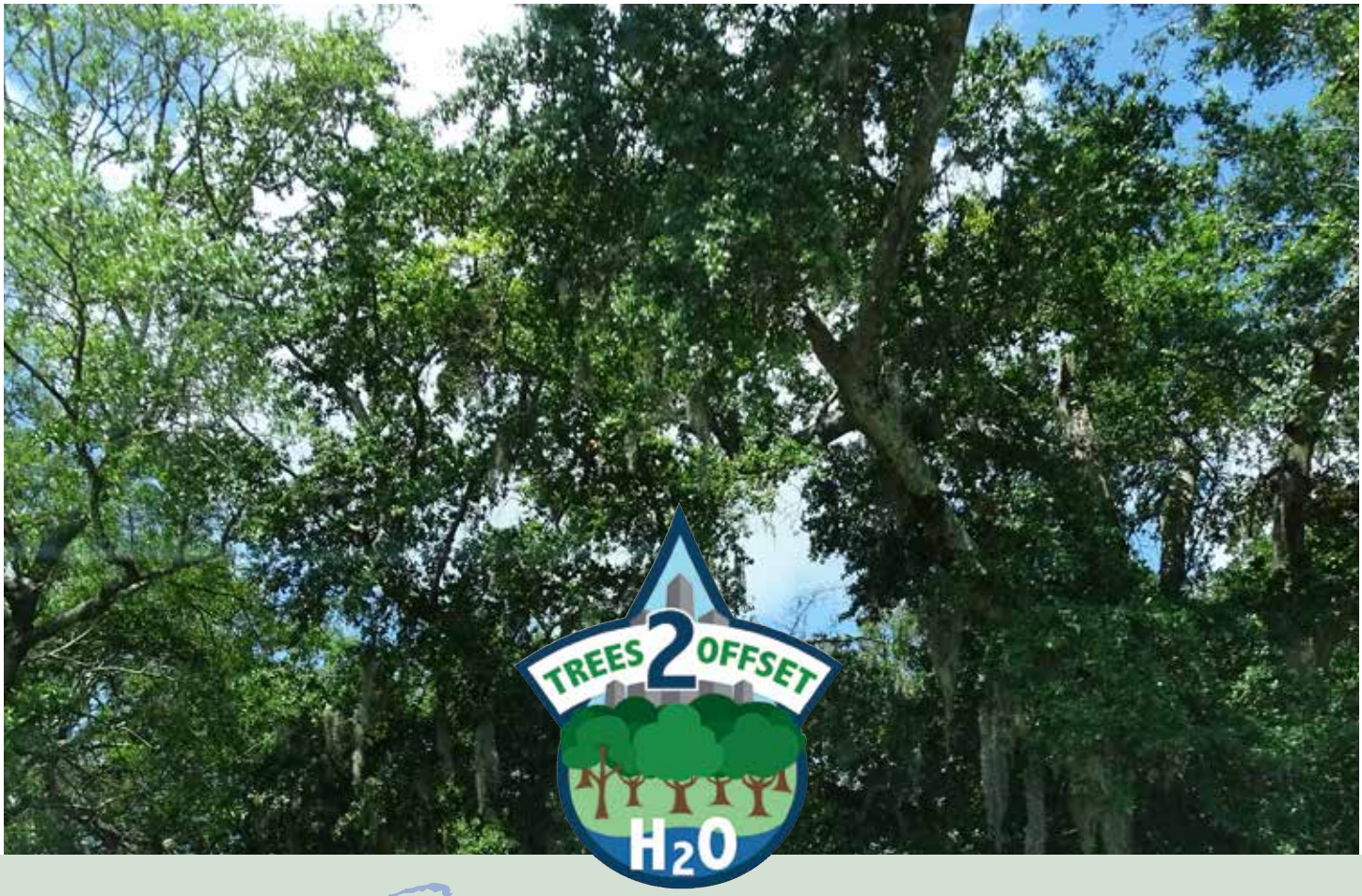

Summary

TREES TO OFFSET STORMWATER

A Study of 12 Communities

Green Infrastructure Center

June 2019

The Green Infrastructure Center Inc. is the technical services consultant for this project and the author. Illustrations in the report are by the Green Infrastructure Center Inc. (GIC).

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Summary

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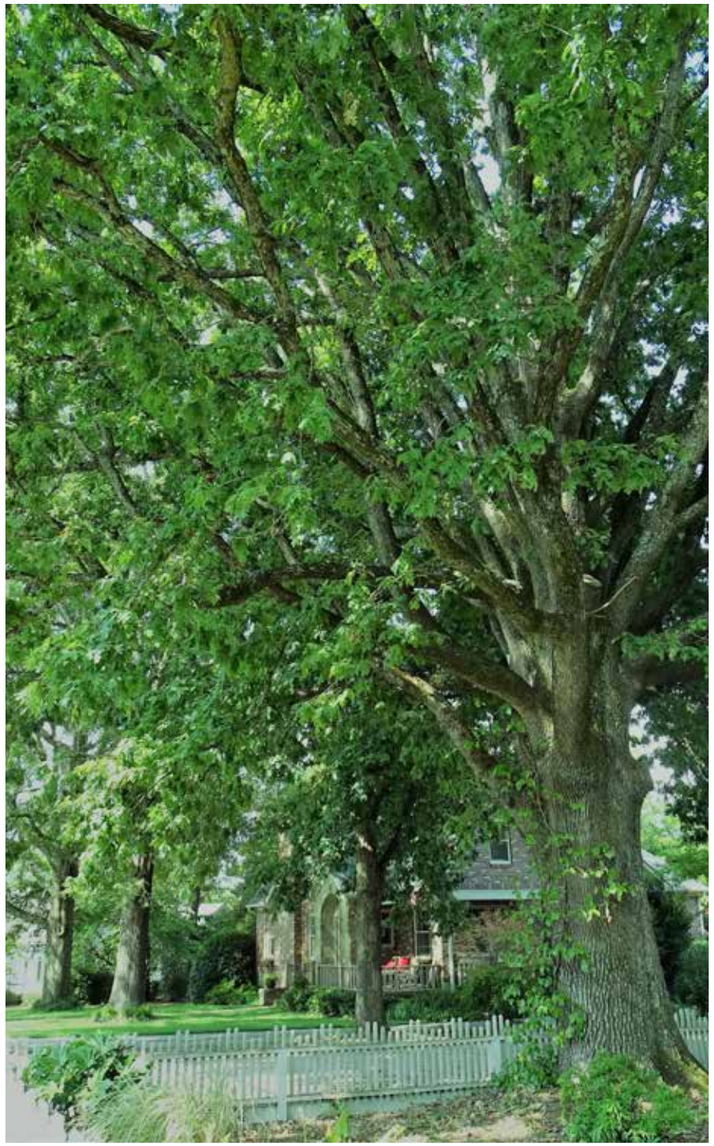
INTRODUCTION

The Trees to Offset Stormwater project is a study of the role of urban tree canopy in taking up, storing and releasing water to reduce impacts from stormwater runoff. The nonprofit Green Infrastructure Center Inc. (GIC) developed the project with urban and community forestry program coordinators for forestry agencies in Virginia, North Carolina, South Carolina, Georgia, Florida and Alabama. The GIC studied the role of the urban forest in mitigating the impacts of stormwater runoff across 12 communities from large to small cities in locations varying from mountains to the hills of the Piedmont to the coastal plain. The project began in Fall 2016 and concluded in spring 2019. A case booklet was published for each of the 12 communities with specific recommendations and a longer review was sent to each city. The case studies can be found on GIC's website at http://www.gicinc.org/trees_stormwater.htm

Each community received a model they could use to determine how much water their trees currently intercept as well as how much more stormwater runoff could be avoided by planting more trees or increased if trees were lost. The study also entailed a review of each cities codes, ordinances and policies for the degree to which they maximize stormwater infiltration and reviewed their urban forest management.

This summary report includes the project's findings, the process to create a model of the role of trees in stormwater uptake and links to the best practices audit tool to help cities reducing imperviousness and better manage their urban forest.



WHY THIS STUDY WAS NEEDED

The project was spurred by the on-going decline in forest cover throughout the southern United States coupled with increasing stormwater runoff and flooding. This study modeled the role that trees play in stormwater management and shows how cities can benefit from tree conservation and replanting. It also evaluates ways for cities to improve forest management as they grow or redevelop.

Municipalities are losing four million trees annually nationwide due to population growth and pressures to clear land for commercial and residential development (Nowak 2010). In addition to development pressures, cities are also losing older, established trees from storms, diseases, old age and other factors (Nowak and Greenfield 2012).

This tree is in poor condition due to lack of post-planting care as evidenced by die off of the top branches.

Cities also need to do a better job in planning and caring for their urban forests. On average, for every 100 street trees planted, only 50 will survive 13-20 years (Roman et al 2014). This is due to poor planting and management practices. But this does not have to be the case. Cities can do a better job in planting trees in conditions that will support them, such as having adequate planting wells and selecting the right species for each location. They also can ensure better tree care. Long lived trees will pay cities dividends for years to come in improved property values, energy savings, increased sales taxes, shade and beauty.

However, other factors, besides lack of care, are harming the urban forest. More recently, sea level rise is also taking a toll on trees in coastal cities, as areas become wetter or flood more often, causing impacts to trees unaccustomed to saturated conditions. As coastal trees are lost, buffering and filtering benefits of forest buffers are diminished and areas become more susceptible to damages from wind and storm surges. And as more areas are paved for development, water also does not replenish underground aquifers and land subsides, exacerbating the problems of rising water.

After Hurricane Katrina ravaged cities on the Gulf Coast, some cities noticed additional flooding issues, long after the initial effects of the storms had dissipated. And while these cities along the Gulf lost a lot of trees, the problem of additional standing water and flooding increased. Unfortunately, cities attempted to solve the problems of more water by simply digging more stormwater ponds. Tree replacement was not part of the solution to excess water, even though loss of trees contributed to the problem! This is because cities were not considering trees as part of their stormwater management.

> *When asked why cities dug more stormwater ponds, cities responded that they needed to manage their stormwater and that means digging more holes to detain water.*

The severity and frequency of storms appear to be increasing.[1] As a result, cities are seeing more damages to their urban canopy. Storms such as Hurricanes Irma and Florence have caused extensive flooding and tree losses in the south. The impact of these losses on urban forests is often hard to quantify because many localities have not evaluated their current tree canopy, which makes it difficult to track trends, assess losses or set goals to retain or restore canopy.

[1] https://www.ucsusa.org/global-warming/science-and-impacts/impacts/hurricanes-and-climate-change.html

Many cities are flooding more often, some even on non-rainy days as tides bring more water into cities due to rising sea levels.

Trees filter stormwater and reduce overall runoff volume. So, planting and managing trees is a natural way to mitigate stormwater. Estimates from Dayton, Ohio study found a seven percent reduction in stormwater runoff due to existing tree canopy coverage and a potential increase to 12 percent runoff reduction as a result of a modest increase in tree canopy coverage (Dwyer et al 1992). Conserving forested landscapes, urban forests, and individual trees allows localities to spend less money treating water through the municipal storm systems and also reduces flooding.

Each tree plays an important role in stormwater management. For example, based on the GIC's review of multiple studies of canopy rainfall interception, a typical street tree's crown can intercept between 760 gallons to 3000 gallons per tree per year, depending on the species and age. If a community were to plant an additional 5,000 such trees, annual stormwater runoff could be reduced by millions of gallons. This means less flooded neighborhoods and reduced stress on storm drainage pipes and decreased runoff into the city's creeks.

As their urban forest canopies have declined across the south, municipalities have seen increased stormwater runoff. In considering runoff, the amount of imperviousness is one factor; the other is the degree and type of forested land cover, since vegetation helps absorb stormwater and reduces the harmful effects of runoff. Unfortunately, many cities do not have a baseline analysis of their urban forests or strategies to replace lost trees.

Every city should be aggressively planting the next generation of trees to ensure canopy can be maintained.

