Norfolk

TREES TO OFFSET STORMWATER

Case Study 10: City of Norfolk, Virginia

Green Infrastructure Center

Virginia Department of Forestry

Forest Service U.S. Department of Agriculture

The City of Norfolk

January 2019

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

The contents do not necessarily reflect the views or policies of the USDA Forest Service, nor does mention of trade names, commercial productions, services or organizations imply endorsement by the U.S. Government.

The work upon which this publication is based was funded in whole or in part through an Urban and Community Forestry grant awarded by the Southern Region, State and Private Forestry, U.S. Forest Service and administered by the Virginia Department of Forestry.

Publication Date: January 2019

Norfolk

Case Study 10: Norfolk, Virginia

January 2019

CONTENTS

PROJECT OVERVIEW

This project Trees to Offset Stormwater is a study of Norfolk's tree canopy and its role in taking up, storing and releasing water. This study was undertaken to assist Norfolk in evaluating how to better integrate trees into their stormwater management programs. More specifically, the study covers the role that trees play in stormwater management and shows how the city can benefit from tree conservation and replanting. It also evaluates ways for the city to improve forest management as the city re-develops.

PROJECT FUNDERS AND PARTNERS

The project was developed by the nonprofit Green Infrastructure Center Inc. (GIC) in partnership with the states of Virginia, North Carolina, South Carolina, Georgia, Florida and Alabama. The GIC created the data and analysis for the project and published this report. This study is one of 12 pilot projects evaluating a new approach to estimate the role of trees in stormwater uptake. The USDA Forest Service provided the funding for Virginia to determine how trees can be utilized to meet municipal goals for stormwater management. The Virginia Department of Forestry (VaDOF) administered the pilot studies in Virginia and selected Norfolk to be one of the three test cases. The cities of Harrisonburg and Lynchburg are the other municipalities selected for study.

The project was spurred by the on-going decline in forest cover throughout the southern United States. Causes for this decline arise from multiple sources including land conversion for development, storm damages, lack of tree replacement as older trees die, and for coastal cities such as Norfolk, inundation from Sea Level Rise (SLR). 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. As a result of this project, Norfolk now has baseline data against which to monitor measures for the stormwater and water quality benefits provided by its urban forest, and locations for prioritizing canopy replanting to maximize stormwater uptake.

Forested buffers protect the city's waterways and provide habitat.

OUTCOMES

This report includes those findings and recommendations that are based on tree canopy cover mapping and analysis, the modeling of stormwater uptake by trees, a review of relevant city codes and ordinances, and citizen input and recommendations for the future of Norfolk's urban forest. The GIC previously completed a Green Infrastructure Strategy for Norfolk in July 2018 which included canopy mapping and detailed strategies to re-green the city and increase resilience. To read the plan visit: http://www.gicinc.org/PDFs/GreenPlan-CityofNorfolk-FinalReport%202018.pdf

For this project, the following deliverables were included in the study:

- Analysis of the location of the urban canopy based on tree setting (lawn, forest, over pavement) through high resolution mapping,
- A method to calculate stormwater uptake by the city's tree canopy,
- Analysis of the best places to retain trees or to plant trees for stormwater uptake,
- A review of existing codes, ordinances, guidance documents, programs and staff capabilities related to trees and stormwater management, and recommendations for improvement,
- A community meeting to provide outreach and education,
- Presentation about the pilot studies as a case study at regional and national conferences, and
- A case book and a presentation detailing the study methods, lessons learned and best practices.

The project began in September 2016 and Norfolk staff members have participated in project review, analysis and evaluation. The following city divisions were involved in the project planning and review as the Technical Review Committee (TRC): Department of Public Works, Department of Recreation, Parks and Open Space, Office of Resilience, Department of City Planning, and the Division of Engineering.

The community meeting was held in January 2018. This project had less community meetings than others, since the GIC already held extensive educational events related to the green infrastructure plan completed in July 2018. The January meeting provided opportunities for citizen input on tree care and management in the city and their comments were provided to the city.

Participants included members of the Master Gardeners program who were especially keen to use the information to inform local projects. In addition, participants suggested that the city make an even greater effort to engage the public in strategic tree plantings. People need more public education on the benefits of trees. For example, citizens noted that most people do not know that a well-placed tree can not only shade their house and but also reduce air conditioning costs. Participants also asked that the city make digital records of tree adoption accessible to the public so that they can see the impact private citizens have on growing the urban tree canopy.

Participants also suggested that the city continue to send letters to volunteers letting them know they are appreciated to ensure sustained participation in tree planting initiatives. They also recommended ways to enlist stronger participation from groups such as providing educational materials for Master Gardener's to use during outreach.

GIC presented specific code/ordinance or practice changes recommended for adoption by the city. Meeting attendees were asked to choose the top three changes they felt would most benefit the urban forest and reduce runoff. Each participant voted for the top three strategies they believed to be most effective for growing/protecting the urban forest and they are listed below.

- Provide more guidance to residents about how to reduce stormwater utility fees using BMPS, including trees.
- Increase urban forestry funding.
- Include the downtown district in tree canopy requirements.

Justin Shafer from Public Works explains the project's focus to tree advocates.

Stu Sheppard, GIC's mapping analyst, receives input from a community member.

NORFOLK CAN USE THIS REPORT AND ITS ASSOCIATED PRODUCTS TO:

- *Set canopy goals by watershed and develop management plans for retaining or expanding its tree canopy.*
- *Improve management practices so trees will be well-planted and well-managed.*
- *Educate developers about the importance of tree retention and replacement.*
- *Motivate private landowners (residential, commercial, and institutional) to plant trees.*
- *Support grant applications for tree conservation projects.*

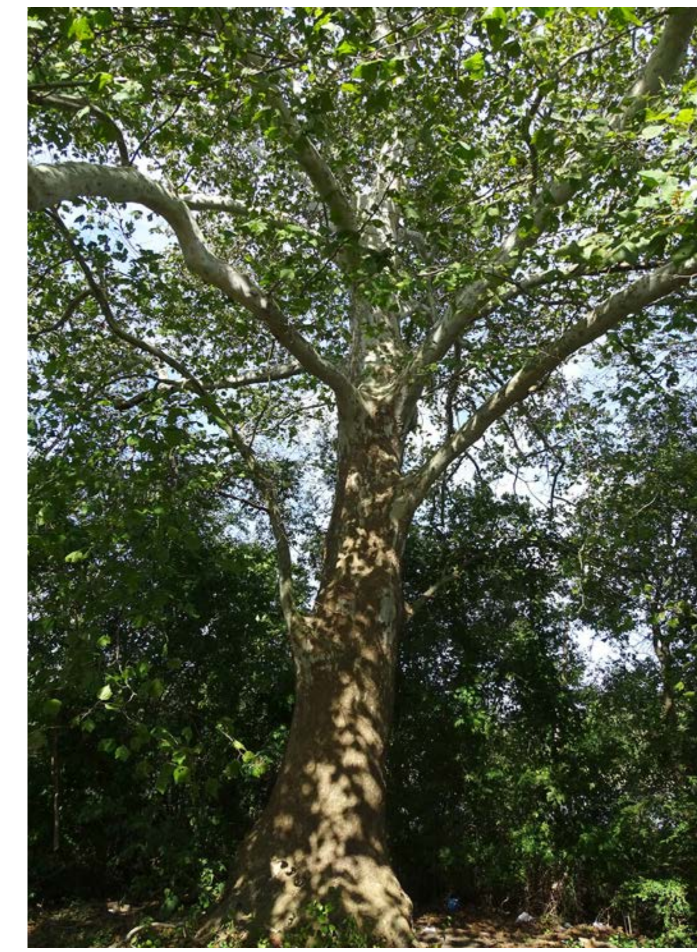
SUMMARY OF FINDINGS

Satellite imagery was used to classify the types of land cover in Norfolk (for more on methods see page 18). This shows the city those areas where vegetative cover helps to uptake water and those areas where impervious land cover is more likely to result in stormwater runoff. High-resolution tree canopy mapping provides a baseline that is used to assess current tree cover and to evaluate future progress in tree preservation and planting. An ArcGIS geodatabase with all GIS shape files from the study was provided to Norfolk.

The goal of this study was to identify ways in which water entering the city's municipal separate storm sewer system (MS4) could be reduced by using trees to intercept and soak up runoff. Tree canopy serves as 'green infrastructure' that can provide more capacity for the city's grey infrastructure (i.e. stormwater drainage systems) by absorbing or evaporating excess water before it runs off. The stormwater model created for this project shows how the city can reduce potential pollution of its surface waters, which can impact Total Maximum Daily Load (TMDL) outcomes and watershed plans.

The detailed land cover analysis created for the project was used to model how much water is taken up by the city's trees in various scenarios. This new approach allows for more detailed assessment of stormwater uptake based on the landscape conditions of the city's forests. It distinguishes whether the trees are growing in a more natural setting (e.g. a cluster of trees in an urban forest), a lawn setting, or over pavement, such as streets or sidewalks. The amount of open space and the condition of surface soils affect the infiltration of water.

As city trees are evaluated, it's important to remember that trees within a cluster provide more value than individual trees alone because they also tend to have a more natural ground cover, more leaf litter (as they are not managed or mowed under) and less compacted soils. Thus, there is more stormwater retention for trees found in a natural setting than a tree over a lawn or over pavement. Trees also shelter one another from wind damages and are less likely to fall. As cities develop and lose forest, trees planted in isolation do not provide equivalent value as the same number of trees found clustered together. Therefore, when counting total trees in a city, managers should also consider the setting in which those trees are found and they should protect intact forested clusters of trees as often as possible. The Chesapeake Bay Program also provides a Best Management Practice (BMP) credit for planting trees. For more on the credit system, see Appendix C.



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

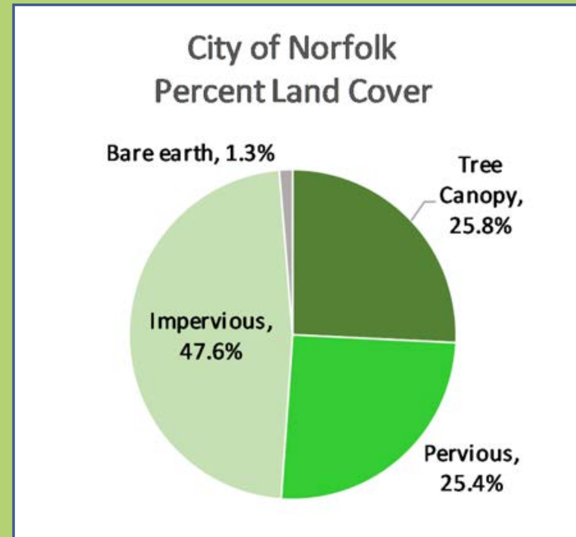
During an average high volume rainfall event in Lynchburg (a 10-year storm), over 24 hours the city's trees take up an average of 65.2 million gallons of water.

That's 99 Olympic swimming pools of water!

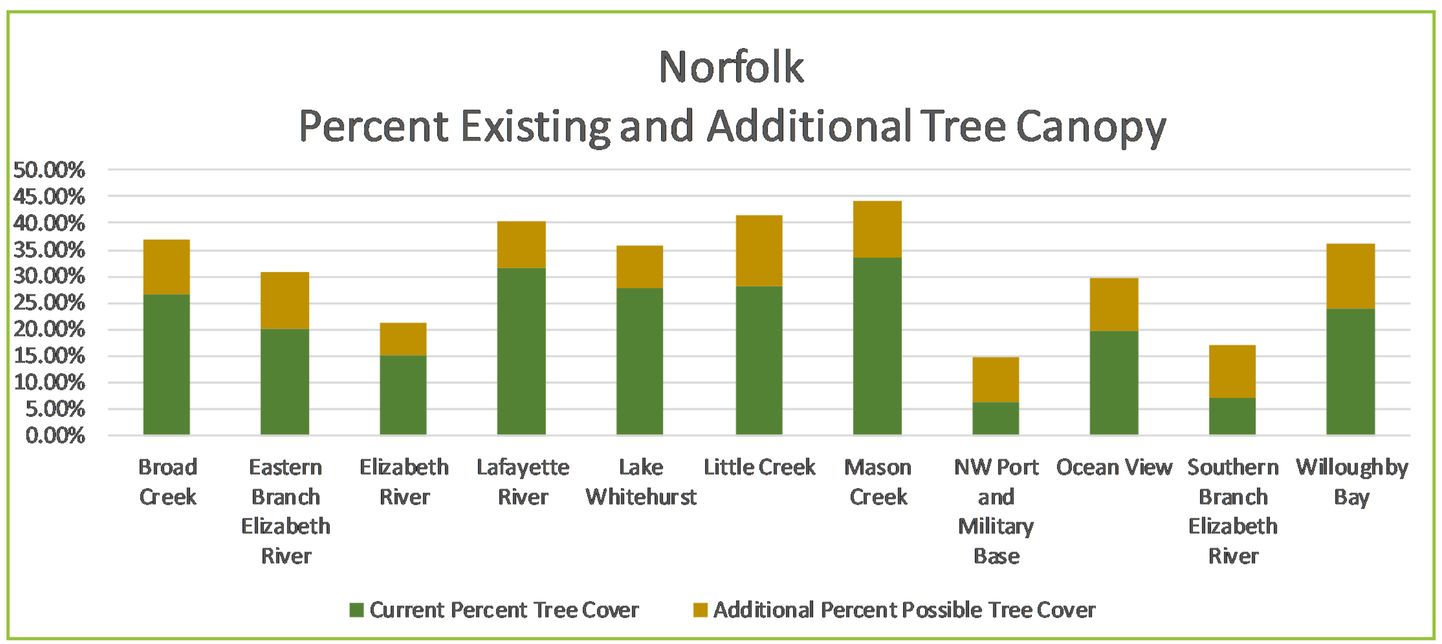
Norfolk: Fast Facts & Key Stats

- Coastal plain community in the Hampton Roads area of Virginia.
- 2017 U.S. Census Population Estimate: ...... 244,703 people
- City Area From Land Cover
  - Total area: .... 66.36 sq. mi.
  - Land: .... 51.3 sq. mi.
  - Water: .... 15.06 sq. mi.
  - Streams: .... 30.96 miles*
  - Tree Canopy: .... 7,395.38 acres

