Slide 1

Give Me the Numbers:
How Trees and Urban Forest Systems Really Affect Stormwater Runoff

Aarin Teague, PhD, PE
Senior Engineer
Watershed Engineering
San Antonio River Authority
ateague@sara-tx.org

Eric Kuehler
Science Delivery/Technology Specialist
USDA Forest Service
ekuehler@fs.fed.us

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Slide 2

Objectives

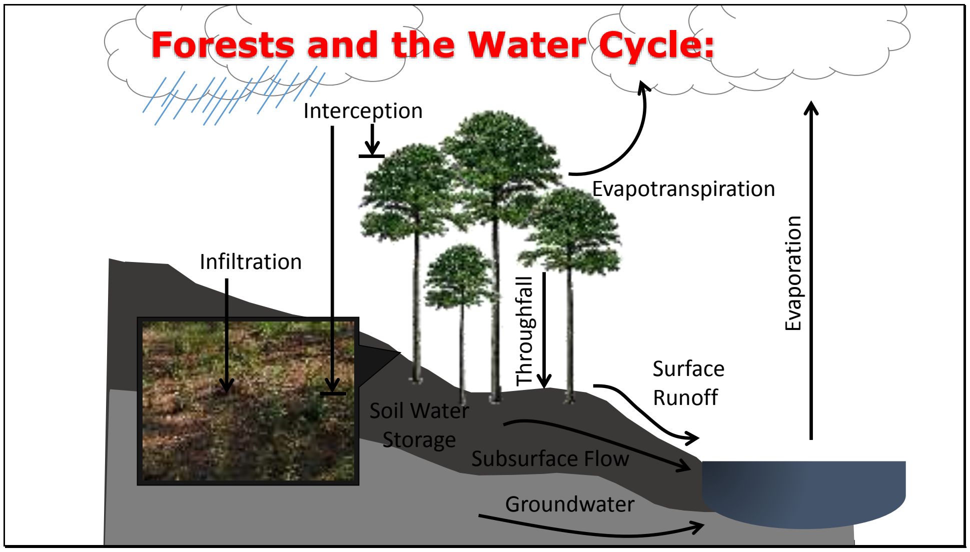
- Current research
  - Retention/detention
  - Rainfall intensity reduction
  - transpiration
- Using data to quantify stormwater benefits
- UF management strategies to maximize stormwater benefits
- Tools to quantify tree canopy volume

Today we would like to share some current research showing how much rainfall trees intercept, retain, detain, transpire, and reduce rainfall intensity.

We will discuss how San Antonio River Authority are using these data to help mitigate stormwater runoff.

If we have time will show how urban forests can be managed in such a way as to maximize stormwater benefits. We will explain some of those strategies.

Slide 3



Before discussing urban forest systems let's talk about how pre-development, forest systems work with the water cycle

- Forests consist of a vertical component (tree canopy), ground cover (mulch or vegetative), and permeable soil
- Rainfall is intercepted by the tree canopy where a portion is retained and evaporated
- After the canopy surface area fills, stormwater drips through the crown as throughfall and runs down the stem as stemflow
- Ground cover retains and stores a portion of the throughfall
- Most of the precipitation that reaches the ground infiltrates into the soil
    - Forest soils are very porous and permeability because of the high organic matter content, lots of roots connecting the soil to the surface, and the burrowing activities of animals, worms, and insects
    - Water that infiltrates into the soil either flows through the soil to nearby streams (subsurface flow), is stored in the upper soil surface (and used by plants), or percolates down into the groundwater aquifer
- Leaving only a small portion of precipitation for surface runoff

Because of the protective cover and limited surface runoff, very little erosion from forestlands
The system also regulates flows and provides consistent stable baseflows (the groundwater contribution to stream flow)

As trees are removed from the system, this process breaks down. Good to have vertically stratified GI projects. Grass and shrubs are good, but need to include trees in plans

