Miami Beach

TREES TO OFFSET STORMWATER

Case Study 05: City of Miami Beach, Florida

FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

FLORIDA FOREST SERVICE Agriculture & Consumer Services

MIAMIBEACH RISING ABOVE

Green Infrastructure Center

September 2018

Images and illustrations in the report are by the Green Infrastructure Center Inc. (GIC).

The work upon which this publication is based was funded, in whole, through a subrecipient grant awarded by the USDA Forest Service through the Florida Department of Agriculture and Consumer Services, Florida Forest Service to Miami Beach. The Green Infrastructure Center is the technical services consultant for the project and the project partner. 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.

Publication Date: September 2018

Case Study 05: City of Miami Beach, FL

September 2018

CONTENTS

PROJECT OVERVIEW

This project Trees to Offset Stormwater, is a study of Miami Beach's tree canopy its role in taking up, storing and releasing water. This study was undertaken to assist Miami Beach 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 Florida, Georgia, Alabama, South Carolina, North Carolina and Virginia. 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. Florida received funding from the USDA Forest Service to determine how trees can be utilized to meet municipal goals for stormwater management. The FL Forest Service administered the pilot studies in Florida and selected Miami Beach to be one of the three test cases. The other Florida municipalities selected were the City of Jacksonville and Orange County.

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 and inundation from Sea Level Rise and lack of tree replacement as older trees die. 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, Miami Beach now has baseline data against which to monitor canopy protection progress, measures of the stormwater and water quality benefits provided by its urban forest, and locations for prioritizing canopy replanting.

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 Miami Beach. More specifically, the following deliverables were included in the pilot study:

- Analysis of the current extent of the urban forest through high resolution tree canopy mapping,
- Possible Planting Area analysis to determine where additional trees could be planted,
- A method to calculate stormwater uptake by the city's tree canopy,
- A review of existing codes, ordinances, guidance documents, programs and staff capabilities related to trees and stormwater management, and recommendations for improvement,
- Two community meetings to provide outreach and education,
- Presentation of the results of the pilot studies as a case study at regional and national conferences, and
- A case book and presentation detailing the study methods, lessons learned and best practices.

The project began in September 2017 and Miami Beach 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): Environment and Sustainability Department; Environmental Resources Division; Urban Forestry Division; Community Services, Parks and Urban Forestry; Public Services, Stormwater Division, and GIS; Planning, Development, and Transportation; and Engineering.

Welcome shade in Miami Beach

COMMUNITY ENGAGEMENT

Two community meetings were held. The first meeting held in April 2018 provided an overview of the project. The second meeting held in September 2018 provided recommendations (listed below) for the city and elicited feedback. All individual comments from both meetings were provided to the city.

Miami Beach residents emphasized the importance of planting native canopy trees because they have far greater stormwater uptake capacity, than palm trees. They also expressed an interest in knowing the composition of the urban forest with regards to tree species. Some residents suggested documenting tree species and planting dates for newly planted trees on private property. Residents also asked for guidance for increasing tree density on their properties and for guidance to select suitable tree species. They also expressed interest in applying data from the Trees and Stormwater Project to show changes in canopy over time. Residents also provided their feedback on current urban forestry initiatives. They expressed support for the urban forestry program's reforestation work and requested more reforestation citywide.

Community members were presented with six specific code/ordinance or practice changes that GIC recommended to the City of Miami Beach. Meeting attendees were asked to choose the top three changes they felt would most benefit the urban forest. The policy or code changes are listed below in priority order (most to least popular).

1. Complete an Urban Forest Management Plan for the city.
2. Use the GIC's s stormwater calculator tool to determine the benefits of maintaining or increasing urban canopy.
3. Use the urban forestry funding calculator to determine an achievable urban tree canopy coverage goal.
4. Conduct a land cover assessment every four years to determine and allow for comparison of tree canopy coverage over time.
5. Develop a Miami Beach Tree Stewards Group to engage the public in helping to build and maintain the urban forest.
6. Perform urban forestry data collection and monitoring.

Residents learned how the tree canopy was mapped and then provided ideas for tree conservation or planting.

Miami Beach can use this report and its associated products to:

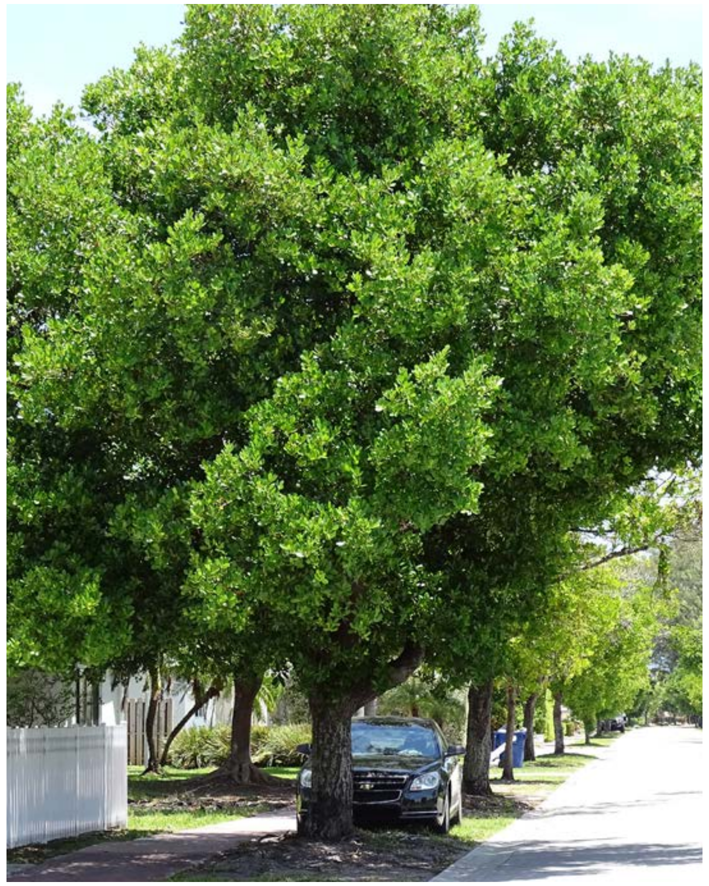
- *Set goals and develop a management plan for retaining or expanding its tree canopy by watershed/island group.*
- *Improve management practices so trees will be well-planted and well-managed.*
- *Educate developers about the importance of tree retention and replacement.*
- *Motivate private landowners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

SUMMARY OF FINDINGS

Satellite imagery was used to classify the types of land cover in Miami Beach (for more on methods see page 15). 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 Miami Beach.

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 model created shows how the city can reduce potential pollution of its surface waters, which can impact Total Maximum Daily Load (TMDL) outcomes and watershed and island 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 or forested wetland), 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.



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

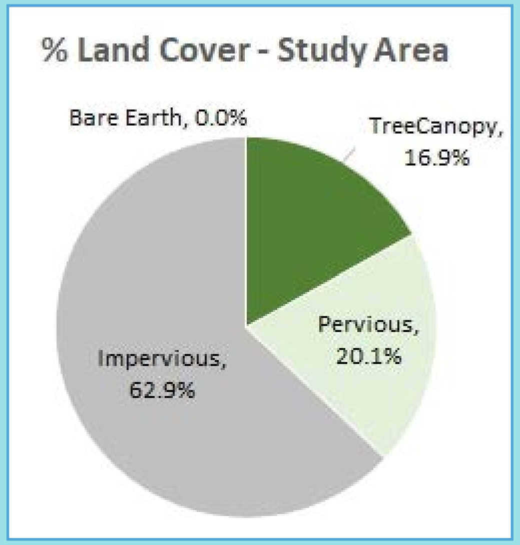
ISLAND GROUP	PERCENT TREE CANOPY
Allison Island	19.21%
Terminal Island 2	0.02%
Bayshore	18.55%
Belle Isle	4.48%
Biscayne Point	14.43%
De Lido Island	21.92%
Fisher Island	12.88%
Flagler Memorial Island	24.80%
Hibiscus Island	25.59%
La Gorce	23.09%
Nautilus	14.62%
Normandy Isle (North)	8.18%
Normand Isle (South)	11.15%
Palm Island	23.70%
Park View Island	7.96%
Rivo Alto Island	24.28%
San Marino Island	23.75%
South Beach	8.45%
Star Island	32.58%
Sunset Island 1	18.74%
Sunset Island 2	24.53%
Sunset Island 3	20.74%
Sunset Island 4	18.67%
Terminal Island	0.49%
Citywide	17%

During an average high volume rainfall event in Miami Beach (a 10-year storm), over 24 hours the city's trees take up an average of 8.5 million gallons of water.