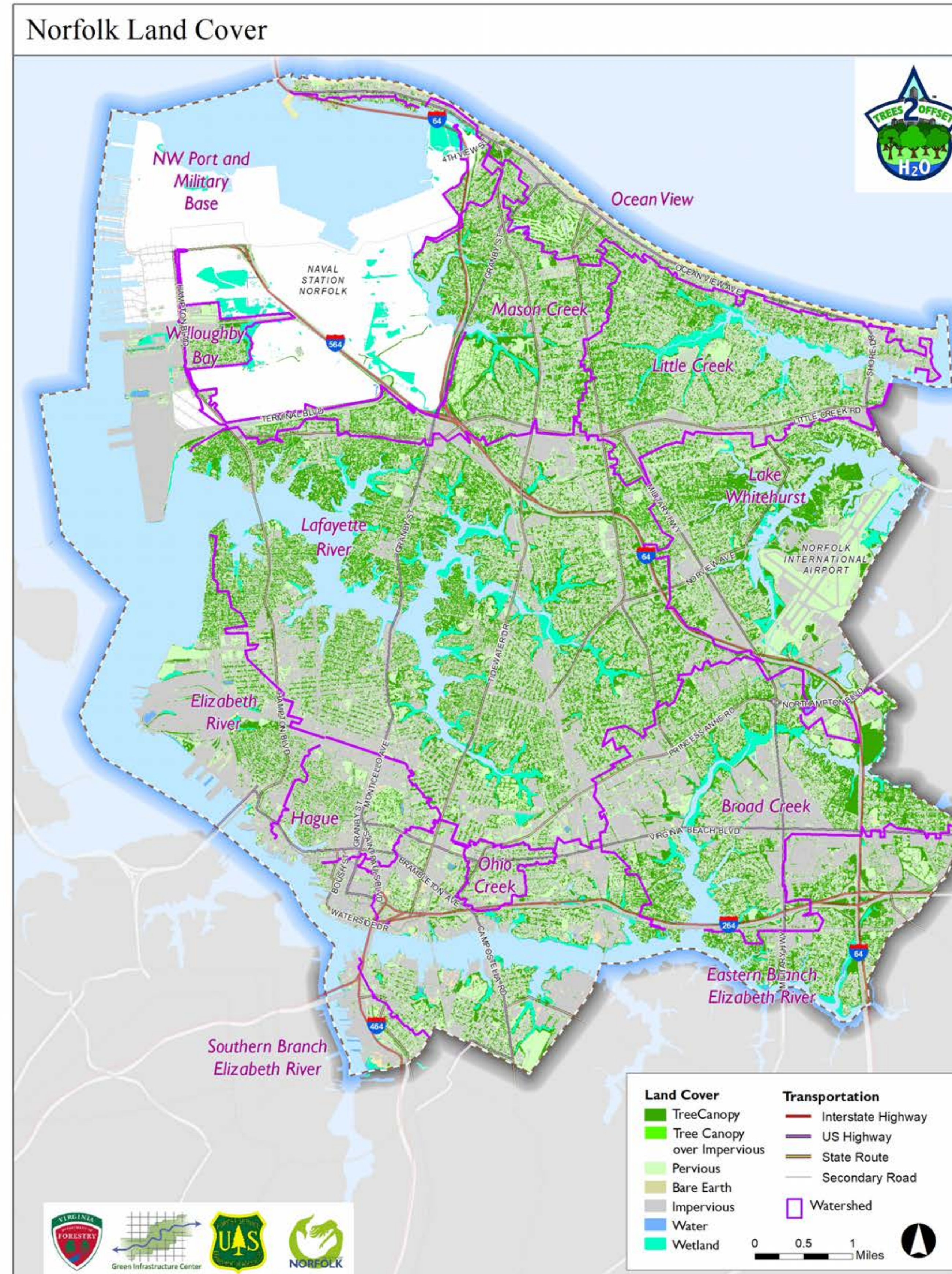
*Source: US Geological Survey



Citywide tree canopy is 25.8 percent.



Percent Tree Cover and Possible Planting Area by Watershed



This map shows the tree canopy of the city which covers 25.8 percent of the area.

WHY PROTECT OUR URBAN FORESTS?

Today, municipalities are losing their trees at an alarming rate, estimated at four million trees annually nationwide (Nowak 2010). This is due, in large part, to population growth. This growth has brought pressures for land conversion to accommodate both commercial and residential development. Cities are also losing older, established trees from the cumulative impacts of land development, storms, diseases, old age and other factors (Nowak and Greenfield 2012). In comparison to other Virginia cities, at 28.8 percent canopy (roughly one quarter of the city), Norfolk has relatively low urban forest coverage.

Norfolk has lost natural forest cover as the city has grown. The city may see more losses in the future if replanting rates decline. As older trees die (or before they die), younger trees need to be planted to restore the canopy. For recommendations on how the city can better protect and manage its urban forests, see the Codes and Ordinances section of this report.

The purpose of this report is not to seek a limit on the city's development, but to help the city better utilize its 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
- increased revenue from tourism and retail sales
- buffering shorelines from wind and erosion damages

Assessment and inventory of trees is key to ensuring a healthy forest.

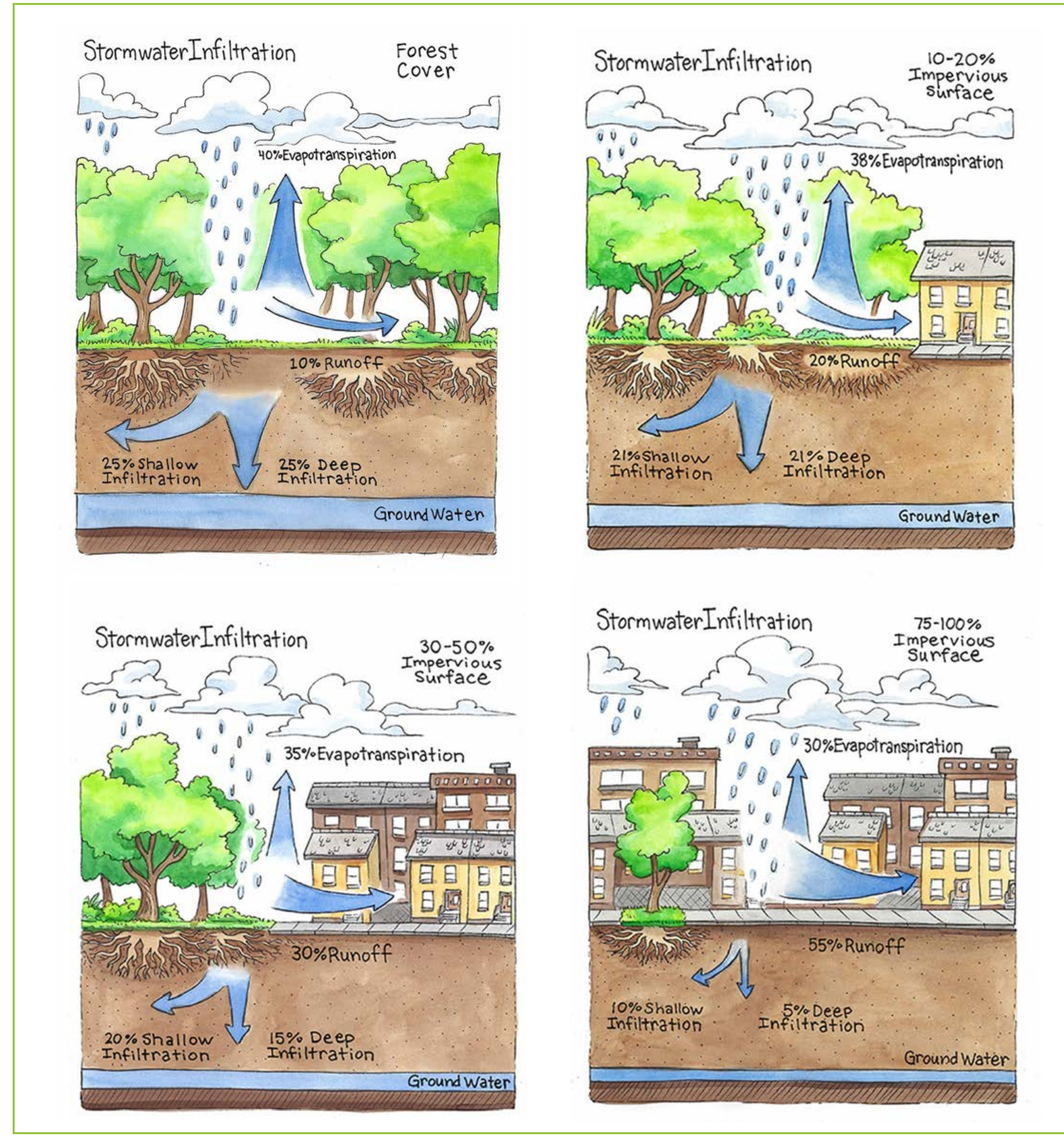
Neighborhood trees.

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.

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

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. When underground aquifers are not replenished, land subsides. Land subsidence is a major problem in the Hampton Roads area.

Another cause of canopy decline is the many recent powerful storms that have affected the Southeastern United States. This study was funded to address canopy decline by helping municipalities monitor, manage and replant their urban forests and to encourage cities to enact better policies and practices to reduce stormwater runoff and improve water quality.



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

It is not just development and storms that contribute to tree loss. Millions of trees are also lost as they reach the end of their life cycle through natural causes. On average, for every 100 street trees planted, only 50 will survive 13-20 years (Roman et al 2014). Even in older developed areas with a well-established tree canopy, redevelopment projects may remove trees. Choosing the wrong tree for a site or climate, planting it incorrectly, or caring for it poorly can all lead to tree canopy loss. It is also important to realize that an older, well-treed neighborhood of today may not have good coverage in the future unless young trees – the next generation – are planted.

Urbanizing counties and cities are beginning to recognize the importance of their urban trees because trees provide tremendous dividends. 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 during a major precipitation event. While stormwater ponds and other management features are designed to attenuate these events, they cannot fully replicate the pre-development hydrologic regime. In addition, as an older city, parts of Norfolk may lack stormwater management practices that are now required for new developments.

Excess impervious areas cause hot temperatures and runoff. Some older paved areas predate regulations requiring stormwater management.

Trees filter stormwater and reduce overall flows. 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.

Another compelling fiscal reason for planning to conserve trees and forests as a part of a green infrastructure strategy is minimizing the impacts and costs of natural disasters. Not only do trees reduce the likelihood of extensive flooding, they also serve as a buffer against storm damages from wind.

In urban areas, Geographic Information Systems (GIS) software is used to map the extent of the current canopy as well as to estimate how many new trees might be fitted into an urban landscape. A Possible Planting Area (PPA) map estimates areas that may be feasible to plant trees. A PPA map helps communities set realistic goals for what they could plant (this is discussed further on in the Methods Appendix).

Planting a Ceremonial Tree at the Botanic Garden to Commemorate Sister City in Norfolk England

Trees in residential yards also help to soak up rainfall.

ADDITIONAL URBAN FOREST BENEFITS

Quality of Life Benefits

During Virginia's hot summers, more shade is always appreciated. Tree cover shades streets, sidewalks, parking lots, and homes, making southern urban locations cooler, and more pleasant for walking or biking. Trees absorb volatile organic compounds and particulate matter from the air, improving air quality, and thereby reducing asthma rates. Shaded pavement has a longer lifespan thereby reducing maintenance costs associated with repairing or replacing roadways and sidewalks (McPherson and Muchnick 2005).

Communities with greener landscapes benefit children by reducing both asthma and ADHD symptoms.