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

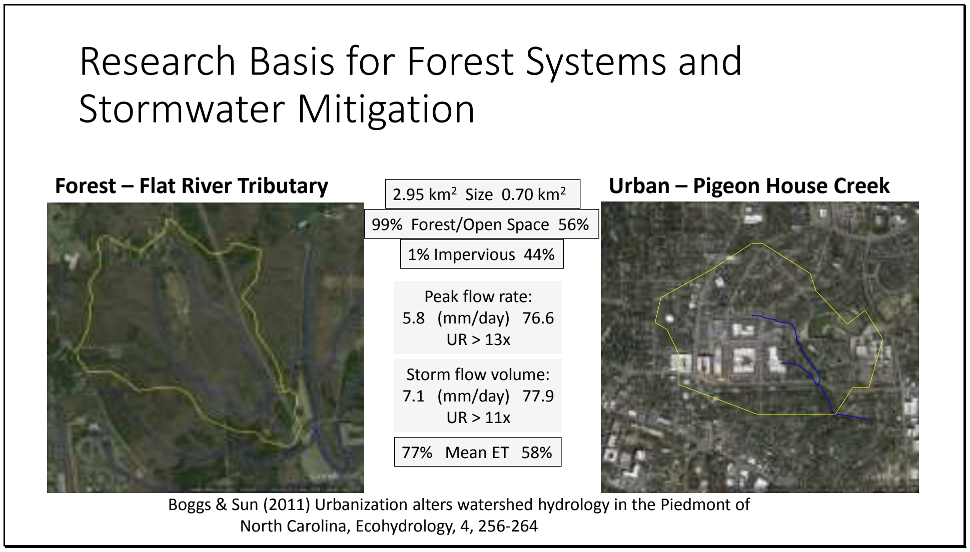
Image courtesy of Google Earth

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 leaving dense, clayey subsoil.

That remaining subsoil 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.

Slide 5

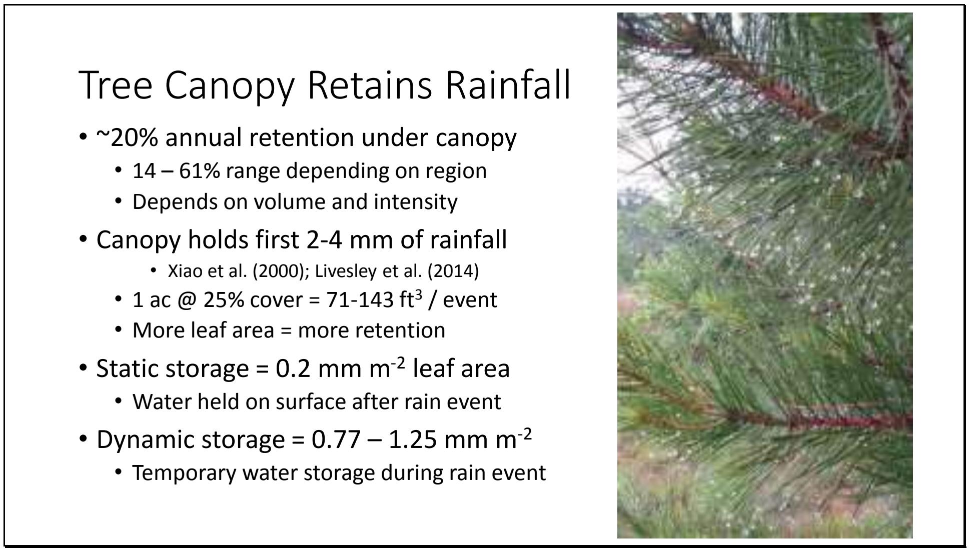


A comparative watershed study was done in North Carolina comparing stormwater runoff between undisturbed, forested landuse and a highly developed land use.

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.

Slide 6



So let's look at some of the research regarding tree canopy cover and rainfall retention.

Leaf and branch surface area of tree canopy drive interception.

Xiao, Livesley, and others have found that tree canopy retains the first 2-4 mm of rainfall or up to 3/16".

For a 1 acre parking lot with 25% canopy cover, we should expect to retain 71-143 ft3 of rainfall in the crowns of trees

Leaf and branch surface area are able to retain rainfall and not allow it to fall to the ground as stormwater runoff through the process of static storage. The average depth of water storage on leaves is approximately 0.2 mm per square meter of leaf area.

During a rainfall event, leaves and branches temporarily store water which eventually drips off. Xiao and McPherson quantified water-holding storage capacities of 20 common street trees in Davis, CA in a rainfall simulation laboratory study.

We can use these values to quantify water storage. Using tools like i-Tree Eco to estimate leaf area of a tree, we can estimate that a 14" hackberry, 50 ft. tall, with a crown spread of 35 ft. has 6927 sq. ft of leaf area. Using 2.53 cu. Ft of H2O retained per 1000 sq. ft. of LA gives us 17.5 ft3 of storage in the crown.