The purpose of this report is not to seek a limit on the development, but to help cities utilize their tree canopy to manage stormwater. Additional benefits of improved canopy include:

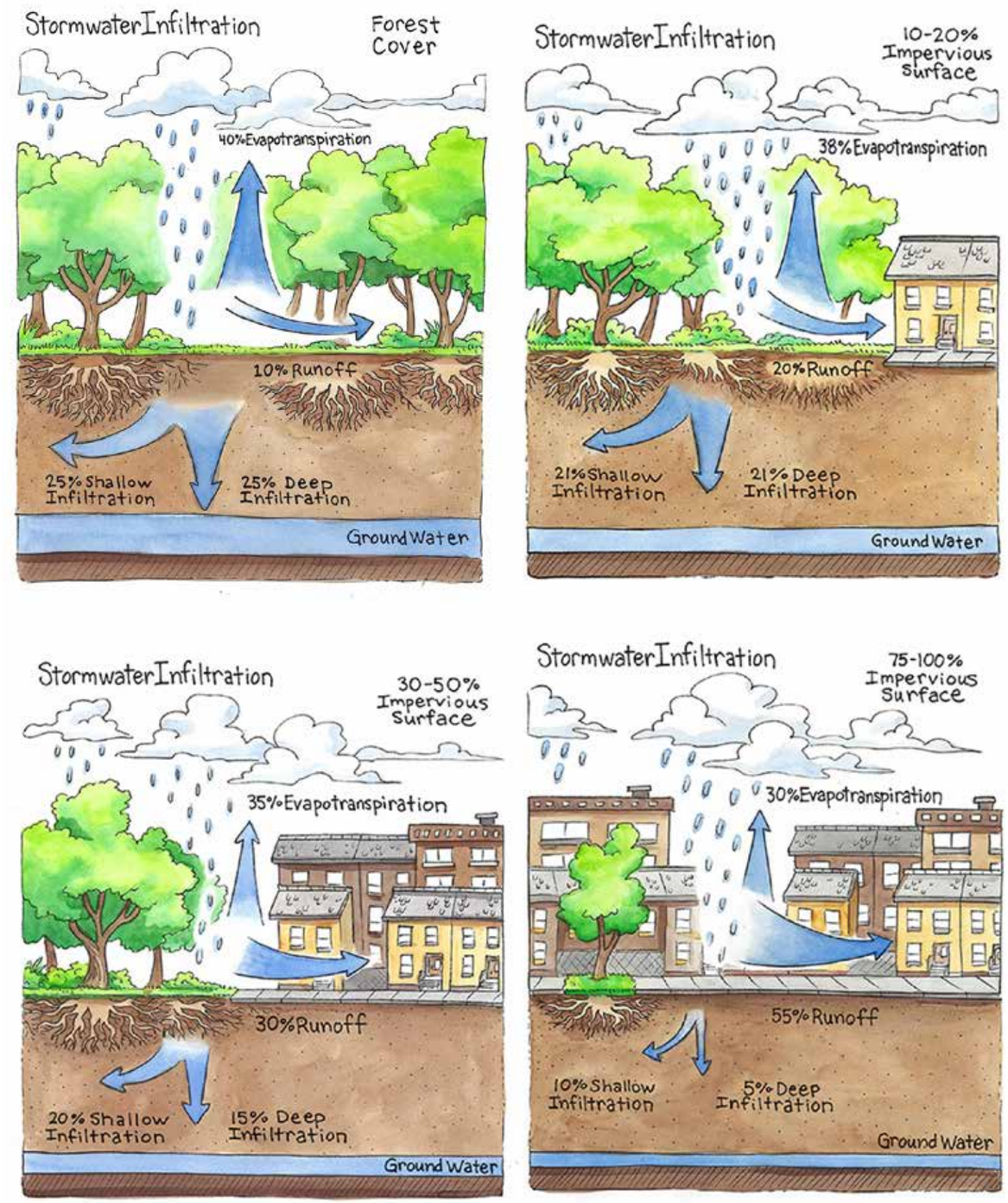
- cleaner air
- aesthetic values
- reduced heating and cooling costs
- decreased urban heat island effects
- buffering structures from wind damage
- increased bird and pollinator habitat
- fostering walkability and multimodal transportation and
- increased revenue from tourism and retail sales

When forested land is converted to impervious surfaces, stormwater runoff increases. This increase in stormwater causes temperature spikes in receiving waters, increased potential for pollution of surface and ground waters and greater potential for flooding. Trees can be used to offset this stormwater runoff. For example, urban canopy can reduce stormwater runoff anywhere from two to seven percent (Fazio 2010). According to Penn State Extension, during a one-inch rainfall event, one acre of forest will release 750 gallons of runoff, while a parking lot will release 27,000 gallons! This could mean an impact of millions of gallons of water during a major precipitation event.

Neighborhood trees add to liveability.

While stormwater ponds and other management features are designed to attenuate these events, they cannot fully replicate the pre-development hydrologic regime. In addition, many older cities lack stormwater management practices that are now required for new developments. According to the U.S. Environmental Protection Agency (EPA), excessive stormwater runoff accounts for more than half of the pollution in the nation's surface waters and causes increased flooding and property damages, as well as public safety hazards from standing water. The EPA recommends a number of ways to use trees to manage stormwater in the book Stormwater to Street Trees.

Bays and creeks depend on forested buffers and citywide tree cover to reduce runoff and pollution that can harm aquatic life.



Runoff increases as land is developed. Information source: U.S. EPA

PARTICIPATING COMMUNITIES BY STATE

VIRGINIA: Cities of **Harrisonburg, Lynchburg,** and **Norfolk**

NORTH CAROLINA: Town of **Apex**, City of **Wilmington**

SOUTH CAROLINA: City of **Charleston**

GEORGIA: Cities of **Norcross** and **Alpharetta**

ALABAMA: City of **Auburn**

FLORIDA: Cities of **Jacksonville** and **Miami Beach**, and **Orange County**

PILOT STUDY DESIGN AND FINDINGS

Twelve communities were selected across the six southern states to collaborate on this project. As noted there is a case booklet for each of the 12 communities at http://www.gicinc.org/trees_stormwater.htm Selected cities were chosen to ensure a diversity of sizes, geography and forest types. Cities included large, medium and small communities in mountain, piedmont, and coastal plain landscapes, ranging from dense urban patterns to lower density suburban development. This diversity in location, size and environment ensure applicability of the findings to a wide range of localities.

Cross Agency Collaboration

Each participating community was required to have a Technical Review Committee made up of diverse city agencies, many of whom do not typically work together. These departments included planning, public works and engineering, urban forestry, parks and recreation, geographic information systems, and if applicable, offices of sustainability or long range planning. These agency representatives participated in project review, analysis and evaluation. Cities were encouraged to include key stakeholders such as universities or tree advocacy groups. In cases where universities comprised significant land within the city, such as in Auburn AL, representatives of those universities' urban forestry programs also participated. In Jacksonville, key community groups also participated. The committees met between 4 to 6 times to review data, learn to use the calculator, discuss codes and policies and to set goals and strategic directions for their urban forests.

Each community had a multi-agency committee to review data, recommendations and plan for implementation.

Community Engagement

Two community meetings were held in each community. The first meeting provided an overview of the project and opportunities to comment on the maps. The second meeting, provided findings and recommendations. Comments from both meetings were provided to the cities. When possible, the GIC also presented the project to members of the city's Tree Commission. Community groups and citizens also contacted GIC at times to share their opinions and GIC provided interviews with radio, television, blogs and local newsletters to share the project's findings.

Common themes and ideas that surfaced time and again at these meetings included the need to work with developers to shrink the development footprint, ways to consider trees as stormwater management practices, needs to increase education about the benefits of trees, requiring tree removal permits, and ending the practice lot line to lot line clearing as well as ensuring tree survival by accommodating large shade trees by providing adequate soil volume.

To meet tree coverage goals, planting needs to occur on private property– where 80 percent of canopy is found. In some cities, there was high cooperation with civic groups to plant trees, such as in Jacksonville, Alpharetta and Norfolk, while in other cities, they did not have strong relationships or on-going projects with citizen groups, even though community groups asked to be engaged.

Cities and urbanizing counties can use the methods and tools from this project to account for their trees' contribution to stormwater management. Participating localities now have baseline data against which to monitor canopy protection progress, measurements of the stormwater and water quality benefits provided by their urban forests, and locations for prioritizing canopy replanting or retention to maximize stormwater uptake. This report describes how other communities can better manage their urban forests, utilize their trees to manage urban runoff and redesign their communities to be infiltrative.

Two community meetings were held in each location to allow for citizen input on city trees and recommendations.

Trees donated for community planting are key to reforestation.

MODELING THE ROLE OF TREES TO REDUCE STORMWATER RUNOFF

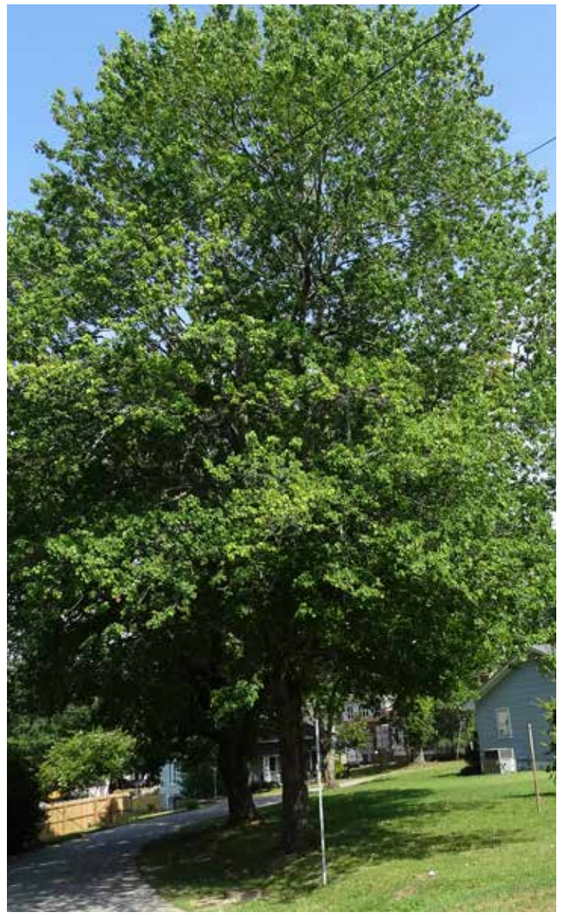
The land cover of the community plays a key role in the rates and quality of stormwater runoff. Forested land cover is very effective in capturing, filtering and evaporating rainfall. One mature large canopy tree, such as a live oak, can intercept thousands of gallons of runoff annually. However, in cities and urbanizing counties, much of the landscape is impervious, causing excessive rainfall runoff and adding pollutants to surface waters. Although the federal Clean Water Act Amendments of 1987 require communities to manage their stormwater, many older urban landscapes in the south were developed prior to these regulations. In these communities, while newer developments are required to treat their stormwater, stormwater from older areas flows untreated into nearby streams, wetlands, lakes and bays causing siltation, erosion, algal blooms and reduced oxygen, among other problems.

To model stormwater interception, the GIC developed a methodology to account for forest cover and potential forest cover and associated runoff. These data were then input into an Excel spreadsheet the "Trees and Stormwater Calculator Tool" which allows planners, urban foresters, stormwater engineers or forest advocates to model the impacts for stormwater runoff of adding or losing trees for storm as well as associated reductions or additions of common water pollutants of nitrogen, phosphorus or sediment.

Creating the land cover maps and data requires computer skills in geographic information systems. The method is summarized in this document so that others can replicate the processes used. The spreadsheet tool can then be populated with these data to allow any city to create their own stormwater calculator tool.

The goal of this study was to identify ways in which stormwater entering a city's municipal separate storm sewer system (MS4) could be reduced by using trees to intercept and soak up stormwater runoff. Tree canopy serves as 'green infrastructure' that can extend the capacity of the city's grey infrastructure (i.e. stormwater drainage systems) by intercepting, absorbing, and/or evaporating excess precipitation before it is converted into runoff. Reducing runoff can help cities limit pollution of surface waters, which can help attain load allocations prescribed in Total Maximum Daily Load's (TMDL), help meet other water quality objectives, and fulfill a variety of goals and objectives of local watershed plans.