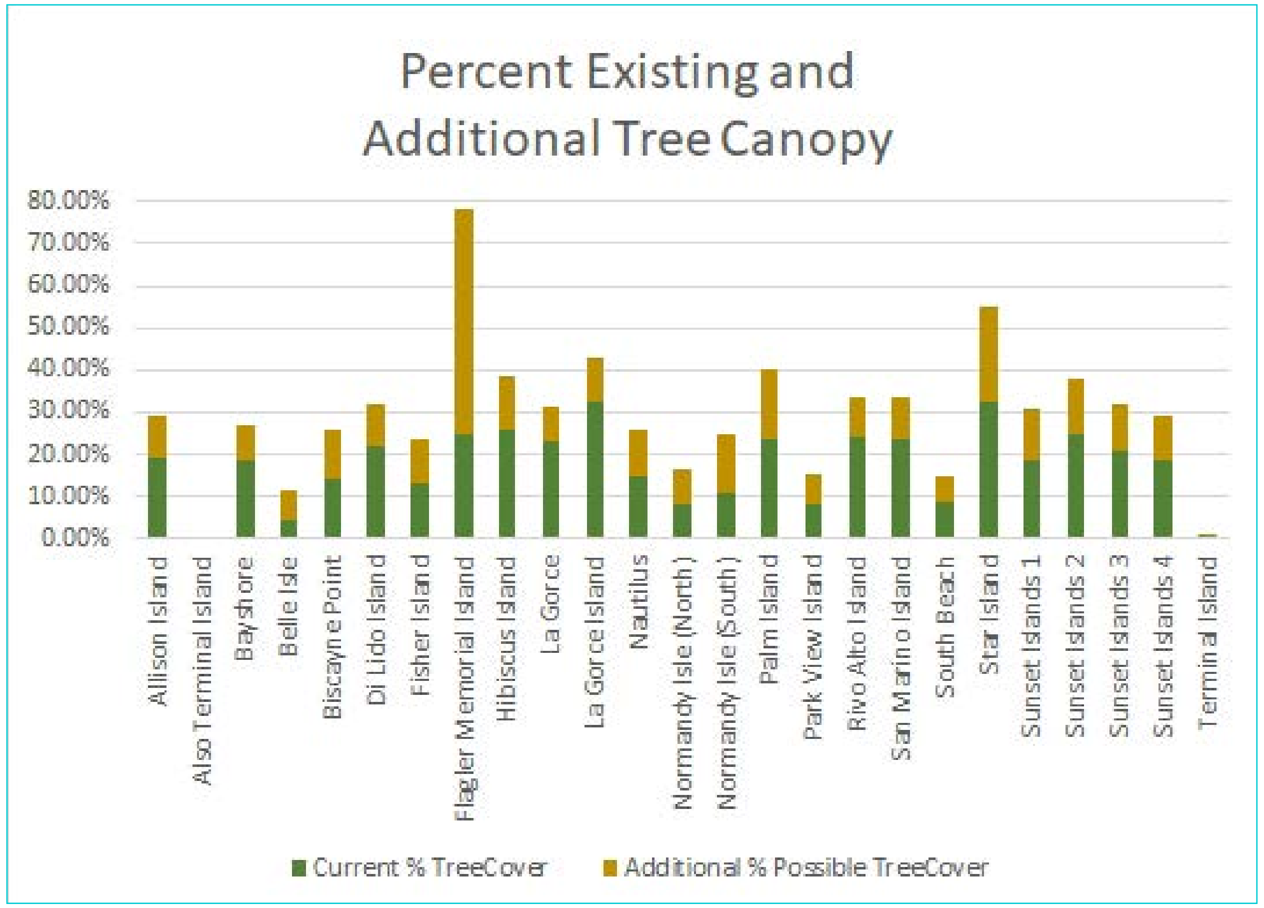
That's 13 Olympic swimming pools of water!

Miami Beach: Fast Facts & Key Stats

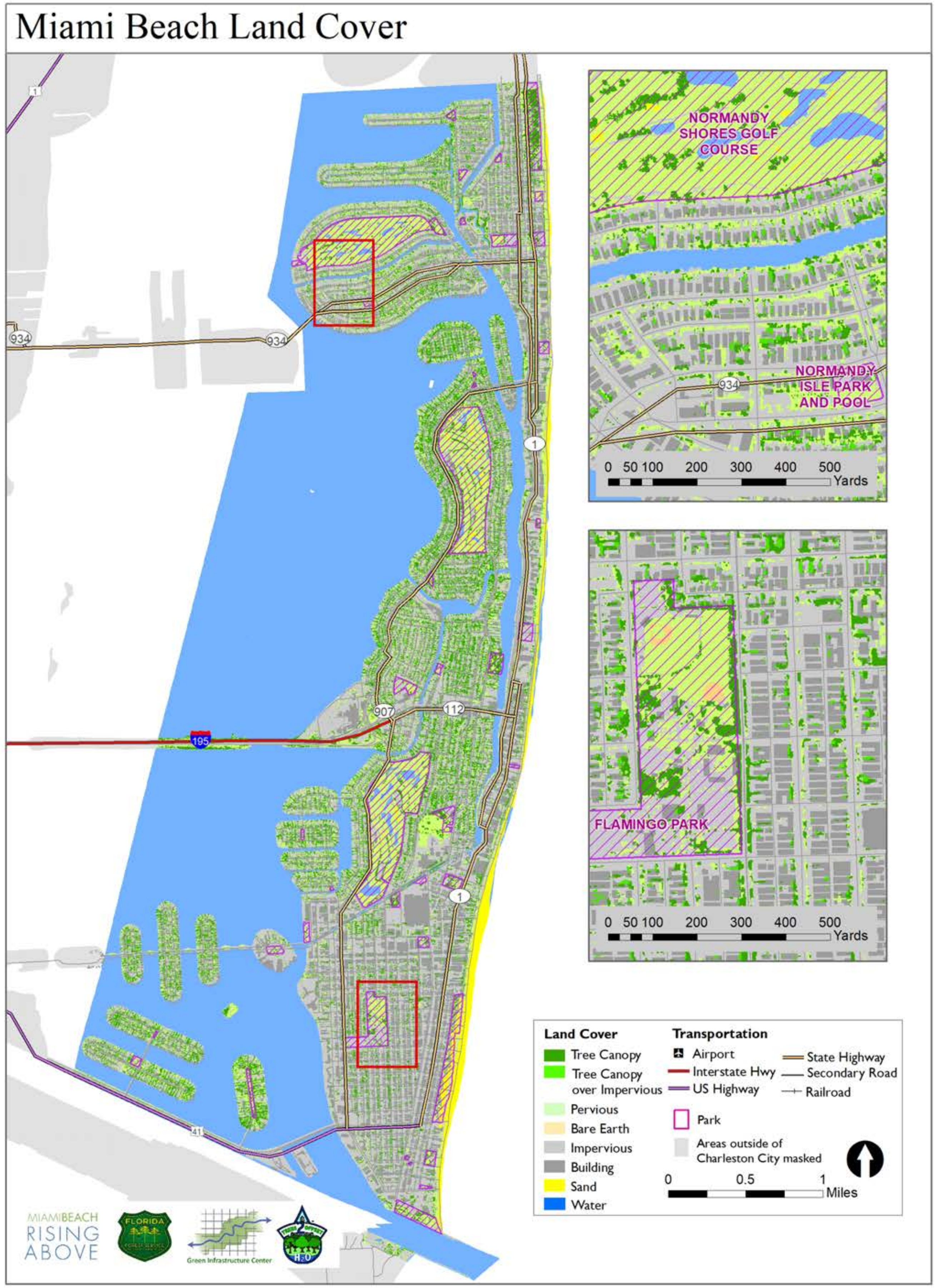
- Coastal beach community in southern Florida
- County: Miami Dade
- 2017 U.S. Census Population Estimate: 92,307 people
- City Area
  - 25 islands make up the City of Miami Beach
  - Total area: 15.22 sq. mi.
  - Land: 7.7 sq. mi.
  - Water: 7.5 sq. mi. (not including bays and oceans)
  - Tree Canopy: 768.5 acres (17%)



Citywide tree canopy is 17 percent.



Percent Tree Cover and Possible Planting Area by Watershed



This map shows the tree canopy of the city which covers 17 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). At just 17 percent canopy, Miami Beach has a relatively small extent of urban forest cover. This is a bit less than that found for the larger urban area of Miami Dade County which is 19.9 percent (2014 data).[1]

Cities, such as Miami Beach, have lost their natural forest cover and mangrove areas as land has been converted or filled. The city may continue to see losses unless planting and urban forest care are better funded. As older trees die (or before they die), younger trees need to be planted to restore the older canopy. For example, canopy coverage in the South Beach area is only 8.45 percent. However, based on an analysis of existing open space, 5.5 percent more area downtown could possibly be planted resulting in 13 percent 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 its stormwater. Additional benefits of improved canopy include:

- fostering a healthful and vibrant community,
- cleaner air,
- aesthetic values,
- reduced heating and cooling costs,
- decreased urban heat island effects,
- buffering structures from wind damage.
- increased bird habitat;
- fostering walkability and multimodal transportation; and,
- increased revenue from tourism and retail sales.

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.