Children who suffer from Attention Deficit Hyperactivity Disorder (ADHD) benefit from living near forests and other natural areas. One study showed that children who moved closer to green areas have the highest level of improved cognitive function after the move, regardless of level of affluence (Wells 2000). Thus, communities with greener landscapes benefit children and reduce ADHD symptoms. Trees also cause people to walk more and walk farther. This is because when trees are not present, distances are perceived to be longer and destinations farther away, making people less inclined to walk than if streets and walkways are well treed (Tilt, Unfried and Roca 2007).

Trees along a natural shoreline.

Trees provide substantial shade and beauty.

Well treed areas encourage people to walk.

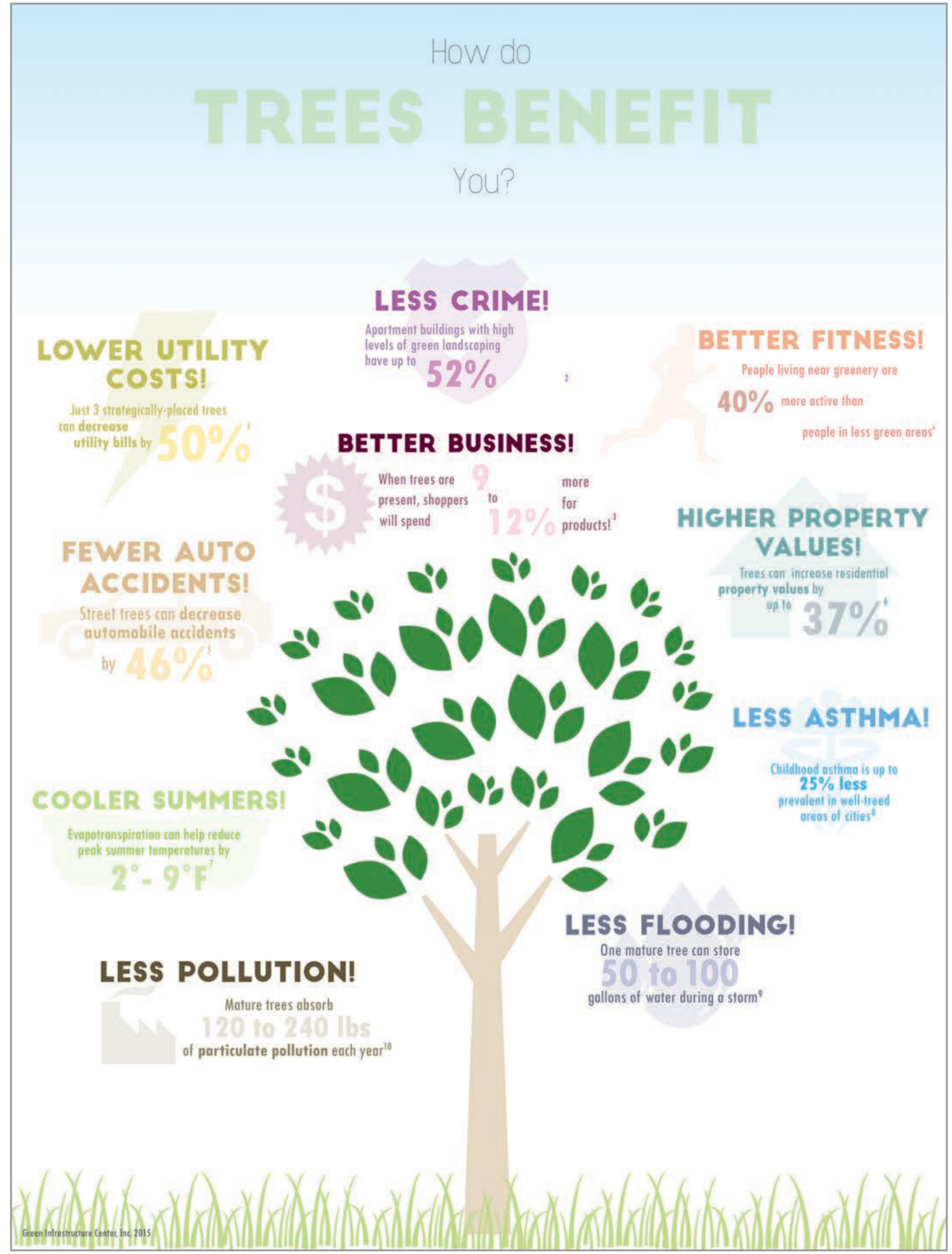
Economic Benefits

Developments that include green space or natural areas in their plans sell homes faster and for higher profits than those that take the more traditional approach of building over an entire area without providing for community green space (Benedict and McMahon 2006). This desire for green space is supported by a National Association of Realtors study which found that 57 percent of voters surveyed were more likely to purchase a home near green space and 50 percent were willing to pay 10 percent more for a home located near a park or other protected area. A similar study found that homes adjacent to a greenbelt were valued 32 percent higher than those 3,200 feet away (Correll et al. 1978).

Meeting Regulatory Requirements

Trees also help meet the requirements of the Clean Water Act. The Clean Water Act requires Virginia to have standards for water quality. When waters are impaired they may require establishment of a Total Maximum Daily Load (TMDL) standard and a clean-up plan (i.e., Best Management Action Plan) to meet water quality standards. Since a forested landscape produces higher water quality by cleaning stormwater runoff (Booth et al 2002), increasing forest cover results in less pollutants reaching the city's surface and ground waters. Two thirds of Virginia are under the Chesapeake Bay TMDL and must follow the bay's Watershed Implementation Plan (WIP) to reduce the impacts of nitrogen, phosphorus and sediment reaching the Bay. The Chesapeake Bay Program has adopted a standard for tree planting to provide credit for the WIP. See Appendix C for an explanation of how to use the credit.

There are many places where trees can be added for shade and beauty.



NATURAL ECOLOGY IN CHANGING LANDSCAPES

Natural history, even of an urbanized location, informs planting and other land-management decisions. Norfolk is located in the Coastal Plain Physiographic Province of Virginia, at the mouth of the Chesapeake Bay. The coastal plain is characterized by a terraced landscape which steps down from the edge of the piedmont towards the coast. Norfolk is located at the easternmost terraces which are geologically the youngest.

HISTORIC LAND COVER

The Coastal Plain was formed over a few million years through fluctuations in sea levels from melting or growing glaciers. The Chesapeake Bay impact crater was formed by a bolide (asteroid) that impacted the eastern shore of North America about 35.5 million years ago, in the late Eocene epoch. When the bolide hit, there was no Chesapeake Bay. The Chesapeake Bay itself did not form until after the Wisconsin glaciation ice sheet melted 18,000 years ago and was created about 5,000 to 6,000 years ago from the flooding of the Susquehanna River.

Coastal plain sediments rest on an eroded surface of older rocks, with two-thirds of the sedimentary wedge made up of late Jurassic and Cretaceous clay, sand, and gravel. Fossil-rich marine sands of Tertiary age overlie the older strata, and were deposited in shallow seas during the on-going marine movements across the Coastal Plain. Over the first 230 years of European settlement, much of the land was cleared for agriculture at one time or another, especially in the Coastal Plain.

Allowing for the growth of understory shrubs and other vegetation will help soak up rainwater and are better than lawns for reducing runoff.

For more see: http://www.dcr.virginia.gov/natural-heritage/natural-communities/document/ncoverviewphys-veg.pdf
The Köppen climate classification lists the city's climate as humid subtropical. Although the landscape of the City of Norfolk is highly altered, the urban forest still supports birds, bees and other pollinators while providing shade and cooling for the city and water quality benefits. The forests also provide a buffer against winds and storms.

Since its very beginnings, the City of Norfolk has had to adapt – to changes in government, revolutionary and civil wars, and expansion of its boundary and population and demographic shifts. Alterations to the landscape began in precolonial days as Native Americans hunted, fished and inhabited the landscape that is now Norfolk. Colonists settled in the area in 1636 and it was formally incorporated into a borough by charter from King George II in 1736. Colonialization led to dramatic changes as swampy lands were 'improved' to allow for its original inhabitants to farm tobacco and other crops and accelerated most dramatically with urbanization in the latter half of the 20th century.

Vegetated shorelines buffer waterways from land runoff.

GROWTH AND DEVELOPMENT CHALLENGES

By 1845, Norfolk was incorporated as a city of more than 10,000 people, although it lost a third of its population to the yellow fever epidemic ten years later. Seven years later the city became famous for the Battle of Hampton Roads between the first two ironclad battleships – the USS Monitor and CSS Virginia (formerly the USS Merrimac). Two months later, in May 1862, Norfolk surrendered to Union forces and was under Federal occupation for the remainder of the Civil War. Since then, Norfolk has grown tremendously to 246,703 residents and embraced its rich cultural heritage through its diverse neighborhoods, a strong presence of Naval Station Norfolk, universities of Old Dominion and Norfolk State as well as Norfolk Community College, and many diverse business and trades, making the city a dynamic and vibrant place to live and work.

Today, the city faces a new challenge as rising seas require the city to consider new ways of planning to accommodate rising water levels. According to the National Oceanic and Atmospheric Agency (NOAA), challenges posed by sea level rise have made Norfolk the second most threatened landscape in the United States[1]. The problem of Sea Level Rise (SLR) is compounded by the fact that the Hampton Roads area is sinking 7-10 times faster than the surrounding region. This is caused by groundwater withdrawals and a lack of sediment to replenish the land that is now overlain by urban landforms.

Norfolk is a city surrounded by water and although SLR is a threat, the city has undertaken new planning initiatives and zoned the city according to where development is more desirable (higher ground) and where development investments are less desired and where more open spaces may be in the future (lower ground). The city's extensive trail network, such as the Elizabeth River Trail, and its dozens of parks provide abundant opportunities to explore the outdoors and to interact with the rivers and coast. Norfolk is a member of the 100 Resilient Cities network which provides support to plan for climate change.

Trees in the city's parks have room to grow and thrive.

As Norfolk grows, demands for green space increase. The city can use current park and school sites to help ensure tree cover is maintained and to plant more trees on public lands and right of way spaces as existing canopy ages. The majority of areas that can be planted are on private lands. The chart shows that almost 60 percent of the plantable area is on private property, so planting by private landowners is key to maintaining the city's canopy coverage.

Plantable Area Ownership	% Plantable
City	12.16%
Federal	0.75%
Private	59.25%
State	6.22%
Transportation	21.62%
Total	100%

Parks enhance the city's livability and soak up rainfall.

[1] Norfolk is second only to Louisiana in rising threats from sea level rise. https://coast.noaa.gov/states/stories/sea-level-rise-adaptation-advances-on-multiple-fronts.html

DEVELOPMENT AND STORMWATER

As an older city, established in 1736, there are areas that pre-date the 1987 Clean Water Act Amendments which require the treatment of stormwater runoff. Adding stormwater treatment for older areas is achieved by either retrofitting stormwater best management practices into the landscape, or adding them as properties are re-developed. Adding more trees is a best management practice that provides other benefits beyond stormwater uptake, such as shade, air cleansing and aesthetic values. Recommendations for improvements to better utilize trees to manage stormwater and to reduce imperviousness are found in the Codes, Policies and Practices section of this report.

Vegetation planted here would help clean stormwater before it enters the drain.

Trees in downtown areas encourage foot traffic.

There are many places where trees are needed to capture stormwater.

Reducing imperviousness and increasing vegetation are one way to ease the frequency of flooding because this limits the amount of water that needs to be drained by the storm drainage system. Vegetation reduces water entering the system by intercepting, capturing and transpiring that water.

The requirements set forth by the Clean Water Act of 1972 for the Environmental Protection Agency's National Pollution Discharge Elimination System (NPDES) permitting program, and subsequent amendments in 1987 regulating nonpoint source pollution, form the foundation for the city's stormwater management program.

Residents can make a difference in runoff by planting trees and other vegetation to soak up runoff.

ANALYSIS PERFORMED

This project evaluated options for how to best model stormwater runoff and uptake by the city's tree canopy. Its original intended use was for planning at the watershed scale for tree conservation. An example is provided on page 16. However, new tools created for the project allow the stormwater benefits of tree conservation or additions as to be calculated at the large site scale as well.

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 diagram of tree water flow below.

METHOD TO DETERMINE WATER INTERCEPTION, UPTAKE AND INFILTRATION

This project provides a tool for setting goals at the watershed scale for planting trees and for evaluating consequences of tree loss as it pertains to stormwater runoff. The table (right) shows the canopy breakdown by watershed.

Currently, most cities use TR-55 curve numbers developed by the Natural Resources Conservation Service (NRCS) to model expected runoff amounts. This study used modified TR-55 curve numbers to calculate stormwater uptake for different land covers, since they are widely recognized and understood by stormwater engineers and used for site plans to calculate stormwater. The equation used to calculate runoff includes a factor for canopy interception of stormwater.