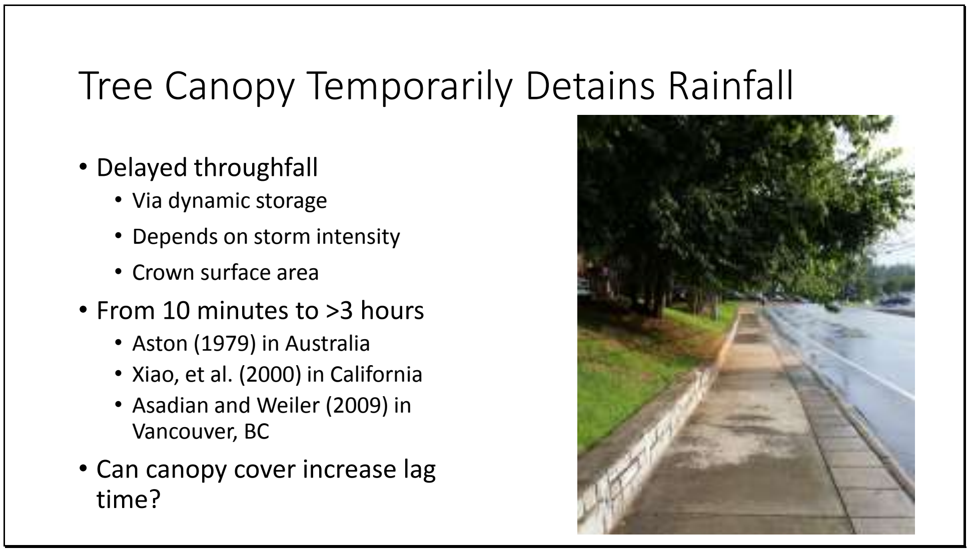
The more surface area there is the greater the interception. Larger trees have greater leaf and branch surface area.

Livesley, S.J., Baudinette, B., and Glover, D. 2014. Rainfall interception and stem flow by eucalypt street trees – the impacts of canopy density and bark type. *Urban Forestry & Urban Greening*. 13: 192-197

Xiao, Q., McPherson, G., Ustin, S.L., Grismer, M.E., and Simpson, J.R. 2000. Winter rainfall interception by two mature open-grown trees in Davis, California. *Hydrological Processes*. 14: 763-784.

Xiao, Q. and McPherson, E.G. 2016. Surface water storage capacity of twenty tree species in Davis, California. *Journal of Environmental Quality*. 45: 188-198.

Slide 7



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.

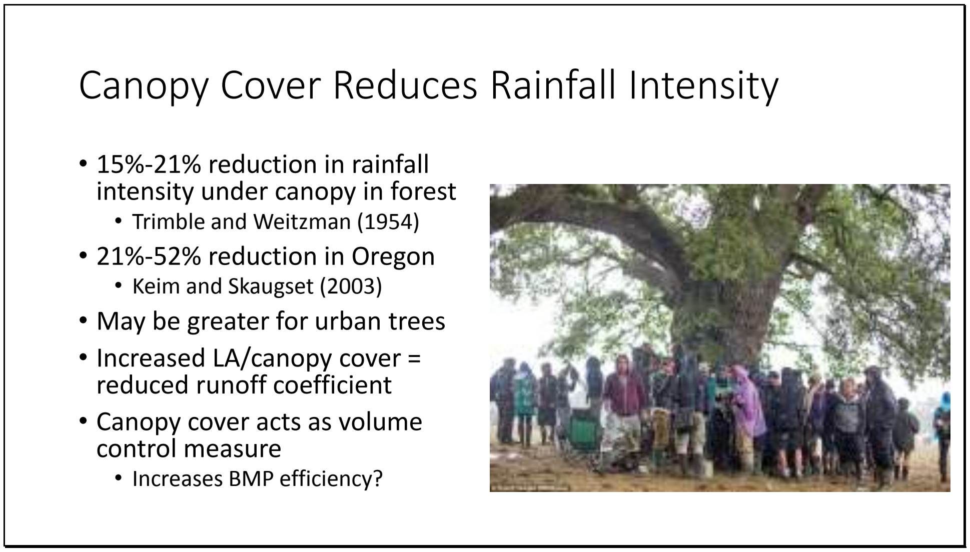
We have a research gap in urban systems regarding how much delay there is in peak discharge. Research is on-going to quantify this and develop models to calculate.

Asadian, Y. and Weiler, M. 2009. A new approach in measuring rainfall intercepted by urban trees in coastal British Columbia. *Water Qual. Res. J. Can*. 44: 16-25.