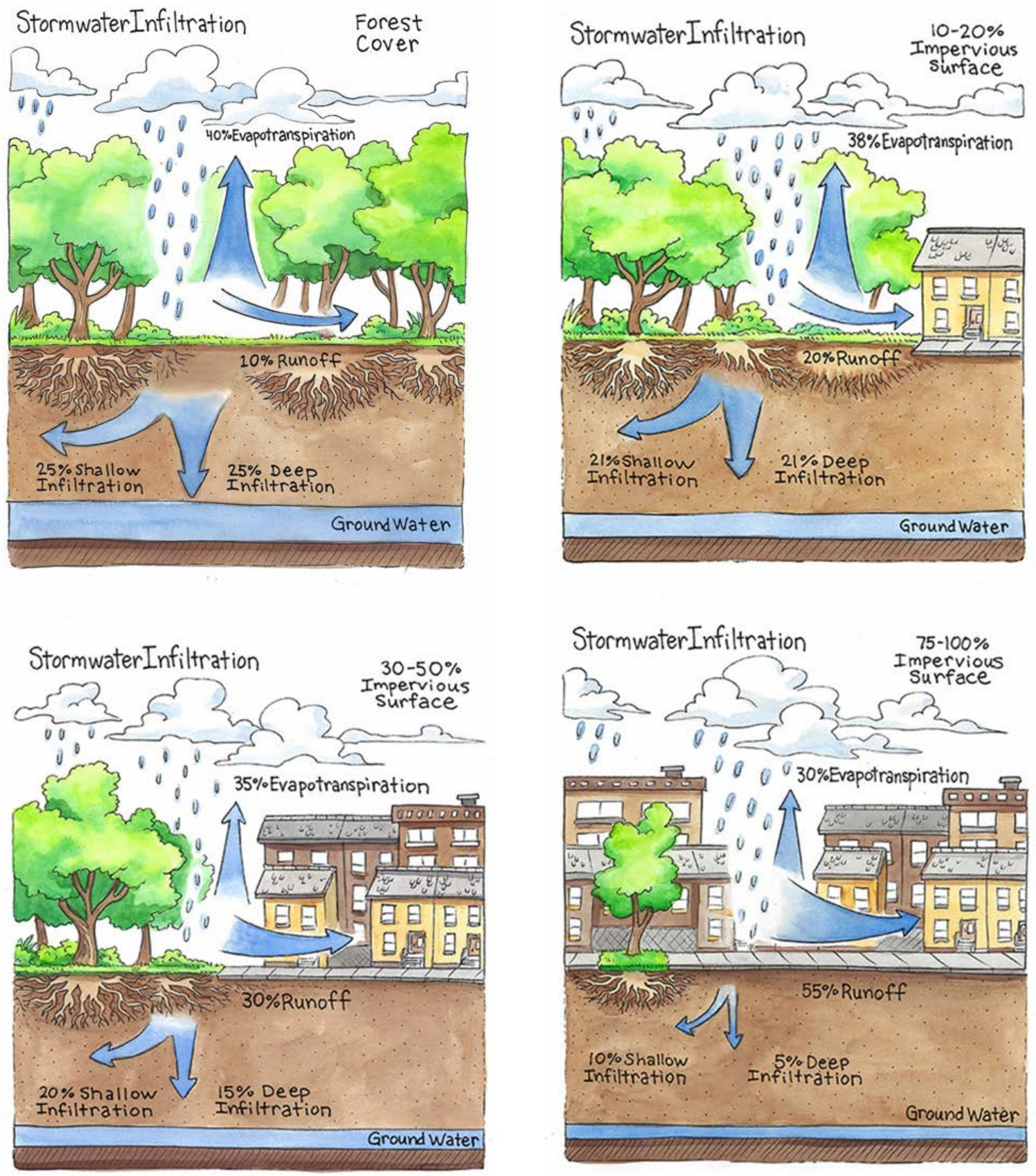
In considering runoff, the amount of imperviousness is one factor; the other is the degree and type of forested land cover, since vegetation helps absorb stormwater and reduces the harmful effects of runoff. As their urban forest canopies have declined across the south, municipalities have seen increased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

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. In Miami Beach, there is also a phenomenon of water seepage upward through the ground, as rising seas and high tides cause the water table to move upwards.

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.

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. 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.

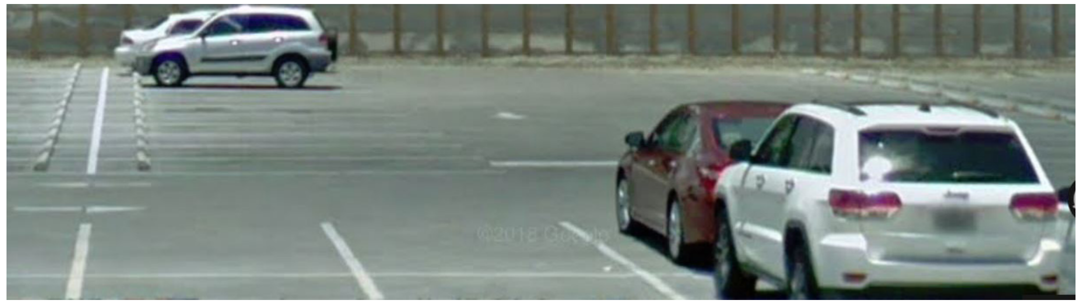
Urbanizing counties and cities are beginning to recognize the importance of their urban trees because trees provide tremendous dividends. For example, urban canopy can reduce stormwater runoff anywhere from two to seven percent (Fazio 2010). According to Penn State Extension, during a one-inch rainfall 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, parts of Miami Beach are older and may lack stormwater management practices that are now required for new developments.



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

[1] http://milliontrees.miamidade.gov/library/miami-dade_utc-assessment_final-lr.pdf

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 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, the total reduced runoff per year could amount to millions of gallons of reduced runoff. This means less flooded neighborhoods and reduced stress on storm drainage pipes and decreased runoff into the city's bays, ponds and the ocean.

Newly planted tree in Miami Beach.

Tree in a Miami Beach yard.

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).

ADDITIONAL URBAN FOREST BENEFITS

Quality of Life Benefits

During Florida'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. An average summer daytime temperature reduction of 6.4 (degrees F) has been documented in association with a typical large tree in Miami (Souch and Souch 1996). In addition, 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.

Trees provide shade and substantial savings on air conditioning.

A local bromeliad, a Staghorn Fern, enjoys support from the tree.

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).

Well treed areas encourage people to walk and bike.

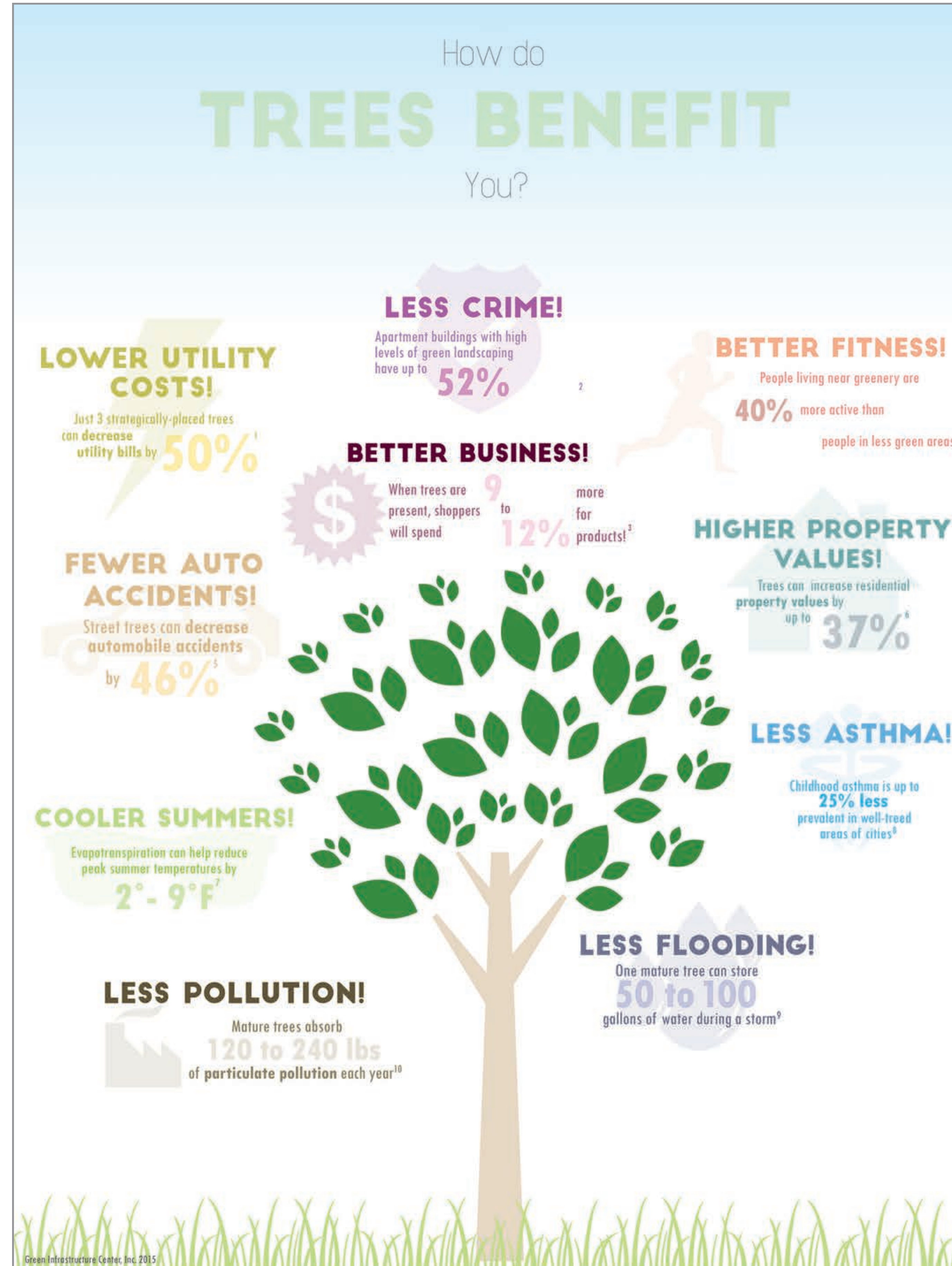
Economic Benefits

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 more 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 Florida 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.

There are many spots were trees can be replanted.



NATURAL ECOLOGY IN URBAN CONDITIONS – CHANGING LANDSCAPES

Natural history, even of an urbanized location, informs planting and other land-management decisions. Miami Beach is located in the Southern Florida Coastal Plain which is characterized by flat plains, wet soils, marshes, cypress swamps, mangrove swamps (and in the Everglades, sawgrass prairies). Southern Florida has seen dramatic alterations to water flows and drainage, which in turn have dramatically altered its flora and fauna.

Non-native invasive species have taken a toll on native flora. Plants such as Brazilian pepper, Australian punk tree (melaleuca) and Australian pine (casuarina) have overtaken many areas. Southern Florida is also home to some of the largest wading bird colonies in nation including breeding populations of smooth-billed anis, snail kites, and white-tailed kites.

Non-native and invasive Australian pines should be removed.

HISTORIC LAND COVER

The island was first developed for agricultural production of avocado. To make way for this crop, mangrove forests that once made up much of the area were cleared as land was ditched and drained and added to with fill, expanding the barrier island's available land for development. Miami Beach became a premier beach resort destination beginning in the early 1910s as entrepreneurs further developed crop lands and also constructed canals to drain the lands and transport crops.