Curve numbers produced by this study can be utilized in the city's modeling and design reviews. The project's spreadsheet calculator tool makes it very easy for the city to change the curve numbers if they so choose. The input to the calculator comes from the GIS land cover maps. When those maps are updated in the future (GIC recommends updates every 5 years) then new data can be input into the spreadsheet. A canopy interception factor is added 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. In a study, 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:

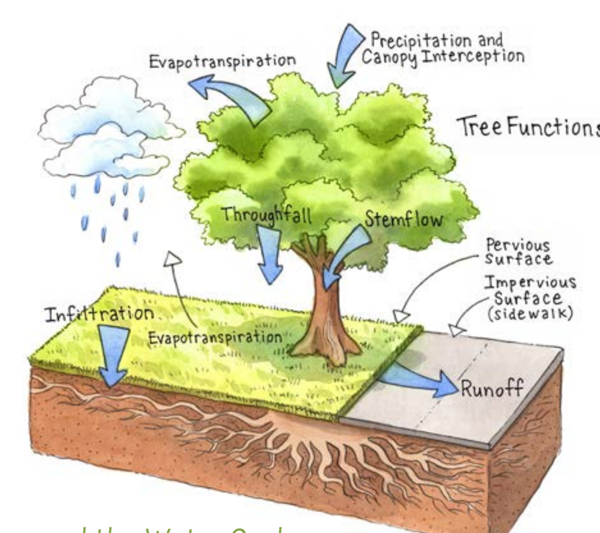
Unit of Analysis: Watersheds	% Tree Canopy
Broad Creek	26.42%
Eastern Branch Elizabeth River	19.96%
Elizabeth River	14.96%
Lafayette River	31.46%
Lake Whitehurst	27.76%
Little Creek	28.07%
Mason Creek	33.63%
NW Port and Military Base	6.32%
Ocean View	19.68%
Southern Branch Elizabeth River	6.99%
Willoughby Bay	23.95%

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

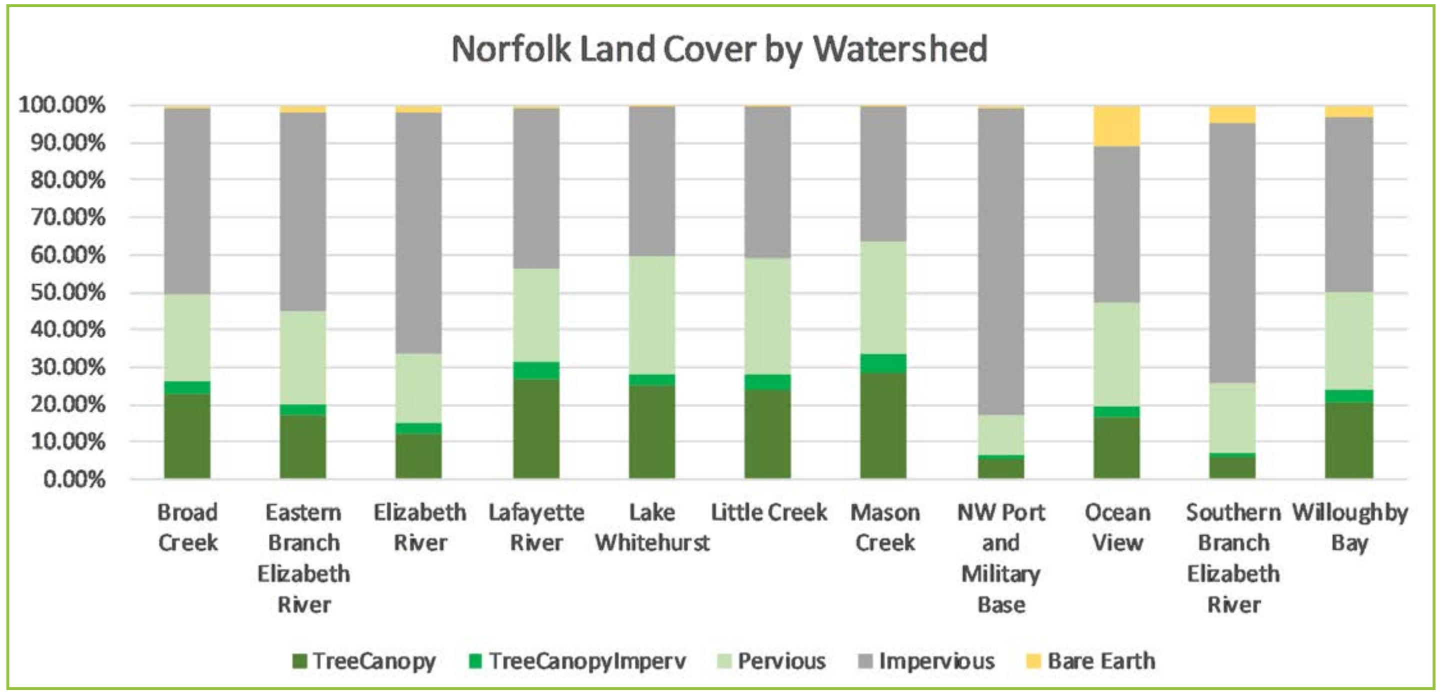
Where R is runoff, P is precipitation, Ia is the initial abstraction for captured water, which is the fraction of the storm depth after which runoff begins, and S is the potential maximum retention after runoff begins for the subject land cover (S = 1000/CN – 10).

Major factors in determining Curve Numbers (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
- Hydrologic condition – density of vegetative cover, surface texture, seasonal variations
- Treatment – design or management practices that affect runoff



Trees and the Water Cycle



What is new about the calculator tool is that the curve numbers relate to the real land cover conditions in which the trees are found. 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 and an estimation of potential future planting areas, as described following. These new land cover analyses can be used for many other projects, such as looking at urban cooling, walkability (see map of street tree coverage on following pages), trail planning and for updating the comprehensive plan.

An example of how this modeling tool can be used for watershed-scale forest planning is shown below The actual model spreadsheet was provided to Norfolk. It links to the land cover statistics for each type of planting area. It also allows the city to hypothetically add or reduce tree canopy to see what are the effects for stormwater capture or runoff. The key finding from this work is that removal of mature trees generates the greatest impacts for stormwater runoff. As more land is re-developed in Norfolk, the city should maximize tree conservation to maintain surface water quality and groundwater recharge. This will also benefit the city's quality of life by fostering clean air, walkability, and attractive residential and commercial districts. Several studies have shown that higher tree canopy percentage is associated with lower overall hospitalization numbers and also with lower hospital visits from asthma.

Norfolk, VA — **Urban Tree Canopy Stormwater Model** — version

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.

Green Infrastructure Center

	Area	Current Tree Cover	Current Impervious Cover	Tree H20 Capture	Increased H2O w/xx% tree loss	Added H2O Capture w/xx% PPA	Tree Cover Goal
	TOTALS	26%	47.5%	65.2	21.3	11.4	31%
		%		million gallons			%
1	Broad Creek	26.4%	49.9%	7.30	1.16	1.51	32%
2	Eastern Branch Elizabeth River	20.0%	53.1%	6.60	2.43	1.77	25%
3	Elizabeth River	15.0%	64.3%	2.70	1.45	0.58	18%
4	Lafayette River	31.5%	43.4%	23.37	8.84	3.14	36%
5	Lake Whitehurst	27.8%	39.9%	8.92	2.04	0.86	32%
6	Little Creek	28.1%	40.7%	5.90	2.19	1.43	35%
7	Mason Creek	33.6%	36.1%	7.07	2.21	1.00	39%
8	NW Port and Military Base	6.3%	82.0%	0.44	0.11	0.23	10%
9	Ocean View	19.7%	41.4%	1.51	0.48	0.41	25%
10	Southern Branch Elizabeth River	7.0%	69.8%	0.17	0.06	0.12	12%
11	Willoughby Bay	24.0%	46.7%	1.20	0.38	0.31	30%

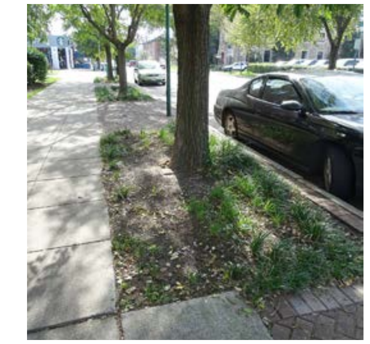
	Area	Pick an Event: Event	Pick a loss scenario: % UTC loss	% FOS Loss	Converted Land: % Imperv	PCA	PPA	Canopy Added: % of Land	Enter % to be planted: % of PPA	Canopy Pollution Load % Reduction: N	P	Sed	Additional Canopy Pollution Load % Reduction: N	P	Sed
	TOTALS									4.9%	5.0%	1.4%	1.1%	1.1%	0.3%
1	Broad Creek	10 yr / 24 hour	5%	0%	40%	36.9%	10.5%	5.2%	50%	4.7%	4.7%	1.3%	1.2%	1.2%	0.3%
2	Eastern Branch Elizabeth River	10 yr / 24 hour	10%	0%	40%	30.7%	10.8%	5.4%	50%	3.9%	4.0%	1.1%	1.2%	1.2%	0.3%
3	Elizabeth River	10 yr / 24 hour	10%	0%	40%	21.3%	6.3%	3.2%	50%	3.1%	3.1%	0.9%	0.7%	0.7%	0.2%
4	Lafayette River	10 yr / 24 hour	10%	0%	40%	40.3%	8.8%	4.4%	50%	6.3%	6.5%	1.8%	1.0%	1.0%	0.3%
5	Lake Whitehurst	10 yr / 24 hour	10%	0%	40%	35.6%	7.9%	3.9%	50%	4.3%	4.4%	1.2%	0.9%	0.9%	0.2%
6	Little Creek	10 yr / 24 hour	10%	0%	40%	41.6%	13.5%	6.7%	50%	5.9%	6.0%	1.6%	1.5%	1.5%	0.4%
7	Mason Creek	10 yr / 24 hour	10%	0%	40%	44.0%	10.3%	5.2%	50%	6.2%	6.3%	1.8%	1.1%	1.2%	0.3%
8	NW Port and Military Base	10 yr / 24 hour	10%	0%	40%	14.6%	8.2%	4.1%	50%	0.9%	0.9%	0.3%	0.9%	0.9%	0.2%
9	Ocean View	10 yr / 24 hour	10%	0%	40%	29.5%	9.8%	4.9%	50%	3.9%	4.0%	1.1%	1.1%	1.1%	0.3%
10	Southern Branch Elizabeth River	10 yr / 24 hour	10%	0%	40%	17.2%	10.2%	5.1%	50%	1.5%	1.5%	0.4%	1.1%	1.1%	0.3%
11	Willoughby Bay	10 yr / 24 hour	10%	0%	40%	35.9%	12.0%	6.0%	50%	4.7%	4.7%	1.3%	1.3%	1.3%	0.4%

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

The stormwater runoff model provides estimates of precipitation capture by tree canopy and the resulting reductions in runoff yield. It takes into account the interaction of land cover and soil hydrologic conditions. It can also be used to run 'what-if' scenarios, specifically losses of tree canopy from development and increases in tree canopy from tree planting programs.

The trees and stormwater model can be used to estimate the impact of the current canopy, possible losses to that canopy, and potential for increasing that canopy. As shown on page 16 bottom, for a 10-year,* 24-hour storm, a loss of 10% of the urban tree canopy would increase runoff by 2.5 million gallons, while increasing canopy coverage from the current 25.8 percent to 31 percent will decrease runoff by almost 11.4 million gallons for that storm event.

This new approach allows for more detailed assessments of stormwater uptake based on the landscape conditions of the city's forests. It distinguishes whether the trees are within a tree cluster, a lawn setting, a forested wetland or over pavement, such as streets or sidewalks. Tree setting is considered because the conditions in which the tree is living affect the amount of water the tree can intercept. The amount of open space and the condition of surface soils affect the infiltration of water. In order to determine these conditions, a detailed land cover assessment was performed as described following. The analysis can be used to create plans for where adding trees or better protecting them can reduce stormwater runoff impacts and improve water quality.


Tree over street


Trees over forest


Tree over lawn

Tree over parking lot


Norfolk's urban forest contributes to livability. Image credit: City of Norfolk.

* A 10-year storm refers to the average recurrence interval, or a 10 percent chance of that level of rainfall occurring.

LAND COVER, POSSIBLE PLANTING AREA, POSSIBLE CANOPY AREA ANALYSIS

The land cover data were created using 2016 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. Ancillary data for roads (from Norfolk government), 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.