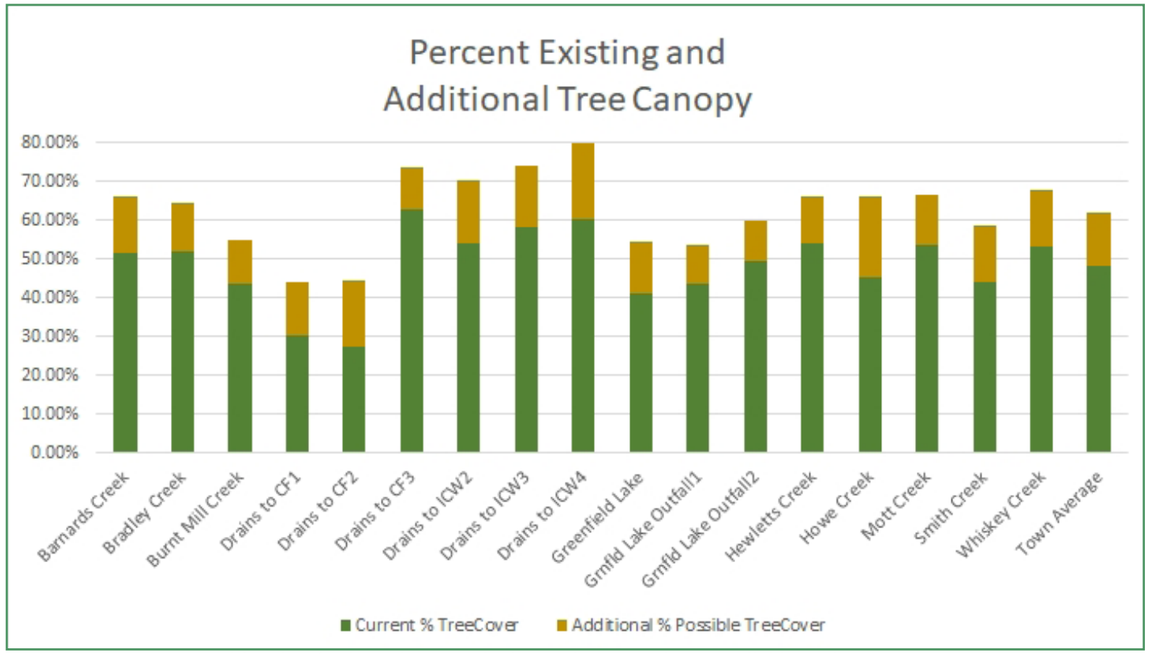
The Trees to Offset Stormwater Tool developed for this project models how much water is taken up by a city's trees for specific storm events. This new approach allows for more detailed assessment of stormwater uptake based on the landscape conditions of the city's forests. Cities varied greatly in the extent and types of forest cover. For example, in the study city of Charleston SC, the extensive forested wetlands within the city's boundaries resulted in a high canopy percentage –60.6%-- and



One mature tree can absorb thousands of gallons of water per year.

they were very important to stormwater retention whereas a study city of Harrisonburg VA has a relatively lower canopy at 17% and few to no forested wetlands.

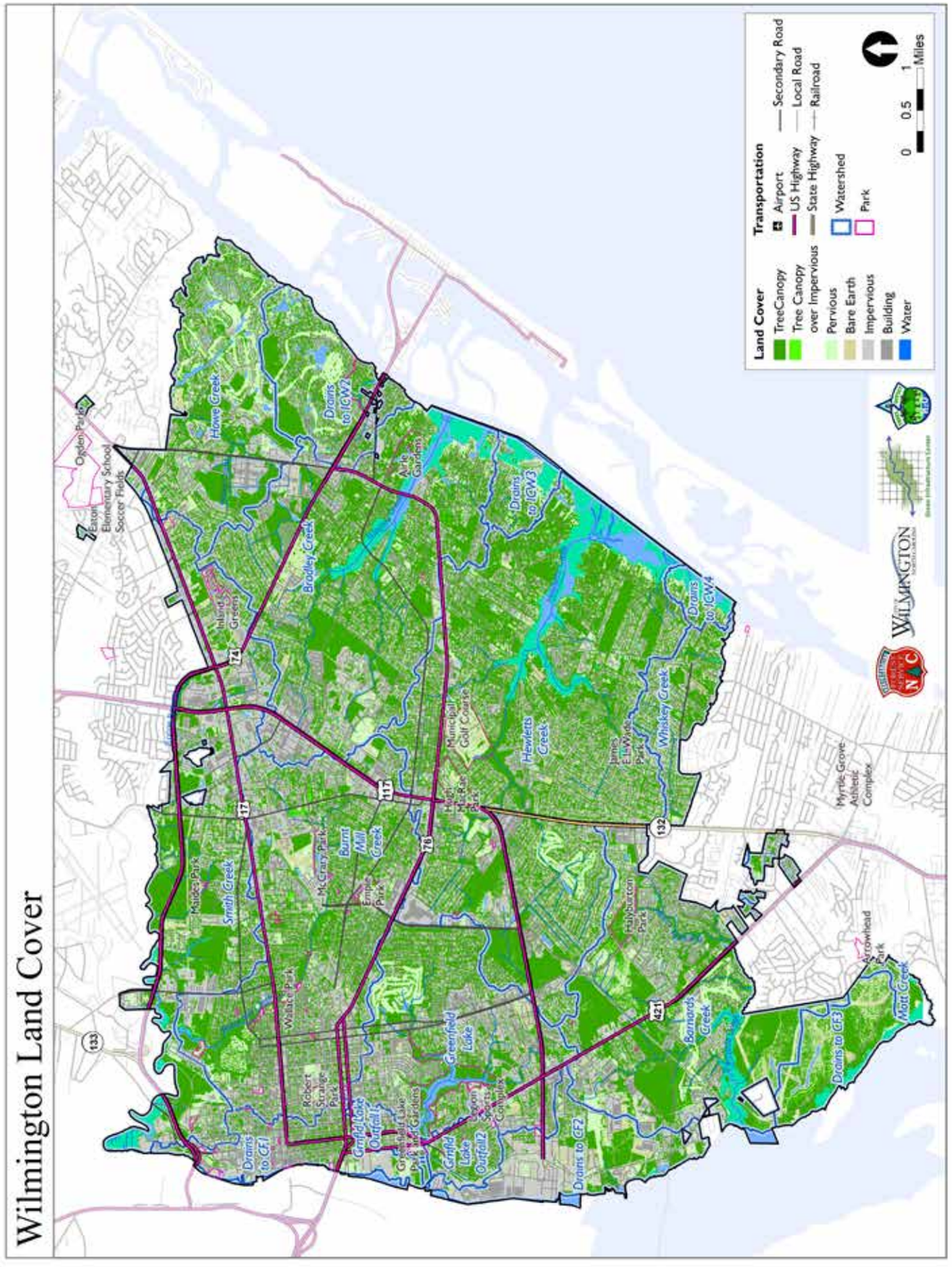
In order to determine how much water a community's trees intercept, the extent and location of tree canopy must be determined as well as the settings for where trees are growing. This is important since a tree growing in an open land setting will be able to absorb far more water than a tree planted in a tight planting strip bordered by sidewalks and roads that block water from reaching tree roots. It is also important to know canopy location and extent so that cities can understand where canopy is high, low or lacking and determine strategies for expanding or protecting it.



Resulting data is shown by watershed – treed areas and area available to plant more trees.

Satellite imagery was used to classify the types of land cover in the study cities and to determine the extent of canopy coverage and the conditions in which the trees were planted. For the 12 communities in this study, the GIC created the land cover data, including tree canopy, and provided each locality with an ArcGIS geodatabase with all GIS data from the study.

Technical instructions for how to customize a canopy map to be used with the Trees and Stormwater Calculator Tool are on GIC's website at http://www.gicinc.org/trees_stormwater.htm . Creating the data and canopy map and possible planting areas requires expertise in using Geographic Information Systems (GIS) software. Cities usually have a GIS staff person, but not all GIS staff are skilled in creating maps from remotely sensed data. GIC staff are also available for hire to create these maps for communities. In addition, there is a free tool available to create a basic land cover map. For more see http://www.gicinc.org/land_image_analyst.htm However, even if the free tool is used, the data will need further work using GIS to add roads and sidewalks manually to determine if canopy is overhanging paved surfaces and to calculate plantable open spaces.

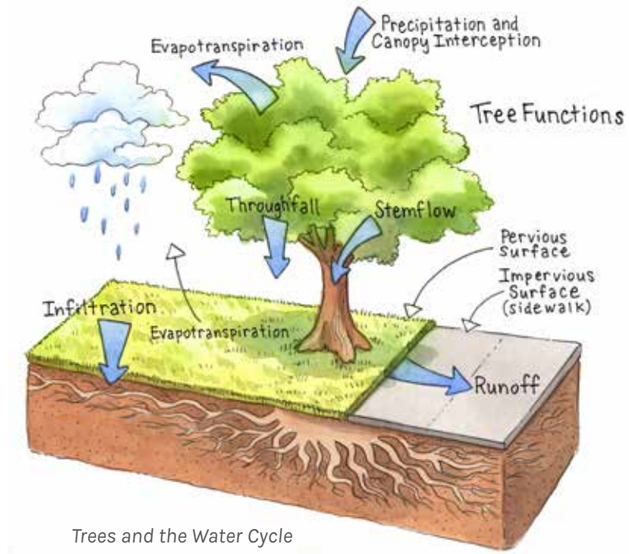


This map shows the tree canopy of the city which covers 48.1 percent of the area.

METHODS TO MODEL STORMWATER CAPTURE BY TREES

This project modeled stormwater runoff and uptake by a city's tree canopy at the watershed scale. However, an area of interest, such as a master planning area or smaller subwatershed could also be used as the area of analysis. The technical manual posted at http://www.gicinc.org/trees_stormwater.htm describes how to prepare data to use for analysis for a city.

As noted, trees intercept, take up and slow the rate of stormwater runoff. Canopy interception varies from 100 percent at the beginning of a rainfall event to about three percent at the maximum rain intensity. Trees take up more water early on during storm events and less water as storm events proceed and the ground becomes saturated (Xiao et al. 2000). Many forestry scientists, as well as civil engineers, have recognized that trees have important stormwater benefits (Kuehler 2017, 2016).
See the diagram (at right) of tree water flow.



Trees and the Water Cycle

DETERMINING WATER INTERCEPTION, UPTAKE AND INFILTRATION USING MODIFIED CURVE NUMBERS

This project provides a tool for setting goals at the watershed scale for planting trees and for evaluating the consequences of tree loss as it pertains to stormwater runoff. This study used the Natural Resources Conservation Service (NRCS) TR-55 curve number method to calculate stormwater runoff. The TR-55 method calculates stormwater runoff and absorption for different land covers, e.g. bare earth, pavement, lawn, forest. It also accounts for the infiltration rate for various soils.

The TR-55 method is widely recognized and utilized by stormwater engineers to determine stormwater runoff volumes and most cities use TR-55 curve numbers to generate expected runoff amounts for land cover changes. Major factors determining CN are:

- The hydrologic soil group (defined by surface infiltration rates and transmission rates of water through the soil profile, when thoroughly wetted)
- Land cover types – bare earth, pavement, trees etc.
- Hydrologic condition – density of vegetative cover, surface texture, seasonal variations
- Treatment – design or management practices that affect runoff

We modified the TR-55 curve number equation to include a factor for canopy interception (see following equation) to account for the role that trees play in stormwater interception. Trees capture some of the rainfall before it reaches the ground, while some of the rainfall goes through the branches (throughfall) and down the branches and trunk of the tree (trunk flow). Ordinarily, the runoff calculation is based on soils and ignores the role that trees play in rainwater interception and evaporation. Accounting for the role that trees play in capturing, absorbing and evaporating rainfall is critical in understanding how much water is running off the land and how much is retained.

A canopy interception factor is added to the runoff equation to account for the role trees play in interception of rainfall based on location and planting condition (e.g. trees over pavement versus trees over a lawn, or in a forest). Tree canopy reduces the proportion of precipitation that becomes stream and surface flow, also known as water yield. Hynicka and Divers (2016) modified the water yield equation of the NRCS model by adding a canopy interception term (Ci) to account for the role that canopy plays in capturing stormwater, resulting in:

$$R = \frac{(P - C_i - I_a)^2}{(P - C_i - I_a) + S}$$

- Where R is runoff
- P is precipitation (inches)
- Ia is the initial abstraction for captured water, which is the fraction of the storm depth after which runoff begins
- S is the potential maximum retention after runoff begins for the subject land cover (S = 1000/CN – 10).
- Canopy interception (Ci) is subtracted from precipitation (P) to account for the water that trees take up.

LAND COVER, POSSIBLE PLANTING AREA, POSSIBLE CANOPY AREA ANALYSIS

In order to use the equation and model scenarios for future tree canopy and water uptake, the GIC first developed a highly detailed land cover analysis to account for the landscape conditions in which the trees are found (trees overhanging a parking lot versus trees over a lawn). This is important because rain falling though a tree (throughfall) onto a pervious surface, such as a lawn, can still be absorbed, while rain throughfall to a street will become runoff.

Land cover classifications are an affordable method for using aerial or satellite images to obtain information about large geographic areas. The land cover data were created using the most current leaf-on imagery from the National Agriculture Imagery Program (NAIP) distributed by the USDA Farm Service Agency. These data are from aerial images that are flown every two years by the USDA. To obtain this imagery for use in GIS visit https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/

NAIP imagery is available from USDA.

Algorithms are trained to recognize various types of land cover based on color and shape. In this process, the pixels in the raw image are converted to one of several types of pre-selected land cover types. In this way, the raw data (i.e. the images) are turned into information about land cover types of interest, e.g. what is pavement, what is vegetation? This land cover information can be used to gain knowledge about certain issues; for example: What is the tree canopy percentage in a specific neighborhood? Ancillary data for roads, and hydrology (from National Wetlands Inventory and National Hydrography Dataset) were used to determine:

1) Tree cover over impervious surfaces, which otherwise could not be seen due to these features being covered by tree canopy; and
2) Wetlands not distinguishable using spectral/feature-based image classification tools.