The Miami Beach Improvement Company was established to provide for commercial development. The first real tourist structure was Brown's Hotel built in 1915 and it is still in operation today. By 1915, investors had constructed mansions, three additional hotels and two bath houses, an aquarium and even an 18-hole golf course. This growth was enabled by the building of a 2.5-mile wooden bridge connecting the barrier island to the mainland, and later multiple bridges connected the island that now comprises the City of Miami Beach.

Today, Miami Beach's downtown is booming with its restaurants, walkways along the beach, the world-renown collection of restored Art Deco architecture and arts installations and restaurants, as well as vibrant neighborhoods which showcase the city's cultural diversity. The city is recognized for its many unique quality of life aspects and career opportunities in rankings by Livability, US News, Forbes and others.

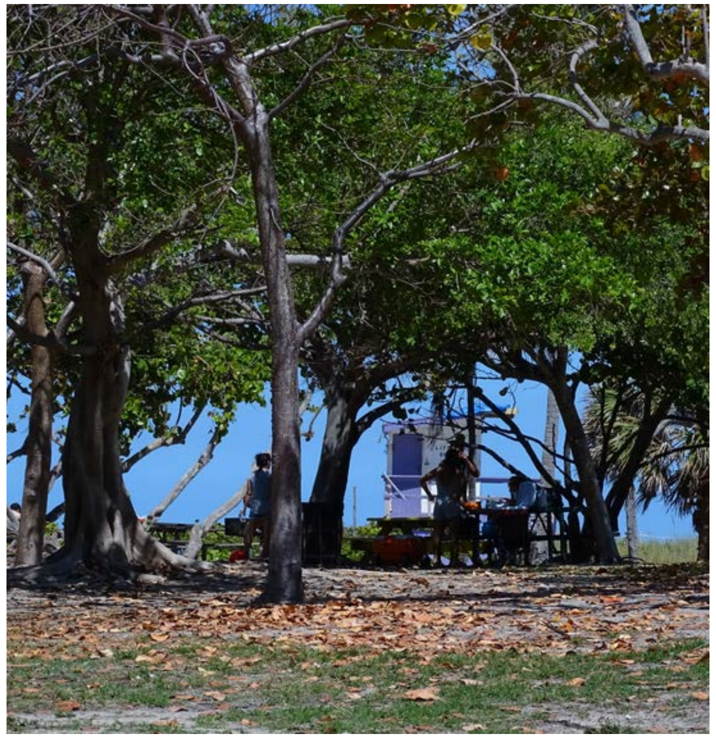
With its 30 city parks, Miami Beach offers abundant opportunities to enjoy the outdoors and support native species. City parks, such as Lummus Park and the Botanical Garden, are popular places to experience nature in the city and add to the city's livability scores.

Miami Beach supports a vibrant and culturally-diverse landscape.

GROWTH AND DEVELOPMENT CHALLENGES

Demands for space to meet the needs for housing, commercial, business, and transportation uses put strains on both the city's grey and green infrastructure. As an older city, there are areas that pre-date the 1987 Clean Water Act Amendments which required 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.

Another well-known challenge is sea level rise. According to the city's Rising Above website, based on NOAA data, in 2015, the projected increase in sea level sea level rise is approximately 6 to 10 inches by the year 2030. This challenge is compounded by the rising groundwater that moves up through the porous 'Miami Limestone' underlying the city. This makes it difficult to build barriers against rising seas.



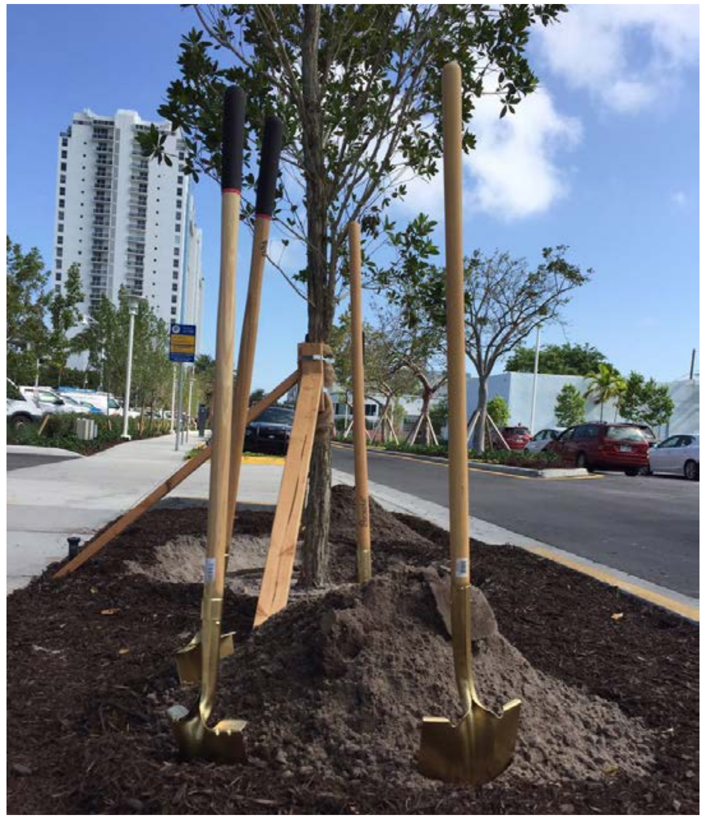
Picnics are enjoyed under the forested dunes in many city parks.

Storm damaged vegetation

Research conducted by the University of Miami and Florida State University found that "significant changes in flooding frequency occurred after 2006, in which rain-induced events increased by 33% and tide-induced events increased by more than 400%" (Wdowinski et al 2016). The tide-induced floods have affected mostly low-lying neighborhoods in the western part of the city, which were built on reclaimed mangrove wetlands, mentioned earlier in this report (Wdowinski et al 2016). 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 an already challenged 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. The City of Miami Beach manages a robust stormwater program. The Stormwater Management Master Plan (SMMP) was adopted by the city in 2011. Its primary level of service criteria is the protection of public safety and property. Its goals are to maintain passable roads for emergency uses and evacuation of traffic, and to control flood stages below homes and buildings as practicable.

Since the SMMP's 2011 adoption and more so since 2014, the city's accomplishments associated with raising the elevation of roads and installing new storm water collection and pumping systems are world renowned. The city has established Best Management Practices (BMPs) that meet, and where feasible, exceed the requirements of the city's NPDES permit through a comprehensive program that includes education and outreach, good housekeeping, and cutting-edge equipment and industry-vetted operational practices. Together, these elements reduce the pollutants that can be picked up by stormwater and they also trap and remove a large percentage of those pollutants entering the city's stormwater system. These activities and the anticipated efficiency for these BMPs and policies and practices for preventing stormwater pollution are detailed annually in the city's NPDES Annual Report, which is reviewed and approved by the Florida Department of Environmental Protection (FDEP).



MIAMI BEACH'S RESILIENT FUTURE

Miami Beach is working to redevelop in ways that support a quality lifestyle for residents and visitors alike, while also meeting state and federal mandates for protecting air and water. Miami Beach is one of the 100 Resilient Cities Program known as Resilient Greater Miami & the Beaches – a collaboration formed in 2016 by Miami-Dade County, the City of Miami Beach and the City of Miami to respond to the region's challenges. The 100 Resilient Cities Program is pioneered by the Rockefeller Foundation which is helping cities around the world become more resilient to social, economic, and physical challenges that are a growing part of the 21st century.

The City of Miami Beach defines resiliency as "The capacity of individuals, communities, and institutions, businesses and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience. "The city considers protection and growth of its urban canopy as a key component of its resilience strategy. For more see: http://www.mbrisingabove.com/climate-mitigation/urban-canopy-2/

Planting more trees is key to reducing runoff.

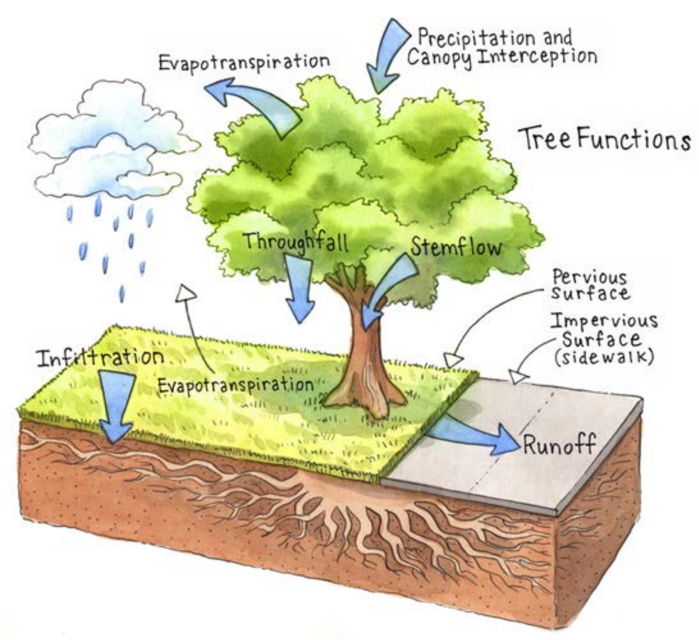
Residents can make a difference in runoff by limiting pavement as this residence has done with a partially green driveway.

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 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



Trees and the Water Cycle

Currently, the city uses TR-55 curve numbers developed by the Natural Resources Conservation Service (NRCS) to generate expected runoff amounts. The city could choose to use the modified TR55 curve numbers (CN) from this study that include a factor for canopy interception. This project is also 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.