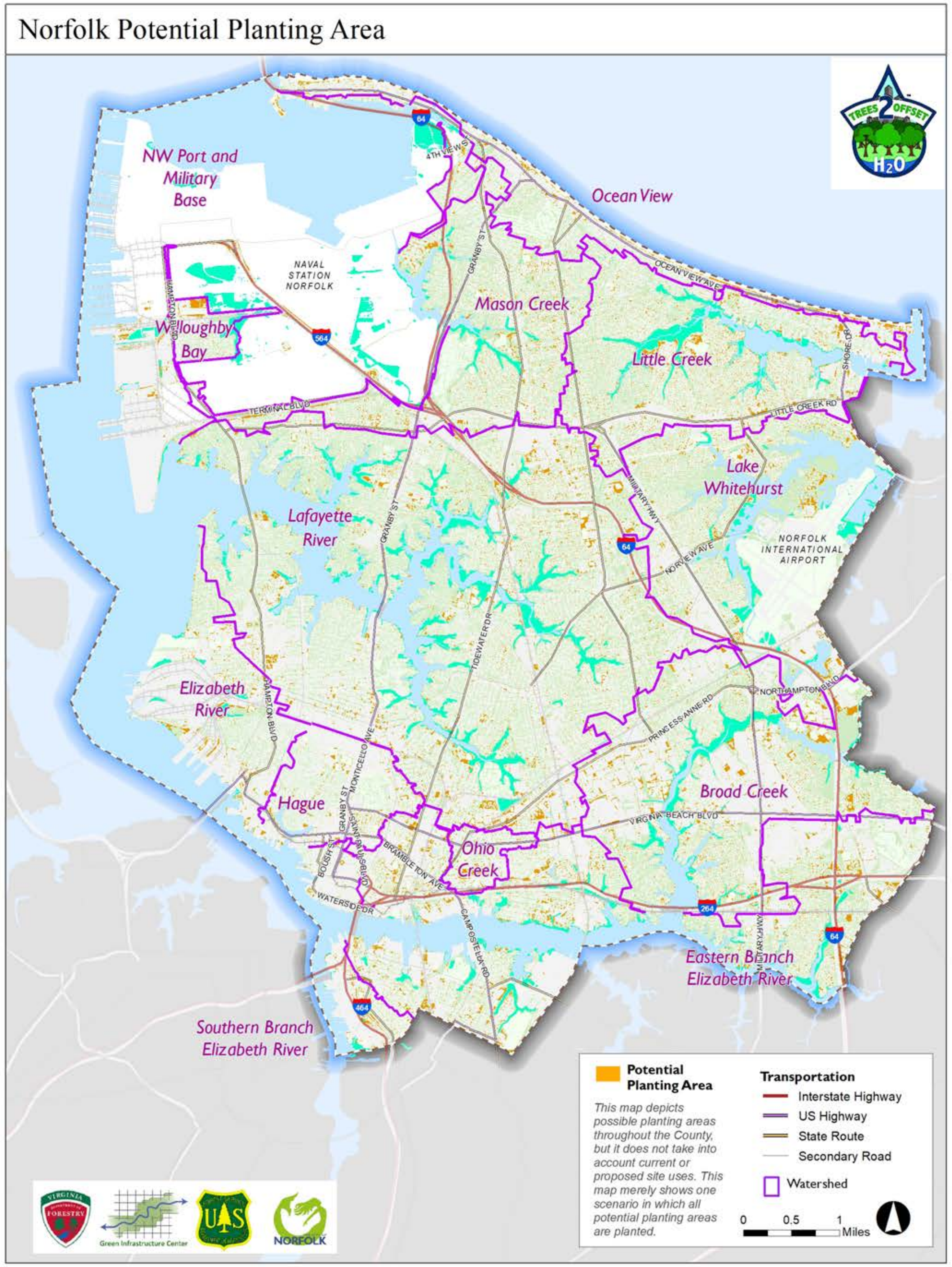
The final classification of land cover consists of six classes listed below. The Potential Planting Area (PPA) is created by selecting the land cover features that have space available for planting trees. (i.e., areas where the growth of a tree will not affect or be affected by existing infrastructure.) Of the six land cover classes, only pervious (grass and scrub vegetation) is considered for PPA.

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

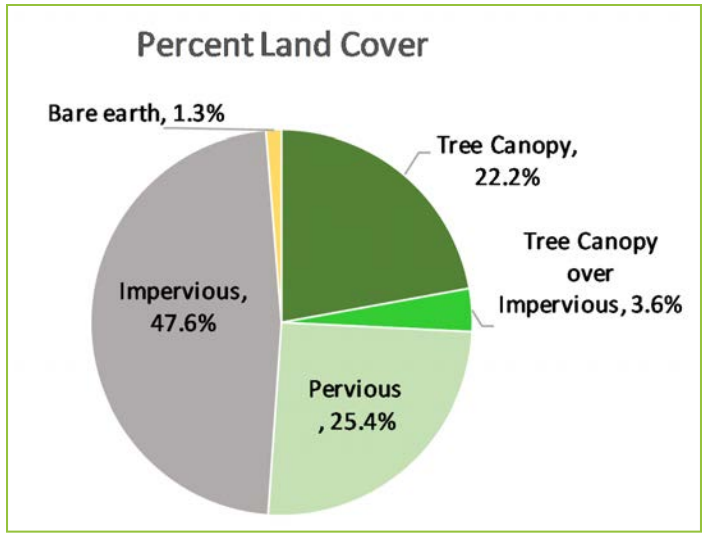
Next, these eligible planting areas are limited based on their proximity to features that might either interfere with a tree's natural growth (such as buildings) or places a tree might affect the feature itself, such as power lines, sidewalks or roads. Playing fields and other known land uses that would 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. 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.

This shows what is currently treed (green) and areas where trees could be added (orange).

Adding more canopy can help alleviate flooding and standing water.



Potential Planting Area (PPA) shown in orange depicts areas where it may be possible to plant trees. All sites would need to be confirmed in the field and may be on private or public lands.



Potential Planting Spots (PPS)

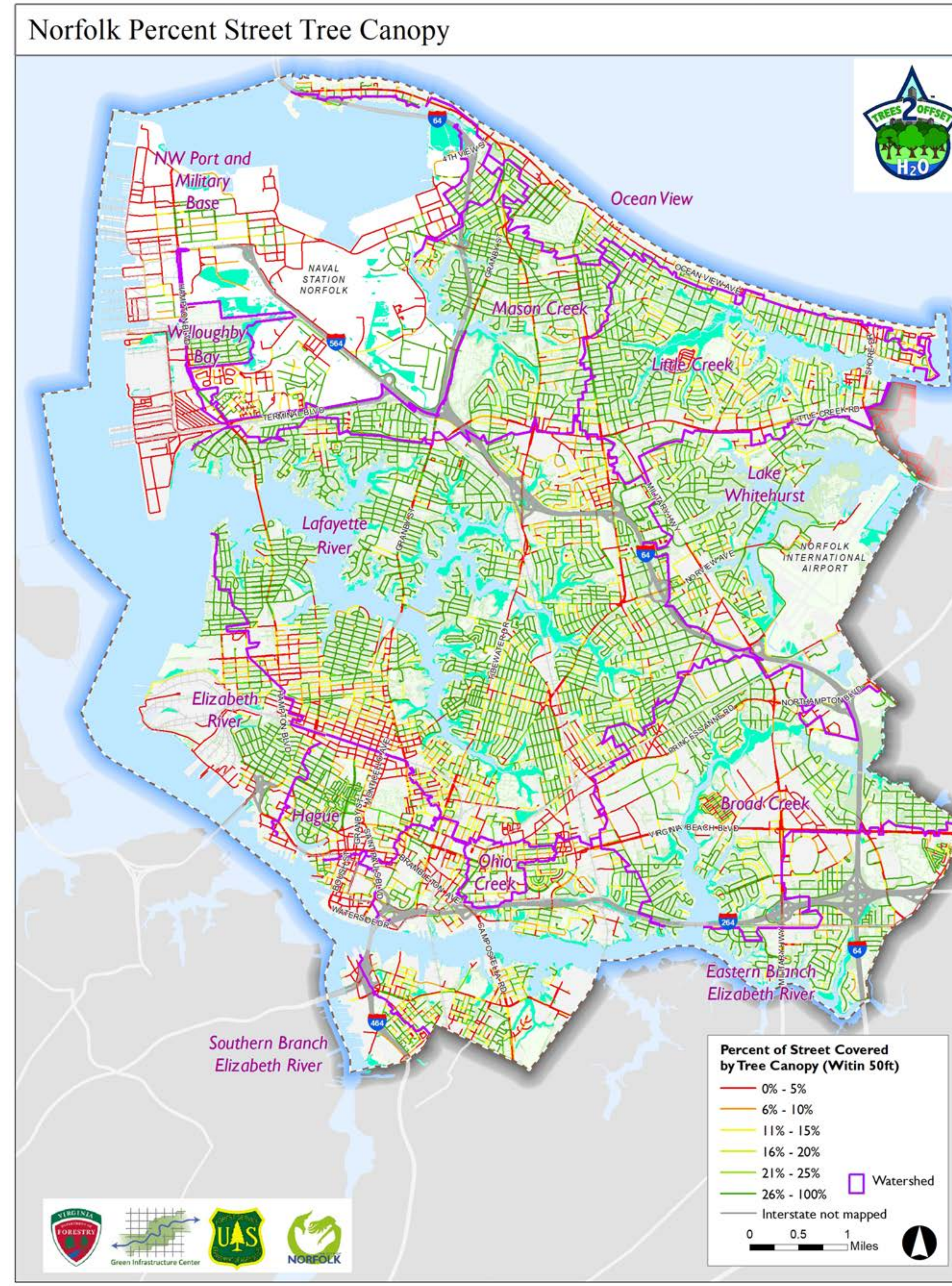
Potential Canopy Area (PCA)

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.

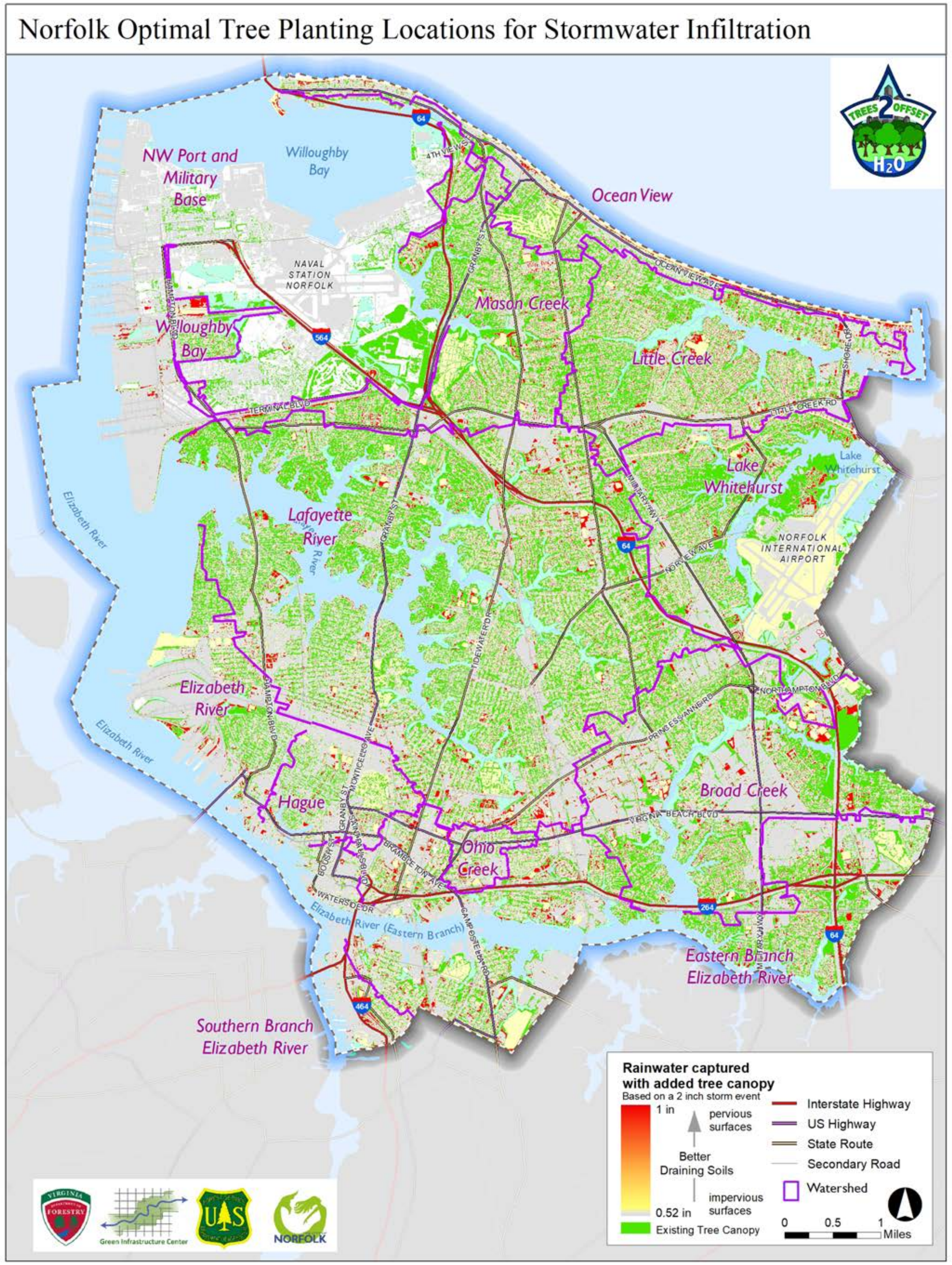
The Potential Canopy Area (PCA) is created from the PPS. Once the possible planting spots are selected, a buffer around each point that represents a tree's mature canopy is created. Similarly, the tree buffer radius is 20 ft. or 40 ft. diameter canopy for each tree. These individual tree canopies are then dissolved together to form the potential overall canopy area.