In cities studied for this project, forested open space was identified as areas of compact, continuous tree canopy greater than one acre, not intersected by buildings or paved surfaces. The final classification of land cover consists of six classes listed below.

In addition to knowing where trees are located, it is also important to know where they could 'potentially' be planted. The Potential Planting Area (PPA) is created by selecting the land cover features that have space available for planting trees. (i.e., areas where the growth of a tree will not affect or be affected by existing infrastructure.) Of the six land cover classes, only pervious (grass and scrub vegetation) is considered for PPA. A city could, however, choose to remove pavement, amend the compacted soil underneath, and plant trees in otherwise unavailable spaces.

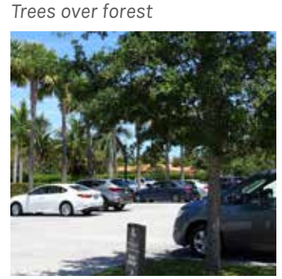
- Tree canopy
- Tree canopy over impervious
- Pervious
- Impervious
- Bare earth
- Water

Next, these eligible planting areas are limited based on their proximity to features that might either interfere with a tree's natural growth (such as buildings) or features that the tree might impact, such as power lines, sidewalks or roads. Playing fields and other known land uses that would not be appropriate for tree cover are also avoided. However, there may be some existing land uses (e.g. golf courses) that are unlikely to be used for tree planting areas, but that may not have been excluded from the PPA. The GIC works to remove areas such as golf courses or ball fields but some could be overlooked. In addition, the analysis did not take into account proposed future developments (e.g., planned developments) that would not likely be fully planted with trees. Therefore, the resulting PPA represents the maximum potential places trees can be planted and grow to full size. A good rule is to assume about half the available PPA space could actually be planted with trees. Every city needs to retain some non-canopied open spaces for gardens, soccer and other uses.

Tree over street

Trees over forest

Tree over lawn



Tree over parking lot

Potential Planting Area (PPA)

The Potential Planting Area (PPA) is created by selecting the land cover features that have space available for planting trees, then eliminating areas that would interfere with existing infrastructure.

Initial Inclusion selected from GIC-created land cover
- Pervious surfaces
- Bare earth

Excluded Land Cover Features (not plantable):
- Existing tree cover
- Water
- Wetlands
- Imperious surfaces
- Ball fields (i.e. baseball, soccer, football) where visually identifiable from NAIP imagery.

Exclusion Features (buffer distance):
- Roads Areas (10ft)
- Sidewalks (10ft)
- Structures (10ft)
- Pump stations (10ft)
- Utility Poles (10ft)
- Parking lots (10ft)
- Rail roads (10ft)
- Fire Hydrants (10ft)
- Water/sewer Mains (10ft)
- Power lines (10ft)

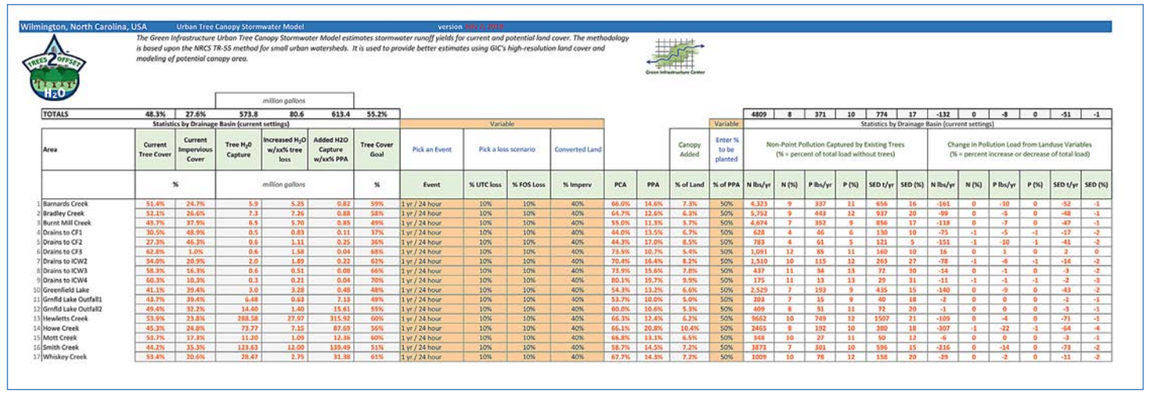
Potential Planting Spots (PPS)

The Potential Planting Spots (PPS) are created from the PPA. The PPA is run through a GIS model that selects those spots where a tree can be planted depending on the size of trees desired. For this analysis, expected sizes of both 20 ft. and 40 ft. diameter of individual mature tree canopy were used with priority given to 40 ft. diameter trees (larger trees have more benefits). It is expected that 30 percent overlap will occur as these trees reach maturity. The result demonstrates a scenario where, if planted today, once the trees are mature, their full canopy will cover the potential planting area and overlap adjacent features, such as roads and sidewalks.

Potential Canopy Area (PCA)

Percent Street Trees is calculated using the Land Cover Tree Canopy and road centerlines, which are buffered to 50 ft. from each road segment's centerline. The percent value represented is the percentage of tree cover within that 50 ft. buffer. This captures both street trees and trees in yards that may overlap the road.

The Trees and Stormwater (TSW) Tool, created by GIC, estimates the capture of precipitation by tree canopies and resulting reductions in runoff yield. It takes into account the interaction of land cover and soil hydrologic conditions. It's intended to be used for running 'what-if' scenarios, specifically losses of tree canopy from development and increases in tree canopy from tree planting programs to inform planning decisions and urban forest management.

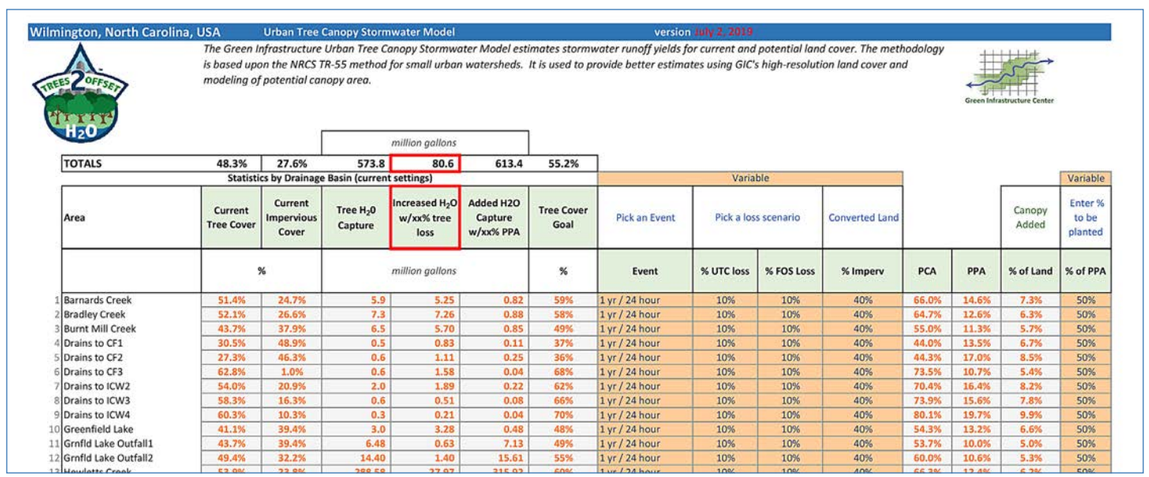


Wilmington, North Carolina, USA — Urban Tree Canopy Stormwater Model — version July 2, 2019

The Green Infrastructure Urban Tree Canopy Stormwater Model estimates stormwater runoff yields for current and potential land cover. The methodology is based upon the NRCS TR-55 method for small urban watersheds. It is used to provide better estimates using GIC's high-resolution land cover and modeling of potential canopy area.

	Area	Current Tree Cover	Current Impervious Cover	Tree H_2O Capture	Increased H_2O w/xx% tree loss	Added H2O Capture w/xx% PPA	Tree Cover Goal	Pick an Event	Pick a loss scenario		Converted Land				Canopy Added	Enter % to be planted	Non-Point Pollution Captured by Existing Trees (% = percent of total load without trees)						Change in Pollution Load from Landuse Variables (% = percent increase or decrease of total load)					
				million gallons				Variable								Variable												
	TOTALS	48.3%	27.6%	573.8	80.6	613.4	55.2%										4809	8	371	10	774	17	-132	0	-8	0	-51	-1
		Statistics by Drainage Basin (current settings)															Statistics by Drainage Basin (current settings)											
		%		million gallons			%	Event	% UTC loss	% FOS Loss	% Imperv	PCA	PPA	% of Land		% of PPA	N lbs/yr	N (%)	P lbs/yr	P (%)	SED t/yr	SED (%)	N lbs/yr	N (%)	P lbs/yr	P (%)	SED t/yr	SED (%)
1	Barnards Creek	51.4%	24.7%	5.9	5.25	0.82	59%	1 yr / 24 hour	10%	10%	40%	66.0%	14.6%	7.3%		50%	4,323	9	337	11	656	16	-161	0	-10	0	-52	-1
2	Bradley Creek	52.1%	26.6%	7.3	7.26	0.88	58%	1 yr / 24 hour	10%	10%	40%	64.7%	12.6%	6.3%		50%	5,752	9	443	12	937	20	-69	0	-5	0	-48	-1
3	Burnt Mill Creek	43.7%	37.9%	6.5	5.70	0.85	49%	1 yr / 24 hour	10%	10%	40%	55.0%	11.3%	5.7%		50%	4,674	7	352	9	856	17	-118	0	-7	0	-47	-1
4	Drains to CF1	30.5%	48.9%	0.5	0.83	0.11	37%	1 yr / 24 hour	10%	10%	40%	44.0%	13.5%	6.7%		50%	628	4	46	6	130	10	-75	-1	-5	-1	-17	-2
5	Drains to CF2	27.3%	46.3%	0.6	1.11	0.25	36%	1 yr / 24 hour	10%	10%	40%	44.3%	17.0%	8.5%		50%	783	4	61	5	121	5	-151	-1	-10	-1	-41	-2
6	Drains to CF3	62.8%	1.0%	0.6	1.58	0.04	68%	1 yr / 24 hour	10%	10%	40%	73.5%	10.7%	5.4%		50%	1,091	12	85	11	160	10	16	0	1	0	2	0
7	Drains to ICW2	54.0%	20.9%	2.0	1.89	0.22	62%	1 yr / 24 hour	10%	10%	40%	70.4%	16.4%	8.2%		50%	1,510	10	115	12	263	27	-78	-1	-6	-1	-14	-2
8	Drains to ICW3	58.3%	16.3%	0.6	0.51	0.08	66%	1 yr / 24 hour	10%	10%	40%	73.9%	15.6%	7.8%		50%	437	11	34	13	72	30	-14	0	-1	0	-3	-2
9	Drains to ICW4	60.3%	10.3%	0.3	0.21	0.04	70%	1 yr / 24 hour	10%	10%	40%	80.1%	19.7%	9.9%		50%	175	11	13	13	29	31	-11	-1	-1	-1	-2	-3
10	Greenfield Lake	41.1%	39.4%	3.0	3.28	0.48	48%	1 yr / 24 hour	10%	10%	40%	54.3%	13.2%	6.6%		50%	2,529	7	193	9	435	15	-140	0	-9	0	-43	-2
11	Grnfld Lake Outfall1	43.7%	39.4%	6.48	0.63	7.13	49%	1 yr / 24 hour	10%	10%	40%	53.7%	10.0%	5.0%		50%	203	7	15	9	40	18	-2	0	0	0	-1	-1
12	Grnfld Lake Outfall2	49.4%	32.2%	14.40	1.40	15.61	55%	1 yr / 24 hour	10%	10%	40%	60.0%	10.6%	5.3%		50%	409	8	31	11	72	20	-1	0	0	0	-3	-1
13	Hewletts Creek	53.9%	23.8%	288.58	27.97	315.92	60%	1 yr / 24 hour	10%	10%	40%	66.3%	12.4%	6.2%		50%	9662	10	749	12	1507	21	-109	0	-4	0	-71	-1
14	Howe Creek	45.3%	24.8%	73.77	7.15	87.69	56%	1 yr / 24 hour	10%	10%	40%	66.1%	20.8%	10.4%		50%	2465	8	192	10	380	18	-307	-1	-22	-1	-64	-4
15	Mott Creek	53.7%	17.3%	11.20	1.09	12.36	60%	1 yr / 24 hour	10%	10%	40%	66.8%	13.1%	6.5%		50%	348	10	27	11	50	12	-6	0	0	0	-3	-1
16	Smith Creek	44.2%	35.3%	123.63	12.00	130.49	51%	1 yr / 24 hour	10%	10%	40%	58.7%	14.5%	7.2%		50%	3873	7	301	10	596	15	-216	0	-14	0	-73	-2
17	Whiskey Creek	53.4%	20.6%	28.47	2.75	31.38	61%	1 yr / 24 hour	10%	10%	40%	67.7%	14.3%	7.3%		50%	1009	10	78	12	158	20	-29	0	-2	0	-11	-2

Each of the 12 communities in this study received a TSW calculator tool. The TSW tool allows a city to hypothetically add or reduce tree canopy to see what are the effects for stormwater capture or runoff.