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. 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. 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. A study by 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:

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

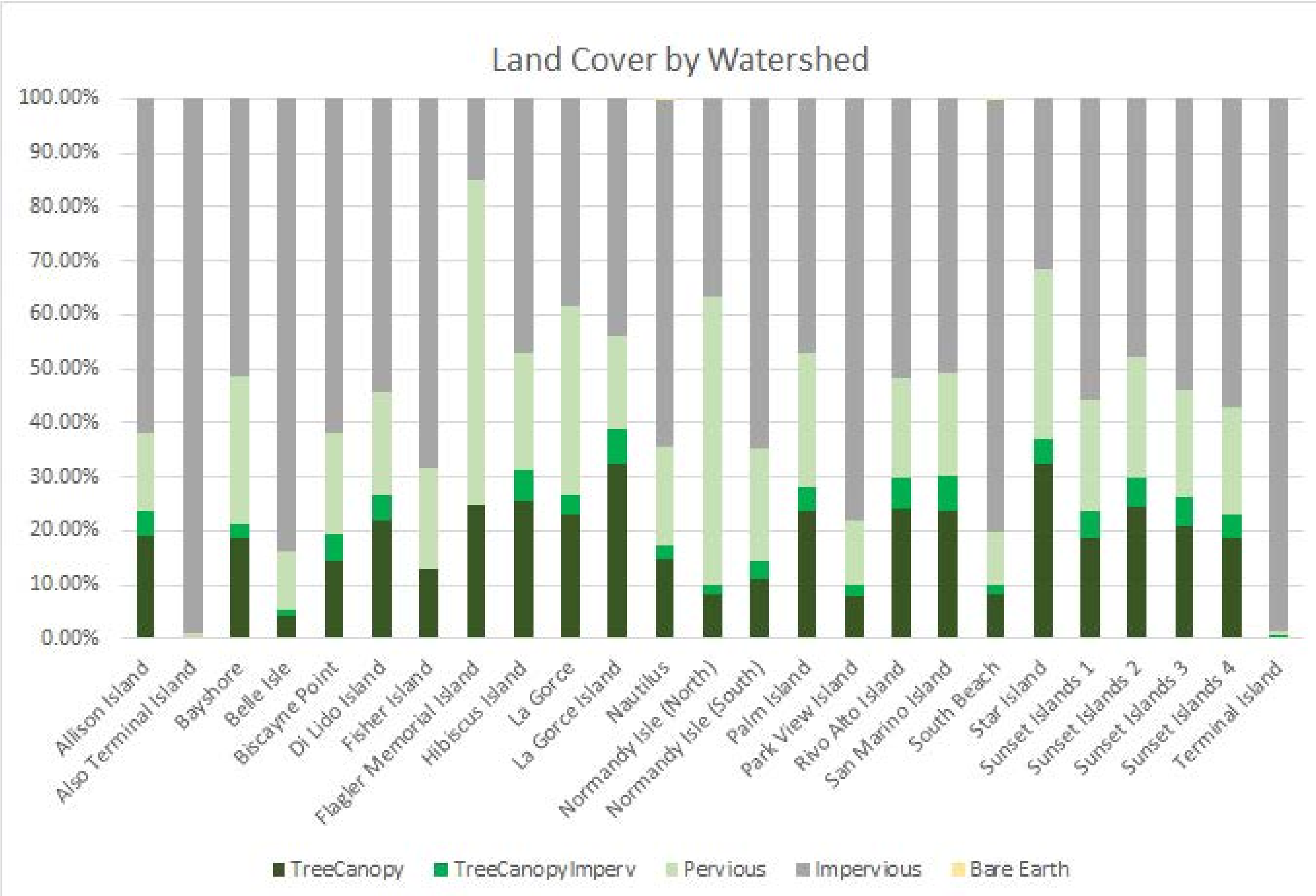
Where R is runoff, P is precipitation, Ia is the initial abstraction for captured water, which is the fraction of the storm depth after which runoff begins, and S is the potential maximum retention after runoff begins for the subject land cover (S = 1000/CN – 10).

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

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 page 21), trail planning and for updating the comprehensive plan.

An example of how this modeling tool can be used for watershed-scale forest planning is indicated below. The actual model spreadsheet was provided to Miami Beach. 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



Trees could be added here for shade and beauty.

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 Miami Beach, the city should maximize tree conservation for maintenance of 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. For example, the recent Million Trees Miami Assessment found that higher tree canopy percentage is associated with lower overall hospitalization numbers and also with lower hospitalization from asthma.

The stormwater runoff model provides estimates of the capture of precipitation by tree canopies 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. Since the city has so many distinct islands, the analysis is done based on each island landform.

Miami, FL — **Urban Tree Canopy Stormwater Model** — **version July 15, 2018**

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

Statistics by Drainage Basin (current settings)

	Area	Current Tree Cover (%)	Current Impervious Cover (%)	Tree H20 Capture (million gallons)	Increased H2O w/xx% (million gallons)	Added H2O Capture w/xx% PPA (million gallons)	Tree Cover Goal (%)	Pick an Event: Event	Pick a loss scenario: % UTC loss
	TOTALS	17%	62.9%	17.0	2.2	1.3	20%		
1	Allison Island	23.9%	61.9%	0.10	0.02	0.01	27%	10 yr / 24 hour	10%
2	Also Terminal Island	0.0%	98.9%	0.00	0.00	0.00	0%	10 yr / 24 hour	10%
3	Bayshore	21.2%	51.5%	1.76	0.46	0.21	24%	10 yr / 24 hour	10%
4	Belle Isle	5.3%	83.8%	0.02	0.00	0.01	8%	10 yr / 24 hour	10%
5	Biscayne Point	19.4%	61.8%	0.42	0.11	0.08	23%	10 yr / 24 hour	10%
6	Di Lido Island	26.5%	54.3%	0.16	0.04	0.02	30%	10 yr / 24 hour	10%
7	Fisher Island	12.9%	68.4%	0.02	0.01	0.01	16%	10 yr / 24 hour	10%
8	Flagler Memorial Island	24.8%	14.9%	0.01	0.00	0.01	39%	10 yr / 24 hour	10%
9	Hibiscus Island	31.3%	46.9%	0.21	0.05	0.03	35%	10 yr / 24 hour	10%
10	La Gorce	26.8%	38.5%	1.43	0.35	0.13	29%	10 yr / 24 hour	10%
11	La Gorce Island	38.9%	43.8%	0.29	0.06	0.02	42%	10 yr / 24 hour	10%
12	Nautilus	17.3%	64.3%	0.62	0.17	0.12	21%	10 yr / 24 hour	10%
13	Normandy Isle (North)	10.0%	36.7%	0.22	0.06	0.06	13%	10 yr / 24 hour	10%
14	Normandy Isle (South)	14.3%	64.8%	0.36	0.10	0.11	19%	10 yr / 24 hour	10%
15	Palm Island	28.2%	46.9%	0.22	0.05	0.04	33%	10 yr / 24 hour	10%
16	Park View Island	10.1%	78.1%	0.02	0.01	0.00	12%	10 yr / 24 hour	10%
17	Rivo Alto Island	29.8%	51.6%	0.13	0.03	0.01	33%	10 yr / 24 hour	10%
18	San Marino Island	30.3%	50.7%	0.11	0.03	0.01	33%	10 yr / 24 hour	10%
19	South Beach	10.2%	80.2%	1.78	0.52	0.36	12%	10 yr / 24 hour	10%
20	Star Island	37.1%	31.5%	0.27	0.06	0.04	43%	10 yr / 24 hour	10%
21	Sunset Islands 1	23.7%	55.7%	0.09	0.02	0.01	27%	10 yr / 24 hour	10%
22	Sunset Islands 2	29.9%	47.7%	0.16	0.04	0.02	34%	10 yr / 24 hour	10%
23	Sunset Islands 3	26.2%	54.0%	0.08	0.02	0.01	30%	10 yr / 24 hour	10%
24	Sunset Islands 4	22.9%	57.3%	0.06	0.01	0.01	26%	10 yr / 24 hour	10%
25	Terminal Island	0.5%	98.5%	0.00	0.00	0.00	1%	10 yr / 24 hour	10%

