

They provide economic benefits by conserving energy through direct shading of buildings and through climate effects.

Huang et al found that for every 10% increase in tree canopy cover ambient air temperature is reduced by 1.2 C and electricity use is reduced by approx. 15%.

Trees generally increase property values by about 5% (+/-).

There is a generally positive relationship between trees/urban forest systems and human health. Kathy Wolf has compiled much of the research on her website.

Environmental benefits include the filtering of particulates from the air, dry deposition of gaseous pollutants onto/into leaves, and avoiding pollution formation by cooling the atmosphere and reducing sunlight.

The Forest Service’s i-Tree tools allow you to quantify environmental benefits.
On-line Resources

- [www.TreesAndStormwater.org](http://www.TreesAndStormwater.org)
  - Searchable resource library

- [www.cwp.org](http://www.cwp.org)
  - Center for Watershed Protection
  - Searchable resources

- [www.VibrantCitiesLab.com](http://www.VibrantCitiesLab.com)
  - Co-benefits of urban forests
  - Search by resource type
We can manage our urban forest systems to maximize runoff mitigation.

If we can increase the amount of vegetation on undeveloped land by layering the canopy cover into over-story, mid-story, and ground cover, we can mimic forest structure and thus increase rainfall retention, reduce rainfall intensity, delay throughfall, increase lag time, and increase transpiration.

The key to this is providing adequate rooting volume for growth and tree health.

Suspended pavement systems such as SilvaCells or using structural soils can provide needed rooting volume.

We are experimenting with planting trees in mineral soil beds adjacent to parking lots using gravel under pavement or as parking stalls.
What do you need?

- Are trees given credit as a runoff mitigation practice?
  - If not, how can we give credits?

- What information do you need to consider trees as a stormwater runoff mitigation practice?

- What are the concerns with using trees in stormwater management?
  - What prevents you from incorporating trees in designs?

http://www.climatechange.org/technology/urban_forestry
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Compared to stormwater dosing on these systems, trees showed better, more consistent P uptake, however, N uptake was less consistent.

Denman also showed that by decreasing saturated hydraulic conductivity (SHC), essentially slowing the water velocity in the soil, decreased P in the runoff effluent and allowed for greater N uptake by trees from these systems.
Several studies have compared nutrient leaching under turf, individual trees, and forested sites in situ.

Amador et al. and Groffman et al. found that intact forested systems are most efficient at utilizing oxidized nitrogen by >75% compared to turf.

Nidzgorski and Hobbie found N leaching into groundwater was reduced under deciduous trees by ~50% compared to turf, but found no difference between turf and evergreens.

They found more consistent reductions in P leaching under individual trees (both deciduous and evergreen) by >50% compared to turf.

By scaling their results up to an urban sub-watershed they estimated that trees reduced P leaching to groundwater by 3.1 – 6.9 kg/km2).

It appears from these studies that the effectiveness of trees on reducing nutrient leaching is related to soil texture and site maturity.