Aston, A.R. 1979. Rainfall interception by eight small trees. *Journal of Hydrology*. 42: 383-396.

Xiao, Q., McPherson, G., Ustin, S.L., Grismer, M.E., and Simpson, J.R. 2000. Winter rainfall interception by two mature open-grown trees in Davis, California. *Hydrological Processes*. 14: 763-784.

Slide 8



In deciduous forests in West Virginia rainfall intensity was shown to be reduced by up to 21%.

Tree canopy cover has been shown to slow rainfall intensity by up to 50% in the pacific NW where rainfall intensity tends to be lighter.

Because urban trees tend to have much greater leaf area than forested trees due to the lack of competition for sunlight, this reduction in rainfall intensity may be greater.

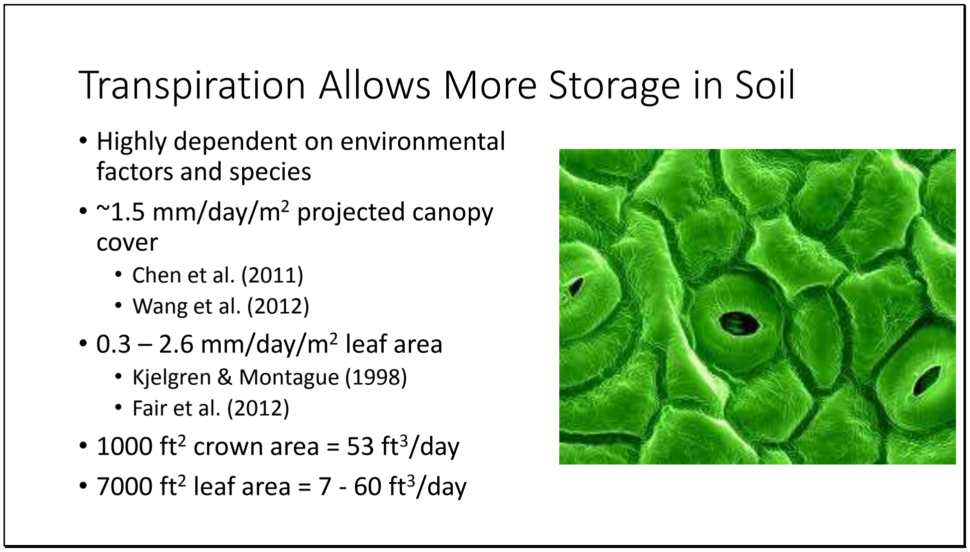
So increased leaf area and canopy cover reduces runoff coefficient and lowers the peak stormwater runoff rate

Through retention and temporary detention tree canopy cover acts to control stormwater volume and intensity which could help to increase the efficiency of stormwater BMPs and reduce their likelihood of inundation.

Trimble, Jr., G.R. and Weitzman, S. 1954. Effect of a hardwood forest canopy on rainfall intensities. *Transactions, American Geophysical Union*. 35: 226-234

Keim, R.F. and A.E. Skaugset. 2003. Modelling effects of forest canopies on slope stability. *Hydrological Processes*. 17: 1457-1467

Slide 9



Lastly, leaves have hundreds of pores or stomata that allow for gas exchange (CO2 in and H2O out). As water passes through these stomata they pull more water up through the stem from the roots and ultimately from the soil in a process called transpiration. As water is being pulled from the soil more space is being made available in the soil profile to store stormwater.

Transpiration is highly dependent on environmental factors such as heat, light, wind, soil moisture, etc.

In China, researchers found that urban trees transpired approximately 1.5 mm/day/m2 of tree canopy cover.

In a couple of studies in the US, transpiration was found to be vary between 0.3-2.6 mm/day/m2 of leaf area.

So using our 14” hackberry with 35’ crown spread (or 962 ft2 projected crown area) and assuming 1.5 mm/m2 projected crown area/day, we would expect to free up between 7 and 60 ft3.

Chen, L., Zhang, Z., Li, Z., Tang, J., Caldwell, P., and Zhang, W. 2011. Biophysical control of whole tree transpiration under an urban environment in Northern China. *Journal of Hydrology*. 402: 388-400.

Wang, H., Wang, X., Zhao, P., Zheng, H, Ren, Y, Gao, F., and Ouyang, Z. 2012. Transpiration rates of urban trees, *Aesculus chinensis*. *Journal of Environmental Sciences*. 24(7): 1278-1287.