Statistics by Drainage Basin (current

	Area	%FOS Loss	Converte d Land: % Imperv	PCA	PPA	Canopy Added: % of Land	Enter % to be plante: % of PPA	Total Area: Acres	Canopy Pollution Load % Reduction: N	P	Sed	Additional Canopy Pollution Load % Reduction: N	P	Sed
	TOTALS								2.6%	2.7%	0.7%	1.7%	1.7%	0.5%
1	Allison Island		40%	36.3%	12.4%	3.1%	25.0%	36	5.0%	5.1%	1.4%	2.5%	2.6%	0.8%
2	Also Terminal Island		40%	0.5%	0.5%	0.1%	25.0%	11	0.0%	0.0%	0.0%	0.1%	0.1%	0.0%
3	Bayshore		40%	31.3%	10.1%	2.5%	25.0%	743	4.6%	4.7%	1.3%	2.1%	2.2%	0.6%
4	Belle Isle		40%	14.8%	9.5%	2.4%	25.0%	33	1.1%	1.2%	0.3%	1.8%	1.9%	0.6%
5	Biscayne Point		40%	34.0%	14.5%	3.6%	25.0%	201	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6	Di Lido Island		40%	38.9%	12.4%	3.1%	25.0%	51	5.6%	5.7%	1.6%	2.5%	2.6%	0.7%
7	Fisher Island		40%	26.0%	13.1%	3.3%	25.0%	15	3.1%	3.1%	0.7%	2.7%	2.8%	0.8%
8	Flagler Memorial Island		40%	81.6%	56.8%	14.2%	25.0%	4	5.9%	5.9%	1.4%	13.0%	13.1%	3.3%
9	Hibiscus Island		40%	46.7%	15.4%	3.9%	25.0%	55	6.6%	6.7%	1.9%	3.3%	3.3%	0.9%
10	La Gorce		40%	36.7%	9.9%	2.5%	25.0%	452	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
11	La Gorce Island		40%	51.7%	12.8%	3.2%	25.0%	56	8.3%	8.4%	2.3%	2.7%	2.8%	0.8%
12	Nautilus		40%	31.0%	13.7%	3.4%	25.0%	332	3.7%	3.8%	1.0%	2.8%	2.9%	0.8%
13	Normandy Isle (North)		40%	20.3%	10.3%	2.6%	25.0%	220	2.1%	2.2%	0.6%	2.1%	2.2%	0.6%
14	Normandy Isle (South)		40%	31.4%	17.1%	4.3%	25.0%	245	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
15	Palm Island		40%	47.1%	19.0%	4.7%	25.0%	65	6.0%	6.1%	1.7%	4.1%	4.2%	1.1%
16	Park View Island		40%	19.5%	9.4%	2.4%	25.0%	18	2.1%	2.1%	0.6%	1.9%	2.0%	0.6%
17	Rivo Alto Island		40%	41.3%	11.5%	2.9%	25.0%	36	6.2%	6.4%	1.8%	2.4%	2.5%	0.7%
18	San Marino Island		40%	42.4%	12.1%	3.0%	25.0%	30	6.2%	6.4%	1.8%	2.5%	2.6%	0.7%
19	South Beach		40%	18.4%	8.2%	2.1%	25.0%	1,751	2.2%	2.2%	0.6%	1.7%	1.7%	0.5%
20	Star Island		40%	61.8%	24.7%	6.2%	25.0%	55	8.1%	8.2%	2.2%	5.6%	5.6%	1.5%
21	Sunset Islands 1		40%	38.3%	14.7%	3.7%	25.0%	33	4.9%	5.0%	1.4%	3.1%	3.1%	0.9%
22	Sunset Islands 2		40%	45.8%	15.9%	4.0%	25.0%	43	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
23	Sunset Islands 3		40%	39.9%	13.7%	3.4%	25.0%	26	5.4%	5.5%	1.6%	2.8%	2.9%	0.8%
24	Sunset Islands 4		40%	36.3%	13.4%	3.3%	25.0%	22	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
25	Terminal Island		40%	1.0%	0.5%	0.1%	25.0%	11	0.1%	0.1%	0.0%	0.1%	0.1%	0.0%

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 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. During an average volume rainfall event in Miami (a 10-year storm), over 24 hours the city's trees take up an average of 8.5 million gallons of water. That's about 13 Olympic swimming pools of water! As shown below, for a 10-year, 24-hour storm, a loss of 10 percent of the urban tree canopy would increase runoff by 2.23 million gallons, while increasing canopy coverage from the current 17 to 20 percent would decrease runoff by 1.3 million gallons.

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.

Understory vegetation absorbs additional water.

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. Ancillary data for roads (from Miami Beach government), the Cooperative Land Cover (CLC) Map (Florida Natural Areas Inventory), 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) Wetland not distinguishable using spectral/feature-based image classification tools.

In other 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. However, since the small City of Miami Beach has no real forests, this was not included.

The final classification of land cover consists of seven 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 seven land cover classes, only pervious (grass and scrub vegetation) is considered for PPA.

- Tree Canopy
- Tree Canopy over Impervious
- Pervious
- Impervious
- Bare Earth
- Sand
- Water

At this size, sea grapes are classified as trees

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

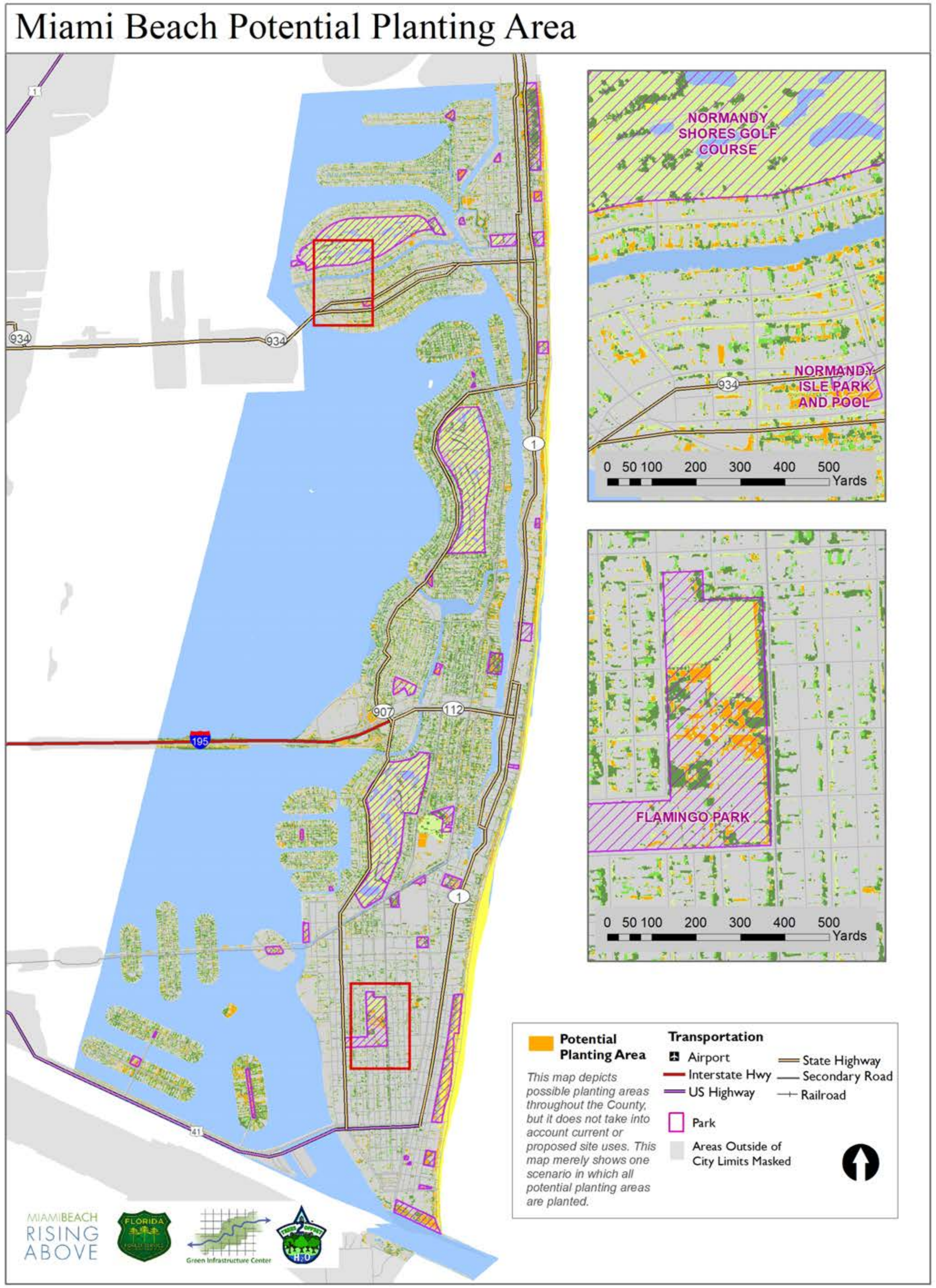
Next, these eligible planting areas are limited based on their proximity to features that might either interfere with a tree's natural growth (such as buildings) or places a tree might affect the feature itself such as power lines, sidewalks or roads. Playing fields and other known land uses that would 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 PPAs represent the maximum potential places trees can be planted and grow to full size. A good rule is to assume about half the available space could be planted with trees.

Tree over street

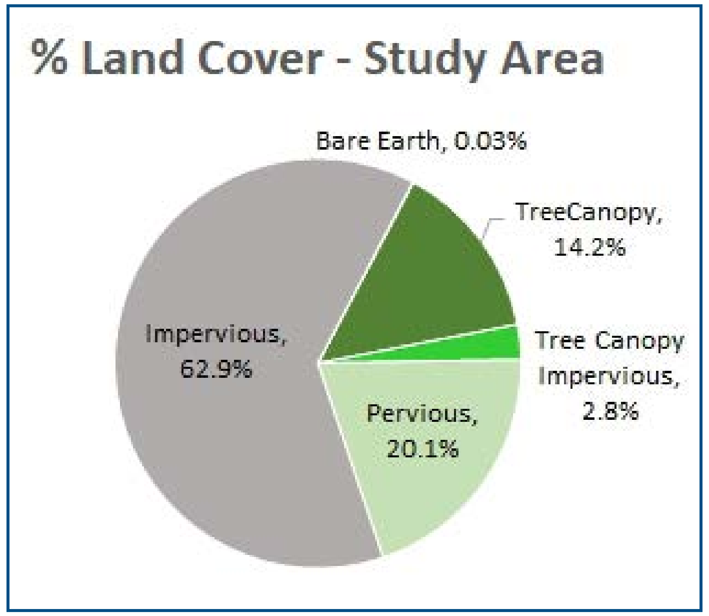
Trees over forest

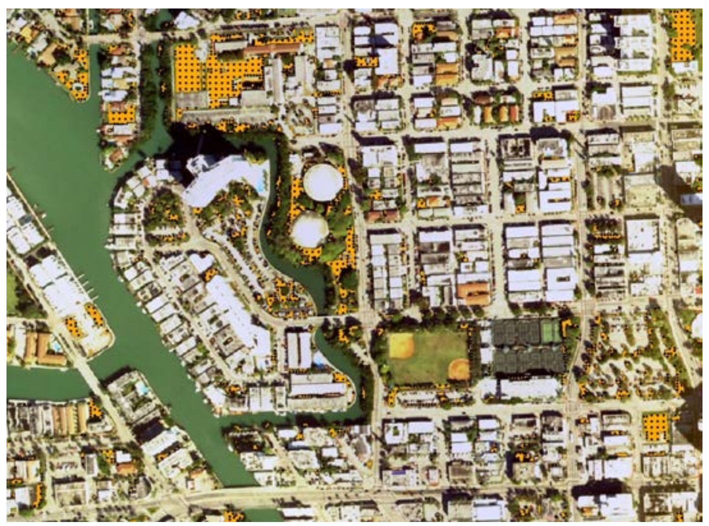
Tree over lawn

Tree over parking lot



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)

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.