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.

See Methods Appendix for more details on mapping methodology.



The street trees map shows which streets have the most canopy (dark green) and which have the least (red). Streets lacking good coverage can be targeted for planting to facilitate uses, such as safe routes to school or beautifying a shopping district.



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

CODES, ORDINANCES AND PRACTICES REVIEW

This review is designed to determine which practices 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). Documents reviewed during the codes, ordinances and practices analysis for the project include relevant sections of the city's current code that influence runoff or infiltration. Data were gathered through analysis of city codes and policies, as well as interviews with city staff, whose input was incorporated directly on the spreadsheet summary prepared by the GIC. The spreadsheet provided to the city lists all the codes reviewed, interviews held and relevant findings. A more detailed memo submitted to the city by GIC provides additional ideas for improvement.

EVALUATION AND RECOMMENDATIONS

Points were assigned to indicate what percentage of urban forestry and planning best practices have been adopted to date by the city. The spreadsheet tool created for city codes can also serve as a tracking tool and can be used to determine other practices or policies the city may want to adopt in the future to strengthen the urban forestry program or to reduce impervious land cover. A final report comparing all studied localities will be issued by GIC in 2019.

Norfolk is one of Virginia's longest certified 'Tree City USA' cities, with 32 years of designation as a city that cares for its trees.

Norfolk invests staff time and funds to manage its urban forest. The city was an early adopter of the 'Tree City USA' designation from the Arbor Day Foundation, which means that it spends adequate funds per capita on tree care, it has a tree ordinance, and it practices tree management. In fact, the City of Norfolk celebrated 32 years as a tree city in 2018. The city has two arborists on staff in the Department of Recreation, Parks and Open Space.

The city has a relatively low canopy coverage compared to tidewater cities in Virginia. For example, Portsmouth's canopy is 38% and Newport News' is 34.5%. To ensure that the canopy is maintained, the GIC recommends the following strategies to increase the protections for, and maintain the size of, the forest in Norfolk. As noted earlier, the city's canopy is 25.8 percent, but it is not distributed equally citywide. Even just maintaining this level of coverage requires new plantings each year.

In fact, Norfolk would like to increase its canopy coverage. Norfolk's current urban tree canopy is 25.8% and the new canopy goal determined during the green infrastructure planning process in 2018, was to seek to increase tree canopy to 30%. This will require the planting of 104,000 more trees at a rate of 5,200 trees annually to reach the goal within 20 years. This additional canopy will help the city absorb and clean more stormwater and reduce flooding.

Norfolk is one of 12 localities in a six-state area of the Southeastern U.S. to be studied and the tenth to be completed. As other places are studied, they will be compared to the city, and vice versa. This project's codes, ordinance and policy review coincided with the city's long planned revamp of many city planning codes in 2017. GIC's longer codes, ordinances and policies report was provided to the city during that review process and informed the city's update. Some ideas (not all) that were not adopted in that process are highlighted in the following list of top recommendations that should still be considered.

The city has many habitat projects.

Volunteers have partnered with the city to restore forested buffers.

Top recommendations to improve forest care and coverage in Norfolk listed in priority order include the following:

1) **Use the GIC's stormwater uptake calculator to determine the benefits of maintaining or increasing tree canopy goals by watershed and to set urban forestry goals.** The calculator provided to Norfolk allows the city to determine the stormwater benefits or detriments (changes in runoff) from adding or losing trees and calculates the pollution loading changes for nitrogen, phosphorus, and sediment. As the city makes new land cover maps, that data can be uploaded to the tool to obtain new results.

2) **Conduct a land cover assessment every four to five years to determine and allow for comparison of tree canopy coverage change over time.** Keeping tree canopy coverages at levels that promote public health, walkability, and groundwater recharge for watershed health is vital for livability and meeting state water quality standards. Regular updates to land cover maps allow for this analysis and planning to occur. This will allow the city to determine if canopy goals are being met and to strategically target areas for planting where declines are excessive.

3) **Develop an Urban Forest Management Plan (UFMP) for the city.** An UFMP details a vision for urban tree canopy care. It meshes local government and community interests, outlining a way to proactively manage the urban canopy and provide long term benefits to the community. Norfolk does not currently have an UFMP but their codes and ordinances do include contain typical UFMP components. These components can be divided into several sections including Documentation of Community Values of Trees, Outlining Urban Forestry Goals and Developing a Maintenance Item Schedule.

4) **Increase the urban forestry budget to effectively manage the urban forest and change from reactive to proactive management to reduce impacts from storms and loss of old or diseased trees.** Trees require maintenance and monitoring is necessary to ensure their health as well as for hazard prevention. Having a calendar of maintenance items can help keep a municipality on track with their tree maintenance. We suggest that such a calendar be developed for Norfolk and that it be incorporated into the Tree Ordinance as well as an Urban Forest Management Plan. On-line tools for field application with cell-phone and tablets are widely available and would allow immediate updates to be viewable by field staff and supervisors. This will help reduce impacts from storms and loss of old or diseased trees thereby moving the city from more reactive to proactive management and making Norfolk more resilient. Since this project began, the city has started surveys of tree conditions in select neighborhoods. However, the city lacks the resource allocation to conduct a city-wide assessment prioritized by those areas most at risk.

5) **Adjust parking standards to match demand to reduce excessive imperviousness. Excessive parking standards have exponential negative effects on stormwater, especially in urban environments.** For a professional office building, for example, three spaces per 1,000 square feet is sufficient. Norfolk's standards specify 1.66 spaces per 1,000 feet of professional office building downtown and 4 spaces per 1,000 square feet of a professional office building in a suburban environment. Norfolk's downtown standards are exceptional but the suburban standards are excessive. They could be reduced to three spaces per 1,000 square feet of professional office building space. Shopping centers are another class of uses for which parking requirements are excessive. The general rule of thumb is 4.5 spaces per 1,000 square feet of gross floor area. Norfolk has broken down their parking requirements by category and has included a catch all 'other' category. The 'other' category has very reasonable standards (ranging from 1:125 to 1:600 parking spaces per square feet enclosed building area) but some of the alternative categories, Eating/ Eating and Drinking/Entertainment Establishments for example exceed the 4.5 spaces per 1,000 square feet model standard and could be revised. Maximum parking requirements can be used in place of minimum parking requirements. National regulations as well as local studies are useful for determining demand for specific parking uses.

6) **Expand the complete streets policy to create complete 'green' streets which also include constructed green infrastructure (e.g. bioswales) and trees as part of integrated on-site stormwater management.** Complete green streets allow for integration of stormwater management and aesthetic goals. By incorporating vegetation as an integral part of the street design, green streets can also create and connect habitat, reduce urban heat island effect, reduce air pollutants, and promote walking and biking. The city should develop a policy that includes the following elements: green infrastructure (trees and other vegetation), pedestrian space, bicycle lanes, and stormwater management. A complete streets study was conducted, but it has not been fully implemented. Now is the time to re-focus on green streets and move from study to implementation! This is also covered by Goal 3, Objective 3 in the Green Infrastructure Plan for Norfolk.

7) **Allow narrower streets based on actual Average daily trip (ADT) intervals which determine allowed street widths. Oversized streets are a common source of excessive impervious surface.** Widths should be modified to allow for a greater percentage of narrow streets to reduce impervious cover on low travel streets and more in-street biofiltration should be allowed, such as in cul-de-sacs. Narrower streets can be allowed for streets with lower usage (less average daily trips (ADT) streets. The City of Norfolk uses VDOT standards to categorize low, medium and high density residential streets. The VDOT categorization qualifies low density residential streets as having less than 400 ADTs. This is extremely low and very few streets in an urban location, such as Norfolk, will feature ADTs this low. In addition, this VDOT standard is also misleading as it typically represents car-dependent suburban situations. The same number of urban residents living on a street as compared to suburban residents will typically have less ADTs simply because they are able to walk or take public transportation to various amenities. If Norfolk wishes to continue using VDOT standards for residential road widths, it is recommended that the ADT ranges for low, medium and high density residential streets be modified to better reflect the conditions found in Norfolk. Using the table below, residential street widths can be scaled to match appropriate usages.

Proposed residential street classifications by projected traffic volume

Residential Street Classification	Projected Traffic Volume (ADT)
Low Density	< 600
Medium Density	600-1600
High Density	1601-3000

8) **A volunteer group should be re-formed by the city to carry out planting projects, outreach and tree care workshops to increase city capacity for expanding and managing the urban forest.** Currently the city partners with many groups such as the Lafayette Wetlands Partnership, Friends of the Elizabeth River, Wetlands Watch and other civic and neighborhood groups. The Master Gardeners group currently runs a volunteer pruning program which includes training for city residents in addition to engaging with other tree efforts. However, additional effort is needed to carry out tree planting projects, provide tree care trainings, and generally increase the public's awareness of the value and care of trees. Norfolk should also form a Tree Stewards or Tree Commission group to provide overall care, guidance and policy support for urban tree management. This group could also manage tree give-aways and other outreach tasks now performed chiefly by city staff.

9) **Improve the Stormwater Utility Fee Mitigation to Include Trees.** The City of Norfolk charges a fee for the stormwater generated by each property in the city to cover the cost of implementing stormwater improvements under the city's Municipal Seperate Stormwater Permit. In Norfolk, this fee is about $112 dollars per residential household. A clear procedure for reducing stormwater utility fees through BMPs should be in place in order to reward those who are treating their stormwater effectively on-site and trees should be added as an approved BMP. The current fee reduction program is not publicized adequately. Lastly, the city could include tips on how to locate qualified contractors (without naming specific companies to avoid favoritism) as well as more technical construction standards. A list of contractors who hold a specific certification, such as a Chesapeake Bay Landscape Professional Certification (CBLP) could be added as a suggestion for homeowners.

10) **Require tree canopy in all zoning districts within the city including the downtown character district.** The Landscape Installation and Tree Canopy Standards in the Zoning Ordinance require that zero percent of a lot in the Downtown Character District and 15 percent of a lot in the Coastal Character District be covered by tree canopy. Reducing urban heat island effect and reducing erosion along shorelines are vital to sustain quality of life in Norfolk. Increasing tree canopy coverage allows these goals to be achieved. The minimum percent of lot under tree canopy should be increased to 10% in the Downtown Character District and 20% in the Coastal Character District. Even for cases where on-lot tree canopy is difficult or impossible to achieve, this would allow the developer to provide trees to be planted in the streetscape to compensate for not meeting canopy goals on site.

11) **Re-use urban waste wood. Establishing an urban waste wood program is an excellent way to engage community members and re-use a valuable product.** Norfolk should have a plan for using storm damaged trees instead of sending them to a landfill. Norfolk should launch a city-wide campaign encouraging the re-use of waste wood and let citizens and businesses know how to participate. Proceeds from sale of urban waste wood can fund tree plantings. For more ideas see: https://www.vibrantcitieslab.com/research/waste-management/

BEST PRACTICES FOR CONSERVING TREES DURING DEVELOPMENT

Tree planting or preservation opportunities can be realized throughout the development process. A first step is to engage in constructive collaboration with developers. The City of Norfolk can hold planning concept reviews at the pre-development stage and should identify large trees on conceptual and final site plans. These meetings, tree reporting and additional funding for the city's urban forestry program could expand the options for conservation of the city's trees.

Encouraging Tree Conservation

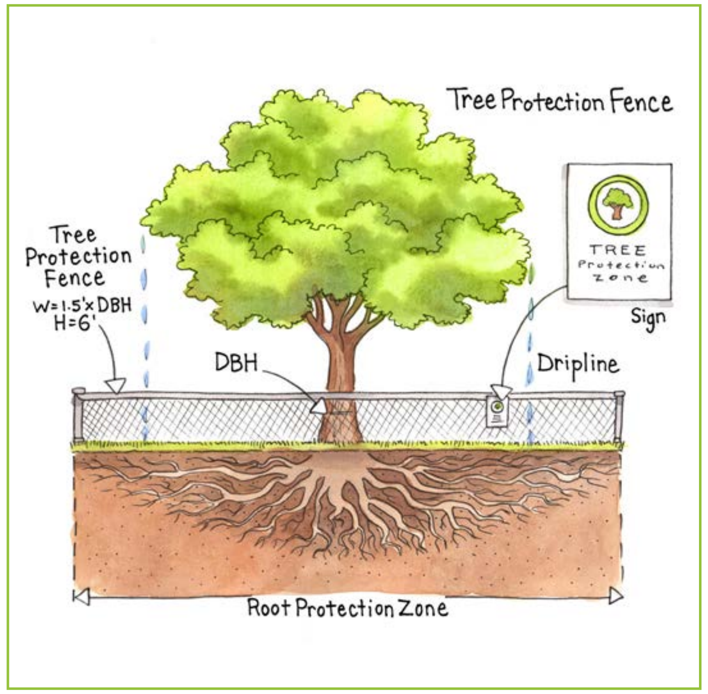
It is also necessary to actively promote the implementation of development designs that minimize the loss of urban forest canopy and habitat. While the city encourages site layouts that conserve trees, developers may not always agree to implement staff suggestions. The GIC has found that economic arguments (real estate values for treed lots, access to open spaces, and rate of sales) are usually the most compelling way to motivate developers to take the extra effort and care to design sites and manage construction activities to promote tree conservation. This will facilitate site designs which save more trees and thereby require less constructed stormwater mitigation. Many developers are willing to cooperate in such ventures, as houses often sell for a higher premium in a well-treed development.