Wilmington, North Carolina, USA — Urban Tree Canopy Stormwater Model — version July 2, 2019

The Green Infrastructure Urban Tree Canopy Stormwater Model estimates stormwater runoff yields for current and potential land cover. The methodology is based upon the NRCS TR-55 method for small urban watersheds. It is used to provide better estimates using GIC's high-resolution land cover and modeling of potential canopy area.

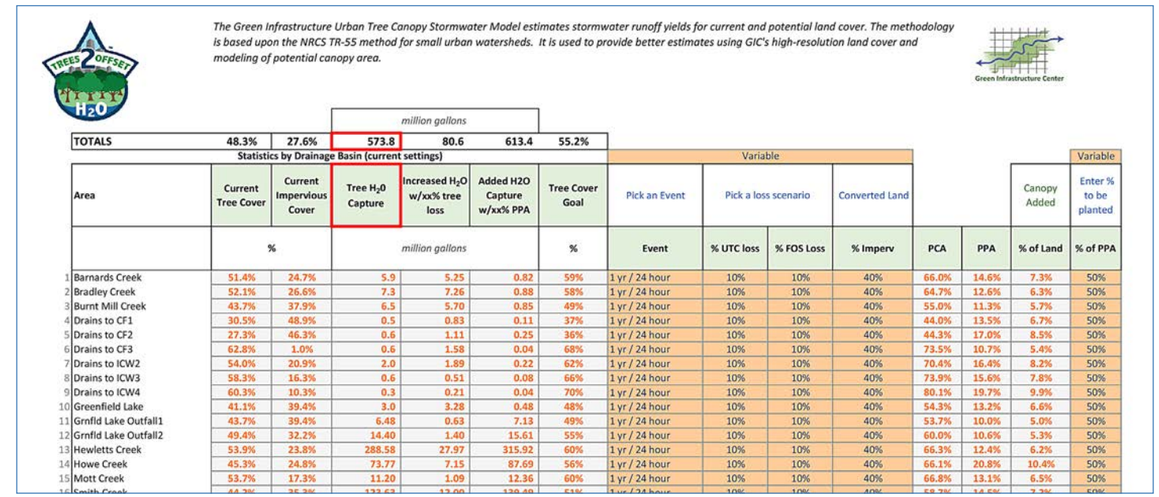
	Area	Current Tree Cover	Current Impervious Cover	Tree H_2O Capture	Increased H_2O w/xx% tree loss	Added H2O Capture w/xx% PPA	Tree Cover Goal	Pick an Event	Pick a loss scenario		Converted Land				Canopy Added	Enter % to be planted
				million gallons				Variable								Variable
	TOTALS	48.3%	27.6%	573.8	80.6	613.4	55.2%									
		Statistics by Drainage Basin (current settings)														
		%		million gallons			%	Event	% UTC loss	% FOS Loss	% Imperv	PCA	PPA	% of Land		% of PPA
1	Barnards Creek	51.4%	24.7%	5.9	5.25	0.82	59%	1 yr / 24 hour	10%	10%	40%	66.0%	14.6%	7.3%		50%
2	Bradley Creek	52.1%	26.6%	7.3	7.26	0.88	58%	1 yr / 24 hour	10%	10%	40%	64.7%	12.6%	6.3%		50%
3	Burnt Mill Creek	43.7%	37.9%	6.5	5.70	0.85	49%	1 yr / 24 hour	10%	10%	40%	55.0%	11.3%	5.7%		50%
4	Drains to CF1	30.5%	48.9%	0.5	0.83	0.11	37%	1 yr / 24 hour	10%	10%	40%	44.0%	13.5%	6.7%		50%
5	Drains to CF2	27.3%	46.3%	0.6	1.11	0.25	36%	1 yr / 24 hour	10%	10%	40%	44.3%	17.0%	8.5%		50%
6	Drains to CF3	62.8%	1.0%	0.6	1.58	0.04	68%	1 yr / 24 hour	10%	10%	40%	73.5%	10.7%	5.4%		50%
7	Drains to ICW2	54.0%	20.9%	2.0	1.89	0.22	62%	1 yr / 24 hour	10%	10%	40%	70.4%	16.4%	8.2%		50%
8	Drains to ICW3	58.3%	16.3%	0.6	0.51	0.08	66%	1 yr / 24 hour	10%	10%	40%	73.9%	15.6%	7.8%		50%
9	Drains to ICW4	60.3%	10.3%	0.3	0.21	0.04	70%	1 yr / 24 hour	10%	10%	40%	80.1%	19.7%	9.9%		50%
10	Greenfield Lake	41.1%	39.4%	3.0	3.28	0.48	48%	1 yr / 24 hour	10%	10%	40%	54.3%	13.2%	6.6%		50%
11	Grnfld Lake Outfall1	43.7%	39.4%	6.48	0.63	7.13	49%	1 yr / 24 hour	10%	10%	40%	53.7%	10.0%	5.0%		50%
12	Grnfld Lake Outfall2	49.4%	32.2%	14.40	1.40	15.61	55%	1 yr / 24 hour	10%	10%	40%	60.0%	10.6%	5.3%		50%

The calculator tool developed for this project allows a city to see the water uptake by existing canopy and model impacts from changes, whether positive (adding trees) or negative (removing trees).

The land cover data for each watershed and possible planting area calculations are added to the spreadsheet cells to run the calculator. Creating this data requires advanced skills in Geographic Information Systems. See methods on GIC's website for more details on how to prepare data for the spreadsheet. http://www.gicinc.org/trees_stormwater.htm

Calculating Nutrient Load Reduction by Trees

The TSW tool compares stormwater uptake in treed areas to the same areas modeled as pervious surfaces without trees. In this way, a city has a clear understanding of the city's tree's role in stormwater uptake and mitigation. The TSW tool estimates additional stormwater uptake achieved from planting trees within a municipality. The calculator user determines the level of tree plantings to model (i.e. area to be planted expressed as a percentage of the available planting area in the city). Based on the level of tree plantings, the calculator estimates the additional volume of stormwater uptake (expressed in million gallons).

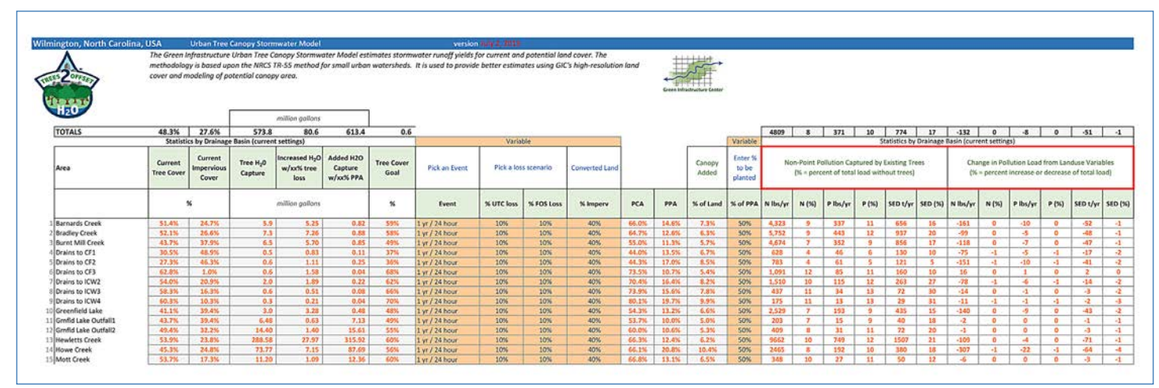


The Green Infrastructure Urban Tree Canopy Stormwater Model estimates stormwater runoff yields for current and potential land cover. The methodology is based upon the NRCS TR-55 method for small urban watersheds. It is used to provide better estimates using GIC's high-resolution land cover and modeling of potential canopy area.

	Area	Current Tree Cover	Current Impervious Cover	Tree H_2O Capture	Increased H_2O w/xx% tree loss	Added H2O Capture w/xx% PPA	Tree Cover Goal	Pick an Event	Pick a loss scenario		Converted Land				Canopy Added	Enter % to be planted
				million gallons				Variable								Variable
	TOTALS	48.3%	27.6%	573.8	80.6	613.4	55.2%									
		Statistics by Drainage Basin (current settings)														
		%		million gallons			%	Event	% UTC loss	% FOS Loss	% Imperv	PCA	PPA	% of Land		% of PPA
1	Barnards Creek	51.4%	24.7%	5.9	5.25	0.82	59%	1 yr / 24 hour	10%	10%	40%	66.0%	14.6%	7.3%		50%
2	Bradley Creek	52.1%	26.6%	7.3	7.26	0.88	58%	1 yr / 24 hour	10%	10%	40%	64.7%	12.6%	6.3%		50%
3	Burnt Mill Creek	43.7%	37.9%	6.5	5.70	0.85	49%	1 yr / 24 hour	10%	10%	40%	55.0%	11.3%	5.7%		50%
4	Drains to CF1	30.5%	48.9%	0.5	0.83	0.11	37%	1 yr / 24 hour	10%	10%	40%	44.0%	13.5%	6.7%		50%
5	Drains to CF2	27.3%	46.3%	0.6	1.11	0.25	36%	1 yr / 24 hour	10%	10%	40%	44.3%	17.0%	8.5%		50%
6	Drains to CF3	62.8%	1.0%	0.6	1.58	0.04	68%	1 yr / 24 hour	10%	10%	40%	73.5%	10.7%	5.4%		50%
7	Drains to ICW2	54.0%	20.9%	2.0	1.89	0.22	62%	1 yr / 24 hour	10%	10%	40%	70.4%	16.4%	8.2%		50%
8	Drains to ICW3	58.3%	16.3%	0.6	0.51	0.08	66%	1 yr / 24 hour	10%	10%	40%	73.9%	15.6%	7.8%		50%
9	Drains to ICW4	60.3%	10.3%	0.3	0.21	0.04	70%	1 yr / 24 hour	10%	10%	40%	80.1%	19.7%	9.9%		50%
10	Greenfield Lake	41.1%	39.4%	3.0	3.28	0.48	48%	1 yr / 24 hour	10%	10%	40%	54.3%	13.2%	6.6%		50%
11	Grnfld Lake Outfall1	43.7%	39.4%	6.48	0.63	7.13	49%	1 yr / 24 hour	10%	10%	40%	53.7%	10.0%	5.0%		50%
12	Grnfld Lake Outfall2	49.4%	32.2%	14.40	1.40	15.61	55%	1 yr / 24 hour	10%	10%	40%	60.0%	10.6%	5.3%		50%

Calculator tool highlighting the Total Tree H2O Capture cell.

The calculator also models the pounds per year of nitrogen and phosphorus and tons per year of sediment captured by the existing tree canopy coverage in a municipality. These values are also expressed as percentages (i.e. the percent of the total nitrogen, phosphorus, and sediment load captured by trees).[2]



The Green Infrastructure Urban Tree Canopy Stormwater Model estimates stormwater runoff yields for current and potential land cover. The methodology is based upon the NRCS TR-55 method for small urban watersheds. It is used to provide better estimates using GIC's high-resolution land cover and modeling of potential canopy area.