Fair BA, Metzger JD, Vent J. 2012. Characterization of physical, gaseous, and hydrologic properties of compacted subsoil and its effects on growth and transpiration of two maples grown under greenhouse conditions. *Arboriculture & Urban Forestry*. **38(4)** : 151-159.

Kjelgren R, Montague T. 1998. Urban tree transpiration over turf and asphalt surfaces. *Atmospheric Environment*. **32(1)** : 35-41.

Slide 10

Tools for Design

- Water Environment Research Foundation (WERF)
  - Estimates Curve Numbers for BMPs
  - Site Design of BMPs including Urban Trees and Tree Box Filters

$$CN = \frac{1}{Area_{Total}} \sum_i CN_i Area_i$$

Practice/Land Type	CN
Rain gardens	35
Infiltration practices	40
Porous pavement	40
Soil amendments	60
Vegetated swales	60
Tree cover	70
Rain barrels/cisterns	75
Vegetated roofs	75
Downspout disconnection	80
Filter strips	80
Pocket wetlands	80
Tree box filters	85
Urban area	90
Impervious area	98

https://www.werf.org/liveablecommunities/toolbox/model.htm

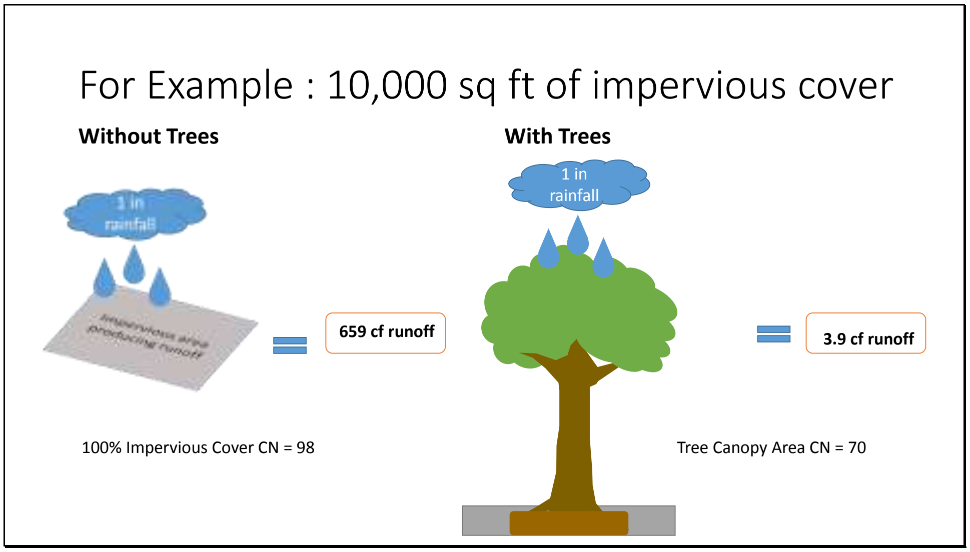
WERF has developed the Stormwater BMP Interactive Model to allow users to assess runoff reductions achieved by various stormwater BMPs. The model uses TR-55, SCS curve number method to model the runoff reduction. This method is a familiar engineering model that is commonly used in land development practice.

When assessing the combined effect of a combination of BMPs, the area of each BMP is used with its designated BMP curve number. Then the curve number is area weighted.

The curve number for each BMP is derived from observation of BMP performance.

If you look at the numbers, trees perform slightly better than small scale rain barrels and less than vegetated swales. This is logical when you think of the function and performance of how a tree works.

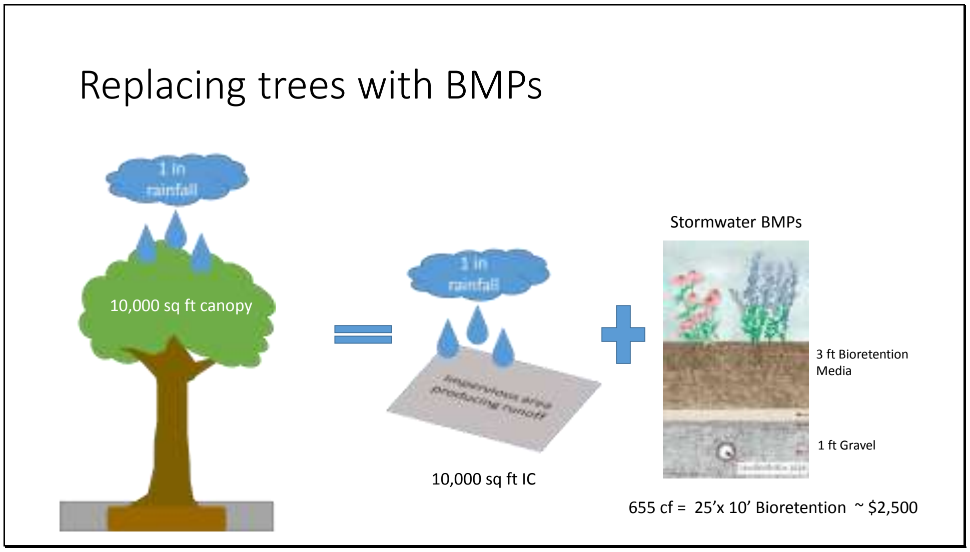
https://www.werf.org/liveablecommunities/toolbox/model.htm