Tree Protection Fencing and Signage

Trees slated for protection may still suffer development impacts such as root compaction and trunk damage. The most common form of tree protection during construction is tree protection fencing. It is a physical barrier that keeps people and machines out of tree's critical root zones during land disturbance.

Small roots at the radial extents of the tree root area, uptake water and absorb nutrients. Protection of these roots is critical for the optimal health of a tree. While protection up to the dripline is an accepted practice, it does not adequately protect the roots. A value of 1.5 feet per DBH inch of trunk is a recommended practice. Norfolk should expand the protection area to ensure full root zone protection during construction or other disturbances

Tree protection signage communicates how work crews should understand and follow tree protection requirements. It also informs crews and citizens about the consequences of violating city code. The city does not have requirements for tree protection signage. It is important that building materials are not placed in tree protection zones and that protective fences not be moved.



Tree Protection Fence and Signage

TREE PLANTING

In urban environments, many trees do not survive to their full potential life span. Factors such as lack of watering or insufficient soil volume and limited planting space put stresses on trees, stunt their growth and reduce their lifespans. For every 100 street trees planted, only 50 will survive 13-20 years (Roman et al 2014). This means that adequate tree well sizing standards are a critical factor in realizing the advantages of a healthy urban forest. At a minimum, canopy trees require 1000 cubic feet of soil volume to thrive. In areas where space is tighter or where heavy uses occur above roots, 'Silva cells' or other trade technologies can be used to stabilize and direct tree roots towards areas with less conflicts (e.g. away from pipes).

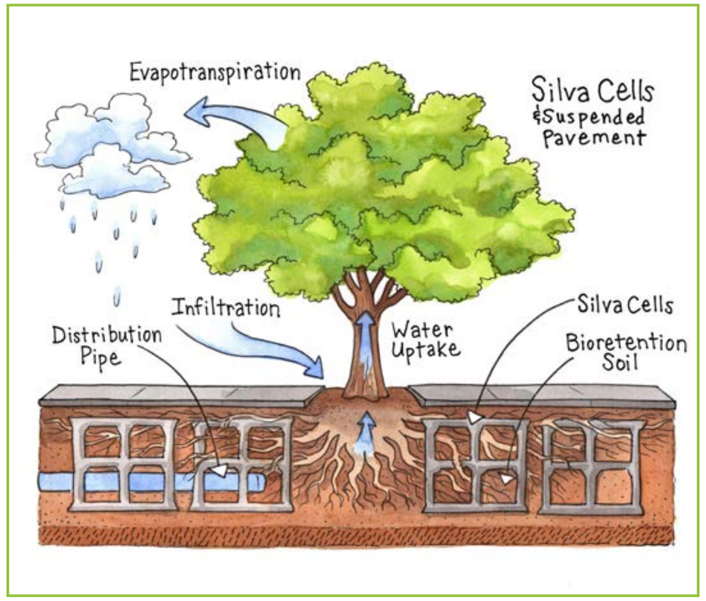
In addition, Norfolk has too many single species trees. Crepe Myrtle is considered to comprise up to 40 percent of the city's street trees. While they tend to resist most pests, cities should never have monocultures of the exact same tree on every street. America suffered devastating tree losses when Dutch elm disease wiped out canopy from entire neighborhoods that were over-planted with elm trees. Cities are now beginning to see ash tree losses caused by the Emerald Ash Borer. The key is to plant a diversity of species so that no one disease or insect can wipe them out all at once. Norfolk also needs to select salt and inundation tolerant trees for those species planted in areas along the water and in areas subject to recurrent flooding.

The city is also considering whether some large impervious surfaces on vacant lots might be converted to open space and planted to provide more canopy in less well treed areas of the city and to uptake more stormwater along with other tree benefits.

Emerald Ash Borer is an invasive beetle from northeast Asia that kills Ash Trees by boring and feeding under their bark, thereby disrupting the movement of water and nutrients through the tree.

Norfolk is a city that values its volunteers and engages with partners to conduct many projects. The city encourages people to retain stormwater on site through its 'Retain Your Rain' campaign. The city also partners with civic associations and nonprofit groups to plant habitat and shoreline restoration projects. The key to maintaining city canopy is to engage even more residents as partners in city tree care and in planting on both public and private property.

Tree planting will be most successful when trees are planted in the right locations. Large trees should not be planted where they may interfere with overhead transmission lines or underground utilities. These and other practices, implemented to provide long term care, protection and best planting practices for the urban forest, will help ensure that investments in city trees pay dividends for reducing stormwater runoff, as well as cleaner air and water, lower energy bills, higher property values and natural beauty long into the future.



Silva Cells and Suspended Pavement

Trees are often too large for narrow spaces. GIC's PPA analysis ensures that there is enough open space for large or for small trees.

Salt and floods have caused tree loss. The city will need to plant different species the next time.

Trees protect Lake Whitehurst, which is a drinking water reservoir.

CONCLUSION

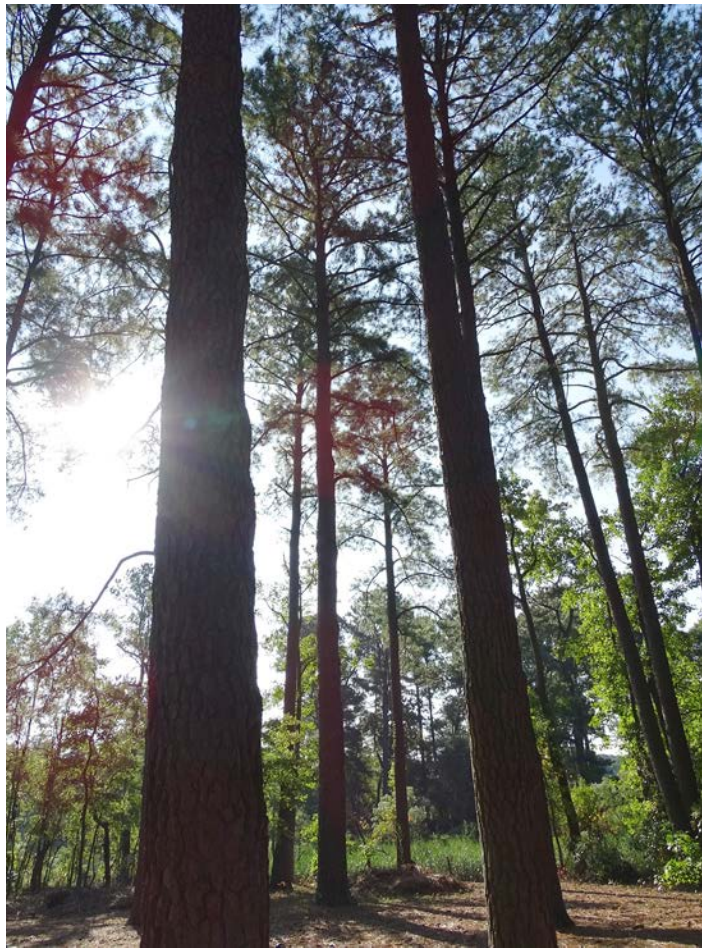
Adapting codes, ordinances and municipality practices to use trees and other native vegetation for greener stormwater management will allow Norfolk to treat stormwater more effectively. Implementing these recommendations will significantly reduce the impact of stormwater sources (impervious cover) and benefit the local ecology by using native vegetation (trees and other vegetation) 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.

The city can use the canopy data, analysis and recommendations and stormwater calculator tool to continue to create a safer, cleaner, cost-effective and more attractive environment for all. Norfolk can use the canopy map and updates to track change over time and to set goals for increasing or maintaining canopy by neighborhood. The city will use the canopy data to inform the future land use plan to strategize where to plant new trees.

Additionally, the city is currently implementing the Green Infrastructure Plan for Norfolk and this document supports the tree protection and canopy goals found in that plan's strategies. For more see http://www.gicinc.org/PDFs/GreenPlan-CityofNorfolk-FinalReport 2018.pdf. In the Green Infrastructure Plan, it is recommended that Norfolk establish an urban tree canopy goal to attain 30 percent coverage. This will require planting approximately 5,200 trees (canopy and understory) annually on public and private property over the next 20 years to achieve this goal. Since approximately 60 percent of the city plantable area is found on private lands, the city needs to partner with its citizens, businesses and institutions to achieve planting goals. The city already gives away trees annually to the public, but they can now use the maps created for this project to provide trees to the most strategic areas where tree planting will soak up the greatest volume of stormwater.

Furthermore, the ability to link tree planting to stormwater uptake is a key argument for allocating additional funds to tree planting and conservation. This is particularly true for Norfolk where the Virginia Institute of Marine Science has predicted that recurrent flooding will continue to increase, especially for low lying areas of Norfolk. For more see http://ccrm.vims.edu/recurrent_flooding/Recurrent_Flooding_Study_web.pdf

Lastly, reducing the amounts and requirements for unnecessary impervious areas will go a long way towards reducing flooding and creating a more resilient city. This report and the longer codes, policies and practices report provided as part of this study identify key strategies for reducing impervious surface by limiting the requirements for excessive pavement and lot clearing. Planting trees for better stormwater capture, uptake and filtration is key; but runoff reduction goals must also be linked to simultaneous reduction of impervious areas in order to achieve a net gain in runoff reduction. With this report, the infiltration maps for tree planting and conservation, and the stormwater calculator, Norfolk has new tools to be more effective in achieving its goal to be a forward thinking, resilient coastal city.



APPENDIXES

APPENDIX A: TECHNICAL DOCUMENTATION

This section provides technical documentation for the methodology and results of the land cover classification used to produce both the Land Cover Map and Potential Planting Scenarios for Norfolk.

Land cover classifications are an affordable method for using aerial or satellite images to obtain information about large geographic areas. 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?

Land Cover Classification

NAIP 2016 Leaf-on imagery (4 band, 1-meter resolution) was used for the land cover classification. The full set of NAIP data was acquired through the Earth Resources Observation and Science (EROS) Center of the U.S. Geological Survey.

Pre-Processing

The NAIP image tiles were first re-projected into the coordinate system used by the city.

NAD_1983_StatePlane_Virginia_North_FIPS_4501_Feet
WKID: 2283 Authority: EPSG

Projection: Lambert_Conformal_Conic
False_Easting: 11482916.66666666
False_Northing: 6561666.666666666
Central_Meridian: -78.5
Standard_Parallel_1: 38.03333333333333
Standard_Parallel_2: 39.2
Latitude_Of_Origin: 37.66666666666666
Linear Unit: Foot_US (0.3048006096012192)

Geographic Coordinate System: GCS_North_American_1983
Angular Unit: Degree (0.0174532925199433)
Prime Meridian: Greenwich (0.0)
Datum: D_North_American_1983
Spheroid: GRS_1980
Semimajor Axis: 6378137.0
Semiminor Axis: 6356752.314140356
Inverse Flattening: 298.257222101

Supervised Classification

The imagery was classified using an object based supervised classification approach. The ArcGIS extension Feature Analyst was used to perform the primary classification with a 'bull's eye' object recognition configuration was used to identify features based on their surrounding features. Feature Analyst software is an automated feature extraction extension that enables GIS analyst to rapidly and accurately collect vector feature data from high-resolution satellite and aerial imagery. Feature Analyst uses a model-based approach for extracting features based on their shape and spectral signature.

For better distinction between classes, an NDVI image was created using Raster Calculator used instead of ArcGIS' Imagery Analyst menu for consistency. The NDVI image along with the source NAIP bands (primarily 4, 1 and 2) were used to identify various features where they visually matched the imagery most accurately.

Further revisions were made using 2017 (leaf-off) high resolution aerial photography provided by the city. These revisions included large areas cleared since the 2016 NAIP imagery was acquired. Effort was made to keep an accurate representation of change instead of simply classifying areas as bare earth. Where available plans were used from available public resources (New I-564 High way, IKEA, Outlet Mall) and where not available (Bay Oaks Park) the neighboring city block was transposed in place.

Post-Processing

The raw classifications from Feature Analyst then went through a series of post-processing operations. Planimetric data were also used at this point to improve the classification. Roads, sidewalks, and trails were 'burned in' to the raw classification (converted vector data to raster data, which then replaced the values in the raw classification). The 'tree canopy' class was not affected by the burn-in process, however, because tree canopy can overhang streets. These data layers were also used to make logic-based assumptions to improve the accuracy of the classification. For example, if a pixel was classified as 'tree canopy,' but that pixel overlaps with the roads layer, then it was converted to 'Tree Cover Over Impervious.' The final step was a manual check of the classification. Several ArcGIS tools were built to automate this process. For example, the ability to draw a circle on the map and have all pixels classified as 'tree canopy' to 'non-tree vegetation,' which is a process usually requiring several steps, is now only a single step.