	Area	Current Tree Cover	Current Impervious Cover	Tree H_2O Capture	Increased H_2O w/xx% tree loss	Added H2O Capture w/xx% PPA	Tree Cover Goal	Pick an Event	Pick a loss scenario		Converted Land				Canopy Added	Enter % to be planted	Non-Point Pollution Captured by Existing Trees (% = percent of total load without trees)						Change in Pollution Load from Landuse Variables (% = percent increase or decrease of total load)					
				million gallons				Variable								Variable												
	TOTALS	48.3%	27.6%	573.8	80.6	613.4	0.6										4809	8	371	10	774	17	-132	0	-8	0	-51	-1
		Statistics by Drainage Basin (current settings)															Statistics by Drainage Basin (current settings)											
		%		million gallons			%	Event	% UTC loss	% FOS Loss	% Imperv	PCA	PPA	% of Land		% of PPA	N lbs/yr	N (%)	P lbs/yr	P (%)	SED t/yr	SED (%)	N lbs/yr	N (%)	P lbs/yr	P (%)	SED t/yr	SED (%)
1	Barnards Creek	51.4%	24.7%	5.9	5.25	0.82	59%	1 yr / 24 hour	10%	10%	40%	66.0%	14.6%	7.3%	50%		4,323	9	337	11	656	16	-161	0	-10	0	-52	-1
2	Bradley Creek	52.1%	26.6%	7.3	7.26	0.88	58%	1 yr / 24 hour	10%	10%	40%	64.7%	12.6%	6.3%	50%		5,752	9	443	12	937	20	-69	0	-5	0	-48	-1
3	Burnt Mill Creek	43.7%	37.9%	6.5	5.70	0.85	49%	1 yr / 24 hour	10%	10%	40%	55.0%	11.3%	5.7%	50%		4,674	7	352	9	856	17	-118	0	-7	0	-47	-1
4	Drains to CF1	30.5%	48.9%	0.5	0.83	0.11	37%	1 yr / 24 hour	10%	10%	40%	44.0%	13.5%	6.7%	50%		628	4	46	6	130	10	-75	-1	-5	-1	-17	-2
5	Drains to CF2	27.3%	46.3%	0.6	1.11	0.25	36%	1 yr / 24 hour	10%	10%	40%	44.3%	17.0%	8.5%	50%		783	4	61	5	121	5	-151	-1	-10	-1	-41	-2
6	Drains to CF3	62.8%	1.0%	0.6	1.58	0.04	68%	1 yr / 24 hour	10%	10%	40%	73.5%	10.7%	5.4%	50%		1,091	12	85	11	160	10	16	0	1	0	2	0
7	Drains to ICW2	54.0%	20.9%	2.0	1.89	0.22	62%	1 yr / 24 hour	10%	10%	40%	70.4%	16.4%	8.2%	50%		1,510	10	115	12	263	27	-78	-1	-6	-1	-14	-2
8	Drains to ICW3	58.3%	16.3%	0.6	0.51	0.08	66%	1 yr / 24 hour	10%	10%	40%	73.9%	15.6%	7.8%	50%		437	11	34	13	72	30	-14	0	-1	0	-3	-2
9	Drains to ICW4	60.3%	10.3%	0.3	0.21	0.04	70%	1 yr / 24 hour	10%	10%	40%	80.1%	19.7%	9.9%	50%		175	11	13	13	29	31	-11	-1	-1	-1	-2	-3
10	Greenfield Lake	41.1%	39.4%	3.0	3.28	0.48	48%	1 yr / 24 hour	10%	10%	40%	54.3%	13.2%	6.6%	50%		2,529	7	193	9	435	15	-140	0	-9	0	-43	-2
11	Grnfld Lake Outfall1	43.7%	39.4%	6.48	0.63	7.13	49%	1 yr / 24 hour	10%	10%	40%	53.7%	10.0%	5.0%	50%		203	7	15	9	40	18	-2	0	0	0	-1	-1
12	Grnfld Lake Outfall2	49.4%	32.2%	14.40	1.40	15.61	55%	1 yr / 24 hour	10%	10%	40%	60.0%	10.6%	5.3%	50%		409	8	31	11	72	20	-1	0	0	0	-3	-1
13	Hewletts Creek	53.9%	23.8%	288.58	27.97	315.92	60%	1 yr / 24 hour	10%	10%	40%	66.3%	12.4%	6.2%	50%		9662	10	749	12	1507	21	-109	0	-4	0	-71	-1
14	Howe Creek	45.3%	24.8%	73.77	7.15	87.69	56%	1 yr / 24 hour	10%	10%	40%	66.1%	20.8%	10.4%	50%		2465	8	192	10	380	18	-307	-1	-22	-1	-64	-4
15	Mott Creek	53.7%	17.3%	11.20	1.09	12.36	60%	1 yr / 24 hour	10%	10%	40%	66.8%	13.1%	6.5%	50%		348	10	27	11	50	12	-6	0	0	0	-3	-1

Calculator tool highlighting the Non-Point Source Pollution Load Reductions.

[2] The TSC tool calculates the reduction of non-point source pollution from land runoff and does not include data on point source pollution that may also affect surface waters in a municipality.

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				million gallons										
TOTALS	48.3%	27.6%	573.8	80.6	613.4	55.2%								
Statistics by Drainage Basin (current settings)							Variable							Variable
Area	Current Tree Cover	Current Impervious Cover	Tree H_2O Capture	Increased H_2O w/xx% tree loss	Added H2O Capture w/xx% PPA	Tree Cover Goal	Pick an Event	Pick a loss scenario		Converted Land			Canopy Added	Enter % to be planted
	%		million gallons			%	Event	% UTC loss	% FOS Loss	% Imperv	PCA	PPA	% of Land	% of PPA
1 Barnards Creek	51.4%	24.7%	5.9	5.25	0.82	59%	1 yr / 24 hour	10%	10%	40%	66.0%	14.6%	7.3%	50%
2 Bradley Creek	52.1%	26.6%	7.3	7.26	0.88	58%	1 yr / 24 hour	10%	10%	40%	64.7%	12.6%	6.3%	50%
3 Burnt Mill Creek	43.7%	37.9%	6.5	5.70	0.85	49%	1 yr / 24 hour	10%	10%	40%	55.0%	11.3%	5.7%	50%
4 Drains to CF1	30.5%	48.9%	0.5	0.83	0.11	37%	1 yr / 24 hour	10%	10%	40%	44.0%	13.5%	6.7%	50%
5 Drains to CF2	27.3%	46.3%	0.6	1.11	0.25	36%	1 yr / 24 hour	10%	10%	40%	44.3%	17.0%	8.5%	50%
6 Drains to CF3	62.8%	1.0%	0.6	1.58	0.04	68%	1 yr / 24 hour	10%	10%	40%	73.5%	10.7%	5.4%	50%
7 Drains to ICW2	54.0%	20.9%	2.0	1.89	0.22	62%	1 yr / 24 hour	10%	10%	40%	70.4%	16.4%	8.2%	50%
8 Drains to ICW3	58.3%	16.3%	0.6	0.51	0.08	66%	1 yr / 24 hour	10%	10%	40%	73.9%	15.6%	7.8%	50%
9 Drains to ICW4	60.3%	10.3%	0.3	0.21	0.04	70%	1 yr / 24 hour	10%	10%	40%	80.1%	19.7%	9.9%	50%

Additional water capture by planting x% possible planting area.

The TSW tool also calculates the decrease of nitrogen, phosphorus and sediment loading levels as a result of tree plantings within a municipality. These values are expressed as both pounds/tons per year and percentages. The TSW tool also calculates the increase of nitrogen, phosphorus and sediment loading levels as a result of development and increased impervious surfaces in a municipality. These values are expressed as both pounds/tons per year and percentages.

Increased stormwater runoff and nutrient loading as a result of creating more impervious surfaces (e.g. sidewalks, roads, buildings)

The TSW tool estimates stormwater runoff from development conditions as specified by the user (i.e. percent imperviousness of the development, percent loss of urban forest or forested open space). The TSW tool compares the stormwater runoff volume that would occur as a result of a proposed development to that of the existing land cover to show the stormwater runoff impacts from land use changes.

The calculator shows results by storm event. That is how stormwater is modeled by engineers. The larger the event the more frequent its occurrence. So a 2-year storm happens often, while a 50-year storm is less frequent, but yields more rainfall. The calculator accounts for the decrease in rainfall absorption over time, as higher volume storms have more runoff once soils become saturated. A drop-down menu allows the user to change the storm event.

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				million gallons										
TOTALS	48.3%	27.6%	573.8	80.6	613.4	55.2%								
Statistics by Drainage Basin (current settings)							Variable							Variable
Area	Current Tree Cover	Current Impervious Cover	Tree H_2O Capture	Increased H_2O w/xx% tree loss	Added H2O Capture w/xx% PPA	Tree Cover Goal	Pick an Event	Pick a loss scenario		Converted Land			Canopy Added	Enter % to be planted
	%		million gallons			%	Event	% UTC loss	% FOS Loss	% Imperv	PCA	PPA	% of Land	% of PPA
1 Barnards Creek	51.4%	24.7%	5.9	5.25	0.82	59%	1 yr / 24 hour	10%	10%	40%	66.0%	14.6%	7.3%	50%
2 Bradley Creek	52.1%	26.6%	7.3	7.26	0.88	58%	1 yr / 24 hour	10%	10%	40%	64.7%	12.6%	6.3%	50%
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5 Drains to CF2	27.3%	46.3%	0.6	1.11	0.25	36%	1 yr / 24 hour	10%	10%	40%	44.3%	17.0%	8.5%	50%
6 Drains to CF3	62.8%	1.0%	0.6	1.58	0.04	68%	1 yr / 24 hour	10%	10%	40%	73.5%	10.7%	5.4%	50%
7 Drains to ICW2	54.0%	20.9%	2.0	1.89	0.22	62%	1 yr / 24 hour	10%	10%	40%	70.4%	16.4%	8.2%	50%
8 Drains to ICW3	58.3%	16.3%	0.6	0.51	0.08	66%	1 yr / 24 hour	10%	10%	40%	73.9%	15.6%	7.8%	50%
9 Drains to ICW4	60.3%	10.3%	0.3	0.21	0.04	70%	1 yr / 24 hour	10%	10%	40%	80.1%	19.7%	9.9%	50%
10 Greenfield Lake	41.1%	39.4%	3.0	3.28	0.48	48%	1 yr / 24 hour	10%	10%	40%	54.3%	13.2%	6.6%	50%

Note: The calculator assumes the site's post-development urban soils are in the D Hydrologic group (i.e. poorly draining). Following development, urban soils typically consist of rubble and are often compacted. Municipalities requiring soil amendments or another BMP that would increase permeability, beyond that of a typical Hydrologic Group D soil, can account for this improvement in soil permeability by manually adjust the curve numbers in the calculator.

A city can use the modified TR-55 CN from this study for its modeling and development design reviews, for watershed plans and for setting urban canopy goals. The TSC tool makes it very easy for a city to change the curve numbers if they so choose. The TSC tool can be used for setting tree planting goals at the watershed scale and for evaluating consequences of tree loss as it pertains to stormwater runoff.

Wilmington, North Carolina, USA — Urban Tree Canopy Stormwater Model — version July 2, 2019

The Green Infrastructure Urban Tree Canopy Stormwater Model estimates stormwater runoff yields for current and potential land cover. The methodology is based upon the NRCS TR-55 method for small urban watersheds. It is used to provide better estimates using GIC's high-resolution land cover and modeling of potential canopy area.