Using TR 55, if you were to simulate 1 inch of rainfall on 10,000 square feet of impervious cover, it would produce approximately 659 cubic feet of runoff. In contrast, 1 inch of rainfall on tree canopy produces approximately 3.9 cubic feet of rainfall.

Thus over 10,000 sf, tree canopy would reduce runoff by 655 cubic feet of runoff.

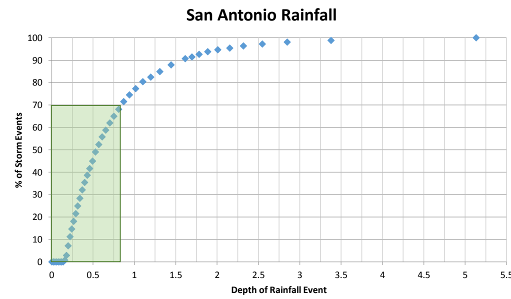
Slide 12



If you were to try and replicate the function of the tree canopy by replacing the canopy with stormwater BMPs (assuming standard design specifications), it would require 250 square feet of bioretention. This would cost approximately $2,500, using local cost numbers from San Antonio, Texas.

Slide 13

How an urban tree performs



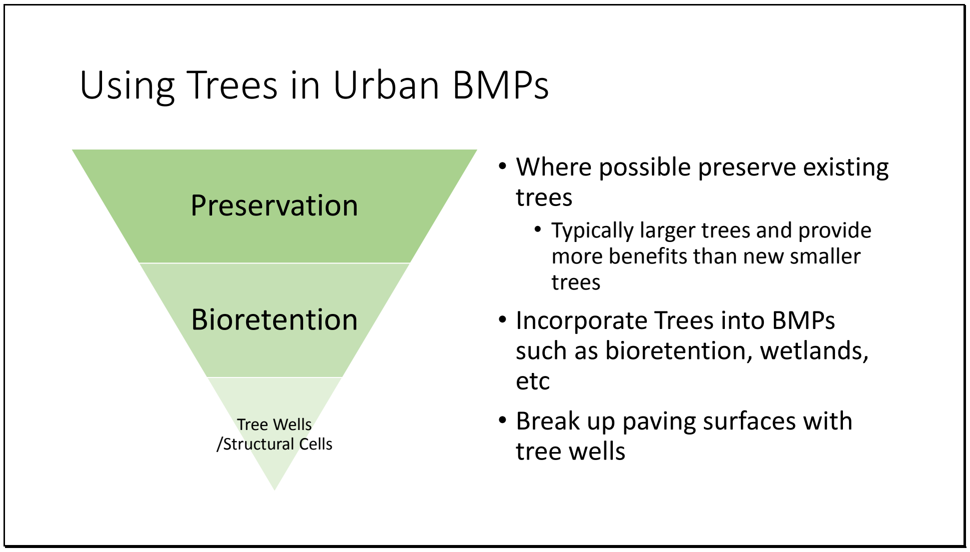
- Provides 0.2 to 0.8 *inches/unit canopy area* initial abstraction
- San Antonio Texas = 25% to *70 %* of Rainfall Events

Using the TR-55 method, it can be assumed that 5% to 20% of sorptivity will be initial abstraction. ** see source below

Therefore, a tree would be able to retain between 0.2 to 0.8 inches of stormwater. When this is compared to the rainfall record of San Antonio, Texas, it shows that tree canopy would retain 25% to 70% of events annually.