Potential Planting Area Dataset

The Potential Planting Area dataset has three components. These three data layers are created using the land cover layer and relevant data in order to exclude unsuitable tree planting locations or where it would interfere with existing infrastructure.

1. **Potential Planting Area (PPA)**
2. **Potential Planting Spots (PPS)**
3. **Potential Canopy Area (PCA)**

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:

- Existing tree cover
- Water
- Wetlands
- Imperious surfaces
- Ball fields (i.e.: baseball, soccer, football) where visually identifiable from NAIP imagery. Digitized by GIC.
- Navy Base
  - Navy flight path
- Beach/Dunes
- Airport
- Industry (port and train yard)
- Cemeteries
- Landfill
- Norfolk Redevelopment and Housing Authority (NRHA) land (requested by city)

Exclusion Features: (buffer distance)

- Buildings (10 ft.)
- Sidewalks (5 ft.)
- Street lights (5 ft.)
- Roads (10 ft.)
- Driveways (10 ft.)
- Railroads (10 ft.)
- Structures (10 ft.)
- Storm pipes (10 ft.)
- Water lines (10 ft.)
- Sewer lines (10 ft.)
- Power lines and other identifiable utilities (10 ft.)

Potential Planting Spots

The Potential Planting Spots (PPS) are created from the PPA. The potential planting areas (PPA) is run through a GIS model that selects spots a tree can be planted depending on the size trees that are desired. The tree planting scenario was based on a 20 ft. and 40 ft. mature tree canopy with a 30 percent overlap.

Potential Canopy Area

The Potential Canopy Area (PCA) is created from the PPS. Once the possible planting spots are given a buffer around each point, this represents a tree's mature canopy. For this analysis, they are given a buffer radius of 10 or 20 ft. that results in 20 and 40 ft. tree canopy.

NAIP Image 2016

Potential Planting Area (PPA)

Potential Planting Spots (PPS)

Potential Canopy Area (PCA)

APPENDIX B: BIBLIOGRAPHY

______ Appendix: Hynicka, Justin, and Marion Divers. “Relative reductions in non-point source pollution loads by urban trees.” in Cappiella, Karen, Sally Claggett, Keith Cline, Susan Day, Michael Galvin, Peter MacDonagh, Jessica Sanders, Thomas Whitlow, and Qingfu Xiao. “Recommendations of the Expert Panel to Define BMP Effectiveness for Urban Tree Canopy Expansion.” (2016).

________Runoff and infiltration graphic. EPA Watershed Academy Website. Accessed February 19, 2019: https://cfpub.epa.gov/watertrain/moduleFrame.cfm?parent_object_id=170

_______Complete Green Streets. Smart Growth America. Web site accessed February 20, 2018 https://smartgrowthamerica.org/resources/complete-and-green-streets/

_______ Penn State Extension, Trees and Stormwater http://extension.psu.edu/plants/green-industry/landSCaping/culture/the-role-of-trees-and-forests-in-healthy-watersheds

_______Stormwater to Street Trees. U.S. Environmental Protection Agency. September 2013. EPA report # EPA 841-B-13-001Web site accessed June 01,2016: https://www.epa.gov/sites/production/files/2015-11/documents/stormwater2streettrees.pdf

Akbari, Hashem, Melvin Pomerantz, and Haider Taha. “Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas.” *Solar energy* 70, no. 3 (2001): 295-310.

Benedict, Mark A., and Edward T. McMahon. 2006. Green Infrastructure: Linking Landscapes and Communities. Washington, D.C.: Island Press.

Benedict, Mark A. and McMahon. “*Green Infrastructure: Smart Conservation for the 21st Century*.” Washington, D.C., Sprawl Watch Clearing House, May 2002. Accessed February 2018 http://www.sprawlwatch.org/greeninfrastructure.pdf

Booth, Derek B., David Hartley, and Rhett Jackson. “Forest cover, impervious surface area, and the mitigation of stormwater impacts.” *JAWRA Journal of the American Water Resources Association* 38, no. 3 (2002): 835-845.

Cappiella, Karen, Sally Claggett, Keith Cline, Susan Day, Michael Galvin, Peter MacDonagh, Jessica Sanders, Thomas Whitlow, and Qingfu Xiao. “Recommendations of the Expert Panel to Define BMP Effectiveness for Urban Tree Canopy Expansion.” (2016).

Correll, Mark R., Jane H. Lillydahl, and Larry D. Singell. “The effects of greenbelts on residential property values: some findings on the political economy of open space.” *Land economics* 54, no. 2 (1978): 207-217.

Dwyer, John F., E. Gregory McPherson, Herbert W. Schroeder, and Rowan A. Rowntree. “Assessing the benefits and costs of the urban forest.” *Journal of Arboriculture* 18 (1992): 227-227.

Ernst, Caryn, Richard Gullick, and Kirk Nixon. “Conserving forests to protect water.” Am. Water W. Assoc 30 (2004): 1-7.

Fazio, James R. “How trees can retain stormwater runoff.” Tree City USA Bulletin 55 (2010): 1-8.

Gregory, J.H., Dukes, M.D., Jones, P.H. and Miller, G.L., 2006. Effect of urban soil compaction on infiltration rate. *Journal of soil and water conservation*, 61(3), pp.117-124.

Gregory, Justin H., Michael D. Dukes, Pierce H. Jones, and Grady L. Miller. “Effect of urban soil compaction on infiltration rate.” *Journal of soil and water conservation* 61, no. 3 (2006): 117-124.

“Climate Project.” *Urban ecosystems* 1, no. 1 (1997): 49-61.

Kuehler, Eric, Jon Hathaway, and Andrew Tirpak. “Quantifying the benefits of urban forest systems as a component of the green infrastructure stormwater treatment network.” *Ecohydrology* 10, no. 3 (2017).

McPherson, E. Gregory, and Jules Muchnick. “Effect of street tree shade on asphalt concrete pavement performance.” *Journal of Arboriculture* 31, no. 6 (2005): 303.

McPherson, E. Gregory, David Nowak, Gordon Heisler, Sue Grimmond, Catherine Souch, Rich Grant, and Rowan Rowntree. “Quantifying urban forest structure, function, and value: the Chicago Urban Forest”

Nowak, David J., E. Robert III, Daniel E. Crane, Jack C. Stevens, and Jeffrey T. Walton. “Assessing urban forest effects and values, Washington, DC’s urban forest.” Assessing urban forest effects and values, Washington, DC’s urban forest. Resour. Bull. NRS-1. Newcity Square, PA: US Department of Agriculture, Forest Service, Northern Research Station. 24 p. 1 (2006).

Nowak, D.J., and E.J. Greenfield. 2012. “Tree and impervious cover change in U.S. cities.” *Urban Forestry & Urban Greening*, Vol. 11, 2012; pp 21-30. http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1239&context=usdafsfacpub

Nowak et al. 2010. *Sustaining America’s Urban Trees and Forests*: https://www.fs.fed.us/openspace/fote/reports/nrs-62_sustaining_americas_urban.pdf

Roman, Lara A., John J. Battles, and Joe R. McBride. “Determinants of establishment survival for residential trees in Sacramento County, CA.” *Landscape and Urban Planning* 129 (2014): 22-31.

Roman, Lara A., and Frederick N. Catena. “Street tree survival rates: Meta-analysis of previous studies and application to a field survey in Philadelphia, PA, USA.” *Urban Forestry & Urban Greening* 10, no. 4 (2011): 269-274.

Souch, C. A., and C. Souch. “The effect of trees on summertime below canopy urban climates: a case study Bloomington, Indiana.” *Journal of Arboriculture* 19, no. 5 (1993): 303-312.

Tilt, Jenna H., Thomas M. Unfried, and Belen Roca. “Using objective and subjective measures of neighborhood greenness and accessible destinations for understanding walking trips and BMI in Seattle, Washington.” *American Journal of Health Promotion* 21, no. 4_suppl (2007): 371-379.

Wang, Jun, Theodore A. Endreny, and David J. Nowak. “Mechanistic simulation of tree effects in an urban water balance model.” *JAWRA Journal of the American Water Resources Association* 44, no. 1 (2008): 75-85.

Wells, Nancy M. “At home with nature: Effects of “greenness” on children’s cognitive functioning.” *Environment and behavior* 32, no. 6 (2000): 775-795.

Xiao, Qingfu, E. Gregory McPherson, Susan L. Ustin, Mark E. Grismer, and James R. Simpson. “Winter rainfall interception by two mature open-grown trees in Davis, California.” Hydrological processes 14, no. 4 (2000): 763-784.

APPENDIX C: TREE PLANTING CREDIT UNDER THE CHESAPEAKE BAY WATERSHED IMPLEMENTATION PLAN

Introduction:

The Chesapeake Bay Program (CBP) is a regional organization that coordinates Chesapeake Bay restoration and protection for federal agencies and state partners along with local governments, non-profit organizations, and academic institutions. The CBP developed over 200 best management practices (BMPs) for accreditation in the Phase 6 Implementation of Chesapeake Bay Watershed Model. Many BMPs, including urban tree planting, are eligible for nitrogen, phosphorus, and sediment reductions toward their Phase III Watershed Improvement Plan (WIP) targets. This appendix explains how to calculate nitrogen, phosphorus, and sediment reductions through urban tree planning BMPs. This is derived from "Quick Reference Guide for Best Management Practices, Nonpoint Source BMPs to Reduce Nitrogen, Phosphorus and Sediment Loads to the Chesapeake Bay and its Local Waters" (Pub. CBP/TRS-323-18)[1]

Types of Urban Tree Planting BMPs

CBP developed three classes of urban tree planting BMPs. Each one yields a different nitrogen, phosphorus, and sediment reduction per acre and loading reductions vary by state as well. See below for a description of each.

Urban Tree Canopy Expansion

The Urban Tree Canopy Expansion BMP credits planting of urban trees. Trees do not need to be planted in a contiguous manner but cannot be part of a riparian forest buffer or a structural BMP. For the BMP, 300 trees planted is equivalent to one acre of urban tree canopy expansion.

Urban Forest Planting

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 must include no fertilization and minimal mowing to aid tree understory establishment.

Urban Forest Buffer

The Urban Forest Buffer BMP credit is for contiguous forest planted in a recommended buffer of 100' or a minimum buffer of 35.'

Note: Trees may not be double credited. For example, if an acre of trees is planted along a stream in a developed area as an urban forest buffer, the same acre of trees may not be credited as urban forest planting or urban tree canopy expansion.

Calculating Nitrogen, Phosphorus, and Sediment Reductions

Trees are credited based on the standard that 300 trees comprise one acre of trees. This is based on the Chesapeake Bay panel's recommendation of 144 square foot average of canopy trees planted. To calculate the credit, first determine the type of urban tree planting BMP performed (Urban Tree Canopy Expansion, Urban Forest Planting, or Urban Forest Buffer). Calculate the number of trees planted (note that some BMPs require trees to be planted contiguous while others do not). Divide the number of trees planted by 300 and multiply by the corresponding nitrogen, phosphorus, and sediment reduction coefficient.

For example, if 600 trees were planted throughout an urban area in a noncontiguous fashion and not as part of a riparian forest buffer, these trees would be credited under the Urban Tree Canopy Expansion BMP. To determine the acres of trees planted, divide the number of trees planted (600) by 300. This yields two acres of Urban Tree Canopy Expansion. Multiply the nitrogen, phosphorus and sediment average reductions/acre for Urban Tree Canopy Expansion (see Table below) by two to find total nitrogen, phosphorus, and sediment reductions for the BMP. Thus,

- Total nitrogen reduction is 3.64 lb. (1.82 lb./ac x 2 ac).
- Total phosphorus reduction is 0.30 lb. (0.15 lb./ac x 2 ac).
- Total sediment reduction is 445 lb. (223 lb./ac x 2 ac).

[1] https://www.chesapeakebay.net/documents/BMP-Guide_Full.pdf

Jurisdiction	BMP	Nitrogen Average reduction per acre, Edge of tide (lbs/ac)	Phosphorus Average reduction per acre, Edge of tide (lbs/ac)	Sediment Average reduction per acre, Edge of tide (lbs/ac)
Virginia	Forest buffer	8.77	1.61	854
	Forest planting	7.33	1.16	451
	Tree planting - canopy	1.82	0.15	223

Above values are from Table D-7-1. Bay-wide average nitrogen, phosphorus and sediment reductions per acre of implementation. Pounds reduced edge-of-tide (EOT): TN and TP rounded to nearest hundredth of a pound; TSS rounded to nearest whole pound. Values derived in Phase 6 version of CAST and available by county or state. These values provided as useful estimates but the actual reductions for specific BMPs will be different from these average estimates. Source: BMP Pounds Reduced and Cost by State, July 13, 2018 version, available under "Cost Effectiveness" section at http://cast.chesapeakebay.net/Documentation/DevelopPlans