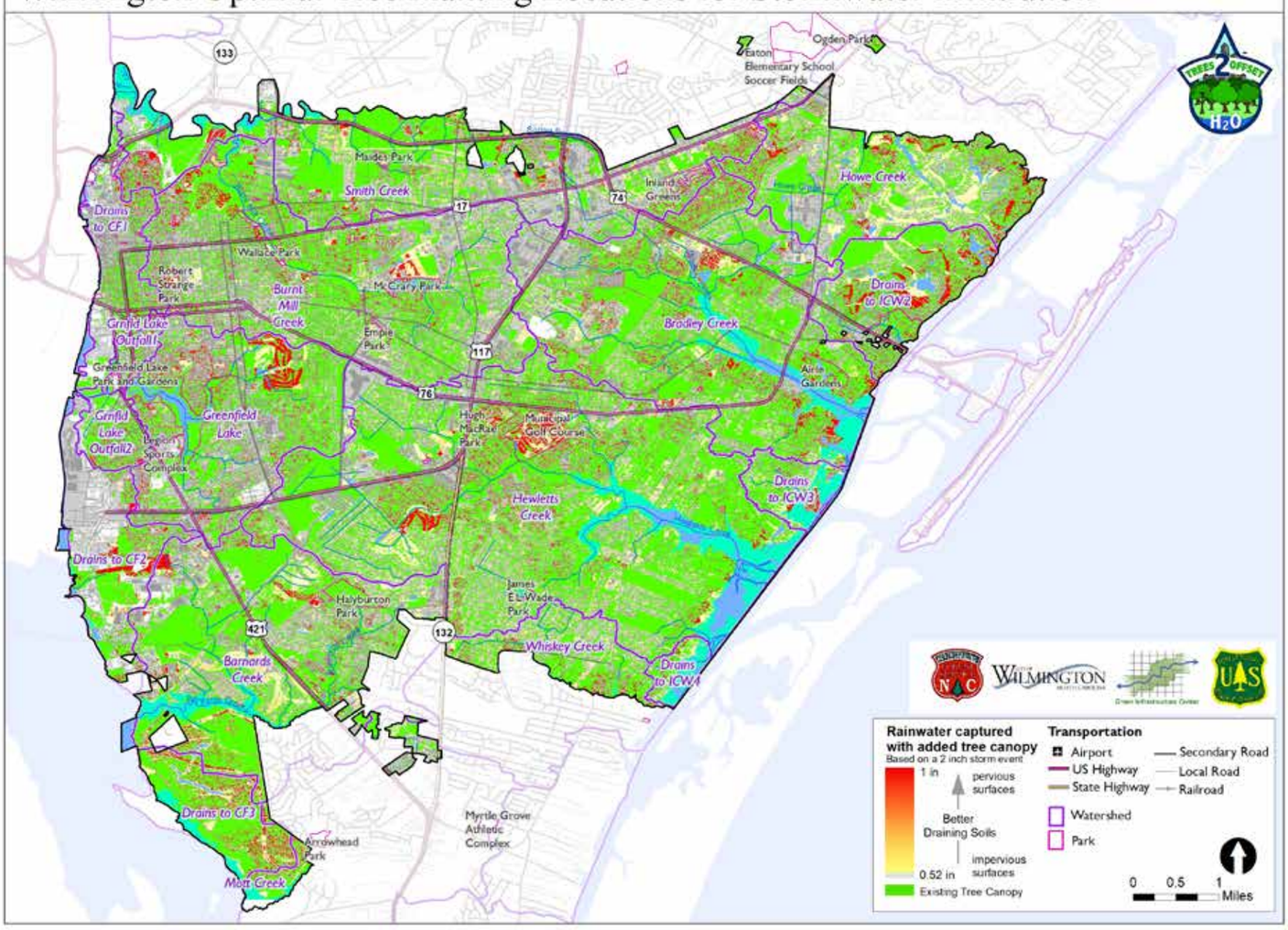
				million gallons										
TOTALS	48.3%	27.6%	573.8	80.6	613.4	55.2%								
Statistics by Drainage Basin (current settings)							Variable							Variable
Area	Current Tree Cover	Current Impervious Cover	Tree H_2O Capture	Increased H_2O w/xx% tree loss	Added H2O Capture w/xx% PPA	Tree Cover Goal	Pick an Event	Pick a loss scenario		Converted Land			Canopy Added	Enter % to be planted
	%		million gallons			%	Event	% UTC loss	% FOS Loss	% Imperv	PCA	PPA	% of Land	% of PPA
1 Barnards Creek	51.4%	24.7%	5.9	5.25	0.82	59%	1 yr / 24 hour	10%	10%	40%	66.0%	14.6%	7.3%	50%
2 Bradley Creek	52.1%	26.6%	7.3	7.26	0.88	58%	1 yr / 24 hour	10%	10%	40%	64.7%	12.6%	6.3%	50%
3 Burnt Mill Creek	43.7%	37.9%	6.5	5.70	0.85	49%	1 yr / 24 hour	10%	10%	40%	55.0%	11.3%	5.7%	50%
4 Drains to CF1	30.5%	48.9%	0.5	0.83	0.11	37%	1 yr / 24 hour	10%	10%	40%	44.0%	13.5%	6.7%	50%
5 Drains to CF2	27.3%	46.3%	0.6	1.11	0.25	36%	1 yr / 24 hour	10%	10%	40%	44.3%	17.0%	8.5%	50%
6 Drains to CF3	62.8%	1.0%	0.6	1.58	0.04	68%	1 yr / 24 hour	10%	10%	40%	73.5%	10.7%	5.4%	50%
7 Drains to ICW2	54.0%	20.9%	2.0	1.89	0.22	62%	1 yr / 24 hour	10%	10%	40%	70.4%	16.4%	8.2%	50%
8 Drains to ICW3	58.3%	16.3%	0.6	0.51	0.08	66%	1 yr / 24 hour	10%	10%	40%	73.9%	15.6%	7.8%	50%
9 Drains to ICW4	60.3%	10.3%	0.3	0.21	0.04	70%	1 yr / 24 hour	10%	10%	40%	80.1%	19.7%	9.9%	50%
10 Greenfield Lake	41.1%	39.4%	3.0	3.28	0.48	48%	1 yr / 24 hour	10%	10%	40%	54.3%	13.2%	6.6%	50%
11 Grnfld Lake Outfall1	43.7%	39.4%	6.48	0.63	7.13	49%	1 yr / 24 hour	10%	10%	40%	53.7%	10.0%	5.0%	50%
12 Grnfld Lake Outfall2	49.4%	32.2%	14.40	1.40	15.61	55%	1 yr / 24 hour	10%	10%	40%	60.0%	10.6%	5.3%	50%
13 Hewletts Creek	53.9%	23.8%	288.58	27.97	315.92	60%	1 yr / 24 hour	10%	10%	40%	66.3%	12.4%	6.2%	50%
14 Howe Creek	45.3%	24.8%	73.77	7.15	87.69	56%	1 yr / 24 hour	10%	10%	40%	66.1%	20.8%	10.4%	50%
15 Mott Creek	53.7%	17.3%	11.20	1.09	12.36	60%	1 yr / 24 hour	10%	10%	40%	66.8%	13.1%	6.5%	50%
16 Smith Creek	44.2%	35.3%	123.63	12.00	139.49	51%	1 yr / 24 hour	10%	10%	40%	58.7%	14.5%	7.2%	50%
17 Whiskey Creek	53.4%	20.6%	28.47	2.75	31.38	61%	1 yr / 24 hour	10%	10%	40%	67.7%	14.3%	7.2%	50%

This bioswale planted with a tree reduces runoff and cleans stormwater before it enters a stormdrain.

In addition to the spreadsheet tool and canopy and planting area maps, GIC also created maps from the soils and canopy data that allow quick visualization the TSC tool for where tree planting adds the most value for stormwater uptake and where tree removals add the most impacts for stormwater runoff. These maps (shown on the following pages) can inform tree planting campaigns as well as master plans, development proposals and other land disturbance or management questions, such as where should trees be conserved on a development area, where should new trees be planted.

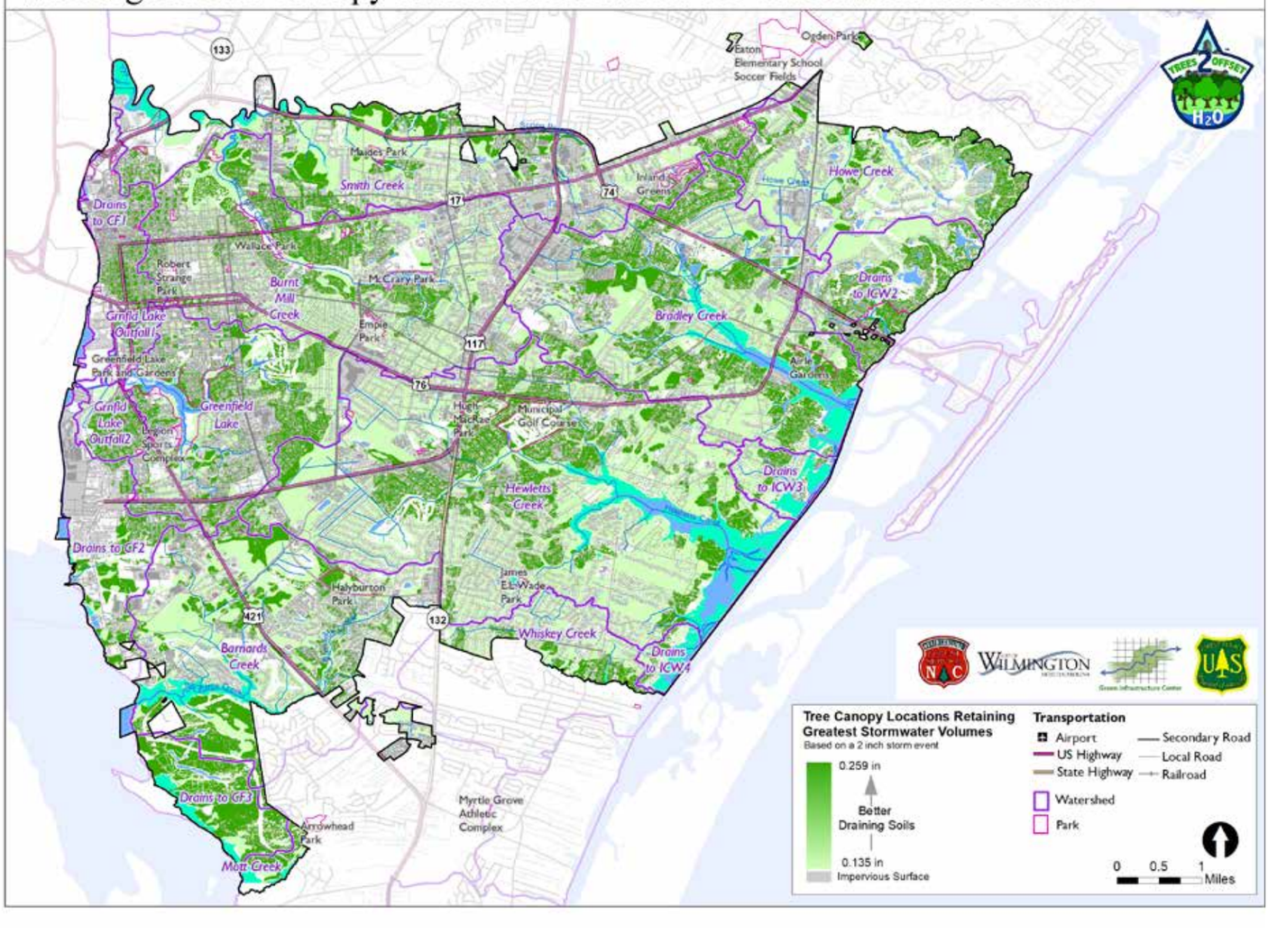
Strategies for retaining the urban forest varied by city. In a city such as Charleston, the key strategy became retention of existing forestland, while in Harrisonburg, replanting became the city's key strategy. The GIC also developed an Urban Forestry Budget Calculator which uses the project data to show how many trees can be fitted into the city and at what cost.

Wilmington Optimal Tree Planting Locations for Stormwater Infiltration



This map shows where tree planting will yield the greatest benefits for stormwater infiltration (darkest orange).

Wilmington Best Canopy Retention Locations for Stormwater Infiltration



This map shows where trees should be retained for maximal stormwater interception and infiltration.

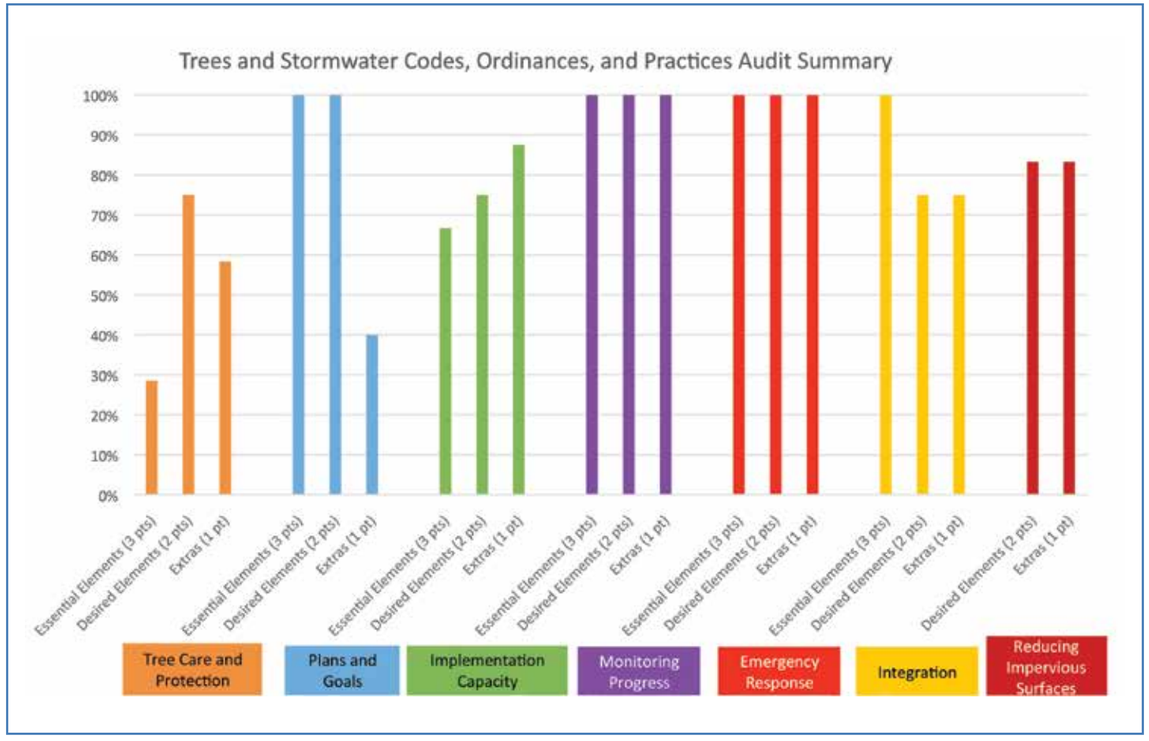
CODES, ORDINANCES AND FOREST PRACTICES AUDIT TOOL

GIC reviewed each city to determine which practices, codes and policies make the city more impervious (e.g. too much parking required) and which make it more pervious (e.g. conserving trees or requiring open spaces). The GIC also interviewed city staff, whose input was incorporated directly on the spreadsheet summary prepared by the GIC. A detailed memo provided to each city by GIC offers additional ideas for improvement.