Ia = 5% to 20% of Sorptivity based on USGS Hawkins, R.H.; Jiang, R.; Woodward, D.E.; Hjelmfelt, A.T.; Van Mullem, J.A. (2002). "Runoff Curve Number Method: Examination of the Initial Abstraction Ratio". *Proceedings of the Second Federal Interagency Hydrologic Modeling Conference, Las Vegas, Nevada*. U.S. Geological Survey. doi:10.1111/j.1752-1688.2006.tb04481.x. Retrieved 24 November 2013.

Slide 14



So if you want to use trees to capture and treat stormwater, there is a hierarchy of methods.

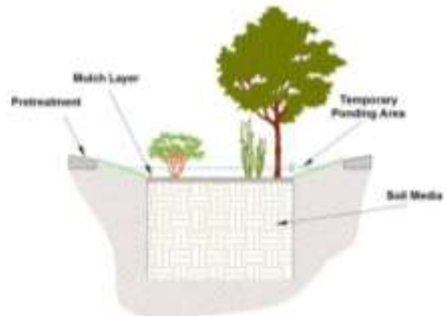
First, the preference is to preserve trees, especially groupings of trees, whenever possible. This takes advantage of established trees, which is important because tree function improves with the size and establishment of the trees.

Second, where possible, incorporate trees into BMPs. North Carolina guidelines require that every bioretention unit incorporate a tree. This enhances both the BMP and the tree by combining the function of each.

Third, when not possible to achieve the first two, generally where there is substantial impervious cover, tree wells or structural tree cells can be used. These BMPs will break up impervious cover providing pockets of treatment.

Tree BMP Guidance

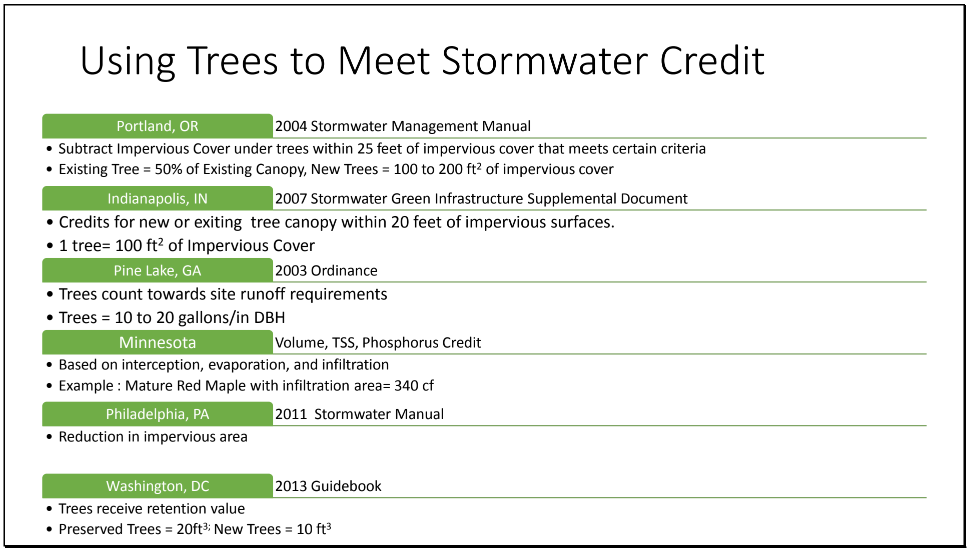
- North Carolina
  - "A minimum of one (1) tree, three (3) shrubs, and three (3) herbaceous species should be incorporated in the bioretention planting plan unless it is a grassed cell."
- Minnesota
  - "Incorporating trees into traditional bioretention practices is *Highly Recommended*."
  (http://stormwater.pca.state.mn.us/index.php/Types_of_tree_BMPs)



Various entities have recognized the value of using trees in conjunction with stormwater BMPs.

Minnesota and North Carolina require or highly recommend that trees be incorporated into bioretention.