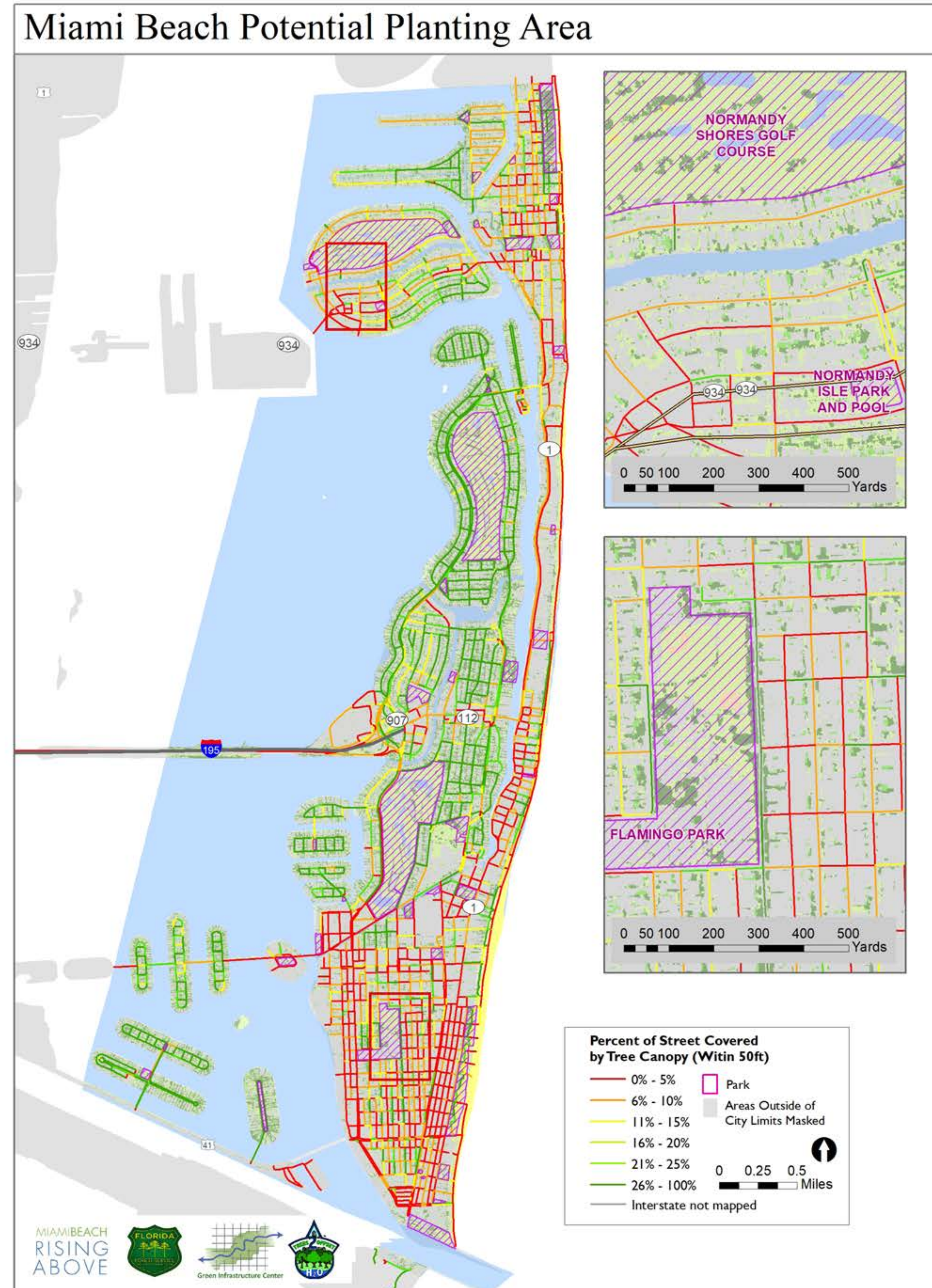
Potential Canopy Area (PCA)

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.

Street tree canopy

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. See Methods Appendix for more details on mapping methodology.

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, also provides more 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 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.

Miami Beach invests staff time and funds to manage its urban forest. The city has an Urban Forestry Division that is in charge of protecting the urban canopy through building permit reviews and through inspections conducted across the city. The Urban Forestry Division works in conjunction with the Public Works Department's Greenspace Management Division that conducts maintenance on the trees in the public right-of-way. In fact, the city just celebrated its eighteenth year of being recognized as a 'Tree City USA' by 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. The city also holds tree giveaways to help residents plant and care for trees too.

The recommendations provided in this report are a way to increase the protections for, and size of, the forest in Miami Beach. As noted earlier, although the city's canopy is about 17 percent, it is not distributed equally citywide. Miami Beach is one of 12 localities in a six-state area of the Southeastern U.S. to be studied and the fifth to be completed. As other places are studied, they will be compared to the city, and vice versa.

Top recommendations to improve forest care in Miami Beach listed in priority order:

1. **Use the GIC's stormwater uptake calculator to determine the benefits of maintaining or increasing tree canopy goals by island group.** The calculator provided to the City of Miami Beach allows the city to determine stormwater benefits or detriments (changes in runoff) from adding or losing trees. It also calculated the pollution loading reductions for nitrogen, phosphorus, and sediment.

2. **Use the urban forestry funding calculator to assist in setting tree planting goals.** Budget increases are required to increase tree canopy coverage levels. The calculator can be used to determine the feasibility for achieving tree canopy coverage goals and the amount of additional funds required to obtain and manage additional trees.

3. **Conduct a land cover assessment every four years to measure and compare tree canopy coverage change over time.** Tree canopy coverage should be expanded and maintained to promote public health, walkability, water quality and groundwater recharge. Regular updates to land cover maps allow for this analysis and planning to occur.

4. **Develop a stormwater best management practice design manual for Miami Beach.** Include trees and constructed green infrastructure. Without standards, innovative stormwater techniques such as green roofs, suspended pavement systems, vegetated swales and tree pits cannot be credited toward stormwater requirements. The city should develop stormwater best management practice standards and provide incentives for developers and homeowners to install green stormwater technology. The sustainability division is currently pushing for an ordinance to require either green roofs, or reflective roofs on buildings throughout the city.

5. **Develop an urban forest management plan for the city.** An urban forest management plan (UFMP) details a vision and the process for managing the city's urban tree canopy. It achieves loc al government and community goals for proactively managing the urban canopy and achieving long term benefits. Miami Beach is currently working on developing its Urban Forestry Master Plan. The city's UFMP will describe the condition of the urban forest, current maintenance costs, urban tree canopy coverage goals and the process to achieve them.

6. **Determine urban forestry data needs and which software can best meet urban tree data collection and management needs.** Implement the data

There is plenty of room to add trees, even at the edges of open spaces.

collection process as part of the urban forestry program. Monitoring urban forest composition and health is necessary for maintaining a thriving urban forest that serves both people and wildlife. Urban forest survey and management technologies can make data collection far less arduous than it has been in the past. Use of these software systems allows urban forest managers to make informed decisions.

7. **Conduct proactive tree risk assessments yearly in highly trafficked areas of the city.** Tree risk assessments can be used to determine and develop plans to mitigate risk associated with trees such as falling limbs. In highly trafficked areas, these assessments should be done annually. The city currently completes tree risk assessments only when requested by citizens. The city should fund and implement proactive tree risk assessments.

8. **Continue the Integration of planning for trees in all planning and development activities.** Holding pre-development conferences, calculating stormwater impact from tree removal or planting, and sketching site designs allow for exploration of ideas for tree conservation before extensive funds are spent on site planning.

9. **Prioritize forestry activities. Develop a contingency budget for the urban forest to allow critical urban forestry maintenance items to continue through economic downturns.** Establish minimum budget requirements to ensure maintenance of the urban forest.

10. **Educate special magistrates and staff about the importance of tree canopy coverage, and the social and financial benefits.** Magistrates often do not uphold enforcement of violations of the city's tree protection regulations. As some members of the development community realize that illegal tree removals may not be enforced, many more tree removals could occur and Miami Beach's urban forest canopy levels may decline further. To avoid this, the city should provide training and education for special magistrates on tree canopy benefits and the importance of tree protection.

11. **Train code enforcement staff in basic tree health and care.** Codes and ordinances are only as effective as their enforcement. Miami Beach has codified tree protection, but due to a lack of staff knowledge about tree care and health, some codes are not enforced. The city should provide comprehensive staff trainings or designate one code violations officer to become certified as an arborist.

This park space has room for trees with large roots to grow.

12. **Require and enforce 600, 1,000, and 1,500 cubic feet soil volume planting requirements for small, medium, and large trees respectively.** At a minimum, canopy trees require 1,000 cubic feet of soil volume to thrive, as recommended by the Environmental Protection Agency (Stormwater to Street Trees, 2013). The city urban forester should be consulted to recommend soil volumes, based on species.

13. **Identify key streets where green infrastructure and bike lanes are needed.** There is a current effort in Miami Beach to make space on busy streets for more trees and bike lanes. Use the street tree coverage map developed by GIC to target streets with low tree canopy coverage and work with transportation staff to continue to expand the shaded bike network in Miami Beach.

14. **Develop more information for citizens detailing how they can engage in supporting the city's urban canopy.** Community engagement is a challenge for many municipalities. However, as most of the city's urban forest is in private ownership, the community should be engaged in urban forestry management and tree planting. For example, the city could create a Tree Stewards group and provide the group with resources and guidance concerning urban forest management. A Tree Stewards group can partner with HOAs, homeowners, parks etc. to accomplish tree planting projects that city staff many not have the time or budget to undertake.