Anyone can conduct this review of their city or urbanizing county using the project's Codes, Ordinances and Forest Practices Audit Tool (COFPAT). The COFPAT tool is a simple excel sheet with a series of queries concerning legal requirements for a city that make it more likely to expand or lessen impervious surfaces and a section concerning best practices for urban forest management. The tool's purpose is to help communities recognize ways to reduce excess impervious areas and to maximize forest cover and good urban forest management. To create the COFPAT tool, GIC reviewed many related survey tools and then created this comprehensive tool which adds many more criteria. It is the only assessment tool that looks at both impervious surface reduction, infiltration and urban forestry. This tool requires some familiarity with planning and forestry regulations, but it can be filled out by a novice with basic excel skills and time to review the relevant codes and practices.

Each practice receives established points based on its importance. For example, having standards to adequately size tree wells is very important for tree survival and so this practice receives more points than less important practices, such as reusing urban waste wood, which while a good practice, will not affect the city's rate of tree retention. The excel sheet and instructions for using the audit tool can be downloaded from GIC's website at http://www.gicinc.org/trees_stormwater.htm The tool provides results for where a city has done well and shows areas to improve.

Each city received a detailed report on their status and areas for possible improvement. To determine which actions are needed for any city, download and fill in the COFPAT tool from GIC's website. Once cities fill in their codes report, they can see results in chart form. It's very important to score cities not just for presence or absence of a policy, but also for whether it is implemented. GIC found some cities had good requirements but staff were sometimes unaware of them, or they lacked the capacity to enforce them.



WHAT THE REVIEW SHOWED

Minimizing Storm Risk

Distinct differences were observed with respect to cities' abilities to prepare for and respond to storm damages. Some cities are far better equipped to address storm damages by conducting pre-storm risk assessments and post-storm cleanup.

Emergency preparation is another area for which cities varied considerably. Most cities had not conducted a tree risk assessment. Not only are tree risk assessment critical for finding problems and addressing them before problems arise, they are also key for cities who would like to utilize FEMA funds after storms to pay for tree replacement. If a city's trees have been classified as their "green infrastructure" and if their location and condition have been inventoried BEFORE the storm, they can be considered for reimbursement. At the very least, cities should inventory trees on public lands as well as along important city streets, especially where damages are more likely due to wind or storm surges. For more, see EPA's guide to storm smart cities https://www.epa.gov/sites/production/files/2018-04/documents/storm_smart_cities_508_final_document_3_26_18.pdf

Tree Planting and Survival

Cities have diverse standards for tree planting and care. Trees vary in their ability to withstand difficult planting conditions. The southern live oak (Quercus virginiana), is especially hardy in overcoming difficult urban environments. Even so, they can live longer and stronger when roots are provided with room to breathe and grow. Some cities utilize innovative tree planting technologies such as Auburn, which employed silva cells and suspended pavements to support tree roots, and permeable pavers to allow water to reach roots and avoid runoff. Charleston, which has a large collection of live oaks planted in tight urban spaces, employed sidewalk ramps in some areas to give some oaks room to breathe and to avid trip hazards.

Walkway over tree in Charleston.

Removal Avoidance

Cities also vary considerably in how they plan for avoidance of excessive tree removals. Cities such as Alpharetta, minimize potential tree losses from development through a robust pre-development review to assist in identifying ways and locations to retain canopy, while cities such as Jacksonville, do not yet include forestry staff in pre-development proposal review. When forestry professionals are not engaged or consulted in review of sites with significant canopy, opportunities to save trees or shape development footprints to avoid trees are missed.

Crediting Trees as Stormwater Management BMPs

None of the 11 cities and 1 county studied currently had a credit to use trees as stormwater management. Several are working on ideas for how to do so. There are some precedents for counting trees for stormwater management. The City of Portland provides a 'tree credit' that can be used to offset 10 percent of a site's impervious surface as stormwater management and they also use trees extensively in bioswales and other green infrastructure practices. For more see https://www.portlandoregon.gov/bes/article/582102

The Chesapeake Bay Program (CBP) developed over 200 best management practices (BMPs) for accreditation in the Phase 6 Implementation of Chesapeake Bay Watershed Phase III Watershed Improvement Plan (WIP) targets. For the Tree Planting BMP, 300 trees planted is equivalent to one acre of urban tree canopy expansion. The Urban Forest Planting BMP offers credit for conversion of developed turf grass to urban forest. For credit to be granted, trees must be planted contiguously and urban forest plantings must be documented in a planting and maintenance plan that meets state planting density and associated standards for establishing forest conditions. These standards include no fertilization and minimal mowing to aid understory establishment. For more details and credits for nitrogen, phosphorus and sediment removal values see https://www.chesapeakebay.net/documents/BMP-Guide_Full.pdf .

Pine Lake, GA, provides 10 gallons of credit per inch of the diameter at breast height (DBH) for preserving existing trees under 12" DBH, and 20 gallons of credit per inch of DBH for preserving existing trees over 12" DBH. (DBH is tree diameter measured at 4.5 ft. (137 cm) above ground level). Washington D.C. also provides a volume credit of 20 cubic feet for each preserved tree, and 10 cubic feet for each planted tree. Trees that are planted as part of another best management practice (BMP), such as in a bioretention BMP, also receive 10 cubic feet credit. Many recent articles have reviewed the crediting of trees for stormwater management. For more see https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6134866/

The Center for Watershed Protection also has suite of tools for how to provide credit for the volume and nutrient removal values of trees. For more see https://www.cwp.org/making-urban-trees-count/

Cities also varied considerably in the degree to which policies and practices made the city more pervious or impervious. For example, Apex did not allow for variable space sizing in parking lots while Norcross had a program to allow for flexible design to reduce the number of spaces required by allowing a mix or large and small car spaces, leaving more room to add trees to parking areas to capture water. In addition, cities such as Auburn and Charleston employed bioswales in parking lots to allow recessed treed islands to capture and treat stormwater on site. Orange County also utilized permeable parking spaces, but has not yet done so on a broad scale.

Cities also varied considerably in their application of trees in and around stormwater ponds. Some cities stated that trees can never be used in stormwater ponds although this practice is commonly used in many cities and counties. For example, Fairfax County VA undertook a study to retrofit its stormwater ponds by adding trees, wetlands benches and other retrofits to make the ponds function better for water quality treatment. Several Florida cities routinely plant trees around stormwater ponds. This does not prevent maintenance as space can be left for ingress and egress of backhoes and other large equipment.

Trees planted with permeable pavers can filter more runoff and grow better..

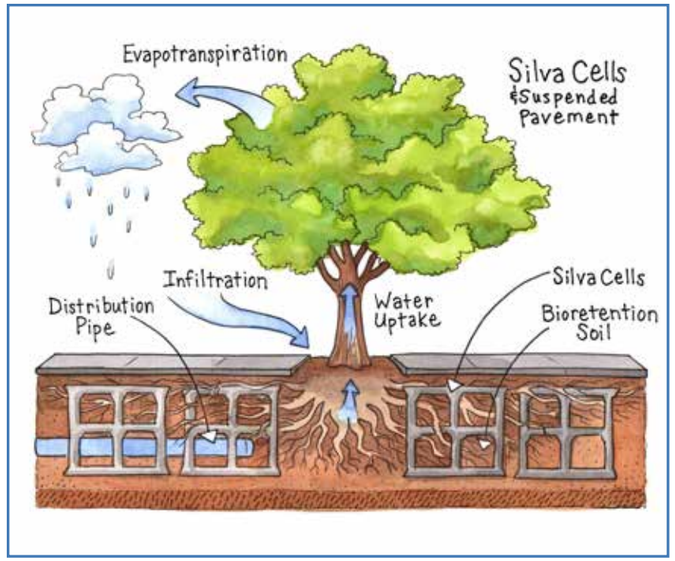
Vegetated stormwater pond helps detain and clean runoff..

WHAT IS NEEDED

Following is a list of recommendations across the cities. To see individual recommendations in detail, see the case study booklet for each city. Study cities also received a 30+ page summary report on policy and code changes.

Top 20 recommendations to improve forest care and coverage in 12 study communities:

1. **Use the GIC's TSW calculator tool to determine the stormwater benefits of maintaining or increasing tree canopy goals by watershed and utilize the tool for stormwater planning.**
2. **Create a tree canopy goal and update land cover every 5 years to determine if goals are being met. Use the urban forestry budget calculator to determine funds needed to reach planting goals and create feasible budgets.**
3. **Hold inter-departmental meetings about proposed master plans and development projects to discuss and minimize site conflicts resulting in excess tree loss and retain healthy tree clusters whenever possible.**
4. **Hold pre-development reviews with developers to inform choices about tree conservation and to avoid excessive removals before site plans are completed.**
5. **Work with developers to shrink the development footprint to minimize impervious surface by holding a pre-development conference allows all parties to explore ideas for tree conservation before extensive funds are spent on land planning.**
6. **Require a tree inventory of all hardwood trees 18" DBH and over, softwood trees 24" DBH and over, and understory species 8" DBH and over on concept and final site plan submittals for both publicly and privately owned properties.**
7. **Protect trees during development with adequate fencing at 1.5" distance from the drip line and post signage with rules in various languages (depending on location).**
8. **Require 600, 1,000 and 1,500 cubic feet soil volume planting requirements for small, medium, and large trees respectively for all tree plantings.**
9. **Conduct a land cover assessment every four years to determine current canopy coverage and share forestry data across city agencies.**
10. **Utilize and train staff in urban forestry data collection software.**
11. **Perform tree risk assessments. Increase assessment intervals in densely populated portions of the city or areas subject to higher winds or storm surges.**
12. **Adopt a forested steam buffer ordinance and base buffer size on stream order and feasibility.**
13. **Reduce acreage of parking lots by allowing variable space sizing to allow for smaller lots and to add tree cover to existing lots that lack trees to reduce impervious land cover.**
14. **Adopt a complete green streets policy that incorporates trees and stormwater management in the design (in addition to pedestrian space, bicycle lanes, benches etc.)**
15. **Include tree plantings as an approved stormwater Best Management Practice (BMPs) (this may require a change to state code, however approved BMPs such as raingardens can include trees).**
16. **Develop an Urban Forest Management Plan to guide tree care and maintenance (funding is available from state urban forestry programs.).**
17. **Develop a Forestry Emergency Response Plan (FERP) that include tree benefits, risk management and pre-disaster response, and post-disaster response plans.**
18. **Link urban forestry to the city's stormwater infrastructure through program documentation including tree risk assessments and classify trees as "green infrastructure" so they can be eligible for FEMA replacement after storms.**
19. **Re-use urban waste wood by establishing an urban waste wood program for using storm damaged trees instead of sending them to landfill and use proceeds from the sales to fund tree plantings. For more see: https://www.vibrantcitieslab.com/research/waste-management/**
20. **Engage the community in tree planting and form partnerships with community groups to plant trees on private property where most planting space is available and where tree survival will be better.**



Silva Cells and Suspended Pavement

CONCLUSION

Adapting codes, ordinances, and municipality practices to use trees and other native vegetation for enhanced stormwater management will allow cities and urbanizing counties to treat stormwater more effectively. Most importantly, retaining trees will reduce stormwater volumes and velocities and reduce pollutants in that runoff. Implementing ideas in the COFPAT tool and the top recommendations in this report can significantly reduce the impact of stormwater sources (impervious cover) and benefit the local ecology by using native vegetation (trees and other shrubs) to uptake and clean stormwater. It will also lower costs of tree cleanup from storm damages, since proper pruning or removal of trees deemed to be 'at risk' can be done before storms occur.

Cities can use canopy data, analysis and recommendations from the COFPAT tool and the TSW calculator tool to create goals and outcomes to make cities more resilient to flooding and standing water. Cities should create and utilize canopy data to inform future land use plans and to strategize where to plant new trees. Cities interested in creating ordinances to credit urban trees for stormwater management BMPs should see the literature references earlier in this report. Even if a city is not able to create its own Tree BMP ordinance for stormwater credits, creating rules for tree retention, such as adopting minimum canopy standards, is a good first step.

Working closely with the development community to educate them on the value of the urban forest for real estate values, salability and faster rates of sales will help reduce land clearing for new developments. Finally, requiring permits for tree removals and strong incentives for tree retention on development plans, as well as high standards for tree planting conditions, will go a long way to ensuring trees can remain in cities and even expand.

The most beautiful, memorable and healthful cities in the world are those with excellent tree coverage and high standards for tree care and planting. Most urban foresters are familiar with this catchy Chinese proverb: "The best time to plant a tree was 20 years ago. The second best time is now." Just be sure they are the right tree, for the right space, and that they are protected and well cared for too.

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