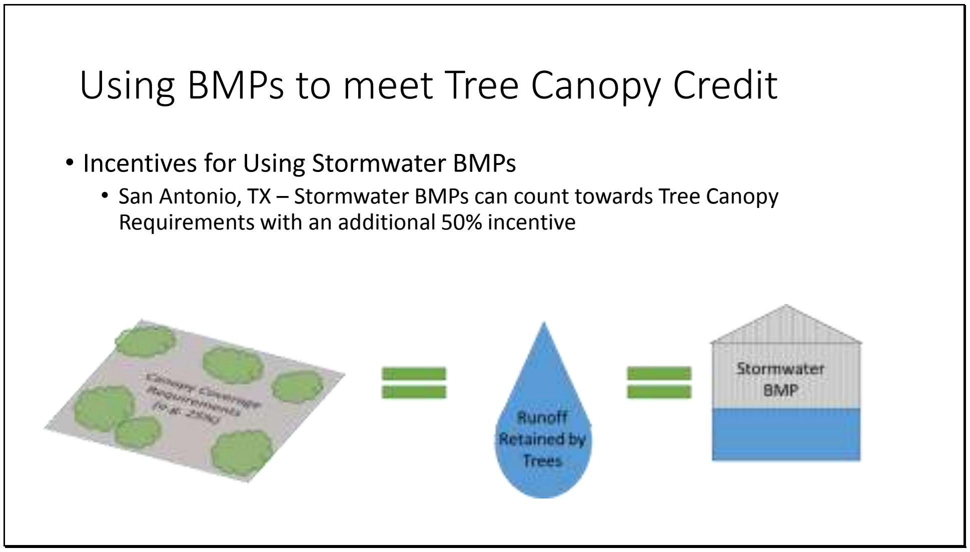
Slide 16



http://stormwater.pca.state.mn.us/index.php/Calculating_credits_for_tree_trenches_and_tree_boxes
http://dec.vermont.gov/sites/dec/files/wsm/stormwater/docs/ManualUpdate/sw_White_Paper_site_scale_credits_2014_0_%2006_draft.pdf

Moreover, municipalities and states across the US have recognized that trees are valuable stormwater BMPs by allocating credit within their stormwater ordinances. Most ordinances give a greater amount of credit to existing trees. Many ordinances use impervious cover offsets or stormwater treatment volume credits.

Slide 17



Recognizing the function of trees to mitigate the impacts of stormwater, the City of San Antonio gives credit to stormwater BMPs under the tree ordinance. The credit structure calculates the stormwater function of the tree canopy and allows the implementation of BMPs in lieu of the required canopy coverage.

Slide 18

We can manage our urban forest systems to maximize runoff mitigation.

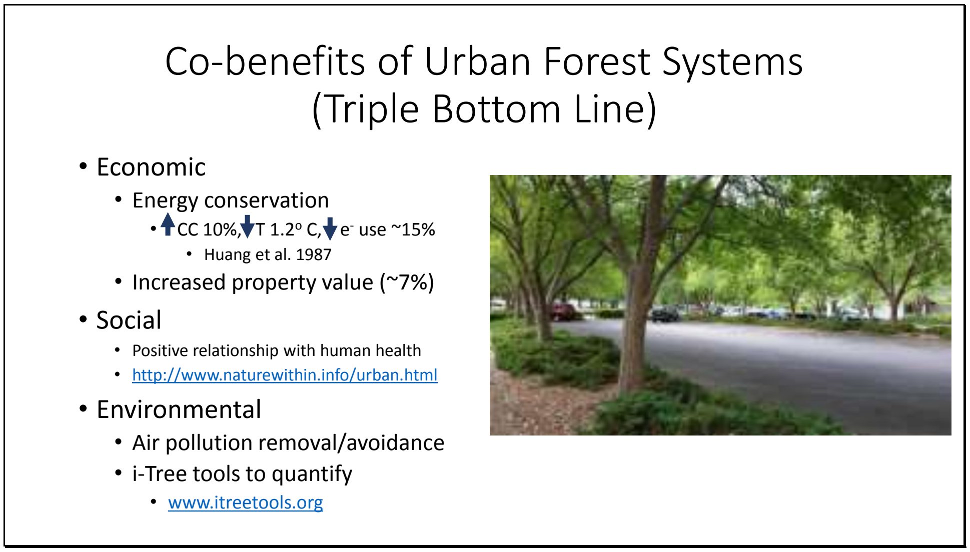
If we can increase the amount of vegetation on undeveloped land by layering the canopy cover into over-story, mid-story, and ground cover, we can mimic forest structure and thus increase rainfall retention, reduce rainfall intensity, delay throughfall, increase lag time, and increase transpiration.

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.

Slide 19



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 7% (+/-).

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.

Slide 20

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
- Canopy cover reduces rainfall intensity
  - Deciduous canopy 15 – 21%
  - Coniferous canopy 21 – 52%
- Trees transpire
  - ~1.5mm/day/m^2 canopy cover
  - 0.3 – 2.6 mm/day/ m^2 leaf area
  - Species and microclimate dependent

Slide 21

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