15. **Re-use urban waste wood.** Use the Southeast Urban Wood Exchange website to establish an urban waste wood program. Establishing an urban waste wood program is an excellent way to engage community members in re-using a valuable wood product. The city should launch a city-wide campaign to encourage the re-use of waste wood and let citizens know how they can get involved. It allows those who have extra wood (e.g. a downed tree) and those who need it (e.g. carpenters) to efficiently access the resource. For more information, see http://www.urbanwoodexchange.org/

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 Miami Beach holds planning concept reviews, but they are not mandatory. Also, the city forester may not be available to attend all scheduled reviews. Greater encouragement for these meetings and funding for additional staffing within the city's urban forestry program could expand the frequency and benefits from these meetings.

However, it will also be necessary to actively promote the implementation of development designs that minimize the loss of urban forest canopy and habitat. While the city actively 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 manage 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 premium in a well-treed development.

Tree Protection Fencing and Signage

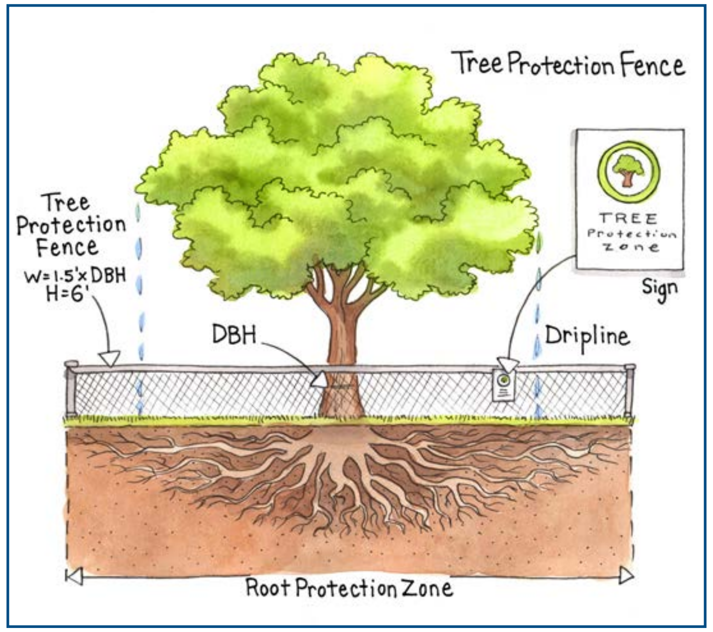
The most common form of tree protection is tree protection fencing. It is a physical barrier that keeps people and machines out of tree's critical root zones during construction. However, some municipalities only require plastic orange fencing and wooden stakes. This type of fencing can be removed or trampled easily and makes tree protection efforts less effective. Trees slated for protection may suffer development impacts such as root compaction and trunk damage. The city should require sturdy metal chain link fencing in high risk areas (e.g. near heavy construction equipment and active site grading) and use orange plastic fencing in lower risk areas (e.g. along the tree line at the edge of a development property)

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. Current code language only requires tree protection fence placement 10' from the trunk of the tree, thereby impacting tree roots critical for survival. Currently, city staff request that tree protection fence be placed at the dripline. While protection at the dripline is an accepted practice, it does

Ficus tree roots

not adequately protect the roots. Instead, the city should require placement of tree protection fencing at a distance 1.5' times the tree's diameter at breast height (DBH) from the tree.

The city currently requires tree protection signage. However, the city's signage does not provide information about what can and cannot occur in tree protection zones. Tree protection signage communicates how work crews should understand and follow tree protection requirements. It also informs construction crews and citizens about the consequences of violating city code. Construction crew members may not understand that building materials may not be placed in tree protection zones and that moving the protective fencing around the tree is never permitted. The city should design a standard tree protection sign which summarizes the do's and don'ts of working near and around tree protection zones. Additional training may be helpful to ensure that developers comply with the city's tree ordinances and understand how to protect trees during construction.

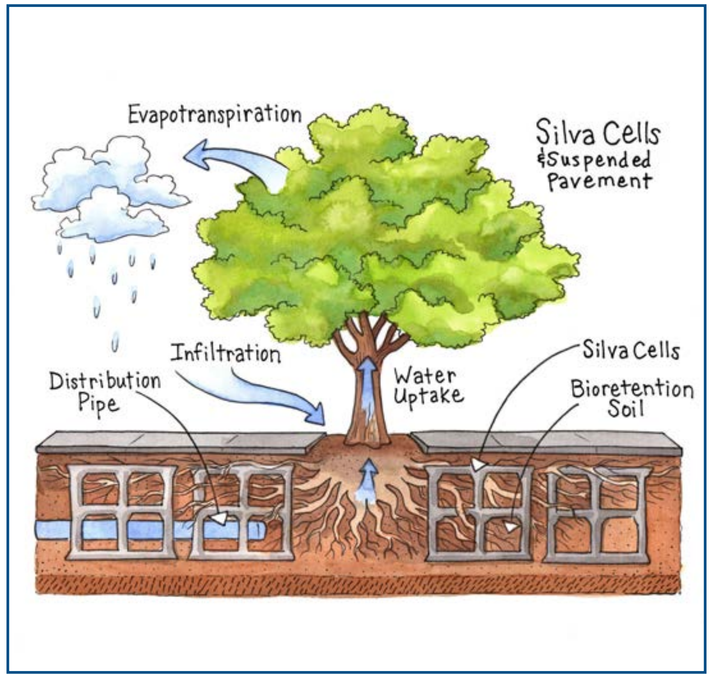


Tree Protection Fence and Signage

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, 'Silva cells' can be used to stabilize and direct tree roots towards areas with less conflicts (e.g. away from pipes).

In addition, large trees should not be planted where they may interfere with overhead lines. 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 will 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 and power lines don't mix well.

CONCLUSION

Adapting codes, ordinances and municipality practices to use trees and other native vegetation for greener stormwater management will allow Miami Beach 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.

Miami Beach should use the canopy map and updates to track change over time and to set goals for increasing canopy by neighborhood. 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.

At the time of this report, the city is beginning to craft an urban forest management plan, convert a large parking lot downtown into a park, and has a bond referendum for several million dollars on the November ballot to fund new tree planting. The City of Miami Beach clearly cares about creating a clean, green and safe city. Adopting the recommendations and ideas from this report and the city's many dedicated citizens will help the city meet it's goals for becoming resilient and 'rising above.'

APPENDIXES

APPENDIX A: METHODS — 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 the City of Miami Beach.

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 such as determining the tree canopy percentage in a specific neighborhood.

Land cover classification

NAIP 2015 (acquired between Oct 2015 and Jan 2016) Leaf-on imagery (4 band, 1-meter resolution) was used for the Landcover classification. The full set of NAIP data was acquired through the Earth Resources Observation and Science (EROS) Center of the U.S. Geological Survey. Additional inputs included in classification were LiDAR from various acquisition dates ranging from 2007 to 2017. The most current data were used where available.

Pre-processing

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

NAD_1983_NSRS2007_StatePlane_Florida_East_FIPS_0901_Ft_US
WKID: 3512 Authority: EPSG

Projection: Transverse_Mercator
False_Easting: 656166.6666666665
False_Northing: 0.0
Central_Meridian: -81.0
Scale_Factor: 0.9999411764705882
Latitude_Of_Origin: 24.33333333333333
Linear Unit: Foot_US (0.3048006096012192)

Geographic Coordinate System: GCS_NAD_1983_NSRS2007
Angular Unit: Degree (0.0174532925199433)
Prime Meridian: Greenwich (0.0)
Datum: D_NAD_1983_NSRS2007
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 "bulls eye" object recognition configuration to identify land cover types based on their surrounding features. Feature Analyst software is an automated feature extraction extension that enables a 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.

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.'

During the process of data review and verification, it was discovered that the classification over estimated tree cover due to the inclusion of Palm Trees and other planted/boxed-in vegetation. Furthermore, there was some confusion between other scrub and tree cover. Hedges taller than 10 feet are very common in Miami Beach and may appear tree-like in aerial imagery. Sea grapes may also be bushes or they may be trimmed and allowed to grow into a tree-form, further complicating classification. The spectrally-classified tree cover was filtered through LiDAR data to eliminate any non-tree type vegetation. For areas where 2016/17 LiDAR data were available, the feature's height needed to be above 12 feet to be classified as tree cover. Where 2007 data were available, the tree height needed to be above eight feet. Also, to remove individual trees (most likely palms), a boundary clean algorithm was used to isolate those canopy types that more closely resembled that of a palm (more rounded and smaller diameter).

Potential Planting Area Dataset

The Potential Planting Area dataset has three components. These three data layers are created using the landcover layer and relevant data in order to exclude unsuitable tree planting locations or areas 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 Landcover 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 Landcover features

- Existing tree cover
- Water
- Wetlands
- Imperious surfaces
- Ball Fields (i.e.: Baseball, Soccer, Football) where visually identifiable from NAIP imagery. (Digitized by GIC)

Exclusion Features: (buffer distance)

- Roads Areas (10ft)
- Parking lots (10ft)
- Sidewalks (3ft)
- Rail roads (10ft)
- Structures (10ft)
- Fire Hydrants (5ft)
- Pump stations (5ft)
- Water/sewer Mains (5ft)
- Utility Poles (5ft)
- Other identifiable utilities (5ft)

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 tree's 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 that represents a tree's mature canopy is created. 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 2015

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.

Wdowinski, Shimon, Ronald Bray, Ben P. Kirtman, and Zhaohua Wu. "Increasing flooding hazard in coastal communities due to rising sea level: Case study of Miami Beach, Florida." *Ocean & Coastal Management* 126 (2016): 1-8.

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.